Arrow Energy Pty Ltd

Surat Gas Project

Updated CSG Water Monitoring and Management Plan

Updated CSG Water Monitoring and Management Plan

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EXECUTIVE SUMMARY

The Surat Gas Expansion Project[1] (SGP) will develop coal seam gas (CSG) resources in the Surat Basin, approximately 250 km west of Brisbane.

The SGP was approved by the Australian Government under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC) decision 2010/5344, and requires that prior to commencement, the proponent must submit an Updated CSG Water Monitoring and Management Plan (WMMP) for the approval of the Minister.

This document is the Updated CSG WMMP for the Arrow Energy (Arrow) SGP. It includes, and builds upon, all the matters of the Stage 1 CSG WMMP.

Groundwater resources

The SGP area includes three main aquifer systems: the surficial alluvial aquifers (including the Condamine Alluvium aquifer), the consolidated sedimentary aquifers (Great Artesian Basin aquifers), and the volcanic (basalt) aquifers. Groundwater has historically been utilised extensively throughout the Surat Basin for a range of purposes including irrigation, agriculture, grazing, industry and urban supply. Groundwater also supports dependent ecosystems in some areas within and in the vicinity of the SGP area.

Non-CSG groundwater use (primarily irrigation, agriculture, grazing, industry and urban supply) has led to a widespread decline in groundwater pressures, particularly in the Condamine Alluvium, which has historically been over-developed and over-allocated with respect to the productive yield of the system resulting in significant lowering of the watertable. Pressure declines in deeper GAB formations have also resulted.

The Walloon Coal Measures (WCM) host the target coal seams for CSG production. Depressurisation of the WCM for gas production may propagate to overlying and underlying formations. Consideration of altered groundwater availability and quality for existing users and dependent ecosystems as a result of the Action is therefore required.

Surface water resources

The highly variable, permanent to semi-permanent Condamine River flows north through the Cecil Plains-Dalby area, north-west and west towards Chinchilla, then south-west from Condamine, eventually becoming the Balonne River that feeds into the Murray-Darling River system.

The Juandah Creek (a tributary of the Dawson River) is the major watercourse in the north of the SGP area, and flows north-east through Guluguba and Wandoan. In the south of the SGP

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[1] Referred to as the Surat Gas Project (SGP) in this plan

area, major watercourses include Wyaga Creek and Commoron Creek, which flow south-west towards Goondiwindi.

Lake Broadwater and Long Swamp are key surface water features located in the central part of the SGP area to the north-west of Tipton. Lake Broadwater is a Category ‘A’ Environmentally Sensitive Area under the Queensland Environmental Protection Regulation (2008) and a Nationally Important Wetland under the EPBC Act. Long Swamp is a palustrine wetland to the north-east of Lake Broadwater, recognised locally as a natural and important wetland.

Updated groundwater modelling

A key feature of the modelling presented in this Updated CSG WMMP is the revised field development plan (FDP) (Updated FDP Case) and the adoption of the OGIA 2016 Groundwater Model (in place of the Arrow SREIS Groundwater Model, a version of the 2012 OGIA Groundwater Model).

Specific modelling work undertaken and addressed in this Updated WMMP includes:

- A comparison between the 2012 OGIA Groundwater Model and 2016 OGIA Groundwater Model;
- Modelling of the revised Updated FDP case;
- Revised integrated groundwater-surface water modelling; and
- Comparison of Stage 1 FDP case and Updated FDP case modelling results.

Results

Modelling undertaken in support of Arrow’s Updated CSG WMMP was compared to previous modelling undertaken for Arrow’s Stage 1 CSG WMMP. These models incorporated CSG water production from all proponents. The results indicate that Arrow’s contribution to the predicted water production volume is larger for the Updated case compared with the Stage 1 case. However, the peak in water production rate is smaller for the Updated case than for the Stage 1 CSG WMMP, and is distinguished by a broader predicted water production profile.

The differences in drawdown between the Stage 1 FDP Case and the Updated FDP Case are minor, however the timing of maximum drawdown has changed, and differences predicted are influenced by the revised staging and location of Arrow’s Updated FDP Case production, as well as revisions to geological interpretation in the OGIA 2016 Groundwater Model that underpins the modelled flux change to the Condamine Alluvium.

The modelling demonstrates that the maximum flux changes to the Condamine River are small and the predicted impacts to the river and water resource are negligible under both FDP cases.

Groundwater dependent ecosystems

To satisfy the commitments made in the Stage 1 CSG WMMP and to address Approval Condition 17 (g), comprehensive field investigations were conducted at four sites: Burunga

Lane, Glenburnie, Long Swamp and Lake Broadwater. The field investigations, conducted in two parts, aimed to characterise groundwater dependent ecosystems (GDEs) and their reliance on groundwater (3D Environmental/Earth Search 2018) and to quantify the degree of inter-aquifer connectivity between the WCM and overlying formations (Arrow Energy 2018), at each of the four sites.

Investigations and findings

Multiple lines of evidence from the field investigations demonstrated that ecosystems at each of the selected sites are unlikely to be dependent on the regional groundwater systems and therefore unlikely to be at risk of impact from groundwater extraction associated with cumulative CSG development in the Surat CMA. The following are salient findings:

- The deeper-rooted trees at all four sites, with the exception of Lake Broadwater, are considered likely to be tapping downward-percolating water moving under gravity through a near-saturated vadose zone.
- The depth to the regional aquifer (which could be subject to CSG depressurisation) at each site is considerably deeper than: (i) the deepest observed rooting depth; (ii) the inferred likely zone of predominant soil moisture uptake by trees and (iii) with the possible exception of Burunga Lane, the likely maximum tree rooting depth for deeper rooted potential GDE species (such as River Red Gums).
- The relatively shallow maximum tree root depths observed (maximum of 7.6 m at Glenburnie) in comparison to the maximum anticipated depth threshold of 18 m based on literature studies (3D Environmental/Earth Search 2018).
- Limited potential for hydraulic connection between the WCM and overlying aquifers at each of the sites, the exception being potential connectivity between the Springbok Sandstone and WCM at Lake Broadwater.
- A shallow alluvium unit hosts a perched groundwater system associated with Lake Broadwater, however numerical modelling has demonstrated that groundwater extraction from the WCM in association with CSG development in the vicinity of Lake Broadwater, is unlikely to contribute to discernible drawdown in the shallow alluvium. Accordingly, ecosystems dependent on the shallow perched groundwater at Lake Broadwater are not considered at risk of impact from CSG production in the Surat CMA.

The terrestrial GDE risk mapping in the Stage 1 CSG WMMP was revised with the Updated CSG WMMP modelling outputs, updates to the geological and GDE mapping of the Surat CMA, and the outcomes of the GDE and inter-aquifer connectivity field programs. The Updated WMMP risk mapping assessment aimed to address (in part) Approval Condition 17(g) which seeks to identify any uncertainty in the groundwater dependency of ecosystems that may be subject to potential impacts as a consequence of the Action. The Updated WMMP assessment did not identify any new areas of terrestrial GDEs at risk of potential impact from groundwater drawdown due to the Action, and in turn, no additional site-specific field investigations were indicated by the assessment to be required.

Early warning monitoring system

The approval conditions variably require early warning indicators, trigger thresholds and limits, as summarised in the table below. Collectively, this is the early warning monitoring system (EWMS).

System	**Early warning indicator**	**Trigger threshold**	**Groundwater or drawdown limit**
Consolidated aquifers	-	-	✓
Condamine Alluvium	✓	✓	✓
GDEs	✓	✓	-
Aquatic ecosystems	✓	✓	-

The EWMS for the SGP includes tiered investigation levels with escalating responses:

1. Early warning indicators, for early identification of potential issues.
2. Trigger thresholds, for identifying the potential to exceed limits, and enable actions to be selected and implemented to reduce the likelihood of limit-exceedance.
3. Limits, that define levels of impact not to be exceeded.

Early warning indicators, trigger thresholds and limits, are level-based, and derived from cumulative modelled drawdown predictions. Buffer values, referred to as ‘drawdown factors’, are included to minimise triggering caused by spurious water level changes from non-CSG causes, and are derived from the bore trigger thresholds under the Queensland Water Act 2000.

Early warning indicators are specified in three-yearly time steps and taken from the maximum predicted drawdown in each three year period. Trigger thresholds are assigned as a drawdown level half-way between the early warning indicator and the limit.

Drawdown limits are minimum potentiometric groundwater levels specified for consolidated aquifers (i.e. the Springbok, Hutton and Precipice sandstone aquifers). Groundwater limits are minimum groundwater levels specified for the Condamine Alluvium and non-spring GDEs. The limit assigned for the consolidated aquifers and the Condamine Alluvium aquifer are based on the maximum model-predicted P95 cumulative (CSG + non-CSG) drawdown level predicted to occur in 100 years (from commencement of the Action), at any point in the relevant aquifer on Arrow tenure, plus a drawdown factor.

The limit assigned for non-spring GDEs, determined to be at potential risk of impact, is derived from the maximum model-predicted P95 cumulative (CSG + non-CSG) drawdown level predicted to occur in 100 years (from commencement of the Action), at any point in the GDE host aquifer on Arrow tenure.

EWMS operation is underpinned by an early warning monitoring network. Data from this network will be analysed and compared to the assigned early warning indicators, triggers and limits. The data will also be used to generate new impact forecasts and help consolidate the understanding of groundwater systems across the SGP, and for updating groundwater models that support the WMMP.

Monitoring network and program

Groundwater

A groundwater monitoring network and sampling and analysis program (presented in the Stage 1 CSG WMMP) has been developed to monitor CSG-related groundwater drawdown, to provide baseline data, and to enable the identification of early warning conditions as monitoring data are acquired over time.

The monitoring network utilises Arrow's existing and planned monitoring locations as required by the Surat Cumulative Management Area Underground Water Impact Report Water Management Strategy (WMS).

The CSG WMMP monitoring network comprises 105 monitoring bore/vibrating wire piezometer intervals (including 57 WCM intervals at 32 discrete monitoring locations). A total of 31 monitoring intervals across the unconsolidated and consolidated aquifers at 29 discrete monitoring locations will serve as the early warning monitoring network as part of the EWMS. Groundwater pressure will be monitored at all monitoring network locations. Where data loggers are installed, hourly measurements will be recorded, with bi-annual manual readings. Where data loggers are not installed, fortnightly manual readings will be recorded.

Groundwater quality will be monitored in fifteen monitoring bores. During the first year of monitoring of a particular bore, a full analytical suite will be adopted at a bi-annual sampling frequency. Following this, the laboratory analytical suite may be modified on a bore by bore basis to remain aligned with the UWIR analysis suite (where it has changed).

Surface water and aquatic ecology

Surface water and aquatic ecosystems are not predicted to be impacted by WCM depressurisation to the extent that adverse ecosystem effects would arise. Further, under the Arrow CSG WMS, discharge of produced water to surface water systems is not proposed. Therefore, consistent with the Stage 1 CSG WMMP, monitoring of surface water systems and aquatic ecology is not required.

Should future project requirements include the need for discharge, or if future changes to the FDP result in the potential for impact to surface water systems and aquatic ecology, Arrow will update the CSG WMMP to ensure the monitoring network and program remains appropriate, seek approval of the revised WMMP from the Minister, and acquire adequate baseline data prior to any discharge.

Contents

List of Figures

List of Tables

1 INTRODUCTION

The SGP was approved by the Australian Government under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC) decision 2010/5344, and requires that prior to commencement, the proponent must submit an Updated Coal Seam Gas (CSG) Water Monitoring and Management Plan (WMMP) for the approval of the Minister.

This document is the Updated CSG WMMP for the Arrow Energy (Arrow) Surat Gas Expansion Project[2] (SGP). It includes, and builds upon, all the matters of the Stage 1 CSG WMMP (Appendix A).

This WMMP addresses the Australian Government approval conditions relating to the assessment, management, and mitigation of surface and groundwater impacts as a result of project development, and also addresses relevant Arrow commitments in the SGP environmental impact statement (EIS) (Arrow Energy, 2012) and Supplementary Report to the EIS (SREIS) (Arrow Energy, 2013).

1.1 Approvals and conditions

The SGP was approved by the Australian Government under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC) decision 2010/5344. Conditions 13 to 16 of the approval outline requirements for the Stage 1 CSG WMMP, and are addressed in Appendix A. The Stage 1 CSG WMMP was approved by the Minister on 18th December 2018.

Conditions 17 to 25 of the approval are addressed in this Updated CSG WMMP. The approval requires that prior to commencement, the proponent must submit a Stage 1 CSG WMMP for the approval of the Minister, peer reviewed by a suitably qualified water resources expert appointed and approved by the Minister. Dr Glenn Harrington of Innovative Groundwater Solutions Pty Ltd was the peer reviewer appointed by the Minister on 7 July 2015.

An evaluation of the SGP EIS/SREIS was also completed by the Queensland Department of Environment and Heritage Protection (EHP). An assessment report was prepared by EHP pursuant to Sections 58 and 59 of the *Environmental Protection* (EP) *Act* which recognises that through the EIS and SREIS processes Arrow has committed to the management and monitoring of groundwater and surface water resources and CSG water, and is also obliged to carry out further investigations and monitoring under the approval processes.

The approach taken in addressing the Updated WMMP approval conditions has involved preparation of three technical memoranda addressing the conditions. These were developed and provided to the appointed peer reviewer for progressive endorsement. The content of these memoranda is summarised within this plan. The memoranda are included as appendices and are summarised in Table 1-1.

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[2] Referred to as the Surat Gas Project (SGP) in this plan. The SGP was approved by the Queensland Government on 25 October 2013 and the Australian Government on 19 December 2013.

Table 1-1 Summary of technical memoranda

Technical Memoranda	Conditions addressed	Appendix
Groundwater Modelling and Research Technical Memorandum	17(b), 17(c), 17(d), 23	C
Stream Connectivity and GDE Impact Assessment Memorandum	13(c), 13(p), 17(f), 17(g)	D
Monitoring, Risk Response and Adaptive Management Memorandum	17(a), 17(e), 17(h), 17(i), 22	G

A table cross-referencing the Updated WMMP approval conditions is provided in Table 1-2.

Table 1-2 Approval condition compliance reference summary

Approval Condition	Condition description	Relevant WMMP section (and supporting documentation)
17	The approval holder must submit an Updated CSG Water Monitoring and Management Plan (Updated CSG WMMP) for written approval of the Minister. The Updated CSG WMMP must:	
17(a)	Include all matters in the Stage 1 CSG WMMP, and discuss how the Stage 1 CSG WMMP is informing adaptive management for the Updated CSG WMMP.	Section **Error! Reference source not found.** (Appendix A)
17(b)	Include any updated modelling for the project, including in respect of the OGIA model or any updates to the OGIA model by OGIA.	Section 4 (Appendix C)
17(c)	Include an explanation of how the approval holder will contribute to the Condamine Interconnectivity Research Project. The Updated CSG WMMP must present the findings of the Condamine Interconnectivity Research project and any modelling done by the OGIA to validate predicted drawdown and a review of trigger thresholds and corrective actions for the action.	Section 3.2 (Appendix C)
17(d)	Report on the potential for flow reversal from the Condamine Alluvium to underlying aquifers, based on data obtained during the Stage 1 CSG WMMP.	Section 4.3.2 (Appendix C)
17(e)	Review and update the monitoring network in Stage 1 WMMP to reflect changes in understanding of impacts to water resources, including from baseline monitoring and relevant research.	Section 3.1 Section 7.1 (Appendix G)
17(f)	Identify any predicted changes in stream connectivity due to groundwater drawdown from the action and assess potential impacts to	Section 4.4 Section 5.2

Approval Condition	Condition description	Relevant WMMP section (and supporting documentation)
	groundwater dependent ecosystems due to any predicted changes in stream connectivity, including to water quality, quantity and ecology.	(Appendix C, Appendix D)
17(g)	Address any uncertainty in the groundwater dependency of ecosystems and springs with supporting evidence from field-based investigations for any groundwater-dependent ecosystems and springs confirmed in the OGIA model.	Section 5.3 (Appendix D)
17	Provide details of an ongoing monitoring plan that:	
17(h)i	Sets out the frequency of monitoring and rationale for the frequency.	Section 7.3 (Appendix G)
17(h)ii	Includes continued collection of baseline data for each monitoring site over the life of the project.	Section 3.1 Section 7.3 (Appendix G)
17(h)iii	Outlines the approach to be taken to analyse the results including the methods to determine trends to indicate potential impacts.	Section 7.4 (Appendix G)
17(h)iv	Builds on the groundwater early warning system required at condition 13j and sets out early warning indicators and trigger thresholds and limits for groundwater and surface water.	Section 7.5 (Appendix G)
17(i)	Include a risk based exceedance response plan that details the actions the approval holder will take and the timeframes in which those actions will be undertaken if: early warning indicators and trigger threshold values contained in the Updated CSG WMMP are exceeded, or there are any emergency discharges.	Section 7.6 Section 8.2 (Appendix G)
18	The Updated CSG WMMP must be peer reviewed by a suitably qualified water resources expert/s approved by the Minister in writing prior to the plan being submitted to the Minister for approval. The approval holder must, at the same time as the Updated CSG WMMP is submitted for approval, provide to the Minister: a) a copy of the peer review; and b) a statement from the suitable qualified water resources expert/s stating that they carried out the peer review and endorse the findings of the Updated CSG WMMP.	Section 8.5 (Appendix I)

Approval Condition	Condition description	Relevant WMMP section (and supporting documentation)
19	The approval holder must not exceed the groundwater drawdown or groundwater limits specified in the Updated CSG WMMP.	NA
20	The Minister may direct in writing that the approval holder cease water/gas extraction and/or water discharge or use if: a) an early warning indicator, trigger threshold, or limit is exceeded, and b) the Minister is not satisfied that the corrective activities proposed or taken by the approval holder will reduce likely impacts on matters of national environmental significance (MNES) to acceptable levels.	NA
20A	If condition 20 applies, the Minister may direct the approval holder to implement alternative corrective activities at the expense of the approval holder, provided those corrective activities are unlikely to have a significant impact on MNES.	NA
20B	If condition 20 applies, the approval holder must not recommence such extraction or discharge or use until the Minister has given approval in writing for the recommencement of that extraction, discharge or use. a) Approval to recommence such extraction, discharge or use may be subject to such conditions as the Minister considers reasonably necessary to ensure that impacts on MNES will be acceptable. b) If the Minister approves the recommencement of extraction, discharge or use subject to conditions, the approval holder must comply with such conditions.	NA
21	The approval holder must not commence the extraction of gas from any coal seam gas production wells unless the Updated CSG WMMP has been approved by the Minister in writing. The approved Updated CSG WMMP must be implemented. The Stage 1 CSG WMMP will apply until the commencement of the approved Updated CSG WMMP.	NA
21A	If the Minister has approved the Updated CSG WMMP, the approval holder may commence extraction of gas from: a) 250 coal seam gas production wells; b) a larger number of coal seam gas production wells as specified by the Minister if he or she is satisfied that: (i) the approval holder has commenced gas extraction from at least 125 coal seam gas production wells; (ii) the approval holder has requested an increase in the number of wells from which gas can be extracted under the approved Updated CSG WMMP; and (iii) extraction of gas from the additional number of	NA

Approval Condition	Condition description	Relevant WMMP section (and supporting documentation)
	coal seam gas production wells will not have an unacceptable impact on MNES.	
22	Revoked	NA
23	If the OGIA model ceases to exist, then the approval holder must: a) submit an alternate model that replaces the OGIA model for approval by the Minister; b) revise the Updated CSG WMMP to incorporate the approved alternate model, and submit the revised plan to the Minister for approval; and c) implement the approved revised plan.	Section 4.6
24	Revoked	NA
25	The Minister may, by written request to the approval holder, require the Stage 1 or Updated CSG WMMP to be revised, including to address expert advice. Any request must be acted on by the approval holder within the timeframe specified in the request.	NA

1.2 Project description

The Surat Basin, located approximately 250 km west of Brisbane in Queensland, hosts a number of gas fields with significant coal seam gas resources. Arrow is developing these resources through exploration, field development, and gas production.

Since preparation of the SGP EIS further knowledge of the gas reserves has been gained and subsequently, parcels of land within Arrow's exploration tenements have been relinquished. The size of the tenure for the project development has reduced from approximately 6,000 km^2 to 5,600 km^2 (refer Figure 2-1).

The SGP project description, described in Appendix C of the Stage 1 CSG WMMP (Appendix A of the Updated CSG WMMP), has been revised for the Updated CSG WMMP to incorporate an updated Field Development Plan (FDP), hereafter referred to as the 'current FDP'.

The current SGP FDP involves an expansion of Arrow's CSG production in the Surat Basin. As described in the Supplementary Report to the Environmental Impact Statement (SREIS), the SGP comprised a FDP based on 6,500 wells and total water production of 510 GL. This production has been subsequently revised, and the Updated CSG WMMP is based on an updated FDP comprising 2,612 wells and total water production of 575 GL.

Table 1-3 provides a summary comparison of historical SGP FDP cases and the current Updated CSG WMMP FDP.

Table 1-3 FDP comparison

FDP Case	Arrow case descriptor	Water production			Duration (years)
		Forecast total (GL)	Modelled total (GL)	Modelled peak rate (GL/a)	
SREIS FDP	5x	510	702	34	65
OGIA (UWIR) 2016 FDP	8b	460	1204	n/a	54
Stage 1 CSG WMMP FDP	SREIS case	510	710 (1)	138 ML/d (2)	65
Updated CSG WMMP FDP	**10a**	**575**	**1178**	**123.3 ML/d**	**40**

Notes:
(1) Median modelled value (CDM Smith, 2016).
(2) Based on median modelled value 138 ML/d (CDM Smith, 2016).

In addition to the development detailed above, Arrow operates existing Surat Basin gas fields, facilities and infrastructure in the area surrounding Dalby, comprising the Daandine, Kogan North and Tipton West production areas.

1.3 Definitions

Key terms relevant to the WMMP are defined in Table 1-4. Other technical terms in this document, where not specifically defined, are assumed to have the same meaning as defined in the SGP EIS/SREIS.

Table 1-4 Definitions

Term	Definition[3]
Background level	Non-Arrow CSG influenced existing conditions (levels or quality).
Consolidated aquifer	Aquifer in a consolidated sedimentary formation.

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[3] Where relevant, the terms are defined in relation to the SGP induced change.

Term	Definition[3]
Drawdown factor	Derived from the Queensland Water Act[4] for similar systems, being 5 m for consolidated aquifers and 2 m for unconsolidated aquifers. No drawdown factor is added for non-spring GDEs or for spring GDEs.
Groundwater drawdown due to the Action	Change in head relative to the background level arising from the Action.
FDP	Field development plan. Describes the CSG wellfield plan and timing for the Action.
SGP area	The Surat Gas Project development area and surrounding land within the extent of drawdown impact as a result of the Action.
The Action	The Arrow SGP.
Early warning indicator	A first-tier drawdown level that provides early indication of potential for an impact.
Trigger threshold	A second-tier drawdown level that triggers response actions.
Groundwater limit[5] or drawdown limit[6]	A groundwater level-based limit for an aquifer or GDE[7] not to be exceeded.
MNES	Matters of National Environmental Significance (water resources and the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin)

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[4] Taken from the bore trigger thresholds under the Queensland Water Act 2000.

[5] Refers specifically to Approval Condition 13(j)ii.

[6] Refers specifically to Approval Condition 13(j)i.

[7] Limit for GDEs voluntarily adopted as per Table 5-1.

2. ENVIRONMENTAL SETTING

The SGP area is located within the Darling Downs region of South East Queensland, and encompasses authorities to prospect (ATPs) and petroleum leases (PLs) located from Wandoan in the north to Millmerran in the south, in an arc west of Dalby (refer Figure 2-1).

Intensive agriculture and settlement have occurred along the Condamine River valley, central to the SGP. Agriculture, forestry, oil and gas development and coal mining are the main land uses. Agriculture includes intensive irrigation, cropping, poultry farming, grazing, piggeries, and cattle feedlots.

The SGP is located within the Brigalow Belt bioregion and is characterised by patches of remnant woodland and forest communities (mainly eucalypt). Most native vegetation is confined to large areas of state forests and linear tracts of vegetation along road reserves and watercourses.

The following sections provide a brief overview of the SGP setting with further detail provided in the SGP EIS and SREIS.

2.1 Climate

The SGP climate is characterised under the Köppen–Geiger climate classification system as a humid subtropical climate (class Cfa). Summers are warm to hot, but without dry months.

The mean maximum monthly temperature ranges from 19.7C in winter to 32.5C in summer. The mean annual evaporation is approximately 2260 mm, and the monthly mean evaporation data when compared with the rainfall data shows a seasonal water deficit.

Table 2-1 presents representative mean monthly rainfall from Dalby Airport and potential evaporation data for the Daandine area.

Table 2-1 Mean climate characteristics

Precipitation (mm)	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Annual**
Mean	78	77	59	19	38	32	23	24	32	56	73	94	605
Dalby Airport (Station number 41522) (data downloaded May 2017)													
Evaporation (mm)	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Annual**
Mean	280	215	225	175	110	90	95	140	170	235	245	280	2260
Daandine area (data downloaded Nov 2016)													

Source: *Bureau of Meteorology data (www.bom.gov.au).*

ARROW ENERGY - SURAT GAS PROJECT

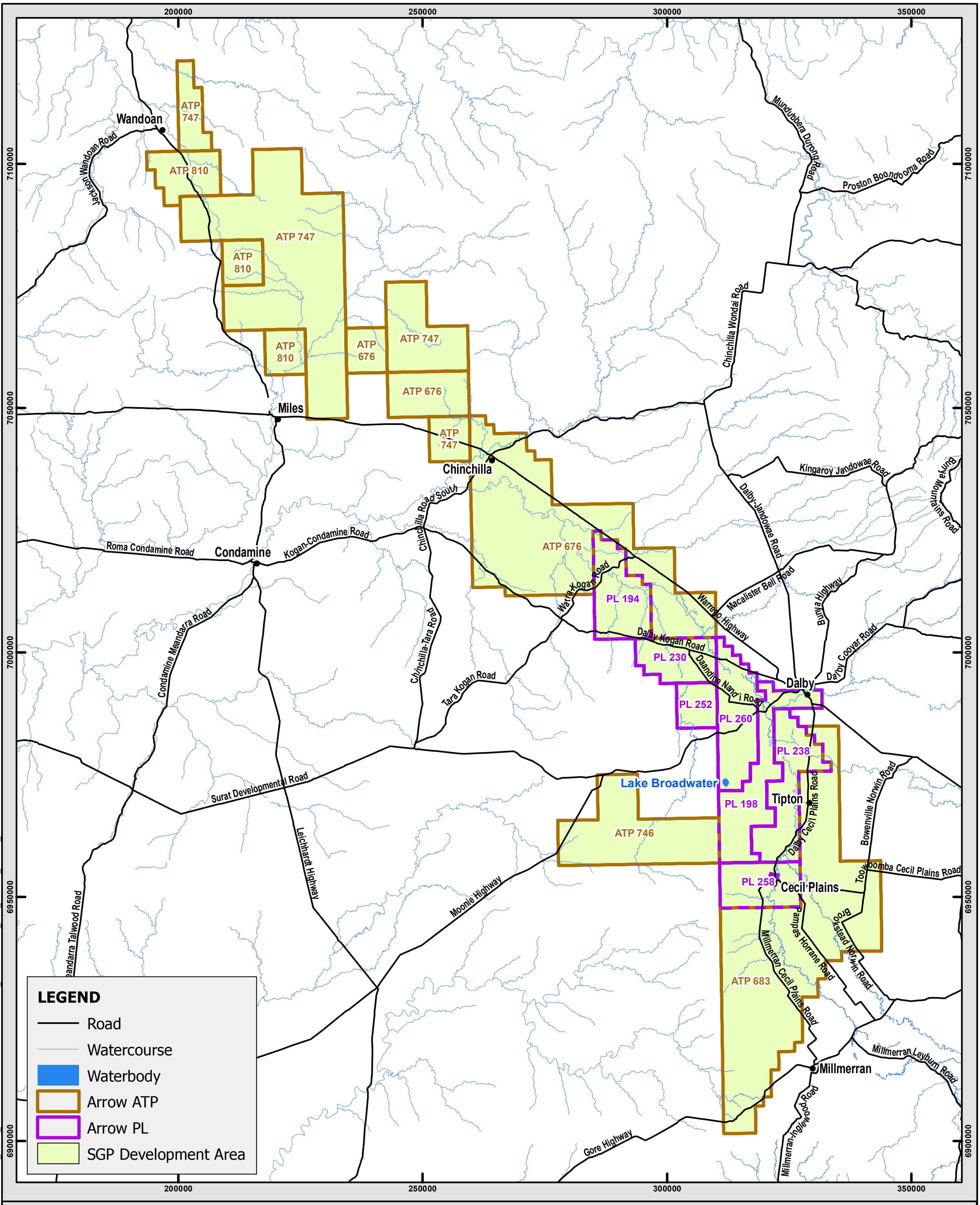

Figure 2.1 Surat Gas Project area

Source:
Arrow Energy Pty Ltd

Date: 11/02/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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go further

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2.2 Topography and landform

Topography across the SGP area is predominantly low relief, with elevation ranging between 200 and 400 metres Australian Height Datum (mAHD) and overall sloping gently towards the south-west.

Several major physiographic regions are present, which are functions of the underlying geology and geomorphic evolution.

The major feature is the Condamine River valley which is bounded by the Great Diving Range to the east and Kumbarilla Ridge to the west (Figure 2-2). The valley extends north and south into the Dawson and Border Rivers catchments respectively. At its broadest, the valley is approximately 50 km wide. Where the Condamine River has incised the Kumbarilla Ridge to the west of Chinchilla, the valley is appreciably narrower at about 5 km wide.

The Great Dividing Range highlands comprise resistant igneous rocks overlying generally coarse-grained sandstones. The Kumbarilla Ridge uplands, along the west of the SGP area, are characterised by gentle slopes developed on consolidated sedimentary formations, with maximum elevations of around 420 mAHD.

2.3 Hydrology and drainage

The Condamine and Balonne rivers dominate the hydrology of the SGP area and are part of the greater Murray-Darling Basin. Figure 2-3 presents the major drainage systems in the region.

2.3.1 Drainage and river systems

Condamine River

The Condamine River is the main regional river system in the SGP area. The highly variable, permanent to semi-permanent Condamine River flows north through the Cecil Plains-Dalby area, north-west and west towards Chinchilla, then south-west from Condamine, eventually becoming the Balonne River that feeds into the Murray-Darling River system.

In the Condamine River valley, watercourses are generally incised with well-defined channels that are dissociated from their floodplains, particularly along the fringes of the Kumbarilla Ridge.

Incision, bank erosion, channel migration and avulsion of the rivers and creeks have left palaeochannel meander scars and terraces within the more recent alluvial deposits. Depositional features, such as levees and sandbars are common, indicating that in recent geological times the watercourses have been dynamic systems.

Dawson River

The Dawson River catchment is in the north of the SGP area. The Juandah Creek, a tributary of the Dawson River, is the major watercourse and flows north-west through Guluguba and Wandoan.

The watercourses are similar in morphology to those in the Condamine River catchment being generally incised and having well-defined channels. Sandy alluvium has been deposited along the valley floors adjacent to the creeks.

Border Rivers

The Border Rivers catchment is in the south of the SGP area. Major watercourses include Wyaga Creek and Commoron Creek, which flow south-west towards Goondiwindi. The catchment falls within two broad terrain types: uplands associated with the sandstone Kumbarilla Ridge, falling to broad clay and sandy alluvial plains.

Adjacent to the major watercourses sandy alluvium has been deposited over floodplain areas. Linear relict fans, terraces and levees composed of reworked alluvium indicate the dynamic nature and down-cutting of watercourses in recent geological times (Thwaites and Macnish, 1991).

The Border Rivers catchment is drier than the Condamine and Dawson Rivers catchments, being further inland and in the Kumbarilla Ridge rain-shadow.

2.3.2 Lakes and wetlands

Lake Broadwater and Long Swamp are key surface water features within the SGP area. They are located in the central part of the SGP area to the west of Tipton (refer Figure 2-3).

Lake Broadwater is a Category ‘A’ Environmentally Sensitive Area under the Queensland Environmental Protection Regulation (2008) and a Nationally Important Wetland under the EPBC Act. Lake Broadwater has high conservation value due to its intactness, the importance of its seasonal aquatic habitat, and its potential habitat for the EPBC Act listed Murray Cod.

Long Swamp is a palustrine[8] wetland to the north-east of Lake Broadwater, considered to be an older course of the Condamine River. It is not classified under state or commonwealth legislation but is recognised locally as a natural and important wetland. Long Swamp is hydraulically connected to Lake Broadwater, filling during wet periods, and has local conservation status due to the range and diversity of riparian vegetation along the length of the wetland.

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[8] Lacking flowing water, or marshy.

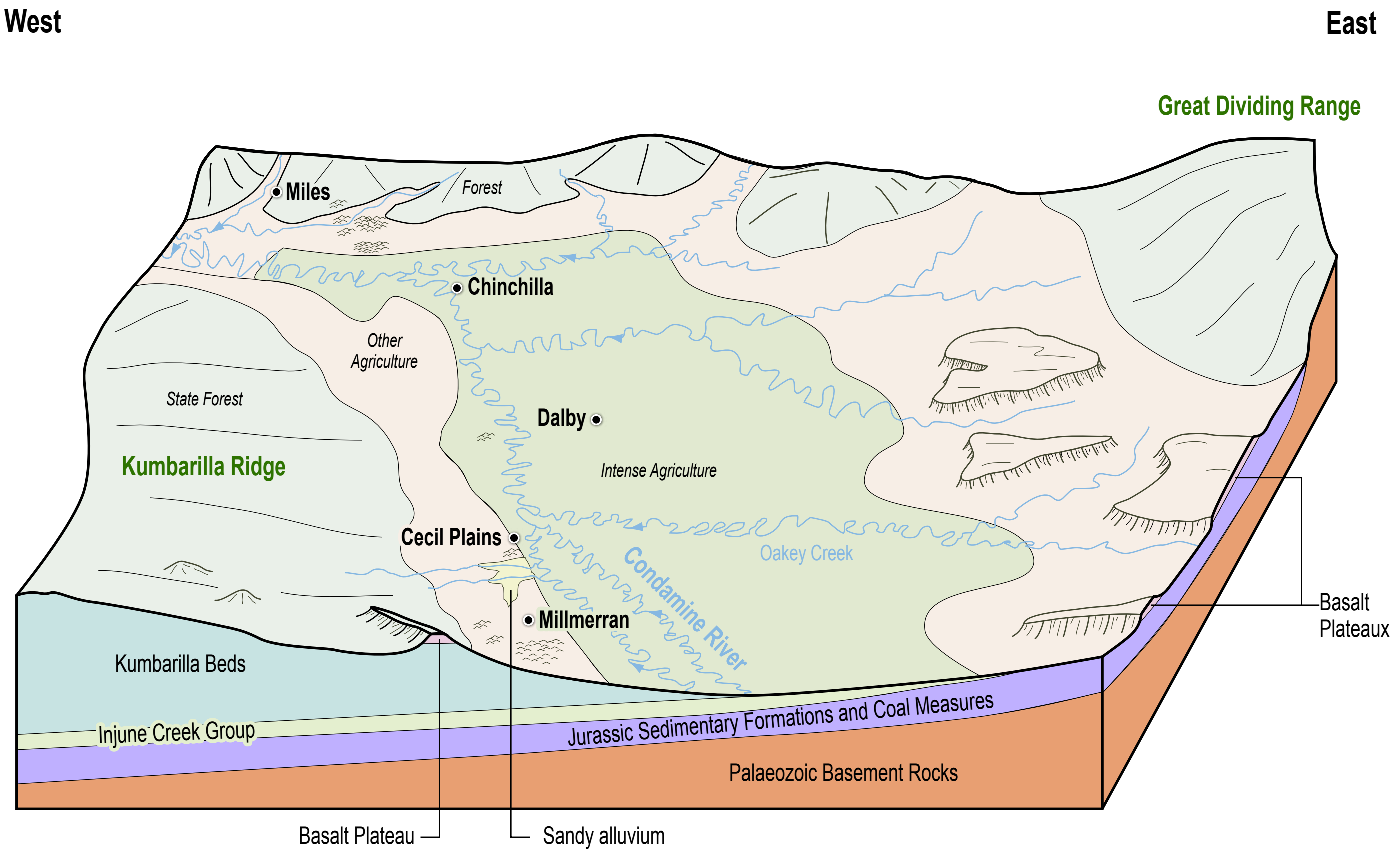

Figure 2.2 Landform characteristics of the Condamine River Valley

Source:
Arrow Energy Pty Ltd

Date: 11/01/2019
Issued To: Arrow Energy
Author: Helen.Unkovich/Richard.Heath

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ARROW ENERGY - SURAT GAS PROJECT

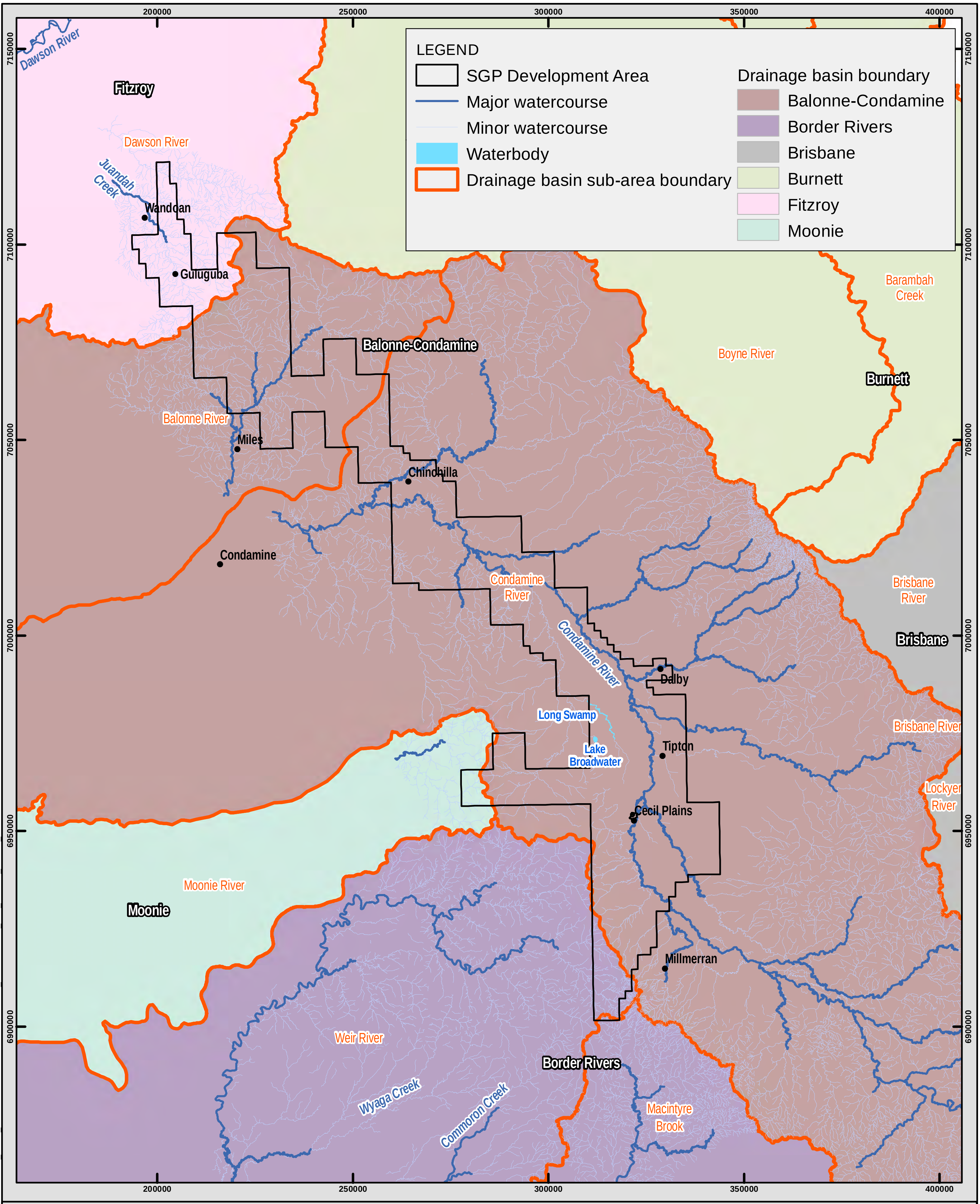

Figure 2.3 Major drainage systems in the Surat Gas Project area

Source:
Arrow Energy Pty Ltd

Date: 11/02/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

Scale: 1:1,250,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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2.4 Geology

2.4.1 Surat Basin structure and geological controls

The SGP lies within three major structural Mesozoic basins: the Surat Basin (in the south and west) which unconformably overlies the Bowen Basin in the north and is separated from the Clarence-Moreton basin to the east by the Kumbarilla Ridge, an anticlinal structure. Figure 2-4 presents important structural elements of the study area.

Disconformably underlying parts of the Surat Basin is a gently folded Permian to Triassic sequence of the north-south aligned Taroom Trough, which is the sub-surface extension of the Bowen Basin. In this area, a sedimentary sequence up to 2,500 m thick in the down-warped south/south-east to north/north-west trending Mimosa Syncline has been recorded (Reiser, 1971).

The Surat Basin stratigraphy includes folded sedimentary sequences, intersected in places by faults. These fault structures can be fully or partially penetrating through the full geological sequence, and major faulting within the Surat Basin is generally an expression of boundary faults of the underlying Bowen Basin (Arrow, 2013).

2.4.2 Stratigraphy

Many of the sedimentary formations of the Surat Basin are relatively consistent over significant distances. However facies changes, the influence of structural controls and other factors result in variable lithology in laterally equivalent or inter-fingered formations.

Table 2-2 presents the generalised stratigraphy and lithology of the Surat Basin, including hydrostratigraphy. It is noted that actual strata present at any location varies across the region.

Further detail is provided in the SGP EIS and the 2016 Surat Cumulative Management Area (CMA) Underground Water Impact Report (UWIR) (DNRM, 2016a).

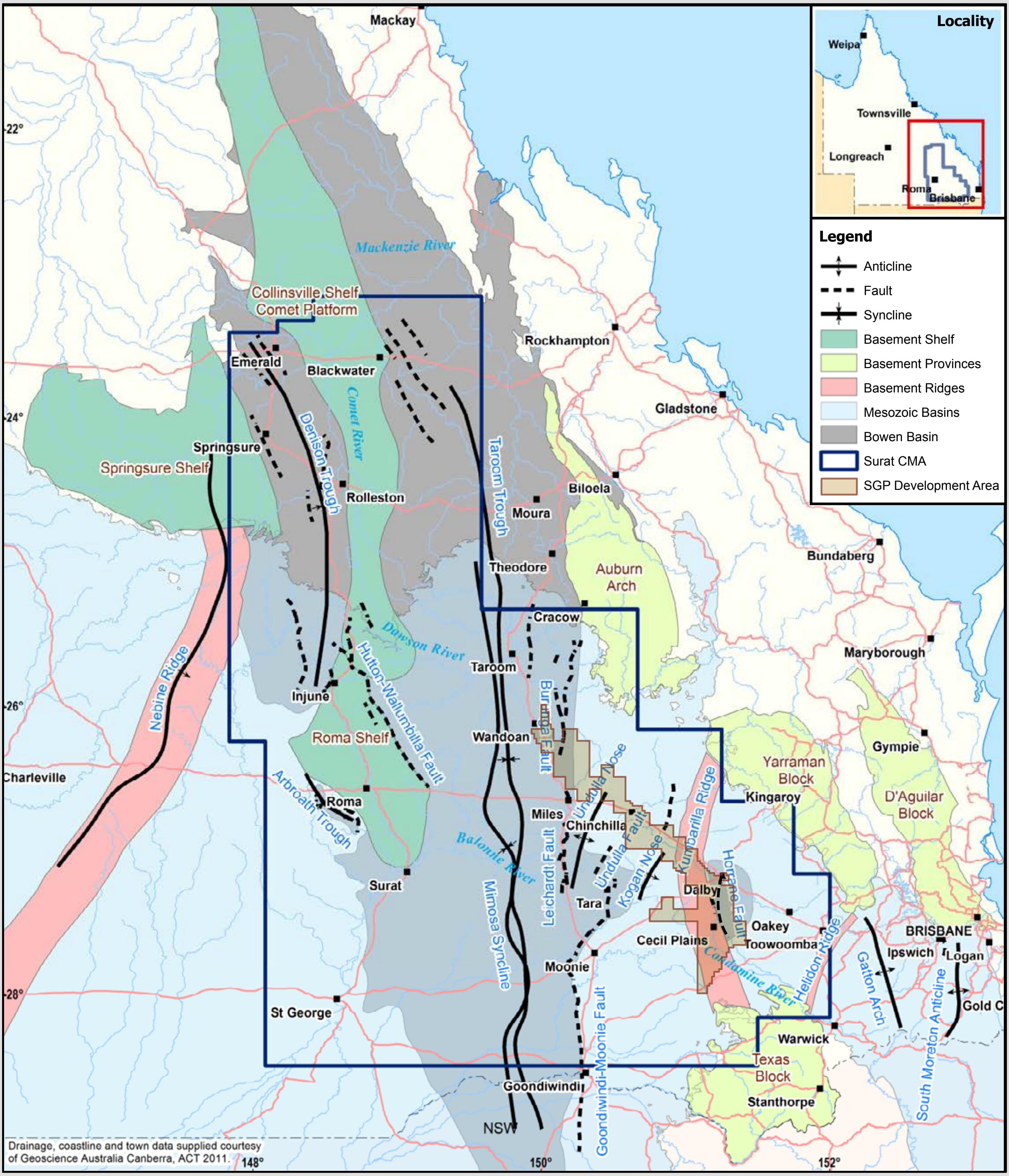

Figure 2.4

Major geological structures in the Surat CMA

Source:
UWIR 2016,
Department of Natural Resources
and Mines 2016

Date: 11/01/2019
Issued To: Arrow Energy
Author: Helen.Unkovich/Richard.Heath

0 20 40 80 120 160 200
Kilometres

Scale: 1:4,000,000 @ A4

Coordinate System: GCS GDA 1994

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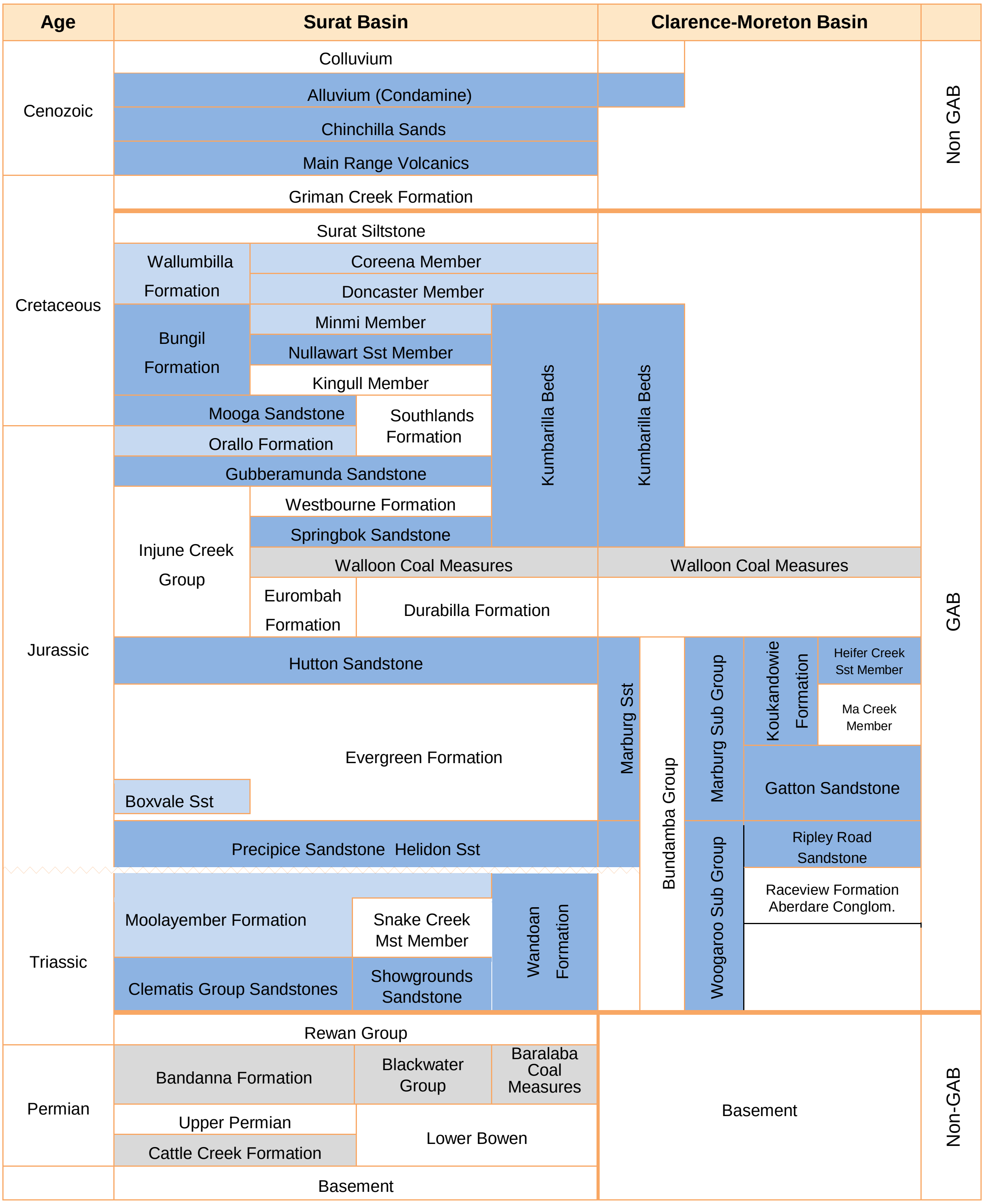
Table 2-2 Generalised Surat Basin stratigraphy



Age	Surat Basin				Clarence-Moreton Basin					
Cenozoic	Colluvium									Non GAB
	Alluvium (Condamine)									
	Chinchilla Sands									
	Main Range Volcanics									
Cretaceous	Griman Creek Formation									
	Surat Siltstone									GAB
	Wallumbilla Formation	Coreena Member								
		Doncaster Member								
	Bungil Formation	Minmi Member		Kumbarilla Beds	Kumbarilla Beds					
		Nullawart Sst Member								
		Kingull Member								
	Mooga Sandstone		Southlands Formation							
Jurassic	Orallo Formation									
	Gubberamunda Sandstone									
	Injune Creek Group	Westbourne Formation								
		Springbok Sandstone								
		Walloon Coal Measures			Walloon Coal Measures					
		Eurombah Formation	Durabilla Formation							
	Hutton Sandstone				Marburg Sst	Bundamba Group	Marburg Sub Group	Koukandowie Formation	Heifer Creek Sst Member	
	Evergreen Formation								Ma Creek Member	
	Boxvale Sst							Gatton Sandstone		
	Precipice Sandstone Helidon Sst						Woogaroo Sub Group	Ripley Road Sandstone		
Triassic	Moolayember Formation	Snake Creek Mst Member		Wandoan Formation				Raceview Formation Aberdare Conglom.		
	Clematis Group Sandstones	Showgrounds Sandstone								
	Rewan Group				Basement					Non-GAB
Permian	Bandanna Formation	Blackwater Group	Baralaba Coal Measures							
	Upper Permian	Lower Bowen								
	Cattle Creek Formation									
	Basement									

Minor discontinuous aquifer	Major aquifer	Productive coal seam	Aquitard

Source: *DNRM (2016a). SSt = sandstone Mst = mudstone Fm: formation*

Condamine Alluvium

The Condamine Alluvium extends in a north-south direction from around Chinchilla in the north to Millmerran in the south (refer Figure 2-5). It is present in the central and eastern regions of the SGP area, and includes an alluvial flood plain that comprises predominantly Quaternary basal alluvium and an overlying finer grained sheetwash sediment associated with the Condamine River and its tributaries.

The alluvial sediments comprise fine to coarse grained gravels and channel sands interbedded with clays. The finer grained sheetwash deposits overlie the fluvial floodplain deposits and thicken to the east. Individual clay and silt horizons of the sheetwash can be over 20 m thick and may represent confining layers where laterally continuous. The sheetwash is derived from the Tertiary Main Range Volcanics to the east that form a significant vertisol (black soil) cover over much of the Condamine River valley.

A layer of basal alluvial clays and weathered material exists between the lowermost granular sediments of the Condamine Alluvium and the uppermost unit of the Walloon Coal Measures (WCM).

Figure 2-5 presents a schematic cross section illustrating the conceptual relationship between the Condamine Alluvium and the underlying formations through the centre of the SGP area, and highlights how the Condamine Alluvium is incised into the WCM. To the north along the western margin of the alluvium the Springbok Sandstone also underlies the Condamine Alluvium and to the south, along the eastern margin, the Hutton Sandstone underlies the Condamine Alluvium.

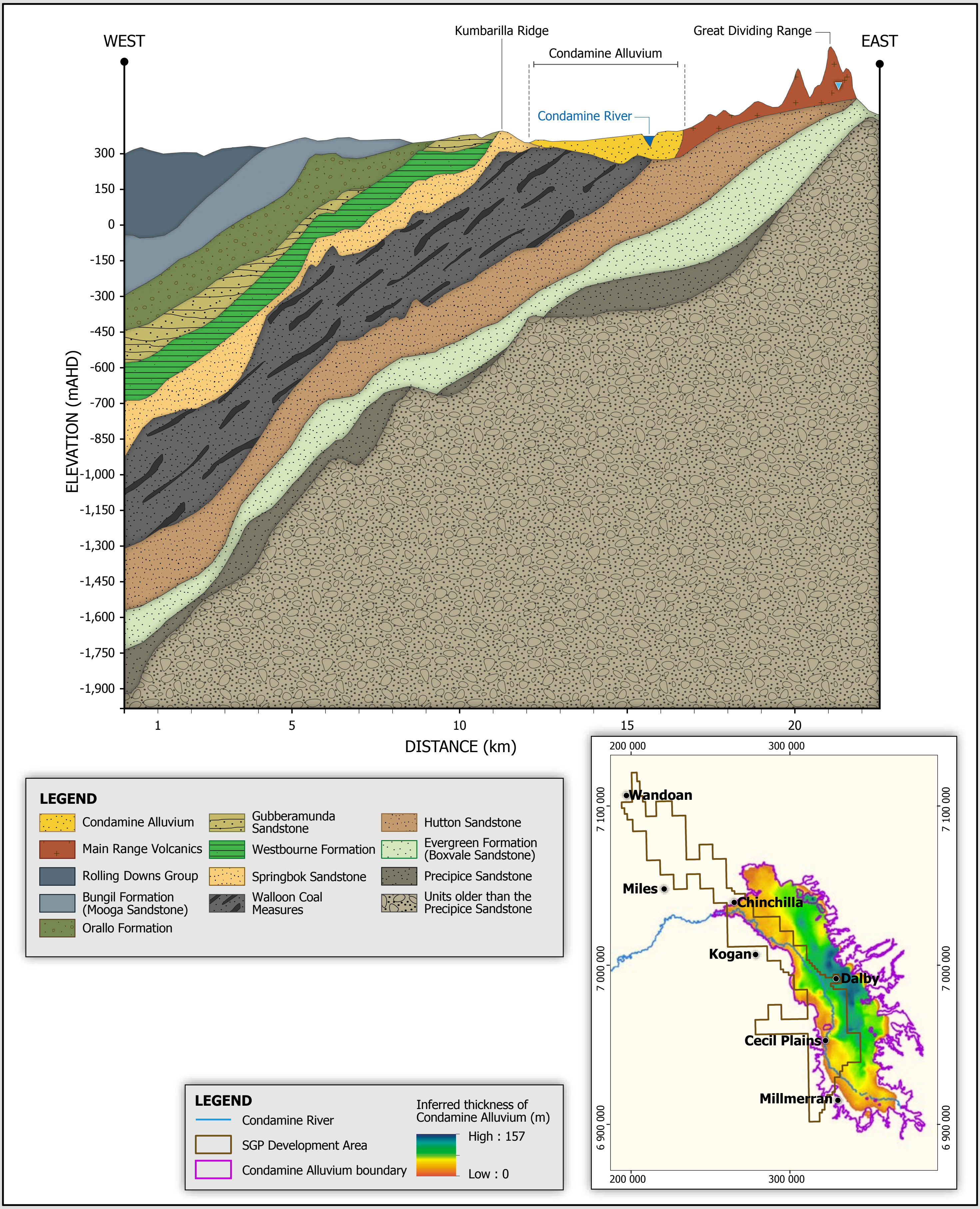


Figure 2.5 **Schematic cross-section of Condamine Alluvium and underlying units**

Source:
Coffey

Date: 11/01/2019
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Author: Helen.Unkovich/Richard.Heath

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2.5 Hydrogeology

Extraction of CSG requires depressurisation of the coal measures. In the Surat Basin, the WCM host the target coal seams for CSG production. Depressurisation of the WCM may propagate to overlying and underlying formations, and an understanding of the hydrogeology of the Surat Basin is required to predict the impacts associated with CSG development.

The Surat Basin includes three main aquifer systems: the consolidated sedimentary aquifers (Great Artesian Basin aquifers), the surficial alluvial aquifers (including the Condamine Alluvium aquifer), and the volcanic (basalt) aquifers.

Groundwater resources in the Surat Basin are used extensively for agriculture, and abstraction has led to a broad decline in groundwater pressures, particularly in the Condamine Alluvium, but also in deeper GAB formations.

Further detailed information on the hydrogeological conceptualisation is provided in the SGP EIS/SREIS as well as more recent reports developed by the Office of Groundwater Impact Assessment (OGIA) including the Surat CMA UWIR (DNRM, 2016a).

2.5.1 Hydrostratigraphy

The SGP area contains both unconfined and confined aquifers. Table 2-2 presents the regional hydrostratigraphy. Major aquifer formations include:

- Condamine Alluvium: shallow unconsolidated and unconfined aquifer.
- Gubberamunda and Mooga Sandstone: consolidated unconfined to confined sandstone aquifers of the GAB.
- Springbok Sandstone: consolidated unconfined to confined sandstone GAB aquifer. Can have significant mudstone and siltstone content in some areas where it behaves more like an aquitard.
- Walloon Coal Measures: generally confined siltstone, mudstone and clayey sandstone aquifer within the GAB. Thin permeable coal and sandstone seams can yield usable quantities of water (DNRM, 2016a).
- Hutton[9] Sandstone: deeply buried confined consolidated sandstone GAB aquifer.
- Precipice Sandstone: deeply buried confined consolidated sandstone and siltstone GAB aquifer.

2.5.2 Aquifer recharge

Recharge mechanisms of the Condamine Alluvium

Recharge includes infiltration from the Condamine River, with contribution from rainfall infiltration and laterally from the surrounding bedrock and alluvium of the tributaries of the Condamine River (DNRM, 2016a) However, water balance modelling completed (KCB, 2011a) indicates that while

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[9] Includes laterally equivalent Marburg Sandstone where present.

rainfall recharge rates are low, volumetrically, diffuse rainfall recharge to the watertable is a major component of the water balance as it occurs over such a large area.

Other recharge mechanisms for the Condamine Alluvium include interaction with underlying formations, bedrock contribution from the east and west, flux from upstream (throughflow), tributary and meander channel seepage, flood recharge and irrigation deep drainage (KCB, 2011a).

Recharge mechanisms of GAB formations

Recharge to GAB formations is primarily by direct rainfall infiltration where the formations outcrop to the north, north-west and north-east of the Surat Basin along the Great Dividing Range. Recharge is primarily along preferential flow pathways including bedding planes and fractures (DNRM, 2016a). South of the Great Diving Range where the SGP is largely located, groundwater flow direction is largely south and south-west, away from the recharge areas. North of the Great Dividing Range there is some northerly flow component (DNRM, 2016a).

Vertical leakage between GAB aquifers is restricted in many areas by the low permeability aquitards present throughout the GAB, including the Evergreen and Westbourne formations and their equivalents (DNRM, 2016a).

2.5.3 Influence of faulting

Regional-scale faults in the Surat CMA with significant displacement are indicated to be restricted to formations in the underlying Bowen Basin and do not typically extend to the overlying formations of the Surat Basin (QWC, 2012; Sliwa, 2013; DNRM, 2016b). Within the overlying Surat Basin the most common faults are steeply dipping normal faults. These faults are considered to be relatively minor structural features with throws that are generally less than 20 m.

Sliwa (2013) reports that the mild deformation observed in Surat Basin post-dates deposition, and a phase of rift-style normal (extensional) faulting has occurred. This was followed by a return to compressional tectonics that resulted in mild reactivation of the Moonie-Goondiwindi Fault system (located to the west of Arrow’s tenements), partial inversion of some normal faults, tightening of the underlying Bowen Basin folds, and development of gentle folding in overlying younger Surat rocks (Sliwa, 2013).

A low angle unconformity between the upper-most coal seams of the WCM and the overlying Springbok Sandstone is indicated through seismic analysis. Sliwa (2013) reports that from the seismic data none of the Surat normal faults were found to propagate vertically to an extent sufficient to terminate against the Springbok unconformity. This indicates that the period of normal faulting is likely to have occurred during or prior to the end of WCM deposition, prior to the subsequent erosional period and low angle unconformity, and prior to the deposition of the Late Jurassic Springbok Sandstone.

Hence, based on the seismic evidence, and also by inference due to the timing constraints, it is concluded that the fault structures do not extend to the Springbok Sandstone. Therefore, in the SGP area fault induced drawdown propagation across the Springbok, or younger formations including the Westbourne Formation and Gubberamunda Sandstone is not expected.

In addition, hydrothermal precipitation and induration may have led to sealing of fault damage zones since Jurassic times. Because the tectonically stable Surat Basin remains relatively inactive, fault permeability is expected to continue to decrease over time (DNRM, 2016b), and the majority of faults in the Surat CMA are therefore not expected to provide a conduit for vertical flow from overlying aquifers to the coal measures.

DNRM (2016b) also report that as the coal seams within the major gas reservoirs generally represent less than 10% of the unit thickness, any displacement is likely to result in a barrier to horizontal groundwater flow, as the more permeable coal seams are juxtaposed with lower-permeability siltstone, claystone or mudstone members.

2.5.4 Groundwater use

Groundwater has historically been utilised extensively throughout the Surat CMA for a range of purposes including irrigation, agriculture, grazing, industry and urban supply. Groundwater is primarily extracted from GAB (consolidated) aquifers, the Condamine Alluvium and Main Range Volcanics for these purposes.

Groundwater extraction associated with the petroleum and gas industry is also increasing with the expansion of CSG activity throughout the Surat CMA.

Groundwater use is detailed in the following sections.

Non-petroleum and gas related groundwater extraction

The Condamine Alluvium has historically been over-developed and over-allocated with respect to the productive yield of the system (QWC, 2012) resulting in significant lowering of the watertable, and in some areas resulting in disconnection of the Condamine River with the Condamine Alluvium.

The impact on this resource has been recognised since 1970, and access to Condamine Alluvium groundwater systems in the Upper Condamine Catchment was limited through a moratorium on development of groundwater which commenced in June 2008 and ended in December 2014 (DNRM, 2017). In addition, announced allocations in a number of subgroup areas of the Central Condamine Alluvium Groundwater Management Area for the 2017 water year were 50% to 70% of nominal entitlements to address this issue (DNRM, 2017).

A summary of the non-petroleum groundwater extraction bores and extraction volumes reported in the Surat CMA UWIR (DNRM, 2016a) is provided in Table 2-3, and Table 2-4 provides surface water licensing for comparison.

There are over 22,500 water bores within the Surat CMA with a combined water extraction in the order of 203,000 ML/yr. Of this, around 53,000 ML/yr is sourced from GAB formations, and 150,000 ML/yr from other aquifers. The total groundwater extraction presented in Table 2-3 represents groundwater used for agricultural, industrial, urban and stock and domestic purposes.

Non-GAB aquifers having the greatest number of groundwater bores and extraction volumes in the Surat CMA include the Condamine Alluvium, Main Range and Tertiary Volcanics. Production from the GAB aquifers is mainly from the Hutton-Marburg Sandstone, the WCM, and the Precipice/Helidon Sandstone (DNRM, 2016a).

Table 2-3 Non-petroleum groundwater extraction in the Surat CMA

Formation	Number of bores			Estimated groundwater extraction (ML/yr)				Total (ML/yr)
	Non-S&D	S&D	Total	Agriculture	Industrial	Town water supply	S&D	
Non-GAB upper formations								
Condamine Alluvium	1,144	2,709	3,853	64,251	1,476	4,227	2,070	72,024
Main Range Volcanics & Tertiary Volcanics	1,293	5,924	7,217	39,200	2,659	4,459	4,726	51,044
Other alluvium	322	1,201	1,523	16,130	555	1,311	1,447	19,443
Other units	18	375	393	826	4	11	1,041	1,882
Sub-total	2,777	10,209	12,986	120,407	4,694	10,008	9,284	**144,393**
GAB formations								
Hutton and Marburg Sandstones	342	2,303	2,645	8,810	777	2,141	3,255	14,983
Walloon Coal Measures	253	1,394	1,647	8,995	370	425	1,628	11,418
Precipice and Helidon Sandstones	29	293	322	1,970	2,092	1,704	672	6,438
Evergreen Formation	45	559	604	1,483	1,874	218	1,287	4,862
Gubberamunda Sandstone	62	499	561	1,777	810	585	1,450	4,622

Formation	Number of bores			Estimated groundwater extraction (ML/yr)				Total (ML/yr)
	Non-S&D	S&D	Total	Agriculture	Industrial	Town water supply	S&D	
Springbok Sandstone	32	233	265	2,393	742	199	1,003	4,337
Other units	50	2,141	2,191	1,101	2	341	4,531	5975
Sub-total	813	7,422	8,235	26,529	6,667	5,613	13,826	**52,635**
Non-GAB (lower) formations*								
Bowen Permian	27	716	743	1,541	67	144	1,229	2,981
Clematis Sandstone	7	145	152	-	-	326	981	1,307
Bandanna Formation	10	93	103	437	59	406	167	1,069
Other units	12	199	211	231	37	0	439	707
Sub-total	56	1,153	1,209	2,209	163	876	2,816	**6,064**
Total	**3,646**	**18,784**	**22,430**	**149,145**	**11,524**	**16,497**	**25,926**	**203,092**

Source: *DNRM (2016a).*

** Comprises Bowen Basin, Galilee Basin and basement formations underlying the Surat Basin.*

Table 2-4 Surface water licensing in the Condamine region

Allocation	Volume (GL/year)
Licensed entitlements	
Condamine-Balonne un-supplemented registered entitlements	0.2
Condamine-Balonne harvesting of overland flow - registered entitlements	23.2
Upper Condamine water supply scheme (zones 01 to 04)	23.2
Chinchilla Weir water supply scheme	2.9
Total	**49.5**
Modelled water use in IQQM	
Upper Condamine IQQM model	108.5
Middle Condamine IQQM model	272.6
Total	**381.1**

Source: CSIRO, (2008); CDM-Smith (2016).

Petroleum and Gas activity associated groundwater extraction

Petroleum tenure holders are entitled to extract groundwater under the Petroleum and Gas (P&G) Act for the purpose of production. In the Surat Basin, this includes conventional oil and gas production from dominantly sandstone formations, as well as CSG production.

Conventional petroleum and gas extraction within the Surat CMA has historically been from the Precipice Sandstone and Evergreen Formation of the Surat Basin and the Showgrounds Sandstone of the Bowen Basin (DNRM, 2016a) but production is presently in decline.

DNRM (2016b) reports that approximately 20 conventional petroleum and gas wells remain in operation across the Tinker, Taylor and Waggamba fields operated by AGL, and the Moonie field operated by Santos. In addition, a small amount of water is also reportedly produced from three wells at the Pleasant Hills gas field.

The volume of water production associated with conventional oil and gas operations had declined from 1,800 ML/yr in 2012 to 1,000 ML/yr in late 2014 (DNRM, 2016a). This volume comprises less than 2% of the 59,000 ML/yr CSG produced water (July 2015 reported data) for the Surat CMA, or less than 0.5% of the 203,000 ML/yr landholder extraction.

2.6 Groundwater dependent ecosystems

The identification of landscapes that may contain groundwater dependent ecosystems (GDEs) is documented in detail in the SGP EIS/SREIS and in the Stage 1 CSG WMMP (Appendix A).

GDEs relevant to the SGP and this Updated CSG WMMP are defined as:

- **Surface Expression GDEs:** Ecosystems dependent on the surface expression of groundwater (i.e. springs, groundwater-fed wetlands and baseflow contribution to watercourses). These are collectively referred to as spring-GDEs.
- **Terrestrial (vegetation) GDEs**: Ecosystems dependent on the subsurface presence of groundwater (i.e. plants accessing shallow groundwater or the capillary fringe, or deeper-rooted vegetation accessing deeper groundwater). This includes riparian vegetation.
- **Aquatic Ecosystems**: Aquatic ecosystems dependent on surface water resources that are maintained by groundwater levels, but not groundwater-fed (i.e. connected but losing streams).

The level of groundwater dependency of the ecosystems is expected to be variable. Ecosystems identified as being dependent, or potentially dependent on groundwater in the vicinity of the SGP area are summarised in Table 2-4 (refer also to Appendix C of the Stage 1 CSG WMMP).

EPBC springs within the Surat CMA are locations where a community of native species is dependent on natural discharge of groundwater from the Great Artesian Basin, or listed threatened species are reliant on springs (Section 8.2.3 of the Supplementary Report to the Surat Gas Project EIS [Arrow Energy, 2013]). There are currently no EPBC springs located within Arrow tenure and there are currently no off-tenure EPBC springs allocated to Arrow for monitoring and management in accordance with the JIP.

The JIP provides reference to OGIA’s Spring Impact Management Strategy (SIMS) in the Surat CMA UWIR which provides an assessment of potential impacts to springs. Arrow has no assigned responsibilities regarding potentially affected springs under the SIMS. The SIMS is considered to adequately address the potential impact to springs and no further assessment has been undertaken in this plan. In addition, no springs within Arrow tenure other than those identified and considered in the Surat CMA UWIR are known to be present.

Table 2-4 Known and potential GDEs within and in the vicinity of the SGP area

Feature type	Description	Known or potential GDE	Within or outside of SGP tenure
Terrestrial GDE	Potential terrestrial GDE landscapes (WetlandInfo, 2015) with an assigned groundwater dependence potential of either high or moderate	Potential	Within and in the vicinity of SGP tenure
	Riparian environments along the Condamine River, Wilkie Creek, Wambo Creek, Kogan Creek, Braemar Creek and Dogwood Creek	Potential	Within and in the vicinity of SGP tenure
Spring vent complex	Tribelco (Orana) (complex 765)	Known	Western boundary of SGP tenure
	Bowenville (complex 585)	Known	Outside
	Wambo (complex 584)	Known	Outside
	601 (Main Range Volcanics 3 and 4 (complexes 601 and 602 respectively))	Known	Outside
Watercourse spring	UWIR Sites: • W14 and W15 (Hutton Sandstone source aquifer) • W77 and W78 (Mooga/Gubberamunda Sandstone source aquifer) • W100 (Quaternary sediments source aquifer) • W160 (Kumbarilla Beds source aquifer)	Known	Outside
	Reaches of: • Roche Creek, north-east of Wandoan • Juandah Creek south of Wandoan • The Condamine River south of Chinchilla • Tributary of Wyaga Creek in upland areas (southern extent of SGP area)	Potential	Within and in the vicinity of SGP tenure

2.7 Aquatic ecology and ecosystems

Environmental conditions with regards to aquatic ecology and aquatic ecosystems across the SGP area have been assessed as generally being highly disturbed. A summary of the nature and distribution of aquatic ecosystems is presented in (Appendix A) and the SGP EIS/SREIS.

3. MONITORING AND RESEARCH

3.1 Groundwater and surface water baseline monitoring program

3.1.1 Baseline data

The Stage 1 CSG WMMP monitoring network (Appendix A) comprises a total of 105 discrete monitoring intervals (including 57 WCM intervals at 32 discrete monitoring locations). The monitoring network includes 26 co-located (nested) sites, which assist with the assessment of vertical pressure gradients.

The distribution of the Stage 1 WMMP groundwater pressure/level monitoring network is presented for each targeted formation in Figure 3-1. Where multiple intervals are monitored for pressure/level in the WCM, the number of intervals monitored is represented in brackets following the bore identification. Figure 3-2 presents the distribution of the Stage 1 WMMP groundwater quality monitoring network for all targeted formations.

Comprehensive water monitoring data have already been collected for the SGP, providing a baseline against which impacts can be assessed and trends established. Groundwater level baseline monitoring for the CSG WMMP monitoring network commenced in 2008 and as monitoring bores have been installed, the baseline monitoring program, and the data collected, has expanded.

Table 3-1 lists the year baseline groundwater level monitoring commenced for monitoring intervals in each formation of the CSG WMMP monitoring network. The majority of the baseline groundwater level monitoring commenced in 2013 and 2014, providing 4 to 5 years of historic groundwater level data to date. By the end of Quarter 1 2019, 101 of the 105 intervals were operating and collecting data.

Fifteen monitoring bores (Figure 3-2) have been chosen for groundwater quality sampling to provide baseline groundwater quality data as well as ongoing groundwater level monitoring data. Formations targeted for baseline groundwater quality monitoring include the Condamine Alluvium, Westbourne Formation, Springbok Sandstone, WCM, Hutton Sandstone and Precipice Sandstone. Groundwater sampling of these locations for baselining purposes commenced in 2013 and 2014 and at bi-annual frequencies in accordance with the program specified in the Stage 1 CSG WMMP (Appendix A), providing 4 to 5 years of historic groundwater baseline quality data to date.

Since 2013, Arrow has collected and analysed a total of 136 groundwater samples in accordance with UWIR obligations:

- 2013: 4 groundwater samples across 3 monitoring sites
- 2014: 16 groundwater samples across 13 monitoring sites
- 2015: 36 groundwater samples across 14 monitoring sites
- 2016: 27 groundwater samples across 15 monitoring sites
- 2017: 26 groundwater samples across 13 monitoring sites
- 2018: 27 groundwater samples across 13 monitoring sites

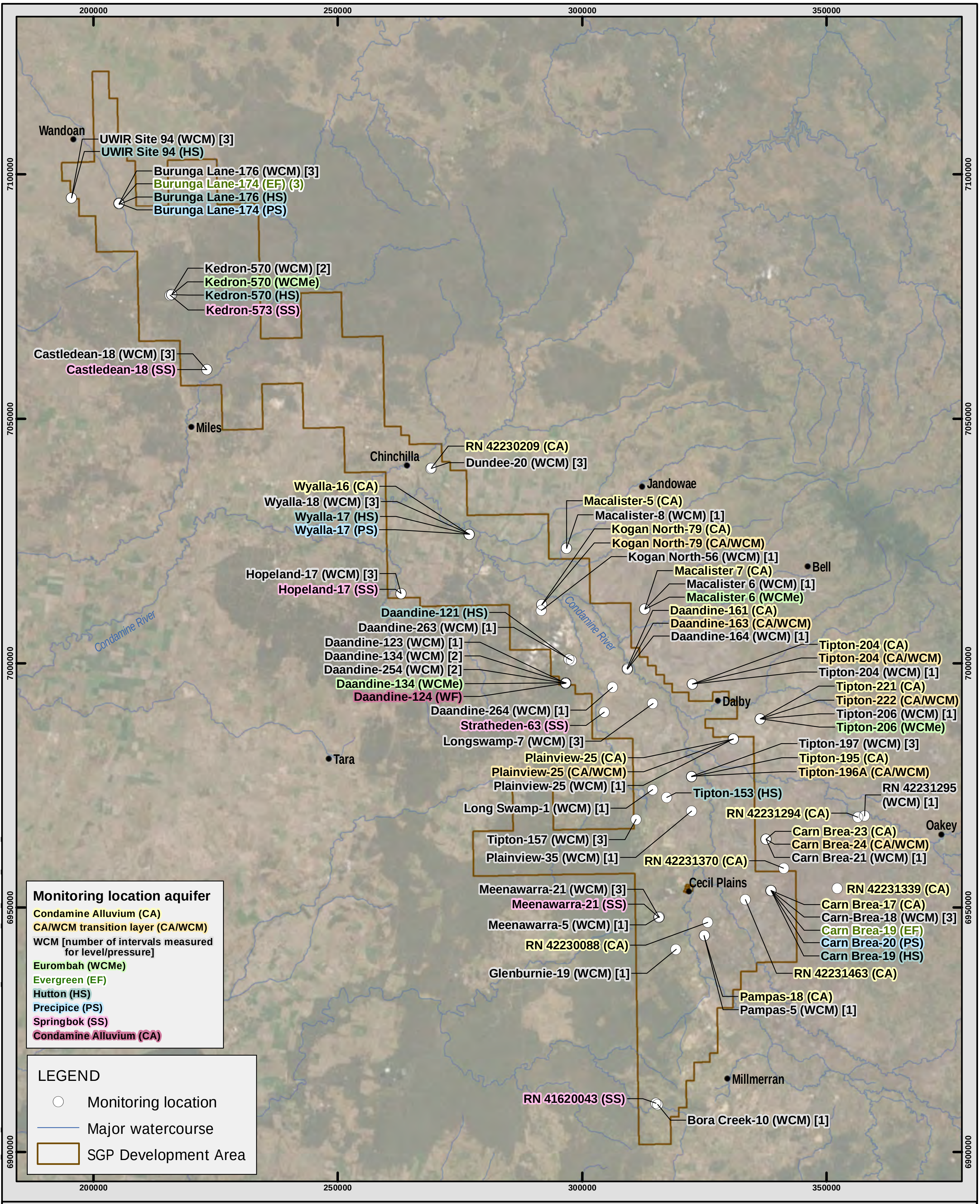
During the first year of monitoring of a particular bore, a full laboratory analytical suite will be adopted at a bi-annual sampling frequency, which aligns with current UWIR groundwater quality sampling requirements. Following this, the laboratory analytical suite may be modified on a bore by bore basis to remain aligned with the UWIR analysis suite (where it has changed).

In addition to the baseline data already collected across the Stage 1 CSG WMMP network, a substantial volume of data is available across the broader Surat CMA UWIR network as well as monitoring bores registered in the DNRME database.

As concluded in the Stage 1 CSG WMMP, significant impacts to surface water resources or aquatic ecosystems are not predicted and subsequently a monitoring network to address these components of Approval Conditions 13(e) and 13(f) is not currently proposed.

A network of surface water and aquatic ecology baseline monitoring locations was established as part of the SGP EIS/SREIS process, inclusive of surface water quality, flow and aquatic ecology monitoring locations. Further to this, baseline data are available via the Queensland DNRME state monitoring network, with 17 currently open surface water gauging stations situated in or in close proximity to Arrow’s tenure, 15 of which monitor water quality.

It is noted that the OGIA set out the requirements for responsible tenure holders for monitoring of potentially affected watercourse springs. As Arrow is not the responsible tenure holder for any identified watercourse springs, no monitoring sites nominated by the OGIA are located within relevant areas for the SGP, and therefore Arrow is not proposing to monitor any watercourse springs.



Monitoring location aquifer

- Condamine Alluvium (CA)
- CA/WCM transition layer (CA/WCM)
- WCM [number of intervals measured for level/pressure]
- Eurombah (WCMe)
- Evergreen (EF)
- Hutton (HS)
- Precipice (PS)
- Springbok (SS)
- Condamine Alluvium (CA)

LEGEND

- ○ Monitoring location
- Major watercourse
- ▭ SGP Development Area

Figure 3.1 Stage 1 WMMP baseline groundwater level monitoring network

Source:
Arrow Energy Pty Ltd

Date: 20/08/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

N

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ARROW ENERGY - SURAT GAS PROJECT

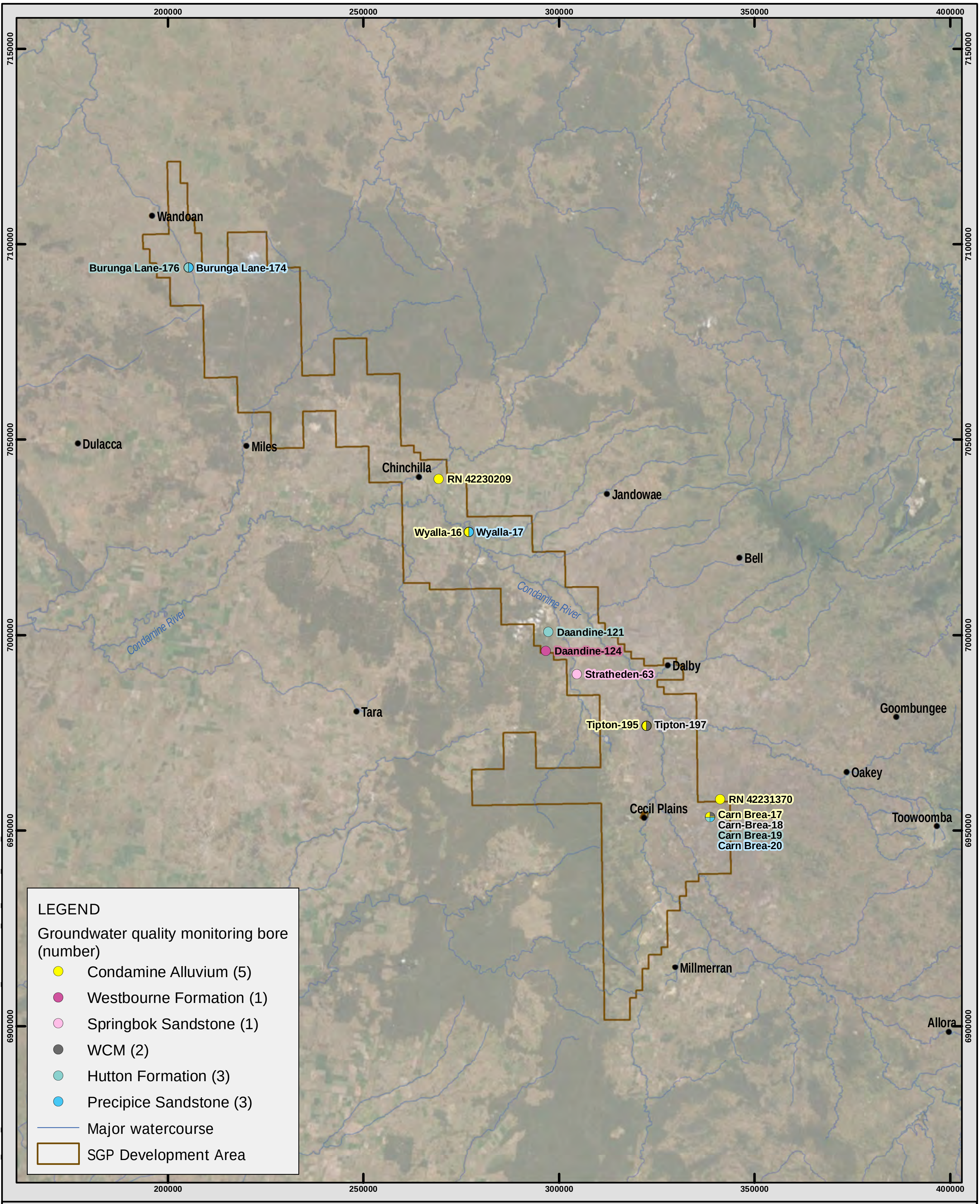

Figure 3.2 Stage 1 WMMP baseline groundwater quality monitoring network

Source:
Arrow Energy Pty Ltd

Date: 22/07/2019
Issued To: Arrow Energy
Author: helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,250,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

N

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Table 3-1 WMMP monitoring network – history of groundwater level baseline activities

Formation	Commencement year for baseline level monitoring and no. of intervals for water pressure and water quality monitoring								
	2008	**2013**	**2014**	**2015**	**2016**	**2017**	**2019**	**Year to be advised (1)**	**Total monitoring intervals**
Condamine Alluvium		5 WP 4 WP&WQ	2 WP 1 WP&WQ	1 WP	3 WP	2 WP			**13 WP** **5 WP&WQ** **18 total**
CA / WCM transition layer		1 WP	3 WP	1 WP		2 WP			**7 WP** **7 total**
Westbourne Formation		1 WP&WQ							**1 WP&WQ** **1 total**
Springbok Sandstone		3 WP 1 WP&WQ	1 WP	1 WP					**5 WP** **1 WP&WQ** **6 total**
Walloon Coal Measures	4 WP	10 WP	25 WP 2 WP&WQ	9 WP	3 WP	1 WP		3 WP (2)	**55 WP** **2 WP&WQ** **57 total**
Eurombah Formation		1 WP	1 WP	1 WP		1 WP			**4 WP** **4 total**
Hutton Sandstone		1 WP	3 WP&WQ				2 WP	1 WP (3)	**4 WP** **3 WP&WQ** **7 total**

Formation	Commencement year for baseline level monitoring and no. of intervals for water pressure and water quality monitoring								
	2008	**2013**	**2014**	**2015**	**2016**	**2017**	**2019**	**Year to be advised (1)**	**Total monitoring intervals**
Evergreen Formation		1 WP	1 WP						**2 WP** **2 total**
Precipice Sandstone		1 WP&WQ	2 WP&WQ						**3 WP&WQ** **3 total**
Total monitoring intervals	**4 WP**	**22 WP** **7 WP&WQ**	**33 WP** **8 WP&WQ**	**13 WP**	**6 WP**	**6 WP**	**2 WP**	**4 WP**	**90 WP** **15 WP&WQ** **105 total (4)**

Notes:
WP: Water pressure monitoring interval
WP&WQ: Water pressure and water quality monitoring interval
Only a subset of these bores will serve as the early warning monitoring network. This is further discussed in Section 7.
(1) Based on correspondence with OGIA, nested bores at UWIR Site 94 are proposed for installation by the end of 2022.
(2) Walloon Coal Measures monitoring bore - UWIR Site 94 is proposed for installation and will comprise three WP monitoring intervals.
(3) Hutton Sandstone monitoring wells - UWIR Site 94 is proposed for installation and will comprise one WP monitoring interval.
(4) Upon completion of the proposed Walloon Coal Measures and Hutton Sandstone monitoring bores, the monitoring network will consist of 90 WP monitoring intervals and 15 WP&WQ intervals, totalling 105 monitoring intervals.

3.1.2 UWIR conclusions on background trends

According to the 2016 Surat CMA UWIR, approximately two thirds of the 133 GAB bores with long-term records exhibit declining trends prior to CSG development commencing. Although the number of long-term records with background trends in the GAB formations in the area of CSG development is limited, nevertheless sufficient information is available to support the following conclusions:

- In most of the long-term water pressure records, long-term declining trends which pre-date CSG development are apparent, and these reflect below-average rainfall across much of the recharge area over the period of 1990–2011 and increased water extraction for agriculture and other non-CSG purposes.
- The effect of lower rainfall on water pressure is clear in recharge areas, however, in areas more remote from recharge, subdued effects are also apparent. Water extraction from the major aquifers, for agriculture and other non-CSG purposes, has progressively increased over a long period, and in areas close to significant CSG development, this has contributed to the declining trend.

The 2016 Surat CMA UWIR reports that there is little evidence of a departure from background trends other than in the coal formations. The report notes that although there are declining background trends in the Hutton Sandstone, some records show recent relatively large declines of up to two metres per year (i.e. RN160634 and RN160439). It was considered likely that this is a response to progressive increases in water extraction from the Hutton Sandstone for non-CSG purposes. However, in the absence of a long-term record at this location, it was not possible (at the time of the 2016 UWIR) to determine if the rate of decline has increased since CSG development began.

The most recent (2018) annual report for the Surat CMA UWIR indicated that while pressures at most Springbok Sandstone monitoring locations have remained relatively stable or show no departure from background trends, it is possible CSG impacts were observed at a number of bores.

Groundwater levels at a number of monitoring points in the Hutton Sandstone, including at RN160634 and RN160439, had continued to decline since the UWIR 2016. It was concluded by OGIA that the observed pressure decline was largely due to non-CSG water extraction from the Hutton Sandstone, with no definitive evidence of contribution from CSG extraction from the overlying Walloon Coal Measures.

OGIA also reported that it was undertaking a review of the available groundwater level and water quality data for all monitored aquifers, with a particular emphasis on investigating potential causes for observed heightened pressure declines in the Hutton Sandstone.

3.1.3 Baseline assessment – summary of findings

The assessment of the Stage 1 WMMP groundwater and surface water baseline monitoring program is described in Section 3.2 of the Monitoring, Risk Response and Adaptive Management Memorandum (Appendix G). A concise summary is provided herein.

Groundwater level and quality data collected between 2013/14 and 2018 as part of the SGP Stage 1 WMMP baseline monitoring program has provided a comprehensive dataset from which background groundwater conditions in the key hydrogeological units including the Condamine Alluvium, Condamine Alluvium-WCM transition layer, Springbok Sandstone, Hutton Sandstone and Precipice Sandstone, have been characterised. In total, 38 monitoring bores were assessed for groundwater level trends, while 12 monitoring bores were assessed for groundwater quality trends.

While rainfall has been variable, for the period of assessment between 2013/14 to 2018, a rainfall deficit has been experienced across the SGP.

Within the Condamine Alluvium, Condamine Alluvium-WCM transition layer and Springbok Sandstone, the groundwater level trend was typically recorded as stable or slightly declining at rates of between 0.1 to 0.5 m/yr. A number of bores in these units exhibited steeper declining trends consistent with pressure equalisation post-construction. Longer term monitoring is required to establish background groundwater level trends at these bores. For the Hutton Sandstone and Precipice Sandstone, consistently declining trends of between 0.5 to 1.5 m/yr were recorded.

The assessment concluded that background groundwater level trends in bores constituting the monitoring network are generally influenced by long term rainfall patterns and/or non-CSG groundwater extraction. CSG development activities are not considered, at present, to have affected any groundwater monitoring bores within the SGP Stage 1 WMMP monitoring network.

The groundwater level trends and groundwater quality data reported in the SGP EIS and SGP SREIS are broadly consistent with the monitoring data collected and analysed as part of the SGP Stage 1 WMMP baseline monitoring program. Some spatial variability in groundwater level trends and groundwater quality data was observed between the earlier studies and the current monitoring program for the Condamine Alluvium, Springbok Sandstone, Hutton Sandstone and Precipice Sandstone aquifers. This variability is believed to be due to temporal changes in rainfall patterns / groundwater extraction influencing the monitoring data, and in some cases local scale processes.

In summary, the Stage 1 WMMP baseline monitoring network is considered suitable for the purposes of defining background groundwater conditions in the key hydrogeological units across the SGP and capturing the range of variability expected at the local scale. Furthermore, data collected from the greater UWIR monitoring network, consisting of 675 groundwater pressure and/or quality monitoring points (of which 491 were established at the time of the release of the 2016 UWIR), and non-UWIR monitoring locations with the Surat CMA, has contributed to the understanding of background trends and aquifer responses within production areas on a more regional scale. On the basis of the ongoing suitability of the groundwater monitoring network no modification are deemed necessary in the Updated CSG WMMP. The outcomes of this review respond to Approval Condition 17(e) (in part), and all the commitments made in Stage 1 regarding the evaluation of the Stage 1 baseline groundwater monitoring network.

3.2 Condamine Interconnectivity Research Project (CIRP)

The approach to the CIRP study (DNRM 2016d), and key findings as they relate to conceptualising the level of hydraulic connectivity between the Condamine Alluvium and the WCM, are described in the Updated CSG WMMP Groundwater Modelling and Research Technical Memorandum (Appendix C).

The CIRP was led by the OGIA with Arrow undertaking drilling and pumping test investigations, and collaborative arrangements with parties that included Queensland University of Technology for assessing hydrochemical data. The results are reported in the 2016 UWIR, and in the OGIA hydrogeological investigation report “Groundwater connectivity between the Condamine Alluvium and the WCM” (DNRM 2016b) and are of direct relevance to the existing body of work undertaken for prediction of impacts from the SGP to the Condamine Alluvium and Condamine River.

3.2.1 Findings from the CIRP

The CIRP (DNRM 2016d) concluded that the level of hydraulic connectivity between the Condamine Alluvium and the WCM is low. The project pursued several lines of investigation resulting in a range of findings that supported this conclusion. Conceptualisation, as well as the confidence in conclusions about the connectivity, has improved significantly due to the CIRP investigations. The following are key findings:

- The geological data show that a clay-rich or mudstone horizon at the base of the Condamine Alluvium and the top of the WCM acts as a physical barrier that impedes inter-formation flow.
- Persistent differences in groundwater levels between the formations, and the flow patterns within the formations, demonstrate that impediments to flow exist between the formations.
- Hydrochemical data indicate little past movement of water between the formations, even in areas where significant groundwater level differences have existed for a prolonged period.
- Detailed aquifer pumping tests at two sites found no significant flow of water between the formations in response to pumping tests around those sites. The tests showed that the vertical hydraulic conductivity for the material between the formations is consistent with that of a highly effective aquitard.

The findings demonstrate that the assumptions incorporated into past model versions (such as the OGIA 2012 Groundwater Model), in particular that a low-permeability transition layer controls and limits groundwater flux impacts from the SGP to the Condamine, are supported by field investigations relying on multiple lines of evidence and are therefore valid and reasonable for predictive purposes.

3.2.2 Implications for assigning EWMS triggers

The CIRP findings, including revisions to the geological model of the interface between the Condamine Alluvium and Walloon Coal Measures in the form of the OGIA Condamine Geological Model (DNRM 2016b), have been adopted for the 2016 UWIR, and are incorporated into the 2016 OGIA Groundwater Model (refer Section 4).

However this groundwater model was not used for setting or reviewing trigger thresholds and corrective actions (refer Section 7.5) because uncertainty analysis was not undertaken by OGIA (hence a P95 prediction is not available for the 2016 model, and therefore levels for assignment of triggers cannot be extracted or compared).

Instead, the assignment of trigger thresholds is based on simulations from the 2012 OGIA Groundwater Model. This approach is supported, because a comparison was made between the 2012 and 2016 OGIA models. The comparison demonstrated that the outputs are compatible (refer Section 4.2) and that the 2012 OGIA model is unlikely to under-predict groundwater impacts.

4. NUMERICAL GROUNDWATER MODELLING

Modelling and analysis to predict the effects of CSG water production was carried out as part of the SGP EIS/SREIS and the Stage 1 CSG WMMP. Because CSG and water production has been revised since the Stage 1 CSG WMMP, updated modelling supports the Updated CSG WMMP.

An analysis of the modelling is provided in the Groundwater Modelling and Research Technical Memorandum (Appendix C), including the basis for selection of modelling outputs that inform the Updated CSG WMMP. A summary is provided in this chapter.

Modelling results supporting Condition 17(b)

Key features of the Updated CSG WMMP modelling include the revised Updated FDP Case water production, and the adoption of the OGIA 2016 Groundwater Model in place of the OGIA 2012 Groundwater Model. Specific modelling work addressing Condition 17(b) and summarised in this chapter includes:

- Comparison between OGIA 2016 and 2012 model codes (Section 4.2).
- Updated CSG WMMP modelling results (Section 4.3).
- Comparison of Stage 1 and Updated WMMP modelling results (Section 4.3.3).
- Updated integrated groundwater-surface water modelling (Section 4.4).

The revised water production for the Updated FDP Case is described in Section 4.1.

4.1 Revised water production

The SGP will expand Arrow’s CSG production in the Surat Basin[10]. As described in the SREIS, the SGP comprised a FDP based on 6,500 wells and total water production of 510 GL. This production has been subsequently revised, and the Updated CSG WMMP is based on an updated FDP (referred to herein as the Updated FDP Case) comprising approximately 2,612 wells and total water production of 575 GL.

Table 4-1 provides a summary comparison of historical SGP FDP cases and the Updated FDP Case.

---

[10] Arrow also operates existing Surat Basin gas fields near Dalby, comprising the Daandine, Kogan North and Tipton West production areas.

Table 4-1 FDP comparison

FDP Case	FDP developed or updated (year)	Arrow FDP case descriptor	Water production			Duration (years)
			Forecast total (GL)	Modelled total (GL)	Modelled peak rate (GL/a)	
SREIS FDP	2012	5x	510	702	34	65
UWIR 2016 FDP	2016	8b	460	1,204	n/a	54
Stage 1 CSG WMMP FDP	Not updated from SREIS	5x	510	710 (1)	138 ML/d (2)	65
Updated CSG WMMP FDP	2018	10a	575	1,178	123.3 ML/d	40

Notes:
(1) Median modelled value (CDM Smith, 2016).
(2) Based on median modelled value 138 ML/d (CDM Smith, 2016).

4.2 Comparison between OGIA 2016 and 2012 modelling code

In 2016, OGIA released the OGIA 2016 Groundwater Model to inform the Surat CMA 2016 UWIR. Differences between the OGIA 2012 and 2016 groundwater models include model code, layering, and representation of CSG water production. These differences are detailed in Appendix C. This model incorporated Arrow’s UWIR 2016 FDP Case.

The OGIA 2016 Groundwater Model was previously assessed as not being fully equivalent to the OGIA 2012 Groundwater Model, because model comparisons and uncertainty analysis had not been undertaken, and therefore it was not possible to address uncertainty and predictive differences between the OGIA 2016 and OGIA 2012 Groundwater Models. Also, these two models predicted different CSG water production even when simulating the same FDP (refer Section 4.5).

To address this, null-space Monte Carlo uncertainty analysis has been undertaken using the OGIA 2012 Groundwater Model, with the OGIA 2016 Groundwater Model water production. This work (AGE, 2017; CDM Smith, 2018) enabled comparison of the modelling predictions between these two models, under the same UWIR 2016 FDP Case water production case.

The updated OGIA 2012 Groundwater Model version was adjusted to achieve target pressures using the same metrics previously used in the SREIS model at various locations across the production areas, after which uncertainty analysis simulations for cumulative and Arrow only impacts were prepared (AGE, 2017). The uncertainty of model prediction was assessed by running 200 realisations of the model for the following scenarios:

- Base case (no CSG production)
- Arrow case (Arrow-only CSG production)

- Cumulative case (all CSG production)

Baseline water levels and interlayer flux responses for the CSG production cases were subtracted from the base case (for each of the 200 realisations) to derive the drawdowns and change in interlayer fluxes. The results were then processed as a composite suite of predicted impacts, ranked based on the drawdown, and the 5th (P5, or best case) and 95th (P95, or worst case) prediction percentile realisations presented.

Results

Figures 1 and 2 in Appendix C present the regional **P95** groundwater drawdown for the UWIR 2016 FDP Case under Arrow only and cumulative scenarios as simulated in the OGIA 2012 Groundwater Model. As shown in Appendix C, the extents were found to be consistent with the OGIA 2016 Groundwater Model (AGE, 2017).

Figures 3 and 4 in Appendix C compare the calibrated UWIR 2016 FDP Case under the OGIA 2012 and 2016 Groundwater Models, for the WCM and the Springbok Sandstone. The figures also indicate a general similarity in prediction, with minor differences due to geological layer refinement and numerical coding between the two model versions.

As a comparison with the Updated WMMP FDP (refer Section 4.3) Figures 5 and 6 in Appendix C present the regional **P95** groundwater drawdown for Updated WMMP FDP Case under Arrow only and cumulative scenarios in the OGIA 2012 model. In addition, a comparison with the UWIR 2016 FDP case (Figures 1 and 2 in Appendix C) shows that drawdown predicted is similar, for the four key formations presented.

A key purpose of the modelling comparison under the UWIR 2016 FDP Case was to characterise differences in Condamine Alluvium flux predicted by the different model versions. Table 4-2 summarises the modelled flux changes (for the **P95** and **calibrated realisation**) together with the predicted Arrow water production.

Table 4-2 Water production and flux impact summary

Modelled case	Arrow water production (calibrated) (GL)	Flux change - cumulative (GL/100 years)		Flux change due to the Action (GL/100 years)	
		Calibrated	P95	Calibrated	P95
OGIA 2012 model with SREIS FDP Case	702	-78	-101	-63	-79
OGIA 2016 model with UWIR 2016 FDP Case	1,204	-116	na	-70	na
OGIA 2012* model with UWIR 2016 FDP Case	657	-72	-98	-56	-79

Notes: ** AGE 2017 version, na = not assessed*

The results for the OGIA 2012 model show that under the Arrow only (**calibrated realisation**) simulations, the predicted flux change to the Condamine Alluvium for the UWIR 2016 FDP Case is lower than for the SREIS FDP Case (-56 GL compared to -63 GL) and much reduced compared with the OGIA 2016 model simulation of the UWIR 2016 FDP Case (-70 GL).

For the **P95** cases, the flux change to the Condamine Alluvium (simulated with the OGIA 2012 model) is similar for both the UWIR 2016 FDP Case and the SREIS FDP Case (-79 GL).

Correspondingly similar flux change relationships are seen for the cumulative scenarios.

Arrow water production (**calibrated realisation**) for the OGIA 2012 model under the UWIR 2016 FDP Case is lower than for the 2012 SREIS FDP Case (657 GL compared to 702 GL).

Arrow water production for the OGIA 2016 model using the UWIR 2016 FDP Case is much higher at 1,204 GL, a difficult value to reconcile when compared with the OGIA 2012 model under the UWIR 2016 FDP Case (657 GL), or with Arrow Eclipse reservoir modelling (460 GL). This may be due to the behaviour of the 2016 OGIA model which incorporates coding modifications, including for dual-phase flow.

4.3 Updated CSG WMMP (Updated FDP Case) modelling

CSG extraction under the SGP requires groundwater abstraction from the WCM, which will lead to depressurisation of the coal measures and other GAB formations. In addition, this depressurisation can lead to potential changes in flux to the Condamine Alluvium, and hence affect groundwater-surface water interaction with the Condamine River.

The Stage 1 FDP Case (which was the same as the SREIS FDP Case) used the OGIA 2012 model to simulate regional impacts. The model predictions of flux change to the Condamine Alluvium were then used as inputs to the more detailed CCAM, to simulate Condamine Alluvium drawdown. This in turn provided inputs to the IQQM modelling of impact to the Condamine River.

The Updated CSG WMMP is informed by the updated FDP. Therefore, to understand impacts from this development case, additional groundwater modelling was undertaken to build on and revise that previously undertaken in the Stage 1 CSG WMMP for Approval Condition 13(b). This modelling included:

- Predictive analysis using the 2012 OGIA ‘calibrated’ model, with the Updated FDP Case production.
- Predictive uncertainty analysis using the 2012 OGIA NSMC realisations, with the Updated FDP Case production.
- Comparison of the results with the SREIS Groundwater Model uncertainty analysis.
- Updating the OGIA 2016 Groundwater Model with the Updated FDP Case production.

4.3.1 Updated FDP Case modelling

Modelling for the Updated CSG WMMP incorporates the Updated FDP Case within the OGIA 2016 Groundwater Model, to predict drawdown impacts, and to update predictions of flux change to the Condamine Alluvium. Three scenarios were modelled to predict the potential impacts of Arrow's development, relative to the cumulative impacts from other current and future CSG production in the Surat Basin. These scenarios were:

- A base case (no future CSG production in Surat Basin).
- A CSG production case (future CSG production by Arrow and all CSG operators).
- A non-Arrow CSG production case (future CSG production by all CSG operators except Arrow).

The base case simulation provided a predicted baseline, and the predicted impacts of CSG production are quantified relative to this baseline. Arrow's contribution to these impacts is quantified as the difference between the production case simulation and the non-Arrow production case simulation, relative to the base case.

Model verification

Prior to running the above simulations, a verification run of the OGIA 2016 Groundwater Model was undertaken (using the 2016 UWIR calibrated parameter sets and water production file) to confirm that the model predictions (as run by CDM Smith, 2018) accord with the OGIA predictions, and thereby verifying that the model was being used correctly.

The results were verified against the results from the OGIA 2016 Groundwater Model by comparing maps of maximum drawdown induced by CSG development, by comparing water balances, and by comparing the change in total flux between the Surat Basin and Condamine Alluvium induced by CSG development. The verification simulation results indicated an exact match to 2016 UWIR flux of 1,156 ML/yr, and a corresponding match in drawdown (CDM Smith, 2018).

Water production volumes and rates: existing and proposed CSG development

Table 4-3 summarises water production predicted by the OGIA 2016 Groundwater Model for Arrow's Updated FDP Case, and indicates that Arrow's predicted contribution to total CSG water production in the Surat CMA is around 21.7%. Arrow's predicted peak rate of water production in this model is 23.5% of the peak rate of all CSG producers but occurs around 20 years later (CDM Smith, 2018).

Table 4-3 Water production summary (GL)

CSG water production	All CSG producers	Arrow's component
Total water production (1)	5,319	1,153
Peak rate of production	525.5	123.3

CSG water production	All CSG producers	Arrow’s component
Year of peak production	2018	2038

Note:
(1) 2015 onwards.

Figure 7 in Appendix C compares the Updated FDP Case forecast water production based on reservoir modelling, compared with the predicted water production from the OGIA 2016 Groundwater Model under the same FDP.

4.3.2 Change in net vertical flux to Condamine

The predicted change in total flux at the base of the Condamine Alluvium with Arrow’s Updated FDP Case is presented in Table 4-4, and Figure 8 in Appendix C shows how the predicted change in flux from the Surat Basin at the base of the Condamine Alluvium reduces over time (following the peak change) due to water production by all CSG operators.

Table 4-4 Updated FDP Case - predicted change in Condamine Alluvium flux

Base of Condamine Alluvium	All CSG producers	Arrow’s component (Updated FDP)
Total flux change (1)	-104.7 GL	-58.4 GL
Peak flux change (and year of peak)	-4.89 ML/d (2053)	-2.93 ML/d (2049)
Peak flux change (as a % of peak water production shown in Table 4-3)	0.93%	2.4%

Note:
(1) flux change over 100 years.

The predicted peak changes in vertical flux at the base of the alluvium, as a percentage of the predicted peak rate of water production, is indicated to be relatively small (a few percent or less). Figure 9 in Appendix C shows the predicted peak change in flux from the Surat Basin to the Condamine Alluvium due to Arrow under the Updated FDP Case.

4.3.3 Comparison of modelling results for Stage 1 and 2 WMMPs

Modelling undertaken in support of Arrow’s Updated CSG WMMP (OGIA 2016 model under Updated FDP Case) was compared to previous modelling undertaken (prior to 2016) for Arrow’s Stage 1 CSG WMMP using the earlier 2012 version of the OGIA Groundwater Model and Arrow’s Stage 1 FDP Case.

The OGIA 2012 Groundwater Model (as used for the Stage 1 CSG WMMP) included uncertainty analysis using NSMC methods, and 200 realisations were ranked on total water production volume, as follows:

- High-volume case: P95 (worst case)

- Median-volume case: P50 (median case)
- Low-volume case: P5 (best case)

The OGIA 2016 Groundwater Model does not use uncertainty analysis, instead presenting a single calibrated predictive simulation.

Comparison of model predicted CSG water production

Table 4-5 compares water production and flux change to the base of the Condamine Alluvium from the two models.

Table 4-5 Comparison of water production (due to Arrow development)

	Stage 1 FDP Case OGIA 2012 model Stage 1 WMMP		**Updated FDP Case** OGIA 2016 model Updated WMMP
	P50	**P95**	**Calibrated**
Total water production	710 GL	755 GL	1,178 GL
Peak rate of water production	138 ML/d	151 ML/d	123 ML/d
Total flux change at base of CA (100 years)	63 GL (1)	79 GL	58 GL (1)
Peak flux change at base of CA (year of peak)	1.83 ML/d (2057)	2.84 ML/d (2060)	2.93 ML/d (2049)

Note:
(1) Taken from the calibrated case.

The peak water production rate is smaller for Updated FDP Case than for the Stage 1 FDP Case. The Updated FDP Case total water production volume is indicated to be 66% larger than the Stage 1 FDP Case median (P50) water production (CDM Smith, 2018). As noted in Section 4.2, predictions of water production using the OGIA 2016 numerical groundwater model do not reconcile with either previous numerical groundwater modelling or CSG reservoir modelling.

Arrow water production predicted for the Updated FDP Case and Stage 1 FDP Case are also compared in Figure 13 in Appendix C for the Stage 1 FDP Case P5, P50 and P95 realisations, and the minimum and maximum of all realisations. The Updated FDP Case is distinguished by a longer duration broader predicted water production profile.

Induced change in flux at the base of the Condamine Alluvium

Figures 14 and 15 in Appendix C compare the predicted temporal and spatial distributions of induced changes in flux at the base of the Condamine Alluvium due to Arrow, for the Updated FDP Case and Stage 1 FDP Case (P50) as simulated in the 2012 OGIA Groundwater Model.

The differences between the Updated FDP Case and Stage 1 FDP Case are due to differences between the OGIA 2016 and OGIA 2012 groundwater models, differences in model predicted water production, and differences between production and timing of the FDPs.

Induced drawdown in the Condamine Alluvium

Figures 16 and 17 in Appendix C compare the Updated FDP Case and Stage 1 FDP Case (P50) predicted drawdown in the Condamine Alluvium for the cumulative and Arrow cases. The differences in drawdown are minor, however the timing of maximum drawdown has changed for the Arrow case. Differences are influenced by the revised staging and location of Arrow's Updated FDP Case production, as well as revisions to geological interpretation in the OGIA 2016 Groundwater Model that inform the model-predicted flux change to the Condamine Alluvium.

Induced change in flux to the Condamine River

Figure 18 in Appendix C provides a comparison of the predicted induced changes in flux (baseflow) to the Condamine River for the Stage 1 and Updated FDP Cases.

As discussed in Section 4.3.2 of Appendix C, maximum flux changes to the river are small and the predicted impacts are therefore negligible under both FDP cases. Accordingly, the mitigation proposed in the EIS/SREIS, and monitoring under the WMMP, remains valid for management of potential impacts to the Condamine Alluvium and Condamine River.

4.3.4 Updated FDP Case uncertainty analysis

To address uncertainty in the aquifer parameters assigned to the calibrated OGIA model, Arrow commissioned uncertainty analysis using the Updated FDP Case in the OGIA 2012 Groundwater Model[11]. This also enabled a comparison of the model predictive uncertainty under different water production cases, i.e. the Updated FDP Case **P95** compared with the UWIR 2016 FDP Case **P95**.

To undertake the uncertainty analysis, the Updated FDP Case (specifically well locations, production commencement and production cessation) was incorporated in the OGIA 2012 Groundwater Model[12], with updated non-Arrow CSG production (taken from the OGIA 2016 Groundwater Model). Scheduling information and production volumes were provided by Arrow. Water production volumes were also calculated by reservoir simulation models (and are presented in this plan for comparison purposes and to describe water treatment requirements). The use of reservoir model data for these purposes is justified, because the alternative water production estimates (from regional groundwater models) cannot adequately account for multi-phase flow processes and scale effects (Underschultz et al., 2018), and in addition, data available indicates that historic and current estimates of water production have been systematically over-predicted (Underschultz et al., 2018).

A detailed review of production data has shown that actual water production is ~25% of historical estimates by government and academia, and ~70% of the 2010-2011 industry estimates by CSG proponents (including Arrow) (Underschultz et al., 2018).

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[11] The OGIA 2012 model was the basis for prediction of impacts in the EIS/SREIS.

[12] The OGIA 2012 model calculates its own water production volume.

As previously described, a NSMC uncertainty analysis method was used to produce multiple realisations of model parameters for the following scenarios:

- A base case (no CSG production);
- An Arrow case (Arrow-only CSG production); and
- A cumulative case (all CSG production).

The results were then processed as a composite suite of predicted impacts, ranked based on drawdown, and presented as P5 (best case) and P95 (worst case) predictions.

Drawdown results

Regional **P95** groundwater drawdown extents for the Updated FDP Case as simulated in the 2012 OGIA Groundwater Model (Figures 5 and 6 in Appendix C) were found to be consistent with **P95** groundwater drawdown extents for the UWIR 2016 FDP Case as simulated in the 2012 OGIA Groundwater Model (Figures 1 and 2 in Appendix C) (AGE, 2018a).

Condamine flux change

Table 4-6 presents predicted Arrow water production and the reduction in flux to the Condamine Alluvium from the simulations described above, for the **calibrated** and **P95** realisations.

Table 4-6 Water production and flux impact summary – OGIA 2012 model cases

Modelled case	Arrow water production calibrated case (GL)	Cumulative flux change (GL/100 years)		Arrow only flux change (GL/100 years)	
		Calibrated	P95	Calibrated	P95
OGIA 2012 model with SREIS FDP Case	702	-78	-101	-63	-79
OGIA 2012* model with Updated FDP Case	725	-73	-96	-58	-75

Note:
** AGE 2018 version.*

The results show that under the Arrow only **calibrated** scenario, the modelled change in flux to the Condamine Alluvium for the OGIA 2012 model with the Updated FDP Case is lower than for the 2012 SREIS FDP Case (-58 GL compared to -63 GL).

For the **P95** results, flux to the Condamine Alluvium for the OGIA 2012 model with the Updated FDP Case is reduced (-75 GL) compared with the 2012 SREIS FDP Case (-79 GL).

Similar relationships are seen for the cumulative scenarios.

4.4 Updated integrated groundwater-surface water modelling

Comprehensive modelling work (CDM Smith, 2016) to consider groundwater-surface water interactions was previously undertaken, peer-reviewed, and accepted as a basis for achieving the requirements of the EPBC Approval Condition 13(b) to quantify river impacts for the Stage 1 CSG WMMP. This work included the CDM Smith Condamine Alluvium Model and the Condamine River IQQM which is a hydrological modelling tool for water resource evaluation.

Predicted flux changes from the Updated FDP Case modelling, together with updated CCAM and IQQM modelling, has been used to support the Updated CSG WMMP. This is summarised in the following sub-sections.

4.4.1 CCAM model

For this study, and for the previous modelling for the Stage 1 CSG WMMP, the structure, parameterisation of the CCAM and simulation times were unchanged i.e. the CCAM was run for a period of 826 years, from 1980 to 2805, using annual stress periods.

For the predictive simulations, the single simulation used for the 2016 UWIR was replaced by two simulations: one representing water production by all CSG producers including Arrow’s Updated FDP Case, and one representing water production by all CSG producers except Arrow (CDM Smith, 2018).

Predicted change in Condamine Alluvium flux

The change in vertical flux at the base of the Condamine Alluvium is passed from the regional model to the CCAM in a manner consistent with the 2012 UWIR. Note, flux is only passed to the CCAM at locations where Condamine Alluvium is present in both models (refer Section 4.3.2 in Appendix C). The CCAM is then used to predict drawdown at the watertable including river cells which intersect the watertable.

The simulated maximum reduction in groundwater flux to the Condamine Alluvium (due to all CSG producers) is 4.44 ML/d (1,621 ML/year) and represents 2.25% of the total estimated groundwater extraction for the Condamine Alluvium (72,024 ML/year – refer Table 2-3). For Arrow only production, the simulated maximum reduction in groundwater flux to the Condamine Alluvium is 2.74 ML/d (1,000.1 ML/year) and represents 1.39% of the total estimated groundwater extraction for the Condamine Alluvium (72,024 ML/year).

In relative terms, the simulated groundwater flux reduction to the Condamine Alluvium is small in comparison to total licenced surface water allocations[13] (162,186 ML/year) in the Condamine region[14]:

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[13] Surface water allocations cannot be disaggregated sufficiently to report for the Condamine Alluvium area only, noting that the Condamine Alluvium is not a surface water management zone.

[14] Licenced allocation (pre-development flow less ROP flow, for Node J (Chinchilla Weir) in the IQQM model) as reported by CSIRO (2008) in CDM Smith 2018 (Table 8).

- The flux reduction due to all CSG producers (1,621 ML/year) is ~1% of the licenced volumes.

The flux reduction for Arrow's component (1,000.1 ML/year) is ~0.62% of the licenced volumes.

Updated Predicted Condamine Alluvium watertable drawdown

Figure 11 in Appendix C shows maximum drawdown at the watertable due to Arrow water production and shows that maximum drawdown is predicted to occur at different times within the simulation period at different locations within the alluvium.

Maximum drawdown at the watertable due to all CSG producers and Arrow's water production is predicted earliest in areas on the western edge of the Condamine Alluvium between years 2044 and 2400 (CDM Smith, 2018). The largest predicted value of maximum drawdown in a model cell due to all CSG producers is approximately 1.5 m, and approximately 1.1 m due to Arrow's water production within 100 years (CDM Smith, 2018).

Predicted change in Condamine River flux

Table 4-7 presents the maximum reduction in flow from the Condamine Alluvium to the Condamine River (CDM Smith, 2018) as predicted by the CCAM model.

Table 4-7 Condamine Alluvium and Condamine River flux impacts

Component	All CSG producers		Arrow's component (Updated FDP Case)	
	ML/d	Year	ML/d	Year
Maximum reduction in flow from CA to the Condamine River	0.267	2396	0.148	2396

Predicted impact to the Condamine River

Impacts to the Condamine River from CSG water extraction could arise in situations where the groundwater surface is above the river base (baseflow driven or 'gaining' stream situation). In a modelling context, this occurs where river cells and the modelled watertable surface have an equivalent relationship, and therefore the predicted magnitude and timing of impacts to the river is a function of the location of 'connected' river cells and the modelled drawdown.

Analysis of the modelled results for all CSG producers shows that approximately 80% of river cells experience no change in groundwater flux over the simulation period because they are 'disconnected' from groundwater (CDM Smith, 2018).

Most of the predicted impact on the Condamine River due to water production by all CSG producers occurs in river cells located between Warra Town Weir and Chinchilla Weir with maximum flux changes of between 0.001 ML/d and 0.009 ML/d, and a predicted maximum flux change to the entire River of 0.267 ML/d over the simulated period to 2805 (Table 4-5).

For Arrow only production similar patterns are indicated, but with smaller changes (Figure 12 in Appendix C). Maximum flux changes to the River of between 0.001 ML/d and 0.005 ML/d are predicted between Warra Town Weir and Chinchilla Weir, with maximum changes of less than 0.001 ML/d also predicted just upstream of Cecil Plains Weir.

For all practical purposes the predicted impacts are negligible (CDM Smith, 2018).

4.4.2 IQQM modelling

The IQQM models (further described in CDM Smith, 2016 and 2018) were used to assess potential impacts of Arrow's Updated FDP Case on surface water users. The impacts are represented in IQQM by the reduction in flux between the Condamine Alluvium and the Condamine River. The impacts to downstream users and Environmental Flow Objective[15] (EFO) nodes are then assessed against performance indicators specified in the Water Resources Plan (WRP) (CDM Smith, 2018).

Based on the modelling, impacts to the River are predicted to occur almost entirely between Warra Town Weir and Chinchilla Weir, an area within the Middle Condamine IQQM model. No significant impacts are predicted in the area covered by the Upper Condamine IQQM model.

The predicted impacts due to all CSG producers and Arrow's water production were compared to the base case ROP[16] scenario. The results show required performance indicators are achieved for both scenarios. The predicted maximum impact was assessed as negligible, with only the number of low flow days upstream of Chinchilla Weir reporting a change of 0.1% for impacts from all CSG producers and for Arrow. All other performance measures were unchanged relative to the ROP scenario (CDM Smith, 2018).

A very slight change in the low flow regime can be observed at one node where the frequency of low flow days (less than 1 ML/d) has increased by approximately 0.8% for both scenarios, however no discernible change is predicted at the other EFO nodes, showing that there is almost no discernible impact of CSG production (CDM Smith, 2018).

All Water Allocation Security Objectives (WASOs) performance indicators were checked for users downstream of the groundwater loss node. There were no reductions in the performance indicators except at one IQQM node (Brigalow town water supply) where the Annual Volume Probability decreased by 0.3% for both scenarios (CDM Smith, 2018).

4.5 Condamine Alluvium flux change

A range of model versions and FDPs have been considered over time and used to predict Condamine Alluvium flux changes. The Stage 1 WMMP was based on Arrow's FDP at the time, and utilising the

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[15] EFOs adopted are performance indicators for the Condamine and Balonne Water Resource Plan (Queensland Government, 2004)

[16] Upper Condamine and Middle Condamine Resource Operation Plan (DNRM 2008). An ROP describes the rules and requirements to achieve the water resource objectives from the Water Resource Plan. The ROP for the Condamine and Balonne River system was published in 2008 and revised in 2015.

OGIA 2012 numerical groundwater model. The Updated WMMP is informed by development of the Stage 1 WMMP, which was updated using the revised Updated FDP. This FDP has been used to simulate Condamine Alluvium flux changes with both the OGIA 2012 and 2016 models.

Table 4-8 compares the predicted 100-year flux change (reduction) from the Walloon Coal Measures to the Condamine Alluvium, for calibrated versions of the OGIA 2012 and OGIA 2016 numerical groundwater models, including the Stage 1 and Updated FDP cases, as well as earlier FDP cases.

Table 4-8 Comparison of Condamine Alluvium flux change predictions (GL)

FDP case	Arrow FDP descriptor	OGIA model version	
		2012	2016
SREIS FDP	5x	63	-
UWIR 2016 FDP	8b	56	70
Stage 1 WMMP FDP	5x	63	-
Updated WMMP FDP	10a	58	58

Note:
Values are flux change (reduction in flux to the Condamine Alluvium) over 100 years due to the Action under the Arrow-only calibrated case.

Figure 4-1 and Figure 4-2 show the model predicted flux into the Condamine Alluvium (both in and out) as well as the nett flux (in-out) for 120 years of model prediction (1994 to 2114) for both the OGIA 2012 and 2016 groundwater models. Figure 4-3 and Figure 4-4 show the year to negative (downward) flow predicted by the models on a cell-by-cell basis (AGE, 2019).

Differences in the model predictions are related to different model conceptualisation, and the differences in water production predicted by the OGIA 2012 and 2016 models. Although local flow reversal may be indicated, longer term nett flow remains upward from the WCM to alluvium.

A detailed cell-by-cell flow analysis based on the Stage 1 WMMP FDP case was undertaken for the Condamine Alluvium. Under this case, the model predicted that a nett upward vertical flux will be maintained from the Surat Basin to the Condamine Alluvium (as summed over the entire footprint area of the alluvium), however the local direction of vertical flux is downward from the alluvium into underlying strata across approximately 62% of the footprint (1,626 cells) and upward from underlying strata into the alluvium over the remaining 38% of the footprint (997 cells).

Under the Updated WMMP FDP case, the reduction in upward flux to the Condamine Alluvium will be less, noting that the Arrow-only flux reduction to the alluvium under the Updated WMMP FDP case is 58 GL/100 years, a reduced impact compared with the Stage 1 WMMP FDP case reduction of 63 GL/100 years (Table 4-8).

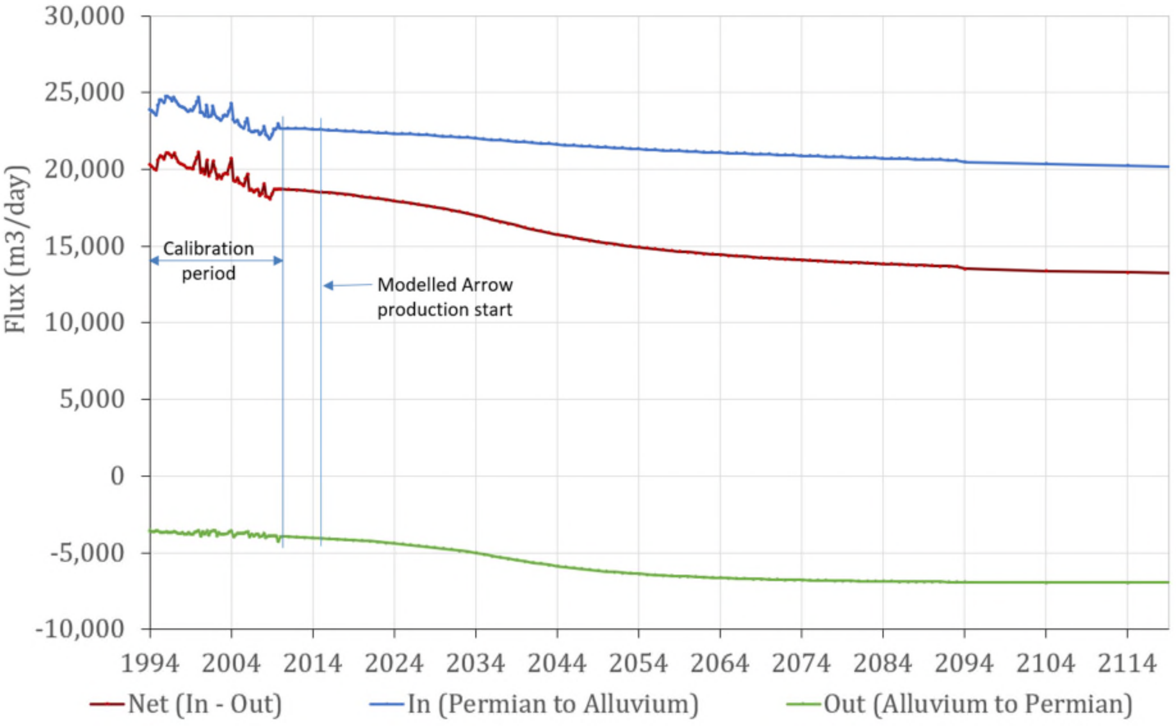

Figure 4-1 Condamine Alluvium flux - OGIA 2012 model

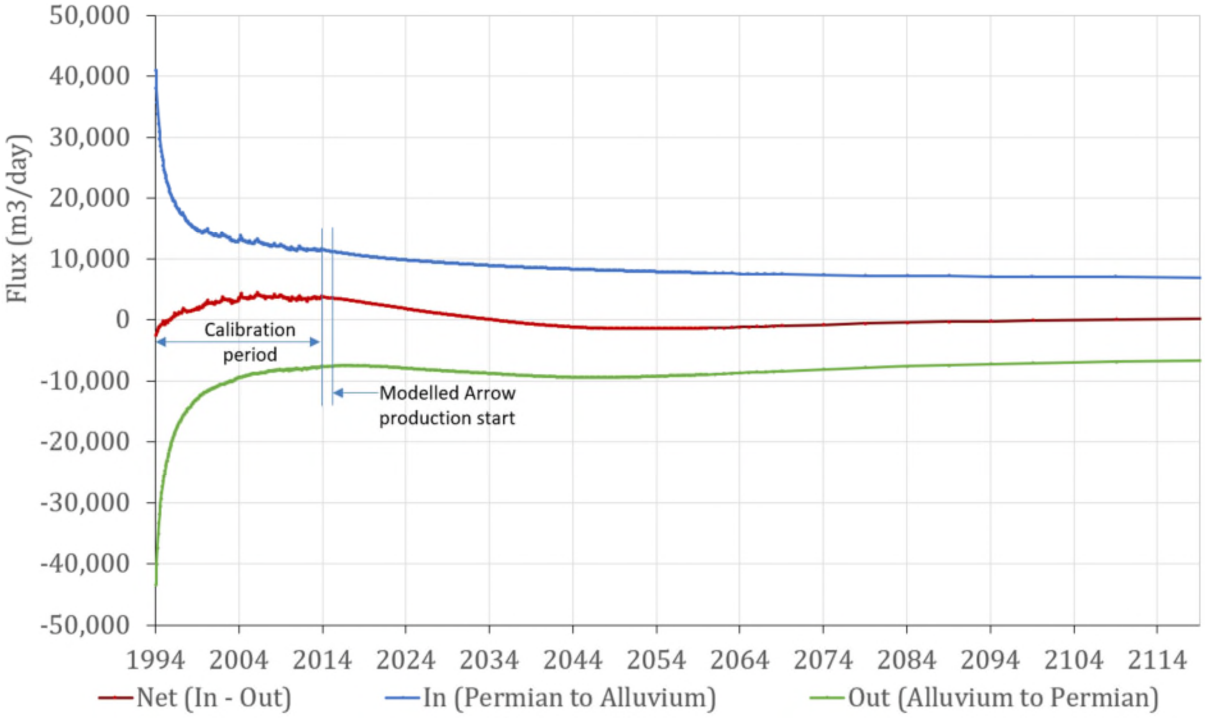

Figure 4-2 Condamine Alluvium flux - OGIA 2016 model

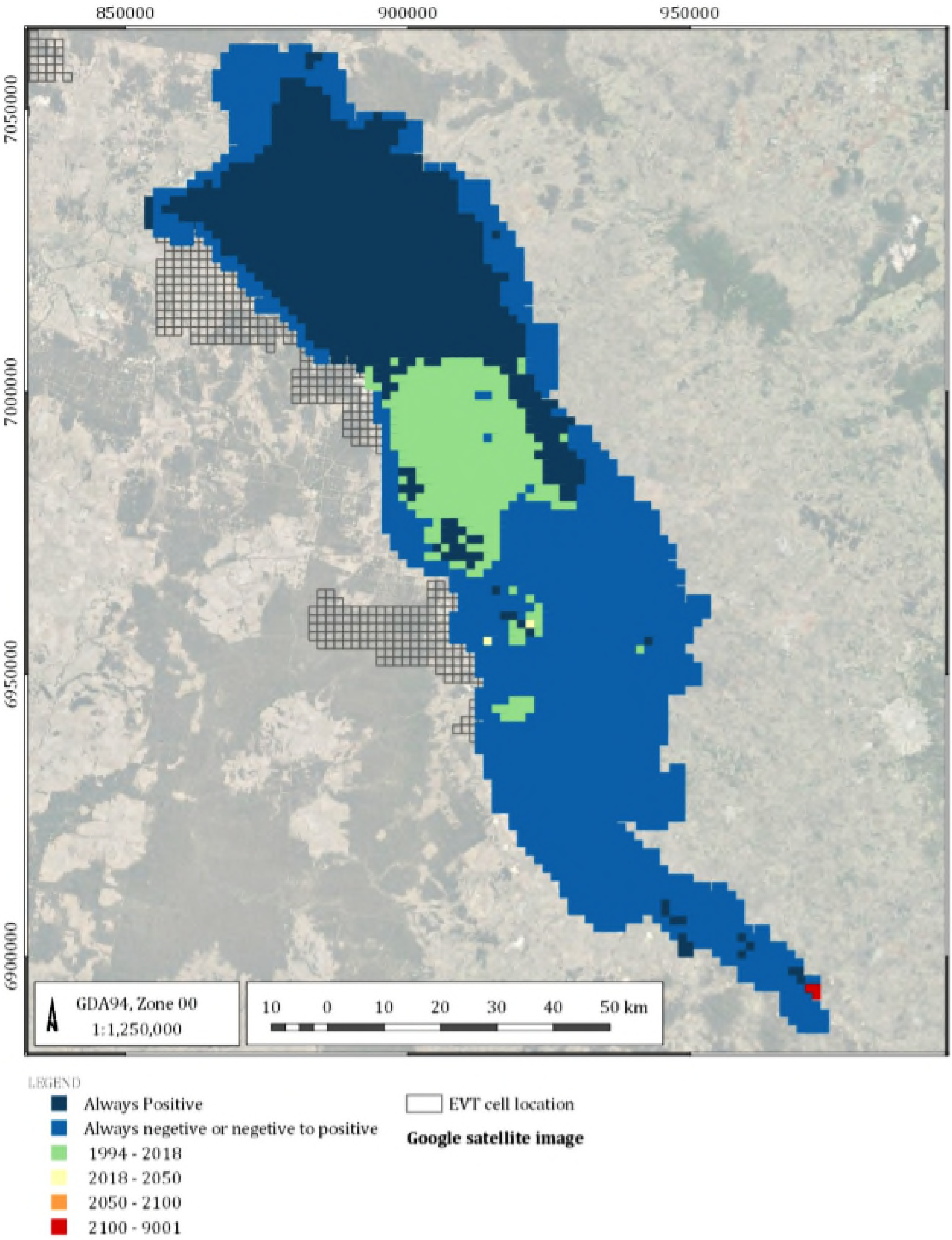

Figure 4-3 Timing of Condamine Alluvium flux – (OGIA 2012 – Updated FDP case)

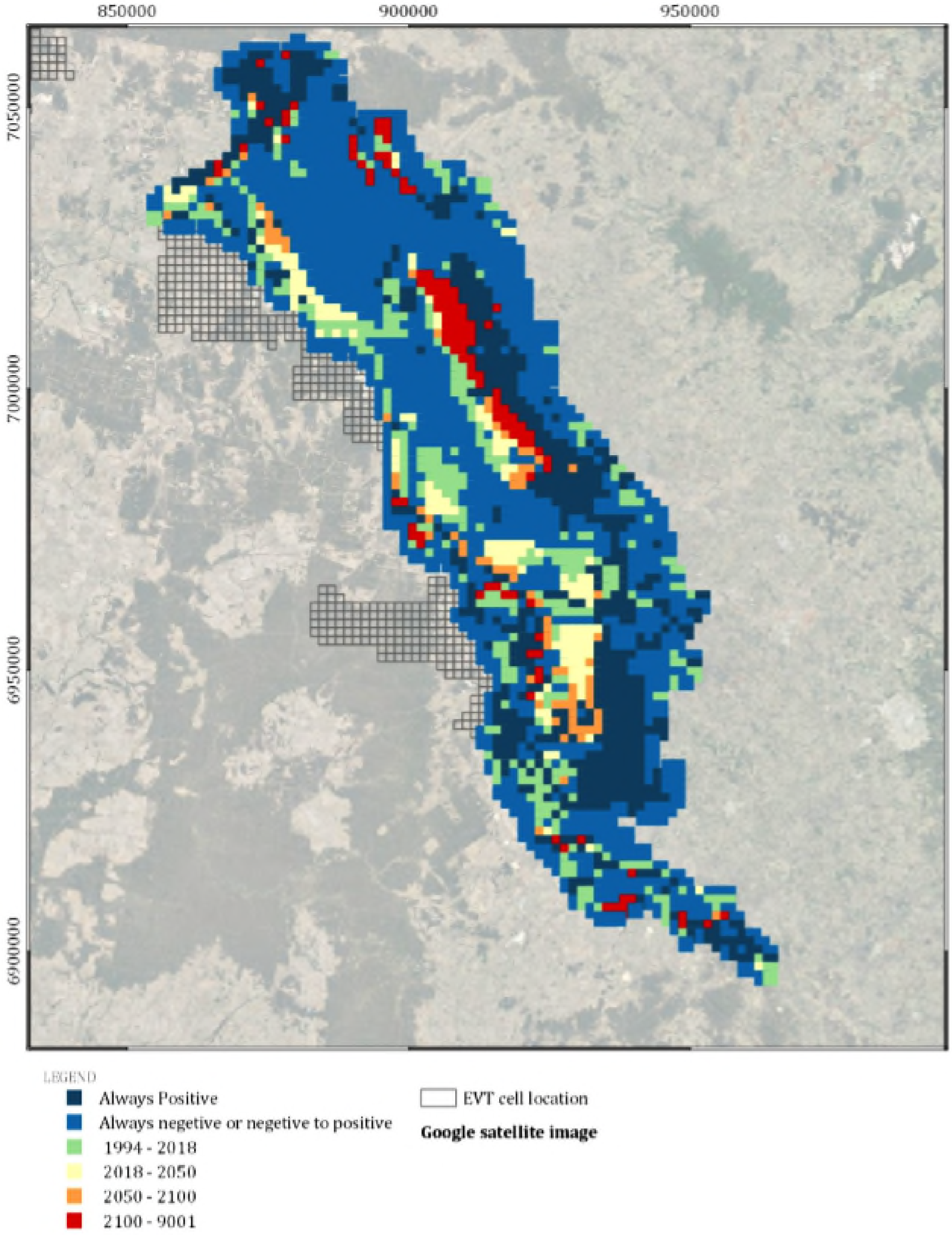

Figure 4-4 Timing of Condamine Alluvium flux – (OGIA 2016 – Updated FDP case)

4.6 Future OGIA modelling

If the OGIA model ceases to exist, Arrow will submit an alternate model, for approval by the Minister, to replace the OGIA model for ongoing modelling that may be required to meet the Approval Conditions.

Where such future modelling triggers an update (Section 8.6) to the SGP CSG WMMP, upon Ministerial approval of the alternate model, Arrow will submit a revised WMMP to the Minister for approval. Arrow would then implement the revised plan following approval.

5. GDE INVESTIGATIONS AND IMPACT ASSESSMENT

5.1 Introduction

The approval conditions relating to GDEs that require fulfilling in the SGP Updated CSG WMMP include Approval Condition 17(f) and 17(g). The requirements of these approval conditions are described in Table 5-1, as is the approach adopted to addressing the conditions.

Table 5-1 GDE Approval Conditions and approach to addressing conditions

Approval Condition	Approach to addressing Approval Conditions
Approval Condition 17(f): *Identify any predicted changes in stream connectivity due to groundwater drawdown from the action and assess potential impacts to groundwater dependent ecosystems due to any predicted changes in stream connectivity, including to water quality, quantity and ecology.*	The results of the numerical modelling assessment conducted as part of the Updated CSG WMMP by CDM Smith (2018) which utilises the 2016 UWIR model and Arrow's Updated FDP to assess the significance of predicted changes in stream connectivity from the Action (Section 4.4) has been used to inform the identification of potential impacts to GDEs associated with the Condamine River. The outcome of the assessment is summarised in Section 5.2.
Approval Condition 17(g)*: Address any uncertainty in the groundwater dependency of ecosystems and springs with supporting evidence from field-based investigations for any groundwater-dependent ecosystems and springs confirmed in the OGIA model.*	This condition has been addressed at four selected sites (Burunga Lane, Glenburnie, Long Swamp and Lake Broadwater) with multiple lines of evidence from two field based investigations (1,2): - 3D Environmental/Earth Search (2018) field based investigations to assess the potential groundwater dependency of ecosystems at the four selected sites. - Arrow Energy (2018) field based investigations to assess the potential level of connectivity between formations overlying the WCM within the four selected sites. The outcomes of the field based investigations are summarised in Section 5.3.

Notes:

(1) The SGP Stage 1 WMMP terrestrial GDE risk assessment identified terrestrial GDEs in the Burunga Lane and Glenburnie sites as potentially dependent on groundwater and at risk of being impacted by Project (Arrow only) related groundwater drawdown. These sites were therefore selected for detailed field investigations in the Updated WMMP.

(2) While potential terrestrial GDEs at the Long Swamp and Lake Broadwater sites were not predicted to be impacted by the Action, in accordance with Approval Condition 13(f), further assessment has been conducted to support development of the Updated CSG WMMP.

In addition, Approval Condition 17(a) requires all matters in the Stage 1 CSG WMMP to be included as well as a discussion on how the Stage 1 CSG WMMP is informing adaptive management for the Updated CSG WMMP. Accordingly, the terrestrial GDE risk assessment conducted in the Stage 1 CSG WMMP to address Approval Conditions 13(c) and 13(p) has been updated in the Updated CSG WMMP to reflect new and additional data and information. The outcomes of the Updated CSG WMMP terrestrial GDE risk assessment are summarised in Section 5.4.

The collective outcomes of the Updated CSG WMMP GDE desk-top assessments and field based investigations are summarised in Section 5.5. Further detail of these studies is provided in the SGP Updated CSG WMMP Stream Connectivity and GDE Assessment Memorandum (Appendix D).

5.2 Potential changes to stream connectivity - Implications for GDEs

Numerical groundwater modelling in the Updated CSG WMMP has assisted in predicting changes in stream connectivity due to groundwater drawdown associated with the Action (Section 4.4). The groundwater modelling outcomes have been used to inform the assessment of potential impacts to GDEs due to any predicted changes in stream connectivity, including to water quality, quantity and ecology; a requirement of Approval Condition 17(f).

As reported in CDM Smith (2018), most of the predicted impact on the Condamine River due to water production by Arrow occurs in river cells located between Warra Town Weir and Chinchilla Weir, with maximum changes in groundwater flux of between 0.001 ML/d and 0.005 ML/d. Maximum changes of less than 0.001 ML/d are also predicted immediately upstream of Cecil Plains Weir. The predicted peak change in the total groundwater flux to the Condamine River due to Arrow’s water production is 0.148 ML/d. Over the simulation period (up to 811 years after the start of simulated water production) the predicted total change in volumetric flux between the Condamine River and Condamine Alluvium is 33.7 GL. These predicted cell flux changes are small (maximum of 0.1 L/s for a cell 500 m × 500 m in size along the alignment of the river) and considered beyond the expected accuracy of the CCAM. Accordingly, for practical purposes the predicted impacts of groundwater flux changes to the connected reaches in the Condamine River from the Action are considered negligible.

Changes to groundwater – surface water connectivity has only limited potential to affect water quality in river systems and therefore only limited potential to impact habitats of aquatic ecosystems in river and riparian zones. In addition, the predicted magnitude of the groundwater flux changes (of up to 0.1 L/s per cell 500 m × 500 m in size) implies that any associated changes to water quality in the Condamine River are likely to be immeasurably small.

From both a river water quantity and quality perspective, potential changes are predicted to be negligible and hence, the potential impacts to existing aquatic ecosystems and surface expression GDEs dependent on the Condamine River are also expected to be negligible.

Surface water and aquatic ecology monitoring was undertaken as part of the SGP EIS/SREIS process (Arrow Energy 2012 & 2013). These included surface water quality, flow and aquatic ecology monitoring locations. Locations were selected to provide baseline data across representative conditions for the different surface water systems and land uses within the SGP area, at the time of the EIS/SREIS. Ongoing monitoring is carried out by the Queensland Government and also tenure holders assigned responsibilities under the Surat CMA UWIR in relation to watercourse springs. Arrow are not the responsible tenure holder for any identified watercourse springs, and no monitoring sites nominated by the OGIA are located within relevant areas for the SGP.

Potential changes to stream connectivity will be reassessed within 90 days of an approved UWIR being issued in the future and upon receiving technical files from OGIA for that UWIR. Reassessment will involve a comparison of the predicted magnitude of the groundwater flux changes provided in this WMMP and that determined using the latest UWIR. If a potential impact to surface water systems and aquatic ecology that is not negligible is identified then Arrow will submit a revised WMMP within 90 days (following the initial 90 days for the reassessment). Identification of further baseline and ongoing monitoring locations will occur, where relevant, should future project requirements and/or future revision of the FDP result in the potential for impact to surface water systems and aquatic ecology.

Monitoring activities will commence in advance of the potential for impact to occur, to enable the establishment of baseline conditions and development of WQOs where required.

5.3 Identification and characterisation of potential terrestrial GDEs

5.3.1 Site selection

On the basis of the outcomes of the GDE risk assessments conducted in the SGP Stage 1 CSG WMMP GDE risk assessment (Appendix A), four sites were chosen for site investigations (Figure 5-1):

- Burunga Lane
- Glenburnie
- Long Swamp
- Lake Broadwater

The first two sites were chosen to satisfy Approval Condition 13(c) whilst monitoring of Lake Broadwater and Long Swamp areas is a requirement of Approval Condition 13(f). The field investigations are intended to address any uncertainty in the groundwater dependency of the ecosystems at the sites, with supporting evidence from field-based investigations; a requirement of Approval Condition 17(g). A description of the setting of each study area is presented in Table 5-2.

ARROW ENERGY - SURAT GAS PROJECT

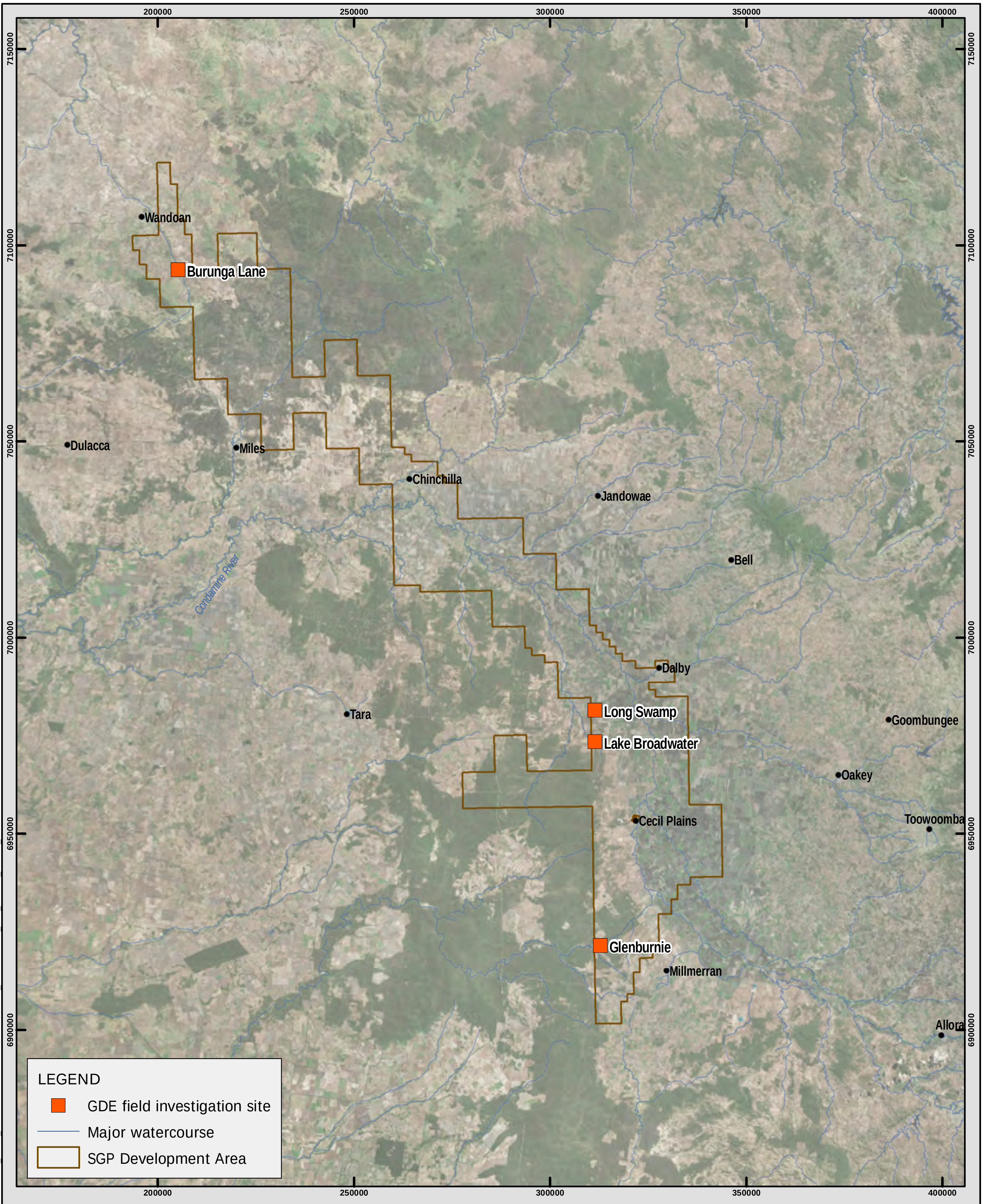

Figure 5.1

Distribution of GDE assessment areas

Source:
3D Environmental
Arrow Energy Pty Ltd

Date: 11/02/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

Scale: 1:1,250,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

arrow energy
go further

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The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.

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Table 5-2 Description of site settings (3D Environmental/Earth Search 2018)

Study Site	Setting
Burunga Lane	The Burunga Lane site is located between the townships of Wandoan and Miles and is situated to the immediate west of the main channel of Juandah Creek. The study site lies on a broad flat to gently undulating partially confined alluvial terrace that extends for approximately 530 m on the western side of the creek, separated from gently undulating sandstone foot-slopes by a narrow overflow channel.
Glenburnie	The Glenburnie study site is located to the west of Millmerran adjacent to Western Creek. Western Creek at this location presents as a dry sandy creek channel with a narrow sinuous overflow flood terrace that has only limited alluvial development. The channel is moderately confined by deeply weathered Springbok Sandstone that variably outcrops in stream benches and along the channel floor with the sandy bedload overlying a weathered sandstone regolith.
Long Swamp	Long Swamp is a broad sinuous overland flow path that extends for approximately 30 km on the Condamine Alluvium. The feature comprises a broad drainage depression, with the central portion underlain by highly vertic surface soils with a strong shrink-swell structure of hummocks and deep cracks.
Lake Broadwater	Lake Broadwater is a naturally occurring, seasonal/intermittent, shallow, freshwater wetland which covers approximately 350 hectares. It is a feature that is mapped as a Wetland of High Ecological Significance (DEHP 2014) and is listed in the Australian Directory of Important Wetlands (Australian Government 2010).

5.3.2 Objectives and approach

The field investigations, conducted in two parts, aimed to characterise ecosystems and their reliance on groundwater (3D Environmental/Earth Search 2018) and quantify the degree of inter-aquifer connectivity between the WCM and overlying formations (Arrow Energy 2018), at each of the four selected sites.

The complete reports for both studies are provided as an attachment to the Stream Connectivity and GDE Impact Assessment Memorandum (Appendix D). A summary of the objectives and broad scope to the studies are provided in Table 5-3.

Table 5-3 Objectives and approach to field investigations

Study	Objectives	Scope
3D Environmental/Earth Search 2018	Identify if vegetation accesses groundwater (permanently or intermittently) to verify assumptions used in previous desktop GDE assessments.	Field ecological and hydrogeological characterisation of potential GDE sites. Installation of monitoring infrastructure. Field and laboratory analysis. Data collation and reporting.

Study	Objectives	Scope
Arrow Energy 2018	Assemble and interrogate field and laboratory data to establish, using multiple lines of evidence, the degree of inter-aquifer connectivity between the WCM and overlying formations within each of the four selected study sites Identify stratigraphy to confirm geological mapping at monitoring sites	Installation of monitoring infrastructure. Field and laboratory analysis. Numerical modelling. Data collation and reporting.

The outcomes of the field investigations at the four selected sites are summarised in turn below.

5.3.3 Burunga Lane

Key findings of the 3D Environmental/Earth Search (2018) GDE investigation at the Burunga Lane site were as follows:

- A sub-artesian aquifer was intersected at 13.5 m depth within a thin coal seam and surrounding sandstone.
- Presence of high moisture content approaching saturation within and above a conglomerate band at 5.8 m depth during drilling. Groundwater was however not present within a monitoring bore installed to a depth of 7.1 m during the sampling event, completed almost 3 months following drilling.
- Drill coring identified tree root material to a maximum depth of 6 m; well above the depth of the regional aquifer.
- Leaf water potential and soil moisture potential measurements at the site suggests that larger river red gums are predominantly sourcing soil moisture from a zone between 4.5 mbgl and 6.5 mbgl which is consistent with observations of tree rooting depth.

The investigations concluded that based on the considerable depth to the regional aquifer and evidence for a shallower source of soil moisture for River Red Gums on the fringes of Juandah Creek, the site is considered unlikely to represent a GDE.

There is a possibility that shallow seasonal groundwater may be present following significant rainfall events causing recharge to the creek alluvium, particularly when the creek is in a state of high flow. The Arrow Energy (2018) connectivity investigations at the Burunga Lane site involved the drilling, installation and testing of three groundwater monitoring bores. The WCM was confirmed to subcrop in the area with a thin alluvial cover of approximately 7 m in thickness at surface; a local scale feature believed to be associated with Juandah Creek. Lower permeable lithology types (e.g. well cemented fine-grained sandstones, hard blocky siltstones and carbonaceous mudstones), separating the more coal permeable coal seams are well represented in the WCM interburden at depth, are expected to significantly impede the vertical movement of groundwater.

The monitoring bore screening the Alluvium, was consistently recorded as dry during each monitoring event, indicating this alluvial feature associated with Juandah Creek is not a permanent aquifer and possibly only stores water, on a temporary basis, following recharge events. Confining conditions in the WCM were confirmed as was an upward vertical hydraulic gradient.

The Arrow Energy (2018) connectivity investigations at the site and accompanying desk-top studies support the conceptualisation of a shallow and generally unsaturated Alluvium unit overlying the confined WCM aquifer with limited potential for vertical movement of groundwater. Multiple lines of evidence from the study, including drilling results, hydrograph analysis, permeability tests and numerical modelling demonstrate a limited potential for interconnectivity between the formations.

5.3.4 Glenburnie

Key findings of the 3D Environmental/Earth Search (2018) GDE investigation at the Glenburnie site were as follows:

- A sub-artesian aquifer, interpreted to be the regional aquifer, was intersected at 27 m depth in the vertical core hole with groundwater rising (in the bore hole during drilling) to approximately 14.4 mbgl. The aquifer is well below the observed maximum tree rooting depth of 7.6 m.
- There was only a shallow profile of alluvial soil of approximately 2.5 m overlying weathered bedrock (Springbok Sandstone) with zones of higher soil moisture availability at approximately 9 to 11.5 mbgl, and at 14.5 to 17 mbgl.
- A shallow saturated seepage zone was noted during drilling of between 13.5 mbgl and 18 mbgl interpreted to be a perched groundwater zone within the Springbok Sandstone.
- Leaf water potential and soil moisture potential measurements indicate moisture being sourced from a zone of soil moisture between 9.0 mbgl and 11.5 mbgl; slightly deeper than the observed maximum tree rooting depth.
- Stable isotope signatures of plant xylem water are considerably enriched above those of soil moisture at depths where trees are predicted to be sourcing their water. While this may indicate a significant contribution of shallow evaporatively enriched surface moisture, it may also indicate potential isotopic fractionation within the tree xylem, or confounding errors associated with the sampling process. There is however no indication that a deeper groundwater source is contributing significantly to the water usage of trees at the locality.

Based on the considerable depth to the regional aquifer, observations of tree rooting depth and evidence for a shallower source of soil moisture from leaf water potential and soil moisture potential analysis, the site is considered unlikely to represent a GDE.

The Arrow Energy (2018) connectivity investigations demonstrated the site consists of a thin layer of unsaturated Alluvium (up to 2.5 m in depth) at surface, underlain by the Springbok Sandstone unit to 21.1 mbgl. The WCM was intersected at 21.1 mbgl and is considered confined at the site due to its depth, the low permeable overburden and interburden between coal seams and observed hydraulic heads between the monitoring bores which indicate an upward vertical hydraulic gradient.

The major ions analysis demonstrates a level of separation between groundwater in the confined WCM aquifer (where chloride is the dominant anion) and shallow perched water in the Springbok Sandstone unit (where carbonate and bicarbonate are the dominant anions) supporting the conceptualisation that appreciable exchange of groundwater between formations at the Glenburnie site is unlikely to be occurring.

The drilling results, hydrograph analysis, permeability testing, groundwater sampling analysis and numerical modelling assessment conducted as part of the Arrow Energy (2018) study indicated limited potential for interconnectivity between the formations. Within the confined WCM aquifer, the substantial thickness of interburden is of low permeability, significantly limiting the potential for vertical groundwater movement and connectivity between the coal seams and overlying formations.

5.3.5 Long Swamp

Key findings of the 3D Environmental/Earth Search (2018) GDE investigation at the Long Swamp site were as follows:

- The regional aquifer was intersected at a depth of 26.5 m within a basal sand of the Westbourne Formation, well below the observed tree rooting depth of 7.1 m.
- A thick sand sequence between depths of 10.8 m to 17.4 m (within the Condamine Alluvium) is interpreted to be a depleted aquifer, which transitions from dry at the top to saturated at the base of the sequence. The upper 5 m of this sand was dry to slightly moist, presenting an impediment for the possible downward growth of recent tree roots, and a potential zone of root desiccation and embolism for any existing mature tree roots.
- Leaf water potential and soil moisture potential measurements indicate larger river red gums are predominantly sourcing soil moisture from a zone between 11.5 mbgl and soil surface (based on an enrichment of stable isotopes in twig water) broadly consistent with observations of tree rooting depth. Stable isotope signatures obtained from sampled twig xylem are enriched above all soil samples except at the soil surface. Although additional research is required to fully elucidate the significance and behaviour of xylem isotopes in relation to seasonal and climatic conditions, there is no apparent suggestion of a deeper groundwater source.

Historic and current declining groundwater level trends in bores monitoring the Condamine Alluvium in proximity to Long Swamp is ascribed to groundwater abstraction and harvesting of surface water and overland flow (reducing natural recharge rates) for non-CSG uses. The consequence of these activities has been a decline in water levels to below the lower root depth threshold zone where severe decline in vegetation condition may occur. These findings are consistent with those of Kath et al (2014), Reardon Smith (2011) and Dafny and Silburne (2014) which all identify significant declines in groundwater levels across the Condamine Alluvium prior to CSG activities.

Based on the considerable depth to the saturated zone and evidence of a shallower source of soil moisture for river red gums in Long Swamp, the site is considered unlikely to represent a GDE.

The Arrow Energy (2018) connectivity investigations at the Long Swamp site, comprising three monitoring bores, confirms the stratigraphy encompasses Condamine Alluvium from surface to 18 mbgl, underlain in succession by the Westbourne Formation to 53 mbgl, Springbok Sandstone to 82 mbgl and the WCM to total bore depth of 128 mbgl. The WCM aquifer is considered confined at the site due to its depth, the low permeable overburden and interburden between coal seams and observed hydraulic heads. A declining hydraulic pressure with depth was recorded, indicating a downward potential for vertical movement of groundwater and limited hydraulic connection between the formations.

Horizontal hydraulic conductivity data derived from the field studies indicates the Springbok Sandstone and WCM are of low permeability at the Long Swamp site. The finding further supports the conceptualisation of a significantly limited potential for hydraulic connection between the Westbourne Formation, Springbok Sandstone and WCM formations.

The field investigations and desk-top studies of the Long Swamp site conducted as part of the Arrow Energy (2018) study indicated a hydrogeological conceptualisation comprising an unconfined Condamine Alluvium aquifer, underlain by an aquitard represented by the Westbourne Formation and thereafter the confined aquifers of the Springbok Sandstone and WCM. The drilling results, hydrograph analysis, permeability testing, groundwater sampling analysis and numerical modelling assessment indicated very limited potential for hydraulic connection between each aquifer at the site.

5.3.6 Lake Broadwater

Key findings of the 3D Environmental/Earth Search (2018) GDE investigation at the Lake Broadwater site were as follows:

- Lake Broadwater is fringed by a low sand ridge on its northern and western margins which overlies a thick plastic clay layer between depths of approximately 3 m and 11.3 m. The interface between the plastic clay and sand hosts a shallow perched aquifer within which groundwater levels would fluctuate dependent largely upon the water levels in the lake, as well as recharge directly to the sand mass fringing the lake.

- Drill coring identified abundant tree root material within the shallow perched aquifer, with deeper roots penetrating heavy clays to a depth of 4 m. This indicates trees are utilising shallow perched water to satisfy all or a portion of their water budget requirements. The deeper roots penetrating into the upper fringe of the underlying heavy clays is interpreted to be both an anchor mechanism and an alternative source of moisture during periods of drought and aquifer depletion.

- Leaf water potential and soil moisture potential measurements at the site support the interpretation that canopy trees are extracting moisture from a saturated zone coinciding with the interface between clay and sand.

Based largely on the identification of tree root material within the perched saturated zone, and supported by measurement of soil moisture, leaf water potential and stable isotopes, Lake Broadwater is considered to represent a GDE. The shallow perched aquifer overlies a 7.8 m thick sequence of massive plastic clays which comprises a thick separation barrier between the perched aquifer and the underlying formations potentially subject to CSG depressurisation.

The Arrow Energy (2018) connectivity investigations at the Lake Broadwater site, comprising three monitoring bores, confirms the stratigraphy encompasses Alluvium from surface to 31 mbgl, overlying the Westbourne Formation to 95 mbgl, followed by the Springbok Sandstone to 178 mbgl and the WCM to total bore depth of 204 mbgl.

The Springbok Sandstone aquifer within the vicinity of the site is low yielding (due to the presence of very well cemented sandstones and hard blocky siltstone) and likely confined with the overlying low permeable lithology of the Westbourne Formation acting as the confining layer. The WCM aquifer is considered confined at this site due to its depth and the low permeable overburden and interburden between coal seams. A distinct difference in hydraulic head between the shallow perched system and the underlying Westbourne Formation was recorded indicating a level of hydraulic separation. The Westbourne Formation displayed a greater hydraulic pressure than the Springbok Sandstone and WCM formations indicating a downward potential for movement of groundwater between the Westbourne Formation and the underlying formations, while the comparative hydraulic pressures recorded for the Springbok Sandstone and WCM may imply a potential hydraulic connection between the two formations.

While the Lake Broadwater surface water is reasonably fresh (at 290 mg/L TDS), groundwater in all monitoring bores is recorded as brackish (3,110 to 3,930 mg/L TDS) with no trend in salinity concentration with formation depth.

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) (2018) assessed potential impacts to Lake Broadwater from CSG extraction in the WCM. AGE constructed a 'sandpit' groundwater model (i.e. simple box model representing just the main hydrostratigraphic layers) to simulate the pressure/pressure differences between the Lake Broadwater monitoring bores and assess when the well drawdown propagates into the shallow water table aquifer.

The calibrated model was used in steady state to assess the rate at which pumping from the Kogan Seam of the WCM at the site has the potential to induce groundwater level drawdown in the Alluvium. The modelling approach indicated a maximum pumpable rate from the coal seam of 10 ML/day. These elevated pumping rates were predicted to have nil drawdown in the Alluvium. Such predictions are expected given that the vertical hydraulic conductivity in layers above the Kogan seam are demonstrated to be low (e.g. laboratory vertical permeability testing of the Springbok Sandstone was recorded at 1.70×10^{-7} m/d which was reasonably consistent with the value applied in the AGE (2018) model), limiting drawdown extending to the overlying Alluvium. Furthermore, a sensitivity analysis of the vertical hydraulic conductivities applied in the model indicated that increasing the vertical hydraulic conductivities of the units beneath the Alluvium by one and two orders of magnitude still contributed to nil drawdown in the Alluvium unit.

The field investigations and desk-top studies of the site conducted as part of the Arrow Energy (2018) study indicates a hydrogeological conceptualisation comprising a perched system associated with Lake Broadwater within the Alluvium, underlain by an aquitard represented by the Westbourne Formation and thereafter the confined aquifers of the Springbok Sandstone and WCM. The findings from this study infer that there is limited potential for hydraulic connection between the upper units at the site. While hydraulic connection between the Springbok Sandstone and the WCM at the site is considered possible based on comparative hydraulic pressures recorded, groundwater modelling indicated that the perched system associated with Lake Broadwater, overlying the alluvium, is unlikely to be affected by CSG pumping from the WCM.

5.4 Terrestrial GDE risk assessment for the Updated WMMP

5.4.1 Introduction

The terrestrial GDE risk mapping exercise, conducted in the Stage 1 CSG WMMP (Appendix A), was revised with the Updated CSG WMMP modelling outputs, updates to the geological and GDE mapping of the Surat CMA, and the outcomes of the GDE and inter-aquifer connectivity field programs described in Section 5.3. The Updated CSG WMMP GDE risk mapping assessment aimed to address (in part) Approval Condition 17(g) which seeks to identify any uncertainty in the groundwater dependency of ecosystems that may be subject to potential impacts as a consequence of the Action, and in response to Approval Condition 17(a) which requires all matters in the Stage 1 CSG WMMP to be included.

5.4.2 Outcomes

The preliminary Updated WMMP GIS based multi-criteria assessment identified potential terrestrial GDE areas at risk of impact from Arrow only and/or cumulative CSG groundwater related drawdown. These areas were subject to further assessment by interrogating publicly available site-specific data to further refine the risk classification. This provided an opportunity to enhance the confidence in the risk classification by using local-scale site specific data and overcoming the constraints of relying on coarse-scale mapping products.

Upon further assessment, the Updated WMMP terrestrial GDE risk assessment did not identify any areas of terrestrial GDEs at potential risk of impact from groundwater drawdown associated with CSG extraction from the Action and cumulative CSG extraction, and in turn, no additional site-specific field investigations were required.

A discussion of the results and outcomes of the desk-top risk assessment is included in the Stream Connectivity and GDE Impact Assessment Memorandum (Appendix D).

5.4.3 Future assessments

The terrestrial GDE desktop risk assessment will be updated with revised OGIA model output within 90 days of the approved UWIR being issued and upon receiving technical files from OGIA for that UWIR. Using the revised OGIA model output, the following assessment, consistent with the Stage 1 and this Updated WMMP methodology, will be undertaken. This following section only applies to potential impacts to terrestrial GDEs not previously assessed as part of the Stage 1 or Updated WMMP.

1. Identification of potentially affected terrestrial GDEs

Potentially affected terrestrial GDEs will be identified by considering potential GDE landscapes (based on available mapping) in relation to the 1 m predicted groundwater level drawdown contour in the source aquifer (where it outcrops or sub-crops and is representative of the watertable). If no potentially affected terrestrial GDEs are identified, no further action will be undertaken and the details of the assessment will be reported in the following annual report.

2. Assessment of likelihood of identified potentially affected terrestrial GDEs of being actual GDEs

Any identified potentially affected terrestrial GDE will be further assessed to determine their likelihood of being actual GDEs. This further assessment will involve a detailed review and conceptualisation of:

- available groundwater level and pressure data
- borehole logs and indicated stratigraphy
- soil types and landscape setting
- vegetation types present and knowledge around their associated groundwater dependence

Where there is sufficient data to demonstrate the ecosystems do not rely on groundwater, no further assessment would be required and the details of the assessment will be reported in the following annual report.

3. Assessment of potential impact

Where it is considered likely an ecosystem relies in some way on groundwater, or where there is insufficient data to rule it out, an assessment of the risk the ecosystem may be impacted, will be undertaken. This assessment will consider the rate of change, in particular in comparison to historic groundwater level trends, an assessment of the adaptability of the vegetation present to changing groundwater levels, and findings from previous field investigations undertaken (including those completed as part of this Updated WMMP). If the assessment concludes there are no ecosystems at risk[17] of being impacted, no further action will be required and the details of the assessment will be reported in the following report.

If, through the updated desktop assessment, a potential terrestrial GDE is predicted to be at risk of being impacted from the Action and/or the cumulative CSG operation, Arrow will submit a revised WMMP within 90 days (following the initial 90 day desktop assessment period). The revision will include an outline for further work (including field investigations if applicable) to be undertaken to gather supporting data to confirm the ecosystem’s reliance on groundwater and validate the findings of the desktop assessment. While further work may include the methods employed in the Updated WMMP terrestrial GDE field investigations (Section 5.3), the scope of any potential further work will be specific to the site being investigated and the gaps identified. The requirement to assign an EWMS to a terrestrial GDE will be determined following the completion of further work and, if required, will be developed in accordance with Section 7.5.4.

Future iterations of the UWIR are expected to consider risks associated with cumulative CSG-related impacts to non-spring GDEs. Arrow will review any updated terrestrial GDE risk assessment approach in any future iterations of the UWIR and will adopt this approach in the next revision of the WMMP to

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[17] The terrestrial GDE assessment process, defined in Appendix D of the Stage 1 WMMP, provides for binary results which identify if a potential terrestrial GDE is either predicted to be at risk of being impacted from the Action and/or the cumulative CSG operation, or it is not. The assessment is based on a detailed review of physical data related to each risk area rather than the application of a risk/impact assessment matrix.

ensure alignment with OGIA. Arrow will comply with requirements concerning the assessment and management of terrestrial GDE’s should any be made in future iterations of the UWIR.

5.5 Summary of Updated WMMP findings

The Updated CSG WMMP stream connectivity and GDE assessment, inclusive of risk mapping, numerical modelling and field investigations, has addressed Approval Conditions 17(f) and 17(g) and fulfilled the relevant commitments made in the Stage 1 CSG WMMP. The assessments conducted in Updated utilise Arrow’s Updated FDP Case and the 2016 UWIR model. Updates to the subcrop geological mapping (Cranfield 2017) and GDE mapping (DES 2018) have also informed the Updated WMMP assessment.

In response to Approval Condition 17(f), numerical modelling was conducted by CDM Smith (2018) utilising the 2016 UWIR model and Arrow’s Updated FDP Case, to assess the potential impacts to the Condamine River from the Action. The modelling exercise predicted that the peak change in the total groundwater flux to the Condamine River due to Arrow’s water production is 0.148 ML/d. Over the simulation period (of over 800 years), the predicted total change in volumetric flux between the Condamine River and Condamine Alluvium is 33.7 GL. The predicted flux changes are small and beyond the expected accuracy of the CCAM, and accordingly, for all practical purposes are considered negligible. On the basis of the predicted negligible change to leakage rates over periods of hundreds of years, it was concluded that any potential impacts to water quality and existing aquatic ecosystems and surface expression GDEs dependent on the Condamine River are also likely to be negligible.

The terrestrial GDE risk mapping exercise conducted in the Updated WMMP did not identify any areas of terrestrial GDEs at potential risk of impact from groundwater drawdown associated with CSG extraction from the Action, and in turn, no additional site-specific field investigations were considered necessary.

To satisfy the commitments made in the Stage 1 CSG WMMP and to address Approval Condition 17(g), comprehensive field investigations were conducted at four sites: Burunga Lane, Glenburnie, Long Swamp and Lake Broadwater (Figure 5-1). The field investigations, conducted in two parts, aimed to characterise ecosystems and their reliance on groundwater (3D Environmental/Earth Search 2018), and to quantify the degree of inter-aquifer connectivity between the WCM and overlying formations (Arrow Energy 2018), at each of the four sites.

Multiple lines of evidence from the joint field investigations conducted in Updated WMMP demonstrated that ecosystems at each of the selected sites are unlikely to be at risk of impact from groundwater extraction associated with cumulative CSG development in the Surat CMA as summarised below.

At Burunga Lane, Glenburnie and Long Swamp:

- The deeper-rooted trees at the three sites are considered likely to be tapping downward-percolating water moving under gravity through a near-saturated vadose zone.
- The depth to the regional aquifer (potentially subject to CSG depressurisation) at each site is considerably deeper than: (i) the deepest observed rooting depth; (ii) the inferred likely zone of predominant soil moisture uptake by trees and (iii) with the possible exception of Burunga

Lane, the likely maximum tree rooting depth for deeper rooted potential GDE species (such as river red gums) of 18 m.

- The relatively shallow maximum tree root depths observed (maximum of 7.6 m at Glenburnie) in comparison to the maximum anticipated depth threshold of 18 m based on literature studies.
- Limited potential for hydraulic connection between the WCM and overlying aquifers at each of the sites.

At Lake Broadwater:

- A shallow alluvium unit hosts a perched groundwater system associated with Lake Broadwater and the site is believed to represent a GDE.
- The depth to the regional aquifer (potentially subject to CSG depressurisation) at the site is, however, considerably deeper than: (i) the deepest observed rooting depth of 4 m; (ii) the inferred likely zone of predominant soil moisture uptake by trees and (iii) the likely maximum tree rooting depth for deeper rooted potential GDE species (such as river red gums) of 18 m.
- Numerical modelling (including a sensitivity analysis that involved increasing the vertical hydraulic conductivities of the units beneath the Alluvium by one and two orders of magnitude) has demonstrated that groundwater extraction from the WCM associated with CSG development at the site, is unlikely to contribute to discernible drawdown in the shallow alluvium.

Furthermore, modelled hydrographs for monitoring bore locations at the four GDE investigation sites do not indicate that depressurisation of the WCM will materially influence groundwater bores in the shallower aquifers at these sites, because the shallow aquifers are not responsive to drawdown in the WCM. Hydrographs for key monitoring bores at Burunga Lane, Glenburnie, Lake Broadwater and Long Swamp are provided in Appendix E.

6. WATER MANAGEMENT

The Arrow CSG Water Management Strategy (CSG WMS) for the SGP is provided in Appendix F. It is based on Arrow’s corporate CSG Water Management Strategy as set out in Attachment 9 of the EIS (Arrow, 2012) and addresses specific requirements for management of CSG co-produced water resulting from activities arising from the SGP FDP including approval conditions 13(l), 13(m) and 13(n).

The CSG WMS provides a basis for compliance and sets out the method for managing CSG water for Arrow’s Surat Basin tenements.

The CSG WMS applies to co-produced water and brine resulting from CSG production activities, but not from exploration activities. Although the WMS includes all possible water and brine management options for the SGP, it is noted that discharge[18] of CSG water to surface water or re-injection of CSG water are not components of the SGP.

Should discharge to surface water systems be proposed in the future, this will necessitate the submission of a revised WMMP within 90 days of identifying the requirement for discharge, for Ministerial approval. An aquatic ecology and ecosystems EWMS will be included in the revised WMMP if this eventuates.

Anticipated water production for the SGP is presented in Table 1-3.

CSG water resulting from the SGP will be treated at existing Arrow facilities and at QCLNG facilities operated by QGC including the Kenya water treatment facility. QGC facilities are considered appropriate for treating the planned volumes. Water treated by QGC will then be returned to Arrow as treated water and brine; legal ownership is not transferred to QGC. Remaining water will be dealt with at the existing Arrow water treatment facilities.

Treated water will be prioritised for supply as substitution for existing Condamine Alluvium allocations. This water will be returned to these end users via a beneficial use network with the exact route to be determined. Remaining treated water will be supplied to existing users, including via the existing SunWater Chinchilla beneficial use scheme. In this case, treated water is transferred to QGC before it is supplied to SunWater under existing commercial and approval arrangements.

Brine produced as part of the water treatment process will be stored in existing brine dams at Daandine and Tipton and in new brine dams to be constructed for Arrow at Kenya. The base case for dealing with stored brine is currently to crystallise the brine to a solid waste salt product and then to landfill this waste at dedicated salt encapsulation facilities (SEF). It is currently assumed that a facility

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[18] Discharge’ and ‘emergency discharge’ are considered as different processes. ‘Discharge’ is considered a planned process, which Arrow is not undertaking. If a future requirement for discharge is identified, the WMMP would be revised, and approval sought before undertaking planned discharge. In contrast, ‘emergency discharge’ is considered to be an unplanned, emergency response. If a requirement for emergency discharge is identified, the Queensland Government has a process which enables application for a temporary emissions licence under the Qld EP Act which applies to emergency situations. Arrow would follow this process and appropriate documentation would be provided as part of the annual reporting.

will be required for the Kenya location and that Arrow will require a separate salt solution for the Daandine and Tipton volumes.

7. MONITORING, RISK RESPONSE AND ADAPTIVE MANAGEMENT

7.1 Stage 1 WMMP – Informing adaptive management

The field based activities, investigations and corresponding assessments that have contributed to the conceptualisation and evaluation of potential impacts in the Updated WMMP, and informed adaptive management, have been described in previous chapters of this report. These include:

- Arrow's ongoing groundwater and surface water baseline monitoring program (Section 3.1) that has enabled review of data to assess whether trends are consistent with expectations and predictions.
- Arrow's contribution to the Condamine Interconnectivity Research Project (CIRP) (OGIA 2016) (Section 3.2). The findings of the project demonstrate that the assumptions incorporated into past model versions, in particular that a low-permeability transition layer controls and limits groundwater flux impacts from the SGP to the Condamine, are supported by field investigations relying on multiple lines of evidence and are therefore valid and reasonable for predictive purposes.
- Updated CSG WMMP numerical modelling utilising the 2016 UWIR model and the 2012 OGIA model, with the revised Updated CSG WMMP FDP (Section 4), demonstrated that predicted impacts under the Updated FDP case would not exceed those from the Stage 1 FDP case.
- Updated CSG WMMP terrestrial GDE risk mapping, which provided opportunity to enhance the risk classification confidence by using local-scale site specific data. The Updated WMMP terrestrial GDE risk assessment did not identify any areas of terrestrial GDEs at risk of impact from drawdown associated with CSG extraction, and no additional site-specific field investigations were required.
- The GDE and inter-aquifer connectivity field investigations (Section 5), intended to address uncertainty in the groundwater dependency of the ecosystems at four sites, with supporting evidence from field-based investigations; a requirement of Approval Condition 17(g).

The outcomes of these initiatives underpin the approaches to adaptive management for the Updated CSG WMMP, as outlined in this chapter and required by Approval Condition 17(a).

In addition, Section 7.1 (below) responds directly to Approval Condition 17(e) by providing a review and update of the Stage 1 WMMP monitoring network to reflect changes in the understanding of potential impacts to water resources.

7.2 Monitoring network

The Surat CMA UWIR sets out regional monitoring requirements for groundwater pressure and quality monitoring, and through this a substantial network of groundwater monitoring locations has been established across the CMA. The regional monitoring network specified in the 2016 UWIR comprises 675 groundwater pressure and/or quality monitoring points, of which 491 were established at the time of the release of the 2016 UWIR. Arrow's UWIR monitoring locations, where in the vicinity of the SGP, are presented in Figure 7-1.

7.2.1 Review of Stage 1 monitoring network

The Updated CSG WMMP baseline monitoring, site investigations and modelling (Section 3) have informed the understanding of potential water resources impacts from CSG development. In conjunction with this, the CSG WMMP monitoring network (proposed in the Stage 1 CSG WMMP) has been reviewed to ensure its ongoing suitability as an early warning monitoring system (EWMS) for the Updated WMMP.

No additional areas or heightened areas of potential impact or risk to water resources and connected receptors have been identified for the Updated CSG WMMP. In response to Approval Condition 17(e), the monitoring network developed and implemented in the Stage 1 CSG WMMP remains valid for characterising background groundwater level and quality trends, and suitable for an EWMS (Appendix G). The CSG WMMP monitoring network therefore comprises 105 monitoring bore/vibrating wire piezometer intervals.

Table 7-1 presents the Updated CSG WMMP monitoring bores and provides the location, target aquifer, status and purpose of the bores. This monitoring network demonstrates Arrow's commitment to groundwater level and quality monitoring across its tenure in each potentially affected aquifer that constitutes the groundwater resource.

The Updated CSG WMMP monitoring network will change in the future to align with any subsequent changes to the UWIR monitoring requirements. Any updates to the monitoring network, for the purposes of aligning with changes to the UWIR monitoring requirements, will be documented during annual reporting on the Updated CSG WMMP.

7.2.2 Early warning monitoring bores

A total of 31 monitoring intervals across the unconsolidated and consolidated aquifers at 29 discrete monitoring locations will serve as early warning monitoring bores in the EWMS (Section 7.5). This represents all the unconsolidated and consolidated aquifers subject to monitoring in the Updated CSG WMMP network with the exception of three Condamine Alluvium monitoring bores (RN42231370, Daandine-161 and Carn Brea-17).

The baseline monitoring assessment (Section 3.1.3) conducted as part of the Updated WMMP indicated regular drawdown and recovery cycles of several metres in these bores as a consequence of nearby groundwater extraction for agricultural or other non-CSG uses. The magnitude of these groundwater fluctuations is such that these bores have limited use for early warning monitoring, and therefore have been excluded as early warning monitoring bores in the CSG WMMP. Data from these bores, whilst excluded from the EWMS, will still be subject to groundwater trend analysis as part of the ongoing monitoring plan described in Section 7.4.

Should any of the bores comprising the EWMS be removed from monitoring in any future UWIR, then such bores will also be removed from the EWMS network.

7.2.3 GDE and spring monitoring bores

The GDE investigations and impact assessment for the Updated CSG WMMP (Section 5) did not identify any terrestrial GDEs at risk of impact from groundwater extraction associated with cumulative CSG development in the Surat CMA. Accordingly, there are no monitoring requirements for terrestrial GDEs in the Updated CSG WMMP.

The Joint Industry Plan (JIP) provides reference to OGIA's Spring Impact Management Strategy (SIMS) in the Surat CMA UWIR which provides an assessment of potential impacts to springs. There are currently no EPBC springs located within Arrow tenure and all off tenure EPBC springs are located closer to other CSG proponents who are the responsible tenure holders under the JIP (DNRM 2016a). Arrow has no assigned responsibilities regarding potentially affected springs under the SIMS. The SIMS is considered to adequately address the potential impact to springs and no further assessment has been undertaken in this plan. In addition, no springs within Arrow tenure other than those identified and considered in the Surat CMA UWIR are known to be present.

7.2.4 Flux monitoring locations

The Stage 1 CSG WMMP identified the need for future WMMPs to review flux monitoring locations and to take into account future modelling predictions based on revised FDPs and data. As noted in the Updated WMMP Groundwater Modelling and Research Technical Memorandum, the results show that, using the same numerical model, the predicted change in Condamine Alluvium flux for the Updated FDP Case is slightly lower than the predicted change in flux for the Stage 1 FDP Case (SREIS Case) (-58 GL compared to -63 GL).

Differences in predicted drawdown in the Condamine Alluvium between the SREIS FDP Case assumed in the Stage 1 CSG WMMP and the Updated FDP Case (in both the cumulative and Arrow-only cases) are minor, noting however that the timing of maximum drawdown has changed for the present case. Differences in timing are influenced by the revised staging and location of Arrow's updated production, as well as revisions to geological interpretation in the OGIA 2016 Groundwater Model that underpins the modelled flux change to the Condamine Alluvium. However, the established Condamine Alluvium flux locations are considered to remain relevant for the Updated CSG WMMP.

The Condamine Alluvium flux monitoring network is shown in Figure 7-2, superimposed upon model-predicted change in groundwater flux (Arrow-only P50 case). The network incorporates locations where there are existing co-located Condamine Alluvium and WCM monitoring wells to help establish differential pressure across the Walloon-Condamine interface. Locations for the flux monitoring network are selected to take account of:

- The extent of the Condamine Alluvium, and the timing of predicted drawdown.
- The predicted maximum drawdown (i.e. consideration of areas of high flux change, and areas of early flux change).
- Availability of suitable Arrow tenement locations (Arrow induced impacts will occur earlier within these tenements than elsewhere).

The network locations ensure that monitoring is at:

  - Sites where flux changes are predicted;

- Sites where early flux changes occur; and
- Sites where early flux changes are not predicted, that represent control sites.

ARROW ENERGY - SURAT GAS PROJECT

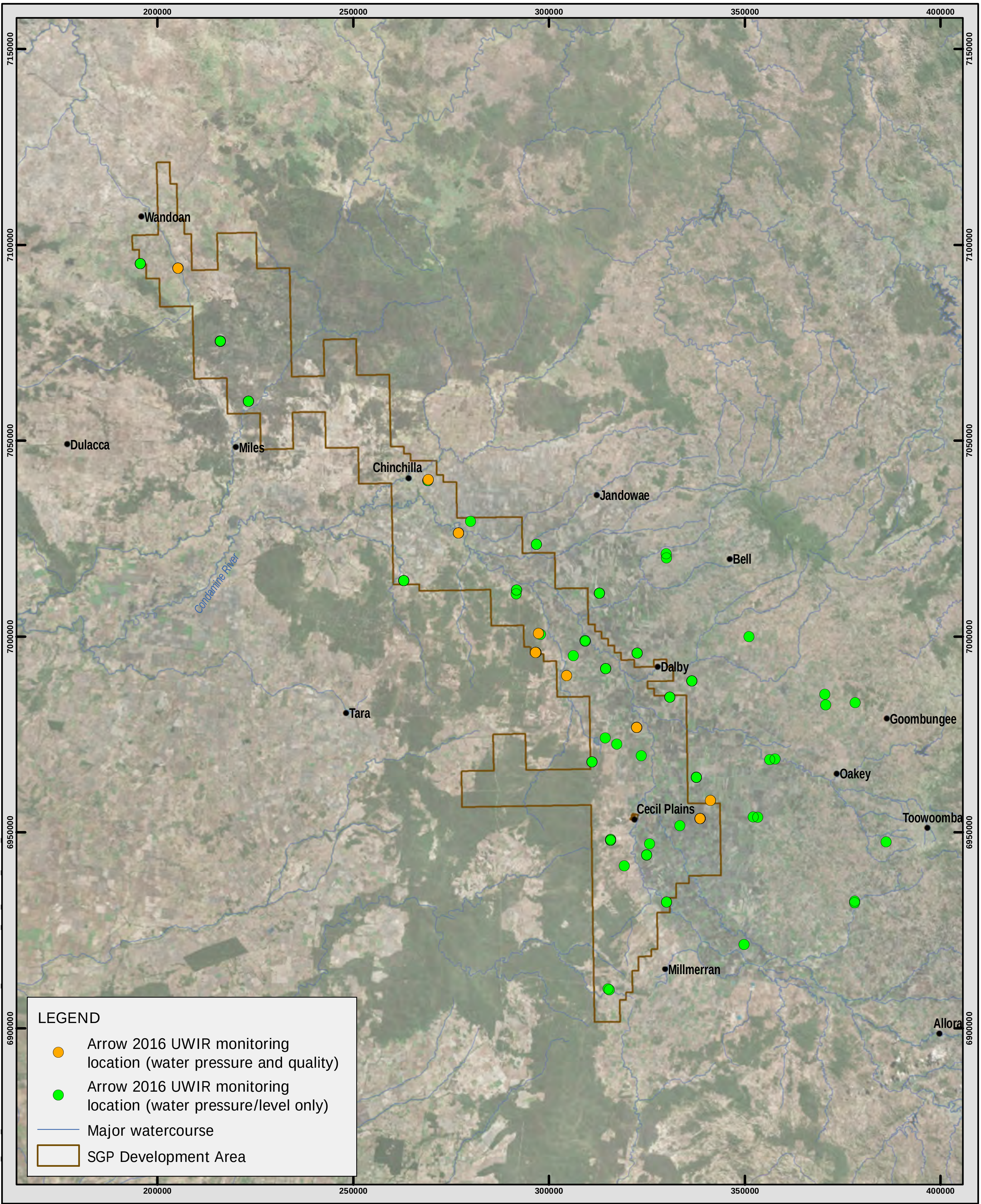

Figure 7.1 Arrow 2016 UWIR monitoring locations

Source:
Arrow Energy Pty Ltd

Date: 11/02/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,250,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

N

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The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.

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Table 7-1 Updated CSG WMMP Monitoring Network

Location ID	Figure ID	OGIA UWIR Site ID	OGIA monitoring Point ID	Latitude	Longitude	Target Aquifer	Status	Monitoring point purpose			
								Level / pressure	Quality	CA-WCM flux	Early warning
Bora Creek-10	BC10_WCM	124	579	-27.9245	151.1249	WCM	Installed	✓			
Burunga Lane-174	BL174_EF	91	625	-26.2427	150.0502	Evergreen	Installed	✓			
Burunga Lane-174	BL174_PS	91	478, 479	-26.2427	150.0502	Precipice	Installed	✓	✓		✓
Burunga Lane-176	BL176_HS	91	476, 477	-26.2429	150.05	Hutton	Installed	✓	✓		✓
Burunga Lane-176	BL176_WCM	91	473, 474, 475	-26.2429	150.05	WCM	Installed	✓			
Carn Brea-17	CB17_CA	8	38, 39	-27.533	151.3664	Condamine Alluvium	Installed	✓	✓	✓	(1)
Carn Brea-18	CB18_WCM	8	40, 41, 42, 43	-27.533	151.3663	WCM	Installed	✓	✓ (at 41 only)	✓	
Carn Brea-19	CB19_EF	8	46	-27.533	151.3662	Evergreen	Installed	✓			
Carn Brea-19	CB19_HS	8	44, 45	-27.533	151.3662	Hutton	Installed	✓	✓		✓
Carn Brea-20	CB20_PS	8	47, 48	-27.533	151.366	Precipice	Installed	✓	✓		✓
Carn Brea-21	CB21_WCM	19	94	-27.4376	151.3575	WCM	Installed	✓		✓	
Carn Brea-23	CB23_CA	19	92	-27.438	151.3576	Condamine Alluvium	Installed	✓		✓	✓
Carn Brea-24	CB24_CAWCM	19	93	-27.438	151.3574	CA / WCM transition layer	Installed	✓		✓	
Castledean-18	CA18_SS	73	375	-26.5529	150.222	Springbok	Installed	✓			✓
Castledean-18	CA18_WCM	73	376, 377, 378	-26.5529	150.222	WCM	Installed	✓			
Daandine-121	DA121_HS	37	182, 183	-27.1004	150.9557	Hutton	Installed	✓	✓		✓
Daandine-123	DA123_WCM	32	159	-27.1441	150.9481	WCM	Installed	✓			
Daandine-124	DA124_WF	32	157, 158	-27.1441	150.948	Westbourne	Installed	✓	✓		
Daandine-134	DA134_WCM	32	162, 163	-27.144	150.9486	WCM	Installed	✓			

Location ID	Figure ID	OGIA UWIR Site ID	OGIA monitoring Point ID	Latitude	Longitude	Target Aquifer	Status	Monitoring point purpose			
								Level / pressure	Quality	CA-WCM flux	Early warning
Daandine-134	DA134_WCMe	32	164	-27.144	150.9486	Eurombah	Installed	✓			
Daandine-161	DA161_CA	34	166	-27.1185	151.0756	Condamine Alluvium	Installed	✓		✓	(1)
Daandine-163	DA163_CAWCM	34	167	-27.12	151.0759	CA / WCM transition layer	Installed	✓		✓	
Daandine-164	DA164_WCM	34	168	-27.12	151.076	WCM	Installed	✓		✓	
Daandine-254	DA254_WCM	32	160, 161	-27.1442	150.9483	WCM	Installed	✓			
Daandine-263	DA263_WCM	37	181	-27.1024	150.9613	WCM	Installed	✓			
Daandine-264	DA264_WCM	29	148	-27.1533	151.0445	WCM	Installed	✓			
Dundee-20	DD20_WCM	55	283, 284, 285	-26.7435	150.6784	WCM	Installed	✓		✓	
Glenburnie-19	GB19_WCM	4	23	-27.6392	151.1677	WCM	Installed	✓			
Hopeland-17	HL17_SS	142	615	-26.9732	150.6118	Springbok	Installed	✓			✓
Hopeland-17	HL17_WCM	142	616, 617, 618	-26.9732	150.6118	WCM	Installed	✓			
Kedron-570	KD570_WCM	143	628	-26.4134	150.1537	Eurombah	Installed	✓			
Kedron-570	KD570_HS	143	629	-26.4134	150.1537	Hutton	Installed	✓			✓
Kedron-573	KD573_SS	143	630	-26.4143	150.1503	Springbok	Installed	✓			✓
Kedron-570	KD570_WCM	143	626, 627	-26.4134	150.1537	WCM	Installed	✓			
Kogan North-56	KN56_WCM	42	209	-27.0093	150.9003	WCM	Installed	✓		✓	
Kogan North-79	KN79_CAWCM	42	208	-26.9989	150.9018	CA / WCM transition layer	Installed	✓		✓	
Kogan North-79	KN79_CA	42	207	-26.9989	150.9018	Condamine Alluvium	Installed	✓		✓	✓
Tipton-153	TP153_HS	17	620	-27.3586	151.1531	Hutton	Installed	✓			✓
Long Swamp-1	LS1_WCM	17	83	-27.3431	151.1242	WCM	Installed	✓			
Longswamp-7	LS7_WCM	28	145, 146, 147	-27.1843	151.1274	WCM	Installed	✓			

Location ID	Figure ID	OGIA UWIR Site ID	OGIA monitoring Point ID	Latitude	Longitude	Target Aquifer	Status	Monitoring point purpose			
								Level / pressure	Quality	CA-WCM flux	Early warning
Macalister-5	MA5_CA	47	245	-26.8951	150.9543	Condamine Alluvium	Installed	✓		✓	✓
Macalister-8	MA8_WCM	47	244	-26.8951	150.9544	WCM	Installed	✓		✓	
Meenawarra-21	MW21_SS	7	619	-27.5798	151.1335	Springbok	Installed	✓			✓
Meenawarra-21	MW21_WCM	7	34, 35, 36	-27.5798	151.1335	WCM	Installed	✓			
Meenawarra-5	MW5_WCM	7	33	-27.5779	151.1338	WCM	Installed	✓			
Pampas-18	PP18_CA	5	24	-27.6147	151.2267	Condamine Alluvium	Installed	✓		✓	✓
Pampas-5	PP5_WCM	5	25	-27.6146	151.2267	WCM	Installed	✓		✓	
Plainview-35	PV35_WCM	15	77	-27.3842	151.2044	WCM	Installed	✓			
Plainview-25	PV25_CAWCM	23	120	-27.2521	151.2922	CA / WCM transition layer	Installed	✓		✓	
Plainview-25	PV25_CA	23	119	-27.2521	151.2922	Condamine Alluvium	Installed	✓		✓	✓
Plainview-25	PV25_WCM	23	121	-27.2521	151.2922	WCM	Installed	✓		✓	
RN 41620043	41620043_SS	124	578	-27.9222	151.1214	Springbok	Installed	✓			✓
RN 42230088	42230088_CA	5	24	-27.5898	151.2341	Condamine Alluvium	Installed	✓		✓	✓
RN 42230209	42230209_CA	55	281, 282	-26.7422	150.6799	Condamine Alluvium	Installed	✓	✓	✓	✓
RN 42231294	42231294_CA	14	75	-27.3993	151.5484	Condamine Alluvium	Installed	✓		✓	✓
RN 42231295	42231295_WCM	14	76	-27.3975	151.5619	WCM	Installed	✓		✓	
RN 42231339	42231339_CA	9	49	-27.5306	151.5037	Condamine Alluvium	Installed	✓			✓
RN 42231370	42231370_CA	10	51, 52	-27.4915	151.3932	Condamine Alluvium	Installed	✓	✓		(1)
RN 42231463	42231463_CA	8	37	-27.5488	151.313	Condamine Alluvium	Installed	✓		✓	✓
Stratheden-63	SE63_SS	29	622, 623	-27.1989	151.0268	Springbok	Installed	✓	✓		✓
Tipton-157	TP157_WCM	13	72, 73, 74	-27.3981	151.0889	WCM	Installed	✓			

Location ID	Figure ID	OGIA UWIR Site ID	OGIA monitoring Point ID	Latitude	Longitude	Target Aquifer	Status	Monitoring point purpose			
								Level / pressure	Quality	CA-WCM flux	Early warning
Tipton-195	TP195_CA	18	84, 85	-27.3205	151.2054	Condamine Alluvium	Installed	✓	✓	✓	✓
Tipton-196A	TP196_CAWCM	18	86	-27.3202	151.205	CA / WCM transition layer	Installed	✓		✓	
Tipton-197	TP197_WCM	18	88, 89, 90, 91	-27.3202	151.2053	WCM	Installed	✓	✓ (at 89 only)	✓	
Tipton-204	TP204_CAWCM	50	150	-27.1496	151.2094	CA / WCM transition layer	Installed	✓		✓	
Tipton-204	TP204_CA	30	149	-27.1496	151.2094	Condamine Alluvium	Installed	✓		✓	✓
Tipton-204	TP204_WCM	50	151	-27.1496	151.2094	WCM	Installed	✓		✓	
Tipton-206	TP206_WCMe	27	141	-27.2157	151.3489	Eurombah	Installed	✓			
Tipton-206	TP206_WCMc	27	142	-27.2157	151.3489	WCM	Installed	✓		✓	
Tipton-221	TP221_CA	27	138	-27.2156	151.3489	Condamine Alluvium	Installed	✓		✓	✓
Tipton-222	TP222_CAWCM	27	139	-27.2156	151.3488	CA / WCM transition layer	Installed	✓		✓	
Macalister 7	MA7_CA	41	203	-27.01	151.114	Condamine Alluvium	Installed	✓		✓	✓
Macalister 6	MA6_WCM	41	204	-27.01	151.114	WCM	Installed	✓		✓	
Macalister 6	MA6_WCMe	41	205	-27.01	151.114	Eurombah	Installed	✓			
Wyalla-17	WY17_HS	48	624	-26.8663	150.755	Hutton	Installed	✓			✓
UWIR Site 94	UWIR Site 94_HS	94	497	-26.2301	149.9534	Hutton	Proposed (UWIR)	✓			✓
UWIR Site 94	UWIR Site 94_WCM	94	494, 495, 496	-26.2301	149.9534	WCM	Proposed (UWIR)	✓			
Wyalla-16	WY16_CA	48	246, 248	-26.8662	150.755	Condamine Alluvium	Installed	✓	✓	✓	✓
Wyalla-17	WY17_PS	48	252, 253	-26.8663	150.755	Precipice	Installed	✓	✓		✓

Location ID	Figure ID	OGIA UWIR Site ID	OGIA monitoring Point ID	Latitude	Longitude	Target Aquifer	Status	Monitoring point purpose			
								Level / pressure	Quality	CA-WCM flux	Early warning
Wyalla-18	WY18_WCM	48	249, 250, 251	-26.8661	150.7551	WCM	Installed	✓		✓	

Note:

(1) The baseline monitoring assessment indicated Condamine Alluvium bores RN 42231370, Daandine-161 and Carn Brea-17, exhibited regular drawdown and recovery cycles of several metres as a consequence of nearby groundwater extraction for agricultural or other non-CSG uses. The magnitude of these groundwater fluctuations is such that these bores have limited use for early warning monitoring, and as such, have been excluded as early warning monitoring bores in the SGP Updated WMMP.

7.3 Monitoring program

Approval Condition 17(h)(i) requires the Updated CSG WMMP to present an ongoing monitoring plan that sets out the frequency of monitoring and rationale for the frequency, and Approval Condition 17(h)(ii) requires continued collection of baseline data for each monitoring site over the life of the project. The Stage 1 CSG WMMP presents these aspects of the CSG WMMP, all matters of which are included in the Updated CSG WMMP in accordance with Approval Condition 17(a).

Ongoing collection of baseline groundwater monitoring data is a key element of the monitoring system and will be collected from each monitoring site over the life of the project and in alignment with the Surat CMA UWIR requirements. The groundwater trend analysis, conducted on a 6-monthly basis, is an iterative assessment that distinguishes between baseline (pre-CSG operation) trends and groundwater level trends (post-CSG operation).

The monitoring frequencies, including any future revisions, will align with the monitoring frequencies specified in the Surat CMA UWIR. Any changes to the monitoring frequencies will be reported in the Annual Report for the WMMP.

A summary of the groundwater pressure/level and groundwater quality monitoring programs are summarised in Section 7.3.1 and 7.3.2, below.

7.3.1 Groundwater pressure/level

Groundwater pressure will be monitored at all monitoring network locations. The following monitoring frequencies will be adopted for the Updated CSG WMMP and are consistent with the Surat CMA UWIR monitoring requirements:

- Hourly frequency of data collection where a data logger is installed.[19] Where this occurs, bi-annual manual readings will also be collected in wells with open standpipes. This data will be used in conjunction with logger download data.
- Where a data logger is not installed, fortnightly data collection.

Monitoring and frequencies will remain consistent with UWIR monitoring requirements, which may change. Any such changes would be reported in the Annual Report for the WMMP.

7.3.2 Groundwater quality

Fifteen groundwater monitoring wells, at nine discrete monitoring locations have been specified for groundwater quality sampling as presented in Figure 3-2 and detailed in Table 7-1. These will provide baseline groundwater quality data as well as ongoing monitoring data.

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[19] Pressure transducer or vibrating wire piezometer (VWP) with data logging capabilities.

The groundwater quality sampling frequency is presented in Table 7-2, and physical parameters and analytical suites for laboratory analysis are presented in Table 7-3. The groundwater quality monitoring program is consistent with the Surat CMA UWIR monitoring requirements.

Table 7-2 Groundwater sampling schedule

	Laboratory sampling suite
	Full suite
Frequency	Bi-annually

Bi-annual sample scheduling for the first year and ongoing sampling is adopted because:

- The frequency is consistent with the UWIR sampling schedule.
- Bi-annual sampling sufficiently reduces the effect of seasonality, due to generally consistent sampling periods from year to year.

Table 7-3 Groundwater sampling parameters and analysis

Suite	Parameters	Explanation
Physical parameters	▪ Electrical conductivity (µS/cm @ 25°C) ▪ pH ▪ Redox potential (Eh) ▪ Dissolved oxygen (DO) ▪ Temperature ▪ Free gas at wellhead (CH_4)	Field analysis only – undertake at each sampling event
Full laboratory analytical suite	▪ Total dissolved solids (TDS) ▪ Major ions (calcium, magnesium, potassium, sodium, chloride, sulfate, bicarbonate, carbonate), total alkalinity ▪ Fluoride ▪ Dissolved metals (arsenic, barium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, strontium, zinc) ▪ Dissolved methane	The full laboratory analytical suite will remain aligned with the UWIR analysis suite.

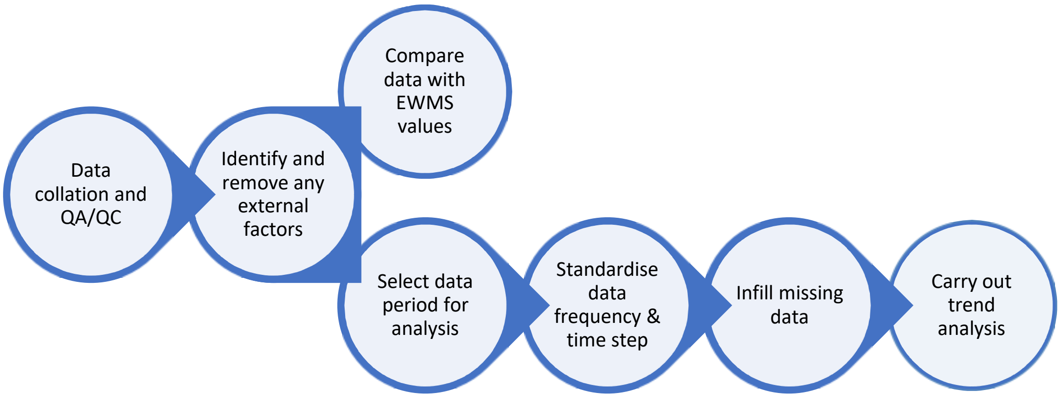
Monitoring for hydrocarbon analytes (TPH, BTEX, etc.) as an indicator of connectivity with coal-bearing formations is not planned, because of the significant potential for false positives due to spurious causes, and in particular due to sources associated with the drilling and well construction process. In addition, modelling predictions demonstrate that pressure gradients due to CSG extraction result in hydraulic gradients towards the Walloon Coal Measures (and not the reverse). Monitoring for hydraulic connectivity will primarily be based on pressure response monitoring.

7.4 Monitoring data and trend analysis

Approval Condition 17(h)(iii) requires that the monitoring plan outlines the approach to be taken to analyse the results including the methods to evaluate trends which may indicate potential impacts. The trend analysis approach adopted is described in the following sections. The outcomes of the trend analysis will be reported in the annual review of the WMMP.

Measurement of groundwater levels, either as hydrostatic pressure or physical water levels in monitoring bores, is the primary means of assessing changes to a groundwater resource. The ongoing and structured monitoring of a network of groundwater monitoring points provides the base data that can be interrogated to enable an understanding of trends and identify whether impacts may occur.

The general trend analysis process is illustrated below. This assessment will be completed within 90 days of the end of each 6 monthly monitoring period. It is underpinned by a hydrogeological conceptualisation and baseline assessment of each monitoring location to identify factors that will influence groundwater level and quality and therefore need to be considered in the trend analysis process. Also shown are the steps to identifying exceedances in the EWMS, further described below and in Section 7.5.



The key steps in the trend analysis process are described in turn below.

<u>Data collection and QA</u>

Under the EWMS, groundwater monitoring data will be collated, checked and controlled by way of the following processes:

- Reviewing and checking data and field documents to identify transcription errors.
- Reviewing and checking the calibration of measurement equipment (e.g. pressure gauges, water quality meter).
- Correlation of logged data against manually gauged data.

<u>Identify and remove any external factors</u>

Groundwater systems are subject to a range of physical influences that can affect the potentiometric levels in aquifers. Some of these influences relate to actual changes in storage, such as pumping from the aquifer, whilst other influences may cause apparent groundwater level changes, with no actual resource volumetric changes, for example, barometric pressure changes. Table 7-4 provides a summary of influences, their relative timescales, and the effect of each in terms of resource storage for aquifers.

Table 7-4 Aquifer influences, timescales and storage effects

Influencing process	Relative time scale	Effect on resource storage
Natural processes		
Aquifer recharge variability due to seasonality	Short to medium term	Affects storage
Aquifer recharge variability due to climate change	Long term	Affects storage
Aquifer recharge variability due to land use changes	Medium to long term	Affects storage
Flood loading compression	Short term	Nil
Atmospheric pressure changes	Short term	Nil
Tides, including earth tides	Short term	Nil
Anthropogenic processes		
Groundwater pumping	Short to long term	Affects storage
CSG water abstraction	Short to medium term in pumped formation Medium to long term across adjacent formations	Affects storage
Urban development (reduced recharge) and land use change	Long term	Affects storage
Managed aquifer recharge schemes	Medium to long term	Affects storage

Careful analysis of data is required to understand the effects of the various influences, and to determine whether impacts to groundwater resources are occurring.

Data may require the removal of confounding influences, such as barometric effects and earth tides, to provide corrected data that does not lead to misinterpretation of trends. Software available for this purpose includes proprietary software provided by data logger manufacturers.

Compare data against EWMS values

The quality checked and controlled data will be subject to a review process that will:

1. Compare the observed data with the assigned early warning indicator, trigger threshold, and limit for each monitoring location (Section 7.5).

2. If the results indicate an exceedance, undertake the risk-based exceedance response in Section 7.6.

Select data period for analysis

The period of analysis can influence the trend analysis results such that different conclusions can be drawn concerning groundwater level behaviour based on examining the whole period of available data versus a shorter, more recent period.

Separation of the data into discrete time periods by visual inspection is a suitable approach where there are obvious changes in the trend of data over time. Where data contains high variability, break points may not be easy to visually identify and further analysis may be required to assist in detecting whether break-point exists. Statistical analysis software packages may be utilised, if necessary, for this purpose.

Standardise data frequency and time step

Data collected at high frequencies may exhibit serial-correlation, which can affect the interpretation of trends. Where this occurs, revised time-series will be generated using time-weighted averages over longer periods.

Infill missing data

Missing data can confound a trend analysis by introducing bias into the trend results. As a guide, it is proposed that where groundwater level data in the bore of interest is missing for less than 5% of the record over the period of analysis, that data will be infilled. The technique for infilling the missing data will be selected for individual bores, being guided by site specific variables. In the event that the missing data is greater than 5% of the record, consideration will be given to not undertaking a trend analysis.

Carry out trend analysis

As described in the Monitoring, Risk Response and Adaptive Management Memorandum (Appendix G), a broad range of methods are available for groundwater level trend analysis. The applicability of any method depends on a range of factors, including the length of the data record, the frequency of data observations, the completeness of the record, and the statistical distribution of the data.

Guidelines for groundwater trend analysis provided by DES (2001) recommend that groundwater data should be analysed for time periods before and after the start of resource activities and linear regressions of the time series data should be completed for the analysis of trends. Where sufficient data are available, the groundwater trend analysis should also include non-parametric statistical tests (e.g. rank-based Mann-Kendall and Spearman's rho tests). Any interpretation of trends in time-series groundwater monitoring data must necessarily consider both the statistical and the practical significance of any detected trends in conjunction.

In reference to the groundwater quality trend analysis, the use of transforms of compositional water quality data using log-ratio variants (as described by Aitchison, 1986, and implemented in CoDaPack), allow for assessment of correlations that are either not apparent in non-transformed data or are spurious because non-transformed data can produce spurious correlations. Given that changes in hydrochemistry maybe small and involve parameters present in trace or small relative concentrations, then compositional data analysis provides a robust method for the assessment of hydrochemical change and minimises potential for spurious correlations.

Where an exceedance is indicated based on preliminary screened data, further detailed trend analysis will be undertaken, and the methods employed will be documented in any exceedance report required (refer Section 7.6). This will include an estimate of:

- The component of drawdown due to Arrow operations, if available based on evaluation through statistical, analytical or modelling methods.
- Assessment of whether the exceedance is due to natural system variability or third-party groundwater abstraction, and where required compared to data from regional monitoring locations to identify whether an apparent exceedance is a result of regional hydrological or climatic changes.
- Groundwater level trend analysis.

Modelling, where adopted to assist in differentiating the SGP component of drawdown from cumulative drawdown, will utilise the latest OGIA model version. In the case that this model is too coarse (in either space or time) more refined modelling approaches based on the OGIA model (or its equivalent) may be adopted. This will enable the calculation of the Arrow-only proportion of the impact for comparison with previous predictions. In addition, this process will also be undertaken within 90 days of the release of each new UWIR and receipt of the associated technical files for that UWIR, to establish revised early warning indicators, trigger thresholds and limits.[20]

7.5 Early warning monitoring system

An EWMS was presented and approved by the Department of Environment and Energy for the SGP Stage 1 CSG WMMP to address Approval Condition 13(j). The EWMS framework is refined and expanded upon in this Updated CSG WMMP to address Approval Condition 17(a) and 17(h)iv.

In accordance with Approval Condition 13(j)(i)(ii), the EWMS is inclusive of the Condamine Alluvium and all consolidated aquifers potentially affected by the action, excluding the WCM. The

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[20] It is understood that the Department is currently reviewing modelling and management methods for CSG projects, and that as a result of the review, different methods for modelling of drawdown and impacts may be specified by the Department.

potentially affected aquifers are the Springbok Sandstone, Hutton Sandstone and Precipice Sandstone. In total, 31 monitoring intervals across the unconsolidated and consolidated aquifers at 29 discrete monitoring locations will serve as early warning monitoring bores (Table 7-1 and Appendix G). Consistent with Approval Condition 13(j)(iii), the EWMS also includes non-spring GDE locations, determined to be at potential risk of impact from the Action.

The EWMS is updated to comply with the Updated WMMP Approval Conditions, and is presented in the Monitoring, Risk Response and Adaptive Management Technical Memorandum (Appendix G) and key aspects are presented below.

7.5.1 Overview

Approval Conditions 13(j) and 13(k) variably require early warning indicators, trigger thresholds, and limits. Factors influencing groundwater drawdown predicted in affected formations include impacts due to the Action (i.e. Arrow drawdown), other CSG developers, and non-CSG users. Because of the relative magnitude of these influences, it is difficult to differentiate impact due to the SGP based on simple analysis of field data. To account for this, an EWMS approach based on cumulative impacts is necessary. Figure 7-2 provides a conceptual illustration and analysis of Arrow and non-Arrow drawdown impacts.

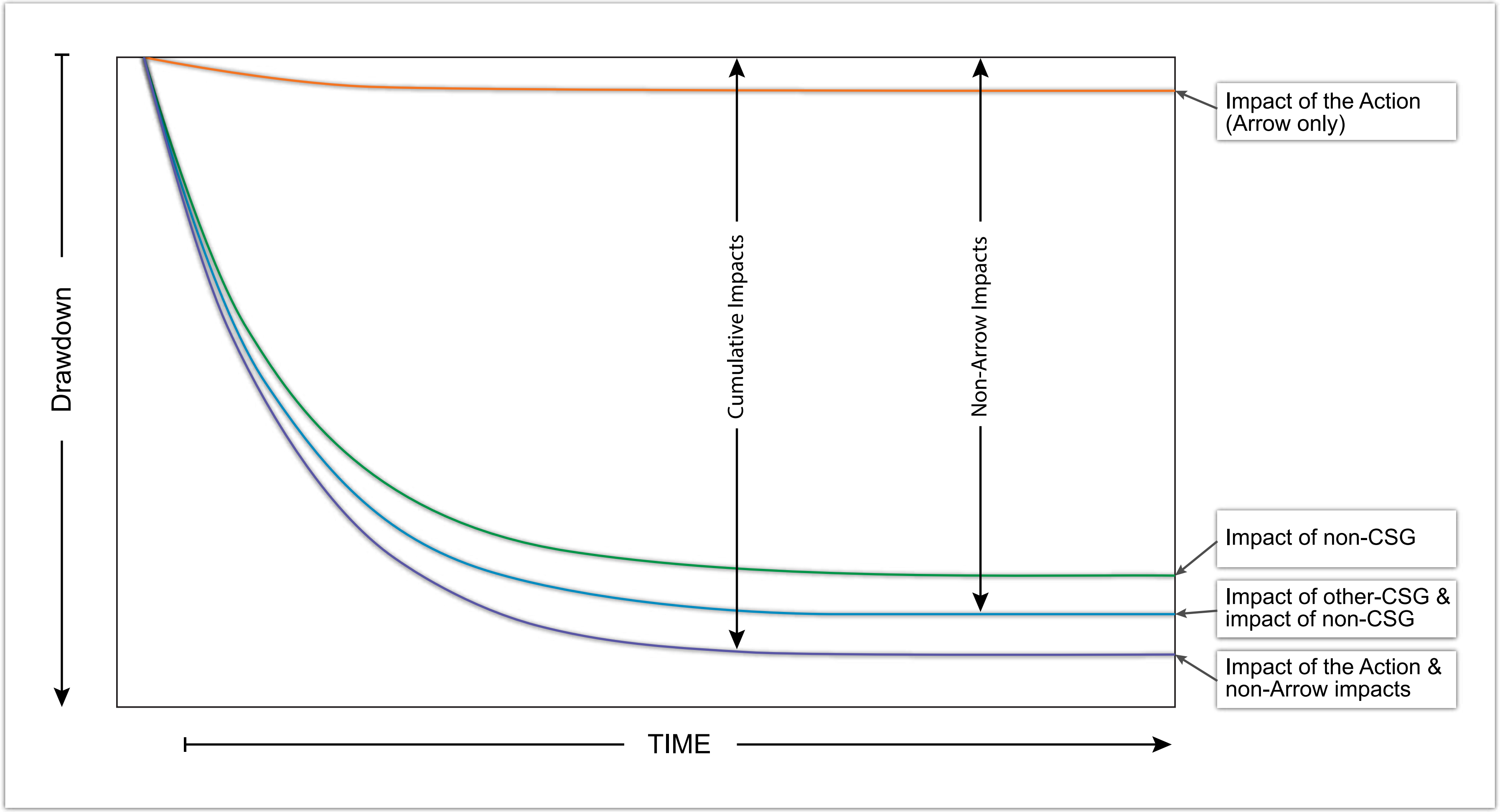

Figure 7.2

Conceptual Representation of SGP Impacts

Source:
Coffey.

Date: 11/01/2019
Issued To: Arrow Energy
Author: Helen.Unkovich/Richard.Heath

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7.5.2 EWMS investigation levels

The EWMS relies on periodic collection, review and assessment of data, and is described in the Monitoring, Risk Response and Adaptive Management Technical Memorandum (Appendix G).

The EWMS includes tiered levels, described below, with escalating responses:

1. Early warning indicators, for early identification of potential issues.
2. Trigger thresholds, for identifying the potential to exceed limits, and enable measures to be selected and implemented to reduce the likelihood of limit-exceedance.
3. Limits, that define levels of impact not to be exceeded.

Drawdown factors, where applied to the tiered levels, are described in the Stage 1 CSG WMMP, and are derived from the bore trigger thresholds under the Queensland Water Act 2000, being 5 m for consolidated aquifers and 2 m for unconsolidated aquifers. The drawdown factors provide a buffer against triggering caused by spurious water level changes from non-CSG causes, for example transient fluctuations in the water levels due seasonal affects or nearby groundwater extractions.

Investigation and actions are incorporated in the EWMS, including processes for trigger and limit exceedances[21], and actions to manage, address and correct exceedances (refer Section 7.5).

Early warning indicators

An early warning indicator has been assigned by taking the maximum model-predicted P95 (or worst case) cumulative (CSG + non-CSG) drawdown on Arrow tenure (within a three year period) and adding half the drawdown factor (i.e. 2.5 m for consolidated aquifers, and 1 m for the Condamine Alluvium).

If any non-spring GDE locations were determined to be at potential risk of impact, early warning indicators would be assigned based on a drawdown level equivalent to the maximum model-predicted P95 cumulative (CSG + non-CSG) drawdown level for a three year period, at any point in the GDE host aquifer on Arrow tenure. No drawdown factor would be added to the prediction. However, as per Section 5, no non-spring GDEs have been identified as potentially at risk from the Action.

Early warning indicators are specified in three-yearly time steps and taken from the maximum predicted drawdown in each three year period.

The three-year review will take into account the maximum model-predicted P95 cumulative (CSG + non-CSG) drawdown on Arrow tenure (for each three year period) and adding half the applicable

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[21] Exceedance is defined as groundwater levels measured in a monitoring bore that are greater than a threshold value for a continuous period of three months, to identify a real signal rather than a temporary spike due to natural or other anthropogenic factors.

drawdown factor (for consolidated aquifers, and the Condamine Alluvium). No drawdown factor will be added for non-spring GDEs.

Trigger thresholds

Trigger thresholds are assigned as a drawdown level half-way between the early warning indicator and the limit.

Groundwater and Drawdown Limits

Drawdown limits are minimum potentiometric groundwater levels specified for consolidated aquifers (i.e. the Springbok, Hutton and Precipice sandstone aquifers). Groundwater limits are minimum groundwater levels specified for the Condamine Alluvium and non-spring GDEs. The limit assigned for the consolidated aquifers and the Condamine Alluvium aquifer is:

- The maximum model-predicted P95 cumulative (CSG + non-CSG) drawdown level predicted to occur in 100 years (from commencement of CSG extraction), at any point in the relevant aquifer on Arrow tenure, plus a drawdown factor (5 m for consolidated aquifers and 2 m for the Condamine Alluvium)[22]; or

- For consolidated aquifers where dewatering of the aquifer itself is not predicted to occur, the top of the aquifer formation.

The limit assigned for non-spring GDEs, determined to be at potential risk of impact, is:

- The maximum model-predicted P95 cumulative (CSG + non-CSG) drawdown level predicted to occur in 100 years (from commencement of CSG extraction), at any point in the GDE host aquifer on Arrow tenure.

Figure 7-3 illustrates the EWMS conceptualisation.

Basis for EWMS levels

EWMS groundwater levels are derived from numerical modelling of cumulative drawdown. The levels are established based on the latest OGIA model version (or its equivalent) P95 predictions and incorporate (where available) updated production data for other CSG producers and non-CSG extractors. The early warning indicator, trigger threshold or limit may be updated with each new OGIA model if an explanation for the change to the limit is provided in an updated WMMP/annual review.

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[22] The drawdown factors provide a buffer against triggering caused by spurious water level changes from non-CSG causes, for example, transient fluctuations in the water levels due seasonal affects or nearby groundwater extractions.

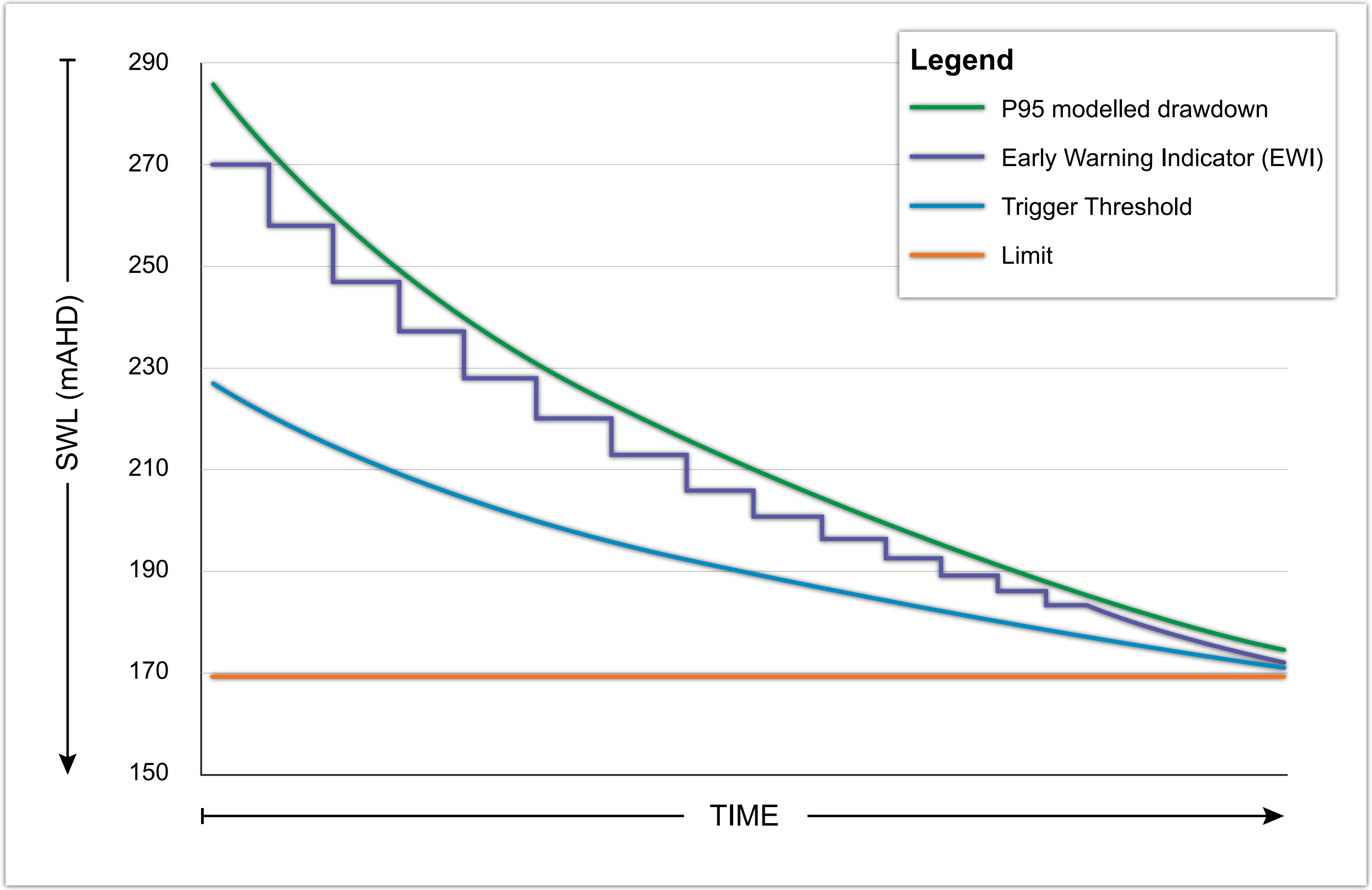

Figure 7.3

EWMS Conceptualisation

Source:
Coffey.

Date: 12/01/2019
Issued To: Arrow Energy
Author: Helen.Unkovich/Richard.Heath

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7.5.3 Specification of levels

The assignment of EWMS levels is based on prediction from the Updated CSG WMMP FDP, utilising the OGIA 2012 UWIR model. While groundwater drawdowns, fluxes and impacts have been characterised and assessed in the Updated CSG WMMP employing the updated 2016 UWIR model (Section 4.2), the absence of a predictive uncertainty analysis means that the current version of the model cannot be used for assigning EWMS levels which require P95 (worst case) drawdown predictions.

Table 7-5 presents the early warning indicators, trigger thresholds and limits for the EWMS, that have been determined for each Condamine Alluvium or consolidated aquifer[23] monitoring bore constituting the CSG WMMP monitoring network, for the period of three years following the commencement of the Action (2020 to the close of 2023). The early warning indicators, trigger thresholds and limits for each successive three year period, as calculated in the Updated CSG WMMP, are reported in Appendix H.

The early warning indicators, trigger thresholds and groundwater limits are also presented graphically against time for 100 years in Figure 7-4 to Figure 7-7 (it should be noted that the modelled drawdown includes cumulative drawdown such as from other groundwater users and CSG proponents).

The early warning indicators, trigger thresholds and limits will be reviewed according to the new OGIA model outputs, within 90 days of the approved UWIR being issued and upon receiving technical files from OGIA for that UWIR.

If an early warning indicator and/or trigger level and/or limit for the next 3 year period (calculated upon review of each release of a new UWIR) is greater than +/-10% of the values reported in the latest version of the WMMP for any of the aquifers, a revised WMMP will be submitted, for Ministerial approval, reflecting the revised drawdown predictions from the new UWIR. Arrow will submit the revised WMMP for Ministerial approval within 90 days, following the initial 90 day review period of the early warning indicators, trigger thresholds and limits.

Where EWMS levels are revised in future, Arrow will provide an explanation of the revision based on the latest groundwater modelling that has led to the revised levels. This would be supported by a review of actual vs predicted performance, based on evaluation of actual and predicted Arrow water production.

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[23] The Springbok, Hutton and Precipice sandstone

Table 7-5 EWMS for the Condamine Alluvium and consolidated aquifers

Aquifer	Maximum model-predicted P95 cumulative drawdown level (1) (over 100 years, at any point on Arrow tenure)	Drawdown factor	Limit (1)	Early warning indicator (EWI) (Commencing Jan-2021 to Dec2023) (1)	Trigger threshold (Commencing Jan-2021 to Dec- 2023) (1)
Condamine Alluvium	16 m	2 m	18 m	7 m	12.5 m
Springbok Sandstone	72 m	5 m	77 m	31 m	54 m
Hutton Sandstone	266 m	5 m	271 m	159 m	215 m
Precipice Sandstone	540 m	5 m	545 m	538 m	541.5 m

Notes:
(1) The EWMS reported in the table applies until the close of year 2023, three years following the commencement of the Action. The model predictions and corresponding limits, early warning indicators and trigger thresholds will be reviewed whenever a new or revised OGIA model simulation in a UWIR has been developed and approved to take effect
(2) The early warning indicator, trigger threshold and limit will be reviewed upon release of each new UWIR. The next UWIR is expected to be released in 2022.

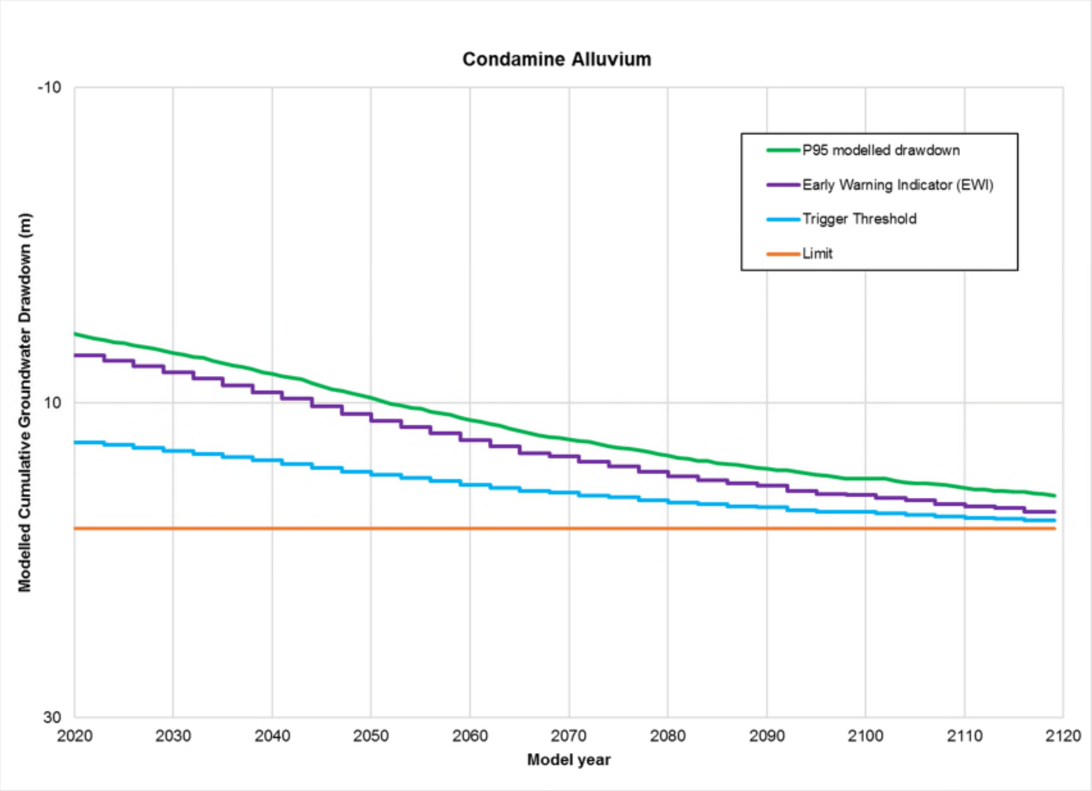

Figure 7-4 EWMS for the Updated CSG WMMP – Condamine Alluvium

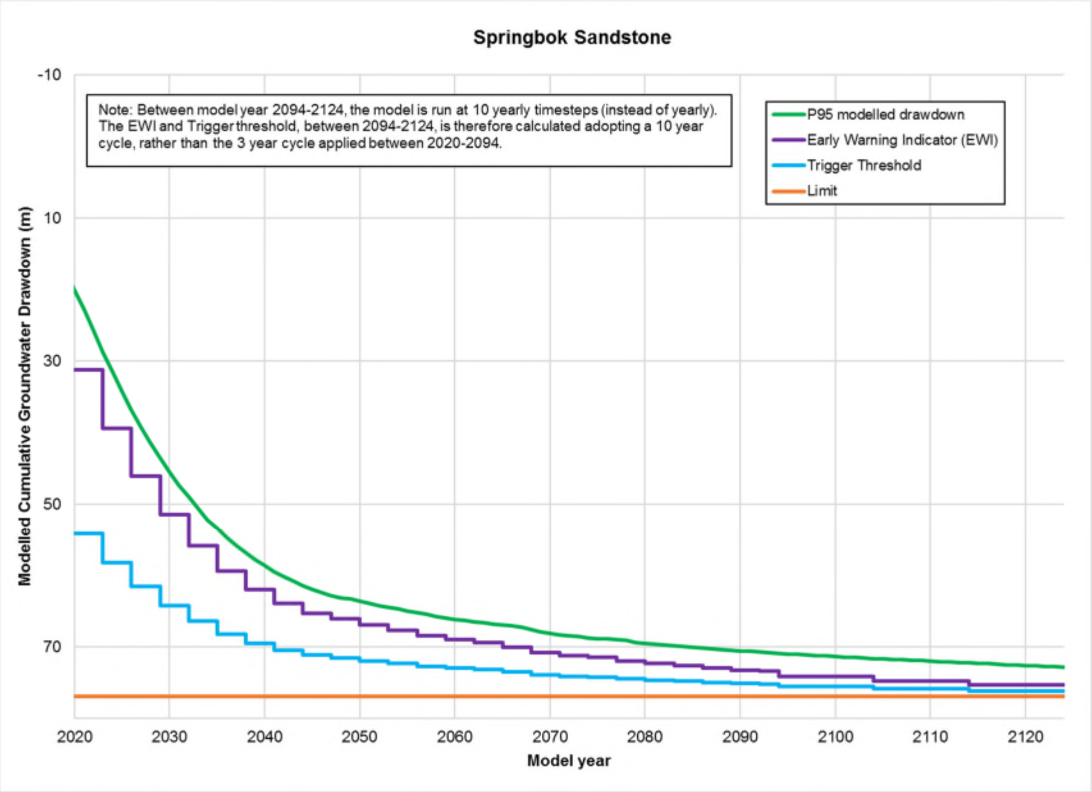

Figure 7-5 EWMS for the Updated CSG WMMP – Springbok Sandstone

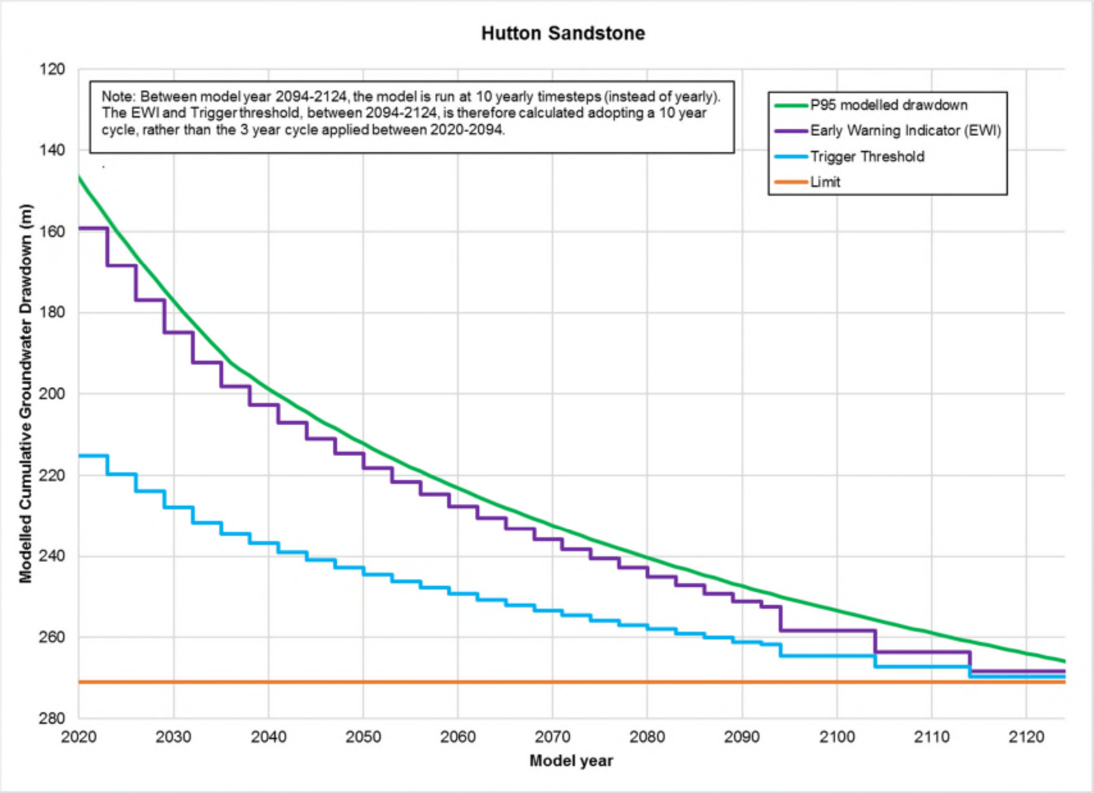
Note: Between model year 2094-2124, the model is run at 10 yearly timesteps (instead of yearly). The EWI and Trigger threshold, between 2094-2124, is therefore calculated adopting a 10 year cycle, rather than the 3 year cycle applied between 2020-2094.

Figure 7-6 EWMS for the Updated CSG WMMP – Hutton Sandstone

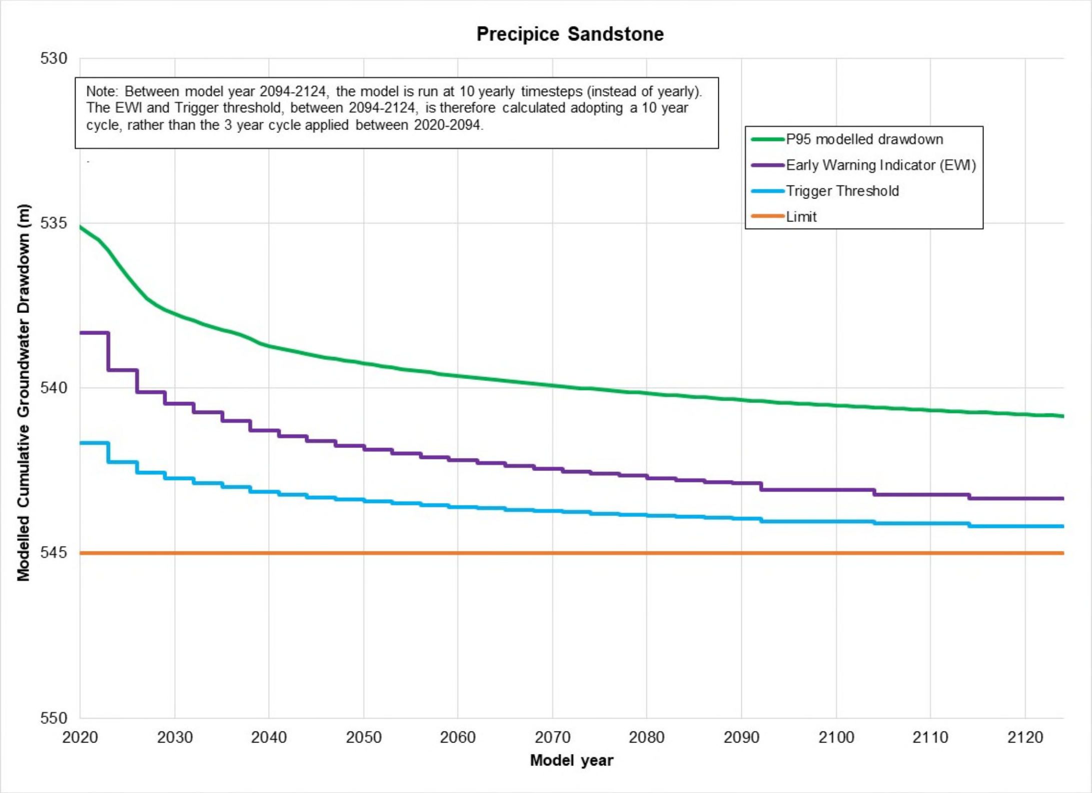
Note: Between model year 2094-2124, the model is run at 10 yearly timesteps (instead of yearly). The EWI and Trigger threshold, between 2094-2124, is therefore calculated adopting a 10 year cycle, rather than the 3 year cycle applied between 2020-2094.

Figure 7-7 EWMS for the Updated CSG WMMP – Precipice Sandstone

7.5.4 GDEs included in the EWMS

The EWMS focuses on GDEs that may be impacted by the Action. The basis for identifying these is set out in the Stage 1 CSG WMMP (Appendix A) and the Updated CSG WMMP (Section 5 and Appendix D).

With reference to non-spring GDEs, and as presented in the Surat CMA UWIR (DNRM, 2016a), assessments and investigations conducted as part of the EIS, SREIS, the SGP CSG WMMP have not identified any non-spring GDEs at potential risk of impact from the Action. Accordingly, there are no monitoring requirements under the SGP for these features, at present.

In line with the process outlined in Section 5.4.3, should any non-spring-GDEs be identified at potential risk of impact from the Action in the future, the EWMS will be reviewed and tailored according to the site-specific requirements of any identified features.

Future iterations of the UWIR are expected to also consider cumulative CSG-related impacts to non-spring GDEs and Arrow will comply with any obligations set out in the UWIR regarding GDEs.

7.6 Risk-based exceedance response

Approval Condition 17(i) requires the Updated CSG WMMP to include a risk based exceedance response plan that details the actions to be taken and timeframes if early warning indicators or trigger threshold values are exceeded. Response actions, in the form of escalating actions for responding to exceedances of early warning indicators or trigger thresholds, form a key component of the EWMS.

EWMS response actions are risk-based in that escalating actions apply to exceedances due to the Action, depending on the level of the exceedance. The levels of exceedance are: 1) an early warning indicator, 2) a trigger threshold, or 3) a limit. It is recognised that incident specific management and mitigation measures will be implemented at the time of any exceedance, but that these cannot be determined prior to the exceedance, due to the variability in circumstances that may arise.

Figure 7-8 illustrates operation of the EWMS.

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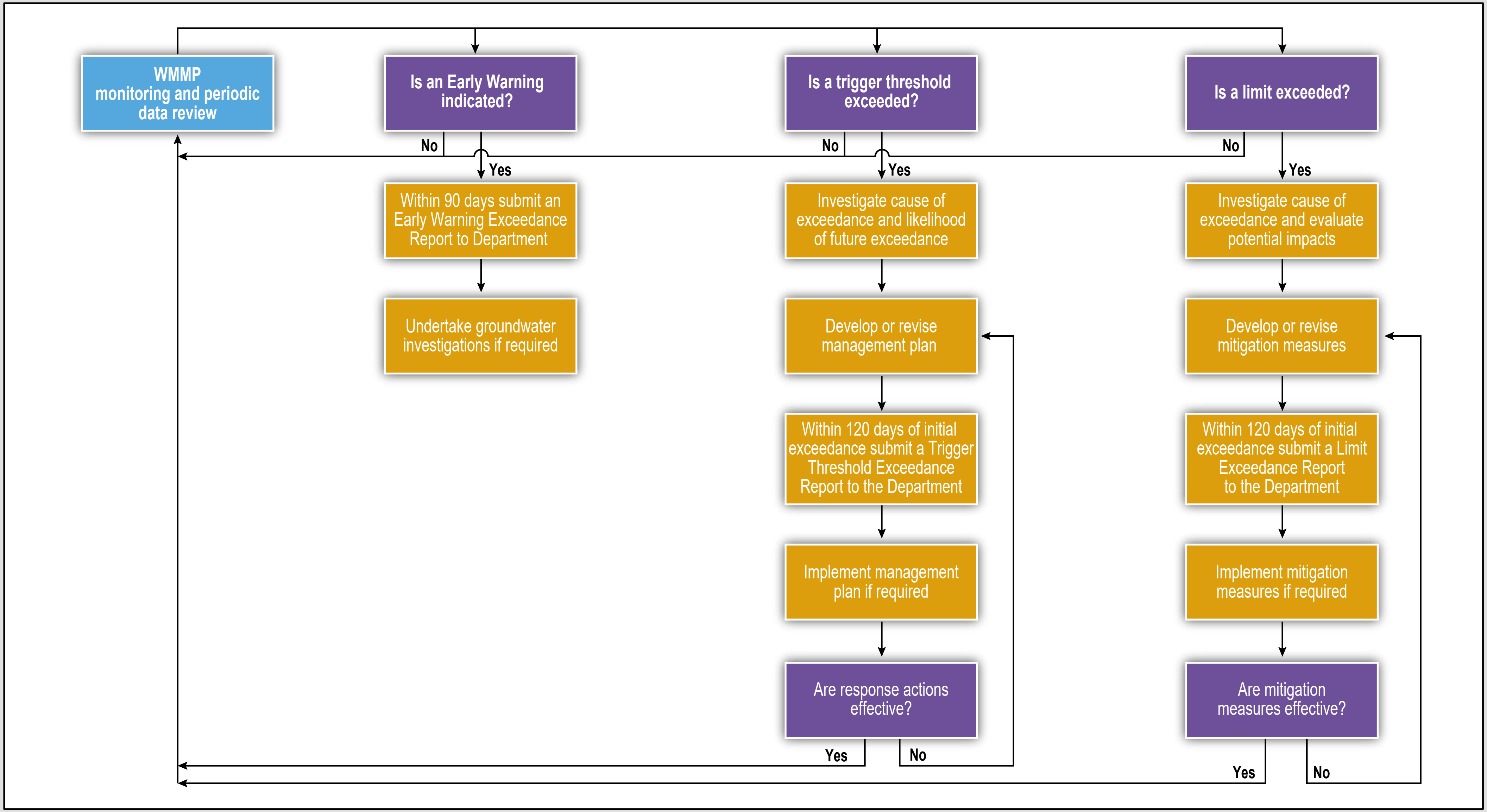

Figure 7.8

EWMS process and actions

Source:
Coffey.

Date: 04/09/2019
Issued To: Arrow Energy
Author: Helen Unkovich

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The response actions for each level are identified in Table 7-6.

Table 7-6 Risk-based exceedance response actions

Risk based exceedance level	Response action
Early warning indicator	Within 90 days, prepare and submit to the Department an Early Warning Exceedance Report which includes: a) The results of an evaluation of the reasons for the EWI exceedance, and the likelihood of a future exceedance of a trigger threshold or limit. b) The scope and schedule for implementing a groundwater investigation, to be undertaken if the evaluation indicated a likely future trigger threshold or limit exceedance. Within 90 days of the release of a new UWIR, comparison will be made between the Arrow only drawdown impact predictions
Trigger threshold	Within 120 days, prepare and submit to the Department a Trigger Threshold Exceedance Report which includes: a) The results of an evaluation of the reasons for the trigger threshold exceedance, and the likelihood of a future exceedance of a limit. b) If the evaluation indicates a likely future limit exceedance; prepare a scope and schedule for a management plan that includes procedures to reduce the likelihood of a future limit exceedance. The overarching principles that will apply to the management plan will include: • A mitigation hierarchy with the sequential steps of avoidance, minimisation, mitigation/management, remediation and offset; • Application of proven methods first; and • Consideration of the potential cumulative (CSG and non-CSG) impacts to water resource and their receptors.
Limit	Within 120 days, prepare and submit to the Department a Limit Exceedance Report that includes: a) The results of an evaluation of the reasons for the limit exceedance, and an evaluation of any impacts that may arise due to the exceedance. b) An evaluation of the risk to groundwater environmental values that adopts local scale modelling and multiple lines of evidence. c) Corrective actions to mitigate against any impacts. The overarching principles that will apply to the corrective actions will include: • A mitigation hierarchy with the sequential steps of avoidance, minimisation, mitigation/management and offset; • Application of proven methods first; and • Consideration of the potential cumulative (CSG and non-CSG) impacts to water resource and their receptors.

7.7 EWMS: aquatic ecology and ecosystems

Approval Condition 13(k) requires an EWMS for aquatic ecology and ecosystems. The EWMS is to include early warning indicators and trigger thresholds, including corrective actions.

Impact to aquatic ecology and ecosystems due to the Action may occur as a result of the discharge of produced water to surface water systems or due to groundwater drawdown.

Discharge of produced water to surface water systems is not part of the SGP. Therefore discharge-related impacts are not considered further in this CSG WMMP. Should discharge be proposed in the future, the WMMP relevant to the stage of work will require update and approval for discharge will be sought from the Minister, and adequate baseline data will be collected prior to the discharge.

The potential for groundwater drawdown related impacts on aquatic ecology and ecosystems would be assessed and managed as for GDEs.

Based on this approach, a stand-alone EWMS for aquatic ecology and ecosystems is not considered necessary. Should discharge to surface water systems be proposed in the future, this will necessitate the submission of a revised WMMP within 90 days of identifying the requirement for discharge, for Ministerial approval. An aquatic ecology and ecosystems EWMS will be included in the revised plan if this eventuates.

8. RECORDS, REPORTING, REVIEW AND PLAN UPDATES

Approval Conditions 27, 28 and 29 require record keeping, reporting and non-compliance notification. Arrow will meet the requirements of these conditions as set out in this Chapter, and in conjunction with Arrow's EIS/SREIS reporting, updating and review commitments.

8.1 Record keeping and data management

Arrow will maintain records of relevant activities carried out in accordance with the Updated CSG WMMP. These records will be made available to the Department[24] upon request.

Implementation of the CSG WMMP will generate significant data including field records and observations, electronically-logged water pressure data, and laboratory water-quality analytical data. The data generated will be stored electronically in a database, containing:

- Monitoring bore locations, construction details and monitored aquifer.
- Bore drilling records, geophysical logs and interpreted stratigraphy.
- Details of permanent bore infrastructure or instrumentation.
- Groundwater level, pressure and quality records.
- Surface water quality and flow records.
- Aquatic ecosystem monitoring records.

Data will be subject to a quality control review program or system to identify data or transcription errors (as described in Section 7.4).

8.2 Reporting

Reporting for the WMMP is detailed below, and includes:

1. Non-compliance reporting.
2. Exceedance reporting for the EWMS.
3. Subsidence action plan reporting.
4. Annual reporting.

8.2.1 Potential non-compliance reporting

In accordance with Approval Condition 29, the Department will be notified in writing no later than ten business days after becoming aware of any potential non-compliance with any Approval Condition. Potential non-compliance notification will occur if:

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[24] Department is defined to mean the Australian Government Department administering the Environmental Protection and Biodiversity Conservation Act 1999 (Commonwealth), currently the Department of the Environment and Energy.

1. A groundwater or drawdown limit has potentially been exceeded.
2. Arrow fail to meet any of the requirements of approval condition 13 (i.e. Arrow do not develop or carry out any of the activities required under approval conditions 13(a) to 13(r).

The notification will include:

- The Approval Condition that has been potentially breached;
- The nature of the potential non-compliance;
- When and how the approval holder became aware of the potential non-compliance;
- How the potential non-compliance may affect the approved action;
- How the potential non-compliance may affect the anticipated impacts of the approved action, in particular any impacts on MNES (water resources and the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin), and the measures to be taken to address the impacts of the potential non-compliance on MNES and to rectify the potential non-compliance; and
- The time by when the approval holder will rectify the potential non-compliance.

8.2.2 Early warning indicator, trigger threshold and limit exceedance reports

Consistent with the EWMS described in Section 5 of Appendix A, exceedance response reports will be prepared for any confirmed early warning indicator, trigger threshold or limit exceedance.

The Department will be provided with copies of any EWMS exceedance response reports.

8.2.3 Subsidence action plan reporting

Consistent with the process described in Section 7 of Appendix A, a trigger threshold exceedance action plan will be prepared within 90 calendar days of a subsidence trigger threshold being exceeded.

The Department will be provided with copies of any trigger threshold exceedance action plans.

8.2.4 Annual report

An annual report on the Updated CSG WMMP[25] will be prepared for the preceding 12 month period. It will be submitted to the Department and published on Arrow's website within three months of every 12-month anniversary of the commencement of the SGP. Each annual report will present a summary of progress towards Arrow's commitments and document Arrow's compliance against the approval conditions.

Annual reports will be factual, and will:

- Detail any updates to the FDP and implications for water monitoring and management.

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[25] Annual reporting of the Stage 1 CSG WMMP will cease following commencement of the Updated CSG WMMP, which will include all matters relating to the Stage 1 CSG WMMP and supersede the Stage 1 reporting requirements.

- Report on any relevant ongoing studies and research projects and include any supporting technical studies as appendices to the annual report.
- Summarise relevant monitoring results, including:
  - Groundwater levels
  - Groundwater chemistry results
  - Surface water monitoring results
  - Surface water chemistry results
  - Analysis and interpretation of data
- Document Arrow's compliance against the approval conditions over the preceding 12 months, including monitoring obligations and implementation of the EWMS.
- Document corrective actions implemented to address any exceedances of trigger thresholds, limits, or non-compliance with approval conditions.
- Report against the performance measure criteria detailed in the Section 8.3.

Relevant electronic data will be provided to the Department upon request and published as in Section 8.4.

8.3 Performance measure criteria

The performance measures are predicated on the assumption that a fundamental purpose of the Approval Conditions is the management of impacts to MNES. Therefore, compliance with these conditions will achieve this outcome.

Performance measure criteria have been established which enable assessment of project performance in the context of protection of MNES. These ensure that the project operational and management aspects that limit, protect or mitigate against impacts to MNES potentially affected by the project, are achieving the required outcome, and that impacts to MNES are either not occurring, or are effectively corrected.

The performance measure criteria for assessment of the protection of MNES are:

- Compliance with the Approval Conditions and UWIR for Surat CMA.
- The desktop terrestrial GDE risk assessment is reviewed following the release of every new UWIR (Section 5.4.3).
- Approach in WMMP is aligned with an adaptive management approach (i.e. assess and monitor potential impacts to MNES where predicted or identified material impact changes significantly).
- Where an exceedance under the EWMS has occurred, the corrective actions for ameliorating impacts from exceedance of the limits are implemented, and effective.

8.4 Publication of data and reports

Arrow will make public the results of data obtained from the water-related aspects of their monitoring network via the following:

- Publication of the approved Updated CSG WMMP on Arrow's website.

- Publication of the annual reports on Arrow’s website. The reports will be published annually within 3 months of each anniversary of the commencement of the SGP.
- Providing raw data to the Queensland DNRME for potential inclusion (at DNRME's discretion) on the ‘Queensland Globe’.[26]

In addition, under the Surat CMA UWIR, a water monitoring report is required to be submitted at the end of March and September each year that includes details of the monitoring data collected under the Water Monitoring Strategy.

8.5 Peer review

Approval Conditions 14 and 18 require formal peer review by a suitably qualified water resources expert of the Stage 1 and Updated CSG WMMP.

The peer reviewer was approved by the Minister for the Environment and was engaged in a progressive review process of the CSG WMMP.

8.5.1 Stage 1 WMMP peer review

The SGP Stage 1 CSG WMMP peer review and statement of endorsement are provided in Appendix A. The Stage 1 CSG WMMP was endorsed by the Minister in December 2018.

8.5.2 Updated WMMP peer review

The Updated CSG WMMP peer review and statement of endorsement are provided in Appendix I.

8.6 Revision of the CSG WMMP

Triggers, and their associated timing, for revising the CSG WMMP are listed below and summarised in Table 8-1.

- Identification of a requirement for discharge (other than emergency discharge) (Section 6 and 7.7). Should discharge to surface water systems be proposed in the future, this will necessitate the submission of a revised WMMP within 90 days of identifying the requirement for discharge, for Ministerial approval. An aquatic ecology and ecosystems EWMS will be included in the revised WMMP if this eventuates.
- Identification of a potential terrestrial GDE that is predicted to be at risk of being impacted from the Action and/or cumulative CSG operations (Section 5.4.3). As outlined in Section 5.4.3, an initial desktop assessment will be undertaken within 90 days after an approved UWIR has been issued and upon receiving technical files from OGIA for that UWIR. If triggered, Arrow will submit a revised WMMP within 90 days for Ministerial approval (following the initial 90 day

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[26] The Queensland Globe is a publicly available Internet database tool that includes physical, geographical and spatial data in a map format, and provides an online resource for environmental data. It provides access to Surat CMA UWIR WMS data, Arrow and other proponent monitoring data and DNRME current and historical records.

desktop assessment period). The revised WMMP will include an outline for further work (including field investigations if applicable) to be undertaken to gather supporting data to confirm the potential terrestrial GDE’s reliance on groundwater and validate the findings of the desktop assessment.

- If an early warning indicator and/or trigger level and/or limit for the next 3 year period (calculated upon review of each release of a new UWIR) is greater than +/-10% of the values reported in the latest version of the WMMP (Section 7.5.3) for any of the aquifers. As outlined in Section 7.5.3, the early warning indicators, trigger thresholds and limits will be reviewed according to new OGIA outputs within 90 days of an approved UWIR being issued and upon receiving technical files from OGIA for that UWIR. If triggered, Arrow will submit a revised WMMP within 90 days for Ministerial approval (following the initial 90 day review period of the early warning indicators, trigger thresholds and limits). The revised WMMP will reflect the revised early warning indicators and/or trigger levels and/or limits based on drawdown predictions from the new UWIR.
- If a potential impact to surface water systems and aquatic ecology through potential changes to stream connectivity is identified (Section 5.2). As outlined in Section 5.2, Arrow will reassess potential changes to stream connectivity within 90 days of an approved UWIR being issued and upon receiving technical files from OGIA for that UWIR. If triggered, Arrow will submit a revised WMMP within 90 days (following the initial 90 days for the reassessment) for Ministerial approval.
- If Arrow proposes to extract gas from more than 250 coal seam gas production wells, Arrow will submit a revised WMMP in accordance with Condition 21A for Ministerial approval.
- If the OGIA model ceases to exist, Arrow will submit an alternate model, for approval by the Minister, to replace the OGIA model for ongoing modelling that may be required to meet the Approval Conditions in accordance with Condition 23 (Section 4.6). Upon Ministerial approval of the alternate model, Arrow will submit a revised WMMP within 90 days for Ministerial approval.

A peer review will not be undertaken for any revised WMMP.

Table 8-1: Summary of timing for revision of the WMMP

Timing commencement	**Timing to revise WMMP**					
	Requirement for discharge	**Potential terrestrial GDE predicted to be at risk of being impacted**	**EWMS values greater than +/-10%**	**Potential impact to surface water systems and aquatic ecology**	**Gas extraction from more than 250 coal seam gas production wells**	**OGIA model ceases to exist**
Identification of requirement for discharge	90 days					
Upon release of each new approved UWIR and upon receiving technical files from OGIA for that UWIR		- 90 days for desktop assessment - 90 days for revision of WMMP (if required)				

Timing commencement	**Timing to revise WMMP**					
	Requirement for discharge	**Potential terrestrial GDE predicted to be at risk of being impacted**	**EWMS values greater than +/-10%**	**Potential impact to surface water systems and aquatic ecology**	**Gas extraction from more than 250 coal seam gas production wells**	**OGIA model ceases to exist**
Arrow propose to extract from more than 250 wells					na	
OGIA model ceases to exist						90 days post Ministerial approval of alternate model

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10. ABBREVIATIONS

Table 10-1 Abbreviations

ACA	Aquatic Conservation Assessment
AHD	Australian Height Datum
ATP	Authority to Prospect
ARI	Average Recurrence Interval
BOM	Bureau of Meteorology
CA	Condamine Alluvium
CCAM	Central Condamine Alluvium Model
CIRP	Condamine Interconnectivity Research Project
CMA	Cumulative Management Area
CSG	Coal Seam Gas
DEHP	Department of Environment and Heritage Protection
DNRM	Department of Natural Resources and Mines
EA	Environmental Authority
EFO	Environmental Flow Objective
EHP	Environment and Heritage Protection
EIS	Environmental Impact Statement
EPBC	Environment Protection and Biodiversity Conservation
EWMS	Early Warning Monitoring System
EWS	Early Warning System
FDP	Field Development Plan
GAB	Great Artesian Basin
GDE	Groundwater Dependent Ecosystem
GL	Gigalitre
InSAR	Interferometric Synthetic Aperture Radar
IQQM	Integrated Quantity and Quality Model
JIP	Joint Industry Plan
ML	Megalitre

MNES	Matters of National Environmental Significance
OGIA	Office of Groundwater Impact Assessment
PL	Petroleum Lease
QWC	Queensland Water Commission
ROP	Resource Operation Plan
SGP	Surat Gas Project
SIMS	Spring Impact Management Strategy
SREIS	Supplementary report to the Environmental Impact Statement
TDS	Total Dissolved Solids
UWIR	Underground Water Impact Report
VWP	Vibrating Wire Piezometer
WCM	Walloon Coal Measures
WMMP	Water Monitoring and Management Plan
WMS	Water Management Strategy
UWIR	Underground Water Impact Report
WQO	Water Quality Objective

APPENDIX A STAGE 1 CSG WMMP

Arrow Energy Pty Ltd

Surat Gas Project

Stage 1 CSG Water Monitoring and Management Plan

arrowenergy.com.au

Stage 1 CSG Water Monitoring and Management Plan

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EXECUTIVE SUMMARY

The Surat Gas Expansion Project[1] (SGP) will develop coal seam gas (CSG) resources in the Surat Basin, approximately 250 km west of Brisbane. This document is the Stage 1 Coal Seam Gas Water Monitoring and Management Plan (WMMP) for the Arrow Energy (Arrow) SGP.

The SGP was approved by the Australian Government under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC) decision 2010/5344, and requires that prior to commencement, the proponent must submit a Stage 1 CSG WMMP for the approval of the Minister.

Groundwater resources

The Surat Basin includes three main aquifer systems: the surficial alluvial aquifers (including the Condamine Alluvium aquifer), the consolidated sedimentary aquifers (Great Artesian Basin aquifers), and the volcanic (basalt) aquifers. Groundwater has historically been utilised extensively throughout the Surat Basin for a range of purposes including irrigation, agriculture, grazing, industry and urban supply. Groundwater also supports dependent ecosystems in some areas within and in the vicinity of the SGP area.

Non-CSG groundwater use (primarily irrigation, agriculture, grazing, industry and urban supply) has led to a broad decline in groundwater pressures, particularly in the Condamine Alluvium which has historically been over-developed and over-allocated with respect to the productive yield of the system resulting in significant lowering of the watertable. Pressure declines in deeper GAB formations have also resulted.

The Walloon Coal Measures (WCM) host the target coal seams for CSG production. Depressurisation of the WCM during gas production may propagate to overlying and underlying formations. Consideration for altered groundwater availability and quality for existing users and dependent ecosystems as a result of the Action is therefore required.

Surface water resources

The highly variable, permanent to semi-permanent Condamine River flows north through the Cecil Plains-Dalby area, north-west and west towards Chinchilla, then south-west from Condamine, eventually becoming the Balonne River that feeds into the Murray-Darling River system.

The Juandah River (a tributary of the Dawson River) is the major watercourse in the north of the SGP area, and flows north-east through Guluguba and Wandoan. In the south of the SGP area, major watercourses include Wyaga Creek and Commoron Creek, which flow south-west towards Goondiwindi.

Lake Broadwater and Long Swamp are key surface water features located in the central part of the SGP area to the west of Tipton. Lake Broadwater is a Category ‘A’ Environmentally Sensitive Area

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[1] Referred to as the Surat Gas Project (SGP) in this plan

under the Queensland Environmental Protection Regulation (2008) and a Nationally Important Wetland under the EPBC Act. Long Swamp is a palustrine wetland to the north-east of Lake Broadwater, recognised locally as a natural and important wetland.

Predicted impacts of the SGP

Groundwater drawdown and flux change

A significant body of groundwater modelling has been undertaken by, and on behalf of, Queensland government agencies including the Office of Groundwater Impact Assessment (OGIA), the Department of Natural Resources and Mines (DNRM) and the Department of Science, Information Technology and Innovation (DSITI). This forms the basis for predicting impacts to groundwater and surface water as a result of the SGP.

The maximum predicted SGP-only drawdown in the Condamine Alluvium is 0.5 m near Dalby. Drawdown of less than 0.18 m is typical across the remainder of the Condamine Alluvium.

The maximum predicted SGP-only drawdown in the Springbok Sandstone and Hutton Sandstone are 10 m and 8 m respectively. The average predicted Arrow only drawdown in the Springbok Sandstone and Hutton Sandstone are <2 m and <5 m respectively.

Predicted SGP-only flux changes to the Condamine Alluvium indicate relatively minor impacts (i.e. reduced flux) peaking at between 1.25 and 2.8 ML/d.

Surface water resources

Modelling was undertaken to quantify the impact that flux changes to the Condamine Alluvium may have on surface water flow in the Condamine River. The predicted impacts are of very small magnitude and considered to have negligible impact.

The predicted maximum change in total groundwater flux to the Condamine River due to SGP water production is between 0.09 and 0.13 ML/d.

Because the watertable is already below the base of the Condamine River across the majority of the Condamine Alluvium (i.e. the river is disconnected from groundwater), the rate of leakage from the Condamine River is therefore substantially independent of groundwater levels. Where some change in flux to the Condamine River was indicated in the modelling, this was primarily downstream of Warra Town Weir, with maximum changes in groundwater flux of between 0.001 ML/d and 0.004 ML/d. Impacts of less than 0.001 ML/d are also predicted just upstream of Talgai Weir, Yarramalong Weir, Cecil Plains Weir and Chinchilla Weir.

Groundwater dependent ecosystems

The assessment of potential impacts to spring groundwater dependent ecosystems (GDEs) is a function of the OGIA and reported under the Spring Impact Management Strategy (SIMS) in the Surat CMA UWIR. Arrow has no assigned responsibilities regarding potentially affected springs under the SIMS, or under the Joint Industry Plan (JIP) early warning system (EWS) for the monitoring and management of springs identified as being potentially impacted by CSG production activities that contain EPBC listed communities or species.

A detailed assessment of predicted impacts to potential terrestrial (non-spring) GDEs as a result of the Action was carried out and identified that:

- Ecosystems to the west of Millmerran (south-west of Cecil Plains) along the western slopes of the Kumbarilla Ridge (and western boundary of Arrow tenure) may be dependent on groundwater in the Springbok Sandstone and may be impacted by project-related groundwater drawdown.
- Ecosystems south and west of Wandoan along minor drainage lines may be dependent on shallow groundwater in the WCM and may be impacted by project-related groundwater drawdown.

The actual dependence of these ecosystems on groundwater is the subject of ongoing investigation by Arrow, the findings of which will be incorporated in to the Stage 2 CSG WMMP.

The groundwater connectivity and dependence of both Long Swamp and Lake Broadwater is not yet fully established. Whilst these features are not predicted to be impacted, further assessment, including field investigations, will be carried out to characterise the groundwater-surface water connectivity. The findings of these assessments will also be incorporated in to the Stage 2 CSG WMMP.

Aquatic ecology and aquatic ecosystems

Existing environmental conditions with regards to aquatic ecology and aquatic ecosystems are assessed as being highly disturbed, and there is not likely to be material impacts to aquatic ecosystems as a result of groundwater drawdown impacts associated with the Action. In addition, discharge of produced water to surface water systems is not proposed.

Water management

CSG water and brine management

Arrow has an established CSG Water Management Strategy (CSG WMS) for the SGP. The CSG WMS provides a basis for compliance, and sets out the method for managing CSG water for Arrow’s Surat Basin tenements. It applies to co-produced water and brine resulting from CSG production activities.

Flood risk management

The flood risk management approach adopted is that of hazard elimination, consistent with standard hierarchies of risk management. An assessment of available land within Arrow’s tenements that is outside of the mapped 1,000 year ARI flood extent was made and compared with proposed water and gas processing infrastructure footprints. This showed that that there is sufficient land available outside the predicted 1,000 year flooding extents for major project infrastructure to be sited.

Arrow plans to locate all major infrastructure outside of the inundation zone, and accordingly the hazards associated with the 1,000 year ARI flooding will therefore be eliminated. Where this cannot be achieved, engineering and administrative controls will be adopted.

Early warning monitoring system

The approval conditions variably require early warning indicators, trigger thresholds, groundwater drawdown limits and groundwater limits for groundwater systems and GDEs, as summarised in Table A. Collectively, this is the early warning monitoring system (EWMS).

Table A. EWMS requirements

System	Early warning indicator	Trigger threshold	Groundwater or drawdown limit
Consolidated aquifers	-	-	✓
Condamine Alluvium	✓	✓	✓
GDEs	✓	✓	-
Aquatic ecosystems	✓	✓	-

The EWMS for the SGP includes tiered investigation levels with escalating responses:

1. Early warning indicators, for early identification of potential issues.
2. Trigger thresholds, for identifying the potential to exceed limits, and enable actions to be selected and implemented to reduce the likelihood of limit-exceedance.
3. Limits, that define levels of impact not to be exceeded.

EWMS operation is underpinned by an early warning monitoring network. Data from this network will be analysed and compared to the assigned early warning indicators, triggers and limits. The data will also be used to generate new impact forecasts and help consolidate the understanding of groundwater systems across the SGP, and for updating groundwater models supporting the WMMP.

Monitoring network and program

Groundwater

A groundwater monitoring network and sampling and analysis program has been developed to monitor CSG-related groundwater drawdown, to provide baseline data, and to enable the identification of early warning conditions as monitoring data are acquired over time.

The monitoring network utilises Arrow’s existing and planned monitoring locations as required by the Surat Cumulative Management Area (CMA) Underground Water Impact Report (UWIR) Water Management Strategy (WMS).

The Stage 1 CSG WMMP monitoring network comprises 105 monitoring well/vibrating wire piezometer (VWP) intervals at 32 discrete monitoring locations.

Groundwater pressure will be monitored at all active monitoring network locations. Where data loggers are installed, hourly measurements will be recorded, with bi-annual manual readings. Where data loggers are not installed, fortnightly manual readings will be recorded.

Groundwater quality will be monitored in fifteen monitoring wells. During the first year of monitoring of a particular well, a full analytical suite will be adopted at a bi-annual sampling frequency. Following this, a standard suite of analytes for particular wells will be established based on the first year of data and adopted for ongoing bi-annual sampling.

Supplemental analysis of additional analytes may be carried out from time to time based on assessment of the available groundwater quality data.

Surface water and aquatic ecology

Surface water and aquatic ecosystems are not predicted to be impacted by WCM depressurisation to the extent that adverse ecosystem effects would arise. Further, under the Arrow CSG WMS, discharge of produced water to surface water systems is not proposed, therefore monitoring of surface water systems and aquatic ecology is not required.

Should future project requirements include the need for discharge, or if future changes to the Field Development Plan (FDP) result in the potential for impact to surface water systems and aquatic ecology, Arrow will update the CSG WMMP to include an appropriate monitoring network and program, seek approval of the updated WMMP from the Minister, and acquire a minimum 12 months baseline data prior to any discharge.

Subsidence

Monitoring of subsidence is carried out using satellite borne Interferometric Synthetic Aperture Radar technology (InSAR). This provides a baseline from which future data can be assessed to determine changes in vertical ground elevation, and also provides a snapshot of current vertical ground movement.

Separate geodetic measurement of ground movement will be taken at three locations to provide a ground-truthing check and control on the InSAR results. Locations for geotechnical ground movement monitoring are proposed to be co-located with groundwater monitoring bores, to provide coverage of the full ground profile potentially influenced by the SGP.

Measurement of settlement and extensometers is proposed on an initially monthly frequency. Ongoing reviews of the baseline established will determine when the monitoring frequency may be reduced for ongoing monitoring.

To demonstrate compliance with the requirements of the approval conditions, Table B presents a summary of the approval conditions, cross-referenced to the relevant sections of the Stage 1 CSG WMMP where the conditions are addressed.

Table B Approval condition compliance reference summary

Approval Condition	Condition description	Relevant WMMP section
13	Prior to commencement, the proponent must submit a Stage 1 Coal Seam Gas Water Monitoring and Management Plan (Stage 1 CSG WMMP) for the approval of the Minister, who may seek the advice of an expert panel. The Stage 1 CSG WMMP must include:	NA
13a	An analysis of the results of the most recent OGIA model (built or endorsed by OGIA), relevant to all of the project's tenement areas.	Appendix E
13b	A fit for purpose numerical simulation to assess potential impacts on water resources arising from the Action in the project area, subsequent surface water-groundwater interactions in the Condamine Alluvium and impacts to dependent ecosystems.	Appendix F
13c	An assessment of potential impacts from the Action on non-spring based groundwater dependent ecosystems through potential changes to surface-groundwater connectivity and interactions with the sub-surface expression of groundwater.	Section 3.4.2 Section 5 of Appendix D
13d	An assessment of predicted project wide groundwater drawdown levels and pressures from the Action, together with confidence levels.	Section 3.2 Section 3.3 Appendix E Appendix F
13e	Parameters and a sampling regime to establish baseline data for surface and groundwater resources that may be impacted by the Action, including: surface water quality and quantity in the project area, and upstream and downstream of potential impact areas; groundwater quality, levels and pressures for areas that may be impacted by the project; and for determining connectivity between surface water and groundwater that may be impacted by the project.	Section 6.1.4 Section 6.1.5 Section 6.2.2 Section 6.2.3 Section 6.3 Appendix J
13f	A best practice baseline monitoring network that will enable the identification of spatial and temporal changes to surface water and groundwater. This must include a proposal for aquifer connectivity studies and monitoring of relevant aquifers to determine hydraulic connectivity (including potential groundwater dependence of Long Swamp and Lake Broadwater) and must also enable monitoring of all aquatic ecosystems that may be impacted by the Action.	Section 6.1.1 Section 6.1.2 Section 6.1.3 Section 6.2.1 Appendix J
13g	A program to monitor subsidence impacts from the Action, including trigger thresholds and reporting of monitoring results in annual reporting required by condition 28. If trigger thresholds are exceeded, the approval holder must develop and implement an action plan to address impacts within 90 calendar days of a trigger threshold being exceeded.	Section 7.1 Section 7.4 Section 7.5

Approval Condition	Condition description	Relevant WMMP section
		Section 9.2.3 Appendix K
13h	Provisions to make monitoring results publicly available on the approval holder's website to facilitate a greater understanding of cumulative impacts.	Section 9.4
13i	A discussion on how the approval holder is contributing to the Joint Industry Plan, including its periodic review. The approval holder must contribute to the Joint Industry Plan and comply with any part of the Joint Industry Plan, or future iterations of the Joint Industry Plan, that applies to the approval holder.	Section 8.1
13j	A groundwater early warning monitoring system, including:	-
13j (i)	Groundwater drawdown limits for all consolidated aquifers potentially impacted by the Action, excluding the Walloon Coal Measures.	Section 5.1 Section 5.2 Section 3 of Appendix I
13j (ii)	For the Condamine Alluvium, appropriate triggers and groundwater limits and a rationale for their selection.	Section 5.1 Section 5.2 Section 4 of Appendix I
13j (iii)	Early warning indicators and trigger thresholds, including for Lake Broadwater, Long Swamp and other groundwater dependent ecosystems that may potentially be impacted by the action, including those that may occur outside the project area and may be impacted by the Action.	Section 5.1 Section 5.2 Section 5.4 Section 5 of Appendix I
13j (iv)	Investigation, management and mitigation actions, including substitution and/or groundwater repressurisation, for both early warning indicators and trigger thresholds to address flux impacts on the Condamine Alluvium.	Section 5.2 Section 4 of Appendix I Section 3.1 of Appendix G
13k	Early warning indicators and trigger thresholds, including corrective actions for both early warning indicators and trigger thresholds, for aquatic ecology and aquatic ecosystems.	Section 5.3 Section 6 of Appendix I

Approval Condition	Condition description	Relevant WMMP section
13l	A CSG water management strategy for produced salt/brine, which discusses how co-produced water and brine will be managed for the Action, including in the context of other coal seam gas activities in the Surat Basin.	Section 4.1 Section 3.2 of Appendix G
13m	An analysis of how the approval holder will utilise beneficial use and/or groundwater repressurisation techniques to manage produced CSG water from the Action, and how any potential adverse impacts associated with groundwater repressurisation will be managed.	Section 3.3 of Appendix G
13n	A discharge strategy, consistent with the recommendations and requirements of the Department of the Environment and Heritage Protection in its Assessment Report (pages 94 to 95 and pages 254 to 255) and that includes scenarios where discharge may be required, the quality of discharge water (including water treated by reverse osmosis), the number and location of monitoring sites (including upstream and downstream sites), frequency of monitoring and how the data from monitoring will be analysed and reported, including recommendations on any changes or remedial actions that would be required.	Discharge is not proposed
13o	A flood risk assessment for processing facilities and any raw co-produced water and brine dams, which addresses flood risks to the environment from the Action in the case of a 1: 1 000 ARI event. The risk assessment should estimate the consequences if major project infrastructure was subject to such an event, including release of brine and chemicals into the environment.	Section 4.2 Appendix H
13p	A cumulative impact assessment based on the outputs of the OGIA model which integrates groundwater model outputs with known and potential groundwater dependent ecosystems and presents the outputs in map form. Contribute to investigations coordinated through the OGIA to assess hydrological and ecological characteristics of Impacted groundwater dependent ecosystems.	Section 8.6 Section 6 of Appendix D
13q	Details of performance measures; annual reporting to the Department; and publication of reports on the internet.	Section 9.2 Section 9.3 Section 9.4
13r	An explanation of how the Stage 1 CSG WMMP will contribute to work undertaken by other CSG proponents in the Surat Basin to understand cumulative impacts, including at the local and regional scale, and maximise environmental benefit.	Section 8.6
14	The Stage 1 CSG WMMP must be peer reviewed by a suitably qualified water resources expert/s approved by the Minister in writing. The peer review must be submitted to the Minister together with the Stage 1 CSG WMMP and a statement from the suitably qualified water resources	Appendix L

Approval Condition	Condition description	Relevant WMMP section
	expert/s stating that they carried out the peer review and endorse the findings of the Stage 1 CSG WMMP.	
15	The approval holder must not exceed the groundwater drawdown or groundwater limits for each aquifer specified in the Stage 1 CSG WMMP.	NA
16	Unless otherwise agreed in writing by the Minister, the approval holder must not commence the Action until the Stage 1 CSG WMMP is approved In writing by the Minister. The approved Stage 1 CSG WMMP must be implemented.	NA

Contents

List of Figures

List of Tables

1 INTRODUCTION

This document is the Stage 1 Coal Seam Gas (CSG) Water Monitoring and Management Plan (WMMP) for the Arrow Energy (Arrow) Surat Gas Expansion Project[2] (SGP).

This WMMP addresses the Australian Government approval conditions relating to the assessment, management, and mitigation of surface and groundwater impacts as a result of project development, and also addresses relevant Arrow commitments in the SGP environmental impact statement (EIS) (Arrow Energy, 2012) and Supplementary Report to the EIS (SREIS) (Arrow Energy, 2013).

1.1 Approvals and conditions

The SGP was approved by the Australian Government under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC) decision 2010/5344. Conditions 13 to 25 of the approval outline requirements for the Stage 1 and subsequent CSG WMMPs. The approval requires that prior to commencement, the proponent must submit a Stage 1 CSG WMMP for the approval of the Minister, peer reviewed by a suitably qualified water resources expert appointed and approved by the Minister. Dr Glenn Harrington of Innovative Groundwater Solutions Pty Ltd was the peer reviewer appointed by the Minister on 7 July 2015.

An evaluation of the SGP EIS/SREIS was also completed by the Queensland Department of Environment and Heritage Protection (EHP). An assessment report was prepared by EHP pursuant to Sections 58 and 59 of the *Environmental Protection* (EP) *Act* which recognises that through the EIS and SREIS processes Arrow has committed to the management and monitoring of groundwater and surface water resources and coal seam gas water, and is also obliged to carry out further investigations and monitoring under the approval processes.

A compliance table cross-referencing EPBC Act approval conditions with this WMMP is provided in Appendix A, and a table cross-referencing Arrow's commitments under the EIS/SREIS is presented in Appendix B.

The approach taken in addressing the approval conditions has involved preparation of seven technical memoranda and one report addressing the conditions. These were developed and provided to the appointed peer reviewer for progressive endorsement. The content of the memoranda is incorporated within this plan and the memoranda are included as appendices.

The technical memoranda are summarised in Table 1.1.

---

[2] Referred to as the Surat Gas Project (SGP) in this plan. The SGP was approved by the Queensland Government on 25 October 2013 and the Australian Government on 19 December 2013.

Table 1-1. Summary of technical memoranda

Technical Memoranda	Conditions addressed	Appendix
GDE and aquatic ecosystem impact assessment technical memorandum	13c and 13p	D
Groundwater modelling technical memorandum	13a, 13b and 13d	E
Condition 13(b) technical report	13b	F
Assessment of impacts and development of management measures technical memorandum	13j(iv)	G
Flood risk technical memorandum	13o	H
Limits, indicators and triggers technical memorandum	13j, 13k, 15	I
Groundwater monitoring network and program technical memorandum	13e, 13f	J
Subsidence technical memorandum	13g	K

1.2 Project description

The Surat Basin, located approximately 250 km west of Brisbane in Queensland, hosts a number of gas fields with significant coal seam gas resources. Arrow is developing these resources through exploration, field development, and gas production.

Since preparation of the SGP EIS further knowledge of the gas reserves has been gained and subsequently, parcels of land within Arrow's exploration tenements have been relinquished. The size of the tenure for the project development has reduced from approximately 6,000 km^2 to 5,600 km^2 (refer Figure 2.1).

The updated SGP project description is provided in Appendix C, and includes changes relating to the relinquishment of tenements since the 2013 approval.

1.3 Definitions

Key terms relevant to the WMMP are defined in Table 1.2, with respect to the impact of the SGP induced change of groundwater levels, pressure and quality, and where relevant, surface water flow and quality.

Other technical terms in this document, where not specifically defined, are assumed to have the same meaning as defined in the SGP EIS/SREIS.

Table 1-2. Definitions[3]

Term	Definition
Background level	Non-Arrow CSG influenced existing conditions (levels or quality).
Consolidated aquifer	Aquifer in a consolidated sedimentary formation.
Drawdown factor	Derived from the Queensland Water Act[4] for similar systems, being 5 m for consolidated aquifers and 2 m for unconsolidated aquifers. No drawdown factor is added for non-spring GDEs or for spring GDEs.
Groundwater drawdown due to the Action	Change in head relative to the background level arising from the Action.
Drawdown limit	A drawdown level for a consolidated aquifer not to be exceeded.
SGP area	The Surat Gas Project development area and surrounding land within the extent of drawdown impact as a result of the Action.
The Action	The Arrow SGP.
Early warning indicator	A first-tier drawdown level that provides early indication of potential for an impact.
Trigger threshold	A second-tier drawdown level that triggers response actions.
Groundwater limit[5] or drawdown limit[6]	A groundwater level based limit for an aquifer or GDE[7] not to be exceeded.
MNES	Matters of National Environmental Significance (water resources and the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin)

---

[3] Where relevant, the terms are defined in relation to the SGP induced change.

[4] Taken from the bore trigger thresholds under the Queensland Water Act 2000

[5] Refers specifically to Approval Condition 13(j)ii

[6] Refers specifically to Approval Condition 13(j)i

[7] Limit for GDEs voluntarily adopted as per Table 5.1

2. ENVIRONMENTAL SETTING

The SGP area is located within the Darling Downs region of South East Queensland, and encompasses exploration tenures and petroleum leases (PLs) located from Wandoan in the north to Millmerran in the south, in an arc west of Dalby (refer Figure 2.1).

Intensive agriculture and settlement has occurred along the Condamine River valley, central to the SGP. Agriculture, forestry, oil and gas development and coal mining are the main land uses. Agriculture includes intensive irrigation, cropping, poultry farming, grazing, piggeries, and cattle feedlots. The SGP is located within the Brigalow Belt bioregion and is characterised by patches of remnant woodland and forest communities (mainly eucalypt). Most native vegetation is confined to large areas of state forests and linear tracts of vegetation along road reserves and watercourses.

The following sections provide a brief overview of the SGP setting with further detail provided in the SGP EIS and SREIS.

2.1 Climate

The SGP climate is characterised under the Köppen–Geiger climate classification system as a humid subtropical climate (class Cfa). Summers are warm to hot, but without dry months.

The mean maximum monthly temperature ranges from 19.7°C in winter to 32.5°C in summer. The mean annual evaporation is approximately 2260 mm, and the monthly mean evaporation data when compared with the rainfall data shows a seasonal water deficit.

Table 2.1 presents representative mean monthly rainfall from Dalby Airport and potential evaporation data for the Daandine area.

Table 2-1. Mean climate characteristics

Precipitation (mm)	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Annual**
Mean	78	77	59.	19	38	32	23	24	32	56	73	94	605
Dalby Airport (Station number 41522) (data downloaded May 2017)													
Evaporation (mm)	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Annual**
Mean	280	215	225	175	110	90	95	140	170	235	245	280	2260
Daandine area (data downloaded Nov 2016)													

Source: Bureau of Meteorology data (www.bom.gov.au)

ARROW ENERGY - SURAT GAS PROJECT

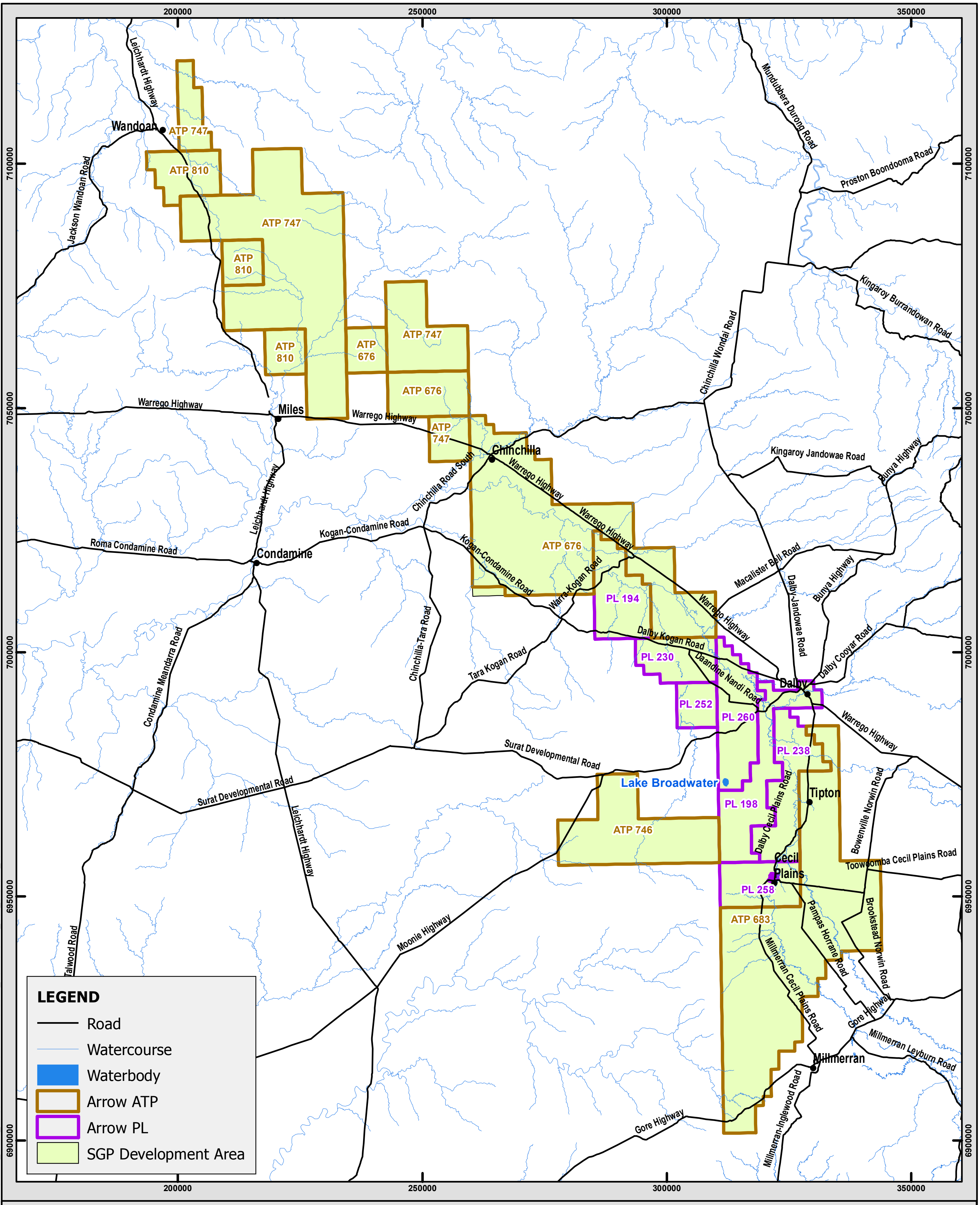

Figure 2.1 Surat Gas Project area

Source:
Arrow Energy Pty Ltd

Date: 13/10/2017
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

N

arrow energy
go further

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2.2 Topography and landform

Topography across the SGP area is predominantly low relief, with elevation ranging between 200 and 400 metres Australian Height Datum (mAHD) and overall sloping gently towards the south-west.

Several major physiographic regions are present, which are functions of the underlying geology and geomorphic evolution.

The major feature is the Condamine River valley which is bounded by the Great Diving Range to the east and Kumbarilla Ridge to the west (Refer Figure 2.2). The valley extends north and south into the Dawson and Border Rivers catchments respectively. At its broadest, the valley is approximately 50 km wide. Where the Condamine River has incised the Kumbarilla Ridge to the west of Chinchilla, the valley is appreciably narrower at about 5 km wide.

The Great Dividing Range highlands comprise resistant igneous rocks overlying generally coarse-grained sandstones. The Kumbarilla Ridge uplands, along the west of the SGP area, are characterised by gentle slopes developed on consolidated sedimentary formations, with maximum elevations of around 420 mAHD.

2.3 Hydrology

The Condamine and Balonne rivers dominate the hydrology of the SGP area and are part of the greater Murray-Darling Basin. Figure 2.3 presents the major drainage systems in the region.

2.3.1 Drainage and river systems

Condamine River

The Condamine River is the main regional river system in the SGP area. The highly variable, permanent to semi-permanent Condamine River flows north through the Cecil Plains-Dalby area, north-west and west towards Chinchilla, then south-west from Condamine, eventually becoming the Balonne River that feeds into the Murray-Darling River system.

In the Condamine River valley, watercourses are generally incised with well-defined channels that are dissociated from their floodplains, particularly along the fringes of the Kumbarilla Ridge.

Incision, bank erosion, channel migration and avulsion of the rivers and creeks have left palaeochannel meander scars and terraces within the more recent alluvial deposits. Depositional features, such as levees and sandbars are common, indicating that in recent geological times the watercourses have been dynamic systems.

Dawson River

The Dawson River catchment is in the north of the SGP area. The Juandah Creek, a tributary of the Dawson River, is the major watercourse and flows north-east through Guluguba and Wandoan.

The watercourses are similar in morphology to those in the Condamine River catchment being generally incised and having well-defined channels. Sandy alluvium has been deposited along the valley floors adjacent to the creeks.

Border Rivers

The Border Rivers catchment is in the south of the SGP area. Major watercourses include Wyaga Creek and Commoron Creek, which flow south-west towards Goondiwindi. The catchment falls within two broad terrain types: uplands associated with the sandstone Kumbarilla Ridge, falling to broad clay and sandy alluvial plains.

Adjacent to the major watercourses sandy alluvium has been deposited over floodplain areas. Linear relict fans, terraces and levees composed of reworked alluvium indicate the dynamic nature and down-cutting of watercourses in recent geological times (Thwaites and Macnish, 1991).

The Border Rivers catchment is drier than the Condamine and Dawson Rivers catchments, being further inland and in the Kumbarilla Ridge rain-shadow.

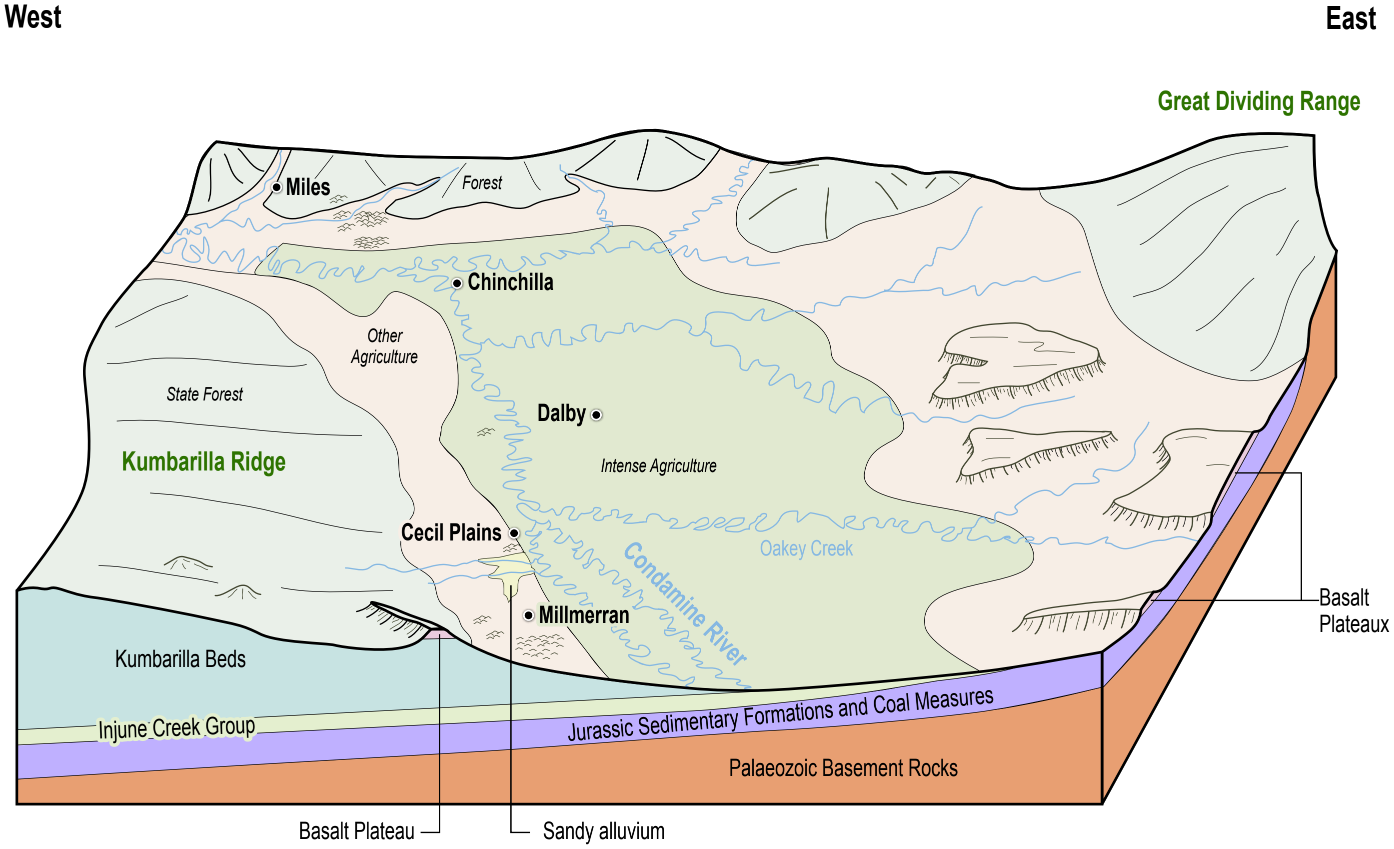

Figure 2.2 Landform characteristics of the Condamine River Valley

Source:
Arrow Energy Pty Ltd

Date:26/09/2017
Issued To: Arrow Energy
Author:Helen.Unkovich

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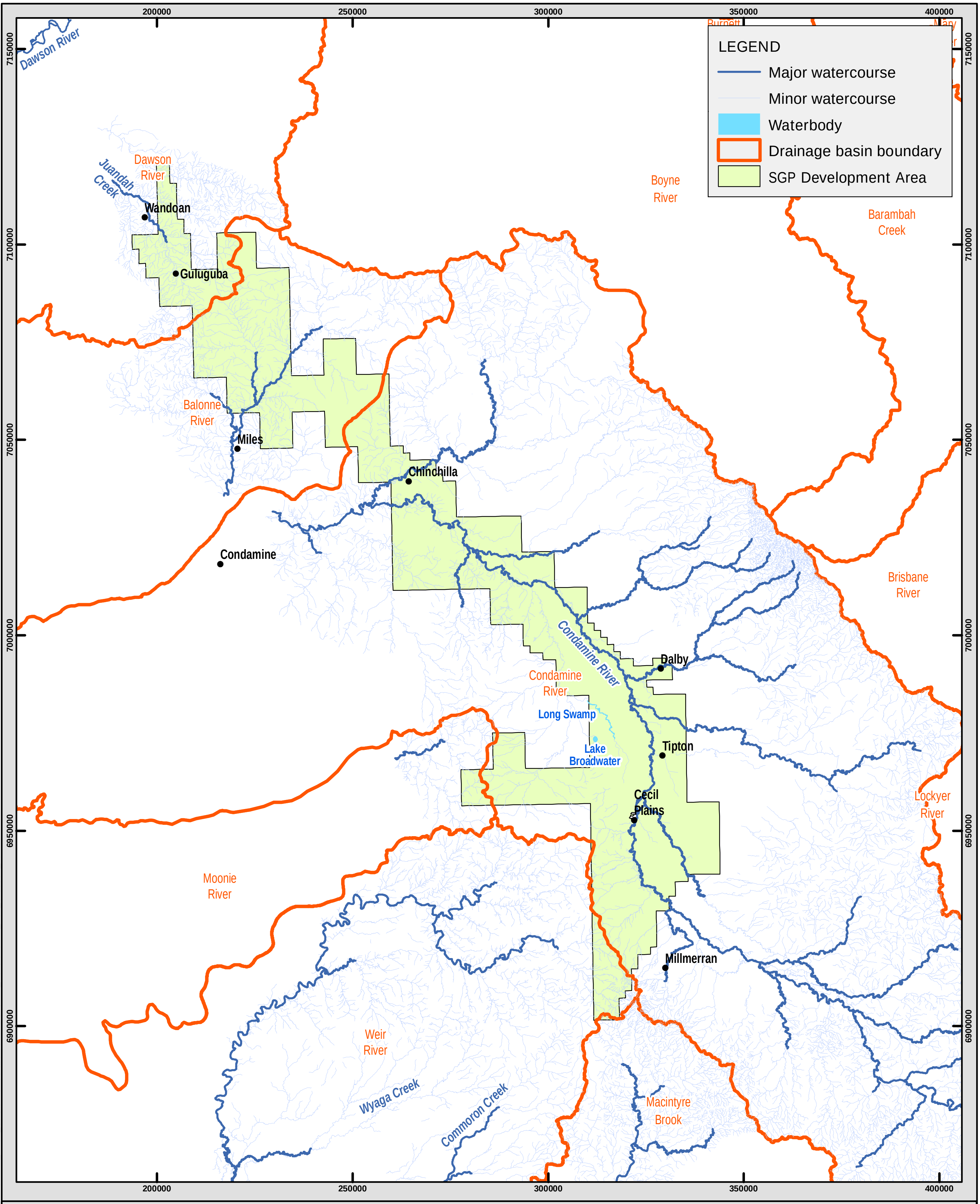

Figure 2.3 Major drainage systems in the Surat Gas Project area

Source:
Arrow Energy Pty Ltd

Date: 27/11/2017
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,250,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

N

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2.3.2 Lakes and wetlands

Lake Broadwater and Long Swamp are key surface water features within the SGP area. They are located in the central part of the SGP area to the west of Tipton (refer Figure 2.3).

Lake Broadwater is a Category ‘A’ Environmentally Sensitive Area under the Queensland Environmental Protection Regulation (2008) and a Nationally Important Wetland under the EPBC Act. Lake Broadwater has high conservation value due to its intactness, the importance of its seasonal aquatic habitat, and its potential habitat for the EPBC Act listed Murray Cod.

Long Swamp is a palustrine[8] wetland to the north-east of Lake Broadwater, considered to be an older course of the Condamine River. It is not classified under state or commonwealth legislation but is recognised locally as a natural and important wetland. Long Swamp is hydraulically connected to Lake Broadwater, filling during wet periods, and has local conservation status due to the range and diversity of riparian vegetation along the length of the wetland.

2.4 Geology

2.4.1 Surat Basin structure and geological controls

The SGP lies within three major structural Mesozoic basins: the Surat Basin (in the south and west) which unconformably overlies the Bowen Basin in the north and is separated from the Clarence-Moreton basin to the east by the Kumbarilla Ridge, an anticlinal structure. Figure 2.4 presents important structural elements of the study area.

Disconformably underlying parts of the Surat Basin is a gently folded Permian to Triassic sequence of the north-south aligned Taroom Trough, which is the sub-surface extension of the Bowen Basin. In this area, a sedimentary sequence up to 2,500 m thick in the down-warped south/south-east to north/north-west trending Mimosa Syncline has been recorded (Reiser, 1971).

The Surat Basin stratigraphy includes folded sedimentary sequences, intersected in places by faults. These fault structures can be fully or partially penetrating through the full geological sequence, and major faulting within the Surat Basin is generally an expression of boundary faults of the underlying Bowen Basin (Arrow, 2003).

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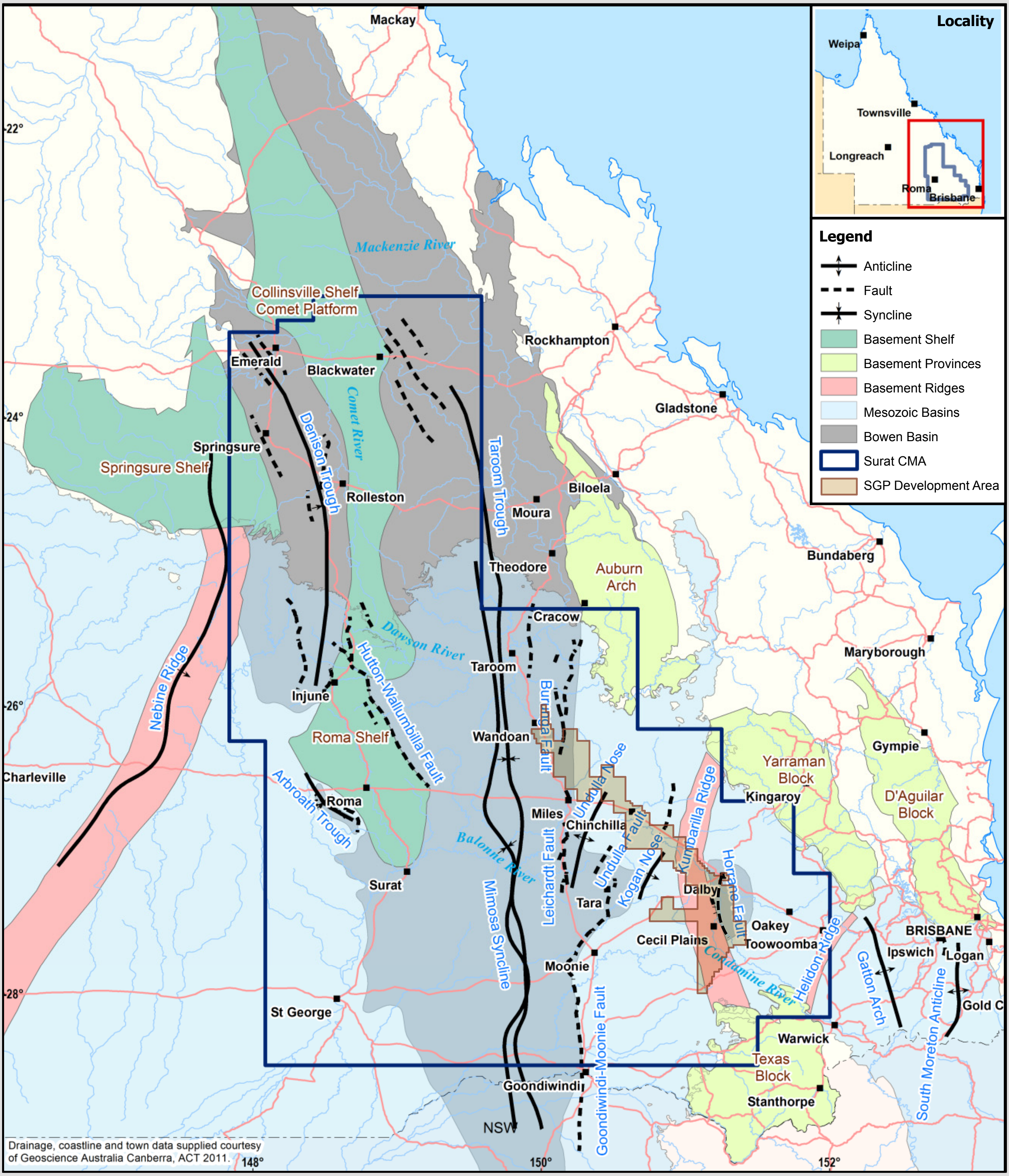
[8] Lacking flowing water, or marshy



Drainage, coastline and town data supplied courtesy of Geoscience Australia Canberra, ACT 2011.

Figure 2.4 **Major geological structures in the Surat CMA**

Source:
UWIR 2016,
Department of Natural Resources
and Mines 2016

Date: 13/10/2017
Issued To: Arrow Energy
Author: Richard.Heath

0 20 40 80 120 160 200
Kilometres
Scale: 1:4,000,000 @ A4
Coordinate System: GCS GDA 1994

N

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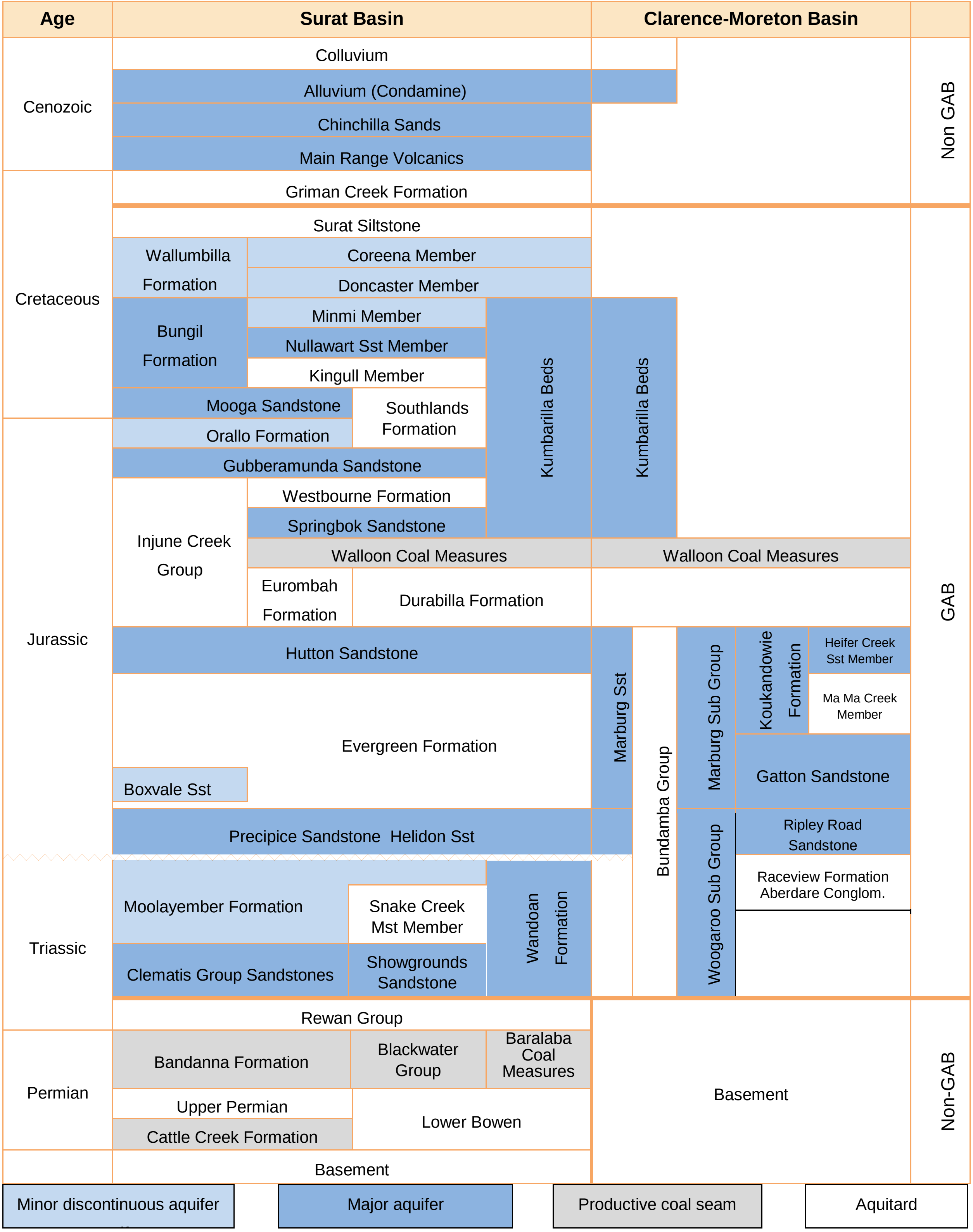
2.4.2 Stratigraphy

Many of the sedimentary formations of the Surat Basin are relatively consistent over significant distances. However facies changes and the influence of structural controls and other factors result in variable lithology in laterally equivalent or inter-fingered formations.

Table 2.2 presents the generalised stratigraphy and lithology of the Surat Basin (including hydrostratigraphy). It is noted that actual strata present at any location varies across the region. Further detail is provided in the SGP EIS and the 2016 Surat Cumulative Management Area (CMA) Underground Water Impact Report (UWIR) (DNRM, 2016).

Table 2-2. Generalised Surat Basin stratigraphy[9]



Age	Surat Basin	Clarence-Moreton Basin	
Cenozoic	Colluvium		Non GAB
	Alluvium (Condamine)	Alluvium (Condamine)	
	Chinchilla Sands		
	Main Range Volcanics		
Cretaceous	Griman Creek Formation		
	Surat Siltstone		GAB
	Wallumbilla Formation: Coreena Member Doncaster Member		
	Bungil Formation: Minmi Member Nullawart Sst Member Kingull Member	Kumbarilla Beds	
	Mooga Sandstone / Southlands Formation	Kumbarilla Beds	
	Orallo Formation / Southlands Formation	Kumbarilla Beds	
Jurassic	Gubberamunda Sandstone / Kumbarilla Beds	Kumbarilla Beds	
	Injune Creek Group: Westbourne Formation Springbok Sandstone	Kumbarilla Beds	
	Injune Creek Group: Walloon Coal Measures	Walloon Coal Measures	
	Injune Creek Group: Eurombah Formation / Durabilla Formation		
	Hutton Sandstone	Marburg Sst / Bundamba Group / Marburg Sub Group / Koukandowie Formation: Heifer Creek Sst Member Ma Ma Creek Member	
	Evergreen Formation Boxvale Sst	Marburg Sst / Bundamba Group / Marburg Sub Group / Gatton Sandstone	
	Precipice Sandstone Helidon Sst	Bundamba Group / Woogaroo Sub Group / Ripley Road Sandstone	
Triassic	Moolayember Formation / Snake Creek Mst Member / Wandoan Formation	Bundamba Group / Woogaroo Sub Group / Raceview Formation Aberdare Conglom.	
	Clematis Group Sandstones / Showgrounds Sandstone / Wandoan Formation	Bundamba Group / Woogaroo Sub Group	
	Rewan Group	Basement	Non-GAB
Permian	Bandanna Formation / Blackwater Group / Baralaba Coal Measures	Basement	
	Upper Permian / Lower Bowen	Basement	
	Cattle Creek Formation / Lower Bowen	Basement	
	Basement	Basement	

Minor discontinuous aquifer

Major aquifer

Productive coal seam

Aquitard

---

[9] Source: DNRM (2016a). SSt = sandstone Mst = mudstone Fm: formation

Condamine Alluvium

The Condamine Alluvium extends in a north-south direction from around Chinchilla in the north to Millmerran in the south (refer Figure 2.5). It is present in the central and eastern regions of the SGP area, and includes an alluvial flood plain that comprises predominantly Quaternary basal alluvium and an overlying finer grained sheetwash sediment associated with the Condamine River and its tributaries.

The alluvial sediments comprise fine to coarse grained gravels and channel sands interbedded with clays. The finer grained sheetwash deposits overlie the fluvial floodplain deposits and thicken to the east. Individual clay and silt horizons of the sheetwash can be over 20 m thick and may represent confining layers where laterally continuous. The sheetwash is derived from the Tertiary Main Range Volcanics to the east that form a significant vertisol (black soil) cover over much of the Condamine River valley.

A layer of basal alluvial clays and weathered material exists between the lowermost granular sediments of the Condamine Alluvium and the uppermost unit of the Walloon Coal Measures (WCM).

Figure 2.5 presents a schematic cross section illustrating the conceptual relationship between the Condamine Alluvium and the underlying formations through the centre of the SGP area, and highlights how the Condamine Alluvium is incised into the WCM. To the north along the western margin of the alluvium the Springbok Sandstone also underlies the Condamine Alluvium and to the south, along the eastern margin, the Hutton Sandstone underlies the Condamine Alluvium.

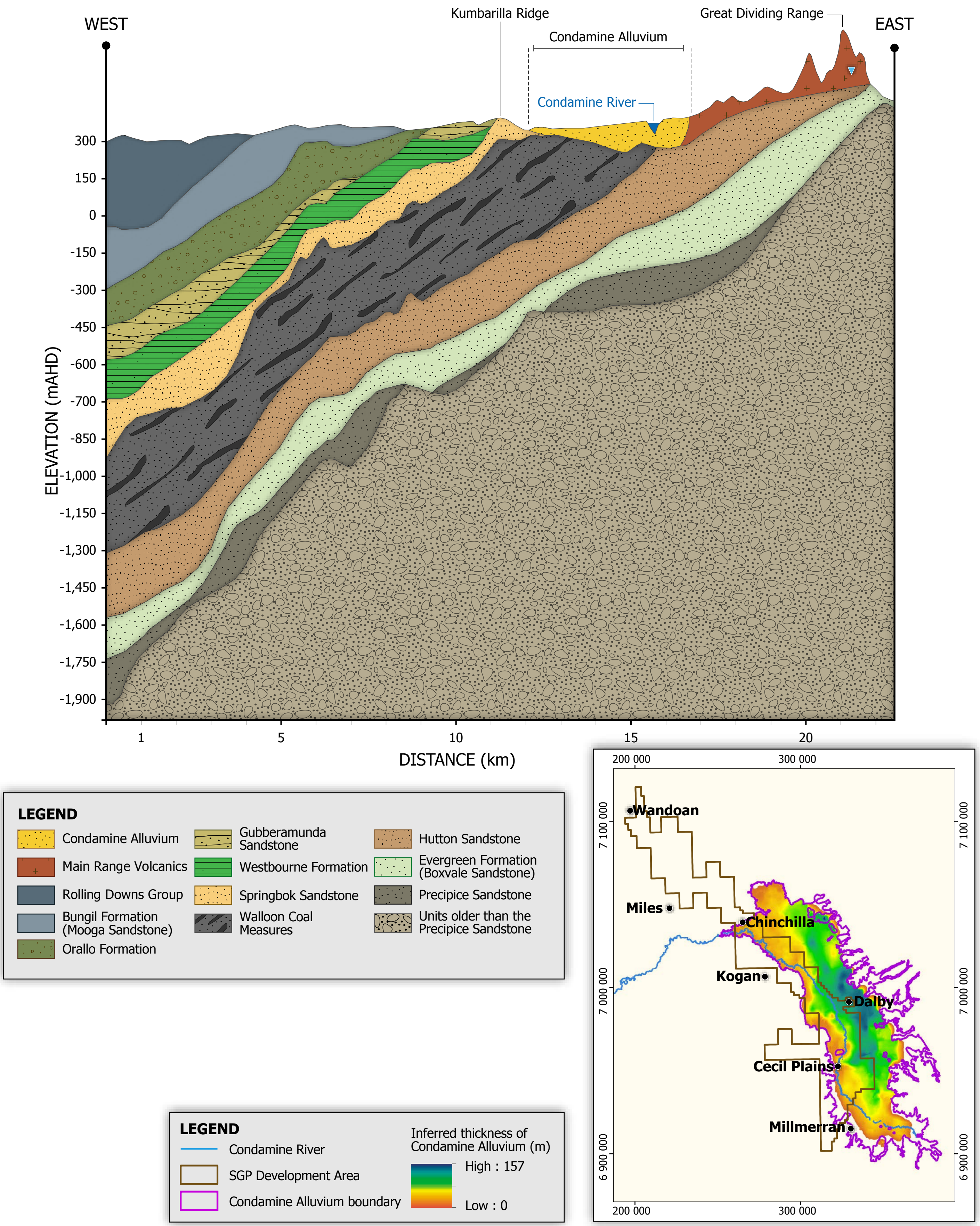


Figure 2.5 Schematic cross-section of Condamine Alluvium and underlying units

Source:
Coffey

Date: 26/09/2017
Issued To: Arrow Energy
Author: Helen.Unkovich / Richard.Heath

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2.5 Hydrogeology

Extraction of coal seam gas requires depressurisation of the coal measures. In the Surat Basin, the WCM host the target coal seams for CSG production. Depressurisation of the WCM may propagate to overlying and underlying formations, and an understanding of the hydrogeology of the Surat Basin is required to predict the impacts associated with CSG development.

The Surat Basin includes three main aquifer systems: the consolidated sedimentary aquifers (Great Artesian Basin aquifers), the surficial alluvial aquifers (including the Condamine Alluvium aquifer), and the volcanic (basalt) aquifers.

Groundwater resources in the Surat Basin are used extensively for agriculture, and abstraction has led to a broad decline in groundwater pressures, particularly in the Condamine Alluvium, but also in deeper GAB formations.

Further detailed information on the hydrogeological conceptualisation is provided in the SGP EIS/SREIS as well as more recent reports developed by the Office of Groundwater Impact Assessment (OGIA) including the Surat CMA UWIR (DNRM, 2016).

2.5.1 Hydrostratigraphy

The SGP area contains both unconfined and confined aquifers. Table 2.2 presents the regional hydrostratigraphy. Major aquifer formations include:

- Condamine Alluvium: shallow unconsolidated and unconfined aquifer.
- Gubberamunda and Mooga Sandstone: consolidated unconfined to confined sandstone aquifers of the GAB.
- Springbok Sandstone: consolidated unconfined to confined sandstone GAB aquifer. Can have significant mudstone and siltstone content in some areas where it behaves more like an aquitard.
- Walloon Coal Measures: generally confined siltstone, mudstone and clayey sandstone aquifer within the GAB. Thin permeable coal and sandstone seams can yield usable quantities of water (DNRM, 2016).
- Hutton[10] Sandstone: deeply buried confined consolidated sandstone GAB aquifer.
- Precipice Sandstone: deeply buried confined consolidated sandstone and siltstone GAB aquifer.

---

[10] Includes laterally equivalent Marburg Sandstone where present

2.5.2 Aquifer Recharge

Recharge mechanisms of the Condamine Alluvium

Recharge includes infiltration from the Condamine River, with contribution from rainfall infiltration and laterally from the surrounding bedrock and alluvium of the tributaries of the Condamine River (OGIA 2016 (UWIR)).

However, water balance modelling completed by KCB (KCB, 2011) indicates that while rainfall recharge rates are low, volumetrically, diffuse rainfall recharge to the watertable is a major component of the water balance as it occurs over such a large area.

Other recharge mechanisms for the Condamine Alluvium include interaction with underlying formations, bedrock contribution from the east and west, flux from upstream (throughflow), tributary and meander channel seepage, flood recharge and irrigation deep drainage (KCB 2011).

Recharge mechanisms of GAB formations

Recharge to GAB formations is primarily by direct rainfall infiltration where the formations outcrop to the north, north-west and north-east of the Surat Basin along the Great Dividing Range. Recharge is primarily along preferential flow pathways including bedding planes and fractures (DNRM, 2016). South of the Great Diving Range where the SGP is largely located, groundwater flow direction is largely south and south-west, away from the recharge areas. North of the Great Dividing Range there is some northerly flow component (DNRM, 2016).

Vertical leakage between GAB aquifers is restricted in many areas by the low permeability aquitards present throughout the GAB, including the Evergreen and Westbourne formations and their equivalents (OGIA, 2016 (UWIR)).

2.5.3 Influence of faulting

Regional-scale faults in the Surat CMA with significant displacement are indicated to be restricted to formations in the underlying Bowen Basin and do not typically extend to the overlying formations of the Surat Basin (QWC, 2012; Sliwa, 2013; DNRM, 2016). Within the overlying Surat Basin the most common faults are steeply dipping normal faults. These faults are considered to be relatively minor structural features with throws that are generally less than 20 m.

Sliwa (2013) reports that the mild deformation observed in Surat Basin rocks post-dates deposition, and a phase of rift-style normal (extensional) faulting has occurred. This was followed by a return to compressional tectonics that resulted in mild reactivation of the Moonie-Goondiwindi Fault system (located to the west of Arrow’s tenements), partial inversion of some normal faults, tightening of the underlying Bowen Basin folds, and development of gentle folding in overlying younger Surat rocks (Sliwa, 2013).

A low angle unconformity between the upper-most coal seams of the Walloon Coal Measures and the overlying Springbok Sandstone is indicated through seismic analysis. Sliwa (2013) reports that from the seismic data none of the Surat normal faults were found to propagate vertically to an extent sufficient to terminate against the Springbok unconformity. This indicates that the period of normal faulting is likely to have occurred during or prior to the end of WCM deposition, prior to the subsequent erosional period and low angle unconformity, and prior to the deposition of the Late Jurassic Springbok Sandstone.

Hence, based on the seismic evidence, and also by inference due to the timing constraints, it is concluded that the fault structures do not extend to the Springbok Sandstone. Therefore, in the SGP area fault induced drawdown propagation across the Springbok, or younger formations including the Westbourne Formation and Gubberamunda Sandstone is not expected.

In addition, hydrothermal precipitation and induration may have led to sealing of fault damage zones since Jurassic times. Because the tectonically stable Surat Basin remains relatively inactive, fault permeability is expected to continue to decrease over time (DNRM, 2016), and the majority of faults in the Surat CMA are therefore not expected to provide a conduit for vertical flow from overlying aquifers to the coal measures.

DNRM (2016) also report that as the coal seams within the major gas reservoirs generally represent less than 10% of the unit thickness, any displacement is likely to result in a barrier to horizontal groundwater flow, as the more permeable coal seams are juxtaposed with lower-permeability siltstone, claystone or mudstone members.

2.5.4 Groundwater use

Groundwater has historically been utilised extensively throughout the Surat CMA for a range of purposes including irrigation, agriculture, grazing, industry and urban supply. Groundwater is primarily extracted from GAB (consolidated) aquifers, the Condamine Alluvium and Main Range Volcanics for these purposes.

Groundwater extraction associated with the petroleum and gas industry is also increasing with the expansion of CSG activity throughout the Surat CMA.

Groundwater use is detailed in the following sections.

Non-petroleum and gas related groundwater extraction

The Condamine Alluvium has historically been over-developed and over-allocated with respect to the productive yield of the system (DNRM, 2012a) resulting in significant lowering of the watertable, and in some areas resulting in disconnection of the Condamine River with the Condamine Alluvium.

The impact on this resource has been recognised since 1970, and access to Condamine Alluvium groundwater systems in the Upper Condamine Catchment was limited through a moratorium on development of groundwater which commenced in June 2008 and ended in December 2014 (DNRM, 2017). In addition, announced allocations in a number of subgroup areas of the Central Condamine Alluvium Groundwater Management Area for the 2017 water year are 50% to 70% of nominal entitlements to address this issue (DNRM, 2017a).

A summary of the non-petroleum groundwater extraction bores and extraction volumes reported in the Surat CMA UWIR (DNRM, 2016) is provided in Table 2.3. There are over 22,500 water bores within the Surat CMA with a combined water extraction in the order of 203,000 ML/yr. Of this, around 53,000 ML/yr is sourced from GAB formations, and 150,000 ML/yr from other aquifers. The total groundwater extraction presented in Table 2.3 represents groundwater used for agricultural, industrial, urban and stock and domestic purposes.

Non-GAB aquifers having the greatest number of groundwater bores and extraction volumes in the Surat CMA include the Condamine Alluvium, Main Range and Tertiary Volcanics. Production from the GAB aquifers is mainly from the Hutton-Marburg Sandstone, the WCM, and the Precipice/Helidon Sandstone (DNRM, 2016).

Table 2-3. Non-petroleum and gas groundwater extraction in the Surat CMA

Formation	Number of bores			Estimated groundwater extraction (ML/year)				Total (ML/year)
	Non-S&D	S&D	Total	Agriculture	Industrial	Town water supply	S&D	
Non-GAB upper formations								
Condamine Alluvium	1,144	2,709	3,853	64,251	1,476	4,227	2,070	72,024
Main Range Volcanics & Tertiary Volcanics	1,293	5,924	7,217	39,200	2,659	4,459	4,726	51,044
Other alluvium	322	1,201	1,523	16,130	555	1,311	1,447	19,443
Other units	18	375	393	826	4	11	1041	1882
Sub-total	2,777	10,209	12,986	120,407	4,694	10,008	9,284	**144,393**
GAB formations								
Hutton and Marburg Sandstones	342	2,303	2,645	8,810	777	2,141	3,255	14,983
Walloon Coal Measures	253	1,394	1,647	8,995	370	425	1,628	11,418
Precipice and Helidon Sandstones	29	293	322	1,970	2,092	1,704	672	6,438
Evergreen Formation	45	559	604	1,483	1,874	218	1,287	4,862

Formation	Number of bores			Estimated groundwater extraction (ML/year)				Total (ML/year)
	Non-S&D	S&D	Total	Agriculture	Industrial	Town water supply	S&D	
Gubberamunda Sandstone	62	499	561	1,777	810	585	1,450	4,622
Springbok Sandstone	32	233	265	2,393	742	199	1,003	4,337
Other units	50	2141	2191	1101	2	341	4531	5975
Sub-total	813	7,422	8,235	26,529	6,667	5,613	13,826	**52,635**
Non-GAB (lower) formations*								
Bowen Permian	27	716	743	1,541	67	144	1,229	2,981
Clematis Sandstone	7	145	152	-	-	326	981	1,307
Bandanna Formation	10	93	103	437	59	406	167	1,069
Other units	12	199	211	231	37	0	439	707
Sub-total	56	1153	1209	2209	163	876	2816	**6064**
Total	**3,646**	**18,784**	**22,430**	**149,145**	**11,524**	**16,497**	**25,926**	**203,092**

Source: DNRM (2016)

* Comprises Bowen Basin, Galilee Basin and basement formations underlying the Surat Basin

Petroleum and Gas activity associated groundwater extraction

Petroleum tenure holders are entitled to extract groundwater under the Petroleum and Gas (P&G) Act for the purpose of production. In the Surat Basin, this includes conventional oil and gas production from dominantly sandstone formations, as well as CSG production.

Conventional petroleum and gas within the Surat CMA has historically been from the Precipice Sandstone and Evergreen Formation of the Surat Basin and the Showgrounds Sandstone of the Bowen Basin (DNRM, 2016) but production is presently in decline.

DNRM (2016) reports that approximately 20 conventional petroleum and gas wells remain in operation across the Tinker, Taylor and Waggamba fields operated by AGL, and the Moonie field operated by Santos. In addition, a small amount of water is also reportedly produced from three wells at the Pleasant Hills gas field.

The volume of water production associated with conventional oil and gas operations had declined from 1,800 ML/yr in 2012 to 1,000 ML/yr in late 2014 (DNRM, 2016). This volume comprises less than 2% of the 59,000 ML/year CSG produced water (July 2015 reported data) for the Surat CMA, or less than 0.5% of the 203,000 ML/year landholder extraction.

2.5.5 Groundwater dependent ecosystems

The identification of landscapes that may contain groundwater dependent ecosystems (GDEs) is documented in detail in the SGP EIS/SREIS and the GDE and Aquatic Ecosystem technical memorandum (Appendix D).

The evolution of the identification of GDE landscapes included the following key steps (further detail provided in Appendix D):

1. Assessment during the SREIS that incorporated the available knowledge at that time within an initial search boundary of:

- The Surat CMA for springs (known spring vents and watercourse springs) and nationally important wetlands that may be groundwater dependent. All identified nationally important wetlands within the Surat CMA, and spring vents and watercourse springs within 30 km of the SGP tenements were described in the SREIS. The impact assessment conservatively included groundwater dependent features within a 10 km buffer zone beyond the 0.2 m drawdown contour for the spring source aquifer as being potentially affected by the Action. This was also consistent with the OGIA approach to the assessment of springs in the 2012 Surat CMA UWIR.
- Arrow tenements and general surrounds for potential surface expression of groundwater and terrestrial GDEs mapped by the Bureau of Meteorology (BoM, 2013). Consistent with the approach for springs, the impact assessment process adopted an assessment area that included a 10 km buffer beyond the 0.2 m drawdown contour in the source aquifer (watertable aquifer for terrestrial GDEs).

2. Refinement of understanding of GDEs in identified risk areas, based on the findings of the SREIS. This included further consideration for the presence of confining layers that would act to limit the propagation of drawdown as a result of the Action to watertable aquifers, and improved landscape conceptualisation. In particular, this step considered the presence and absence of the Westbourne Formation in more detail, and incorporating further assessment in to the separation of the subcrop extent from the generalised Kumbarilla Beds.

3. Development and release of the Queensland GDE mapping dataset, which built on the BoM national assessment and included refinement based on regional ecosystem (RE) mapping and establishment of conceptual landscape models in which GDEs may be situated. Extensive industry consultation was also carried out in the development of this mapping product to incorporate detailed local knowledge in to the system conceptualisation process and definition of dependent ecosystems.

4. Completion of other detailed studies following submission of the SREIS, including:

- Detailed Condamine Alluvium predictive modelling. This modelling aimed to provide an improved tool for the prediction of potential impacts to the Condamine River Alluvium as a result of the Action, focussing on the potential impact on groundwater-surface water connectivity. It was developed specifically to address Approval Condition 13 (b).
- Vegetation mapping undertaken to support other approvals, which provided an improved understanding of the presence of potentially groundwater dependent vegetation.
- Ongoing groundwater level and quality monitoring, which supports the assessment of the presence of potential GDE landscapes, and whether they may be at risk of impact as a result of the Action

5. Incorporation of data made available since the completion of the SREIS in to this Stage 1 CSG WMMP, including the Queensland GDE mapping (WetlandInfo, 2015). This assessment reduces the conservatism applied in the SREIS impact assessment to adopt a practical and pragmatic position for the ongoing assessment of potential impacts to GDEs as a result of the Action. The approach is based on:

- The assessment and management of potential impact to springs (including watercourse springs) being administered under the Surat CMA UWIR.
- The identification of potential terrestrial GDE landscapes based on refinement of the assessment approach adopted in the SREIS. This has enabled the current assessment to better reflect credible impacts to terrestrial GDEs (noting some conservatism still remains) within an area constrained to greater than 1 m predicted drawdown in the source (watertable) aquifer for the potential GDE. The basis for adoption of this area of assessment is provided in Section 2.1.2 of the GDE and Aquatic Ecosystem technical memorandum (Appendix D).

Further detail regarding the impact assessment process and findings is presented in Section 3.4 and the GDE and Aquatic Ecosystem technical memorandum (Appendix D).

GDEs relevant to the SGP and this Stage 1 CSG WMMP are defined as:

- **Surface Expression GDEs:** Ecosystems dependent on the surface expression of groundwater (i.e. springs, groundwater-fed wetlands and baseflow contribution to watercourses). These are collectively referred to as spring-GDEs.
- **Terrestrial (vegetation) GDEs**: Ecosystems dependent on the subsurface presence of groundwater (i.e. plants accessing shallow groundwater or the capillary fringe, or deeper rooted vegetation accessing deeper groundwater). This includes riparian vegetation.
- **Aquatic Ecosystems**: Aquatic ecosystems dependent on surface water resources that are maintained by groundwater levels, but not groundwater-fed (i.e. connected but losing streams).

The level of groundwater dependency of the ecosystems is expected to be variable. Ecosystems identified as being dependent, or potentially dependent on groundwater in the vicinity of the SGP area are summarised in Table 2.4 (refer also Figure 2.6 and the GDE and Aquatic Ecosystem technical memorandum (Appendix D)).

Lake Broadwater and Long Swamp are subject to ongoing investigations regarding potential groundwater dependence. These surface water features are not currently considered to be groundwater dependent, consistent with these landscapes not being identified as potentially groundwater dependent in the Queensland Department of Science, Information, Technology and Innovation (DSITI) GDE mapping (WetlandInfo, 2015), therefore not included in Table 2.4. However as required by Approval Condition 13(f), they are considered further in ongoing assessment. Should they be identified as having reliance on groundwater based on the ongoing investigations, they will be included in future iterations of this plan for assessment of potential impact as a result of the Action.

Further discussion on aquatic and subterranean ecosystems is provided in Section 2.6.

EPBC springs within the Surat CMA are locations where a community of native species is dependent on natural discharge of groundwater from the Great Artesian Basin, or listed threatened species are reliant on springs (Section 8.2.3 of the Supplementary Report to the Surat Gas Project EIS [Arrow Energy, 2013]). There are currently no EPBC springs located within Arrow tenure and there are currently no off-tenure EPBC springs allocated to Arrow for monitoring and management in accordance with the JIP. Further information is provided in Section 5.4.

The JIP provides reference to OGIA’s Spring Impact Management Strategy (SIMS) in the Surat CMA UWIR which provides an assessment of potential impacts to springs. Arrow has no assigned responsibilities regarding potentially affected springs under the SIMS. The SIMS is considered to adequately address the potential impact to springs and no further assessment has been undertaken in this plan. In addition, no springs within Arrow tenure other than those identified and considered in the Surat CMA UWIR are known to be present.

Table 2-4 Known and potential GDEs within and in the vicinity of the SGP area

Feature type	**Description**	Known or potential GDE	**Within or outside of SGP tenure**
Terrestrial GDE	Potential terrestrial GDE landscapes (WetlandInfo, 2015) with an assigned groundwater dependence potential of either high or moderate	Potential	Within and in the vicinity of SGP tenure
	Riparian environments along the Condamine River, Wilkie Creek, Wambo Creek, Kogan Creek, Braemar Creek and Dogwood Creek	Potential	Within and in the vicinity of SGP tenure
Spring vent complex	Tribelco (Orana) (complex 765)	Known	Western boundary of SGP tenure
	Bowenville (complex 585)	Known	Outside
	Wambo (complex 584)	Known	Outside
	601 (Main Range Volcanics 3 and 4 (complexes 601 and 602 respectively))	Known	Outside
Watercourse	UWIR Sites:	Known	Outside

Feature type	**Description**	Known or potential GDE	**Within or outside of SGP tenure**
spring	• W14 and W15 (Hutton Sandstone source aquifer) • W77 and W78 (Mooga/Gubberamunda Sandstone source aquifer) • W100 (Quaternary sediments source aquifer) • W160 (Kumbarilla Beds source aquifer)		
	Reaches of: • Roche Creek, north-east of Wandoan • Juandah Creek south of Wandoan • The Condamine River south of Chinchilla • Tributary of Wyaga Creek in upland areas (southern extent of SGP area)	Potential	Within and in the vicinity of SGP tenure

ARROW ENERGY - SURAT GAS PROJECT

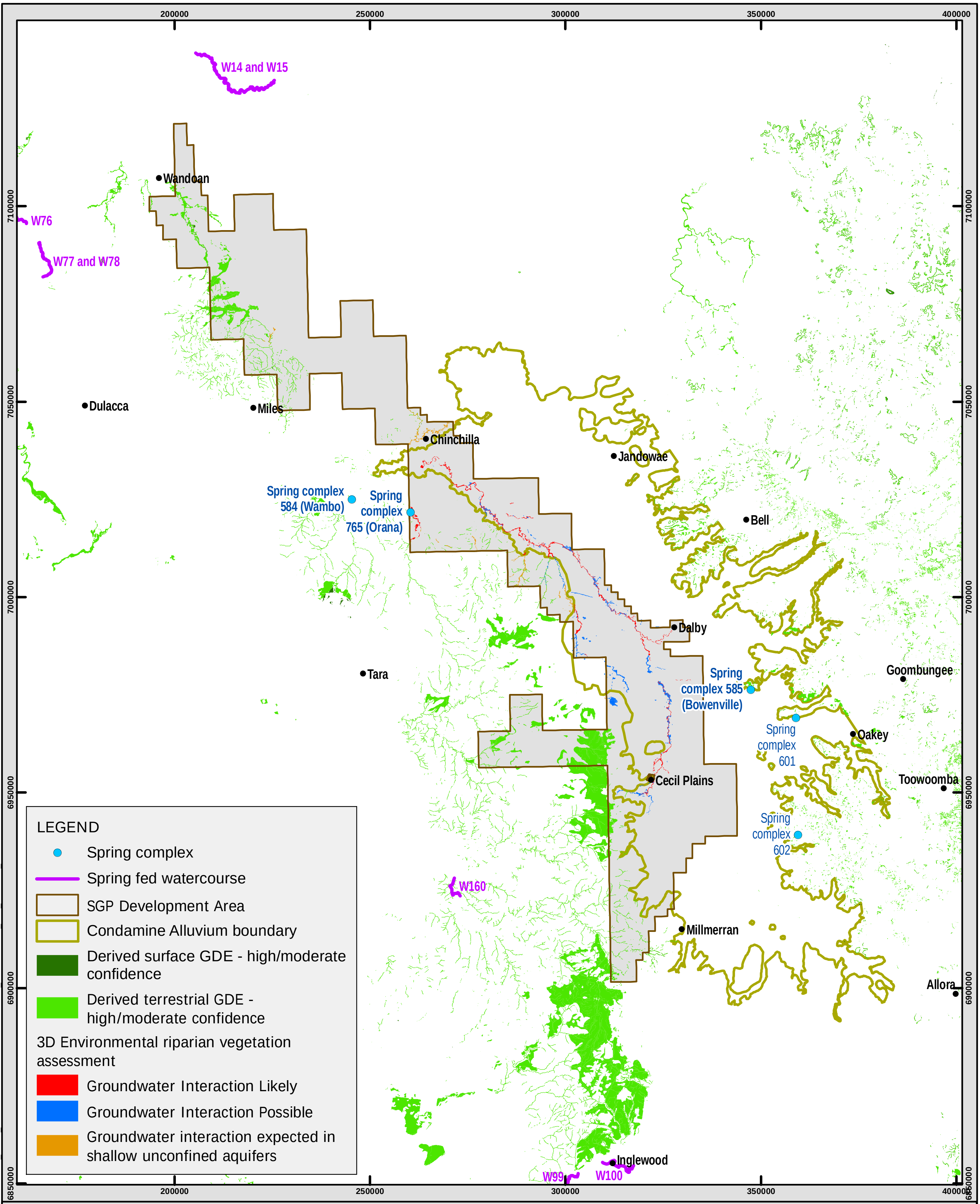

Figure 2.6

Known and potential GDEs

Source:
Arrow Energy Pty Ltd
3D Environmental.
DSITI (WetlandInfo, 2015).

Date: 17/07/2017
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,250,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

N

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2.6 Aquatic ecology and ecosystems

Environmental conditions with regards to aquatic ecology and aquatic ecosystems across the SGP area have been assessed as generally being highly disturbed. A summary of the nature and distribution of aquatic ecosystems is presented in the following sections, with further detail provided in the GDE and Aquatic Ecosystem technical memorandum (Appendix D) and the SGP EIS/SREIS.

2.6.1 Riverine ecosystems

Permanent, semi-permanent and ephemeral watercourses are present within the SGP area. Detailed field studies were carried out as part of the SGP EIS/SREIS which found:

- No macroinvertebrates of conservation significance, and the identified macroinvertebrates were characteristic of watercourses under altered conditions.
- Twenty species of native macrophytes across the broader study area.
- Watercourses had generally uniform macrophyte communities of emergent and floating growth forms.
- Fifteen of 20 known Condamine-Balonne native fish species were found including the EPBC Act-listed species Murray Cod (*Maccullochella peelii peelii*), and the Aquatic Conservation Assessment (ACA) listed Eel-tailed Catfish (*Tandanus tandanus*).
- Two turtle species, the Murray River Turtle (*Emydura macquarii macquarii*) and the Broad-shelled Turtle (*Chelodina expansa*) were found to be widespread throughout the study area.
- Aquatic ecosystems were generally in moderately good ‘health’.
- The permanent/semi-permanent watercourses, including the Condamine River, Wilkie Creek and Oakey Creek contain water all year round but in many cases reduce to isolated pools during the dry season. The disturbance level ranged from minimal to high and the ecosystems are unique on a local scale with regards to biota, communities and processes.
- The ephemeral watercourses comprise unnamed 1st or 2nd order systems that flow for a very limited period of the year, and range from moderately to highly disturbed. These watercourses provide marginal aquatic habitat with a lack of connectivity to larger, permanent waterways, and minimal nursery habitat. They are not unique on a local scale and are likely to be used by aquatic flora and fauna tolerant of significant disturbance that adapt to rapidly colonise and regenerate when conditions are suitable.

Riverine ecosystems with a known or potential dependence on groundwater are summarised in Table 2.4 (refer Watercourse Springs listings). Watercourse Spring GDEs are defined in the Surat CMA UWIR (DNRM, 2016) as a section of a watercourse where groundwater enters the stream from a GAB aquifer through the streambed. OGIA list the known Watercourse Springs in the UWIR, and assign responsible tenure holder to potentially impacted stream reaches, as set out in the Springs Impact Management Strategy (DNRM, 2016).

2.6.2 Non-riverine ecosystems

Lake Broadwater and Long Swamp are the major non-riverine ecosystems in the SGP area. In addition to the descriptions provided in Section 2.3.2, ecologically:

- Lake Broadwater's wetland is diverse in terms of physical characteristics, functions, species, and habitat types. These vary temporally (with the wetting and drying cycle) and spatially.
- Long Swamp has a 'medium' to 'high' local conservation status due to the range of riparian vegetation along the length of the wetland as well as the species diversity and richness.

The potential groundwater dependence of these ecosystems is the subject of ongoing investigations. For the purpose of this Stage 1 CSG WMMP it has been assumed they may have some reliance on groundwater resources. Further detail is provided in Section 3.4.3 and Appendix D.

2.6.3 Subterranean ecosystems

The DSITI have completed sampling in the Condamine Alluvium, and confirmed the presence of a variety of stygofauna, and results of stygofauna sampling in the nearby border rivers region indicated the widespread presence of stygofauna in groundwater (C. Schulz, DSITI, pers. Comm. - cited in CDM Smith 2016; Schulz et al. - cited in CDM Smith 2016).

3. PREDICTED IMPACTS

The Stage 1 CSG WMMP sets a framework for monitoring and managing impacts due to the extraction of water associated with CSG production. Reliable modelling and analysis to predict impacts to hydrological systems underpins the assessment of impacts carried out as part of the SGP EIS/SREIS and confirmed during WMMP development.

A significant body of modelling relating to the SGP has been undertaken, forming the basis for predicting impacts to groundwater and surface water as a result of the Action. A detailed analysis of the modelling is provided in the Groundwater Modelling technical memorandum (Appendix E), including the basis for selection of modelling outputs that underpin impact prediction for the Stage 1 CSG WMMP, as summarized in the following sections.

3.1 Groundwater and surface water modelling

The models used for providing predictions of impact to support the Stage 1 CSG WMMP are:

1. The SREIS Groundwater Model (GHD, 2013) based on the OGIA 2012 Groundwater Model (QWC, 2012).
2. The Condamine Alluvium Model (CDM Smith, 2016) based on the Central Condamine Alluvium Model (KCB, 2012).
3. The Upper and Middle Condamine River Integrated Quantity and Quality Model (CDM Smith, 2016).

3.1.1 Arrow SREIS Groundwater Model

The SREIS Groundwater Model was based on the field development plan presented in the SREIS.

Model predictions comprised a calibrated case, as well as parameterised ‘Monte Carlo’ type uncertainty analysis simulations, including high (P5), median (P50) and low (P95) cases. These involved generation of 200 model predictions (based on statistically generated parameter sets).

Predictions for the ‘Arrow only’ impact assessment were based on the calibrated model case, because this case (by its nature) reflects the best estimate of the ‘real world’ parameter distribution in the SGP area, whereas the model cases for the uncertainty simulations, being based on statistically generated parameter sets (and not constrained by calibration data) cannot always be assumed to represent parameter selections that are plausible representations of field conditions.

Predictions for the ‘cumulative’ impact assessment, are based on both the calibrated case, and on the uncertainty simulations. This is because the model output requirements for the cumulative assessment included specific plots of drawdown for the indicative range from P5 to P95. In those cases, the P50 (median) case was adopted as representative of typical conditions, and where referred to can be considered an approximate analogue to the calibrated case.

The Central Condamine Alluvium Model (CCAM) was used in tandem with the SREIS Groundwater Model to enable predictions of CSG impact (drawdown) in the Condamine Alluvium. This was achieved by removing water volumes equivalent to the predicted changes in vertical groundwater flux between the Surat Basin consolidated aquifers and the Condamine Alluvium from the SREIS Groundwater Model run.

3.1.2 Condamine Alluvium Model

The Condamine Alluvium Model is a numerical model based on the CCAM to enable predictions of drawdown and flux in the Condamine Alluvium due to CSG production. The predictions from this model were then used as inputs to the Condamine River Integrated Quantity and Quality Model (IQQM).

3.1.3 Condamine River Integrated Quantity and Quality Model

IQQM is a hydrological modelling tool used for planning and evaluating water resources, developed by the NSW Department of Primary Industries. It has been implemented in several regulated river systems in Australia for water resource management planning, including by DNRM for the Condamine-Balonne river system.

IQQM models for the SGP area (encompassing the extent of the Condamine Alluvium groundwater model) are:

- Upper Condamine model: from Killarney Weir to Cecil Plains Weir gauge on the Condamine River, and to the Lone Pine gauge on the North Condamine River.
- Middle Condamine model: from Cecil Plains Weir and Lone Pine gauges to Beardmore dam headwater gauge.

Groundwater interaction with the Condamine River is not explicitly simulated in the IQQM, however stream transmission losses were estimated and included in IQQM modelling for the CSG WMMP (refer Appendix F – the Section 13(b) technical report, for further detail).

3.2 Modelled groundwater impacts

Predictions of potential groundwater impacts resulting from the Action were made using a combination of existing groundwater models in preparation of the SREIS Groundwater Model for both the Arrow only case and for the cumulative case (all CSG developers in the Surat Basin).

3.2.1 Arrow Only Case

Predicted water extraction for the Arrow SGP indicated a total production of 510 GL over the projected 40 year operational life, with a peak extraction of around 34 GL/yr approximately 7 years after commencement (refer Attachment 1 of Appendix G).

Consolidated aquifer drawdown

Maximum predicted drawdown under Arrow’s SREIS FDP (based on the calibrated realisation[11] of the SREIS Groundwater Model) in the main consolidated aquifers in the Surat CMA are presented in Figures 3.1 and 3.2 for times that correspond with peak predicted drawdown at different locations across the project area[12].

Peak drawdown in the Springbok Sandstone (based on the calibrated realisation of the SREIS Groundwater Model) is up to 10 m and typically occurs at around 20 years after peak drawdown in the WCM. Peak impact in the Hutton Sandstone is approximately 8 m and typically occurs at around 75 years after peak drawdown in the WCM. Drawdown impacts to the deeper Precipice Sandstone are less than 0.7 m, of limited extent, and off Arrow tenure.

Condamine Alluvium flux changes and aquifer drawdown

Interlayer flux into the Condamine Alluvium (under non-CSG development conditions) comprises upward flow from the WCM. Coal seam water production will cause a reduction in the existing upward flux, which will remain predominantly upward from the WCM to the Condamine Alluvium, with only minor exception. A reduced flux may lead to drawdown in the Condamine Alluvium. Predicted flux changes to the alluvium (presented in the SGP SREIS) indicate relatively minor impacts (reduced flux) peaking at between 1.25 and 2.8 ML/d.

A maximum Arrow-related drawdown in the Condamine Alluvium aquifer (based on the calibrated realisation of the SREIS Groundwater Model) of up to 0.5 m was predicted to occur in central parts of this aquifer. However, this maximum drawdown is only evident in a small proportion (<10%) of the Condamine Alluvium, and drawdown was typically less than 0.18 m across the remainder of the alluvium.

Table 3.1 provides a summary of the predicted drawdown impacts in the key aquifers for the Arrow only SREIS FDP scenario.

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[11] Refer Appendix E for more information on model predictive realisations and calibration. Refer to Section 8.4.3 of the SREIS for explanation of drawdown times selected, which correspond with peak predicted drawdown at different locations across the project area.

[12] Refer to Section 8.4.3 of the SREIS for explanation of drawdown times selected.

Table 3-1. SREIS Predicted Arrow only groundwater drawdown[13]

Aquifer	Average drawdown (m)	Maximum drawdown (m)	Year of maximum drawdown
Condamine Alluvium	<0.18	0.5	2100
Springbok Sandstone	<2	10	2045
Walloon Coal Measures	<50	350	2025
Hutton Sandstone	<5	8	2100
Precipice Sandstone	-	0.7	2105

3.2.2 Cumulative Case

Total modelled water extraction[14] from current and proposed CSG projects to be operated by Arrow, Santos, QGC and Origin within the Surat CMA indicated a peak extraction of around 550 ML/d in 2015.

However actual water production reported by OGIA in the 2016 UWIR for July 2015 was 162 ML/d (59,000 ML/year). The difference can most likely be attributed to changes in field development plans, and delayed implementation timeframes.

Consolidated aquifer drawdown

The maximum cumulative predicted drawdown (calibrated model case) in the main consolidated aquifers in the Surat CMA (Springbok Sandstone, Walloon Coal Measures and Hutton Sandstone) as a consequence of cumulative impacts of CSG projects are shown in Figures 3.3 and 3.4 for the same times as shown in Figures 3.1 and 3.2.

Based on modelling for the 50th percentile cumulative case (GHD 2013) the maximum impact drawdown for the Springbok Sandstone and Hutton Sandstone is 15 m, and for the Precipice Sandstone is <5 m (and of limited areal extent).

Condamine Alluvium flux changes and aquifer drawdown

Cumulative predicted flux changes to the Condamine Alluvium (based on the SREIS FDP) indicated relatively minor impacts peaking at between 1.8 and 3.8 ML/d, compared with the Arrow only case peaking between 1.25 and 2.8 ML/d.

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[13] Condamine Alluvium drawdown predicted in the SREIS was only simulated to the year 2100.

[14] Provided at the time of the SREIS

For the modelled period (up to 100 years from commencement) the flux change to the Condamine Alluvium due to cumulative water extraction was 79 GL for the calibrated model realisation, and 90 GL for the 95th percentile model realisation.

For the same period, the maximum predicted cumulative impact in the Condamine Alluvium results in a drawdown of up to 0.9 m near Dalby. Drawdown of less than 0.24 m is typical across the remainder of the Condamine Alluvium.

3.2.3 Ongoing investigation of Condamine Alluvium flux changes

As noted in Section 3.1.1, modelling for the Stage 1 CSG WMMP is based upon the SREIS Groundwater Model (GHD, 2013) which is in turn derived from the OGIA 2012 Groundwater Model (QWC, 2012).

As discussed in Appendix E, it is noted that even though predicted water extraction volumes were lower for the OGIA 2016 modelling results, the predicted flux into the Condamine Alluvium from the WCM increased slightly, requiring further evaluation. Arrow are committed to working with the OGIA to further investigate the changes in flux and presenting the findings of this evaluation in the Stage 2 CSG WMMP. This will consider the underlying hydrogeological conceptualisation of connectivity between the WCM and Condamine Alluvium. The investigation will also include an assessment of implications of this change in flux on the Condamine Alluvium and Condamine River and consideration of appropriate management, monitoring and mitigations (if required).

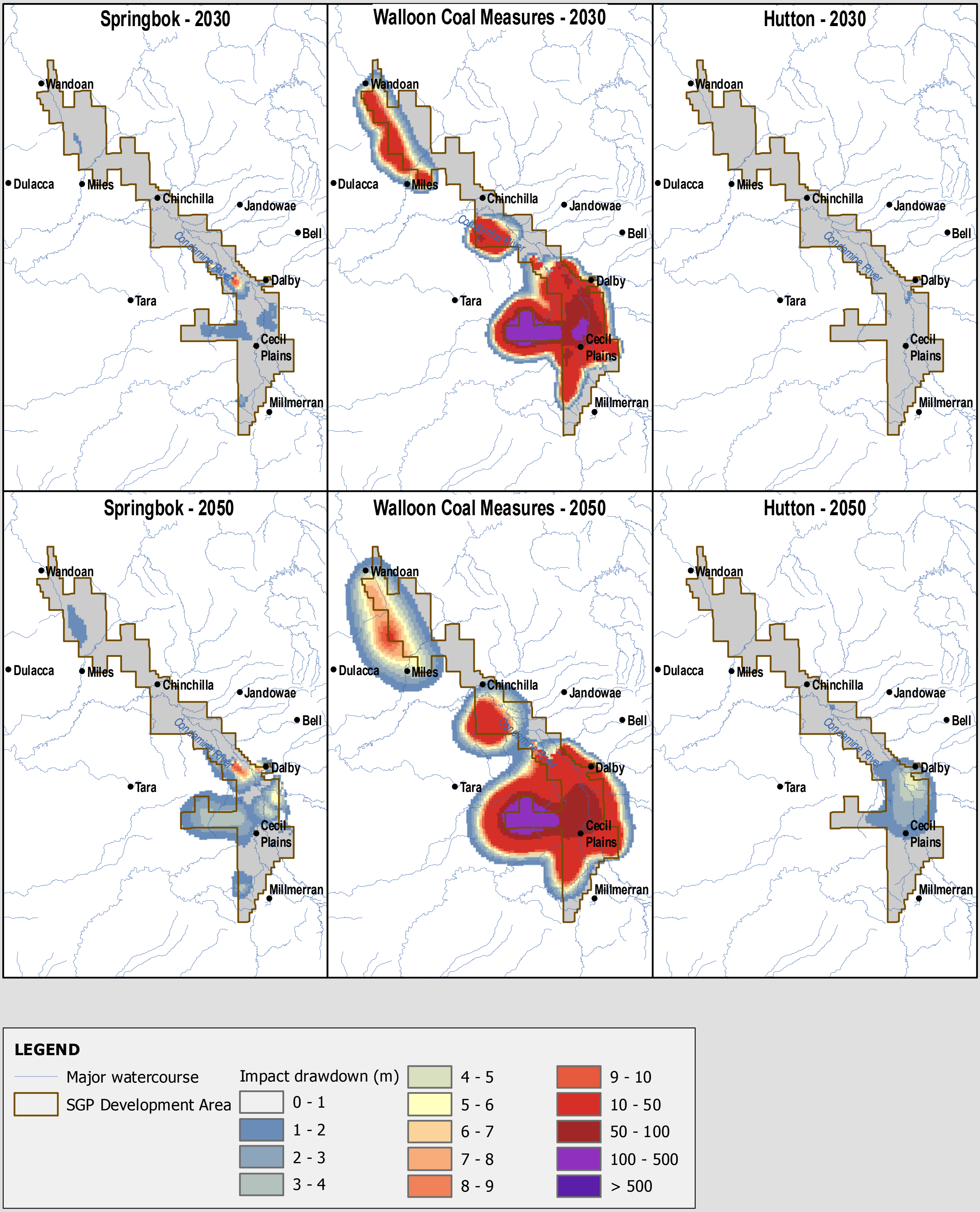

Figure 3.1 Calibrated Case - Arrow only drawdown at years 2030 and 2050

Source:
Arrow Energy Pty Ltd
GHD

Date: 13/07/2017
Issued To: Arrow Energy
Author: grant.young

0 15 30 60 90 120 150 180
Kilometres
Scale: 1:3,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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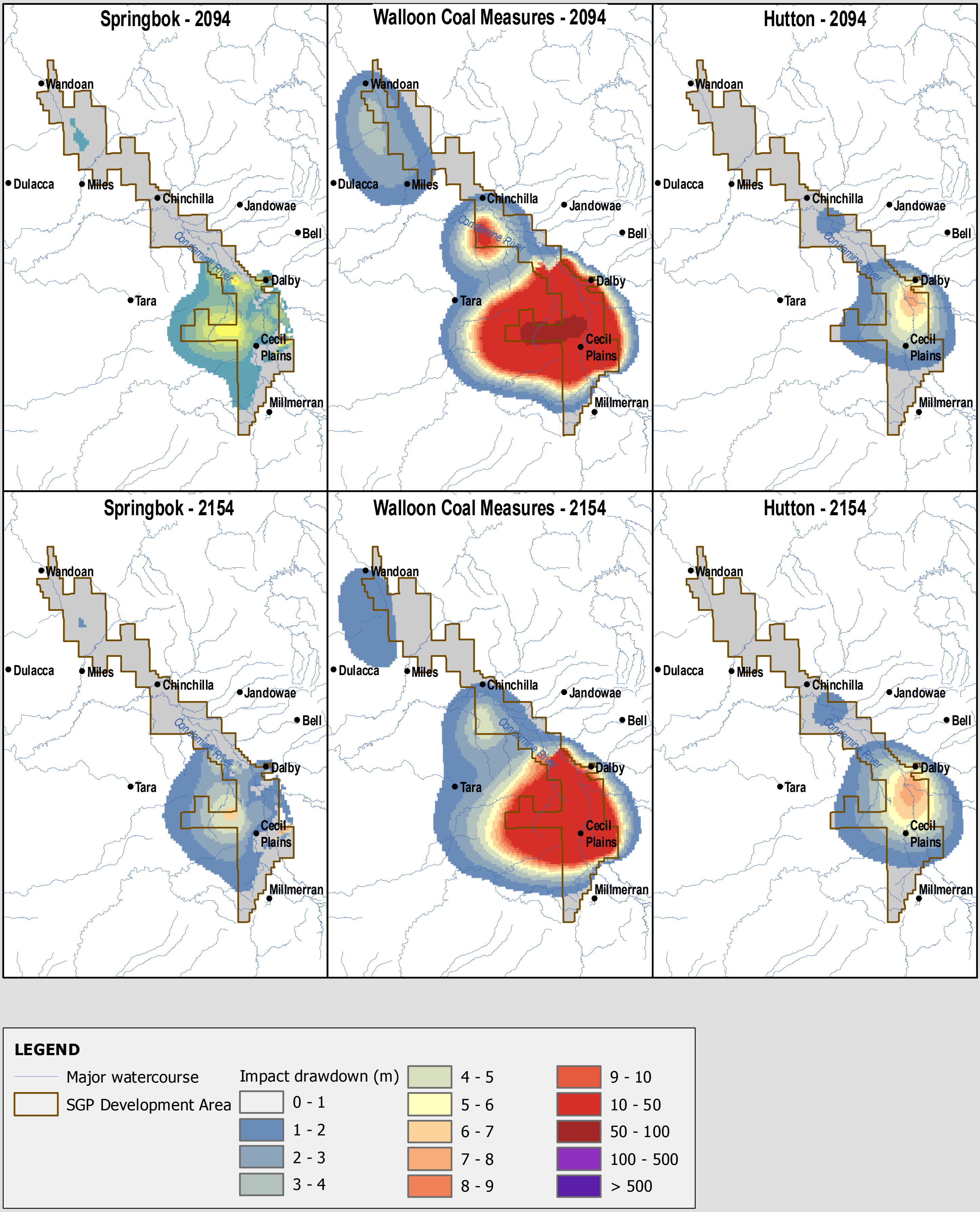

Figure 3.2 Calibrated case - Arrow only drawdown at years 2094 and 2154

Source:
Arrow Energy Pty Ltd
GHD

Date: 13/07/2017
Issued To: Arrow Energy
Author: grant.young

0 15 30 60 90 120 150 180
Kilometres
Scale: 1:3,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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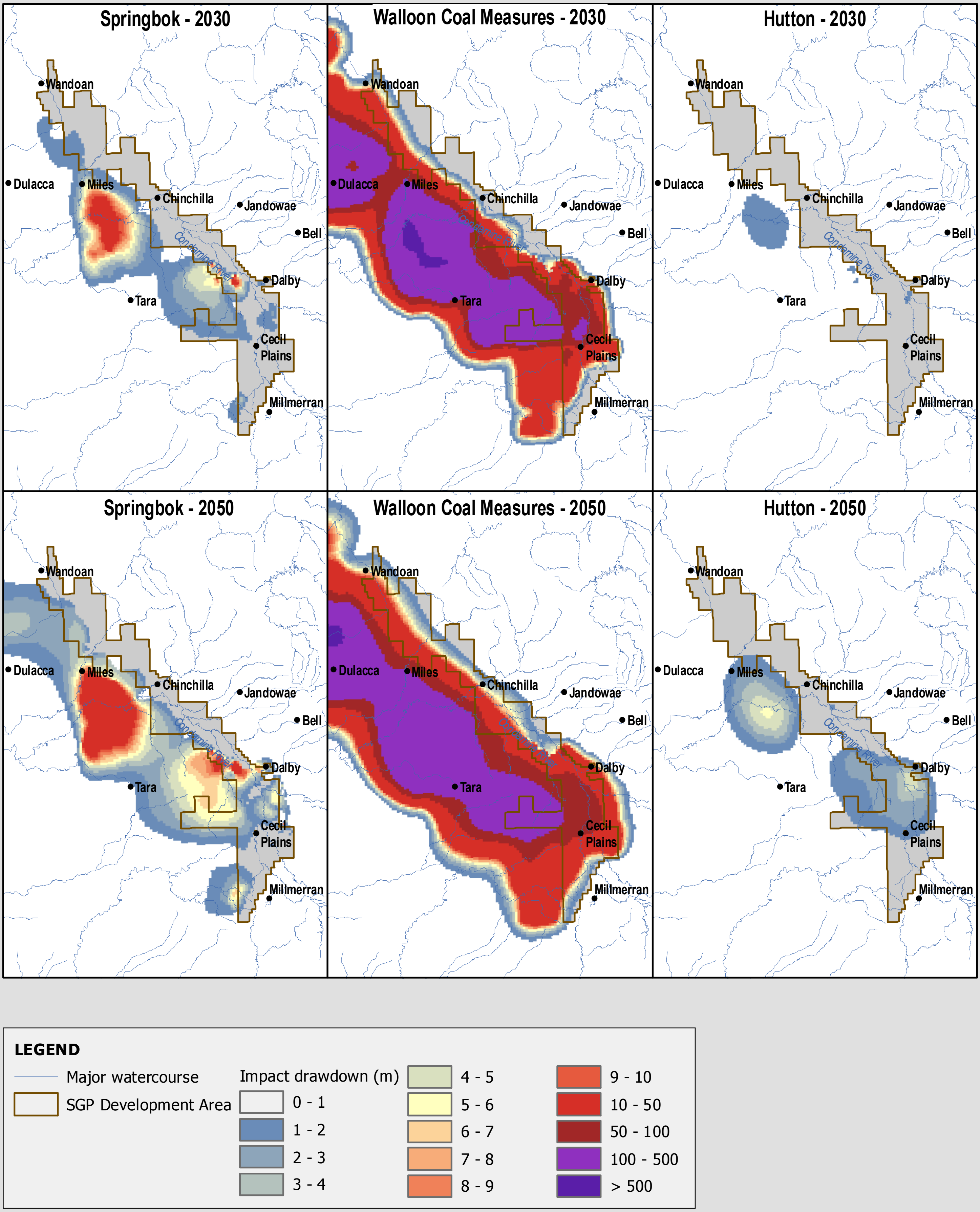

Figure 3.3 Calibrated case - cumulative drawdown at years 2030 and 2050

Source:
Arrow Energy Pty Ltd
GHD

Date: 13/07/2017
Issued To: Arrow Energy
Author: grant.young

0 15 30 60 90 120 150 180
Kilometres
Scale: 1:3,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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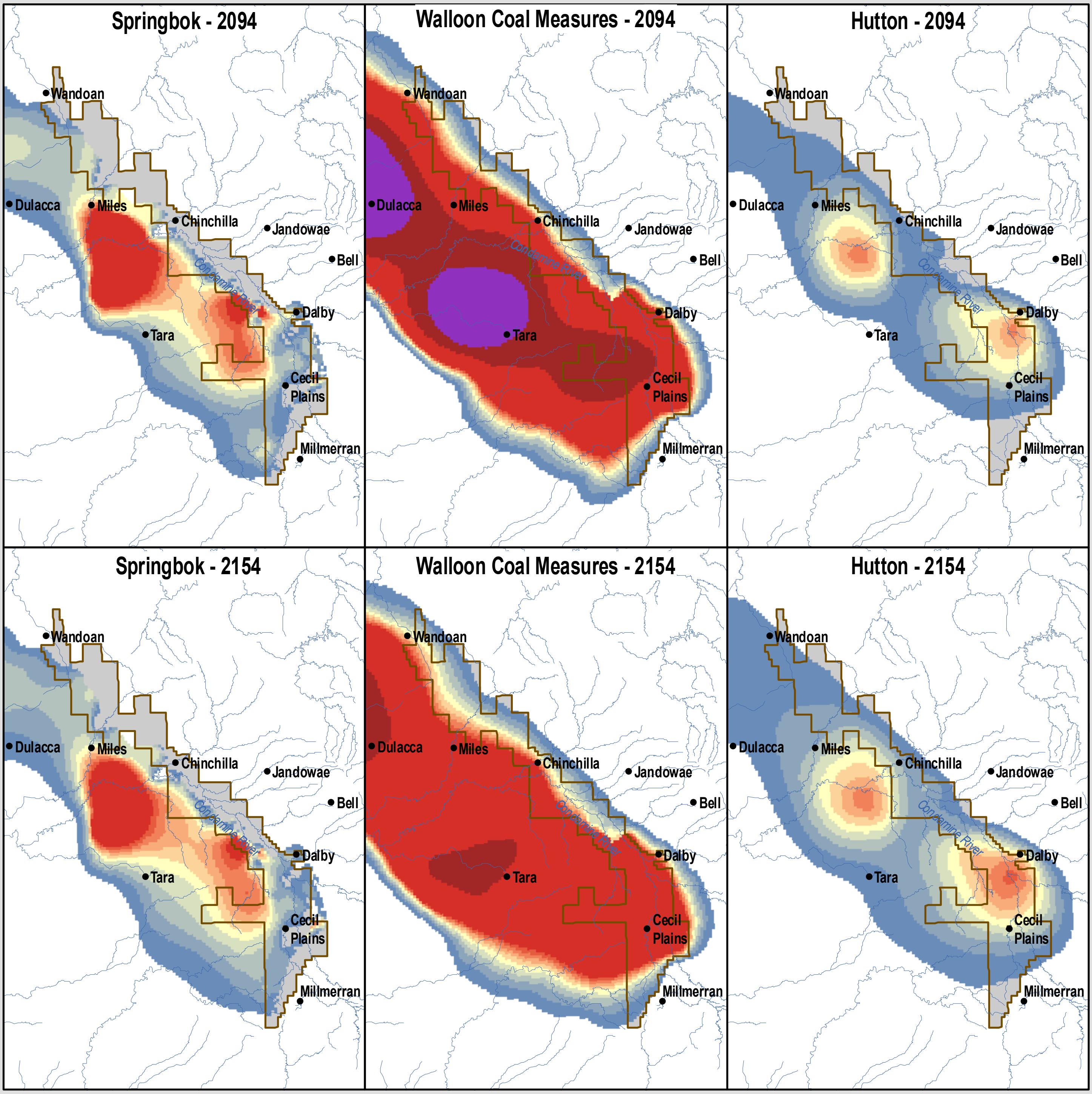

LEGEND

Major watercourse	Impact drawdown (m)		4 - 5		9 - 10
SGP Development Area		0 - 1	5 - 6		10 - 50
		1 - 2	6 - 7		50 - 100
		2 - 3	7 - 8		100 - 500
		3 - 4	8 - 9		> 500

Figure 3.4 Calibrated case - cumulative drawdown at years 2094 and 2154

Source:
Arrow Energy Pty Ltd
GHD

Date: 13/07/2017
Issued To: Arrow Energy
Author: grant.young

0 15 30 60 90 120 150 180
Kilometres
Scale: 1:3,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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arrow energy
go further

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3.3 Modelled surface water impacts

3.3.1 Simulation of Condamine River impacts

Modelling was undertaken to quantify the impact that flux changes to the Condamine Alluvium aquifer may have on surface water resources including flow in the Condamine River. The modelling completed is set out in detail in Appendix E (Groundwater Modelling technical memorandum) and Appendix F (Section 13(b) technical report). Three existing models were used to address condition 13(b):

1. The OGIA 2012 Groundwater Model which predicted the flux impact to the Condamine Alluvium (CA), at the interface of the Walloon Coal Measures (WCM) and the CA.
2. The DNRM Central CA Model (CCAM) which used the outputs of the 2012 OGIA model to predict:
    a. Drawdown at the watertable in the CA, and
    b. Flux impact to the Condamine River.
3. The DNRM IQQM model which used the flux out of the Condamine River (estimated by the DNRM CCAM model) to predict impacts to water resources.

The impacts to the Condamine Alluvium described above in terms of flux rates and drawdowns can also be described in terms of volumetric changes. Table 3.2 presents the changes in net volumetric and vertical flux to the Condamine Alluvium from the Walloon Coal Measures due to the Action, over a 3,000-year simulation period.

Table 3-2. Condamine Alluvium volumetric and flux changes (CCAM area)

	Volumetric change (GL)[1]		**Max flux change (ML/d)[2]**	
	Range[3]	Median	Range	Median
All CSG operators	384 - 508	445	1.64 – 2.99	2.11
Arrow contribution	216 - 292	256	NC	NC

1: Reduction in flow volume over 3,000 year simulation period, between the Walloon Coal Measures and the Condamine Alluvium.
2: Reduction of flow rate between the Walloon Coal Measures and the Condamine Alluvium.
3: Range based on 90% of realisations.
NC – Not computed separately – refer Appendix F.

Predicted impacts to Condamine River

The maximum rate of Arrow water production used in the Surat CMA Groundwater Model, under the SREIS FDP, for the high, median and low case realisations[15] occurs around the same time (between year 2023 and 2024). However depressurisation in the WCM takes time to propagate through to the base of the alluvium, and the simulated maximum change in net vertical flux at the base of the alluvium (i.e. a reduction in flow to the alluvium) occurs 29 to 45 years after the maximum Arrow water production (depending on the realisation).

Similarly there is a lag for flux to migrate through the alluvium to impact the Condamine River. The translation of flux impacts from the CCAM to the IQQM model simulated the impacts to the Condamine River. The modelled realisations are summarised in Table 3.3 to indicate changes in Condamine River flow components that could arise due to the predicted flux changes.

These show that the predicted maximum change in total groundwater flux to the Condamine River due to Arrow water production is 0.12 ML/d, 0.13 ML/d and 0.09 ML/d for the high, median and low drawdown case realisations respectively. Figures 10 and 11 in Appendix E (Groundwater Modelling technical memorandum) present the predicted spatial distribution of flux changes for the high and median cases, and Figure 12 and 13 in Appendix E present the predicted spatial distribution of flux changes for all realisations.

Table 3-3. Predicted changes to Condamine Alluvium flux due to Arrow production

Prediction	High case		Median case		Low case	
	ML/d	Year	ML/d	Year	ML/d	Year
Maximum Arrow water production rate	138	2023	128	2023	123	2024
Maximum reduction in groundwater flux to Condamine Alluvium	2.11	2054	2.67	2052	1.34	2069
Maximum reduction in net groundwater flux to Condamine River	0.12	2146	0.13	2146	0.09	2137

More than 75% of the cells representing the Condamine River in the CCAM experience no discernible change in flux over the simulation period as the watertable is already below the river base and hence they are ‘disconnected’ from groundwater. Therefore the rates of leakage from these river cells are constant and independent of watertable changes. Most of the predicted impact to the Condamine River due to Arrow CSG production occurs in river cells located downstream of Warra Town Weir with maximum changes in groundwater flux of between 0.001 ML/d and 0.004 ML/d. Impacts of less than 0.001 ML/d are also predicted just upstream of Talgai Weir, Yarramalong Weir, Cecil Plains Weir and

---

[15] Refer Appendix E for more detail on uncertainty analysis. Cases defined as high, median and low based on 5%, 50% and 95% probability of exceedance in 200 realisations.

Chinchilla Weir. The predicted impacts are of very small magnitude and considered to have negligible impact.

The Middle Condamine IQQM Resource Operation Plan (ROP) model was used to evaluate the effects on river flows resulting from the modelled flux changes. Environmental Flow Objective (EFO) performance indicators were then reviewed at three reporting nodes downstream of the river reach where the simulated loss to groundwater occurs.

The results, when compared to the base case ROP scenario, show that performance indicators are achieved for all three cases and the predicted maximum impact is negligible (refer Appendix E).

3.4 Impacts to groundwater dependent ecosystems

Assessment of potential impacts to GDEs as a result of the Action carried out as part of the EIS/SREIS has been updated to inform the Stage 1 CSG WMMP and address approval conditions 13c and 13p (Appendix D – GDE and Aquatic Ecosystem technical memorandum).

Further to Section 2.5.5, consistent with the approach adopted in the SREIS, following GDE landscape identification predictive modelling was used to define areas of groundwater drawdown. Where drawdown in the GDE source aquifer was predicted, further characterisation and assessment of the GDE landscape and nature of the drawdown impact was undertaken. This included consideration of:

- Direct observation during site visits to confirm the presence or otherwise of groundwater dependent vegetation.
- Site conceptualisation, including stratigraphy, depth to groundwater (including historical variability), characteristics of vegetation present and position in landscape.
- Ecosystem resilience and adaptability.
- Predicted rate of change of groundwater level due to the Action, and comparison to historical fluctuations (natural variability as well as non-Arrow abstractive influences).

This information was used to assess the likelihood of the ecosystem being groundwater dependent, as well as the likelihood of adverse impact arising due to the Action.

Further detail on the assessment process including the study area and identification process is provided in Appendix D – GDE and Aquatic Ecosystem technical memorandum.

3.4.1 Spring GDEs

The assessment of potential impacts to springs (Surface GDEs) is a function of the OGIA, and reported under the Spring Impact Management Strategy (SIMS) in the Surat CMA UWIR. Arrow has no assigned responsibilities regarding potentially affected springs under the SIMS. The SIMS is considered to adequately address the potential impact to springs and no further assessment has been undertaken in this plan. In addition, no springs within Arrow tenure other than those identified and considered in the Surat CMA UWIR are known to be present. Arrow will comply with the UWIR obligations for water course springs along the Condamine River.

There are currently no EPBC springs located within Arrow tenure and all off tenure EPBC springs are located closer to other CSG proponents who are the responsible tenure holders under the JIP (DotEE, 2013). In accordance with the JIP, Arrow does not currently have any monitoring obligations under the JIP. Further information is provided in Section 5.4.

In addition, Arrow has no assigned responsibilities regarding potentially affected springs under the OGIA's SIMS. The SIMS is considered to adequately address the potential impact to springs and no further assessment has been undertaken in this plan. In addition, no springs within Arrow tenure other than those identified and considered in the Surat CMA UWIR are known to be present. Further information is provided in Section 5.4.

3.4.2 Terrestrial vegetation GDEs

The GDE and Aquatic Ecosystem technical memorandum (Appendix D) presents a detailed assessment of predicted impacts to potential terrestrial GDEs as a result of the Action to address approval condition 13c. The assessment identified that (refer also Figure 3.5):

- Ecosystems to the south-west of Cecil Plains along the western slopes of the Kumbarilla Ridge (southern part of Risk Area 3b) may be dependent on groundwater in the Springbok Sandstone and may be impacted by project-related groundwater drawdown.
- Ecosystems in the northern parts of Risk Area 4 near Wandoan may be dependent on shallow groundwater in the WCM and may be impacted by project-related groundwater drawdown.
- Ecosystems in Cumulative Risk Area 6 (south of Risk Area 3b) may be dependent on groundwater in the Springbok Sandstone and may be impacted by project-related groundwater drawdown.

The actual dependence of these ecosystems on groundwater is the subject of ongoing investigation (described in Appendix D), the findings of which will be incorporated in to the Stage 2 CSG WMMP.

This assessment of potential impacts to terrestrial GDEs will be reviewed, and if necessary, revised, during development of the Stage 2 CSG WMMP to take in to consideration:

- New information such as industry project mapping, updated fault data and GDE field investigations.
- Include further consideration for and discussion around the presence and influence of the Westbourne Formation based on available information.
- Revised conceptual understanding on groundwater-surface water connectivity based on the results of the GDE field studies being completed Long Swamp and Lake Broadwater.

ARROW ENERGY - SURAT GAS PROJECT

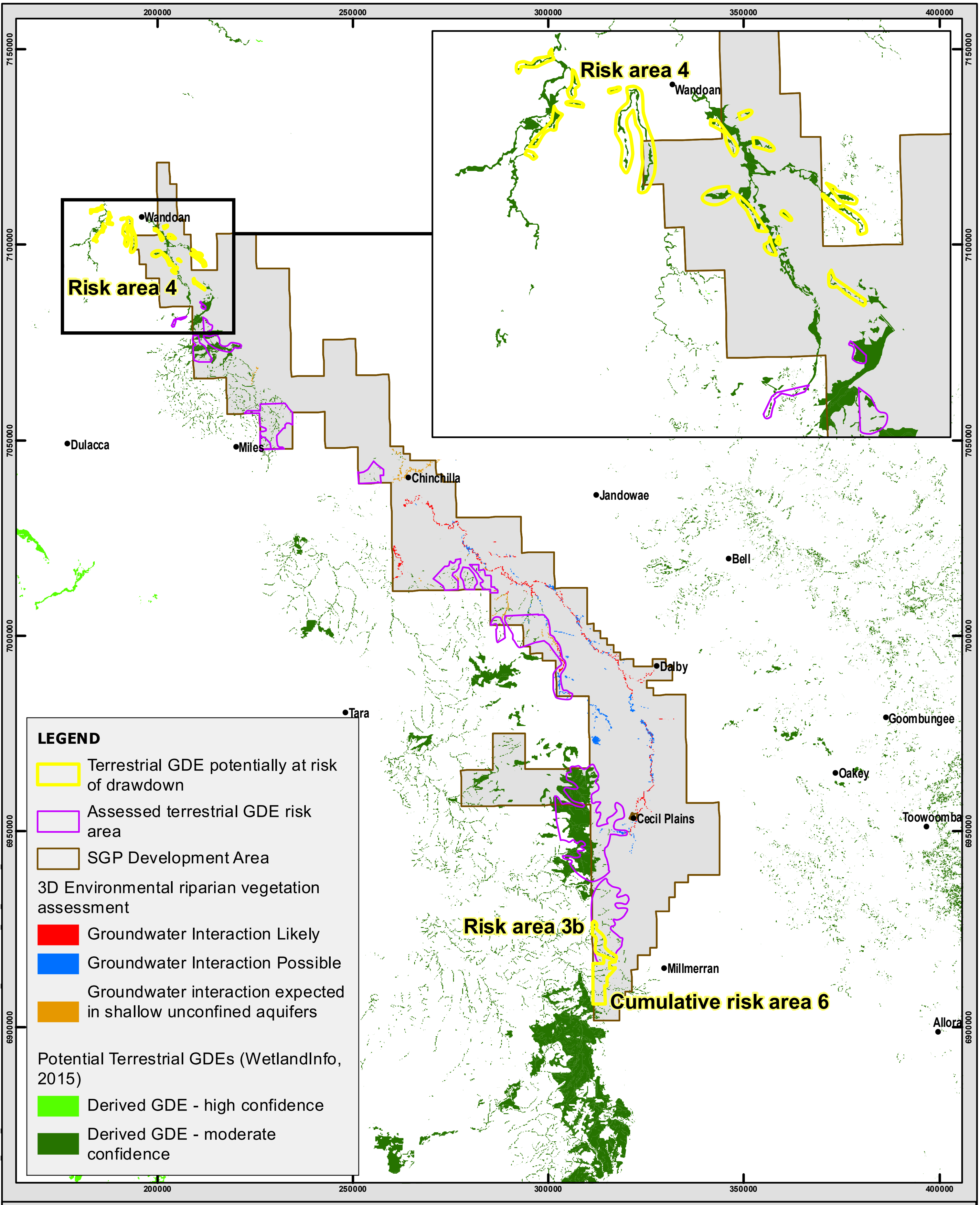

Figure 3.5 **Potentially impacted GDEs**

Source:
Arrow Energy Pty Ltd

Date: 14/07/2017
Issued To: Arrow Energy
Author: grant.young

0 5 10 20 30 40 50 60
Kilometres
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3.4.3 Long Swamp and Lake Broadwater

Lake Broadwater is situated on Westbourne Formation colluvium overlying Westbourne Formation regolith. The weathered profile of the formation is expected to be lateritised in places, and the lake is described (3D Environmental, 2017) as being a perched depositional feature on a claypan, with potential for a deep wetting profile below the regolith.

Long Swamp is described as being situated on a thick layer of clay to loamy clay.

The groundwater connectivity and dependence of these surface water features is not yet fully established. As presented in the GDE and Aquatic Ecosystem technical memorandum (Appendix D), these features are not predicted to be impacted by the Action. Nevertheless, in accordance with approval condition 13(f) further assessment will be carried out.

Shallow geological and hydrogeological investigations are proposed at both Lake Broadwater and Long Swamp to further characterise the potential for the surface water features to interact with groundwater systems that may be impacted by the Action (refer Appendix D). The results of these investigations will be incorporated in the Stage 2 CSG WMMP in accordance with approval condition 17(e).

3.5 Aquatic ecology and aquatic ecosystems

Across the SGP area, no significant impacts to aquatic ecology and aquatic ecosystems are predicted as a result of the Action. This is based on no discharge to surface water environments being proposed. Therefore there is no potential for impact aquatic ecology and aquatic ecosystems that are not connected to groundwater to arise. These type of ecosystems have therefore not been considered or discussed further in this plan.

As set out in the SGP EIS/SREIS and the GDE and Aquatic Ecosystem technical memorandum (Appendix D), environmental conditions with regards to aquatic ecology and aquatic ecosystems are assessed as being highly disturbed, and there is not likely to be significant impacts to aquatic ecosystems as a result of the Action.

3.5.1 Surface water ecosystems

The impact to surface water flows in the Condamine River as a result of flux changes in the Condamine Alluvium are considered to be negligible. This is based on (refer also Appendix D and Appendix F):

- Where surface water systems are connected to groundwater, and flows are in regulated surface water systems, negligible change to surface water flow regimes are predicted therefore negligible impact to aquatic ecosystems and surface expression GDEs will occur.
- Where surface water systems are connected to groundwater, and flows are not regulated by allocations, very limited to no impact is predicted to aquatic ecosystems and surface expression GDEs based on negligible altered leakage rates over a period of hundreds of years (refer Appendix F).

3.5.2 Subterranean GDE

As per Section 2.6.3 stygofauna have been identified in the Condamine Alluvium (CDM Smith, 2016) and found to be heterogeneously distributed. Limited data is publicly available to assess the presence and distribution of stygofauna across the broader Surat CMA.

Stygofauna can be sensitive to changing water levels or disturbance because they adapt to specific groundwater conditions and can have narrow spatial distributions. If a declining groundwater table exceeds the rate at which they can migrate, or reduce available habitat as strata become unsaturated, then impact will occur. Laboratory-based studies have indicated that the response of stygofauna to groundwater drawdown (at rates of between 1,000 to 2,600 mm/day) is taxon specific (Stumpp and Hose; 2013). In addition, survival of stygofauna decreased with decreasing sediment saturation and that there was limited survival in unsaturated sediment beyond 48 hours.

In areas of the Condamine Alluvium stygofauna have been identified where monitoring records indicate current groundwater level decline at a rate greater than 100 mm/year (0.27 mm/day). The predicted rate of decline as a result of Arrow’s SGP development is in the order of 1 to 2 mm/year (0.0027 to 0.005 mm/day). This rate of change will not be discernible from natural variation (i.e. climatic) and in most areas significantly less than anthropogenic affects (i.e. existing groundwater extraction), hence considered to have a negligible impact on stygofauna.

4. WATER MANAGEMENT

4.1 CSG water and brine management

The Arrow CSG Water Management Strategy (CSG WMS) for the SGP is provided in Attachment 1 of Appendix G. It is based on Arrow's corporate CSG Water Management Strategy as set out in Attachment 9 of the EIS (Arrow, 2012) and addresses specific requirements for management of CSG co-produced water resulting from activities arising from the SGP FDP including approval conditions 13(l), 13(m) and 13(n).

The CSG WMS provides a basis for compliance, and sets out the method for managing CSG water for Arrow's Surat Basin tenements. It applies to co-produced water and brine resulting from CSG production activities, but not exploration activities. Although the WMS includes all possible options for the SGP, it is noted that discharge of CSG water to surface water or re-injection of CSG water are not components of the SGP.

Should future project requirements include the need for these mechanisms, Arrow will update the CSG WMMP and seek approval of the updated WMMP from the Minister.

4.2 Flood risk management

SGP approval condition 13(o) requires that the WMMP include a flood risk assessment for processing facilities and any raw co-produced water and brine dams, which addresses flood risks to the environment from the Action in the case of a 1:1,000 year Average Recurrence Interval (ARI) event. A risk assessment was conducted which included an estimate of consequences if major project infrastructure was subject to such an event, including release of brine and chemicals into the environment.

The risk assessment process is provided in Section 4.2.1 and 4.2.2, with further detail provided in the Flood Risk technical memorandum (Appendix H).

4.2.1 Hierarchy of controls

Arrow has applied a hierarchy of controls for managing flood risks to major gas and produced water infrastructure (refer Figure 4.1). This hierarchy is based on:

1. **Hazard elimination:** Seek to locate infrastructure outside of the mapped inundation area (based on the modelled 1,000 year ARI event). Where major infrastructure is located outside of the mapped inundation area the hazard is deemed to have been eliminated and no further risk assessment is required.

2. **Substitution:** There are currently no alternatives to the gas processing and co-produced water infrastructure and gasfield layout proposed by Arrow. Substitution is not a feasible control option.

3. **Engineering controls:** Where gas processing and co-produced water infrastructure cannot be located outside the 1,000 year ARI extent:

a. Demonstrate (using modelling or other methods) that infrastructure siting will minimise the potential for changes to overland flow paths that would result in adverse impact to neighbouring properties;

b. Design and operate the structures to withstand, as far as practicable, bank erosion and failure caused by flood waters eroding structure embankments;

c. Design and operate the structure to the relevant standards with sufficient freeboard to minimise the potential for overtopping, causing bank erosion and failure from within;

d. Model dam failure including brine fate and transport in the event of failure during a flood event; and

e. If required, identify appropriate mitigation informed by additional impact assessment which identifies the consequences of brine/chemical release to the environment.

4. **Administrative controls:** Where engineering controls do not provide sufficient mitigation of flood risks administrative controls may be applied. Administrative controls may include monitoring of storm warning systems and implementing management controls that reduce the risk of infrastructure failing or malfunctioning in such events.

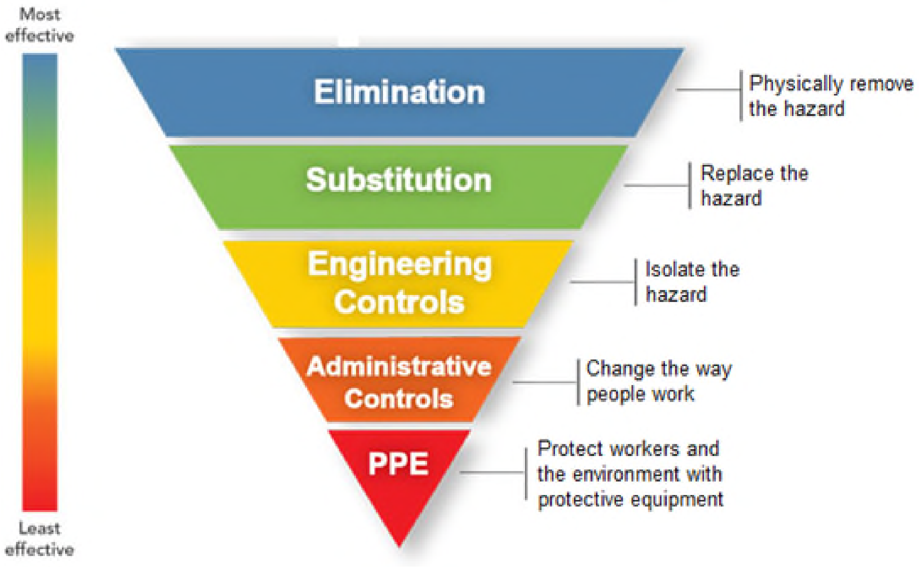

Fig. 4.1: Hierarchy of controls

4.2.2 Risk assessment and mitigation

Flood prediction

Flood modelling has been completed by Worley Parsons (2013). Flood levels, extents of inundation, maximum depths and velocities of floodwaters for the 50, 100, 500 and 1,000 years ARI flood events were simulated along prominent drainage lines within Arrow’s tenements.

Hazard elimination

An assessment of available land within Arrow's tenements that is outside of the mapped 1,000 year ARI extent was made and compared with water and gas processing infrastructure footprints (where known and/or currently proposed) (refer Table 4.1).

In the hierarchy of risk management, the preferred approach is to eliminate the hazard, and the assessment carried out indicates that there is sufficient land available outside the predicted 1,000 year ARI flood extents for major project infrastructure. Arrow plans to locate all major infrastructure outside of the flood inundation zone, and accordingly the hazards associated with the 1,000 year ARI will be eliminated.

Where major infrastructure is to be located in close proximity to the 1,000 year ARI flood inundation zone, and also in close proximity to smaller drainage features with no mapped flood inundation risk, Arrow will conduct further investigations that may include site-based flood modelling. This approach seeks to address any local scale uncertainty that may exist in the regional modelling.

Figure 4.2 shows proposed facility locations in relation to the modelled extents of the 1,000 ARI flood event.

Table 4-1. Estimated land outside flood extent compared to proposed infrastructure footprint[16]

Drainage area and property	Proposed infrastructure and footprint	Available land outside inundation zone	Assessment against flood mapping
2 / CGPF2	Integrated processing facility 800 m x 250 m, plus up to 2 km^2 for water storage 20 ha plus 200 ha; 220 ha in total	2,208 ha	The property identified as CGPF2 has limited exposure to mapped flooding extents. Three large areas of land are located outside of the flood inundation extents: south-west (300 ha), north-west (630 ha) and east (1,164 ha). All three areas present feasible options for the integrated processing facility.

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[16] Based on locations/properties Arrow has acquired

Drainage area and property	Proposed infrastructure and footprint	Available land outside inundation zone	Assessment against flood mapping
7 / CGPF7	Integrated processing facility 800 m x 250 m, plus up to 2 km^2 for water storage 20 ha plus 200 ha; 220 ha in total	2,700 ha	The property identified as CGPF7 straddles Wilkie Creek. The parcels of land on the west side of the creek experience significant inundation in the area immediately adjacent to the creek, and the smaller tributary. Overall, a significant area of land (2,700 ha) lies outside the flood extent, towards the eastern and western boundaries of the property. Flood extents divide the available land into five parcels, all of which are of sufficient size for the integrated processing facility.
8 / CGPF8	Integrated processing facility 800 m x 250 m, plus up to 2 km^2 for water storage 20 ha plus 200 ha; 220 ha in total	8,175 ha	The property identified as CGPF8 experiences shallow flooding across the eastern third of the land from a flood runner that connects the Condamine River and Wilkie Creek. 6,600 ha of land across the remaining property is outside of the 1,000 year ARI flood extent. This land comprises three contiguous parcels that offer several options for the integrated processing facility.

Drainage area and property	**Proposed infrastructure and footprint**	**Available land outside inundation zone**	**Assessment against flood mapping**
9 / CGPF9	Integrated processing facility 800 m x 250 m, plus up to 2 km^2 for water storage 20 ha plus 200 ha; 220 ha in total	2,367 ha	The eastern sections of the property identified as CGPF9 are predicted to be inundated up to depths of 2 to 3 m. Channel flow bisects the north-east parcel of the property which drains localised rainfall runoff. Land west of Millmerran-Cecil Plains Road is bisected by Crawlers Creek with a 300 m wide flood inundation area. Unaffected land to the north totals 620 ha and unaffected land to the south totals 586 ha. The shapes of both areas of unaffected land are likely to be suitable options for the integrated processing facility. Land east of Millmerran-Cecil Plains Road comprises two separate properties; north and south of Crawlers Creek. The southern property has approximately 690 ha of non-flood inundated land that is likely to provide a suitable option for the infrastructure. The northern property has approximately 300 ha of non-flood inundated land. The irregular shape of the land may not be suitable for the proposed integrated processing facility.
Unconfirmed	Field Compression Facility (FCF) 100 m x 50 m 0.5 ha	Unconfirmed	While the need for FCFs has not been confirmed, this infrastructure may be required depending on wellhead pressures realised across the gas field. Unlike other gas processing infrastructure, FCFs may have less flexibility in their location. In the case where FCFs are required, and fall within the 1,000 year ARI event flood inundation zone, flood risks will be assessed further on a case by case basis applying the hierarchy of controls.

Engineering and administrative controls

Under the current FDP no further controls are required as the flood risk hazards have been eliminated. The location of proposed infrastructure considered in this assessment is that presented in the SREIS. The actual locations will be refined during the front end engineering design phase and flood risks re-assessed as required. Should the final FDP result in infrastructure that cannot be located outside the modelled 1,000 year ARI extent, further risk assessment will be conducted to develop suitable engineering and administrative controls.

This further or ongoing risk assessment process will be tailored to the specific scenario being assessed and may include one or more of the following elements:

- Flood modelling to assess potential impacts, inform design of the facilities and develop management measures for operation of the facilities.
- Assessment of the likely changes to overland flow paths and assessment of impacts on neighbouring properties.
- Assessment of the consequences if major project infrastructure was subject to a 1,000 year ARI event, including release of brine and chemicals into the environment.

The risk assessment process will drive the development of a range of specific engineering controls to mitigate risks due to flooding. Engineering controls may include:

- Development of infrastructure design and operating guidelines so that the potential for bank erosion and failure caused by flood waters eroding structure embankments is minimized.
- Design and operation of structures to relevant engineering standards with sufficient freeboard to minimise the potential for overtopping, causing bank erosion and failure from within.
- Modelling of dam failure during a 1,000 year ARI event, including brine fate and transport. Where adverse impacts are indicated, further design elements/controls will be considered to provide adequate mitigation to reduce the impact of brine/chemical release to the environment.

Administrative controls may also be specified to supplement engineering controls. These may include monitoring of storm warning systems and adopting management controls that reduce the risk of infrastructure failing or malfunctioning in major storm events.

Arrow will develop and implement site-specific stormwater management plans, as required by the Queensland EHP Environmental Authorities for environmentally relevant activities associated with the development of major infrastructure.

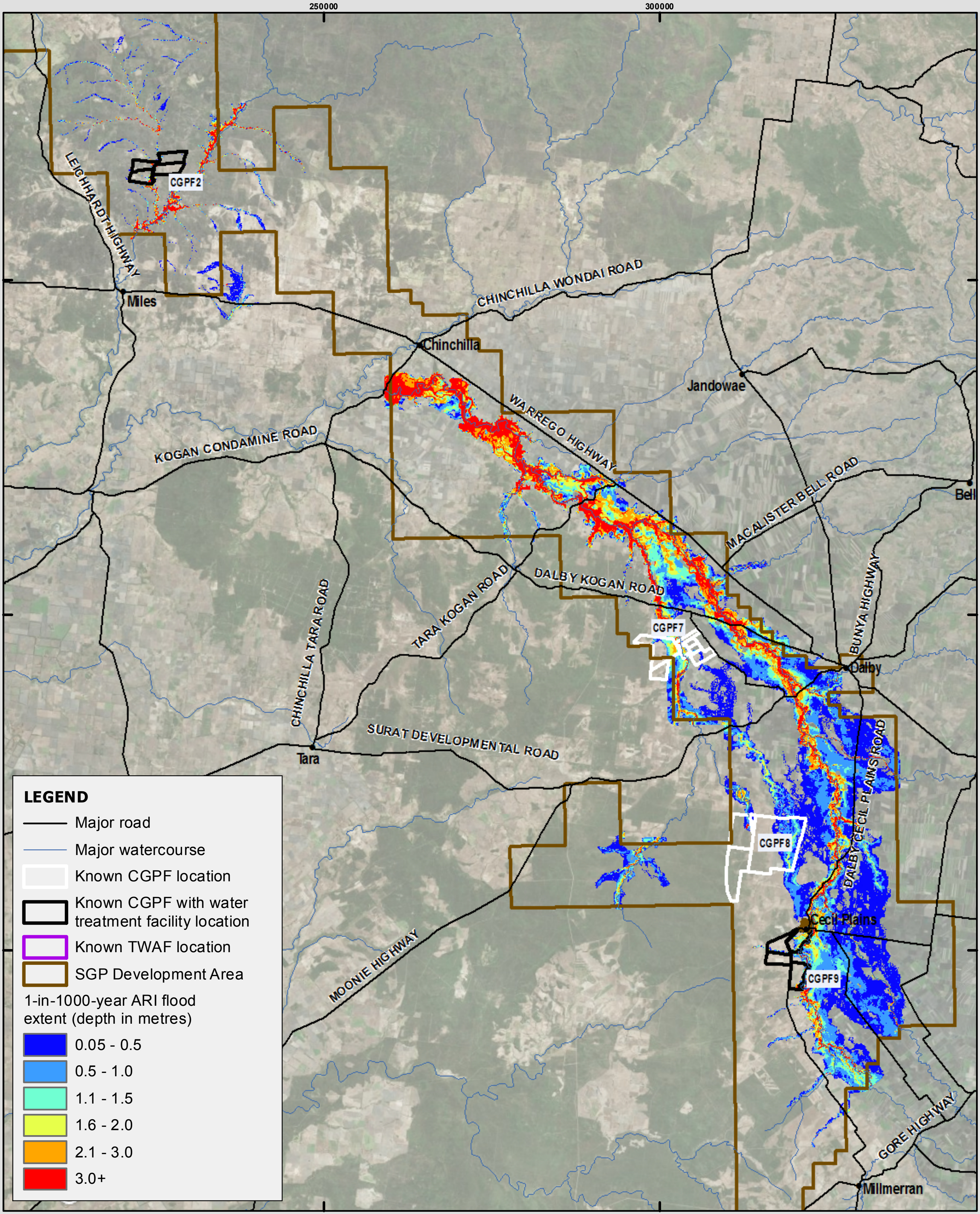

Figure 4.2 Proposed Surat Gas Project water storage facilities with 1:1000 ARI flood modelling

Source:
Arrow Energy Pty Ltd
Alluvium
Bing Maps Online

Date: 13/07/2017
Issued To: Arrow Energy
Author: grant.young

0 5 10 20 30 40
Kilometres
Scale: 1:750,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

N

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5. EARLY WARNING MONITORING SYSTEM

This chapter presents the Early Warning Monitoring System (EWMS) for the SGP Stage 1 CSG WMMP. Arrow will update the EWMS in the Stage 2 CSG WMMP, taking into account revised modelling predictions using the most recent OGIA model version and updated field development plans. The annual reports will include relevant updates to the EWMS.

5.1 Early warning monitoring system - overview

Approval Conditions 13(j) and 13(k) variably require early warning indicators, trigger thresholds, and limits. Table 5.1 provides a summary of the condition requirements for the EWMS.

Table 5-1 EWMS requirements

System	Early warning indicator	Trigger threshold	Groundwater or drawdown limit
Consolidated aquifers	-	-	✓
Condamine Alluvium	✓	✓	✓
GDEs	✓	✓	-
Aquatic ecosystems	✓	✓	-

Factors influencing groundwater drawdown predicted in affected formations include impacts due to the Action (i.e. Arrow drawdown), other CSG developers, and non-CSG users. Because of the relative magnitude of these influences, it is difficult to differentiate impact due to the SGP based on simple analysis of field data. To account for this, an EWMS approach based on cumulative impacts is necessary. Figure 5.1 provides a conceptual illustration and analysis of Arrow and non-Arrow drawdown impacts.

The EWMS includes tiered investigation levels with escalating responses:

1. Early warning indicators, for early identification of potential issues.
2. Trigger thresholds, for identifying the potential to exceed limits, and enable measures to be selected and implemented to reduce the likelihood of limit-exceedance.
3. Limits, that define levels of impact not to be exceeded.

EWMS operation is underpinned by an early warning monitoring network. Data from this network will be analysed and compared to the assigned early warning indicators, triggers and limits. The data will also be used to generate new impact forecasts and help consolidate the understanding of groundwater systems across the SGP, and for updating groundwater models supporting the WMMP.

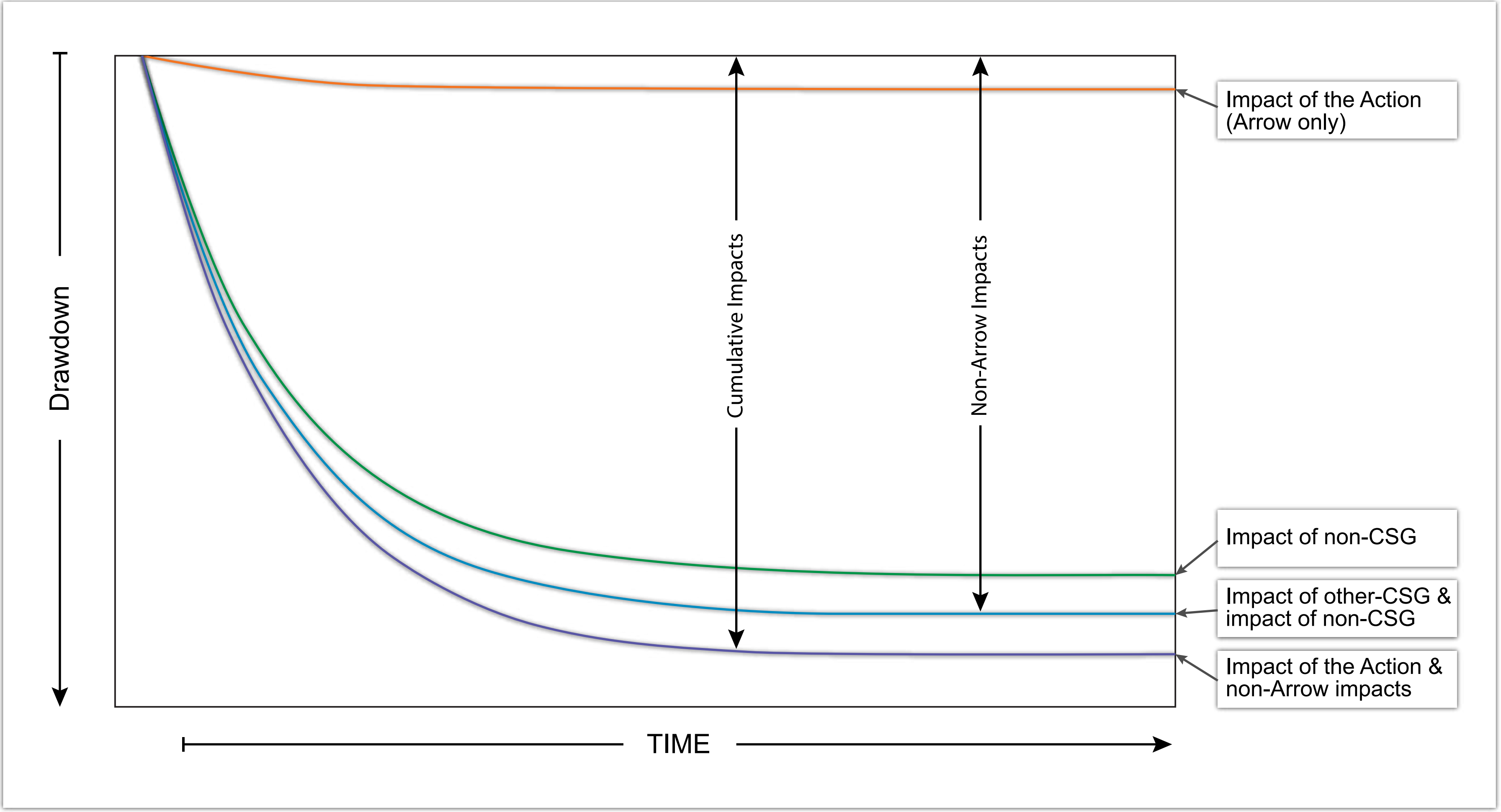

Figure 5.1

Conceptual Representation of SGP Impacts

Source:
Coffey.

Date: 21/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich/Richard.Heath

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5.1.1 EWMS rationale

The EWMS relies on periodic collection, review and assessment of data, and is developed from the basis described in the Early Warning, Triggers and Limits technical memorandum (Appendix I). The following primary elements are incorporated:

- **Early warning indicator** – the greatest drawdown from any location within that aquifer for a 3-yearly period taken from the predicted P95 (cumulative) case plus half the applicable drawdown factor (note; no drawdown factor is added for GDEs).
- **Trigger threshold** – a drawdown that is half-way between the early warning indicator and the limit.
- **Limit** - a level of change due to the action that is considered unacceptable. The limit is:
  - Derived from the greatest predicted P95 drawdown across Arrow tenure within an aquifer (cumulative case plus the applicable drawdown factor);
  - Taken from the drawdown predicted to have occurred in 100 years; and
  - Recognises that the model will not perfectly predict where or when impact will occur.
- Drawdown factor[17] – Taken from the bore trigger threshold set for consolidated and unconsolidated aquifers in the Queensland Water Act (2000) (i.e. for similar systems) and being 5 m for consolidated aquifers and 2 m for unconsolidated aquifers.

Figure 5.2 illustrates the EWMS conceptualisation. The monitoring network that underpins the EWMS is described in Chapter 6.

Basis for EWMS levels

The EWMS approach is based on groundwater level. For the Condamine Alluvium, groundwater flux was also considered as an alternative EWMS metric, but not considered further as this parameter cannot be directly measured in the field.

EWMS levels are derived from numerical groundwater modelling of cumulative drawdown. The levels will be established in the Stage 2 CSG WMMP based on the latest OGIA model version (or its equivalent) and will incorporate (where available) updated production data for other CSG producers and non-CSG extractors. The early warning indicator, trigger threshold or limit may be updated with each new OGIA model if an explanation for the change to the limit is provided in an updated WMMP/annual review.

5.1.2 GDEs included in the EWMS

The basis for identifying GDEs that may be impacted by the Action is set out in Appendix D – GDE and Aquatic Ecosystem technical memorandum - and the SGP EIS/SREIS.

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[17] No drawdown factor is applied for GDEs.

The EWMS focuses on GDEs that may be impacted by the Action including spring GDEs which are managed through the JIP and are further discussed in Section 5.4. The GDE and Aquatic Ecosystem Technical Memorandum (Appendix D) provides the basis for the assessment of impact to non-spring GDEs.

Future iterations of the UWIR are expected to also consider cumulative CSG-related impacts to non-spring GDEs and Arrow will comply with all obligations set out in the UWIR regarding GDEs.

Lake Broadwater and Long Swamp are the subject of ongoing investigations to assess the connectivity of these systems to underlying aquifers that may be affected by the Action (in accordance with approval condition 13(f)). Where connectivity is demonstrated, the EWMS set out for GDEs will be applied to these features as part of the Stage 2 CSG WMMP. This is an appropriate approach as no gas extraction is permitted prior to Ministerial approval of the Stage 2 CSG WMMP therefore no impact to these features can occur in the interim. As described in Appendix F, the predicted groundwater impacts to these features are low.

5.1.3 EWMS response actions

EWMS response actions are escalating actions that apply to exceedances (due to the Action) of an early warning indicator, trigger threshold, or limit. The EWMS function is described in Sections 5.2 and 5.3. Details of the groundwater monitoring network are provided in Section 6, and in the Groundwater Monitoring Network and Program technical memorandum (Appendix J).

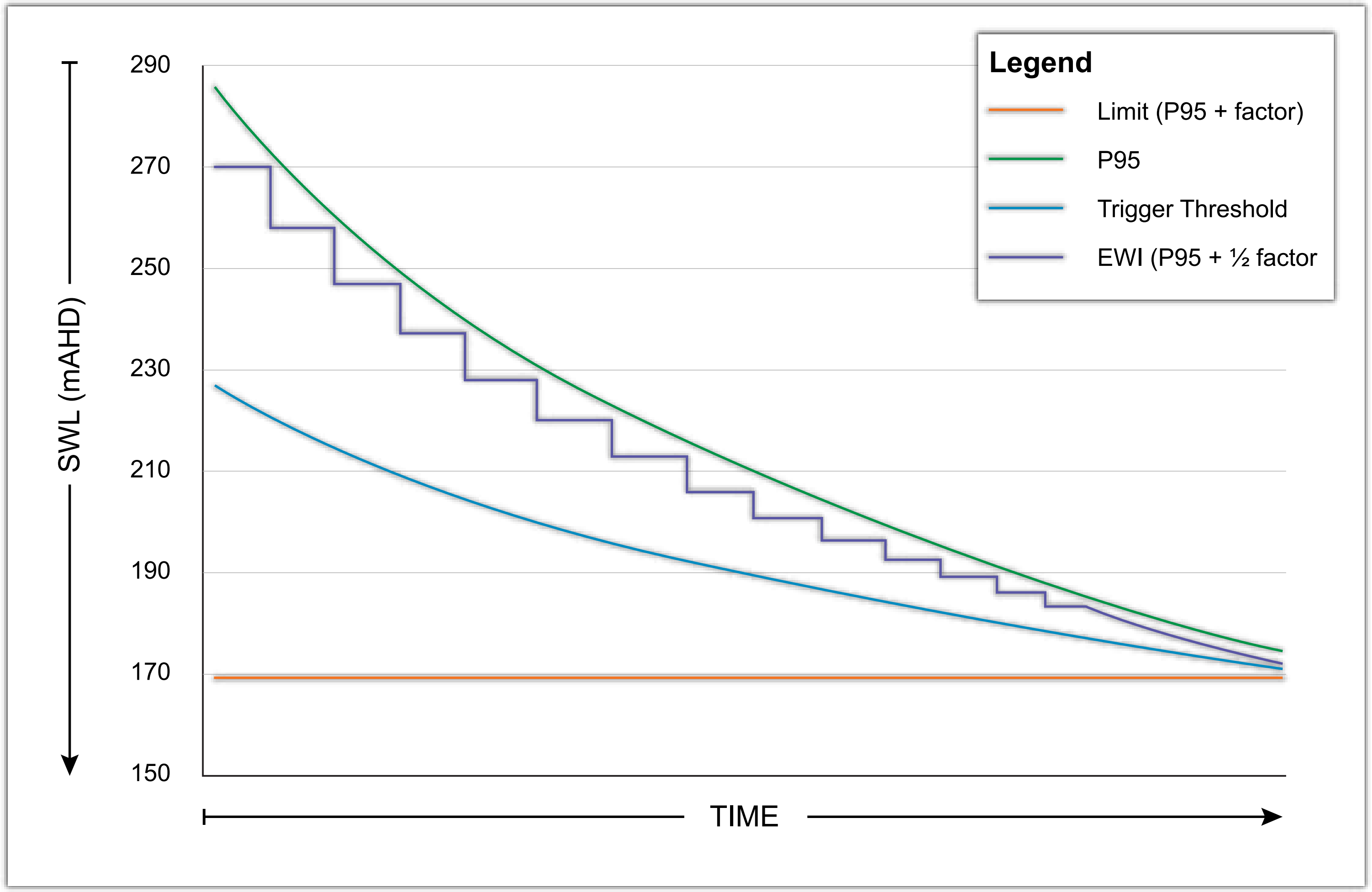

Figure 5.2 EWMS Conceptualisation

Source:
Coffey.

Date: 10/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

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5.2 EWMS: consolidated aquifers, Condamine Alluvium, GDEs

Events triggering an EWMS level initiate prescribed investigation and actions to mitigate against groundwater limit exceedances. Figure 5.3 illustrates operation of the EWMS.

Assignment and update of EWMS levels

Limits, early warning indicators and trigger thresholds will be established as part of the Stage 2 CSG WMMP in accordance with approval condition 17(h)(iv) by analysing the groundwater model predicted drawdown, and specifying the levels for limits, early warning indicators and trigger thresholds.

The limits, early warning indicators and trigger thresholds will be updated on an ongoing basis every three years if a new or revised OGIA model simulation has been developed (in accordance with Approval Condition 13).

Where EWMS levels are revised, Arrow will provide an explanation of the revision based on the latest groundwater modelling that has led to the revised levels. This would be supported by a review of Arrow’s forecast water production against actual production. This review will be completed for information only and where material difference in forecast versus actual production is identified, it will not trigger any further action.

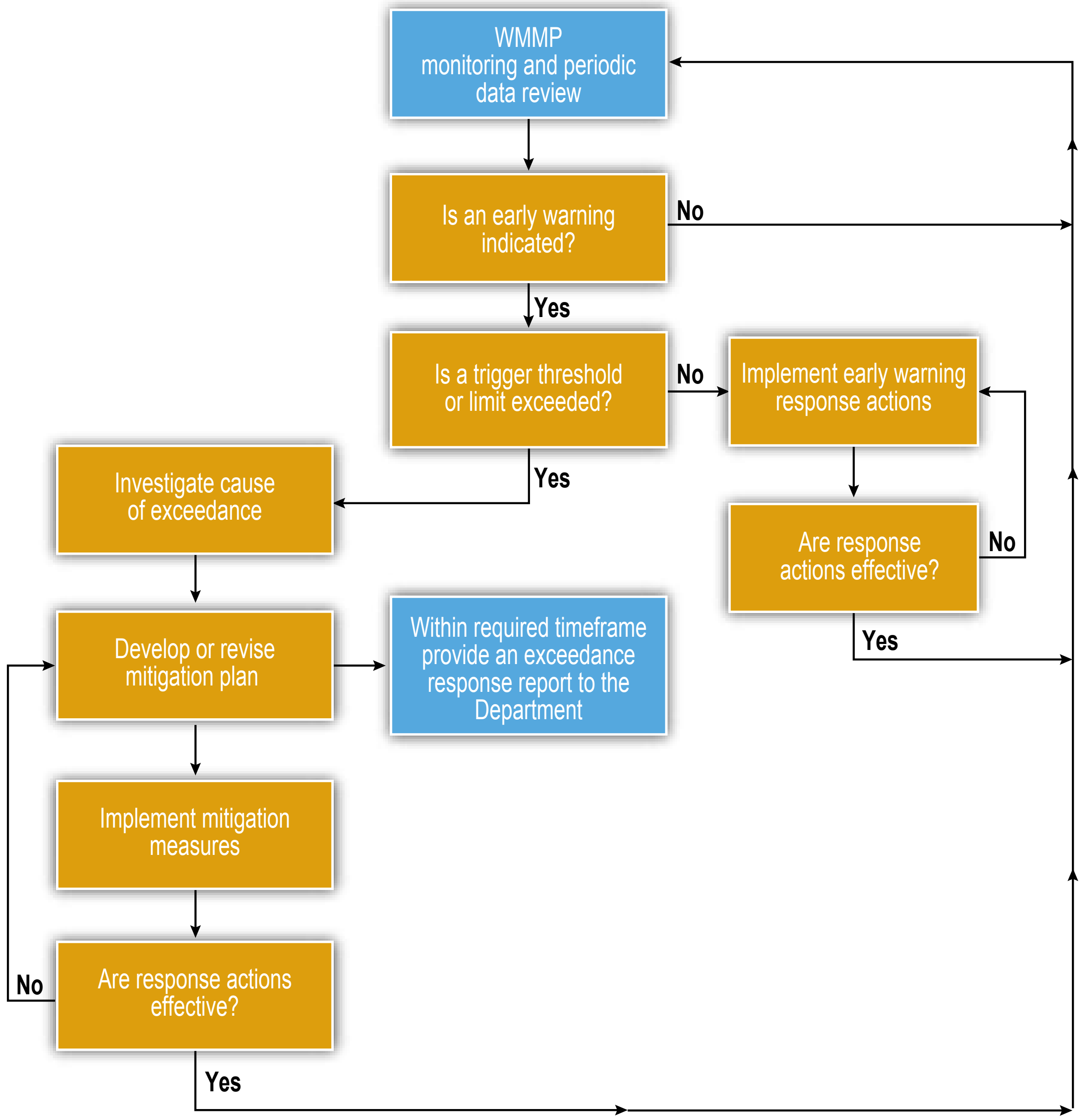

Figure 5.3 **EWMS process and actions**

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Coffey

Date: 19/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich/Richard.Heath

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5.2.1 Groundwater data assessment

For each early warning monitoring location, groundwater monitoring data will be reviewed and assessed against the EWMS levels assigned for the location. Data assessment procedures are described below. Where an early warning indicator, trigger threshold, or limit is exceeded, the response actions in Section 5.2.2 will be implemented.

Data collection and interpretation

The WMMP requires the collection and interpretation of data to understand groundwater-related impacts resulting from the Action. Many factors can influence data trends, including CSG and non-CSG factors, and therefore to properly understand impacts associated with Arrow's CSG operations, data must be analysed in a rigorous manner.

A detailed approach for groundwater level and water quality trend analysis will be established and set out in the Stage 2 CSG WMMP, as required under Condition 17(h).

Data QA/QC

To ensure a robust EWMS, monitoring results will be checked to verify the data by:

- Reviewing and checking data and field documents to identify transcription errors.
- Reviewing and checking the calibration of measurement equipment (for example data loggers and piezometers).
- Barometric compensation of uncompensated logger data.
- Obtaining further field data if necessary to confirm or clarify the results.

Data review

The data review process will:

1. Compare the observed data with the assigned early warning indicator, trigger threshold, and limit for each monitoring location.
2. If the results indicate an exceedance, undertake the following to evaluate whether the results are due to the Action or other factors:
    a. Review aquifer baseline data to assess whether the exceedance is due to natural system variability or due to groundwater abstraction by third-party groundwater users[18].
    b. Review monitoring data from relevant monitoring locations in the region to identify whether an apparent exceedance is a result of regional hydrological change (for example, groundwater decline caused by reduced recharge, drought, or climate variation).

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[18] Due to the dynamic nature of groundwater systems, adverse trends may in certain cases be indicated due to a combination of natural fluctuation and measurement tolerance.

5.2.2 Exceedance response actions

EWMS response actions are escalating actions that apply to exceedances due to the Action of an early warning indicator, trigger threshold, or limit. The actions in Table 5.2 are specific for consolidated aquifers

EWMS response actions are escalating actions that apply to exceedances due to the Action of an early warning indicator, trigger threshold, or limit. The actions are identified in Table 5.2.

Table 5-2. Exceedance response action

Exceedance level	Response action
Early warning indicator	Within 90 days, prepare and submit to the Department an Early Warning Exceedance Report which includes: a) The results of an evaluation of the reasons for the EWI exceedance, and the likelihood of a future exceedance of a trigger threshold or limit, b) The scope and schedule for implementing a groundwater investigation, to be undertaken if the evaluation indicated a likely future a trigger threshold or limit exceedance. Within 90 days of the release of a new UWIR, comparison will be made between the Arrow only drawdown impact predictions
Trigger threshold	Within 120 days, prepare and submit to the Department a Trigger Threshold Exceedance Report which includes: a) The results of an evaluation of the reasons for the trigger threshold exceedance, and the likelihood of a future exceedance of a limit, b) If the evaluation indicates a likely future limit exceedance: • Prepare a scope and schedule for a management plan that includes procedures to reduce the likelihood of a future limit exceedance.
Limit	Within 120 days, prepare and submit to the Department a limit exceedance report that includes: a) The results of an evaluation of the reasons for the limit exceedance, and an evaluation of any impacts that may arise due to the exceedance. b) An evaluation of the risk to groundwater environmental values. c) Corrective actions to mitigate against any impacts.

A detailed mitigation strategy will be designed and a mitigation plan developed and implemented as required in the Stage 2 CSG WMMP (approval condition 17(i)).

5.3 EWMS: aquatic ecology and ecosystems

Approval Condition 13(k) requires an EWMS for aquatic ecology and ecosystems. The EWMS is to include early warning indicators and trigger thresholds, including corrective actions.

Impact to aquatic ecology and ecosystems as a result of the Action may occur as a result of the discharge of produced water to surface water systems or due to groundwater drawdown.

Discharge of produced water to surface water systems is not part of the SGP. Therefore discharge-related impacts are not considered further in this CSG WMMP. Should discharge be proposed in the future, the WMMP relevant to the stage of work will require update and approval for discharge will be sought from the Minister, and a minimum of 12 months of baseline data will be collected prior to the discharge.

The potential for groundwater drawdown related impacts on aquatic ecology and ecosystems will be assessed and managed as for GDEs, under the GDE EWMS (refer Section 5.2).

Based on this approach, a stand-alone EWMS for aquatic ecology and ecosystems is not considered necessary. Should discharge to surface water systems be proposed in the future, this will necessitate an update of this plan and associated Ministerial approval. An aquatic ecology and ecosystems EWMS will be included in the revised plan if this eventuates.

5.4 EWMS: Springs

Monitoring and management of springs located within the Surat CMA is undertaken through the implementation of the JIP. The JIP was developed by key CSG proponents including Santos, APLNG and QGC to provide an early warning system (EWS) for the monitoring and management of groundwater-fed springs identified as being potentially impacted by CSG production activities including springs that contain EPBC listed communities or species dependent on the natural discharge of groundwater from the GAB.

The JIP's EWS was developed to allow adequate time for assessment and implementation of management measures prior to adverse impacts taking effect. Arrow was consulted in the development of the JIP. The JIP is also intended to align with spring monitoring and mitigation requirements obligated by the Surat CMA UWIR.

The fundamental concepts and primary principles of the JIP are:

- To ensure consistency in the approach to springs monitoring and management between the proponents;
- To measure groundwater drawdown at locations and times such that meaningful responses can be undertaken before there is any impact on MNES springs;
- An early warning approach based on modelling and monitoring to manage increasing levels of risk;
- The use of the Surat CMA cumulative impact model (CIM) to assess risks to the springs;
- A clearly defined network of monitoring bores allocated to each of the proponents;
- Single proponent responsibility for each EPBC spring aligning with Surat CMA UWIR Springs Strategy;
- Differences in approaches to limit / trigger setting at monitoring bores for on-tenements and off-tenements springs; and
- Alignment on exceedence response process and timing.

The JIP's EWS network takes into account the mechanisms by which drawdown propagates from the source (CSG production area) to the receptor (spring). It utilises early warning monitoring installations (EWMI) and trigger monitoring points (TMP) as the basis for the monitoring network. The function of these monitoring points is:

- An EWMI will typically be on-tenure and close to the area of CSG water extraction or, between the extraction areas and the spring. These early warning bores are located to provide initial drawdown data, and secondary data in support of interpretation of observations made closer to springs. At these locations groundwater drawdowns are expected to be more pronounced due to their proximity to the source of drawdown; and
- A TMP located closer to the spring i.e. further away from the CSG production area. For on-tenure springs, the TMPs have been selected within close proximity of the springs.

The early warning monitoring network utilises three levels of exceedance criteria, including:

- Investigation trigger: a nominated value at an EWMI and TMP that triggers some action such as data review, model review, increased monitoring frequency, increased monitoring parameters;
- Management / Mitigation Trigger: a nominated value at a TMP that triggers some action to be taken to prevent an impact occurring at an EPBC spring (i.e. a mitigation activity); and
- Drawdown Limit: a nominated value at a TMP that, if exceeded, would result in a breach of the Commonwealth Approval Conditions should drawdown exceed this value.

The JIP identifies the EPBC springs located within the Surat CMA and allocates each of these springs to their respective responsible proponent for monitoring and management through implementation of the JIP to ensure consistency across the industry.

The JIP provides reference to OGIA's SIMS in the Surat CMA UWIR which provides an assessment of potential impacts to all springs (EPBC springs and other spring GDEs). The UWIR identifies 387 spring vents amongst 87 spring complexes and 40 watercourse springs that may be potentially affected petroleum and gas related water extraction (OGIA, 2016). The Queensland Water Act (2000) defines a potentially affected spring as a spring overlying a GAB aquifer in which the modelled long-term predicted reduction in water pressure in any underlying aquifer resulting from petroleum and gas related water extraction exceeds 0.2 metres. Four of these potentially affected springs are classified as EPBC springs.

There are currently no EPBC springs located within Arrow tenure and all off tenure EPBC springs are either currently allocated to other CSG proponents or, where not yet explicitly allocated, are located closer to other CSG proponents who would then be the responsible tenure holders under the JIP. In accordance with the JIP, Arrow does not currently have any monitoring obligations under the JIP. Should Arrow be assigned as the responsible proponent for any EPBC Springs under the JIP, Arrow will, if applicable, adopt the JIP for the monitoring and management of the EPBC spring/s.

In addition, Arrow has no assigned responsibilities regarding potentially affected springs under OGIA's SIMS within the UWIR. No springs within Arrow tenure other than those identified and considered in the Surat CMA UWIR are known to be present and accordingly Arrow has no UWIR assigned monitoring responsibilities. Arrow will comply with the UWIR obligations for water course springs along the Condamine River.

6. MONITORING NETWORK

This chapter presents the proposed monitoring network and monitoring program for the SGP Stage 1 CSG WMMP. Section 6.1 covers groundwater monitoring, Section 6.2 covers surface water and aquatic ecology monitoring and Section 6.3 provides an overview of the currently available baseline monitoring data and high level approach to data analysis.

6.1 Groundwater monitoring

A fit-for-purpose groundwater monitoring network and sampling and analysis program is planned and required to comply with SGP EIS/SREIS commitments (Appendix B). The network will monitor CSG-related groundwater drawdown. Development of the network considered the need to provide baseline data, and to enable the identification of early warning conditions as monitoring data are acquired over time.

Additional detail on the groundwater monitoring network including background, development and requirements is provided in the Groundwater Monitoring Network and Program technical memorandum (Appendix J) and is summarised in the following sections.

6.1.1 UWIR monitoring

The Surat CMA UWIR sets out regional monitoring requirements for groundwater pressure and quality monitoring across the Surat CMA. Through this, a substantial network of groundwater monitoring locations has been established across the Surat CMA, as presented in Figure 6.1 (overview) and Figure 6.1A to I (by aquifer). The regional monitoring network specified in the 2016 UWIR comprises 675 groundwater pressure and/or quality monitoring points, of which 491 were established at the time of the release of the 2016 UWIR. The primary objectives of the UWIR monitoring network across the Surat CMA are to:

- Improve the understanding of system response within production areas.
- Identify pressure changes near specific areas of interest.
- Improve understanding of background trends in pressure.
- Provide sufficient data for model calibration.

Data collected from the greater UWIR monitoring network is considered to provide sufficient information to account for the heterogeneous nature of the system. The assigned UWIR monitoring locations are noted to provide spatial coverage across the key areas of predicted impact across the range of aquifer units. This includes the establishment of a number of nested (co-located) monitoring sites, which assist with the assessment of vertical change in groundwater pressure. The monitoring of these locations has resulted in the collection of a significant data set describing baseline groundwater pressure and quality, and provides OGIA with additional data for ongoing calibration and conceptualisation updates to its groundwater models.

In addition to the UWIR network, OGIA also receives data from tenure holders for other (non-UWIR) monitoring locations within the Surat CMA. In total, OGIA receive data from more than 1,000 monitoring points across the Surat CMA.

Under the Surat CMA UWIR, Arrow is assigned monitoring obligations. The monitoring network infrastructure required to fulfil these obligations is almost completely established as described above, and the network specified for the Stage 1 CSG WMMP in the following sections utilises most of the existing and proposed UWIR monitoring locations.

Section 8.2.3 of the UWIR describes the design principles of the monitoring network, which are in accordance with industry best practice (European Commission, 2004) with the primary focus area for monitoring being the footprint of planned CSG development because the biggest impacts are expected to be near the CSG production areas (DNRM, 2016). The UWIR monitoring network monitoring density is comparable to that achieved in other similar basin-scale aquifer monitoring networks (DNRM, 2016).

The assigned UWIR monitoring locations provide spatial coverage across the key areas of predicted impact across the range of aquifer units, as presented in Figures 6.1 A to 6.1I. The monitoring of these locations has resulted in the collection of a significant data set describing baseline groundwater pressure and quality, and provides OGIA with additional data for ongoing calibration and conceptualisation updates to its groundwater models. Further detail on the existing baseline monitoring network and data as it relates to the Stage 1 CSG WMMP is provided in Section 6.3.

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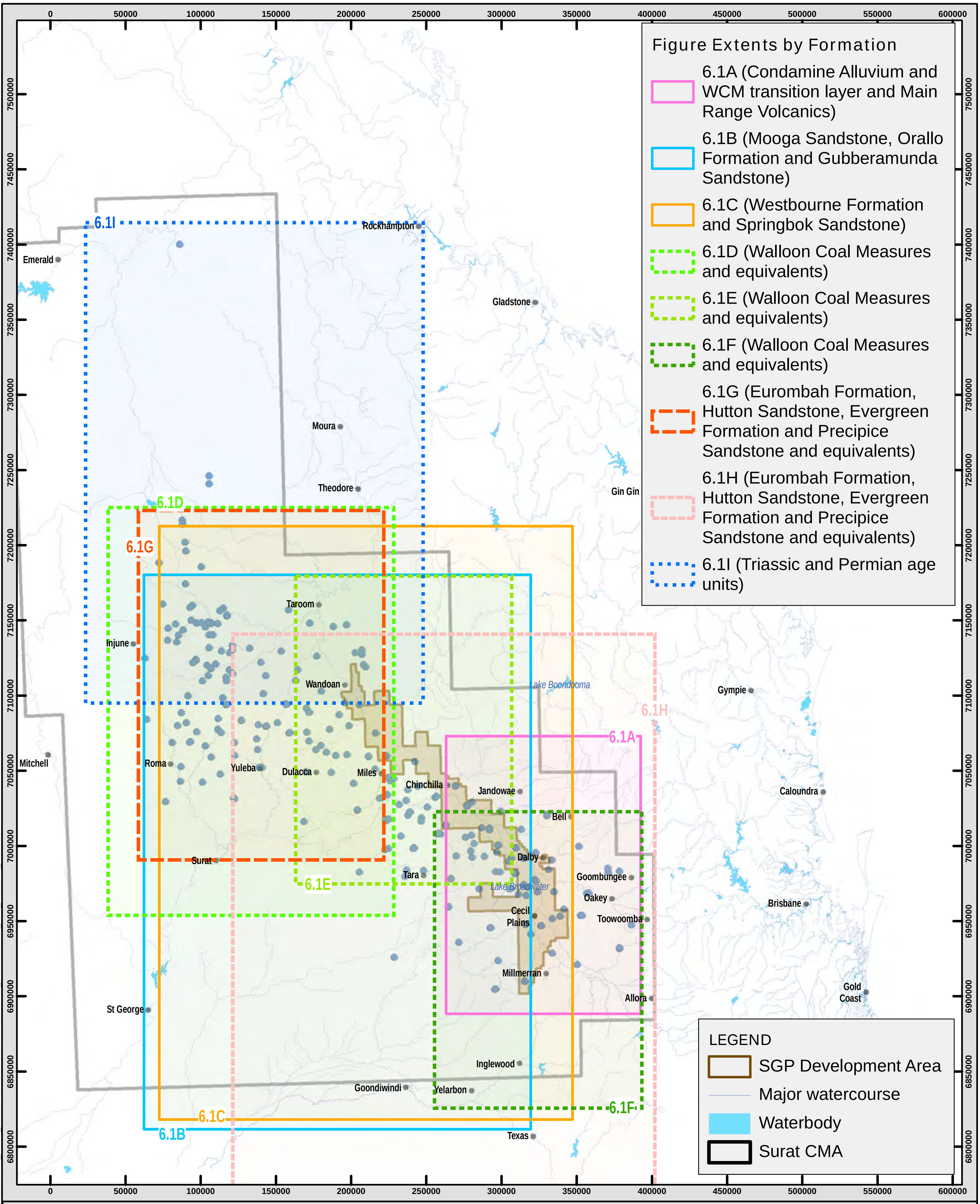

Figure 6.1 Surat CMA UWIR groundwater monitoring network overview

Source:
Arrow Energy Pty Ltd
Coffey, UWIR
CDM Smith

Date: 26/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 15 30 60 90 120 150 180
Kilometres
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Coordinate System: GDA 1994 MGA Zone 56

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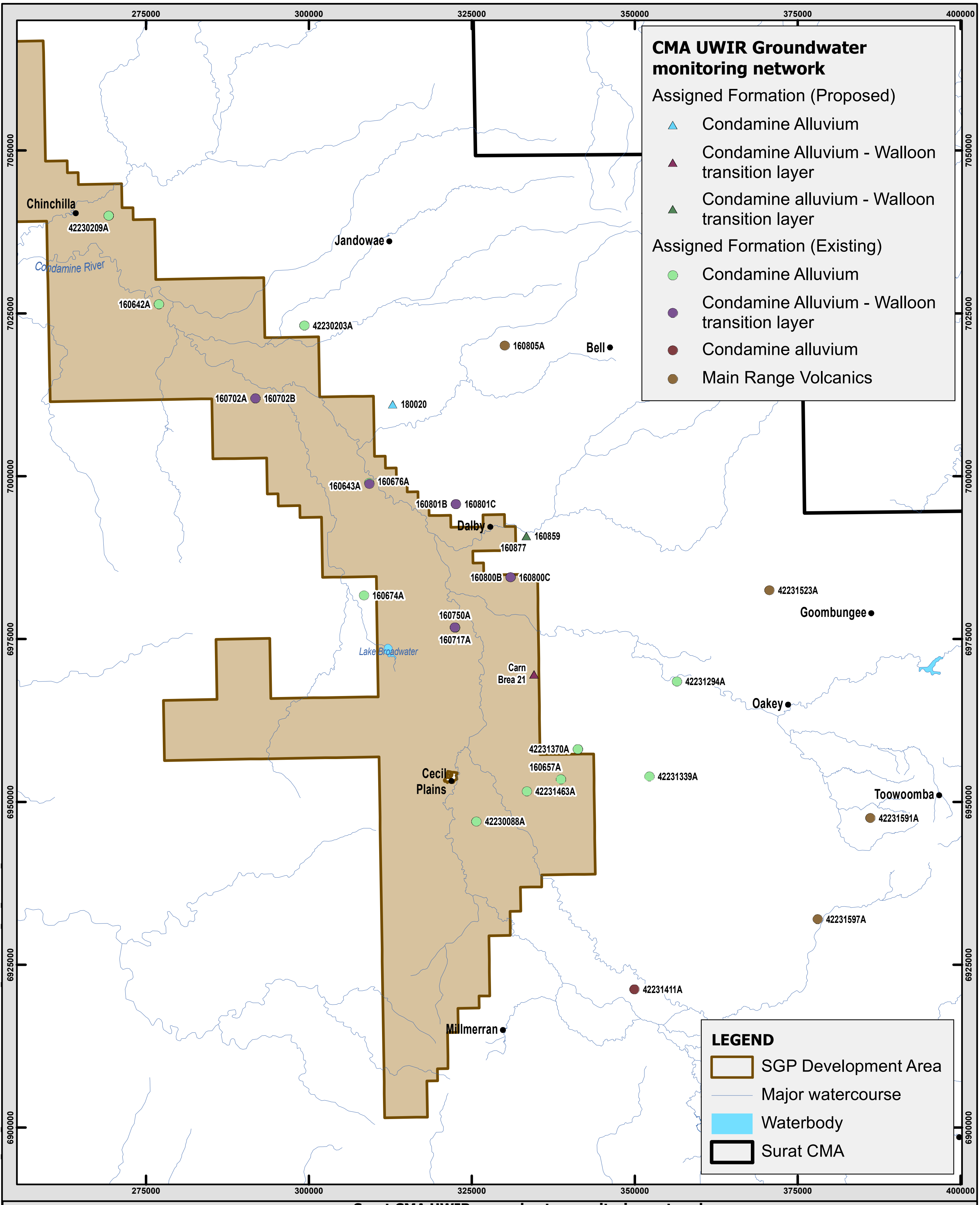

Figure 6.1A

Surat CMA UWIR groundwater monitoring network - Condamine Alluvium and WCM transition layer and Main Range Volcanics

Source:
Arrow Energy Pty Ltd
Coffey, UWIR
CDM Smith

Date: 25/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 3.75 7.5 15 22.5 30 37.5 45
Kilometres
Scale: 1:750,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

N

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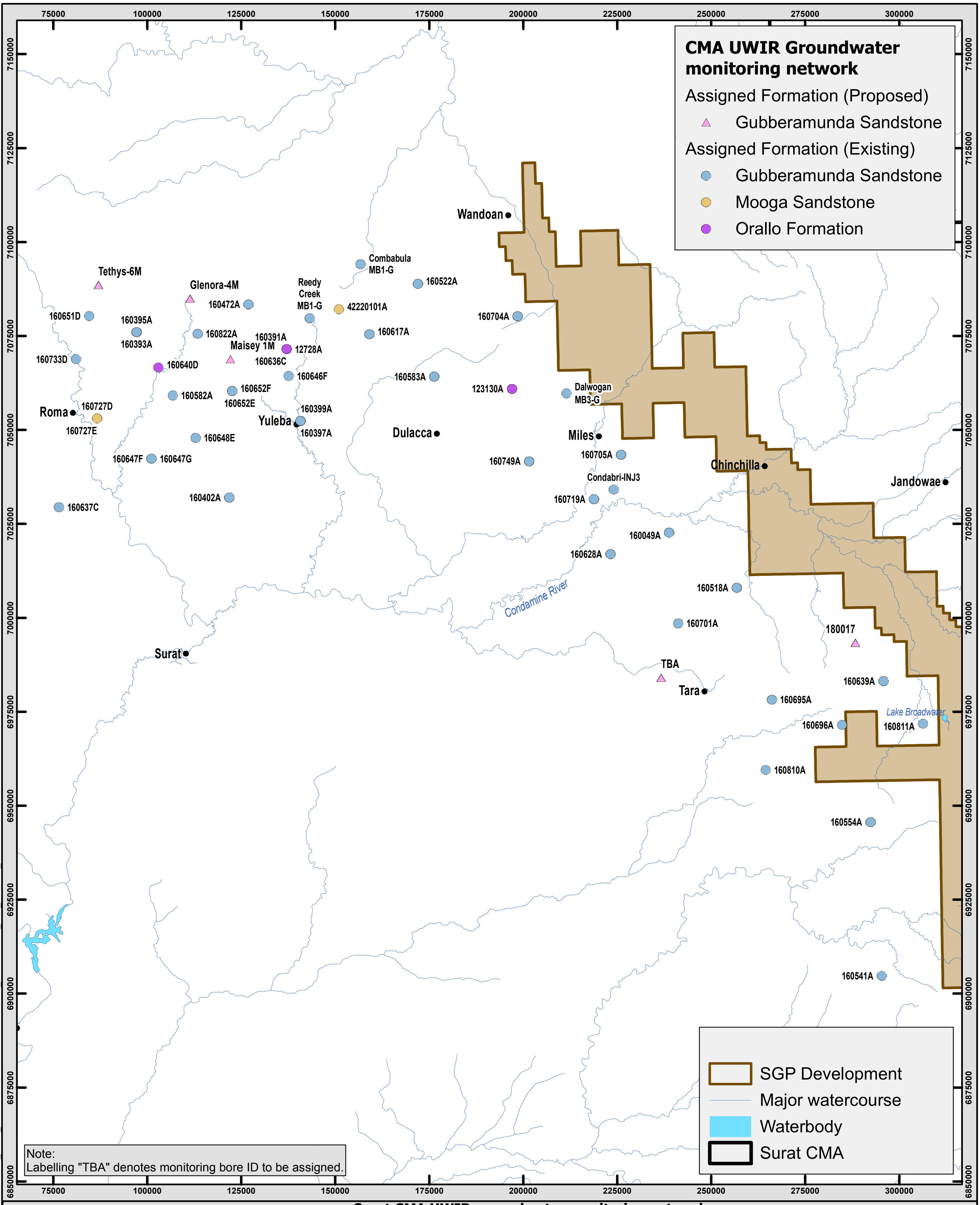

Note:
Labelling "TBA" denotes monitoring bore ID to be assigned.

Figure 6.1B

Surat CMA UWIR groundwater monitoring network
- Mooga Sandstone, Orallo Formation and Gubberamunda Sandstone

Source:
Arrow Energy Pty Ltd
Coffey, UWIR
CDM Smith

Date: 26/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 7.5 15 30 45 60 75
Kilometres
Scale: 1:1,300,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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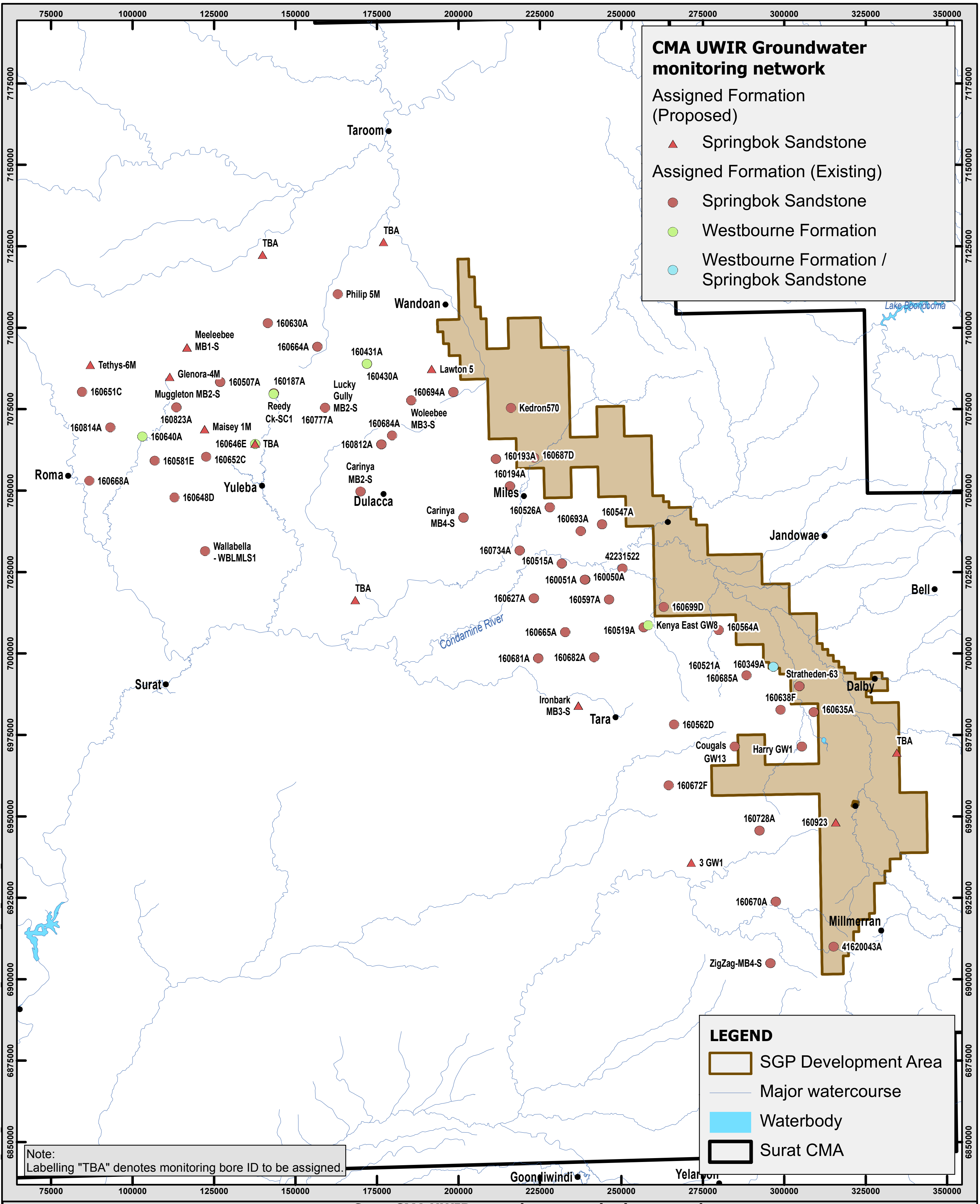

Figure 6.1C

Surat CMA UWIR groundwater monitoring network - Westbourne Formation and Springbok Sandstone

Source:
Arrow Energy Pty Ltd
Coffey, UWIR
CDM Smith

Date: 25/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 7.5 15 30 45 60 75 90
Kilometres
Scale: 1:1,500,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

N

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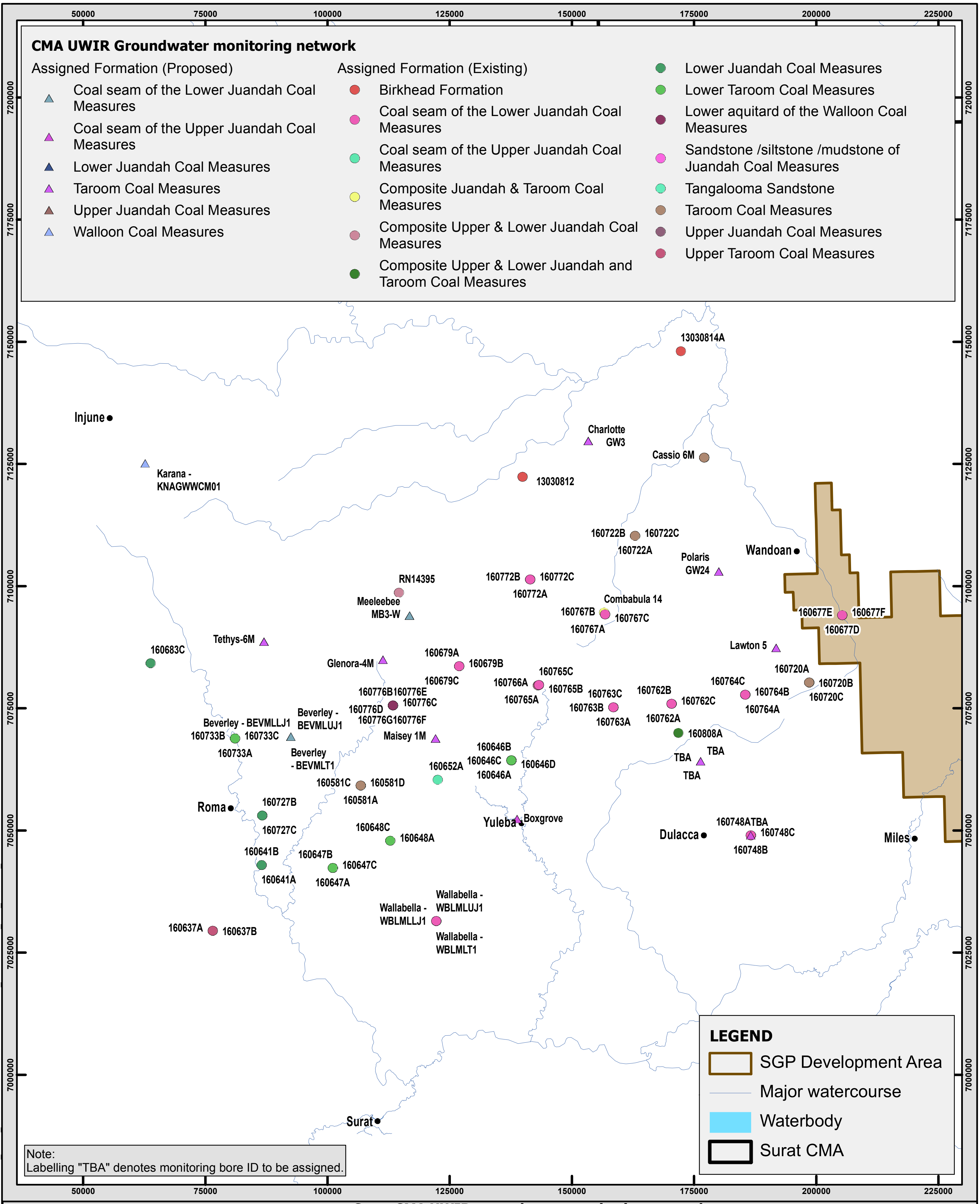

Figure 6.1D

Surat CMA UWIR groundwater monitoring network - Walloon Coal Measures and equivalents - Northern extent

Source:
Arrow Energy Pty Ltd
Coffey, UWIR
CDM Smith

Date: 25/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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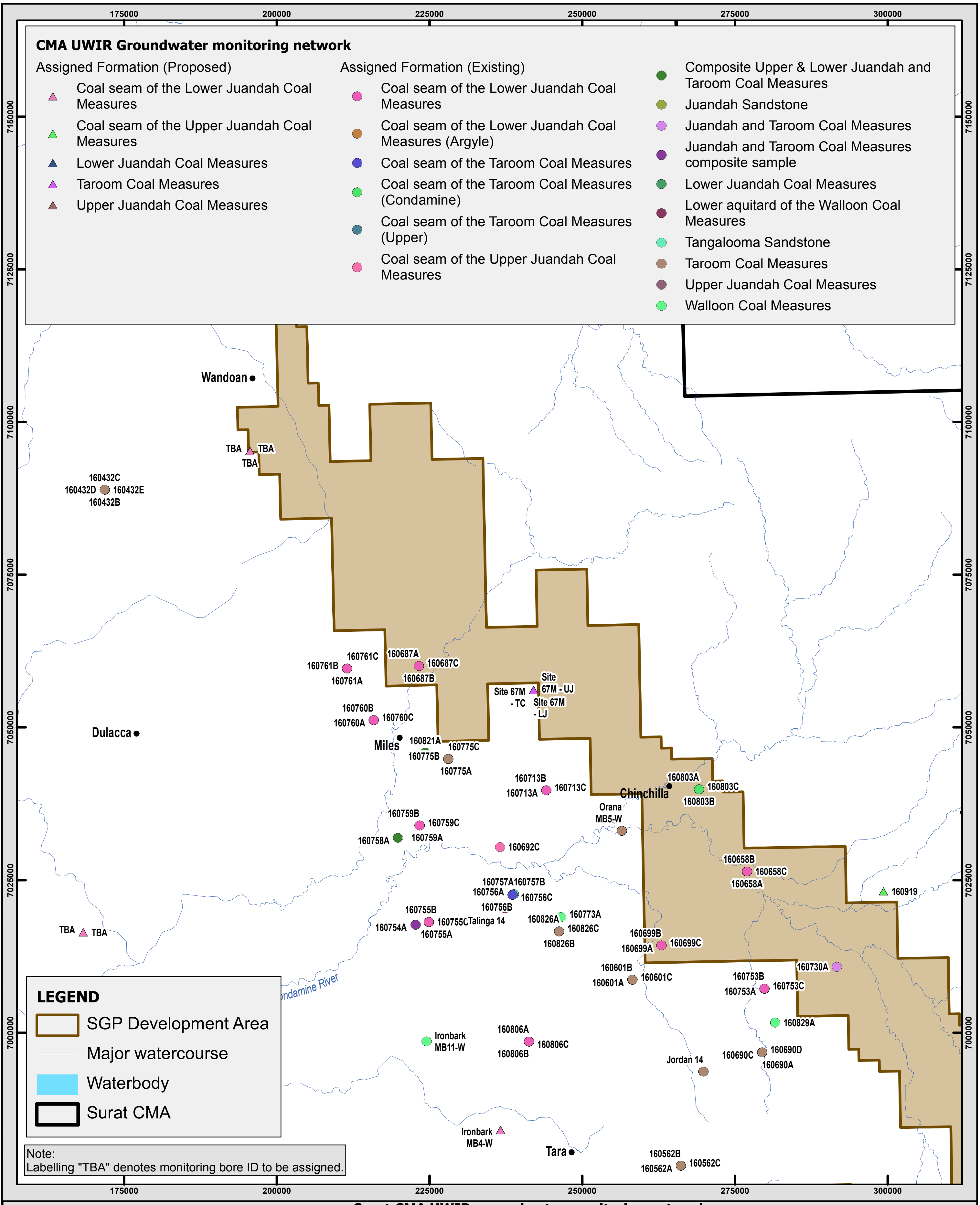

Figure 6.1E

Surat CMA UWIR groundwater monitoring network - Walloon Coal Measures and equivalents - Central extent

Source:
Arrow Energy Pty Ltd
Coffey, UWIR
CDM Smith

Date: 25/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 4 8 16 24 32 40 48
Kilometres
Scale: 1:800,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

N

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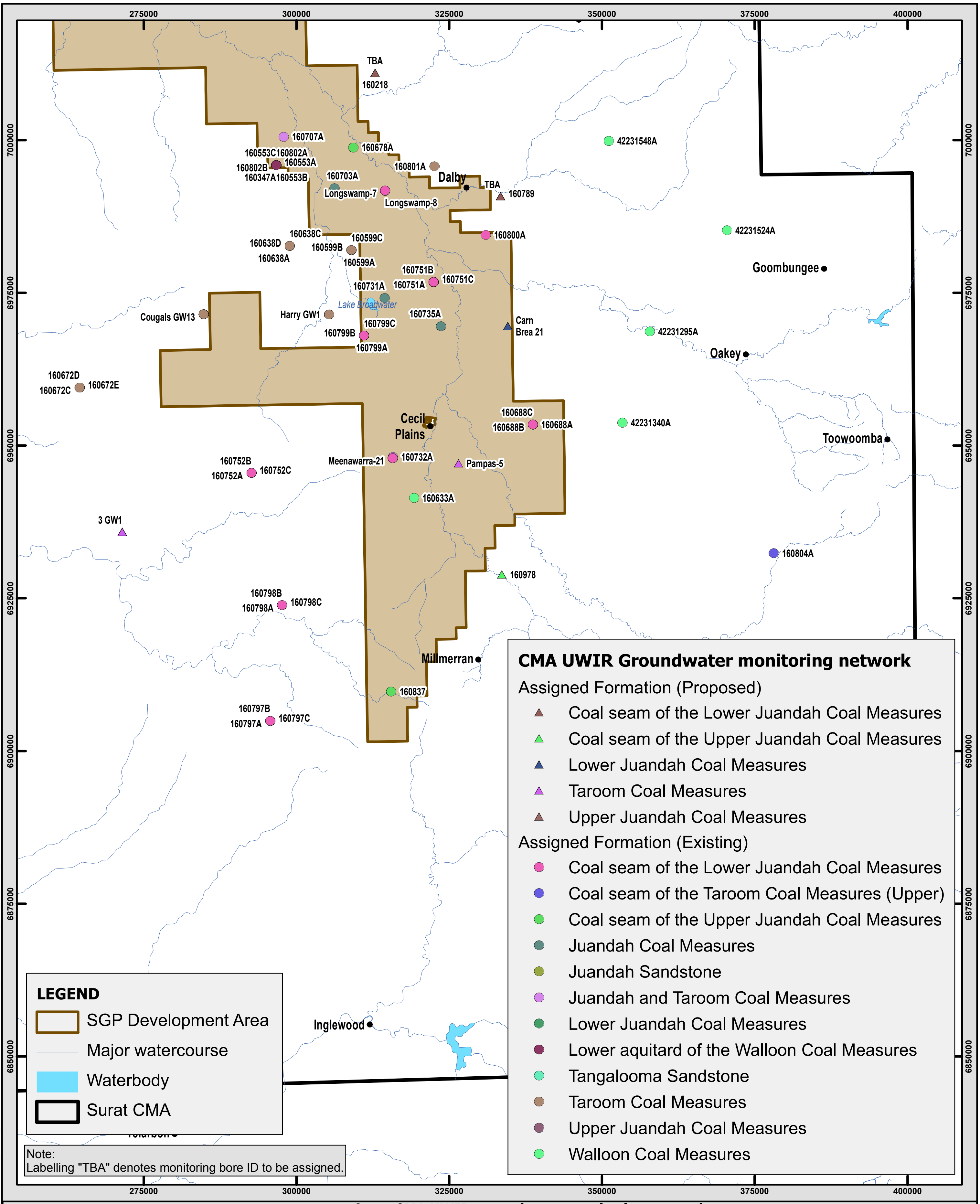

Figure 6.1F

Surat CMA UWIR groundwater monitoring network
- Walloon Coal Measures and equivalents - Southern extent

Source:
Arrow Energy Pty Ltd
Coffey, UWIR
CDM Smith

Date: 25/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 4 8 16 24 32 40 48
Kilometres
Scale: 1:800,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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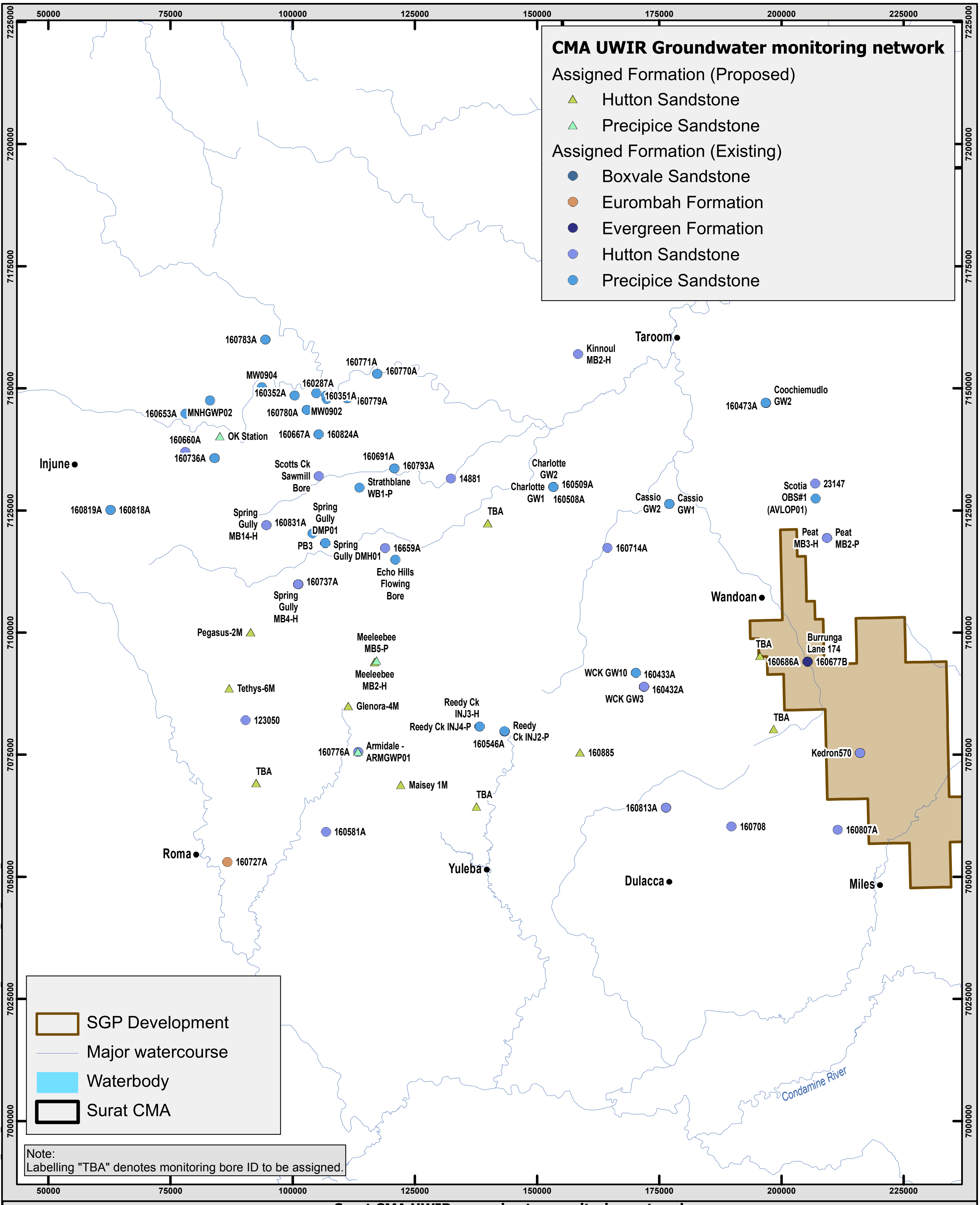

Figure 6.1G

Surat CMA UWIR groundwater monitoring network
- Eurombah Formation, Hutton Sandstone, Evergreen Formation and Precipice Sandstone and equivalents - Western extent

Source:
Arrow Energy Pty Ltd
Coffey, UWIR
CDM Smith

Date: 25/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 4 8 16 24 32 40 48
Kilometres
Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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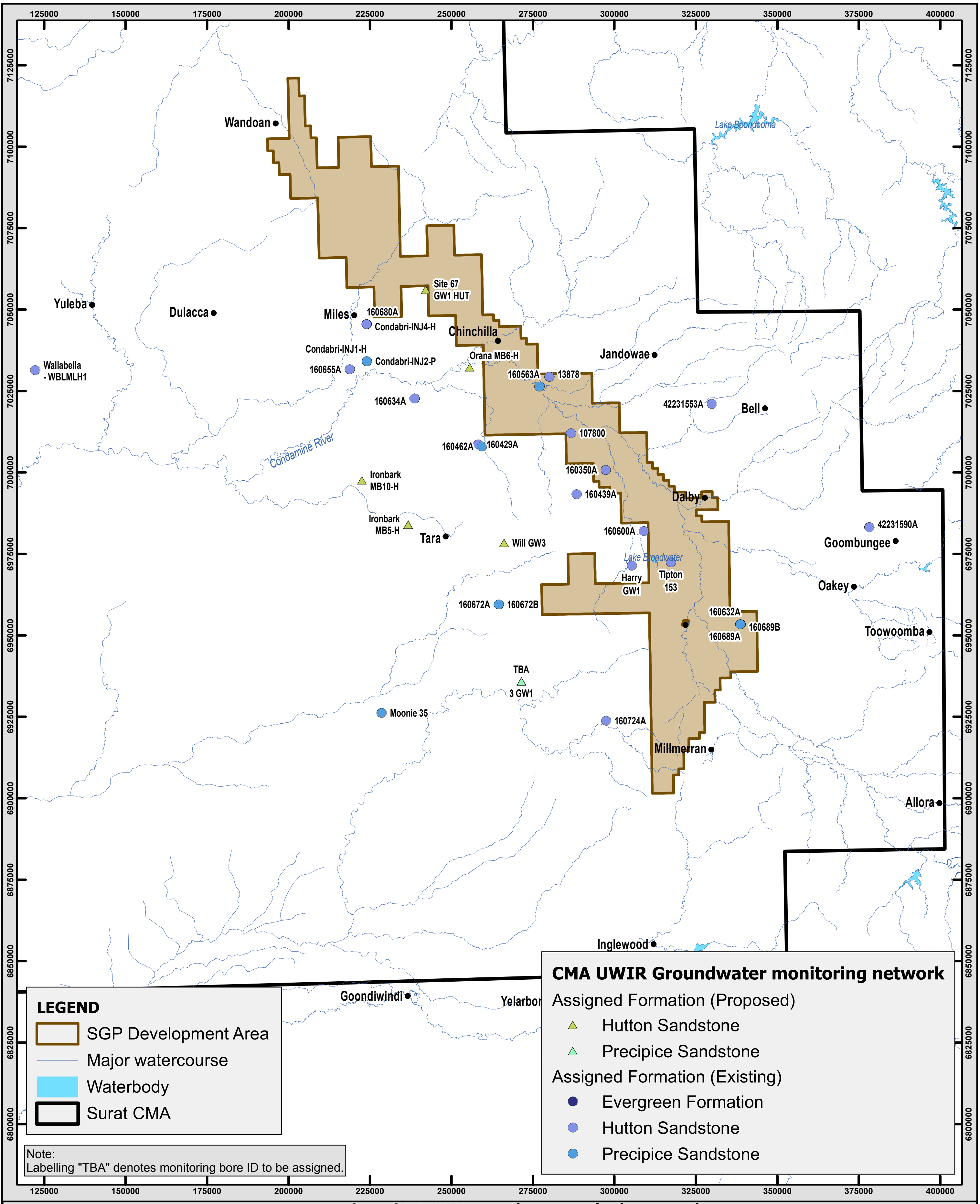

Figure 6.1H Surat CMA UWIR groundwater monitoring network - Eurombah Formation, Hutton Sandstone, Evergreen Formation and Precipice Sandstone and equivalents - Eastern extent

Source:
Arrow Energy Pty Ltd
Coffey, UWIR
CDM Smith

Date: 25/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 7.5 15 30 45 60 75 90
Kilometres
Scale: 1:1,500,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

N

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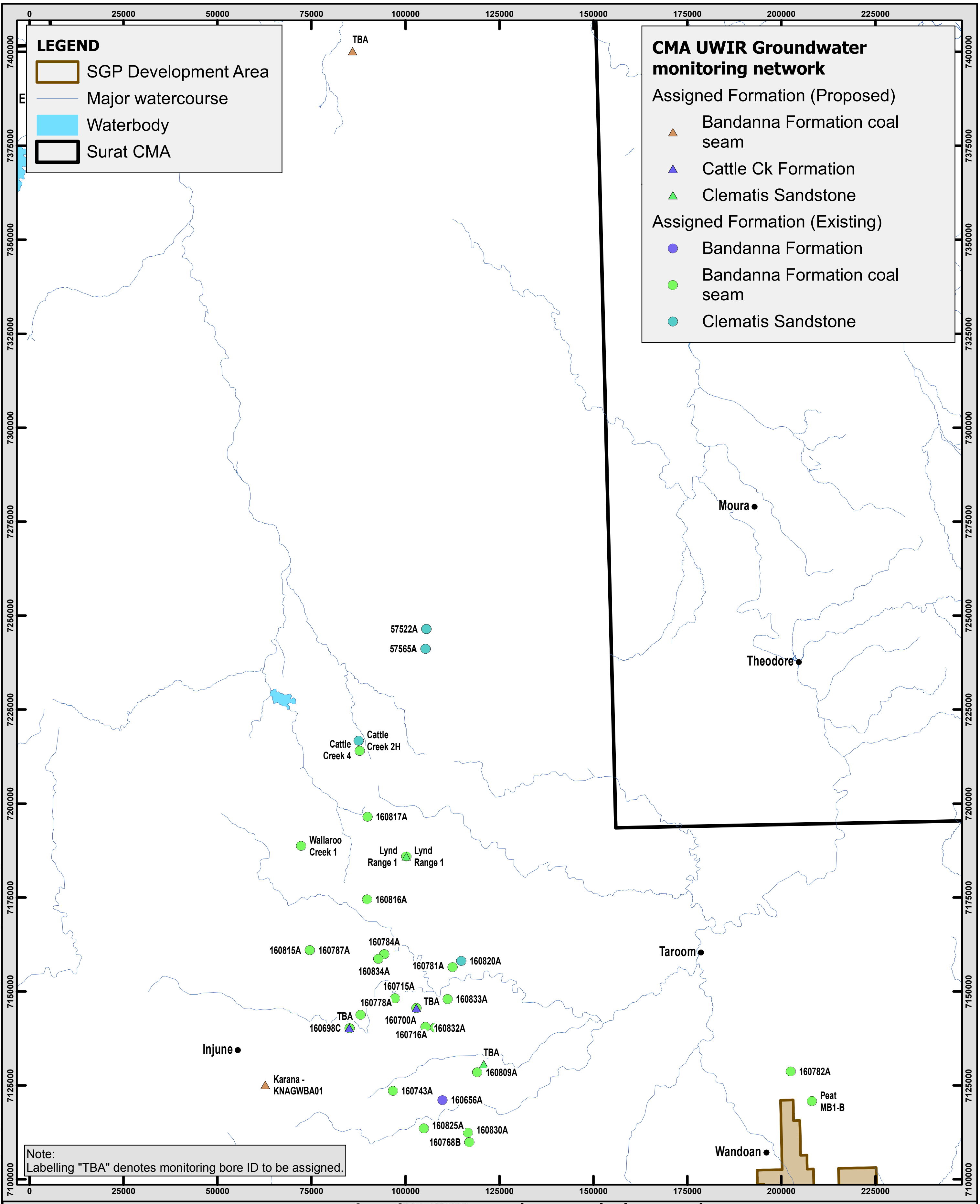

Figure 6.1I

Surat CMA UWIR groundwater monitoring network
- Triassic and Permian age units

Source:
Arrow Energy Pty Ltd
Coffey, UWIR
CDM Smith

Date: 25/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 7.5 15 30 45 60 75
Kilometres
Scale: 1:1,300,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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6.1.2 Stage 1 CSG WMMP baseline network

The baseline monitoring network design is informed by numerical groundwater modelling. In particular, for the establishment of baseline monitoring network locations, key modelling predictions that inform selection of locations are:

- Cumulative groundwater drawdown in consolidated aquifers.
- Cumulative groundwater drawdown in the Condamine Alluvium aquifer.
- Condamine Alluvium flux change due to Arrow water production.
- Condamine Alluvium drawdown timing due to Arrow water production.

The selection of baseline monitoring locations takes into account the predicted extent and timing of aquifer depressurisation due to the Action, as well as the need to acquire baseline data.

The Stage 1 CSG WMMP monitoring network comprises a total of 105 discrete monitoring intervals (including 57 WCM intervals) at 32 discrete monitoring locations, thereby comprising a comprehensive early warning monitoring network. As set out in Section 4.5 of the Groundwater Monitoring Network and Program technical memorandum (Appendix J), the Stage 1 CSG WMMP monitoring network includes 26 co-located (nested) sites, which assist with the assessment of vertical pressure gradients.

Figure 6.2 presents the proposed groundwater monitoring network for the Condamine Alluvium aquifer, superimposed on predicted drawdown (maximum cumulative drawdown (P95 case)) for the Condamine Alluvium.

Figures 6.3 to 6.6 present the network for consolidated aquifer formations, superimposed on the 1 m drawdown contour (P95 case) for the Springbok Sandstone, WCM, Hutton Sandstone and Precipice Sandstone aquifers for the 2050 cumulative case.

Figure 6.7 presents the proposed groundwater flux monitoring network for the Condamine Alluvium aquifer, superimposed upon model-predicted change in groundwater flux (Arrow r27 median case – refer Figure 7-39 in Appendix F). This network utilises locations where there are existing co-located Condamine Alluvium and WCM monitoring wells to help establish differential pressure across the Walloon-Condamine interface. The flux monitoring network locations take into account:

- The timing of predicted drawdown.
- The extent of the Condamine Alluvium.
- The predicted maximum drawdown (i.e. consideration of areas of highest flux change, and areas of early flux change).
- Availability of suitable Arrow tenement locations (Arrow induced impacts will occur earlier within these tenements than outside).

A summary of the number of Stage 1 CSG WMMP monitoring locations for each formation is provided in Table 6.1. Detailed information including the primary purpose of each monitoring location is provided in Table 2.5 of the Groundwater Monitoring Network and Program technical memorandum (Appendix J).

Table 6-1. Stage 1 CSG WMMP formation monitoring locations

Formation	**Number of monitoring locations and discrete monitoring intervals**		
	Pressure only locations (intervals)	**Pressure and water quality locations (intervals)**	**Total locations (intervals)**
Condamine Alluvium	13 (13)	5 (5)	18 (18)
CA / WCM transition layer	7 (7)	0 (0)	7 (7)
Westbourne Formation	0 (0)	1 (1)	1 (1)
Springbok Sandstone	5 (5)	1 (1)	6 (6)
Walloon Coal Measures	30 (55)	2 (2)	32 (57)
Eurombah Formation	4 (4)	0 (0)	4 (4)
Hutton Sandstone	4 (4)	3 (3)	7 (7)
Evergreen Formation	2 (2)	0 (0)	2 (2)
Precipice Sandstone	0 (0)	3 (3)	3 (3)
Total	**65 (90)**	**15 (15)**	**80 (105)**

Over time, changes are likely to be made to the FDP including to incorporate production experience. Necessarily, such changes may result in the requirement to adapt the groundwater monitoring network to revised drawdown predictions. In addition, ongoing development and recalibration of numerical groundwater models may also lead to revised predictions. As a result, additional monitoring locations may be required to ensure monitoring program relevance. These additional locations will be monitored in accordance with the sampling schedule and parameters provided in Section 6.1.4. Similarly, existing monitoring locations may become redundant, or of limited use. Such wells will be designated as inactive, and cease to be monitored. Where this is proposed it will be documented in ongoing revisions of the CSG WMMP, including the Stage 2 CSG WMMP and required annual reports.

6.1.3 GDE monitoring

In addition to the baseline monitoring network specified in Section 6.1.2, Arrow has and is continuing to carry out additional investigations into the presence and connectivity of GDEs and surface water features, including installation and monitoring of nested groundwater monitoring wells.

A program of monitoring well installations and site assessment at four areas of interest (including Lake Broadwater and Long Swamp) is being carried out to establish whether the features are connected to, or dependent on, aquifers that may be impacted by depressurisation of the WCM.

The investigation locations are presented in Figure 6.8, and were informed by the impact assessment carried out as presented in the GDE and Aquatic Ecosystem technical memorandum (Appendix D).

The proposed program of investigations at each site includes:

- Installation of monitoring bores.
- Completion of aquifer parameter testing.
- Downhole geophysical logging, where relevant.
- Evaluation of depth to groundwater table.
- Shallow coring adjacent to a mature tree identified as being potentially groundwater dependent to verify tree root depths through direct observation.
- Installation of data loggers in specified bores to record and compile groundwater level data.
- Groundwater quality sampling and analysis.

The hydraulic connectivity and groundwater dependence of these features is the subject of ongoing assessment and the findings will be reported as part of the Stage 2 WMMP.

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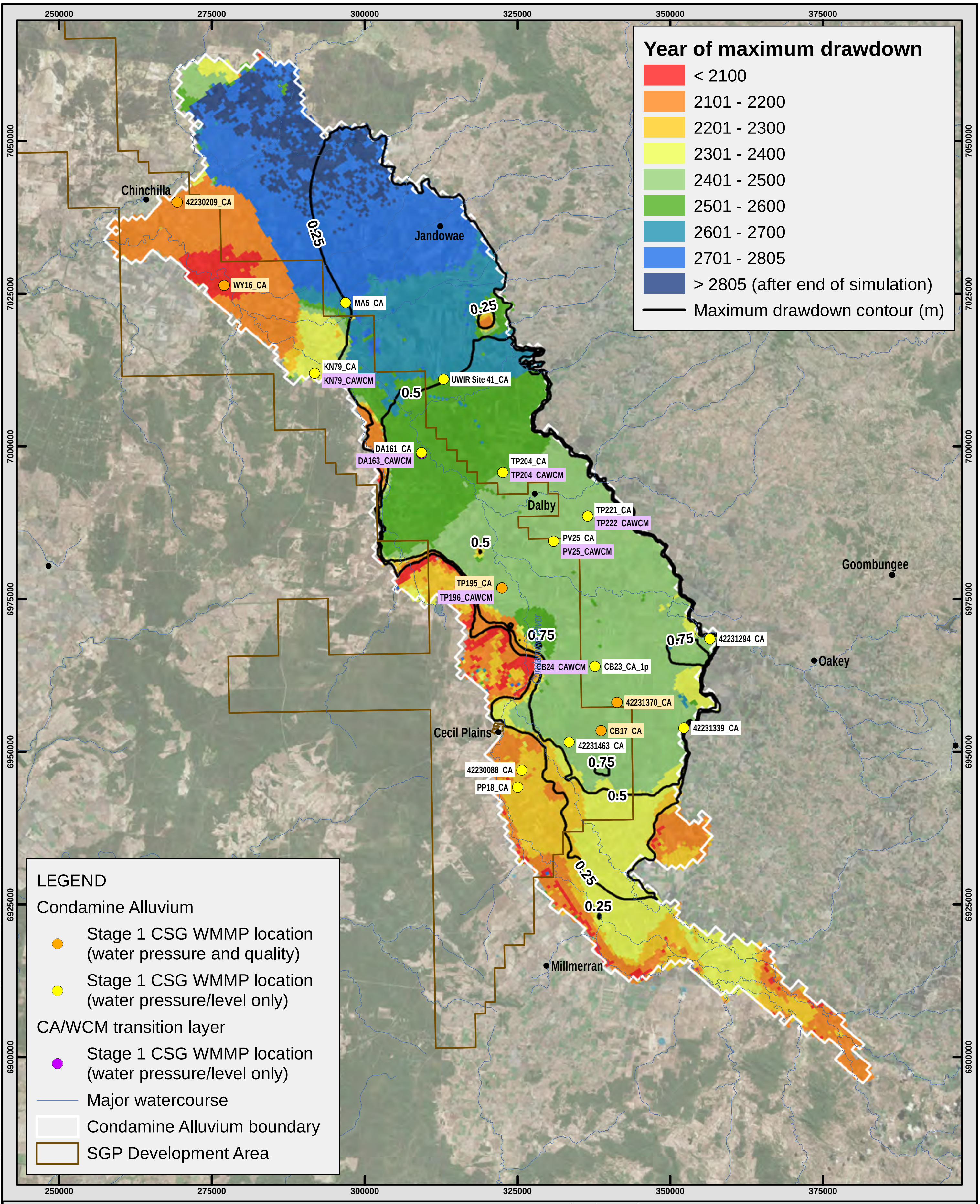

Figure 6.2

Stage 1 CSG WMMP monitoring points
(Condamine Alluvium aquifer and CA/WCM transition layer)

Source:
Arrow Energy Pty Ltd
CDM Smith

Date: 26/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 4 8 16 24 32 40 48
Kilometres
Scale: 1:800,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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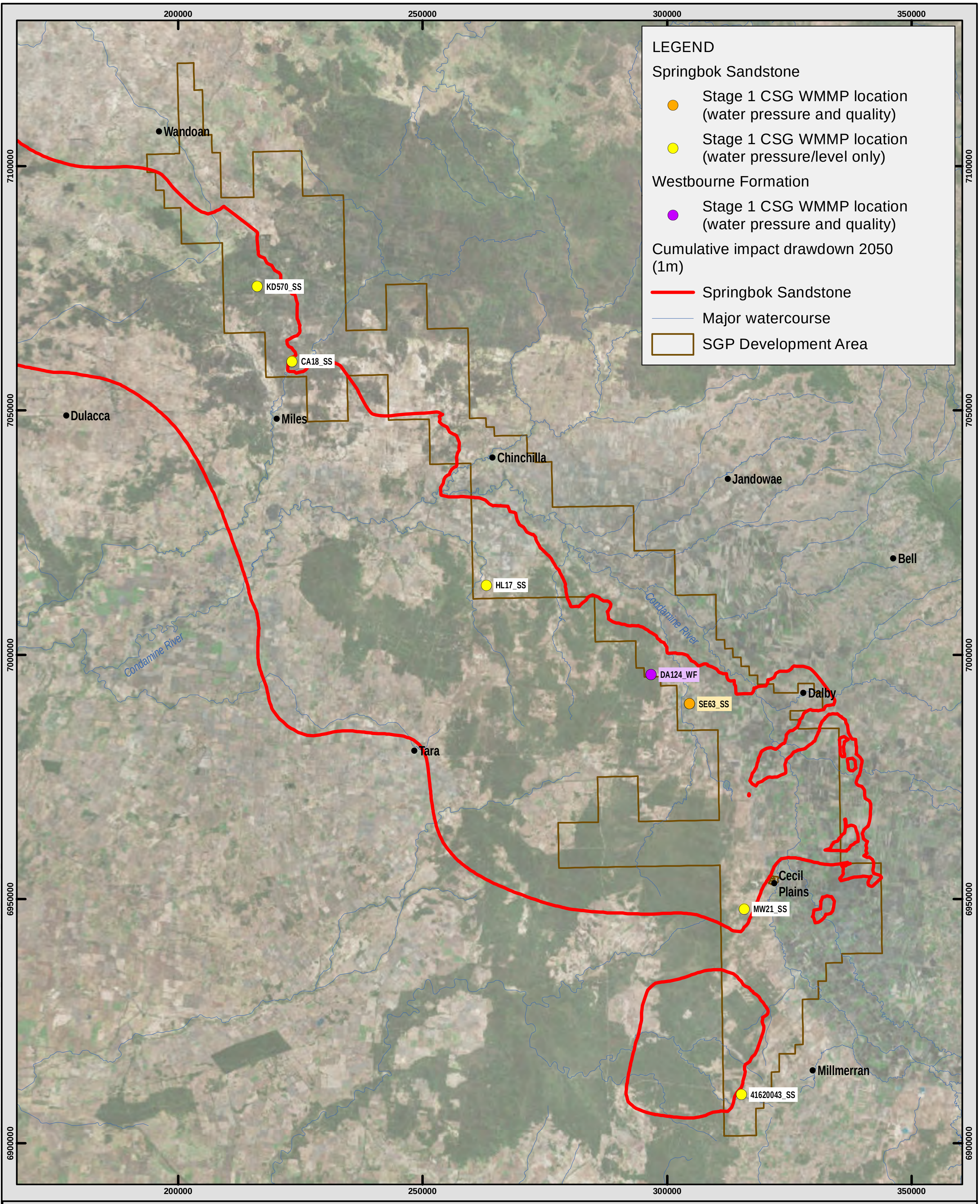

Figure 6.**3** Stage 1 CSG WMMP monitoring points (Springbok Sandstone aquifer and Westbourne Formation)

Source:
Arrow Energy Pty Ltd
GHD, Coffey
ESRI Online

Date: 20/11/2017
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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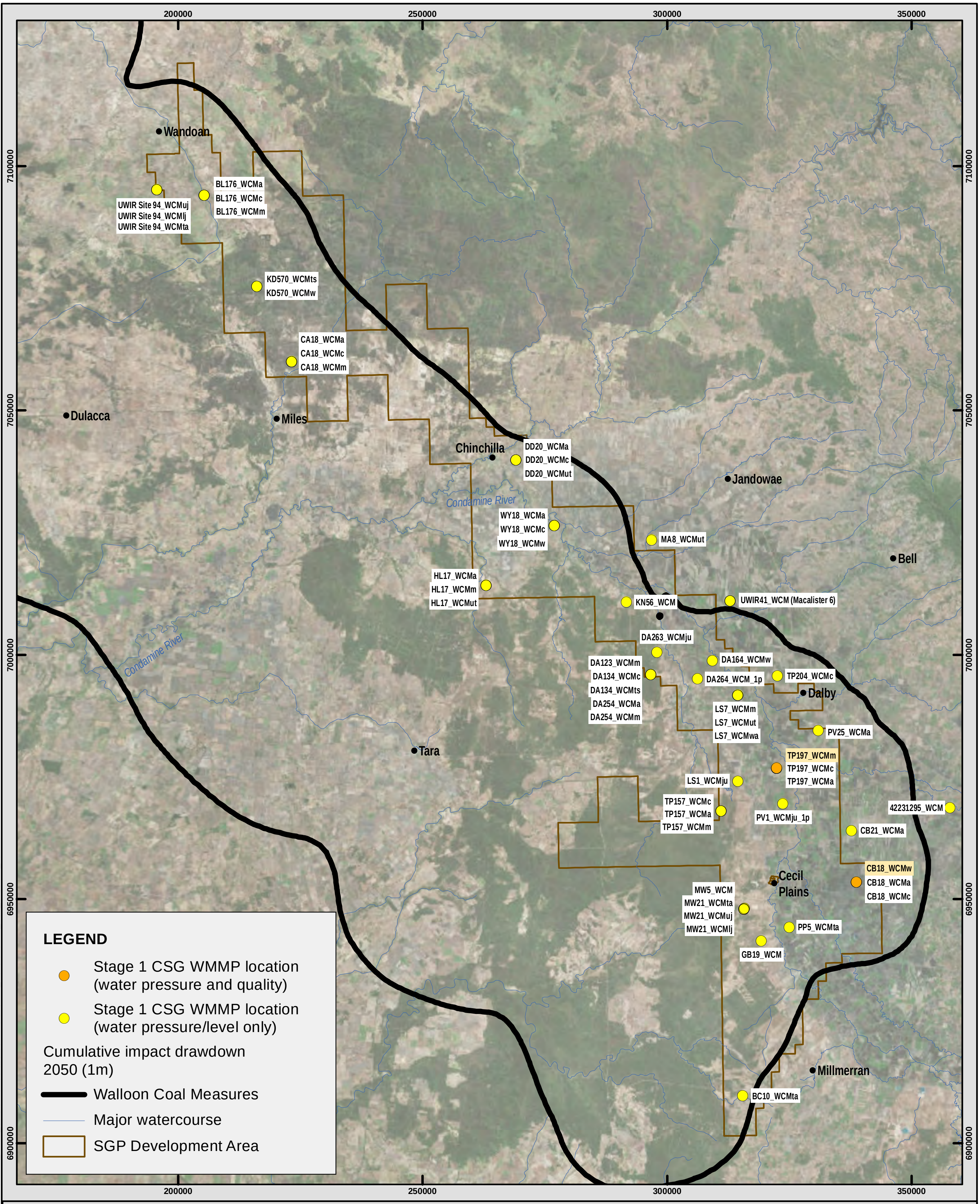

Figure 6.**4** Stage 1 CSG WMMP monitoring points (Walloon Coal Measures)

Source:
Arrow Energy Pty Ltd
GHD, Coffey
Bing Maps Online

Date: 5/12/2017
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

N

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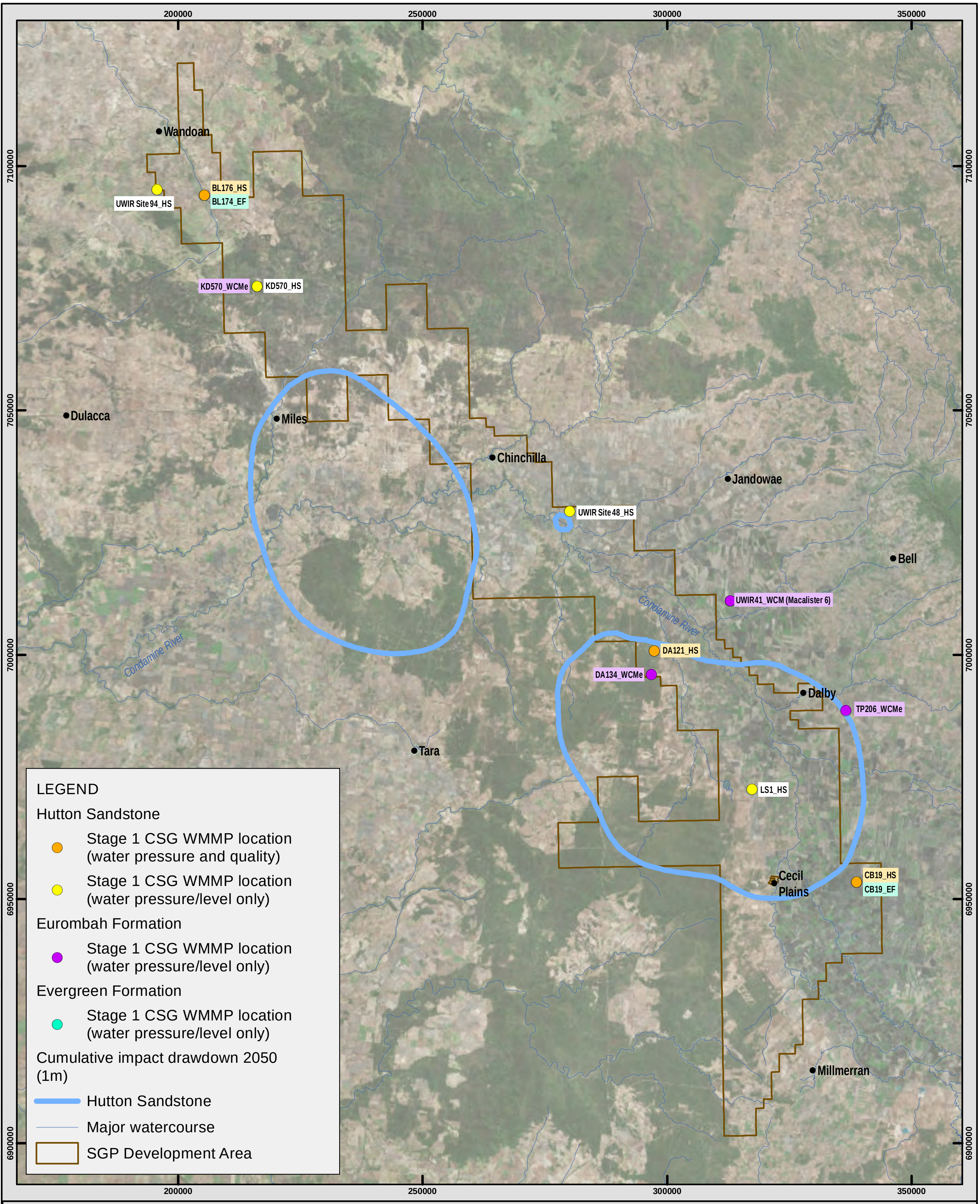

Figure 6.5

Stage 1 CSG WMMP monitoring points
(Eurombah Formation, Hutton Sandstone and Evergreen Formation)

Source:
Arrow Energy Pty Ltd
GHD, Coffey
ESRI Online

Date: 20/11/2017
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres

Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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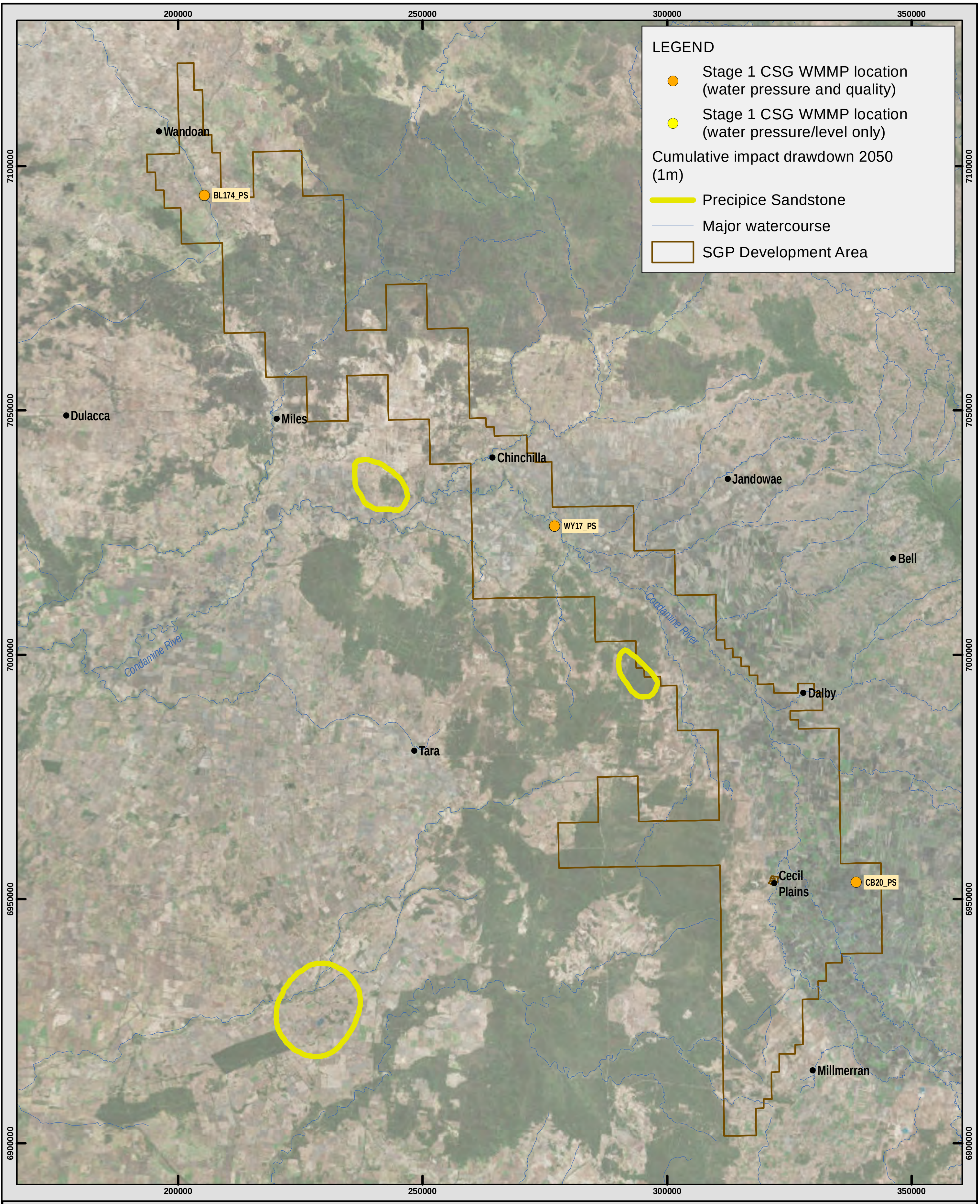

Figure 6.**6** Stage 1 CSG WMMP monitoring points (Precipice Sandstone aquifer)

Source:
Arrow Energy Pty Ltd
GHD, Coffey
ESRI Online

Date: 20/11/2017
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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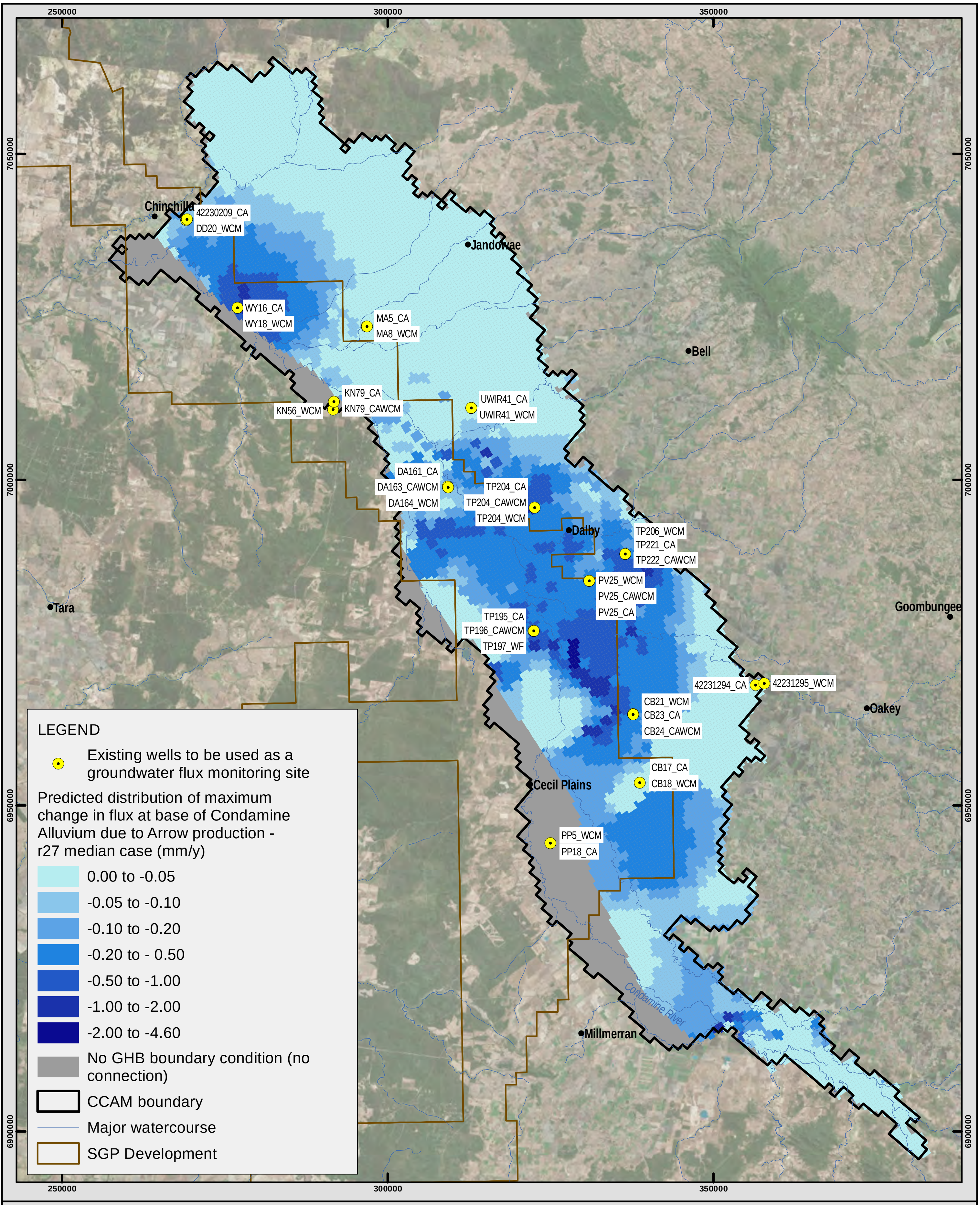

Figure 6.7 Condamine Alluvium flux monitoring locations

Source:
Arrow Energy Pty Ltd
ESRI Online

Date: 8/11/2017
Issued To: Arrow Energy
Author: Helen.Unkovich

0 3.75 7.5 15 22.5 30 37.5 45
Kilometres
Scale: 1:750,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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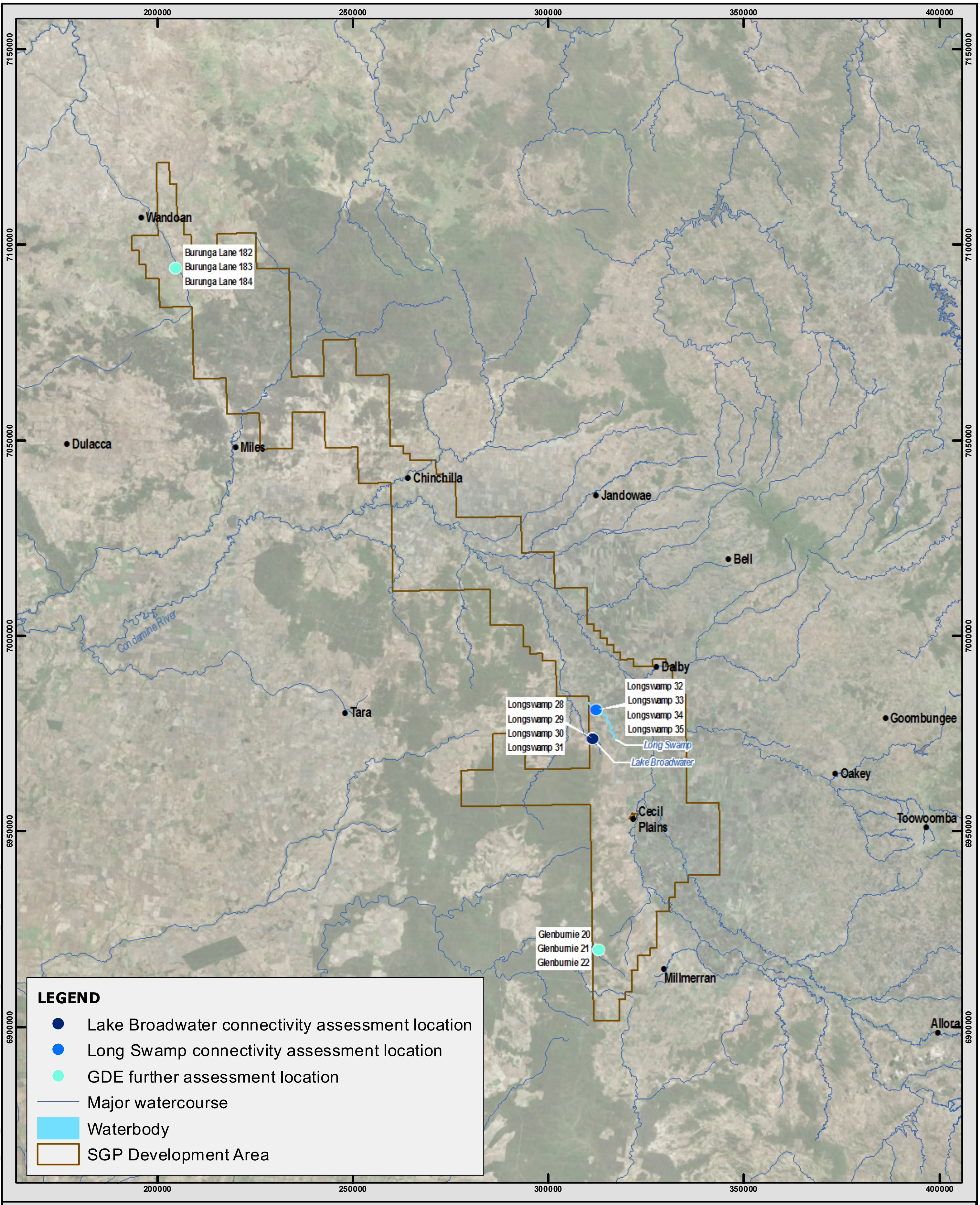

Figure 6.8 GDE investigation locations

Source:
Arrow Energy Pty Ltd

Date: 13/07/2017
Issued To: Arrow Energy
Author: grant.young

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,250,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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6.1.4 Groundwater pressure/level monitoring program

Groundwater pressure will be monitored at all active monitoring network locations. The following monitoring frequencies will be adopted for the Stage 1 CSG WMMP and are consistent with the Surat CMA UWIR monitoring requirements:

- Hourly frequency of data collection where a data logger[19] is installed. Where this occurs, bi-annual manual readings will also be collected in wells with open standpipes. This data will be used in conjunction with logger download data.
- Fortnightly data collection where a data logger is not installed.

Within 30 days of the end of each 6-monthly period, data validation (via the data QA/QC process detailed in Section 6.3.3) and a comparison of data against the EWMS early warning indicators, trigger thresholds and limits of the data collected will be completed. Collection of additional field data (if required) will be completed as soon as practicable but not within the aforementioned 30 day period.

The results of this evaluation will be reported on an annual basis (exceedance response times specified in Section 5 will still apply). Where there is confidence that the baseline trends are established, the monitoring frequency may be reduced.

6.1.5 Groundwater quality monitoring program

Fifteen groundwater monitoring wells, at nine discrete monitoring locations have been specified for groundwater quality sampling as presented in Figures 6.1 to 6.6 and detailed in Table 2.5 of Appendix J (Groundwater Monitoring Network and Program technical memorandum). These will provide baseline groundwater quality data as well as ongoing monitoring data.

The groundwater quality sampling frequency is presented in Table 6.2, and physical parameters and analytical suites for laboratory analysis are presented in Table 6.3.

Table 6-2. Groundwater sampling schedule

	Laboratory sampling suite		
	Full suite	Standard suite	Supplementary suite
Frequency	Bi-annually for first year	Bi-annually (for following years)	Discretionary based on full/standard suite analytical results

Bi-annual sample scheduling for the ongoing sampling is adopted because:

- The frequency is consistent with the UWIR sampling schedule.
- Bi-annual sampling sufficiently reduces the effect of seasonality, due to generally consistent sampling periods from year to year.

---

[19] Pressure transducer or vibrating wire piezometer (VWP) with data logging capabilities

Table 6-3. Groundwater sampling parameters and analysis

Suite	Parameters	Explanation
Physical parameters	▪ Electrical conductivity (µS/cm @ 25°C) ▪ pH ▪ Redox potential (Eh) ▪ Dissolved oxygen (DO) ▪ Temperature ▪ Free gas at wellhead (CH_4)	Field analysis only – undertake at each sampling event
Full laboratory analytical suite	▪ Total dissolved solids (TDS) ▪ Major ions (calcium, magnesium, potassium, sodium, chloride, sulfate, bicarbonate, carbonate), total alkalinity ▪ Fluoride ▪ Dissolved metals (arsenic, barium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, strontium, zinc) ▪ Dissolved methane	Full suite to be analysed during first year. Subsequent to this, the parameter suite may be amended or reduced, depending on the results of the initial analysis (to be assessed on a well-by-well basis).
Supplementary (discretionary)	▪ Stable isotopes ▪ Silica ▪ Bromine ▪ Lithium ▪ Speciated nitrogen (nitrate, nitrite, ammonia) ▪ Total nitrogen, TKN ▪ Total phosphorus	Targeted laboratory analysis where field observations or circumstances indicate need.

Monitoring for hydrocarbon analytes (TPH, BTEX, etc.) as an indicator of connectivity with coal-bearing formations is not planned, because of the significant potential for false positives due to spurious causes, and in particular due to sources associated with the drilling and well construction process. In addition, modelling predictions demonstrate that pressure gradients due to CSG extraction result in hydraulic gradients towards the Walloon Coal Measures (and not the reverse). Monitoring for hydraulic connectivity will primarily be based on pressure response monitoring.

6.2 Surface water and aquatic ecology monitoring

Surface water and aquatic ecosystems are not predicted to be impacted by WCM depressurisation to the extent that adverse ecosystem effects would arise (refer Appendix D). Further, under the WMS (Attachment 1 of Appendix G), discharge of produced water to surface water systems is not proposed, therefore precluding the need to identify monitoring requirements in the Stage 1 CSG WMMP.

The existing environment baseline for surface water and aquatic ecology is described in the SGP EIS/SREIS.

Identification of further baseline and ongoing monitoring locations will occur, where relevant, should future project requirements and/or future revision of the FDP result in the potential for impact to surface water systems and aquatic ecology.

6.2.1 Baseline network

A network of surface water and aquatic ecology monitoring locations was established as part of the SGP EIS/SREIS process. These included surface water quality, flow and aquatic ecology monitoring locations. Locations were selected to provide baseline data across representative conditions for the different surface water systems and land uses within the SGP area, at the time of the EIS/SREIS. The location of these sites is presented in Figures 3.1a, b and c of Appendix J. Further to this, baseline data is available via the Queensland DNRME state monitoring network, with 17 currently open surface water gauging stations situated in or in close proximity to Arrow's tenure, 15 of which monitor water quality (422361A and 422343A do not monitor water quality). These figures show that a network of baseline monitoring locations are established in the vicinity of connected reaches of the Condamine River south of Chinchilla (monitoring site 69 and 422308C), several sites immediately south of Cecil Plains (e.g. monitoring sites 7, 422316A, and DA9-2), monitoring site 422355A south-east of Millmerran and monitoring site 10 at Lake Broadwater. Note; as shown in the figures, additional monitoring of surface water has also been undertaken in reaches of the Condamine River and tributaries not connected to groundwater.

It is also noted that the OGIA set out the requirements for responsible tenure holders for monitoring of potentially affected watercourse springs. Arrow are not the responsible tenure holder for any identified watercourse springs, and no monitoring sites nominated by the OGIA are located within relevant areas for the SGP.

Where field studies at Long Swamp and Lake Broadwater (as described in Section 6.1.3) indicate the potential for these systems to be groundwater dependent, and impact to these systems as a result of the Action is predicted, a best practice baseline monitoring network will be established with consideration for the existing data, and ongoing data requirements to appropriately monitor these features. The following will be taken into consideration when selecting surface water and aquatic ecology monitoring sites for ongoing use, where they are required:

- Establishment of reference sites where required.
- Permanent, semi-permanent, lotic or lentic nature of water bodies.
- Ephemeral or perennial nature of streams.

Changes to the monitoring network and program in relation to aquatic ecology and ecosystems will be captured in annual review reports and the Stage 2 CSG WMMP.

6.2.2 Surface water and aquatic ecology monitoring program

Surface water flow, quality and aquatic ecology monitoring will be carried out at specific locations to establish baseline conditions if future assessment indicates the potential for groundwater drawdown related impact. Monitoring activities will commence in advance of the potential for impact to occur, to enable the establishment of baseline conditions and development of WQOs where required.

Minimum requirements for monitoring data collection are defined (DEHP, 2009) for the establishment of baseline conditions, in particular for the establishment of reference[20] sites.

DEHP (2009) generally requires reference sites to be relatively unaffected by surrounding land use, and not significantly affected by surface water abstraction or regulation. Data collected from reference sites are used to establish water quality guidelines, and ultimately WQOs based on calculated percentiles.

For slightly disturbed to moderately disturbed[21] water bodies, the 20th and 80th percentiles of reference site values should be used based on:

- Eight data points (minimum) collected over at least 12 months from one or two reference sites; or
- Twelve data points (minimum) collected over at least 12 months from three or more reference sites; or
- Eight data points collected over 12 months for interim data sets (subject to validation and update based on further data collection); and
- For ephemeral sites, a minimum of two reference sites are used to derived WQOs.

6.2.3 Surface water and aquatic ecology monitoring schedule

Should future assessment indicate the potential for groundwater drawdown related impact, the monitoring frequency for establishment of baseline conditions and ongoing monitoring is detailed in Table 6.4. This will take in to account existing data and the need for additional baseline data, as relevant to the site.

Table 6-4. Monitoring frequencies for baseline condition and impact monitoring

Monitoring domain	Monitoring type	Frequency	Monitoring suite
Ephemeral streams	Water quality and flow	Continuous (logged)	EC, temperature and water level. Flow derived from level.
	Water quality	Bi-annually (when flowing)	Physical parameters Full surface water baseline
	Aquatic ecology	Annually	Aquatic ecology
Perennial streams	Water quality and flow	Continuous (logged)	EC, temperature and water level. Flow derived from level.
	Water quality Aquatic ecology	Bi-annually (nominally pre- and post-wet season)	Physical parameters Full surface water baseline

---

[20] Sites considered to be suitable baseline or benchmark for the assessment and management of sites in similar water bodies

[21] Watercourses within the SGP area are reported to range from slightly to highly disturbed

Monitoring domain	Monitoring type	Frequency	Monitoring suite
			Aquatic ecology

Given the variable flow conditions and site setting of each monitoring location the specific monitoring requirements at each location will be tailored to suit the specific water quality objectives for that site, and also take into account the robustness of the available dataset. The identification of impacts may also trigger additional monitoring requirements.

Monitoring parameters

The suite of parameters set out (Table 6.5) is consistent with water quality assessments carried out for the SGP EIS/SREIS. For the Stage 2 CSG WMMP the suite will be reviewed and amended as required for site-specific conditions based on available data and the nature of potential impacts predicted.

Table 6-5. Surface water and aquatic ecology monitoring parameters

Suite	Parameters	Explanation
Physical parameters	▪ Electrical conductivity ▪ pH ▪ Dissolved oxygen (DO) ▪ Temperature ▪ Turbidity ▪ Redox potential (Eh)	In-situ analysis only.
Full surface water (laboratory)	▪ Total dissolved solids (TDS) and total suspended solids (TSS) ▪ Major cations and anions (calcium, magnesium, potassium, sodium, chloride, sulfate, bicarbonate alkalinity, carbonate alkalinity) ▪ Total alkalinity ▪ Speciated nitrogen (nitrate, nitrite, ammonia) ▪ Total nitrogen, total oxidised nitrogen, total Kjeldahl nitrogen (TKN) ▪ Reactive phosphorus, total phosphorus ▪ Fluoride ▪ Sodium adsorption ratio ▪ Total and dissolved metals (arsenic, boron, cadmium, cobalt, copper, lead, mercury, nickel, selenium, vanadium, zinc) ▪ Phenol ▪ Triethylene glycol (TEG)	Full suite to be analysed during first year. Subsequent to this the suite may be reduced, depending on the results of the initial analysis and ongoing assessment requirements.
Aquatic ecology	▪ Physical parameters (as above) ▪ AusRivAS assessment (macroinvertebrates) ▪ Fish and habitat assessment	

6.3 Baseline monitoring and data interpretation

As described in Sections 6.1 and 6.2, comprehensive water monitoring data have been collected for the SGP, providing a baseline against which impacts can be assessed and trends established.

Methods for trend analysis will include standard statistical measures, such as Mann-Kendell test and regression analysis. A detailed approach for groundwater level and water quality trend analysis will be established and set out in the Stage 2 CSG WMMP, as required under Condition 17(h).

6.3.1 Groundwater baseline monitoring

Groundwater level baseline monitoring is being undertaken in all active wells (77 in total) forming the Stage 1 CSG monitoring network (Section 6.1.2), according to the program described in Section 6.1.4. Groundwater level baseline monitoring for the Stage 1 CSG WMMP well network commenced in 2008 and as monitoring wells have been installed the baseline monitoring program has expanded.

Table 6.6 lists the year baseline groundwater level monitoring commenced for monitoring wells in each formation of the Stage 1 CSG WMMP monitoring network. As indicated in Table 6.6, the majority of the baseline groundwater level monitoring commenced in 2013 and 2014, providing 4 to 5 years of historic groundwater level data to date.

Table 6-6. Stage 1 CSG WMMP monitoring network – history of groundwater level baseline activities

Formation	Year of commencement of baseline groundwater level monitoring and number of monitoring well locations						
	2008	2013	2014	2015	2016	2017	Total monitoring well locations
Condamine Alluvium		9	3	1	3	2	18
CA / WCM transition layer		1	3	1		2	7
Westbourne Formation		1					1
Springbok Sandstone		4	1	1			6
Walloon Coal Measures	4	5	11	7	3	1	31
Eurombah Formation		1	1	1		1	4
Hutton Sandstone		1	3				4
Precipice Sandstone		1	2				3
Evergreen Formation		1	1				2
Total monitoring well locations	**5**	**24**	**25**	**11**	**6**	**6**	**77**

As described in Section 6.1.5, fifteen groundwater monitoring wells, at nine discrete monitoring locations, have been specified for groundwater quality sampling to provide baseline groundwater quality data as well as ongoing monitoring data. Formations targeted for baseline groundwater quality monitoring include the Condamine Alluvium, Westbourne Formation, Springbok Sandstone, Walloon Coal Measures, Hutton Sandstone and Precipice Sandstone.

Groundwater sampling of these locations for baselining purposes commenced in 2013 and 2014 and at bi-annual frequencies in accordance with the program specified in Section 6.1.5, providing 4 to 5 years of historic groundwater baseline quality data to date.

In addition to the baseline data that has already been collected across the Stage 1 CSG WMMP network, a substantial volume of data is baseline data is available across the broader Surat CMA UWIR network (refer Section 6.1.1) as well as monitoring wells registered in the DNRM database.

6.3.2 Surface water and aquatic ecology baseline monitoring

A network of surface water quality, flow and aquatic ecology monitoring locations was established as part of the EIS/SREIS process and ongoing monitoring is carried out by the Queensland government and also tenure holders assigned responsibilities under the Surat CMA UWIR in relation to watercourse springs.

For the EIS/SREIS baseline monitoring, locations were selected to provide baseline data across representative conditions for the different surface water systems and land uses within the SGP development area. Table 6.7 presents a summary of the currently available baseline surface water and aquatic ecology data.

Table 6-7. Stage 1 CSG WMMP monitoring network – history of groundwater level baseline activities

	Project phase	No. sites monitored	Monitoring events
Surface water quality	EIS	35	October 2009 November 2009 March 2010
	SREIS	15	February 2013
	DNRME[1] active network	10[2]	1993 - present (continuous EC and temperature monitoring)
		15[2]	1962 - present (Periodic monitoring of a broad water quality suite)
Aquatic ecology	EIS	11	November 2009 May 2010
	SREIS	22	February / March / May 2013

1: DNRME: Department of Natural Resources, Mining and Environment

2: Active monitoring sites within or in close proximity to the SPG

6.3.3 Data validation, exceedances and trend analysis

Rigorous interpretation of data to understand groundwater-related impacts resulting from the Action is required, and will include QA/QC procedures to validate data, and statistical methods for assessing trends.

Data QA/QC to be undertaken will include checking and verifying data by:

- Reviewing and checking data and field documents to identify transcription errors.
- Reviewing and checking the calibration of measurement equipment (for example data loggers and piezometers).
- Barometric compensation of uncompensated logger data.
- Data cleansing/filtering to minimise the effects of spurious data.
- Correlation of logged data against manually gauged data.

If necessary, further field data can be obtained to confirm or clarify the results.

Where an exceedance is indicated based on preliminary screened data, further detailed trend analysis will be undertaken and the methods employed will be documented in the exceedance report. This will include an estimate of:

- The component of drawdown due to Arrow operations, based on evaluation through statistical or modelling methods.
- Assessment of whether the exceedance is due to natural system variability or third-party groundwater abstraction, and where required compared to data from regional monitoring locations to identify whether an apparent exceedance is a result of regional hydrological or climate change.

An analysis of trends may be undertaken to assist with the assessment of data. Methods may include standard statistical measures, such as (for example) Mann-Kendell test, regression analysis, and serial correlation.

Modelling, where adopted to differentiate Arrow’s component of drawdown from cumulative drawdown, will utilise the latest OGIA model version (or its equivalent), recalibrated as necessary and incorporating (where available) updated production data for other CSG and non-CSG extractors, and other relevant data. This will enable the calculation of the Arrow-only proportion of the impact for comparison with previous predictions. In addition, this process will also be undertaken within 90 days of the release of each new UWIR, to establish revised early warning indicators, trigger thresholds and limits.

7. SUBSIDENCE ASSESSMENT AND MONITORING

A technical memorandum relating to subsidence was prepared to support development of the Stage 1 CSG WMMP and to address the requirements of condition 13(g) and is provided in Appendix K.

7.1 Baseline monitoring

Monitoring of subsidence was carried out by Altamira using satellite borne Interferometric Synthetic Aperture Radar technology (InSAR), a radar technique used in geodesy and remote sensing (Altamira, 2016). Data was obtained from Radarsat-2 satellite images covering 10,736 km^2 of Arrow SGP leases. InSAR makes use of the amplitude and the absolute phase of the return signal data to enable accurate determination of surface elevation. The change in phase difference between locations can be used to interpret changes in relative position, and indicate subsidence for different regions within areas potentially affected by CSG drawdown.

The InSAR data provides a baseline from which future data can be assessed to determine changes in vertical ground elevation, and also provides a snapshot of current vertical ground movement.

7.2 Assessment of subsidence

Predictions of drawdown resulting from the Action underpin the predictions of potential subsidence.

7.2.1 Predicted subsidence

The method for predicting subsidence is presented in detail in Appendix K.

When assessing subsidence impacts, consideration was given to both the absolute subsidence magnitude, as well as differential settlement.

Predicted subsidence effects on general farmland, small dams, and river hydrology, for movements of less than 100 mm over a distance of 1 km, are not considered likely to result in adverse impacts. Farmhouses, farm sheds and other small buildings can be assessed under the criteria for other buildings and structures.

Mines and mine infrastructure are typically subject to local ground movement associated with the mining operation and are also considered unlikely to be adversely affected by the anticipated magnitudes of CSG induced subsidence.

Assessed subsidence contours associated with predicted drawdown from Arrow operations only and cumulative cases for 2030 and 2050 for both the high and low settlement assumptions are presented in Figures 7.1 and 7.2 respectively.

Figures 7.3 and 7.4 present the predicted subsidence at 2030, for the high assessment, overlaid upon the Arrow SGP drainage areas for each scenario (Arrow only and cumulative cases respectively).

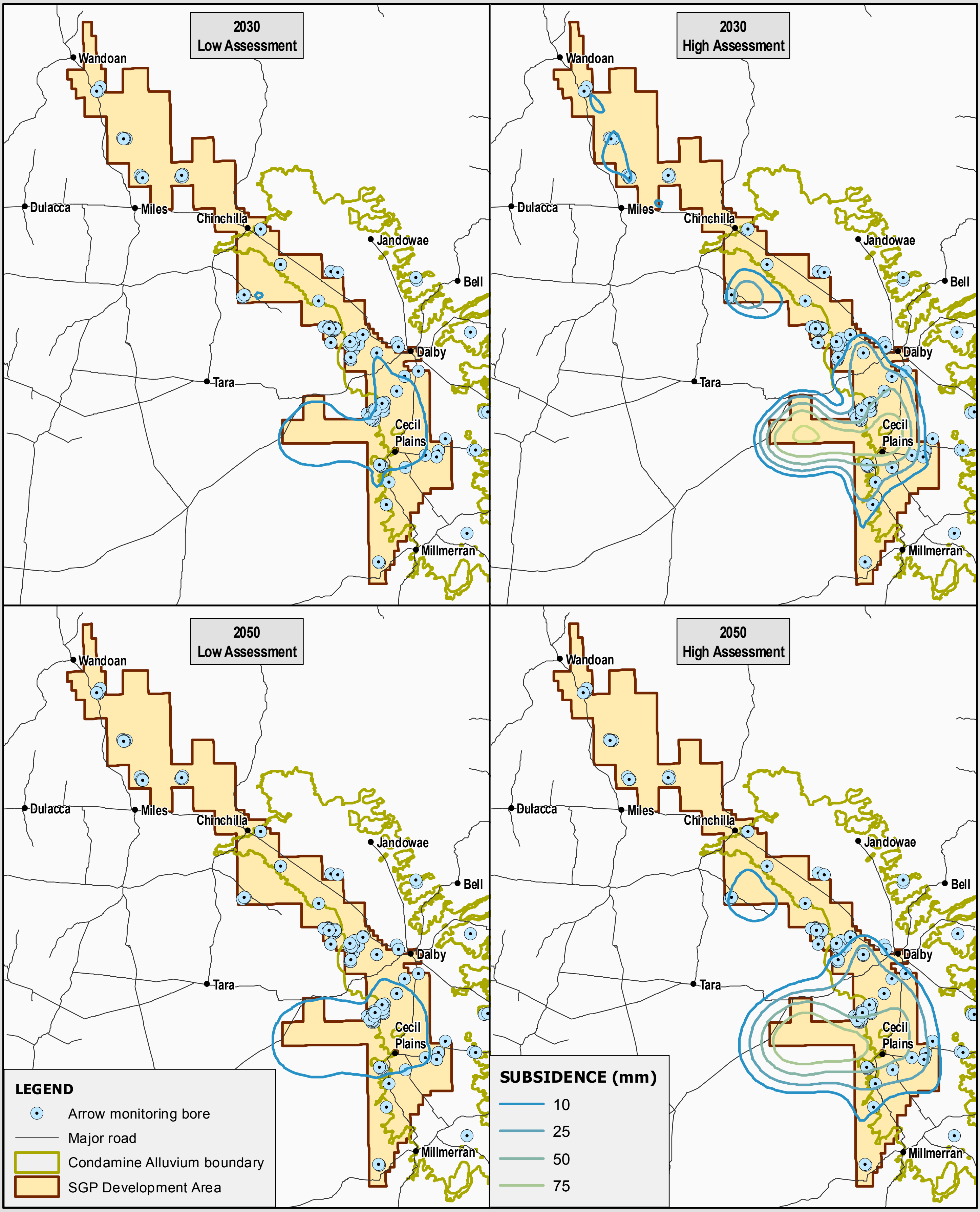

Figure 7.1 **Subsidence assessment - Arrow only case**

Source:
Arrow Energy Pty Ltd
Coffey

Date: 14/07/2017
Issued To: Arrow Energy
Author: grant.young

0 10 20 40 60 80 100 120
Kilometres
Scale: 1:2,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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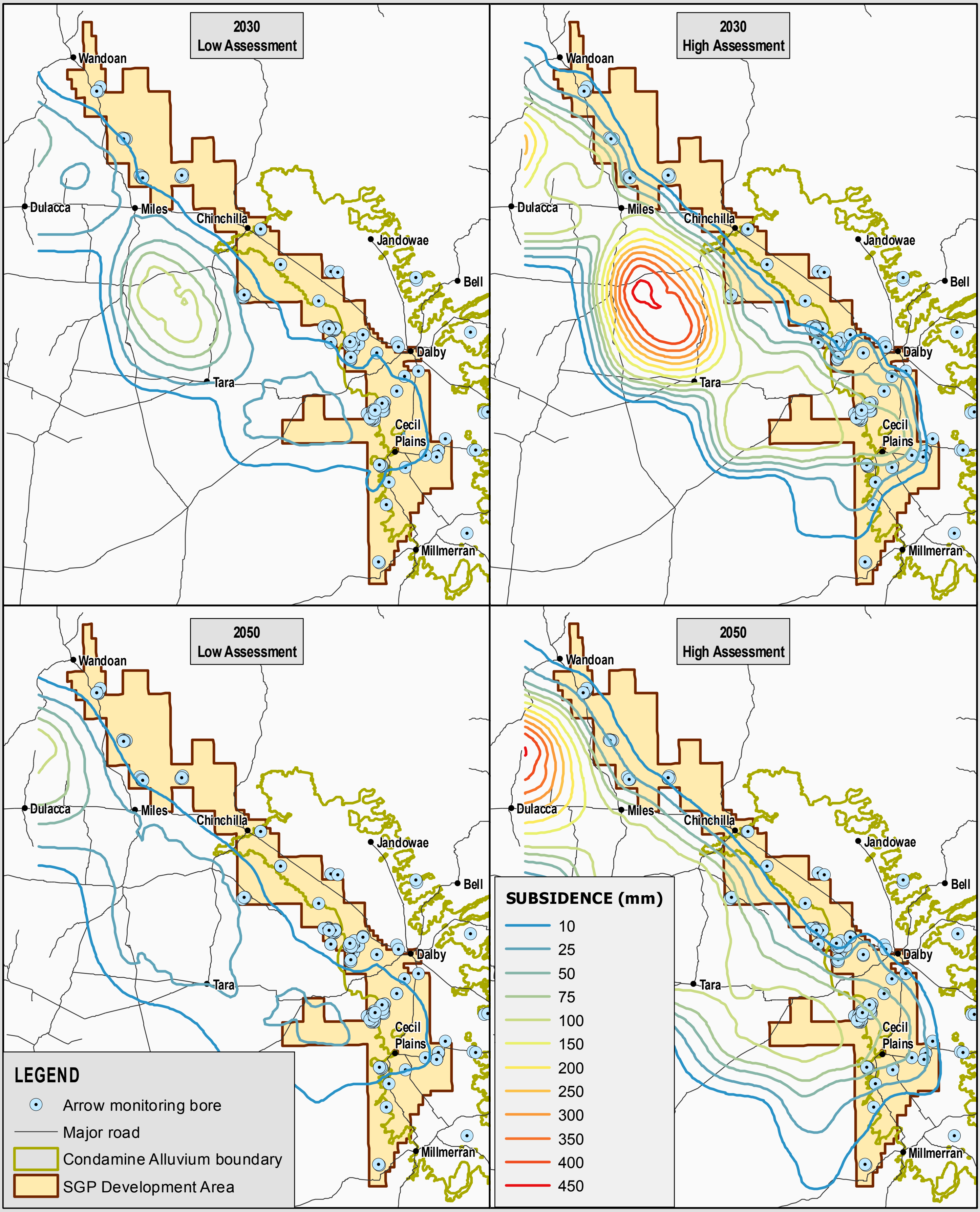

Figure 7.2 Subsidence assessment - cumulative case

Source:
Arrow Energy Pty Ltd
Coffey

Date: 14/07/2017
Issued To: Arrow Energy
Author: grant.young

0 10 20 40 60 80 100 120
Kilometres
Scale: 1:2,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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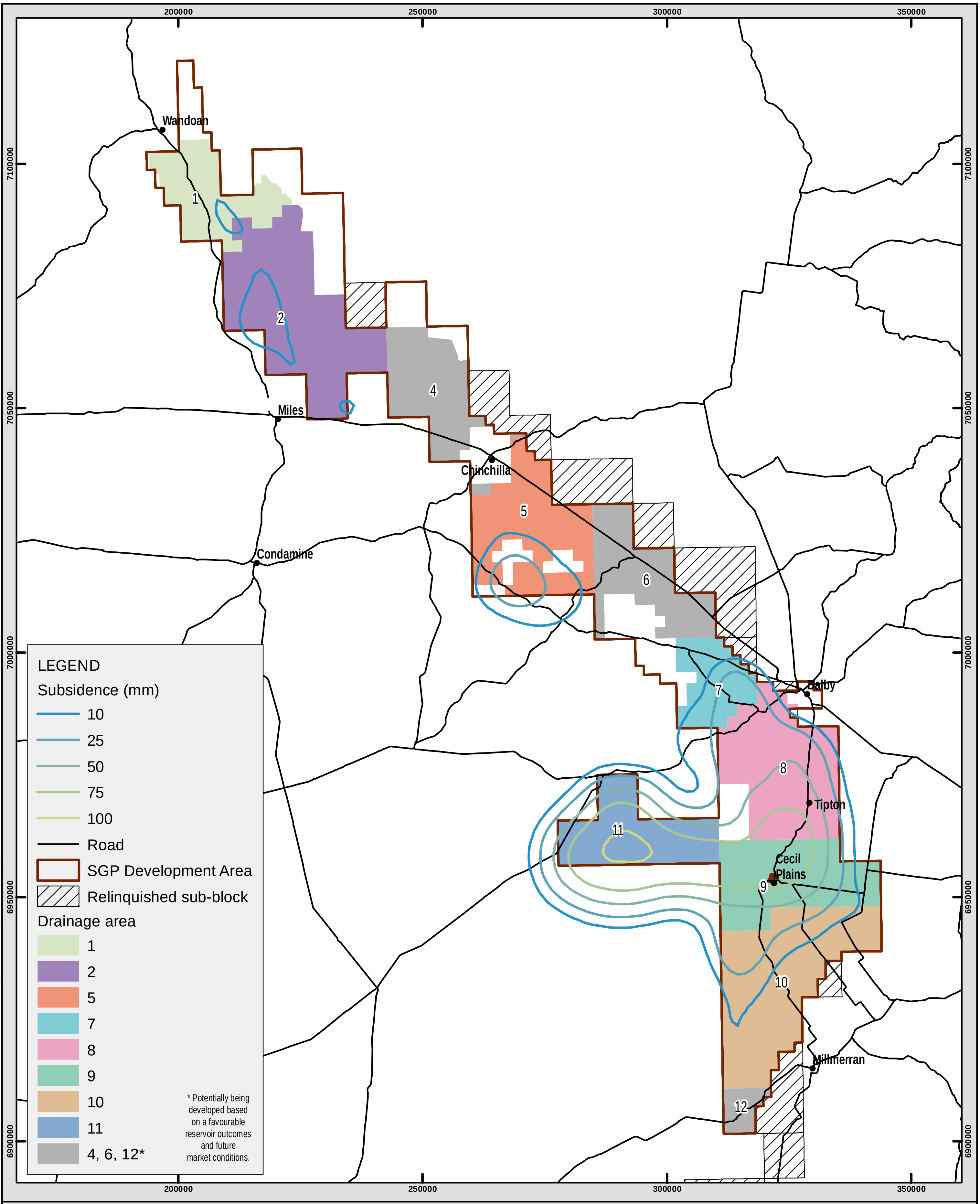

Figure 7.3 Predicted subsidence 2030 High assessment - Arrow only case

Source:
Arrow Energy Pty Ltd
Coffey

Date: 8/11/2017
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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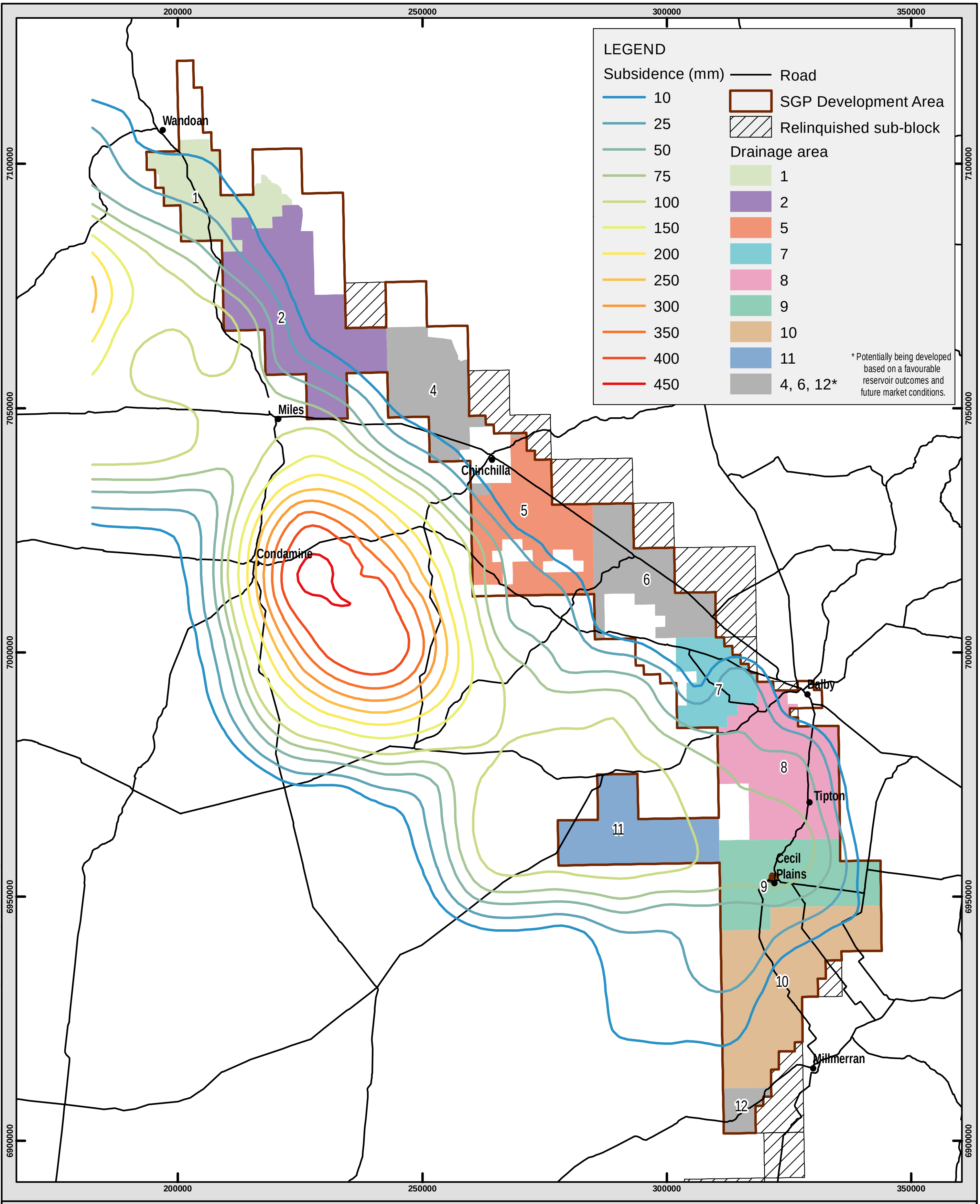

Figure 7.4

Predicted subsidence 2030 High assessment - Cumulative case

Source:
Arrow Energy Pty Ltd
Coffey

Date: 27/11/2017
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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7.3 Risk assessment

Risks associated with subsidence caused by CSG extraction were assessed using the approach set out in the Australian and New Zealand Standards Association Handbook SA/SNZ HB 89:2013. Under this approach, an ‘event’ is considered as CSG induced subsidence movement affecting an existing asset.

The likelihood of subsidence of a particular magnitude was assessed by reference to the subsidence measured to date, and the predictions for future subsidence. The consequence of an event of particular magnitude was assessed based on the nature of an asset and its sensitivity to movement.

7.4 Subsidence trigger thresholds

Trigger thresholds have been developed for CSG induced [22]subsidence as required by approval condition 13(g). They are derived from calculated risk assessments of potential subsidence, and taking into account the outcomes of the risk assessment process.

An initial screening level has been set to identify areas for targeted further assessment of settlement and evaluation of whether the trigger thresholds have been exceeded. The general assessment process that will be implemented is presented in Figure 7.5.

7.4.1 Screening level

Initial screening will involve identification of areas where significant subsidence is occurring based upon the annual rate of subsidence reported from InSAR monitoring results. This initial screening will involve identification of areas of 1 km by 1 km where more than 50% of the InSAR monitoring points indicate an annual subsidence rate of more than 8 mm/yr (a movement rate discernible using InSAR methods). In areas where this level of movement is recorded, further assessment will be carried out to assess whether the investigation levels as nominated in section 7.4.2 are exceeded.

7.4.2 Investigation Levels

In areas where the screening level is exceeded, further assessment of relevant data relating to subsidence will be undertaken. This will include an assessment of the CSG-related subsidence component of the reported InSAR measurements with consideration for the cumulative industry impact and reported subsidence since the commencement of the Action.

Investigation levels have been defined as set out in Table 7.1. Where the CSG-related subsidence exceeds the investigation levels set out in Table 7.1, further assessment will be carried out to assess the site-specific infrastructure that may be impacted and identify whether an impact has occurred as a result of the Action.

---

[22] Subsidence rates that have non-CSG influences (i.e. natural fluctuation and other anthropogenic influences) removed

7.4.3 Trigger threshold

Where the investigation levels nominated in Table 7.1 are breached additional investigation of the affected area will be carried out using conventional survey methods for a period of six months. The results of the survey will be tested against asset-specific thresholds (refer Appendix K for further detail). For example in the case of structures, assessment of damage categories as a result of ground movement would be based upon the guidance presented in Burland, 2012.

Where adverse impacts are identified to have occurred based on the results of the site-specific investigation, a trigger threshold is considered to have been exceeded and mitigation measures will be employed following the approach set out in Section 7.4.3.

7.4.4 Trigger threshold exceedance response actions

Approval condition 13(g) requires the development and implementation of an action plan to address identified subsidence impacts within 90 calendar days of a trigger threshold being exceeded.

Trigger threshold exceedance response actions are dependent on the evaluation of the cause of the exceedance, and if the potential for detrimental impacts is confirmed, a mitigation (action) plan will be developed and implemented within 90 days to minimise impact. The mitigation plan will:

- Identify potential mitigation measures and response actions.
- Select suitable response actions, tailored to site-specific conditions, impact cause, timing and magnitude.
- Evaluate time frames within which impacts would be expected to occur and within which mitigation actions would need to be successful.
- Schedule mitigation implementation, with consideration for the anticipated timing of the indicated impact.
- Contain procedures to evaluate the effectiveness of the mitigation measures.

Where an action plan is not developed and implemented within 90 calendar days of the identified trigger threshold exceedance this represents a non-compliance and the Minister will be notified.

Item	Description	Criteria	Relevant assets	Basis for selection / comment
Screening level	Settlement rate	8 mm/year (for >50% of sampling points in 1 km by 1 km block)	All natural features, man-made features and built infrastructure	Areas where this criterion is exceeded will be subject to investigation of subsidence (refer Appendix K).
Investigation levels	Gradient change	0.03 % (300 mm per 1,000 m)	Irrigation system (laser levelled)	Based upon half the slope of minimum grades recommended by the Cotton Research and Development Corporation for furrow irrigation. Areas where this criterion is exceeded will be subject to investigation of subsidence (refer Appendix K), including review of laser levelling practices.
	Differential settlement (built infrastructure)	0.001 m/m	Buildings, structures	• Selected for buildings as the most sensitive item in this group (refer Appendix K). • Not relevant to linear infrastructure (roads, rail, transmission lines and pipelines) as predicted differential settlement is well within the tolerance of these facilities. • Not relevant to bushland or farmland.
	Change in slope (natural features)	25 mm/1,000 m	Flood flow in watercourses	• Taken as 5% of topographic gradient of the Condamine Plain. • Applies only to the main channel of the Condamine River. • Review of effects on flow and conventional survey would be carried out to assess the significance of the change.
Trigger threshold	Outcome of site specific monitoring using conventional survey and review of risk to asset.	Individual threshold based on the local conditions	Irrigation system, structure or watercourse	• Site specific assessment based upon conventional survey of identified asset. In the case of potential impacts on structures within populated areas the assessment will be based upon selected structures considered to be most vulnerable.

Table 7-1. Subsidence monitoring screening level, investigation levels and trigger threshold

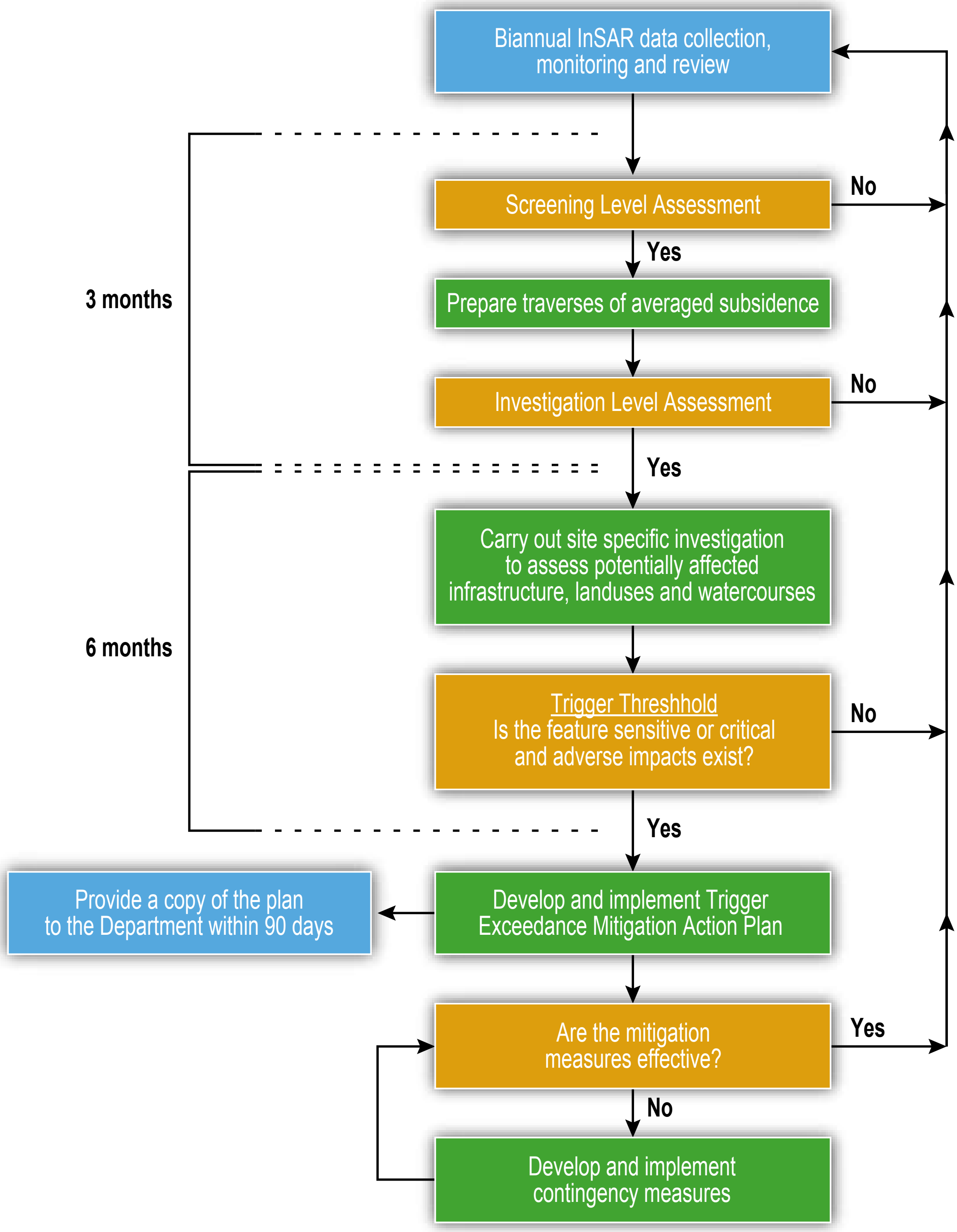

Figure 7.5 Subsidence monitoring assessment flow chart

Source:
Coffey

Date: 19/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich / Richard.heath

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7.5 Monitoring program

The current monitoring program provides groundwater level monitoring, and monitoring of subsidence using InSAR technology. InSAR technology provides high resolution and wide coverage, however separate geodetic measurement of ground movement will be taken at selected locations to provide a ground-truthing check and control on the InSAR results.

7.5.1 Measurement techniques and subsidence monitoring stations

Measurement techniques that can contribute to the assessment of subsidence impacts include:

- Tiltmeters, to measure small changes in ground slope.
- Survey using traditional or GPS methods.
- Extensometers in boreholes.
- Condition assessments of structures at risk.

Of these methods, the use of extensometers and survey to ground truth-the results of InSAR monitoring are considered most useful. Extensometers allow identification of the horizons in the ground profile contributing to surface settlement.

Locations for geotechnical ground movement monitoring will be co-located with groundwater monitoring bores where possible to provide coverage of the full ground profile potentially influenced by the SGP. Instrumented sites will be preferentially located at the centre of selected SGP well-fields, and will be installed to provide baseline information prior to the initiation of water production. The timing of monitoring location installation will reflect the FDP sequencing.

Figure 7.6 sets out locations recommended for establishment of subsidence monitoring stations that would comprise:

- Groundwater monitoring at multiple locations including within, above and below the WCM.
- Geodetic ground movement (vertical) monitoring monument (installed to avoid shrink swell movement of the upper soils).

In addition, at one station (SMS1 in Drainage Area 11, refer Figure 7.6) an extensometer array will be installed to separately record compression within the Juandah Coal Measures and the Taroom Coal Measures (member of the WCM subgroup).

7.5.2 Ongoing monitoring

Measurement of settlement and extensometers is proposed on an initially monthly frequency. Ongoing reviews of the baseline established will determine when changeover to monitoring commences on a quarterly basis (with associated continuous groundwater level measurement using data loggers).

A program for ongoing monitoring will be implemented to confirm that subsidence is within the predicted behaviour of the strata over time. Where deviation from predictions is observed, revised predictions will be prepared and assessment of the significance of the predictions made.

InSAR data updates will be received on a bi-annual basis. Review of the updated InSAR data will be undertaken within 3 months of the data being received.

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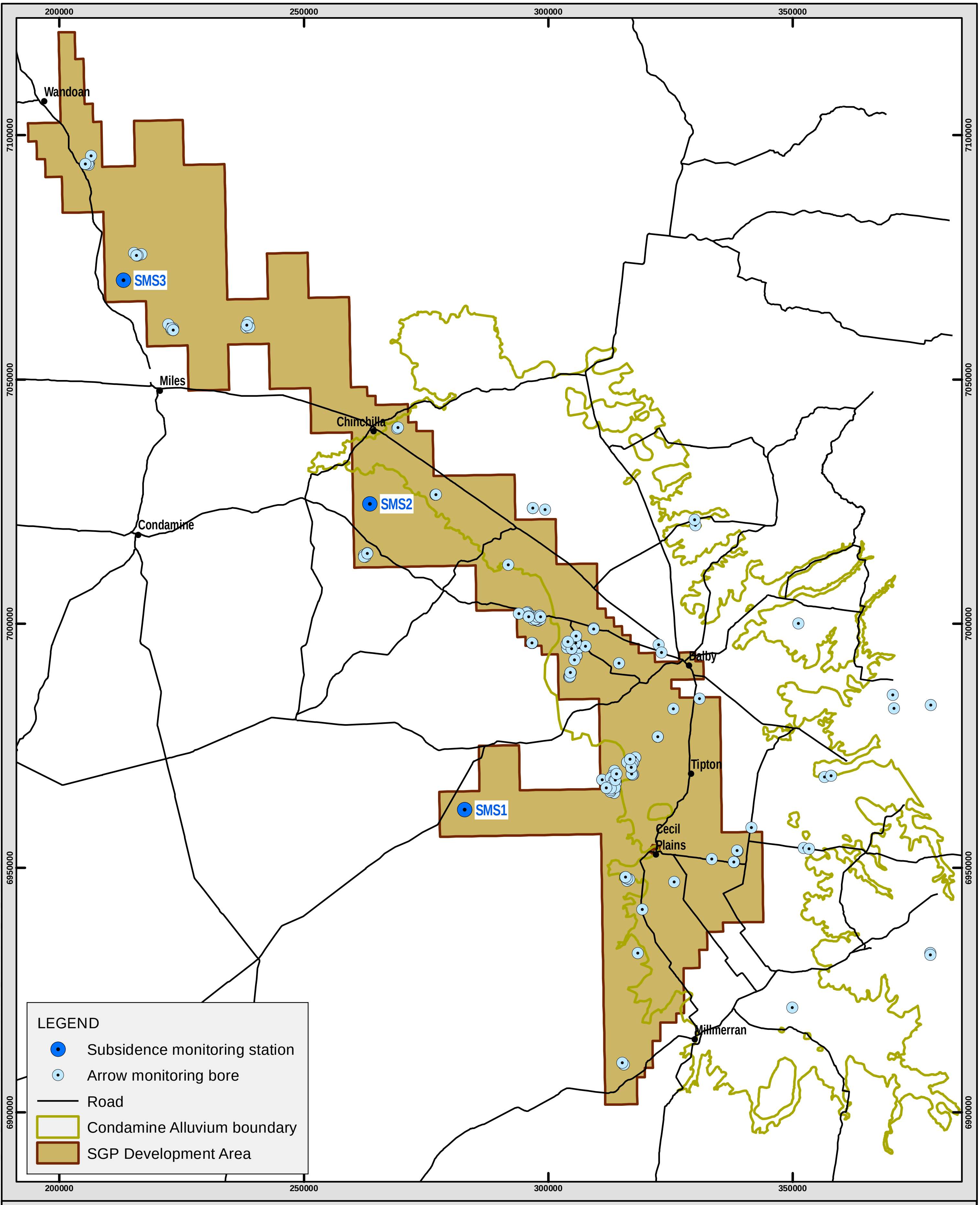

Figure 7.6

Subsidence monitoring stations

Source:
Arrow Energy Pty Ltd
Coffey

Date: 27/11/2017
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50 60
Kilometres
Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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8. CONTRIBUTION TO INDUSTRY PLANS, KNOWLEDGE AND RESEARCH

8.1 Joint industry plan

Arrow supports the ongoing application of the JIP, although no EPBC springs have been identified on Arrow’s tenure, and no off-tenure EPBC springs fall under Arrow’s responsibility as defined by the Surat CMA UWIR SIMS. As a result, Arrow currently has no active obligations under the JIP.

Arrow will contribute to periodic review of the JIP, including information that supports the JIP, through water-related data collected from Arrow’s contribution to the Surat CMA UWIR WMS. Arrow will also contribute to the development of knowledge around ecosystem groundwater dependence and interaction through site-specific studies. Should Arrow be assigned as the responsible proponent for any EPBC Springs under the JIP, Arrow will, if applicable, comply with the requirements of the JIP or seek to update the JIP to account for Arrow’s obligations.

8.2 Condamine Alluvium groundwater-surface water connectivity

Arrow commissioned the development of an integrated groundwater-surface water model to quantify the impact that flux changes to the Condamine Alluvium may have on surface water flow in the Condamine River, and to address approval condition 13(b). The full modelling process and results of the study is documented in Appendix F.

The modelling approach adopted the 2012 OGIA model, the CCAM and the IQQM (Simons et al, 1996) as described in Chapter 3. A summary of the predicted drawdown and potential impacts to sensitive receptors is also presented in Chapter 3.

8.3 Condamine Interconnectivity Research Project

The Condamine Interconnectivity Research Project (CIRP) (DNRM, 2016c) is an OGIA-directed project to further quantify connectivity between the Condamine Alluvium and the WCM. It involved:

- Interpretation and modelling of geology to map the transition zone between the Condamine Alluvium and the WCM.
- Surveying and mapping of groundwater levels of the Condamine Alluvium and the WCM to establish historic and current differences in groundwater levels between the two formations.
- Assessment of the hydrochemistry to test hypotheses about groundwater mixing between the Condamine Alluvium and the WCM.
- Drilling and aquifer pumping tests to establish physical and hydraulic characteristics of the transition zone, and to establish high-value long-term monitoring sites.

Arrow contributed significantly to the CIRP with on-site investigations, including installation of groundwater monitoring wells and completion of aquifer pumping tests. The CIRP concluded[23] that:

- The geologic data shows that a clay-rich or mudstone horizon at the base of the Condamine Alluvium and the top of the WCM acts as a physical barrier that impedes flow between the formations.
- Persistent differences in groundwater levels between the formations, and flow patterns within the formations, demonstrate that impediments exist to flow between the formations.
- Hydrochemical data suggests that there has been little past movement of water between the formations, even in areas where significant groundwater level differences have existed over a prolonged period
- Detailed aquifer pumping tests at two sites found no significant flow of water between the formations in response to pumping tests around those sites. The tests show that the vertical hydraulic conductivity of the material between the formations is consistent with that of a highly effective aquitard
- CIRP concluded that the level of hydraulic connectivity between the Condamine Alluvium and the WCM is low.

The work undertaken by Arrow will be summarised in the Stage 2 CSG WMMP.

8.4 Altamira subsidence monitoring

Arrow, along with other CSG proponents, maintain a subsidence monitoring program involving the use of satellite imaging using Interferometric Synthetic Aperture Radar (InSAR). This provides baseline ground motion data and regular interpretation of ground movement over the area where CSG extraction or planned extraction is carried out.

Monitoring of ground motion at Arrow tenements via the application of the Global SAR^{TM} methodology to a set of Radarsat-2 images covering 10,736 km^2 has been ongoing since July 2012.

Results of the monitoring are periodically provided to Arrow and used to inform the ongoing assessment of subsidence across Arrow's tenements including the identification of areas of concern.

8.5 Long Swamp and Lake Broadwater connectivity studies

Specific assessment of the hydraulic connectivity of Long Swamp and Lake Broadwater to underlying aquifers that may be affected by depressurisation of the WCM is in progress. Arrow has nominated specific monitoring targets and field program planning is underway.

Groundwater monitoring locations will be established at both Long Swamp and Lake Broadwater. Field studies will be carried out to assess the connectivity of these features to local and regional flow

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[23] DNRM (2016c) Section 9

systems, as well as the potential for groundwater-surface water interaction and the presence of terrestrial GDEs. The proposed scope of work for each monitoring location is:

- Installation of monitoring bores.
- Suitable aquifer parameter testing if required.
- Downhole geophysical logging, where relevant.
- Shallow coring adjacent to a mature tree identified as being potentially groundwater dependent to verify tree root depths through direct observation and, where relevant, laboratory analysis of tree root matter in drill core.
- Installation of data loggers in specified bores to record and compile groundwater level and temperature data.
- Groundwater and surface water quality sampling and analysis.

8.6 OGIA data review, research projects, and industry contribution

Monitoring data that has become available since release of the 2016 UWIR indicates that overall trends in groundwater pressure are similar to those reported, and OGIA is currently reviewing the available groundwater pressure and quality data for all monitored aquifers (DNRM, 2018). Interim findings from trend analysis in the eastern and southern gas fields suggest that the primary cause for a declining pressure trend in the Hutton Sandstone is non-CSG water use, and final outcomes of the analysis will be included in the UWIR 2019 (DNRM, 2018).

OGIA technical research projects include developing groundwater flow system knowledge, and incorporating this in a revised groundwater flow model for the 2019 UWIR. This work will help develop the understanding of cumulative impacts in the Surat CMA, and will inform future updates to the WMMP. Focus areas include revision of the geological model based on up-to-date data, analysis of monitoring trends, investigations of bore connectivity, continued work on studying connectivity of the Condamine Alluvium with the Walloon Coal Measures, development of a sub-regional model, development of monitoring methods for springs, watercourse springs, assessment of terrestrial groundwater-dependent ecosystems and improvement in non-CSG water use estimates (DNRM, 2018).

Findings from these studies will inform future iterations of this WMMP with regards to landscape conceptualisation, groundwater response to abstractive activities and frameworks for the ongoing assessment and management of GDEs.

Arrow currently has no assigned spring monitoring or investigation requirements under the 2016 Surat CMA UWIR. Should this change in future revisions of the Surat CMA UWIR (based on new data) Arrow will contribute to investigations as required by the SIMS and/or other GDE management requirements that may be included in future versions.

Knowledge gained to date from Arrow-initiated investigations around the presence of GDEs in Arrow tenures is presented in the GDE and Aquatic Ecosystem technical memorandum (Appendix D), and will contribute to the overall body of knowledge around GDEs in the Surat CMA.

Arrow’s prior contributions have included:

- The provision of results of prior spring / GDE assessment work, including remote sensing data, geochemical investigations and GDE impact modelling.
- The CIRP (refer Section 8.3) which aimed to improve understanding around the connectivity between the WCM and the Condamine Alluvium.

The results of ongoing investigations will be made available to OGIA in the future. This is expected to include:

- The results of monitoring programs where monitoring of GDEs is indicated in this Stage 1 CSG WMMP.
- The results of further detailed investigations where they may be required in response to exceeding a trigger threshold.
- The results of further studies into aquifer connectivity, if required.

Arrow will continue to contribute to the development of knowledge and understanding around cumulative impacts in the Surat Basin, including at the local and regional scale. A key mechanism for this is the sharing of data collected from the ongoing monitoring of water pressure, level and quality across Arrow’s groundwater monitoring network.

Arrow also actively seeks to identify areas of knowledge that would benefit from improved understanding to better represent the physical processes associated with the development of CSG in the Surat Basin at both the local and regional scale.

During operations and through monitoring obligations, the Stage 1 CSG WMMP, monitoring, research, detailed studies and modelling will complement work being carried out by other CSG proponents and ultimately enhance the technical basis for the ongoing prediction and understanding of cumulative impacts.

These studies and modelling include:

- The CIRP (refer Section 8.3). The CIRP is now complete, and was an OGIA-directed project that aimed to further quantify the connectivity between the Condamine Alluvium and the WCM. Arrow contributed significantly to the CIRP.
- In addressing Condition 13b, Arrow commissioned integrated groundwater-surface water modelling of the Condamine Alluvium aquifer to assess potential impacts on water resources arising from CSG development. This included the assessment of cumulative impact, and impacts to dependent ecosystems.
- Contribution to ongoing industry-led subsidence monitoring and assessment. This is carried out collaboratively between CSG proponents.
- Carrying out monitoring obligations under a best practice monitoring network, including aquifer connectivity studies, in addressing Conditions 13(e) and 13(f). This will directly contribute to improving the collective hydrogeological knowledge of the Surat Basin.
- Targeted field studies of ecosystems potentially at risk of drawdown-related impact, to improve understanding of groundwater dependence.

- Detailed vegetation mapping is in progress, including ground-truthing of the Queensland Government Regional Ecosystem (RE) mapping. This will improve the local scale understanding of vegetation types, presence and distribution.
- Geochemical research that Arrow is currently progressing, relating to geochemical characterisation and development of geochemically constrained modelling.
- Collecting other data through the course of Arrow's drilling and testing programs, including:
    - Borehole core testing and analysis (including permeability).
    - Aquifer parameter testing.
    - Geophysical logging.
    - Seismic surveys.

The outcomes of these projects will be made available through a combination of publicly released papers and reports, and knowledge sharing through the OGIA.

Other research projects Arrow has completed, have underway or are contributing to include:

- Irrigation trials of CSG water.
- CSG feed water treatment bench scale study.
- Brine crystallisation and selective salt recovery technology joint industry study.
- Thermal brine concentration study.
- Connectivity studies (assessment of the connectivity between the Condamine Alluvium and the Walloon Coal Measures) at Daleglade, Lone Pine and in the upper Condamine River Catchment.
- Produced water injection trials.
- Aquifer connectivity using lithium isotopes and hydrochemistry.
- Surat Basin recharge pathway and estimation.
- Characterisation of current groundwater uses in the Surat and Bowen Basins.
- Water chemistry atlas for Surat Basin CSG fields.
- Bowen and Surat Basin hydrocarbon systems analysis.
- Mitigation of silica-associated scaling in CSG water treatment facilities.
- Beneficial use of salt: experimental study of salt-concrete properties.

9. RECORDS, REPORTING, REVIEW AND PLAN UPDATES

Approval Conditions 27, 28 and 29 require record keeping, reporting and non-compliance notification. Arrow will meet the requirements of these conditions, with respect to the Stage 1 CSG WMMP, as set out in this Chapter, and in conjunction with Arrow's EIS/SREIS reporting, updating and review commitments.

9.1 Record keeping and data management

Arrow will maintain records of relevant activities carried out in accordance with the Stage 1 CSG WMMP. These records will be made available to the Department[24] upon request.

Implementation of the CSG WMMP will generate significant data including field records and observations, electronically-logged water pressure data, and laboratory water-quality analytical data. The data generated will be stored electronically in a database, containing:

- Monitoring well locations, construction details and monitored aquifer.
- Well drilling records, geophysical logs and interpreted stratigraphy.
- Details of permanent well infrastructure or instrumentation.
- Groundwater level, pressure and quality records.
- Surface water quality and flow records.
- Aquatic ecosystem monitoring records.

Data will be subject to a quality control review program or system to identify data or transcription errors.

9.2 Reporting

Reporting for the WMMP is detailed below, and includes:

1. Non-compliance reporting.
2. Exceedance reporting for the EWMS.
3. Subsidence action plan reporting.
4. Annual reporting.

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[24] Department is defined to mean the Australian Government Department administering the Environmental Protection and Biodiversity Conservation Act 1999 (Cth.), currently the Department of the Environment and Energy.

9.2.1 Potential non-compliance reporting

In accordance with Approval Condition 29, the Department will be notified in writing no later than ten business days after becoming aware of any potential non-compliance with any Approval Condition. Potential non-compliance notification will occur if:

1. A groundwater or drawdown limit has potentially been exceeded.
2. Arrow fail to meet any of the requirements of approval condition 13 (i.e. Arrow do not develop or carry out any of the activities required under approval conditions 13(a) to 13(r).

The notification will include:

- The Approval Condition that has been potentially breached;
- The nature of the potential non-compliance;
- When and how the approval holder became aware of the potential non-compliance;
- How the potential non-compliance may affect the approved action;
- How the potential non-compliance may affect the anticipated impacts of the approved action, in particular any impacts on MNES (water resources and the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin), and the measures the to be taken to address the impacts of the potential non-compliance on MNES and to rectify the potential non-compliance; and
- The time by when the approval holder will rectify the potential non-compliance.

9.2.2 Early warning indicator, trigger threshold and limit exceedance reports

Consistent with the EWMS described in Section 5, exceedance response reports will be prepared for any confirmed early warning indicator, trigger threshold or limit exceedance.

The Department will be provided with copies of any EWMS exceedance response reports.

9.2.3 Subsidence action plan reporting

Consistent with the process described in Section 7, a trigger threshold exceedance action plan will be prepared within 90 calendar days of a subsidence trigger threshold being exceeded.

The Department will be provided with copies of any trigger threshold exceedance action plans.

9.2.4 Annual report

An annual report on the WMMP will be prepared for the preceding 12 month period. It will be submitted to the Department and published on Arrow's website within three months of every 12-month anniversary of the commencement of the SGP. Annual reporting of the Stage 1 CSG WMMP will cease following commencement of the Stage 2 CSG WMMP, which will include all matters relating to the Stage 1 CSG WMMP and supersede the Stage 1 reporting requirements.

Each annual report will present a summary of progress towards Arrow's commitments and document Arrow's compliance against the approval conditions.

Annual reports will be factual, and will:

- Detail any updates to the FDP and implications for water monitoring and management.
- Report on any relevant ongoing studies and research projects, and include any supporting technical studies as appendices to the annual report.
- Summarise relevant monitoring results, including:
    - Groundwater levels
    - Groundwater chemistry results
    - Surface water monitoring results
    - Surface water chemistry results
    - Analysis and interpretation of data, including across an appropriate transect of bores to assess impact propagation from production areas to sensitive receptors
- Document Arrow's compliance against the approval conditions over the preceding 12 months, including monitoring obligations and implementation of the EWMS.
- Document corrective actions implemented to address any exceedances of trigger thresholds, limits, or non-compliance with approval conditions.
- Report against the performance measure criteria.

Relevant electronic data will be provided to the Department upon request.

9.3 Performance measure criteria

The performance measures are predicated on the assumption that a fundamental purpose of the Approval Conditions is the management of impacts to MNES. Therefore, compliance with these conditions will achieve this outcome.

Performance measure criteria have been established which enable assessment of project performance in the context of protection of MNES. These ensure that the project operational and management aspects that limit, protect or mitigate against impacts to MNES potentially affected by the project, are achieving the required outcome, and that impacts to MNES are either not occurring, or are effectively corrected.

The performance measure criteria for assessment of the protection of MNES are:

- Compliance with the Approval Conditions.
- Impacts to MNES are predicted and monitored.
- Where an exceedance under the EWMS has occurred, the corrective actions for ameliorating impacts from exceedance of the limits are implemented, and effective.

9.4 Publication of data and reports

Arrow will make public the results of data obtained from the water-related aspects of their monitoring network via the following:

- Publication of the approved Stage 1 CSG WMMP on Arrow's website.

- Publication of the annual reports on Arrow's website. The reports will be published annually within 3 months of each anniversary of the commencement of the SGP.
- Providing raw data to the 'Queensland Globe'[25].

In addition, under the Surat CMA UWIR, a water monitoring report is required to be submitted at the end of March and September each year that includes details of the monitoring data collected under the Water Monitoring Strategy.

9.5 Peer review

The SGP Stage 1 CSG WMMP required formal peer review by a suitably qualified water resources expert in accordance with approval condition 14 of the Australian Government approval. The peer reviewer was approved by the Minister for the Environment and was engaged in a progressive review process of the WMMP.

The draft Stage 1 CSG WMMP was submitted to the Minister together with a statement from the suitably qualified water resources expert endorsing the findings and the content of the WMMP. Details of the peer review and statement of endorsement are provided in Appendix L.

9.6 Preparation of Stage 2 CSG WMMP

As set out in Approval Condition 17 (a), all matters contained within the Stage 1 CSG WMMP will be included in the development of the Stage 2 CSG WMMP. Arrow will also carry out review and revision of a number of the detailed assessments completed in support of the Stage 1 CSG WMMP to take account of new data.

Particular focus on the ongoing assessment of GDEs will be made, and specifically this will include:

- Consideration of new information such as industry and government spatial mapping platforms, updated geological data (including outcrop and subcrop mapping, fault mapping) and results of ongoing industry and government GDE field investigations.
- Additional discussion regarding the currently understood extent of the Westbourne Formation and the significance of the presence of this formation with regards to it acting as a likely barrier to the propagation of drawdown to overlying systems that may support GDEs.
- Review and (where necessary) revision of the assessment of surface water – groundwater connectivity taking account of the results of the field investigations currently being completed at Long Swamp and Lake Broadwater.
- Review and revision (if necessary) of the GDE impact assessment based on this information, taking in to consideration the multiple lines of evidence available.

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[25] The Queensland Globe is a publicly available Internet database tool that includes physical, geographical and spatial data in a map format, and provides an online resource for environmental data. It provides access to Surat CMA UWIR WMS data, Arrow and other proponent monitoring data and DNRME current and historical records.

It is noted that Arrow has ongoing obligations under the Surat CMA UWIR where assigned as the responsible tenure holder for GDEs. This obligation will be maintained in the Stage 2 CSG WMMP, and Arrow will comply with the UWIR requirements for watercourse springs along the Condamine River.

It is also understood that the next revision of the Surat CMA UWIR, due for release in late 2019, will include a framework and set out obligations regarding the assessment and protection of non-spring GDEs. Arrow will align the Stage 2 CSG WMMP non-spring GDE (i.e. terrestrial and aquatic ecosystem) impact assessment with this framework where it is made available in time for the Stage 2 CSG WMMP approvals process, or in future plan iterations where the timing does not align for Stage 2 CSG WMMP.

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11. ABBREVIATIONS

Table 11-1. Abbreviations

ACA	Aquatic Conservation Assessment
AHD	Australian Height Datum
ATP	Authority to Prospect
ARI	Average Recurrence Interval
BOM	Bureau of Meteorology
CA	Condamine Alluvium
CCAM	Central Condamine Alluvium Model
CGPF	Central Gas Processing Facility
CIRP	Condamine Interconnectivity Research Project
CMA	Cumulative Management Area
CSG	Coal Seam Gas
DEHP	Department of Environment and Heritage Protection
DO	Dissolved oxygen
DNRM	Department of Natural Resources and Mines
EA	Environmental Authority
EFO	Environmental Flow Objective
EHP	Environment and Heritage Protection
EIS	Environmental Impact Statement
EPBC	Environment Protection and Biodiversity Conservation
EWMS	Early Warning Monitoring System
EWS	Early Warning System
FCF	Field Compression Facility
FDP	Field Development Plan
GAB	Great Artesian Basin
GDE	Groundwater Dependent Ecosystem
GL	Gigalitre
InSAR	Interferometric Synthetic Aperture Radar
IQQM	Integrated Quantity and Quality Model
JIP	Joint Industry Plan
ML	Megalitre

MNES	Matters of National Environmental Significance
OGIA	Office of Groundwater Impact Assessment
PL	Petroleum Lease
QWC	Queensland Water Commission
ROP	Resource Operation Plan
SGP	Surat Gas Project
SIMS	Spring Impact Management Strategy
SREIS	Supplementary report to the Environmental Impact Statement
TDS	Total Dissolved Solids
TEG	Triethylene glycol
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
UWIR	Underground Water Impact Report
VWP	Vibrating Wireline Piezometer
WCM	Walloon Coal Measures
WMMP	Water Monitoring and Management Plan
WMS	Water Management Strategy
UWIR	Underground Water Impact Report
WQO	Water Quality Objective

APPENDIX A APPROVAL CONDITIONS AND COMPLIANCE

To demonstrate compliance with the requirements of the approval conditions, Table A.1 presents a summary of the approval conditions, cross-referenced to the relevant sections of the Stage 1 CSG WMMP where the conditions are addressed.

Table A.1 Approval condition compliance reference summary

Approval Condition	Condition description	Relevant WMMP section
13	Prior to commencement, the proponent must submit a Stage 1 Coal Seam Gas Water Monitoring and Management Plan (Stage 1 CSG WMMP) for the approval of the Minister, who may seek the advice of an expert panel. The Stage 1 CSG WMMP must include:	NA
13a	An analysis of the results of the most recent OGIA model (built or endorsed by OGIA), relevant to all of the project's tenement areas.	Appendix E
13b	A fit for purpose numerical simulation to assess potential impacts on water resources arising from the Action in the project area, subsequent surface water-groundwater interactions in the Condamine Alluvium and impacts to dependent ecosystems.	Appendix F
13c	An assessment of potential impacts from the Action on non-spring based groundwater dependent ecosystems through potential changes to surface-groundwater connectivity and interactions with the sub-surface expression of groundwater.	Section 3.4.2 Section 5 of Appendix D
13d	An assessment of predicted project wide groundwater drawdown levels and pressures from the Action, together with confidence levels.	Section 3.2 Section 3.3 Appendix E Appendix F
13e	Parameters and a sampling regime to establish baseline data for surface and groundwater resources that may be impacted by the Action, including: surface water quality and quantity in the project area, and upstream and downstream of potential impact areas; groundwater quality, levels and pressures for areas that may be impacted by the project; and for determining connectivity between surface water and groundwater that may be impacted by the project.	Section 6.1.4 Section 6.1.5 Section 6.2.2 Section 6.2.3 Section 6.3 Appendix J
13f	A best practice baseline monitoring network that will enable the identification of spatial and temporal changes to surface water and groundwater. This must include a proposal for aquifer connectivity studies and monitoring of relevant aquifers to determine hydraulic connectivity (including potential groundwater dependence of Long Swamp and Lake	Section 6.1.1 Section 6.1.2 Section 6.1.3

Approval Condition	Condition description	Relevant WMMP section
	Broadwater) and must also enable monitoring of all aquatic ecosystems that may be impacted by the Action.	Section 6.2.1 Appendix J
13g	A program to monitor subsidence impacts from the Action, including trigger thresholds and reporting of monitoring results in annual reporting required by condition 28. If trigger thresholds are exceeded, the approval holder must develop and implement an action plan to address impacts within 90 calendar days of a trigger threshold being exceeded.	Section 7.1 Section 7.4 Section 7.5 Section 9.2 Appendix K
13h	Provisions to make monitoring results publicly available on the approval holder's website to facilitate a greater understanding of cumulative impacts.	Section 9.4
13i	A discussion on how the approval holder is contributing to the Joint Industry Plan, including its periodic review. The approval holder must contribute to the Joint Industry Plan and comply with any part of the Joint Industry Plan, or future iterations of the Joint Industry Plan, that applies to the approval holder.	Section 8.1
13j	A groundwater early warning monitoring system, including:	-
13j (i)	Groundwater drawdown limits for all consolidated aquifers potentially impacted by the Action, excluding the Walloon Coal Measures.	Section 5.1 Section 5.2 Section 3 of Appendix I
13j (ii)	For the Condamine Alluvium, appropriate triggers and groundwater limits and a rationale for their selection.	Section 5.1 Section 5.2 Section 4 of Appendix I
13j (iii)	Early warning indicators and trigger thresholds, including for Lake Broadwater, Long Swamp and other groundwater dependent ecosystems that may potentially be impacted by the action, including those that may occur outside the project area and may be impacted by the Action.	Section 5.1 Section 5.2 Section 5 of Appendix I
13j (iv)	Investigation, management and mitigation actions, including substitution and/or groundwater repressurisation, for both early warning indicators and trigger thresholds to address flux impacts on the Condamine Alluvium.	Section 5.2 Section 4 of Appendix I Section 3.1 of

Approval Condition	Condition description	Relevant WMMP section
		Appendix G
13k	Early warning indicators and trigger thresholds, including corrective actions for both early warning indicators and trigger thresholds, for aquatic ecology and aquatic ecosystems.	Section 5.3 Section 6 of Appendix I
13l	A CSG water management strategy for produced salt/brine, which discusses how co-produced water and brine will be managed for the Action, including in the context of other coal seam gas activities in the Surat Basin.	Section 4.1 Section 3.2 of Appendix G
13m	An analysis of how the approval holder will utilise beneficial use and/or groundwater repressurisation techniques to manage produced CSG water from the Action, and how any potential adverse impacts associated with groundwater repressurisation will be managed.	Section 3.3 of Appendix G
13n	A discharge strategy, consistent with the recommendations and requirements of the Department of the Environment and Heritage Protection in its Assessment Report (pages 94 to 95 and pages 254 to 255) and that includes scenarios where discharge may be required, the quality of discharge water (including water treated by reverse osmosis), the number and location of monitoring sites (including upstream and downstream sites), frequency of monitoring and how the data from monitoring will be analysed and reported, including recommendations on any changes or remedial actions that would be required.	Discharge is not proposed.
13o	A flood risk assessment for processing facilities and any raw co-produced water and brine dams, which addresses flood risks to the environment from the Action in the case of a 1: 1 000 ARI event. The risk assessment should estimate the consequences if major project infrastructure was subject to such an event, including release of brine and chemicals into the environment.	Section 4.2 Appendix H
13p	A cumulative impact assessment based on the outputs of the OGIA model which integrates groundwater model outputs with known and potential groundwater dependent ecosystems and presents the outputs in map form. Contribute to investigations coordinated through the OGIA to assess hydrological and ecological characteristics of Impacted groundwater dependent ecosystems.	Section 8.6 Section 6 of Appendix D
13q	Details of performance measures; annual reporting to the Department; and publication of reports on the internet.	Section 9.2 Section 9.3 Section 9.4
13r	An explanation of how the Stage 1 CSG WMMP will contribute to work undertaken by other CSG proponents in the Surat Basin to understand	Section 8.6

Approval Condition	Condition description	Relevant WMMP section
	cumulative impacts, including at the local and regional scale, and maximise environmental benefit.	
14	The Stage 1 CSG WMMP must be peer reviewed by a suitably qualified water resources expert/s approved by the Minister in writing. The peer review must be submitted to the Minister together with the Stage 1 CSG WMMP and a statement from the suitably qualified water resources expert/s stating that they carried out the peer review and endorse the findings of the Stage 1 CSG WMMP.	Appendix L
15	The approval holder must not exceed the groundwater drawdown or groundwater limits for each aquifer specified in the Stage 1 CSG WMMP.	NA
16	Unless otherwise agreed in writing by the Minister, the approval holder must not commence the Action until the Stage 1 CSG WMMP is approved In writing by the Minister. The approved Stage 1 CSG WMMP must be implemented.	NA

APPENDIX B SGP EIS/SREIS COMMITMENTS

Table B.1 presents Arrow’s EIS/SREIS commitments that relate to groundwater and surface water, cross-referencing where each commitment is addressed in the Stage 1 CSG WMMP.

Table B.1 EIS/SREIS commitments cross-reference

Number	Description of commitment	Relevant WMMP section
C053	Avoid disrupting overland natural flow paths and, where avoidance is not practicable, maintain connectivity of flow in watercourses.	Section 4.2 Appendix H
C066	Discharge water from project activities at a rate and location that will not cause or exacerbate erosion. Install erosion protection measures, including energy dissipation structures, at discharge outlets.	Discharge is not proposed.
C067	Incorporate into an emergency response plan or water management plan procedures for the controlled discharge of coal seam gas water under emergency conditions. Procedures will include water balance modelling, weather monitoring and forecasting, stream flow data, notification and reporting.	Discharge is not proposed.
C073	Excavate any saline material during rehabilitation of coal seam water dams or brine dams and select an appropriate option for management for the material (e.g., treat for reuse, or dispose of in a registered landfill).	Attachment 1 of Appendix G
C124	Consider local biological, groundwater and surface water conditions when identifying sites for coal seam gas water dams and brine dams.	Attachment 1 of Appendix G
C125	Consider local groundwater conditions when identifying sites for the installation of buried infrastructure (e.g., gathering lines).	Attachment 1 of Appendix G
C128	Continue an investigative program that will help quantify the connectivity between the Condamine Alluvium and the Walloon Coal Measures. The program will involve: • Monitoring the effects of groundwater extraction in the Walloon Coal Measures on the Condamine Alluvium to estimate horizontal and vertical hydraulic conductivity between the alluvium and the Walloon Coal Measures. • An investigative drilling program that will provide greater definition of the interface between the two units and will evaluate the geological and hydrogeological properties of the material at the interface of the units. • Groundwater chemistry studies to characterise mixing and migration between the units. • Groundwater modelling, utilising the connectivity data obtained through investigative components of the program, to understand important processes in the system and predict potential impacts.	Section 8.3

Number	Description of commitment	Relevant WMMP section
C129	Continue a program of aquifer testing in dedicated groundwater monitoring bores to increase the predictability of aquifer properties and groundwater movement.	Section 8.6
C130	Collect relevant geological and hydrogeological data from existing and future production wells, monitoring bores and registered third-party bores (where possible) together with information collated collaboratively with other proponents and regulatory authorities.	Section 8.6
C131	Update and calibrate the geological model and the numerical groundwater model with relevant data on an ongoing basis, including: • Aquifer thicknesses and interfaces between formations. • Aquifer properties, e.g., porosity, permeability. • The location of sensitive areas, e.g., groundwater discharge springs. • Observed responses in monitoring bores that reflect aquifer behaviour during coal seam gas extraction.	Chapter 3 Appendix E Appendix F
C132	Utilise the updated geological and numerical groundwater models to: • Make ongoing predictions regarding changes to groundwater levels and groundwater quality as the project develops. • Improve confidence in the understanding of the sensitivity and resilience of the aquifers within the identified groundwater systems.	Chapter 3 Chapter 5 Appendix E Appendix F
C133	Perform groundwater modelling simulations to predict impacts on groundwater resources in overlying and underlying aquifers. This information will subsequently be used to evaluate the suitability of these resources for use in make-good measures.	Chapter 3 Appendix E Appendix F
C134	Verify the preferred water management strategy by modelling the effectiveness of substitution ('virtual injection') and injection (if conducted) in mitigating against depressurisation impacts in the Condamine Alluvium.	Section 4.1 Appendix G
C135	Consider injection of coal seam gas water or brine of a suitable quality (if proven technically feasible) into shallow or deep aquifers to mitigate against depressurisation impacts in aquifers.	Section 4.1 Appendix G
C136	Address the potential for surface deformation through participation by Arrow in a collaborative study with other proponents using historical and baseline data from the Advanced Land Observation Satellite covering a timelapse period from January 2007 until January 2011. This will allow a detailed analysis of the region and will enable the analysis of the evolution of measured surface deformation in space and time. The assessment will correlate and calibrate data deliverables (calibrated global map and vector files for measurement points) from	Chapter 7 Appendix K

Number	Description of commitment	Relevant WMMP section
	the Advanced Land Observation Satellite to show the mean deformation rate, identify areas of large-scale deformation and compare patterns with other information (e.g., geology, basin structure, extraction wells and injection data).	
C141	Develop the construction, design and monitoring requirements for new dams (either raw water, treated water or brine dams) and determine the hazard category of the dam in accordance with the requirements of the most recent version of Manual for Assessing Hazard Categories and Hydraulic Performance of Dams (EHP, 2012f). Construct the dams under the supervision of a suitably qualified and experienced person in accordance with the relevant DERM schedule of conditions relating to dam design, construction, inspection and mandatory reporting requirements.	Attachment 1 of Appendix G
C142	Manage potential impacts to groundwater dependent ecosystems (including on identified spring complexes) by: • Supporting the identification of specific aquifers that serve as a groundwater source for the groundwater-dependent ecosystem. • Assessing groundwater-dependent ecosystems that are predicted to be subject to unacceptable impacts through the source aquifer. • Developing monitoring and mitigation strategies to avoid or minimise unacceptable impacts.	Section 2.5.5 Section 3.4 Section 5.2 Chapter 6 Appendix D
C151	When siting facilities, avoid wetlands and consider the following: • Stream processes that may result in channel migration (either over time or as a result of project activities) and areas that are highly susceptible to erosion (i.e., dispersive soils). • Downstream values of nearby watercourses or wetlands. • Minimising changes to natural drainage lines and flow paths. • Flooding regimes and areas subject to inundation.	Section 4.2 Appendix H Attachment 1 of Appendix G
C154	Design coal seam gas water dams in accordance with relevant legislation, standards and guidelines.	Attachment 1 of Appendix G
C155	Site facilities above the 1-in-100-year average flood recurrence interval, where practicable, and design infrastructure taking into consideration overland flow and flooding regimes to reduce impacts on immediate and surrounding areas.	Section 4.2 Appendix H
C156	Manage potential impacts on Lake Broadwater Conservation Park (Category A ESA) through implementation of relevant buffers in accordance with legislative requirements at the time of development in this region.	Section 3.4.3 Section 8.5 Appendix D

Number	Description of commitment	Relevant WMMP section
C171	Develop and implement incident reporting, emergency response and corrective action systems or procedures. Include systems for reporting, investigation and communications of lessons learned.	Chapter 5 Section 9.2
C174	Maximise beneficial use of coal seam gas water.	Attachment 1 of Appendix G
C201	Develop and continually maintain the coal seam gas water and salt management strategy throughout the project life to optimise the investigation and implementation of the potential coal seam gas water management options in alignment with the overall project development.	Attachment 1 of Appendix G
C204	Maintain water balance models for long-term planning and management of coal seam gas water. Review and update modelling in alignment with the production-forecasting schedule.	Attachment 1 of Appendix G
C205	Identify strategies to minimise coal seam gas water surface storage and to promote increased efficiency.	Attachment 1 of Appendix G
C498	Develop a strategy for the discharge of coal seam gas water to watercourses in accordance with relevant legislation. The strategy will incorporate a water quality monitoring program with locations upstream and downstream of the discharge point to inform site specific water quality objectives. A detailed environmental flows assessment informed by water quality monitoring data and an aquatic ecology monitoring program will inform the discharge strategy. Periodic inspections of the physical form and hydrology of the watercourse are to be incorporated in the strategy to monitor geomorphic performance.	Discharge is not proposed.
C521	Ensure methods used to monitor groundwater levels and quality, together with monitoring frequencies and parameters are in accordance with approved regulatory standards.	Chapter 6
C524	Install an appropriate regional groundwater monitoring network (that satisfies Arrow's obligations as described in the underground water impact reports) to: • Establish baseline groundwater level and groundwater quality conditions. • Assess natural variation (i.e., seasonal variations) in groundwater levels. • Monitor groundwater levels during the operations phase. • Monitor groundwater quality during the operations phase. • Establish suitable datum levels for each aquifer system. • Target sensitive areas where more frequent monitoring and investigation is required (e.g., groundwater dependent ecosystems). • Monitor groundwater drawdown as a result of coal seam gas	Chapter 6 Appendix J

Number	Description of commitment	Relevant WMMP section
	extraction. • Monitor impacts in accordance with the Water Act and regulations. • Provide an 'early warning system' that identifies areas potentially impacted by project activities to allow early intervention.	
C525	Comply with inspection and monitoring requirements of the Surat Cumulative Management Area Underground Water Impact Report administered by the Queensland Government Office of Groundwater Impact Assessment.	Section 6.1 Appendix J
C526	Visually inspect physical form and monitor hydrology, turbidity and pH upstream and downstream of central gas processing and integrated processing facility stormwater and coal seam gas water discharge points.	Section 6.2 Appendix J Note: CSG waters are not proposed to be discharged.
C527	Routinely visually inspect physical form integrity and monitor hydrology, turbidity, total suspended solids, pH, dissolved metals and total petroleum hydrocarbons upstream and downstream of authorised locations where water is to be discharged directly to a watercourse.	Section 6.2 Appendix J Note: CSG waters are not proposed to be discharged.
C529	Measure the volume and quality of coal seam gas water released to surface waters on a routine basis in accordance with legislative requirements and approved release limits.	CSG waters are not proposed to be discharged.
C561	Identify reaches vulnerable to bank erosion from the discharge of coal seam gas water and develop site-specific erosion control and management plans for vulnerable reaches.	CSG waters are not proposed to be discharged.
C565	Arrow is committed to mitigating (through substitution and/or purchase of allocations) its component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of coal seam gas water extraction from the Walloon Coal Measures.	Section 5.2 Appendix I

APPENDIX C PROJECT DESCRIPTION

APPENDIX D GDE AND AQUATIC ECOSYSTEM IMPACT ASSESSMENT TECHNICAL MEMORANDUM

APPENDIX E GROUNDWATER MODELLING TECHNICAL MEMORANDUM

APPENDIX F CONDITION 13(B) TECHNICAL REPORT

APPENDIX G ASSESSMENT OF IMPACTS AND DEVELOPMENT OF MANAGEMENT MEASURES TECHNICAL MEMORANDUM

APPENDIX H FLOOD RISK TECHNICAL MEMORANDUM

APPENDIX I LIMITS, INDICATORS AND TRIGGERS TECHNICAL MEMORANDUM

APPENDIX J GROUNDWATER MONITORING NETWORK AND PROGRAM TECHNICAL MEMORANDUM

APPENDIX K SUBSIDENCE TECHNICAL MEMORANDUM

APPENDIX L PEER REVIEW AND MINISTERIAL ENDORSEMENT

APPENDIX B UPDATED PROJECT DESCRIPTION

The SGP project description is described in Appendix C of the Stage 1 CSG WMMP (Appendix A of the Stage 2 CSG WMMP), and has been revised for the Updated CSG WMMP to incorporate an updated Field Development Plan (FDP).

Key details of the updated FDP and a comparison with previous FDP cases is provided below.

Updated FDP

The SGP involves an expansion of Arrow's CSG production in the Surat Basin. As described in the Supplementary Report to the Environmental Impact Statement (SREIS), the SGP comprised an FDP based on 6,500 wells and total water production of 510 GL. This production has been subsequently revised, and the Stage 2 CSG WMMP is based on an updated FDP comprising 2,612 wells and total water production of 575 GL.

Table C1 provides a summary comparison of historical SGP FDP cases and the current Updated CSG WMMP FDP.

Table C1 FDP comparison

FDP Case	Arrow case descriptor	Water production			Duration (years)
		Forecast total (GL)	Modelled total (GL)	Modelled peak rate (GL/a)	
SREIS FDP	5x	510	702	34	65
OGIA (UWIR) 2016 FDP	8b	460	1204	n/a	54
Stage 1 CSG WMMP FDP	SREIS case	510	710 (1)	138 ML/d (2)	65
Updated CSG WMMP FDP	**10a**	**575**	**1178**	**123.3 ML/d**	**40**

Notes:
(1) Median modelled value (CDM Smith, 2016).
(2) Based on median modelled value 138 ML/d (CDM Smith, 2016).

In addition to the development detailed above, Arrow operates existing Surat Basin gas fields, facilities and infrastructure in the area surrounding Dalby, comprising the Daandine, Kogan North and Tipton West production areas.

APPENDIX C GROUNDWATER MODELLING AND RESEARCH TECHNICAL MEMO

Memorandum

Recipient	Arrow Energy Pty Ltd
Memo date	15 March 2019
Author	Coffey Services Australia Pty Ltd
Project number	ENAUABTF20484AB
Memo Subject	SGP Stage 2 WMMP Groundwater modelling and research technical memorandum

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1. Introduction

The Surat Gas Project (SGP) Approval Conditions (EPBC 2010/5344) require the development of a Coal Seam Gas (CSG) Water Monitoring and Management Plan (WMMP) to address potential impacts on surface water and groundwater resources. The requirements of the WMMP are set out in Conditions 13 to 25 and are to be delivered as two plans:

- Stage 1 CSG WMMP for activities in years 1 to 3 (following commencement); and
- Stage 2 CSG WMMP for activities in years 4 to 11.

The Stage 1 CSG WMMP was peer-reviewed and submitted to the Department of the Environment and Energy in 2017. This memorandum addresses the following Stage 2 CSG WMMP Approval Conditions:

Approval Condition 17(b): *Include any updated modelling for the project, including in respect of the OGIA model or any updates to the OGIA model by OGIA.*

Approval Condition 17(c): *Include an explanation of how the approval holder will contribute to the Condamine Interconnectivity Research Project. The Stage 2 CSG WMMP must present the findings of the Condamine Interconnectivity Research project and any modelling done by the OGIA to validate predicted drawdown and a review of trigger thresholds and corrective actions for the action.*

Approval Condition 17(d): *Report on the potential for flow reversal from the Condamine Alluvium to underlying aquifers, based on data obtained during the Stage 1 CSG WMMP.*

Approval Condition 23: *If the OGIA model ceases to exist, then the approval holder must submit an alternate model to be used for the purpose of these conditions that replaces the OGIA model as referred to in these conditions. The alternate model must be approved by the Minister in writing before the next relevant stage of the CSG WMMP is submitted to the Minister for approval.*

A range of documents were reviewed and/or referenced in the development of this memorandum. Key reviewed documents are summarised in Table 1.1.

Table 1.1: Documents reviewed

Reference	Title/ Comment
Australasian Groundwater & Environmental Consultants (AGE), 2017	Arrow Project Case 8b Uncertainty Analysis.
Australasian Groundwater & Environmental Consultants (AGE), 2018	Arrow Project Case 10a Modelling and Uncertainty Analysis.
CDM Smith, 2016	Surat Gas Expansion Project – CSG WMMP Section 13(b) Report. Report prepared for Arrow Energy describing integrated groundwater-surface water modelling.
CDM Smith, 2018	Groundwater modelling for the Stage 2 CSG WMMP. Report prepared for Arrow Energy, May 2018 describing integrated groundwater-surface water modelling, and comparison of Stage 1 and 2 WMMP cases.
Office of Groundwater Impact Assessment (OGIA), 2016	Groundwater connectivity between the Condamine Alluvium and the Walloon Coal Measures.

2. Updated FDP

The SGP involves an expansion of Arrow's CSG production in the Surat Basin. As described in the Supplementary Report to the Environmental Impact Statement (SREIS), the SGP comprised a Field Development Plan (FDP) based on 6,500 wells and total water production of 510 GL. This production has been subsequently revised, and the Stage 2 CSG WMMP is based on an updated FDP comprising 2,612 wells and total water production of 575 GL.

Table 2.1 provides a summary comparison of historical SGP FDP cases and the Stage 2 CSG WMMP FDP.

Table 2.1 FDP comparison

FDP	Case	Water production			Duration (years)
		Forecast total (GL)	Modelled total (GL)	Modelled peak rate (GL/a)	
SREIS FDP	5x	510	702	34	65
OGIA 2016 FDP	8b	460	1204	n/a	54
Stage 1 CSG WMMP FDP	5x	510	710[1]	138 ML/d[2]	65
Stage 2 CSG WMMP FDP	**10a**	**575**	**1178**	**123.3 ML/d**	**40**

Notes: 1 Median modelled value (CDM Smith, 2016)
2 Based on median modelled value 138 ML/d (CDM Smith, 2016).

In addition to the development detailed above, Arrow operates existing Surat Basin gas fields, facilities and infrastructure in the area surrounding Dalby, comprising the Daandine, Kogan North and Tipton West production areas.

3. Modelling

Numerical groundwater modelling for the SGP has supported both the SREIS and the 2016 UWIR, and is described in the Stage 1 CSG WMMP. Table 3.1 provides a summary of the main Surat Basin numerical models that have been utilised for the evolving SGP FDPs and UWIRs.

Table 3.1 Evolution of main Surat Basin numerical models

FDP	Numerical model	Numerical code
SREIS FDP	Arrow SREIS Groundwater Model (incorporating SREIS FDP)	Modflow-Surfact
2012 UWIR	OGIA 2012 Groundwater Model (incorporating SREIS FDP)	Modflow-Surfact
2016 UWIR	OGIA 2016 Groundwater Model (incorporating Case 8b FDP)	Modflow-USG
Stage 1 CSG WMMP	Arrow SREIS Groundwater Model (incorporating Case 5x FDP)	Modflow-Surfact
Stage 2 CSG WMMP	OGIA 2016 Groundwater Model (incorporating Case 10a FDP)	Modflow-USG

The modelling basis for the Stage 1 CSG WMMP is summarised in Section 3.1 below. The numerical modelling basis for the Stage 2 CSG WMMP is described in Section 4.

3.1. Previous modelling (Stage 1 CSG WMMP)

Modelling work for the Stage 1 CSG WMMP comprised simulations using three models: the **Arrow SREIS Groundwater Model** (Appendix 4 of the SREIS), the **CDM Smith Condamine Alluvium Model** (CDM Smith, 2016), and the **Condamine River Integrated Quantity and Quality Model** (IQQM).

This modelling work, undertaken to consider both groundwater and surface water impacts, was undertaken, peer-reviewed, and accepted as a basis for achieving the requirements of the approval conditions for the Stage 1 CSG WMMP. An overview of these models is provided in Table 3.2.

Table 3.2 Stage 1 CSG WMMP modelling

Numerical model	Purpose
Arrow SREIS Groundwater Model (using SREIS FDP)	This numerical model (a version of the OGIA 2012 Groundwater Model) was used to determine the groundwater impacts presented in the SREIS, and these predictions also provided the main basis for impact prediction in the Stage 1 CSG WMMP. This model included both a calibrated simulation, and NSMC simulations.
CDM Smith Condamine Alluvium Model	This numerical model is based on the Central Condamine Alluvium Model (CCAM) originally developed by KCB in 2012. It was used to enable predictions of Condamine Alluvium drawdown due to CSG production under the SREIS FDP. This was achieved by removing water volumes equivalent to the changes in vertical groundwater flux between the Great

Numerical model	Purpose
	Artesian Basin (GAB) and Condamine Alluvium predicted by the Arrow SREIS Groundwater Model.
Condamine River Integrated Quantity and Quality Model	The predicted changes in groundwater drawdown in the Condamine Alluvium (from the CDM Smith Condamine Alluvium Model) were used as inputs to the IQQM which is a hydrological modelling tool used for planning and evaluating water resources. This enabled the evaluation of impacts to river flows due to CSG induced groundwater impacts, for the Stage 1 CSG WMMP.

Because CSG production and associated water take for the SGP has been revised since the Stage 1 CSG WMMP, a revision of modelling has been undertaken to support the Stage 2 CSG WMMP (Section 4).

4. Modelling results supporting Condition 17(b)

To address Approval Condition 17(b), this section provides a review and summary of modelling undertaken since the Stage 1 CSG WMMP. A key feature of the Stage 2 CSG WMMP modelling is the revised FDP (Case 10a) and the adoption of the OGIA 2016 Groundwater Model (in place of the Arrow SREIS Groundwater Model) as the basis for simulating impacts under the Stage 2 CSG WMMP FDP.

Specific modelling work undertaken, and addressed in this section, includes:

- A comparison between the 2012 OGIA Groundwater Model and 2016 OGIA Groundwater Model (Section 4.1)
- Updated Stage 2 CSG WMMP modelling (Case 10a FDP) (Section 4.2)
- Updated integrated groundwater-surface water modelling (Section 4.3)
- Comparison of Stage 1 and Stage 2 CSG WMMP modelling results (Section 4.4)

4.1. Comparison between OGIA 2016 and 2012 Groundwater Models

In 2016 OGIA released a new groundwater model (the OGIA 2016 Groundwater Model) to inform the Surat CMA 2016 UWIR. This model incorporated Arrow's Case 8b FDP and was used by OGIA to inform the 2016 UWIR. It incorporated revised modelling code and other changes, as described in Appendix E of the Stage 1 CSG WMMP.

The OGIA 2016 Groundwater Model was previously assessed as not being equivalent to the OGIA 2012 Groundwater Model because a model comparison and uncertainty analysis had not been undertaken, and as a result of this, it was not possible to address uncertainty and predictive difference between the Arrow SREIS Groundwater Model (based on the OGIA 2012 Groundwater Model) and the OGIA 2016 Groundwater Model.

To address this, Arrow engaged AGE to undertake null-space Monte Carlo (NSMC) uncertainty analysis using the OGIA 2012 Groundwater Model, based on water production extracted from the OGIA 2016 Groundwater Model. This work (AGE, 2017) enabled comparison of the modelling predictions between these 2 model versions, under the same Case 8b water production case. This was required because the two models had different water production despite being based on the same FDP.

Physical differences between OGIA 2012 and 2016 Groundwater Models

The OGIA 2012 Groundwater Model was based on MODFLOW-2005 numerical code. MODFLOW-USG code (beta) was adopted for the OGIA 2016 Groundwater Model.

The 2012 and 2016 OGIA groundwater models also differ in geological and stratigraphic interpretation, reflected in the model layering. The OGIA 2012 Groundwater Model includes 19 layers representing the full GAB sequence and alluvial formations within the Surat CMA and CSG production Bandanna formation in the Bowen Basin (GHD, 2012). The OGIA 2016 Groundwater Model was extended and increased to 32 layers to better represent aquifer geometry in alluvial and coal seam formations (OGIA, 2016a). In the 2016 model, the coal formations are represented using a minimum of three layers to allow a more accurate Condamine Alluvium contact zone representation, and the Springbok Sandstone and Hutton Sandstone have also been subdivided into multiple layers.

Water production

CSG water production is represented in the OGIA 2012 Groundwater Model using a modified evapotranspiration package (EVT) package approach, whereas the 2016 model utilises a modified drain (DRN) package approach (AGE, 2017). Landholder pumping is simulated using the well (WEL) package. Because of the different CSG water representation approaches, a method was adopted to extract the location and timing of non-Arrow CSG water production from the OGIA 2016 Groundwater

Model, and to recreate an evapotranspiration file to represent the updated 2016 CSG water production in the OGIA 2012 Groundwater Model (AGE, 2017).

The updated OGIA 2012 Groundwater Model version was then calibrated and uncertainty analysis simulations for cumulative and Arrow only impacts were prepared (AGE, 2017). The NSMC method was used to produce multiple realisations of model parameters that represent realistic complexity and are constrained by the calibration dataset. The uncertainty of model prediction was assessed by running the model 200 times using these parameter sets[1] for the following scenarios:

- Base case (no CSG production);
- Arrow case (Arrow-only CSG production); and
- Cumulative case (all CSG production).

Baseline water levels and interlayer flux responses for the CSG production cases were subtracted from the base case (for each of the 200 realisations) to derive the drawdowns and change in interlayer fluxes. The results were then processed as a composite suite of predicted impacts, ranked based on the associated probability, and the 5th and 95th prediction percentile realisations presented.

Drawdown results

Figures 1 and 2 present the regional P95 groundwater drawdown for Case 8b FDP under Arrow only and cumulative cases, incorporating 2016 UWIR water production. The extents were found to be consistent with the OGIA 2016 Groundwater Model. Figure 3 and 4 compare the calibrated Case 8b FDP under the recalibrated OGIA 2012 and 2016 Groundwater Models, for the Walloon Coal Measures and the Springbok Sandstone. The figures indicate a general similarity in prediction, with differences in detail arising due to the different geological layering between the two model versions, as well as numerical coding differences.

As a comparison with the current FDP (refer Section 4.2) Figures 5 and 6 present the regional P95 groundwater drawdown for Case 10a FDP under Arrow only and cumulative cases in the OGIA 2012 model.

Condamine flux change

A key purpose of the modelling comparison under Case 8b FDP was to characterise differences in Condamine Alluvium flux predicted by the different model versions. Table 4.1 summarises the modelled flux changes (for the P95 and calibrated cases) together with the predicted Arrow water production.

Table 4.1: Water production and flux impact summary

Modelled case	Arrow water production (calibrated) (GL)	Cumulative flux change (GL/100 years)		Arrow only flux change (GL/100 years)	
		Calibrated	P95	Calibrated	P95
OGIA/Arrow 2012 SREIS	702	-78	-101	-63	-79
OGIA 2016 Case 8b	1204	-116	na	-70	na
OGIA 2012* Case 8b	657	-72	-98	-56	-79

* AGE 2017 version. na = not assessed

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[1] Parameters varied were horizontal hydraulic conductivity, vertical hydraulic conductivity, vertical anisotropy, storage/specific yield, and recharge.

The results show that under the Arrow only calibrated case, flux change to the Condamine Alluvium for the 2012 Case 8b is lower than for the 2012 SREIS case (-56 GL compared to -63 GL) and much reduced compared with the 2016 8b case (-70 GL). For the P95 cases, the flux change to the Condamine Alluvium for the 2012 Case 8b is the same as the 2012 SREIS case (-79 GL).

Correspondingly similar flux change relationships are seen for the cumulative cases.

Arrow water production (calibrated realisation) for the 2012 Case 8b is lower than for the 2012 SREIS case (657 GL compared to 702 GL). For the 2016 Case 8b, the water production is much higher at 1204 GL, a value that is difficult to reconcile, when compared with the 2012 Case 8b model (657 GL), or with Arrow Eclipse reservoir modelling (460 GL). This may be due to the behaviour of the 2016 OGIA model which incorporates coding modifications, including for dual-phase flow.

4.2. Updated Stage 2 CSG WMMP (Case 10a FDP) modelling

CSG extraction under the SGP requires groundwater abstraction from the Walloon Coal Measures, which will lead to depressurisation of this and other GAB formations. In addition, this depressurisation can lead to potential changes in flux to the Condamine Alluvium, and hence affect groundwater-surface water interaction with the Condamine River.

The Stage 1 CSG WMMP was based on the SREIS FDP 5x case which used the Arrow SREIS Groundwater Model to model regional impacts. Flux change predictions from this model to the Condamine Alluvium were then used as inputs to the more detailed CCAM to model Condamine Alluvium drawdown, which in turn provided inputs to the IQQM modelling of impact to the Condamine River.

Current modelling – 10a FDP case

The Stage 2 CSG WMMP is underpinned by the revised Case 10a FDP. Therefore, to understand impacts from this development case, additional groundwater modelling was undertaken to build on and revise that previously undertaken in the Stage 1 CSG WMMP for Approval Condition 13(b). This modelling included:

- Calibration and uncertainty analysis, using the OGIA 2012 model with Arrow’s Case 10a FDP production, and comparison with the SREIS Groundwater Model uncertainty analysis.
- Updating the OGIA 2016 Groundwater Model with Arrow’s Case 8b FDP replaced with Case 10a FDP production.

4.2.1. Case 10a uncertainty analysis

To address the uncertainty in the aquifer parameters assigned to the calibrated OGIA model, Arrow engaged AGE to undertake NSMC uncertainty analysis using Case 10a for the OGIA 2012 Groundwater Model. This work enabled a comparison of the model predictive uncertainty under different water production cases, i.e. the 10a P95 case compared with the 8b P95 case.

Water production

CSG water production in the models, and the method adopted was the same as described in Section 4.1, however the latest FDP for Case 10a was incorporated, with updated non-Arrow CSG production (taken from the OGIA 2016 Groundwater Model) to create an EVT package in MODFLOW-2005 format and compatible with the regional OGIA 2012 Groundwater Model (Age, 2018). Scheduling information and production volumes were provided by Arrow and as calculated by reservoir simulation models.

A NSMC method was used for the Case 10a predictive uncertainty analysis using the OGIA 2012 Groundwater Model, to produce multiple realisations of model parameters that represent realistic complexity and are constrained by the calibration dataset. The uncertainty of model prediction was assessed by running the model 200 times using the same parameters sets derived by OGIA for the following three scenarios:

- Base case (no CSG production);
- Arrow case (Arrow-only CSG production); and
- Cumulative case (all CSG production).

Baseline water levels and interlayer flux responses for the CSG production cases were subtracted from the base case (for each of the 200 realisations) to derive the drawdowns and change in interlayer fluxes. The results were then processed as a composite suite of predicted impacts, ranked based on the associated probability, and presented as 5th and 95th prediction percentiles.

Drawdown results

Regional P95 groundwater drawdown extents for the Case 10a model (Figures 5 and 6) were found to be consistent with P95 groundwater drawdown extents for the Case 8b model (Figures 1 and 2) (AGE, 2018). The largest discrepancy from the SREIS reported derives from the updated non-Arrow production footprint, which differs to the south-west of the Millmerran production area (AGE, 2018).

Condamine flux change

Table 4.2 presents predicted Arrow water production and the reduction in flux to the Condamine Alluvium under Case 10a FDP, for the calibrated and P95 realisations.

Table 4.2: Water production and flux impact summary

Modelled case	Arrow water production (calibrated) (GL)	Cumulative flux change (GL/100 years)		Arrow only flux change (GL/100 years)	
		Calibrated	P95	Calibrated	P95
OGIA/Arrow 2012 SREIS	702	-78	-101	-63	-79
OGIA 2012* Case 10a	725	-73	-96	-58	-75

* AGE 2018 version na = not assessed

The results show that under the Arrow only calibrated case, the modelled change in flux to the Condamine Alluvium for the 2012 Case 10a is lower than for the 2012 SREIS case (-58 GL compared to -63 GL). For the P95 cases, flux to the Condamine Alluvium for the 2012 Case 10a is reduced (-75 GL) compared with the 2012 SREIS 5x case (-79 GL).

Similar relationships are seen for the cumulative cases.

Arrow water production (calibrated realisation) for the 2012 Case 10a is ~3% higher than for the 2012 SREIS case (725 GL compared to 702 GL).

4.3. Updated Integrated groundwater-surface water modelling

Significant modelling work (CDM Smith, 2016) to consider groundwater-surface water interactions was previously undertaken, peer-reviewed, and accepted as a basis for achieving the requirements of the EPBC Approval Condition 13(b) to quantify river impacts for the Stage 1 CSG WMMP. This work was based on the SREIS FDP, and included the CDM Smith Condamine Alluvium Model and the Condamine River Integrated Quantity and Quality Model which is a hydrological modelling tool used for planning and evaluating water resources. This modelling enabled the evaluation of impacts on river flows and users from CSG induced drawdown under the SREIS FDP case.

Predicted flux changes from Arrow's Case 10a FDP modelling together with updated CCAM and IQQM modelling has been used to support the Stage 2 CSG WMMP. This is summarised in the following sub-sections.

4.3.1. Case 10a FDP modelling

Modelling for the Stage 2 CSG WMMP uses Arrow's Case 10a FDP in combination with the OGIA 2016 regional groundwater model to predict flux changes to the Condamine Alluvium. Three model simulations were necessary to predict the potential impacts of Arrow's development relative to the cumulative impacts from other current and future CSG production in the Surat Basin. These cases were:

- Base case (no future CSG production in Surat Basin)
- CSG production case (future CSG production by all CSG operators and Arrow's Case 10a FDP)
- Non-Arrow CSG production case (future CSG production by all CSG operators except Arrow)

The base case simulation provided a predicted baseline without CSG development, and potential impacts of CSG production are quantified relative to this baseline. Arrow's contribution to these impacts is quantified as the difference between the production case simulation and the non-Arrow production case simulation, relative to the base case.

Model verification

In addition to the above simulations, a verification run of the OGIA 2016 Groundwater Model was also undertaken using the 2016 UWIR calibrated parameter sets and water production file (from OGIA). The purpose of this simulation was to confirm that the model predictions (run by CDM Smith) correspond to OGIA predictions, and hence verify that the model was being used correctly.

The results were verified against the results from the OGIA 2016 Groundwater Model by comparing maps of maximum drawdown induced by CSG development, by comparing water balances, and by comparing the change in total flux between the Surat Basin and Condamine Alluvium induced by CSG development.

Results from the verification run in this study were input to the OGIA's post-processing spreadsheet, and indicated an exact match to 2016 UWIR flux of 1,156 ML/y (CDM Smith, 2018).

Figures 3 to 11 in CDM Smith (2018) provide a visual comparison with the 2016 UWIR predictions for individual hydrostratigraphic units, indicating an exact match in drawdown.

Water production volumes and rates: existing and proposed CSG development

Table 4.3 presents a summary of water production predicted by the OGIA 2016 Groundwater Model for Arrow's Case 10a FDP, and indicate that Arrow's predicted contribution to total water production is around 21%. Arrow's predicted peak rate of water production in this model is ~23% of the peak rate of all CSG producers but occurs around 20 years later (CDM Smith, 2018).

Table 4.3: Water production summary (GL)

CSG Water production	All CSG producers	Arrow's component (Case 10a)
Total for simulation	5,498	1,178
Total for future (2015 onwards)	5,319	1,153
Peak rate of production (year of peak)	525.5 (2018)	123.3 (2038)

Figure 7 compares the Case 10a forecast water production based on reservoir modelling, compared with the predicted water production from the OGIA 2016 Groundwater Model under the same FDP. The number of Case 10a active CSG wells are provided on the figure for correlation.

The prediction of Arrow's total water production over the simulation period (1,178 GL) using the OGIA 2016 Groundwater Model is around twice that of the forecast water production (575 GL) from Arrow's reservoir modelling (CDM Smith, 2018) and 63% higher than that predicted by the OGIA 2012 Groundwater Model under Case 10a (725 GL, AGE 2017). The predicted water production significantly exceeds the Eclipse reservoir forecast modelling (575 GL). As previously noted, this may be due to the behaviour of the 2016 OGIA model which incorporates coding modifications, including for dual-phase flow.

Change in net vertical flux to Condamine

The predicted change in total flux at the base of the Condamine Alluvium with Arrow's Case 10a FDP is presented in Table 4.4, and Figure 8 shows how the predicted change in flux from the Surat Basin at the base of the Condamine Alluvium reduces over time (following the peak change) due to water production by all CSG operators.

Table 4.4: Case 10a predicted change in Surat Basin flux to Condamine Alluvium

Flux at base of Condamine Alluvium	All CSG producers	Arrow's component (Case 10a)
Total flux change up to year 10,000	-887.2 GL	-447.9 GL
Total flux change up to year 10,000 as % of predicted total water production	16.1%	38%
Peak change in flux (year of peak)	-4.89 ML/d (2053)	-2.93 ML/d (2049)
Peak flux change as % of peak production	0.93%	2.4%

Approximately 16% of the total change in flux at the base of the Condamine Alluvium is predicted to be drawn from the alluvium, including ~38% of Arrow's component. The predicted peak changes in vertical flux at the base of the alluvium, as a percentage of the predicted peak rate of water production, is indicated to be relatively small (a few percent or less). Figure 9 shows the predicted peak change in flux from the Surat Basin to the Condamine Alluvium due to Arrow under Case 10a.

A few model cells within the subcrop area of the Walloon Coal Measures are indicated to have a maximum change in flux greater than 10 mm/y, but generally the predicted maximum flux changes are less than 5 mm/y (CDM Smith, 2018) and areas of better connectivity between the Surat Basin and Condamine Alluvium are also reflected by predicted earlier occurrences of the maximum flux changes.

Figure 10 shows the distribution of the predicted change in volume to the Condamine Alluvium due to Arrow under Case 10a, and are total volumes in each 1.5 km × 1.5 km model cell over the entire simulation period. The spatial pattern is also similar for all CSG operators (Figure 21 in CDM Smith 2018) and reflects the control exerted by the underlying geological structure in the OGIA 2016 Groundwater Model as well as the pattern and timing of the gas-field development (CDM Smith, 2018).

4.3.2. CCAM model

For this study, and for the previous modelling for the Stage 1 CSG WMMP, the structure and parameterisation of the CCAM are unchanged. Nevertheless, several simulation setup changes were made to allow the predictive simulations to run for a greater period than the model had previously, and these changes were necessary to simulate the potential maximum impact over time to the

Condamine River (CDM Smith, 2018). For this study, and for the previous modelling for the Stage 1 WMMP, the CCAM is run for a period of 826 years, from 1980 to 2805, using annual stress periods.

The types of boundary conditions used to represent net vertical flux at the base of the Condamine Alluvium in the CCAM were also modified so that the changes in net vertical flux predicted using the OGIA 2016 Groundwater Model can be represented with the CCAM (CDM Smith, 2018).

For the predictive simulations in this study, the single predictive simulation used for the 2016 UWIR was replaced by two simulations - one representing water production by all CSG producers including Arrow's Case 10a FDP, and one representing water production by all CSG producers but omitting Arrow's water production (CDM Smith, 2018),

Changes in net vertical flux predicted by the OGIA 2016 Groundwater Model are only passed to the CCAM at locations where Condamine Alluvium is present in both models, and the CCAM was assigned GHB boundary conditions to represent groundwater exchange with the Surat Basin.

Predicted impact on Condamine Alluvium and Condamine River flux

Table 4.5 shows predicted maximum changes (reductions) and timing in the components of flow due to all CSG producers and due to Arrow water production. The results show that depressurisation takes time to propagate through the strata of the Surat Basin to the base of the Condamine Alluvium.

Because the change in vertical flux is only passed to the CCAM at locations where Condamine Alluvium is present in both models (refer Section 4.3.2 above) the maximum reduction in net flux at the base of the Condamine Alluvium from Surat Basin (Table 4.5) is proportionally lower than the Case 10a peak change in flux (Table 4.4) (CDM Smith, 2018).

Table 4.5: Condamine Alluvium and Condamine River flux impacts – CCAM model

Component	All CSG producers		Arrow's component (Case 10a)	
	ML/d	Year	ML/d	Year
Maximum water production rate	526	2018	123	2038
Maximum reduction in net flux at base of CA from Surat Basin	4.44	2052	2.74	2049
Maximum reduction in groundwater flux from CA to the Condamine River	0.267	2396	0.148	2396

The simulated maximum reduction in flow to the Condamine Alluvium due to all CSG producers is less than 0.8% (4.44 ML/d) of the maximum water production rate and occurs 34 years later. For Arrow's water production, the maximum reduction in flow is 2.2% (2.74 ML/d) of the maximum rate of Arrow's water production and occurs 11 years later (CDM Smith, 2018).

Predicted Condamine Alluvium watertable drawdown

Figure 11 shows maximum drawdown at the watertable due to Arrow's water production and shows that maximum drawdown is predicted to occur at different times within the simulation period at different locations within the alluvium. Maximum drawdown is not reached in some areas of the alluvium by year 2805 at the end of the simulation period (CDM Smith, 2018).

Maximum drawdown at the watertable due to all CSG producers and Arrow's water production is predicted earliest in areas on the western edge of the Condamine Alluvium between years 2044 and 2400 (CDM Smith, 2018). The maximum drawdown in the alluvium is predicted to occur after year 2400, approximately ~380 years after the simulated maximum in water production (all CSG producers).

The largest predicted value of maximum drawdown in a model cell due to all CSG producers is approximately 1.5 m, and approximately 1.1 m due to Arrow's water production (CDM Smith, 2018).

Predicted impact to the Condamine River

Impacts to the Condamine River from CSG water extraction can arise in situations where the groundwater surface is above the river base (baseflow driven or 'gaining' stream situation). In a modelling context, this occurs where river cells and the modelled watertable surface have an equivalent relationship, and therefore the predicted magnitude and timing of impacts to the river is a function of the location of 'connected' river cells and the drawdown induced by the simulated water production.

Analysis of the modelled results for all CSG producers shows that approximately 80% of river cells (light grey coloured cells) experience no change in groundwater flux over the simulation period because they are 'disconnected' from groundwater (CDM Smith, 2018).

As shown in Table 4.5, the predicted maximum changes in groundwater flux from the Condamine Alluvium to the Condamine River due to all CSG producers and due to Arrow's water production are an order of magnitude smaller, being 0.05% (0.267 ML/d) of the maximum rate of water production for all CSG producers and occurring 378 years later, and 0.12% (0.148 ML/y) of the maximum rate of Arrow's water production and occurring 358 years later (CDM Smith, 2018).

Most of the predicted impact on the Condamine River due to water production by all CSG producers occurs in river cells located between Warra Town Weir and Chinchilla Weir with maximum flux changes of between 0.001 ML/d and 0.009 ML/d, and a predicted maximum flux change to the River of 0.267 ML/d (Table 4.5). Over the simulation period the predicted total change in volumetric flux between the River and Condamine Alluvium is 60.7 GL (CDM Smith, 2018).

For Arrow only production similar patterns are indicated, but with smaller changes (Figure 12). Maximum flux changes to the River of between 0.001 ML/d and 0.005 ML/d are predicted between Warra Town Weir and Chinchilla Weir, with maximum changes of less than 0.001 ML/d also predicted just upstream of Cecil Plains Weir. Over the simulation period the predicted total change in volumetric flux between the River and Condamine Alluvium is 33.7 GL (CDM Smith, 2018).

For all practical purposes the predicted impacts are negligible (CDM Smith, 2018).

4.3.3. IQQM modelling

IQQM has been implemented in several regulated river systems in Australia for water resources management planning, including the Condamine-Balonne system. IQQM comprises modular components that include an instream water quantity module and a groundwater quantity and quality module (Simons *et al*, 1996).

River systems are represented in IQQM by a series of nodes connected with links, which allow the model to be configured to simulate any river system (Simons *et al*, 1996). Flow and routing is calculated along links at specified time-steps, which may be between one hour and one day.

In Queensland, IQQM data sets are developed and maintained by the Department of Natural Resources and Mines (DNRM). The data sets encapsulate licensing information, so that the model can be used to manage water allocations. IQQM models used by DNRM (and adopted for this project) for the area defined by the extent of the Condamine Alluvium groundwater model are:

- Upper Condamine model:
    - Starts at Killarney Weir.
    - Finishes at Cecil Plains Weir gauge 422316A on the Condamine River, and at the Lone Pine gauge 422345A on the North Condamine River (the northern anabranch).
    - Includes 8 supply storages.
- Middle Condamine model:
    - Starts at Cecil Plains Weir and Lone Pine gauges, where outflows from the Upper Condamine model are passed through as inflows to the Middle Condamine model.
    - Finishes at Beardmore dam headwater gauge 422212B.
    - Includes 17 regulated storages.

The IQQM models are further described in CDM Smith (2016 and 2018) and were used to assess the potential impacts of Arrow's proposed Case 10a FDP on surface water users. The impacts are represented in IQQM by the reduction in flux between the Condamine Alluvium and the Condamine River. The impacts to downstream users and Environmental Flow Objective[2] (EFO) nodes are then assessed against performance indicators specified in the Water Resources Plan (WRP).

Based on the modelling, impacts to the River are predicted to occur almost entirely between Warra Town Weir and Chinchilla Weir, an area within the Middle Condamine IQQM model. No significant impacts are predicted in the area covered by the Upper Condamine IQQM model.

The predicted impacts due to all CSG producers and Arrow's water production were compared to the base case ROP[3] scenario. The results show required performance indicators are achieved for both scenarios. The predicted maximum impact was assessed as negligible, with only the number of low flow days upstream of Chinchilla Weir reporting a change of 0.1% for impacts from all CSG producers

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[2] EFOs adopted are performance indicators for the Condamine and Balonne Water Resource Plan (Queensland Government, 2004)

[3] Upper Condamine and Middle Condamine Resource Operation Plan. An ROP describes the rules and requirements to achieve the water resource objectives from the Water Resource Plan. The ROP for the Condamine and Balonne River system was published in 2008 and revised in 2015 (DNRM 2015).

and for Arrow. All other performance measures were unchanged relative to the ROP scenario (CDM Smith, 2018).

A very slight change in the low flow regime can be observed at one node where the frequency of low flow days (less than 1 ML/d) has increased by approximately 0.8% for both scenarios, however no discernible change is predicted at the other EFO nodes, showing that there is almost no discernible impact of CSG production (CDM Smith, 2018).

All Water Allocation Security Objectives (WASOs) performance indicators were checked for users downstream of the groundwater loss node. There were no reductions in the performance indicators except at one IQQM node (Brigalow Town Water Supply) where the Annual Volume Probability decreased by 0.3% for both scenarios (CDM Smith, 2018).

4.4. Comparison of modelling results for Stage 1 and 2 WMMPs

Groundwater and surface water modelling undertaken in support of Arrow's Stage 2 CSG WMMP (OGIA 2016 model under Case 10a FDP) was compared to previous modelling undertaken (prior to 2016) for Arrow's Stage 1 CSG WMMP using the earlier 2012 version of the OGIA's regional groundwater model and Arrow's Case 5x FDP[4].

Selection of results

The OGIA 2012 Groundwater Model as used for the Stage 1 CSG WMMP was developed using NSMC methods. For the Stage 1 WMMP, the results of 200 realisations for water production were ranked as percentiles on total volume, and the CCAM model was run with three selected realisations that were based on ranking predicted change in total flux at the base of the Condamine Alluvium induced by CSG water production, as follows:

- High-volume P5 case (5% probability of exceedance);
- Median-volume P50 case (50% probability of exceedance); and
- Low-volume P95 case (95% probability of exceedance).

The OGIA 2016 Groundwater Model however does not use the same method for assessing predictive uncertainty, rather it presents a single calibrated predictive simulation. Therefore, to make comparisons between the modelling results from the Stage 1 and 2 CSG WMMPs it is necessary to specify which realisation from the Stage 1 CSG WWMP has been selected, and it is noted that comparisons of spatial results presented in maps use the P50 result from the Stage 1 CSG WMMP (CDM Smith, 2018).

Comparison of water production

Table 4.6 compares water production from the two models and flux change to the base of the Condamine Alluvium.

Table 4.6: Comparison of water production (due to Arrow development)

	Case 5x (OGIA 2012 model, St 1 WMMP)			Case 10a (OGIA 2016 model, St 2 WMMP)
	P95	P50	P5	
Total water production	755 GL	710 GL	653 GL	1,178 GL
Peak rate of water production	151 ML/d	138 ML/d	124 ML/d	123 ML/d

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[4] The 5x case includes Arrow SREIS water production, but with 2014 updated production for other proponents.

	Case 5x (OGIA 2012 model, St 1 WMMP)			Case 10a (OGIA 2016 model, St 2 WMMP)
	P95	P50	P5	
Total flux change at base of CA (up to year 2805)	271 GL	239 GL	206 GL	277 GL
Peak flux change at base of CA (year of peak)	2.84 ML/d (2060)	1.83 ML/d (2057)	1.31 ML/d (2063)	2.93 ML/d (2049)

The results indicate that Arrow's contribution to the predicted water production volume is larger for Case 10a than for Case 5x. However, the peak in water production rate is smaller for Case 10a than for Case 5x. The Case 10a Arrow water production volume is indicated to be 66% larger than the Case 5x median (P50) water production (CDM Smith, 2018).

The total change in Arrow's flux at the base of the Condamine Alluvium is indicated to be ~16% larger than the Case 5x median (P50) realisation and occurs a few years earlier (CDM Smith, 2018).

Predicted CSG water production in the Surat Basin

Arrow water production predicted for the Case 10a and Case 5x FDPs are compared in Figure 13 for the Case 5x P5, P50 and P95 realisations, and the minimum and maximum of all realisations. Case 10a is distinguished by a broader predicted water production profile.

Induced change in flux at the base of the Condamine Alluvium

Figures 14 and 15 compare the predicted temporal and spatial distributions of induced changes in flux at the base of the Condamine Alluvium due to Arrow, for Case 10a and Case 5x (P50).

The differences between case 10 and Case 5x are due to differences between the OGIA 2016 and OGIA 2012 Groundwater Model versions, and also due to differences between the production and timing of the two FDPs.

Induced drawdown in the Condamine Alluvium

Figures 16 and 17 compare the Case 10a and Case 5x (P50) predicted drawdown in the Condamine Alluvium for the cumulative and Arrow cases. The differences in drawdown are minor, however the timing of maximum drawdown has changed for the Arrow case. Differences are influenced by the revised staging and location of Arrow's Case 10a FDP production, as well as revisions to geological interpretation in the OGIA 2016 Groundwater Model that underpins the modelled flux change to the Condamine Alluvium.

Induced change in flux to the Condamine River

Figure 18 provides a comparison of the predicted induced changes in flux (baseflow) to the Condamine River for Case 5x and Case 10a.

As discussed in Section 4.3.2, maximum flux changes to the river are small and the predicted impacts are negligible under both FDP cases.

5. Condition 17(c)

This section provides a review of the investigations undertaken and available information to demonstrate that the work undertaken to date addresses Approval Condition 17(c).

Include an explanation of how the approval holder will contribute to the Condamine Interconnectivity Research Project. The Stage 2 CSG WMMP must present the findings of the Condamine Interconnectivity Research project and any modelling done by the OGIA to validate predicted drawdown and a review of trigger thresholds and corrective actions for the action.

5.1. Summary of the Condamine Interconnectivity Research Project (CIRP)

The CIRP was led by OGIA with collaborative arrangements with parties that included Arrow Energy (for drilling and pumping test investigations) and Queensland University of Technology (for assessing hydrochemical data).

The CIRP concluded that the level of hydraulic connectivity between the Condamine Alluvium and the Walloon Coal Measures is low. The project pursued several lines of investigation resulting in a range of findings that supported this conclusion. In particular, that:

- The geological data shows that a clay-rich or mudstone horizon at the base of the Condamine Alluvium and the top of the Walloon Coal Measures acts as a physical barrier that impedes inter-formation flow.
- Persistent differences in groundwater levels between the formations, and the flow patterns within the formations, demonstrate that impediments to flow exist between the formations.
- Hydrochemical data indicates little past movement of water between the formations, even in areas where significant groundwater level differences have existed for a prolonged period.
- Detailed aquifer pumping tests at two sites found no significant flow of water between the formations in response to pumping tests around those sites. The tests showed that the vertical hydraulic conductivity for the material between the formations is consistent with that of a highly effective aquitard.

The results of the CIRP are reported in the OGIA 2016 UWIR, and in the OGIA hydrogeological investigation report: *Groundwater connectivity between the Condamine Alluvium and the Walloon Coal Measures* (OGIA, 2016b).

5.2. CIRP investigation

The project used multiple lines of investigation to assess connectivity, and included:

- Reinterpreting geology with focus on the contact between the Condamine Alluvium and the Walloon Coal Measures;
- Mapping of regional groundwater level differences between the two systems;
- Hydrochemical analysis of the Condamine Alluvium and the Walloon Coal Measures groundwater systems; and
- Aquifer testing at representative sites and numerically analysing the test data.

An overview of these are provided below.

5.2.1. Interpretation and modelling of the geology

Geological interpretation and geological modelling were undertaken by OGIA to improve the geologic understanding within the Condamine Alluvium, focussing on the transition zone and underlying sediments, to identify the presence or absence of physical barriers to flow between the Walloon Coal Measures and the Condamine Alluvium.

Data from about 3,500 existing bores was utilised, and supplemented with project bore data and the available geophysics. The data provided a basis for interpreting the boundaries of formations:

- Sheetwash;
- Granular alluvium;
- The transition zone; and
- The upper Surat Sediments (mainly comprising the Walloon Coal Measures).

The Condamine Geological Model was developed from this work, and used in the construction of the OGIA 2016 Groundwater Model, to support the preparation of the Surat UWIR 2016.

Key findings

The geological interpretation showed that the transition zone underlies much of the central area of the Condamine Alluvium, but is not a continuous layer. Where present, the transition zone thickness ranges from less than one metre to just over 15 metres (DNRM, 2016b).

The upper part of the Walloon Coal Measures (above the shallowest coal seams) is dominated by mudstone and siltstone which provides a further barrier to water movement between the potential CSG target coal seams and the overlying alluvium.

5.2.2. Surveying and mapping of groundwater levels

Mapping of groundwater levels was undertaken to identify the spatial distribution of differences between groundwater pressure/level between the Condamine Alluvium and the Walloon Coal Measures, to understand how the two groundwater systems have responded to extraction from the Condamine Alluvium over recent decades, which provides information about connectivity between them.

Key findings

Groundwater levels in the more developed parts of the Condamine Alluvium have lowered substantially by irrigation extraction over the past 60 years, significantly altering groundwater flow in the Condamine Alluvium. In contrast, groundwater levels in the Walloon Coal Measures have not materially changed, resulting in a head difference of between 5 and 20 metres between the formations, across much of the central part of the Condamine Alluvium. This demonstrates that there is a significant impediment to flow between the two formations.

5.2.3. Assessment of the hydrochemistry

Hydrochemical data was assessed to identify hydrochemical indicators of any past mixing of water between the Condamine Alluvium and the Walloon Coal Measures. Analytical techniques (including multivariate analysis) using major ion data from ~3,000 groundwater samples from private water supply bores, monitoring bores and CSG wells was investigated to help understand the underlying differences in hydrochemistry of the two systems and corresponding differences in the hydrochemical evolution of water in each system (DNRM, 2016a, 2016b).

Key areas of interest included an area of relatively high salinity in the Condamine Alluvium (which could have resulted from formation interflow) and an area of large groundwater head difference between the formations, which could cause water to move between the formations if significant connectivity existed.

Key findings

The assessment found that the underlying hydrochemical signatures of the two formations are different and are likely to be the result of chemical evolution within the formations rather than the result of the movement of water between the formations.

5.2.4. Aquifer testing

Aquifer pumping tests (including purpose drilled boreholes) were undertaken to help establish the geological and hydrogeological characteristics of the interface between the Condamine Alluvium and the Walloon Coal Measures. The aquifer tests were carried out for at least 30 days, with monitoring continuing during pumping and through the recovery period[5]. All field operations were carried out by Arrow Energy with full OGIA involvement.

Tests were carried out at two locations of different hydrogeological settings. The project established nested observation bores, and continuous core samples were collected to establish lithology. This was supplemented with geophysical logging and lab testing of geological material.

The test method involved pumping water from the Condamine Alluvium, whilst monitoring pressure responses at multiple levels in the two formations. The data were analysed to provide estimates of the vertical hydraulic conductivity of the transition zone.

Key findings

The test data were analysed using a range of techniques and indicated no significant cross-formation flow in response to pumping. Quantitative analysis indicates vertical hydraulic conductivity of the material between the formations of around 10^{-6} m/day (1.2 x 10^{-11} m/sec), typical of an effective aquitard.

5.2.5. Conceptualisation of connectivity

Conceptualisation, as well as the confidence in conclusions about the connectivity, has improved significantly due to project investigations. The following are key findings:

1. Groundwater flow in the Condamine and Walloons is mainly horizontal, with vertical flow impeded by a combination of the transition zone and the firm mudstone/siltstone interburden above the coal seams.
2. The first inter-formation flow barrier is the transition zone (present across much of the area). The transition zone is absent in some areas, such as near the Condamine Alluvium margins. Due to the angular contact of the Walloons and Condamine Alluvium, some of the upper coal seams along the western flank of the alluvium may come into contact with the alluvium where the transition zone is absent. However, in most of this area the Springbok Sandstone and the Westbourne Formation are also wedged between the Condamine Alluvium and the Walloon Coal Measures, providing a significant barrier to flow along the western flank of the alluvium.
3. The second inter-flow barrier is the mudstone/siltstone interburden of the upper Walloon Coal Measures (above the depth at which commercial CSG could be found). The shallow coal seams in the upper part of the Walloons are not targeted for CSG and a minimum separation distance of 30 metres is intended between the base of the Condamine Alluvium and the target coal seams.
4. A combination of 2) and 3) above will function as an aquitard between the formations.

5.2.6. CIRP findings and Arrow modelling

The findings of the CIRP are of direct relevance to the existing body of work undertaken for prediction of impacts from the SGP to the Condamine Alluvium and Condamine River.

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[5] Monitoring at these sites will continue indefinitely to assess responses to long-term pumping cycles and other influences.

The findings demonstrate that the assumptions incorporated into past model versions (such as the Arrow SREIS Groundwater Model), in particular that a low-permeability transition layer controls and limits groundwater flux impacts from the SGP to the Condamine, are supported by field investigations relying on multiple lines of evidence, and are therefore valid and reasonable for predictive purposes.

In addition, the findings (in the form of the OGIA Condamine Geological Model) have been adopted for the 2016 UWIR, and the OGIA 2016 groundwater model. Because predictions derived from this model provide a basis for the Stage 2 CSG WMMP, it follows that trigger values, limits or corrective actions derived from it and presented in the WMMP for the Condamine Alluvium, have a technically supported basis.

6. Condition 17(d)

This section provides information to demonstrate that the work undertaken to date addresses Approval Condition 17(d).

Approval Condition 17(d): *Report on the potential for flow reversal from the Condamine Alluvium to underlying aquifers, based on data obtained during the Stage 1 CSG WMMP.*

Modelling of groundwater flux between the Walloon Coal Measures and the Condamine Alluvium indicate that impacts due to CSG development are comprised of reductions in upward flux to the Condamine Alluvium, as indicated in Figure 19 of CDM Smith (2018).

During early and non-equilibrium stages of the model simulations, flux directions are observed to be variable. However, after the commencement of CSG production the net flux to the Condamine Alluvium increases approximately monotonically, and from approximately 2015 onwards the net flux begins to slowly decrease to the assumed conditions at the start of the predictive period.

The behaviour of groundwater flux under modelled conditions is consistent with previous work undertaken for the SREIS and for the Stage 1 CSG WMMP, and confirms that impacts to the Condamine Alluvium due to the development of Arrow's Case 10a FDP are indirect, in that groundwater is not extracted from the Condamine Alluvium due to the Arrow Surat Gas Project.

7. Condition 23

Approval Condition 23: *If the OGIA model ceases to exist, then the approval holder must submit an alternate model to be used for the purpose of these conditions that replaces the OGIA model as referred to in these conditions. The alternate model must be approved by the Minister in writing before the next relevant stage of the CSG WMMP is submitted to the Minister for approval.*

In the event that the OGIA model ceases to exist, Arrow will submit an alternative model to be used for compliance with the approval conditions. This alternative model would be submitted to the Minister for approval prior to the next relevant stage of the CSG WMMP.

8. Conclusion

Based on the outcomes of this review, the OGIA 2016 Groundwater Model and CDM Smith integrated groundwater-surface water models are appropriate tools for the purposes of predicting groundwater and surface water impacts, developing monitoring and mitigation measures, and informing management decisions for the Stage 2 CSG WMMP.

Table 8.1 provides a summary correlation of specific model uses and objectives with the Approval Conditions addressed in this memorandum.

Table 8.1 Summary of addressed Approval Conditions and associated model basis, outputs and objectives

Approval Condition	Model basis	Summary/comment on basis for compliance with approval condition
17(b) Include any updated modelling for the project, including in respect of the OGIA model or any updates to the OGIA model by OGIA.	Comparison of 2012 and 2016 OGIA Groundwater Models	Compliance is based on the method and results as detailed in Section 4.1, including the NSMC modelling outputs, and comparison between the Case 8b modelling under the OGIA 2012 model with the OGIA 2016 model predictions. Refer Figures 1 to 4 and AGE 2017.
	Updated Stage 2 CSG WMMP (Case 10a) modelling	Compliance is based on the method and results as detailed in Section 4.2, including the Case 10a modelling with the OGIA 2016 model, and the Case 10a NSMC modelling in the OGIA 2012 Groundwater Model. Refer to Figures 5 to 8 and AGE 2018.
	Updated integrated groundwater-surface water modelling	Compliance is based on the method and results as detailed in Section 4.3, including the calibrated Case 10a modelling using the OGIA 2016 Groundwater Model,, the updated CCAM and IQQM models. Refer to Figures 9 to 12 and CDM Smith 2018.
	Comparison of Case 8b modelling and Stage 2 CSG WMMP (Case 10a) modelling	Compliance is based on the method and results as detailed in Section 4.4 which presents the comparison between the Case 8b Stage 1 modelling using the OGIA 2012 Groundwater Model, and the Case 10a Stage 2 modelling using the OGIA 2016 Groundwater Model. Refer to Figures 13 to 18 and CDM Smith 2018.

Approval Condition	Model basis	Summary/comment on basis for compliance with approval condition
17(c) The Stage 2 CSG WMMP must present any modelling done by the OGIA to validate predicted drawdown.	Condamine Interconnectivity Research Project	Compliance is based on the results of the CIRP as discussed in Section 5, and reported in the 2016 UWIR, and in the OGIA hydrogeological investigation report: "*Groundwater connectivity between the Condamine Alluvium and the Walloon Coal Measures*" (OGIA 2016b). The findings demonstrate that the assumptions incorporated into past model versions (such as the Arrow SREIS Groundwater Model), in particular that a low-permeability transition layer controls and limits groundwater flux impacts from the SGP to the Condamine, are supported by field investigations relying on multiple lines of evidence, and are therefore valid and reasonable for predictive purposes. The CIRP findings have been adopted for the 2016 UWIR, and the OGIA 2016 Groundwater Model, the predictions from which provide a basis for the Stage 2 CSG WMMP. It follows that trigger values, limits or corrective actions derived from it and presented in the WMMP for the Condamine Alluvium, have a technically supported basis.
17(d) Report on the potential for flow reversal from the Condamine Alluvium to underlying aquifers, based on data obtained during the Stage 1 CSG WMMP.	Updated integrated groundwater-surface water modelling	Compliance is based on the results of the updated integrated groundwater-surface water modelling as discussed in Section 4.3. The SREIS demonstrated that flux to the Condamine Alluvium at all times remains upward (i.e. no flow reversal. The changes to groundwater flux to the Condamine Alluvium under Case 10a are further reduced from the SREIS FDP case, and flow will remain upward. Refer CDM Smith 2018.

Note: Figures provided as indicative and typical. Timing of predictions to be considered in detail at the groundwater monitoring network and GDE technical memoranda stage.

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Figures

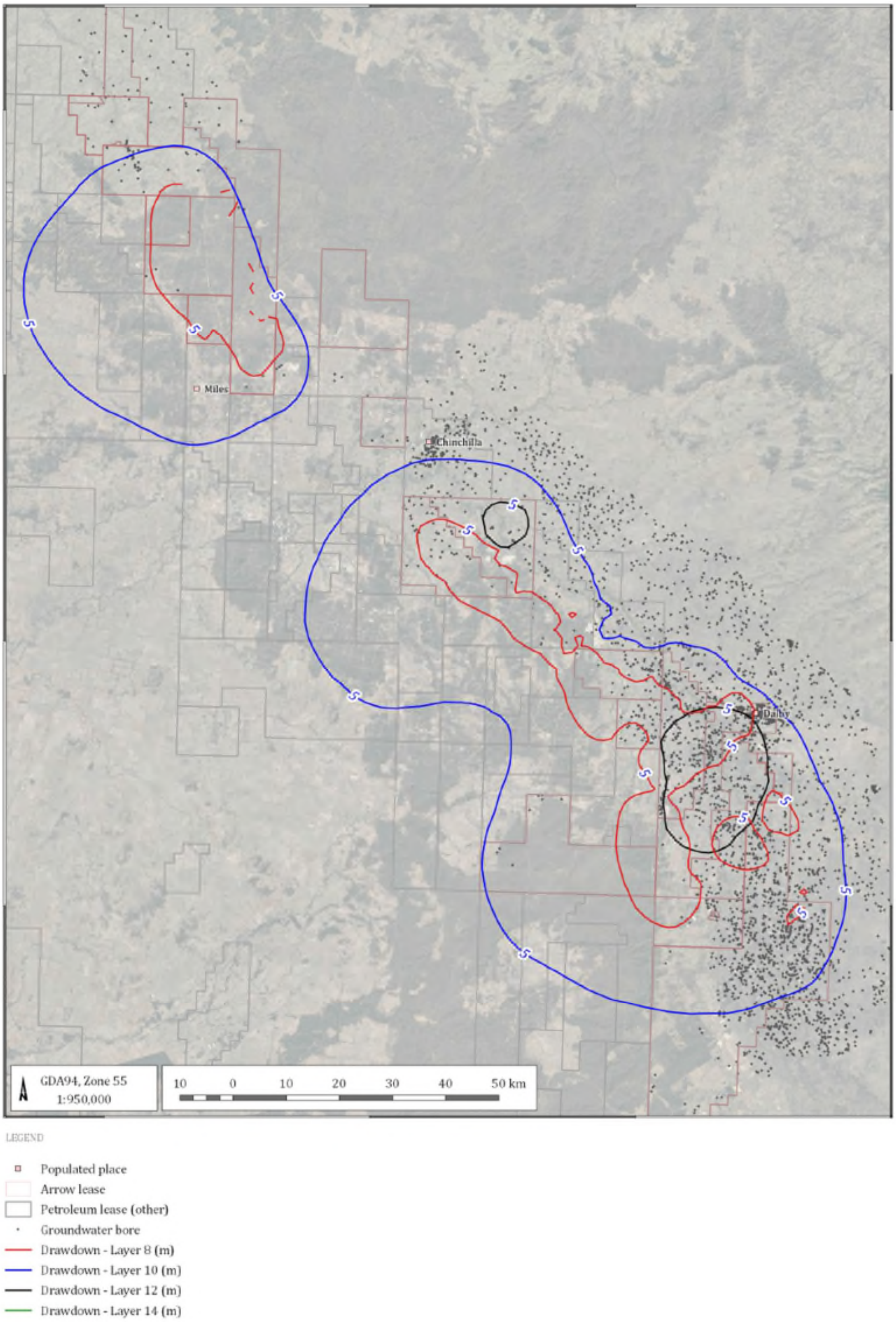

Figure 1 Case 8b Arrow only drawdown – 2012 OGIA model 95th percentile

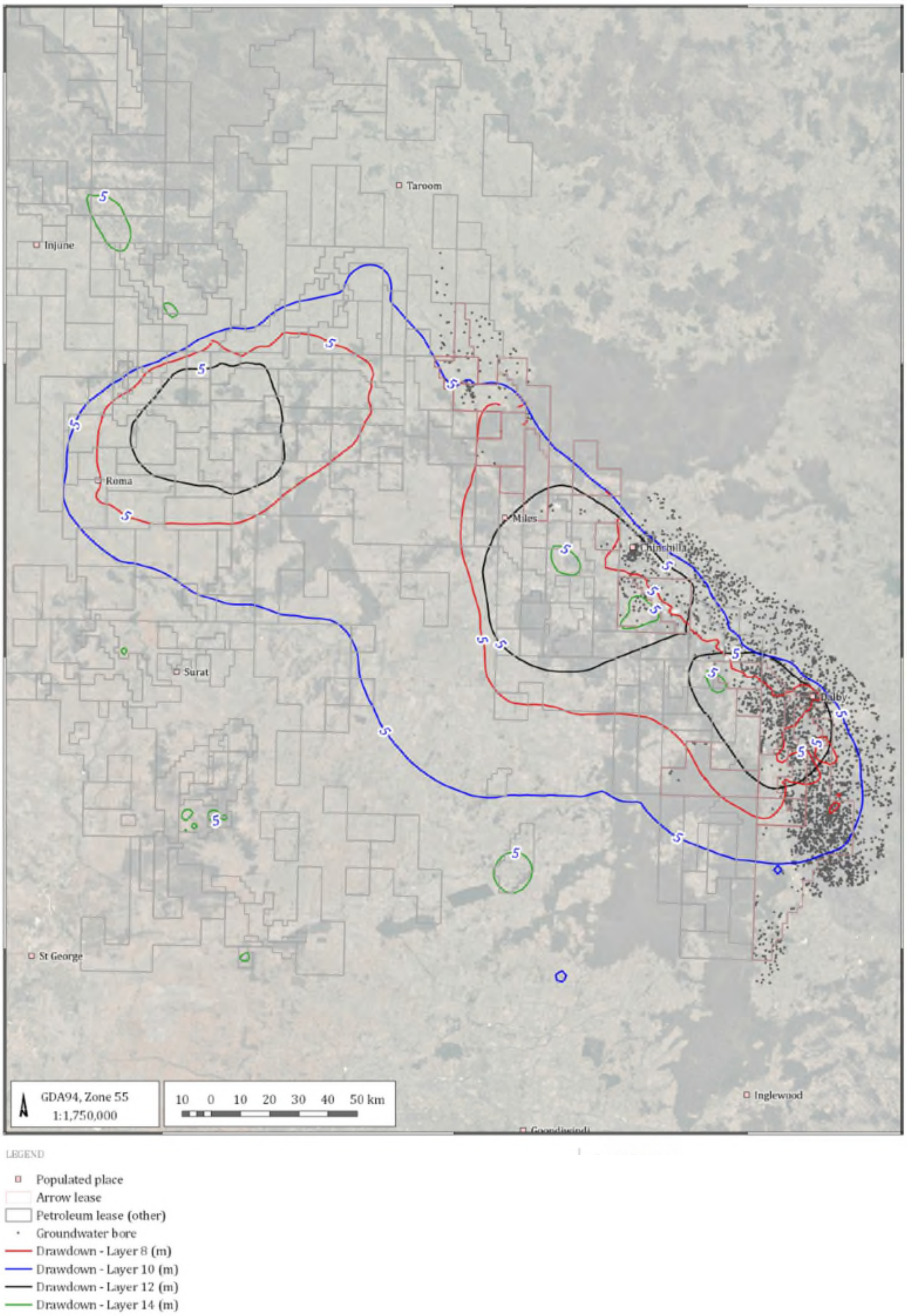

Figure 2 Case 8b cumulative drawdown – 2012 OGIA model 95th percentile

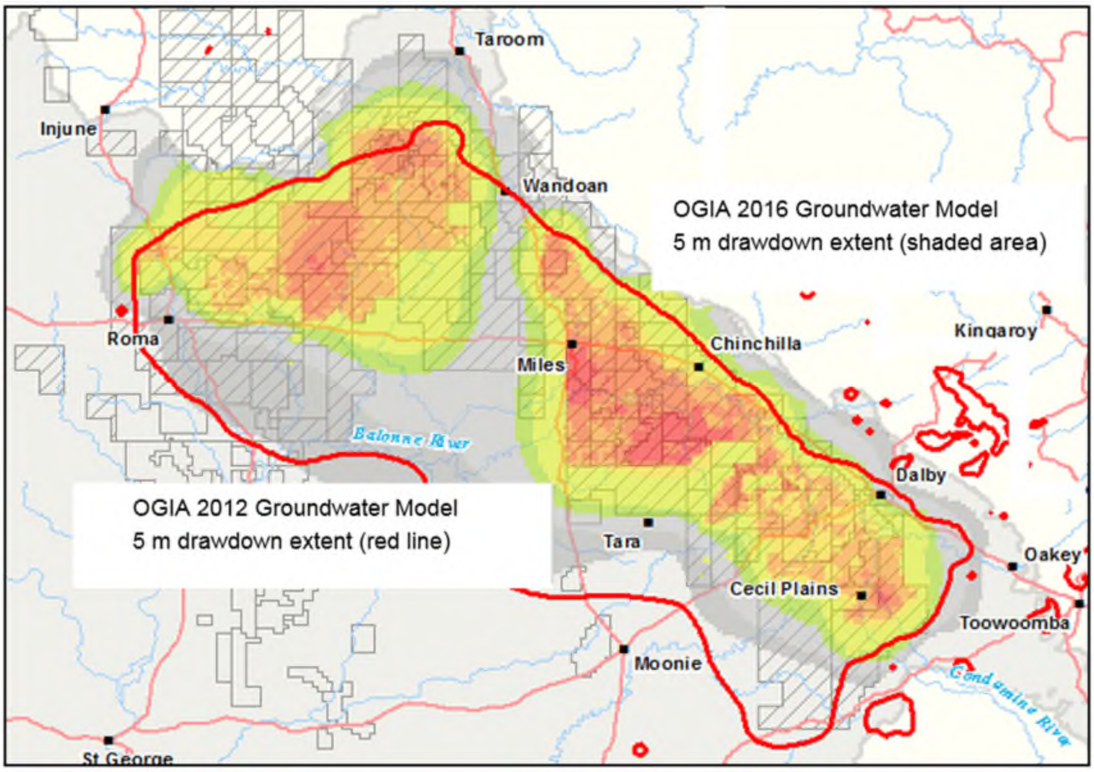

Figure 3 Case 8b cumulative drawdown comparison - Walloon Coal Measures

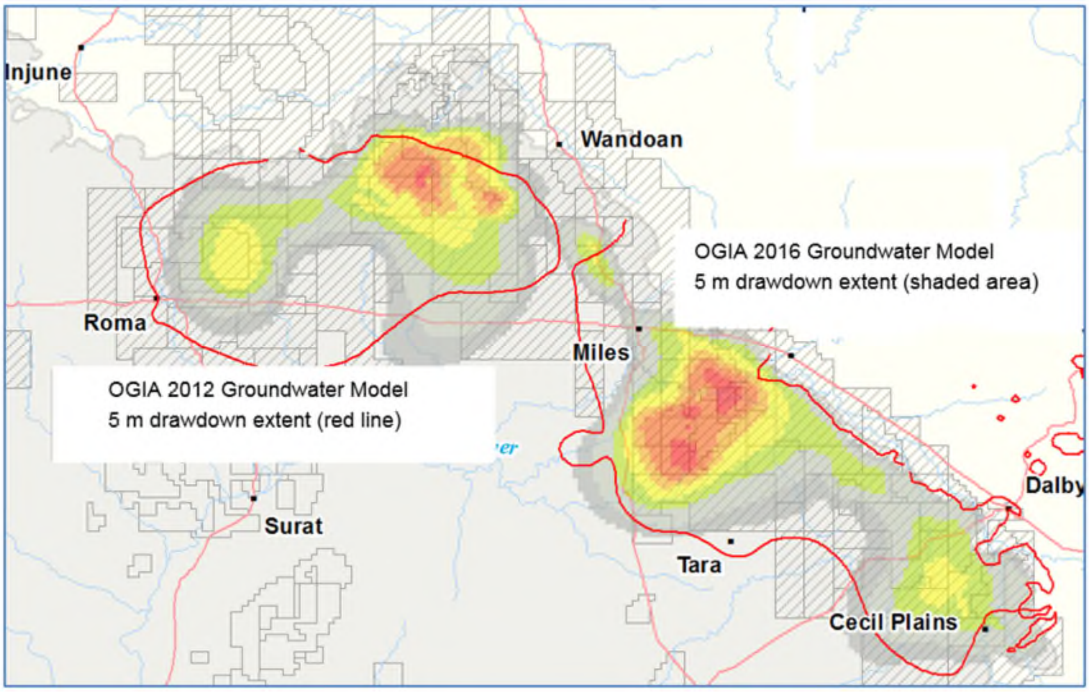

Figure 4 Case 8b cumulative drawdown comparison – Springbok Sandstone

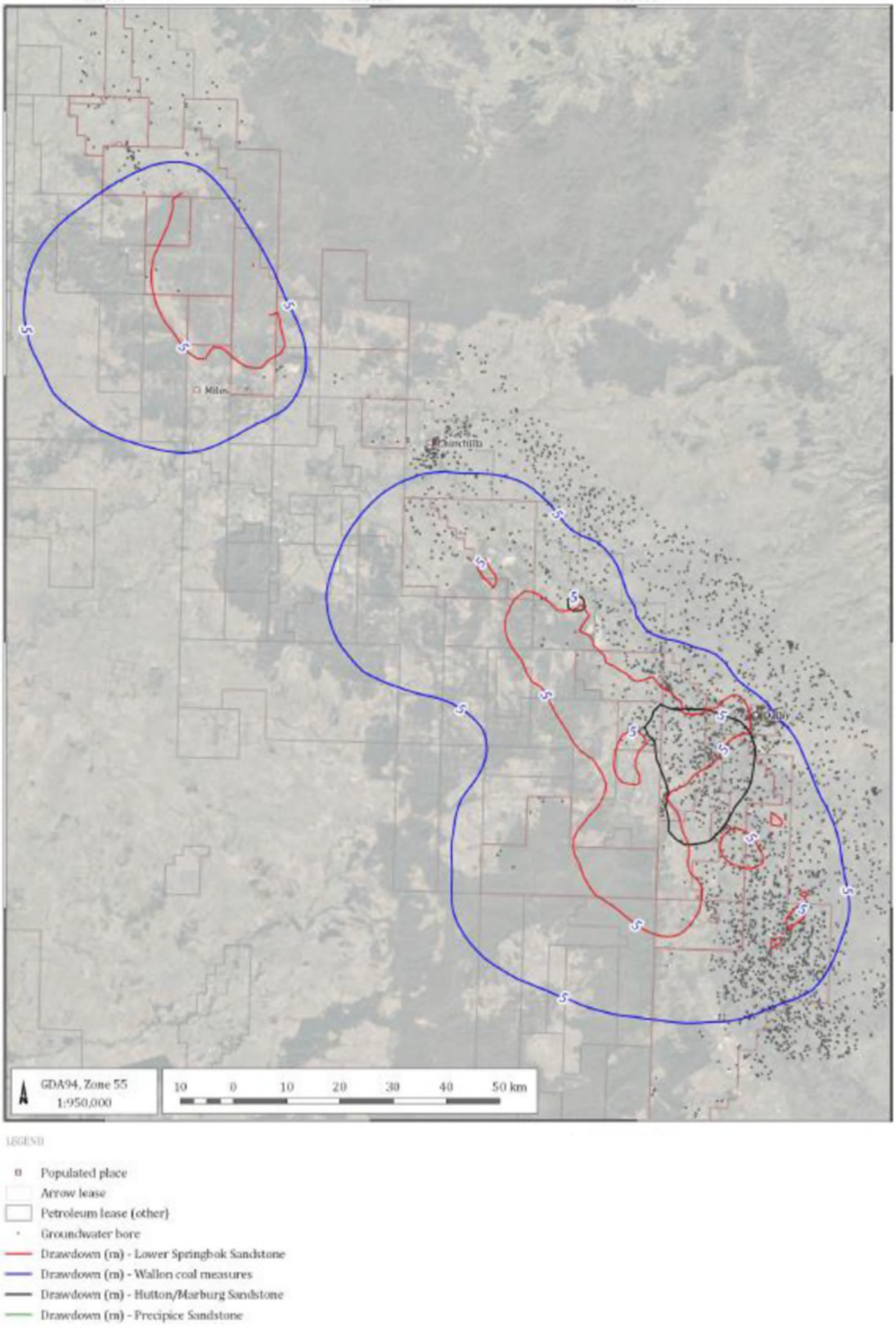

Figure 5 Case 10a Arrow only drawdown – 2012 OGIA model 95th percentile

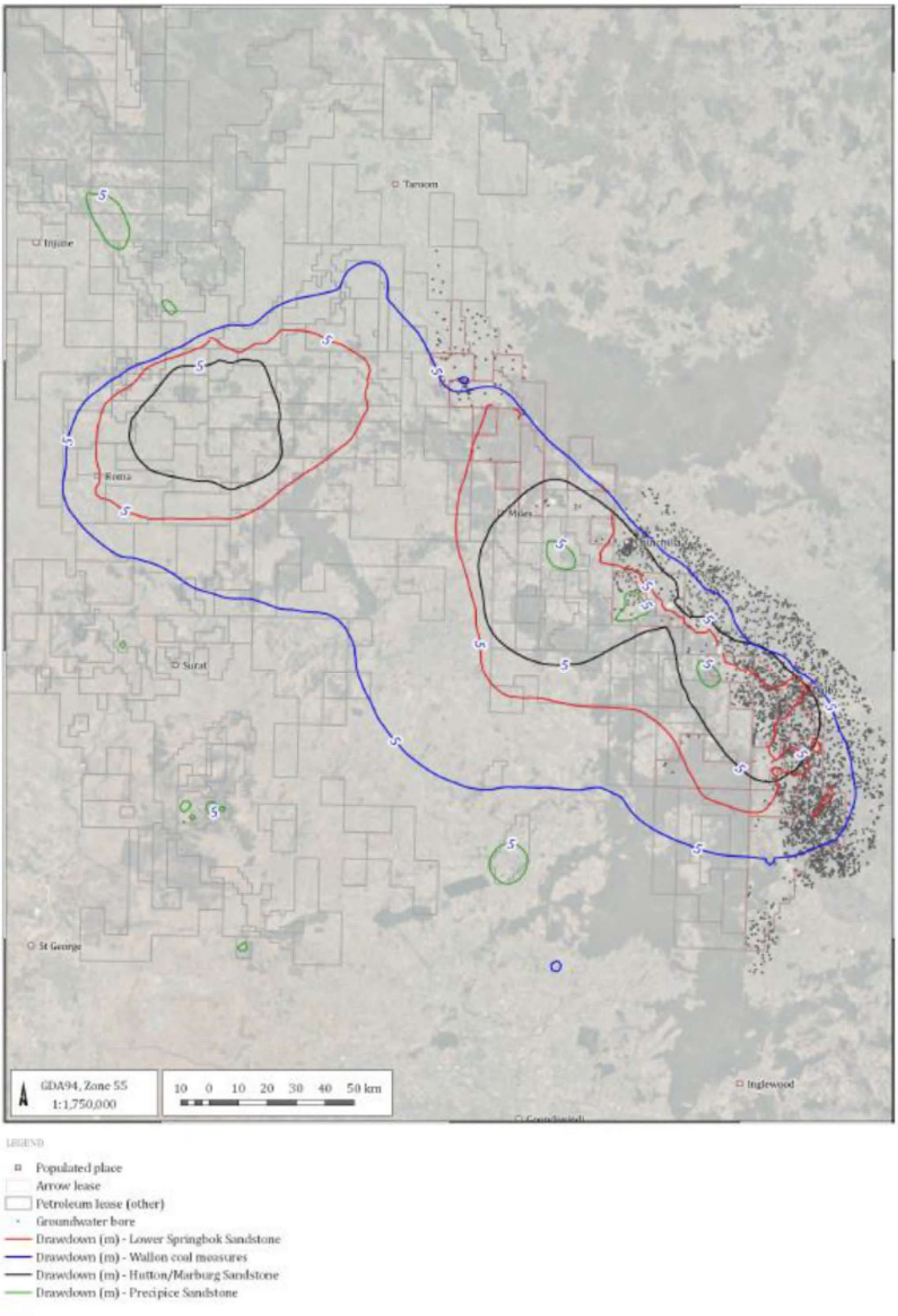

Figure 6 Case 10a cumulative drawdown – 2012 OGIA model 95th percentile

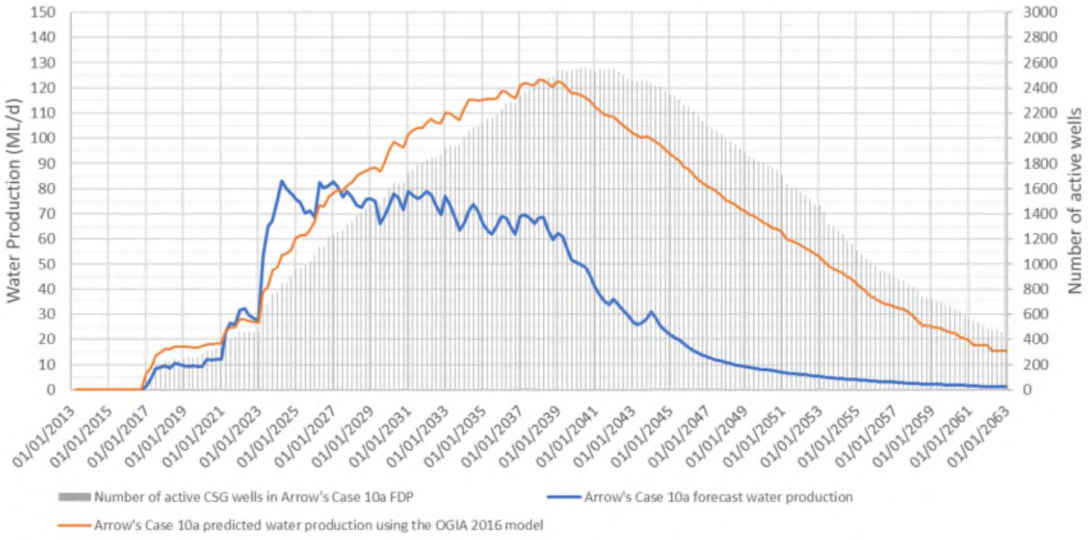

Figure 7 Comparison of forecast and predicted water production by Arrow (Case 10a)

Figure 8 Predicted change in flux to CA base by all CSG producers and Arrow component (Case 10a)

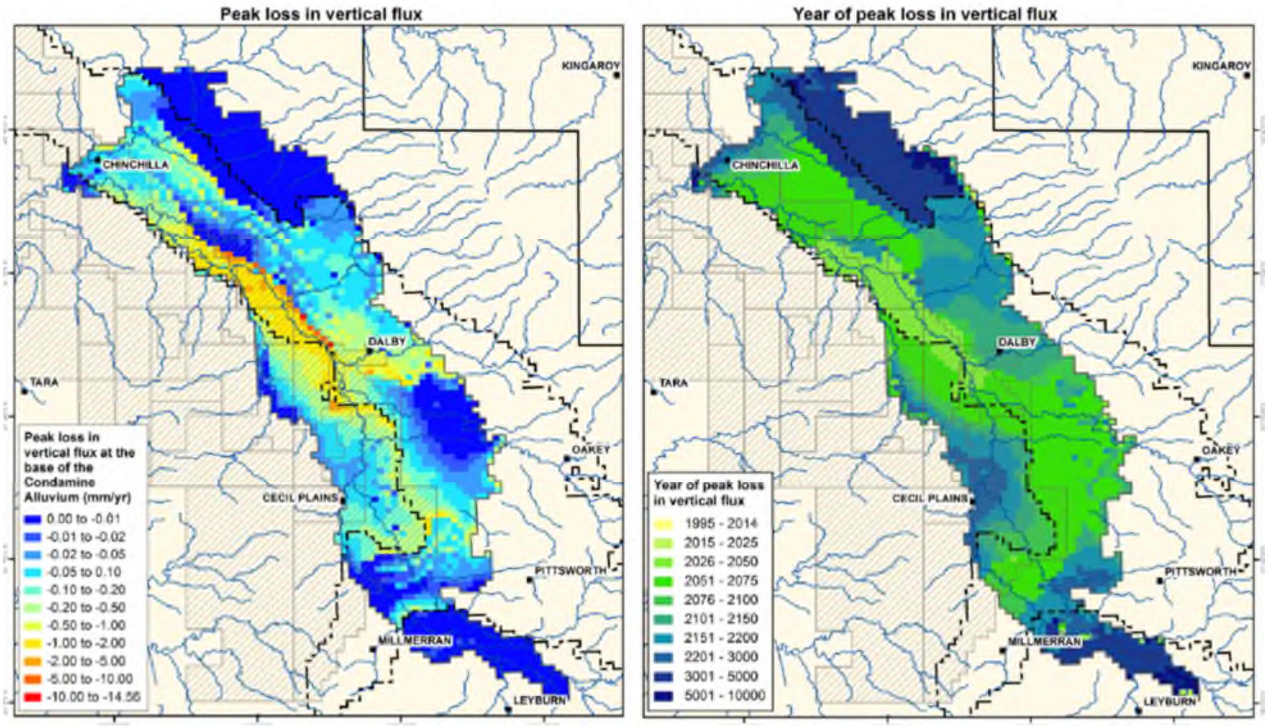

Figure 9 Predicted peak change in flux to CA and timing base by Arrow (Case 10a)

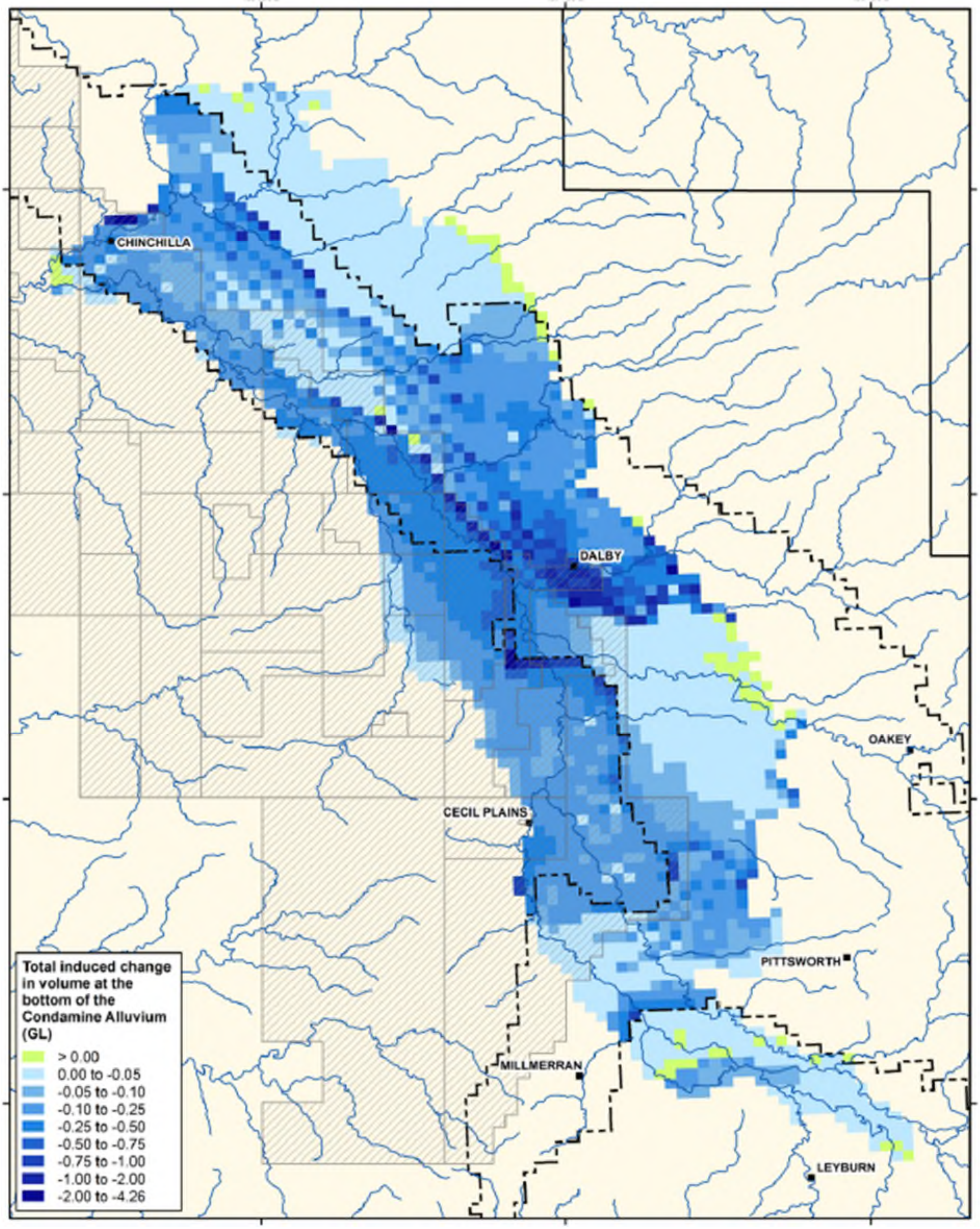

Figure 10 Predicted change in volume to CA due to Arrow (Case 10a)

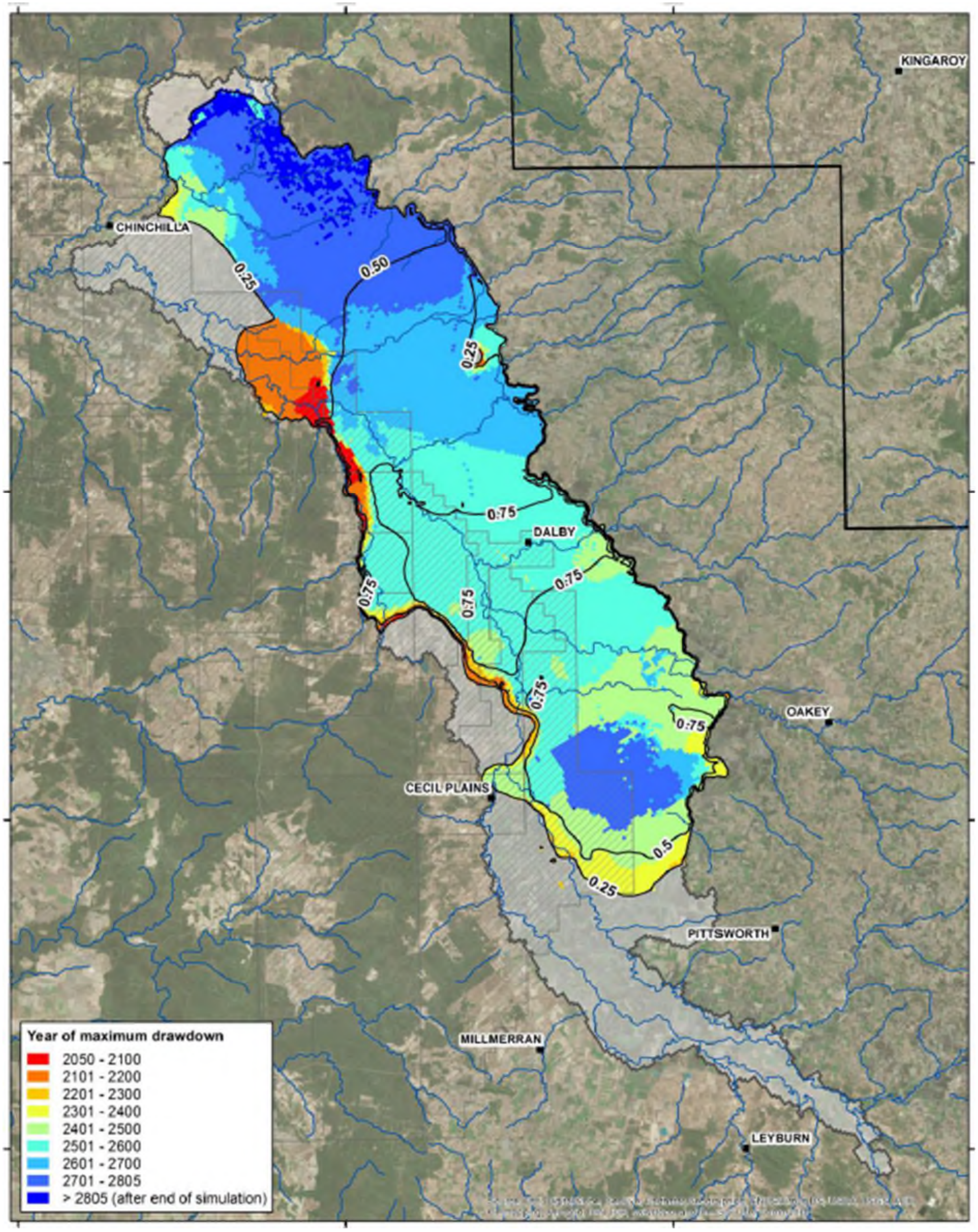

Figure 11 Predicted maximum CA drawdown due to Arrow (Case 10a)

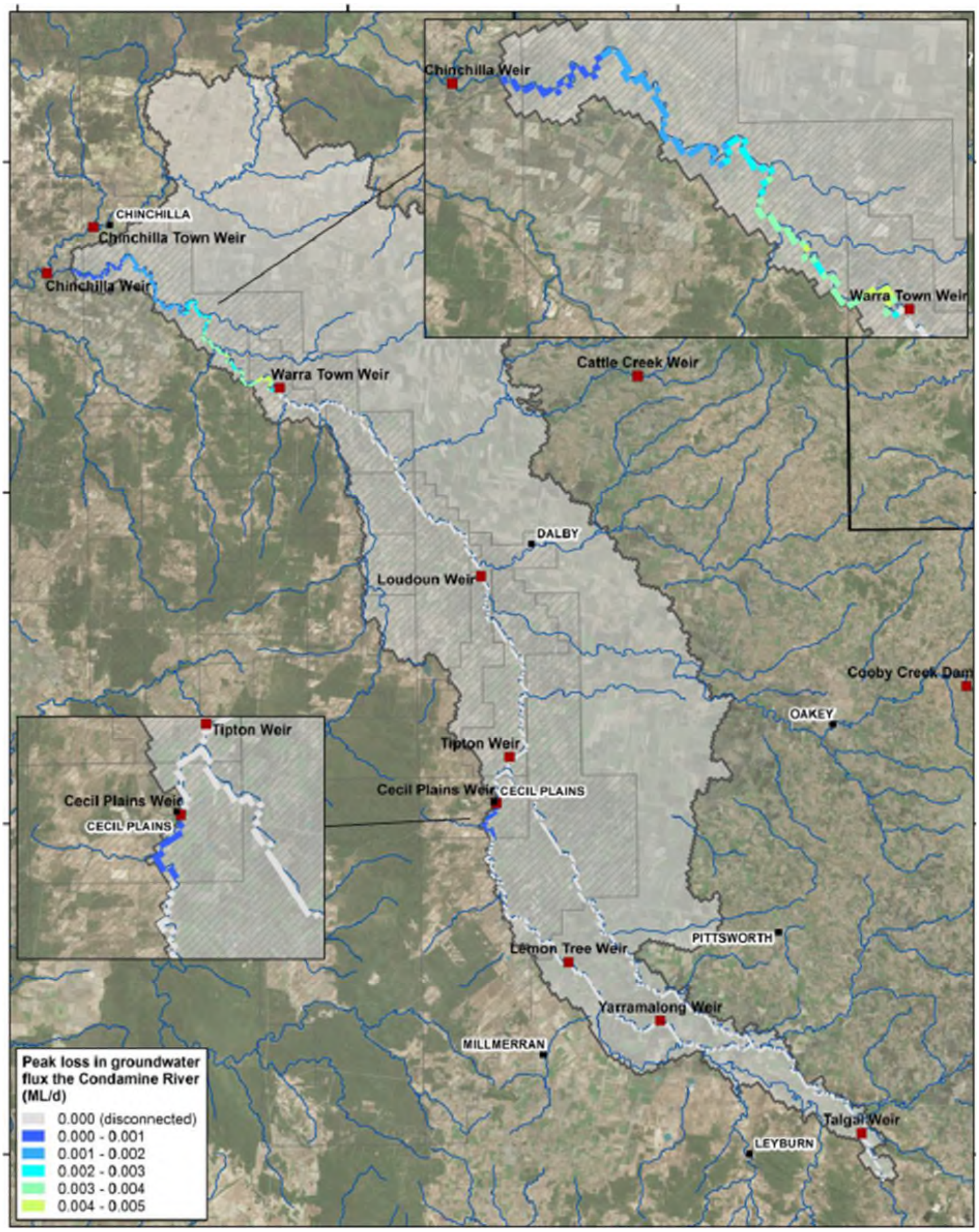

Figure 12 Maximum change in flux to Condamine River – Arrow only Case 10a

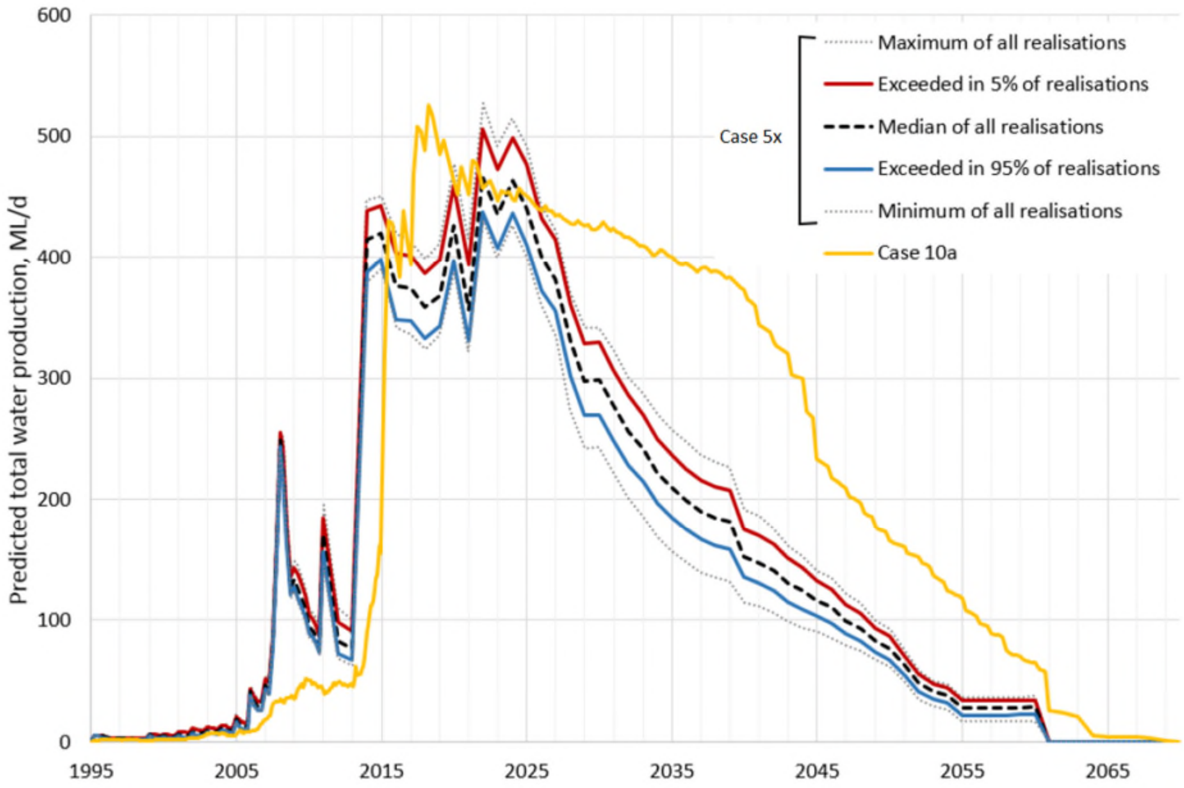

Figure 13 Comparison of predicted water production by – Arrow only Case 5x and 10a

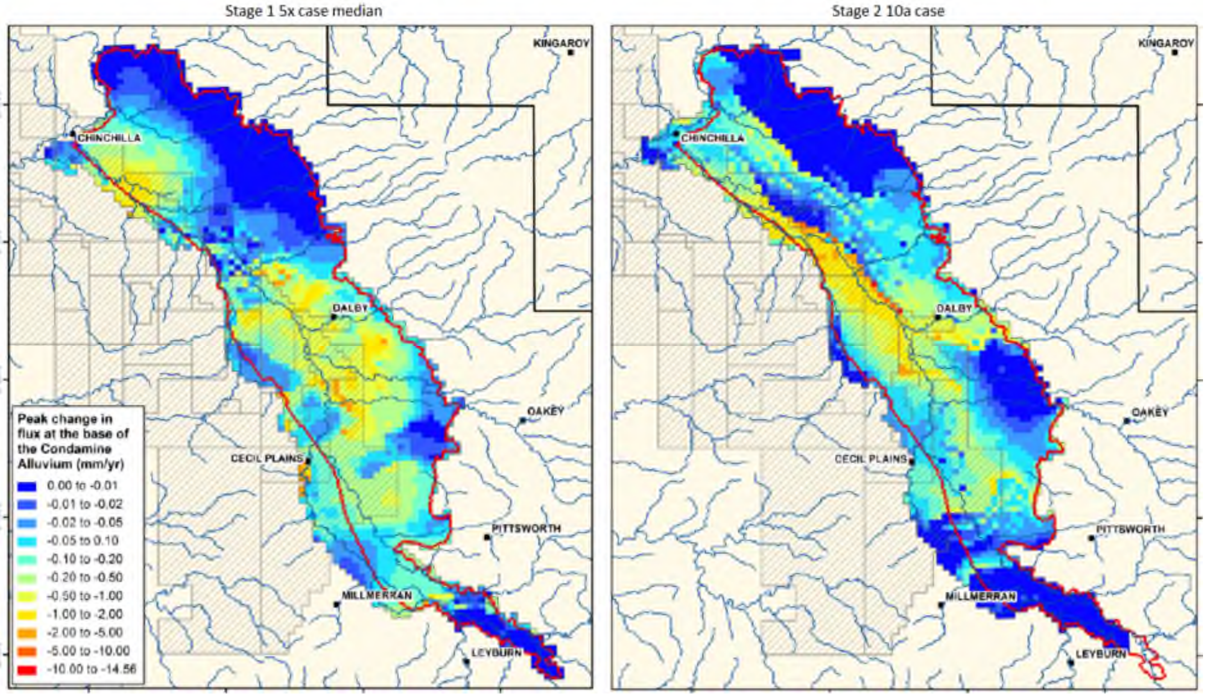

Figure 14 Comparison of distribution of max flux change at base of CA – Arrow only Case 5x and 10a

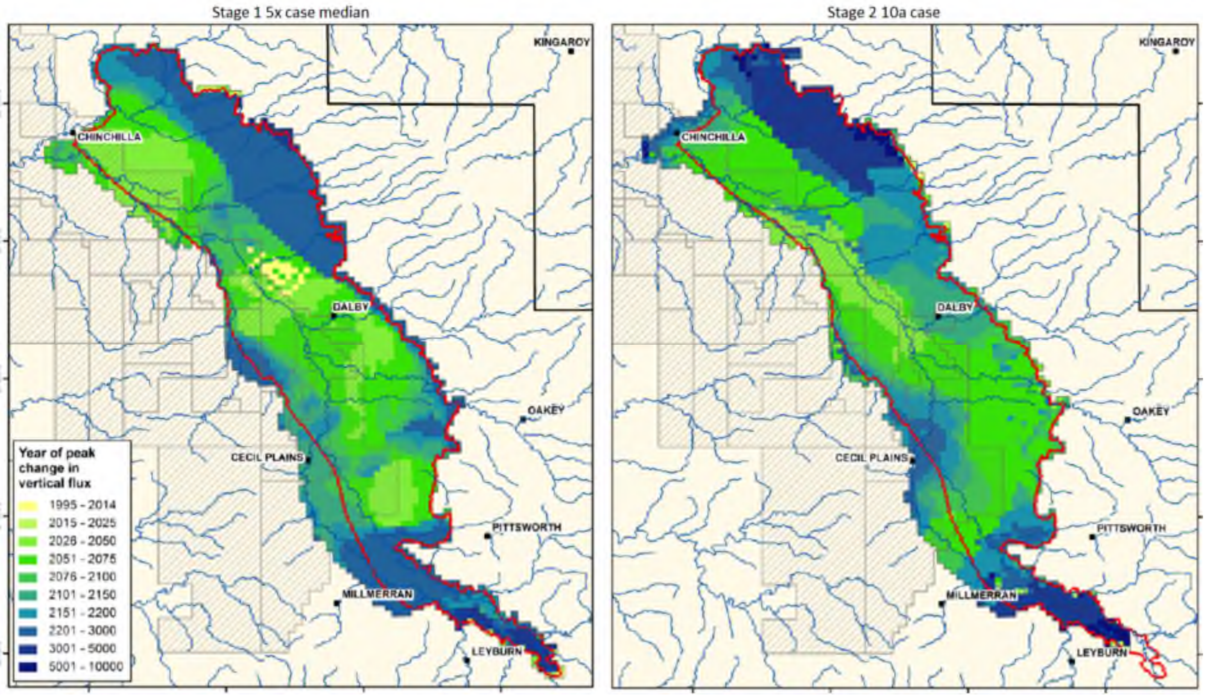

Figure 15 Comparison of distribution of timing of flux change to CA – Arrow only Case 5x and 10a

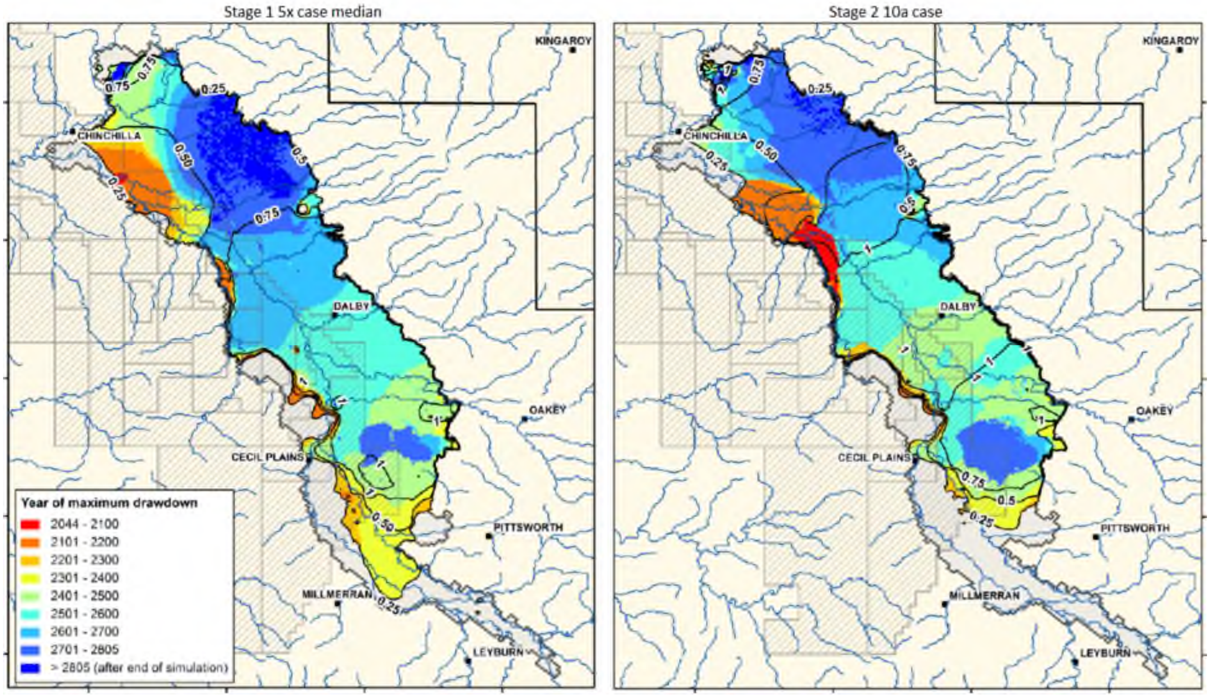

Figure 16 Maximum drawdown to CA watertable – all CSG producers Case 5x and 10a

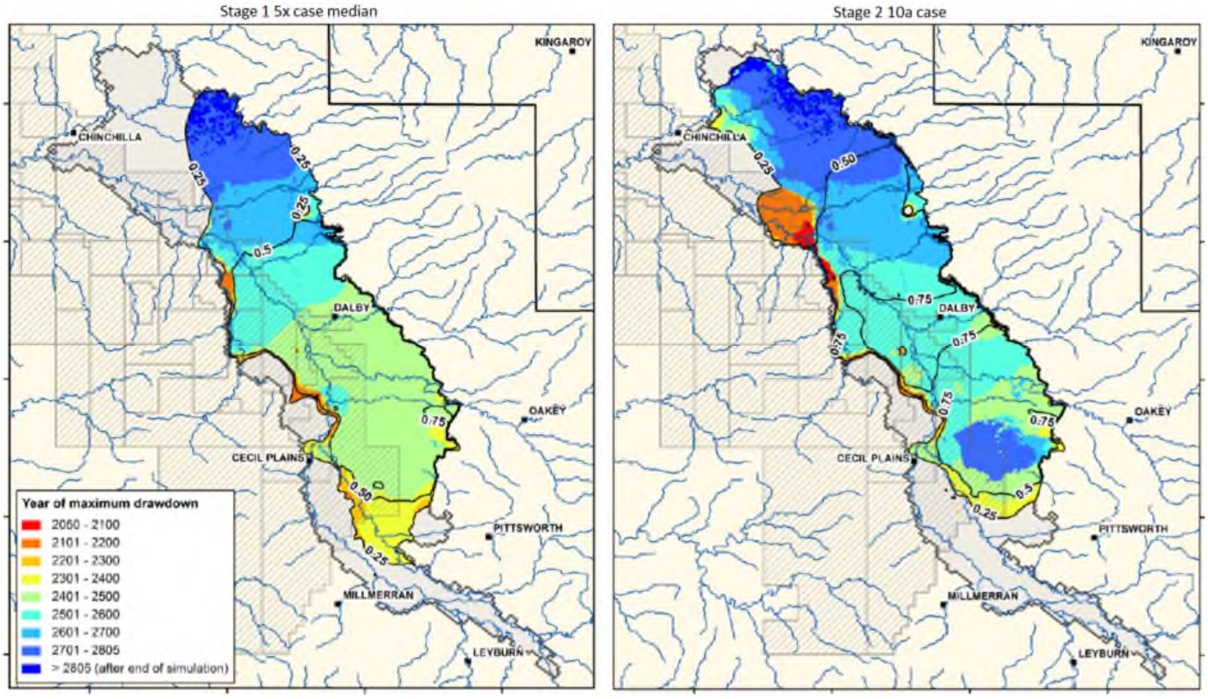

Figure 17 Maximum drawdown in CA watertable – Arrow only Case 5x and 10a

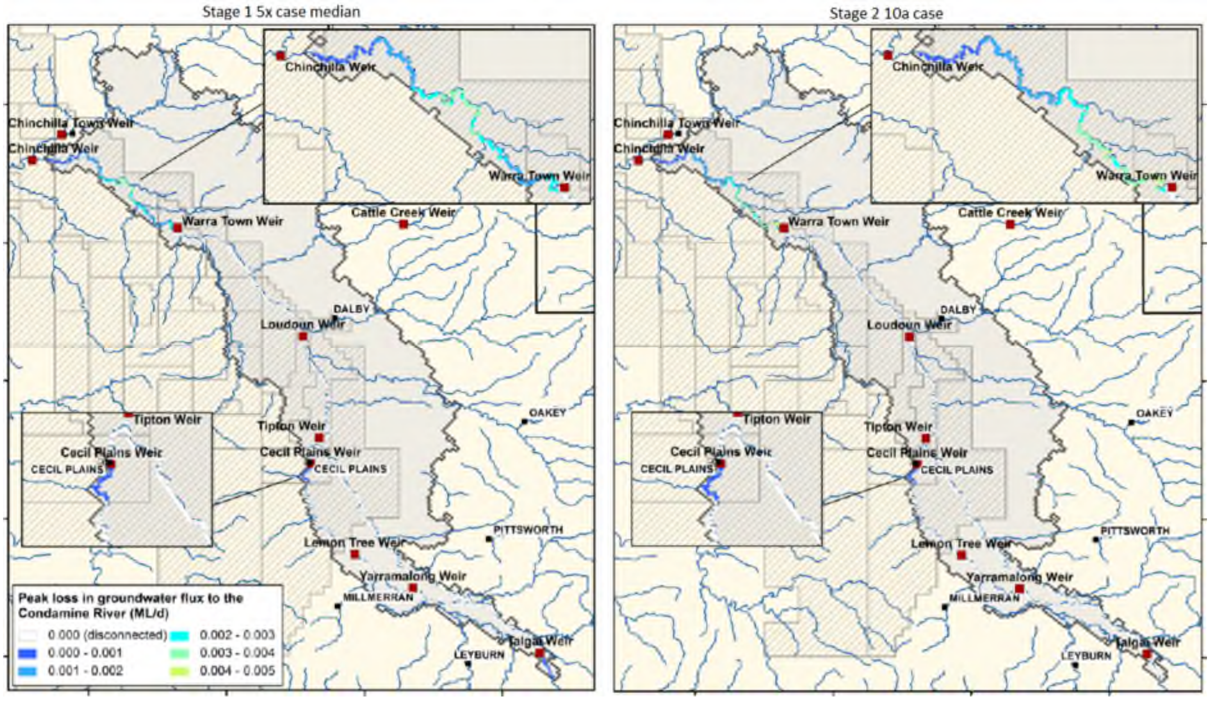

Figure 18 Maximum change flux to the Condamine River – Arrow only Case 5x and 10a

APPENDIX D STREAM CONNECTIVITY AND GDE IMPACT ASSESSMENT MEMO

Memorandum

Recipient	Arrow Energy Pty Ltd
Memo date	16/09/2019
Author	Coffey Services Australia Pty Ltd
Project number	ENAUABTF20484AB
Memo Subject	Surat Gas Project Stage 2 CSG Water Monitoring and Management Plan Stream Connectivity and GDE Impact Assessment

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1. Introduction

1.1. Objectives

Groundwater extraction associated with the development of the Surat Gas Project (SGP) has the potential to impact groundwater dependent ecosystems (GDEs) and other aquatic ecosystems which may be supported by groundwater.

The SGP EPBC Approval Conditions (EPBC 2010/5344), hereafter referred to as the Approval, require the development of a Water Management and Monitoring Plan (WMMP) to address potential impacts on surface water and groundwater resources. The requirements of the WMMP are set out in Conditions 13 to 25 of the Approval which is to be delivered as two plans:

- Stage 1 CSG WMMP for activities in years 1 to 3 (following commencement); and
- Stage 2 CSG WMMP for activities in years 4 to 11.

The Stage 2 CSG WMMP is required to include all matters in the Stage 1 CSG WMMP and address Conditions 17 to 25 of the Australian Government approval.

The Conditions addressed in this memorandum concern matters of stream connectivity and GDEs, specifically:

Approval Condition 13c: *An assessment of potential impacts from the action on non-spring based groundwater dependent ecosystems through potential changes to surface-groundwater connectivity and interactions with the sub-surface expression of groundwater.*

Approval Condition 13p: *A cumulative impact assessment based on the outputs of the OGIA model which integrates groundwater model outputs with known and potential groundwater dependent ecosystems and presents the outputs in map form. Contribute to investigations coordinated through the OGIA to assess hydrological and ecological characteristics of impacted groundwater dependent ecosystems.*

Approval Condition 17(f): *Identify any predicted changes in stream connectivity due to groundwater drawdown from the action and assess potential impacts to groundwater dependent ecosystems due to any predicted changes in stream connectivity, including to water quality, quantity and ecology.*

Approval Condition 17(g): *Address any uncertainty in the groundwater dependency of ecosystems and springs with supporting evidence from field-based investigations for any groundwater-dependent ecosystems and springs confirmed in the OGIA model.*

A key function of the Office of Groundwater Impact Assessment (OGIA) is the assessment and management of cumulative impacts in the declared Surat Cumulative Management Area (CMA), which are set out in the Surat CMA Underground Water Impact Report (UWIR).

The assessment and management of potential impacts to surface expression (e.g. spring) GDEs (refer Table 1-1) are covered under the Surat CMA UWIR Spring Impact Management Strategy (SIMS). Arrow has no assigned responsibilities regarding potentially affected springs under the SIMS. The SIMS is considered to adequately address the potential impact to springs and no further assessment was undertaken as part of the Stage 1 and 2 WMMPs. Spring GDEs are therefore not considered in this memorandum in responding to Approval Conditions 13(c), 13(p), 17(f) and 17(g).

This document sets out the assessment of potential project and cumulative impacts on non-spring GDEs only. It is noted that the next iteration of the UWIR (with an expected release in 2019) will incorporate the assessment and management of cumulative impacts to all environmental values, which is anticipated to include non-spring GDEs.

This memorandum will also be used to underpin other Approval Conditions (including Approval Conditions 17a, 17e, 17h, 17i and 22) which will be addressed in separate memorandums.

1.2. Definition of groundwater dependent ecosystems

The definition of GDEs adopted for the Supplementary Report to the Environmental Impact Statement (SREIS) and the Stage 1 CSG WMMP has been carried through in the development of the Stage 2 CSG WMMP. When considering depressurisation impacts under the requirements of the Stage 2 CSG WMMP, dependent ecosystems that may not directly receive groundwater contribution, but may be supported by shallow groundwater levels and therefore potentially affected by project and cumulative depressurisation activities, have also been assessed.

The definitions of dependent ecosystems adopted in the Stage 2 CSG WMMP are presented in Table 1-1.

Table 1-1 Definition of Dependent Ecosystems

Dependent Ecosystem	Definition
Surface Expression GDEs	Ecosystems dependent on the surface expression of groundwater (i.e. springs, groundwater-fed wetlands and baseflow contribution to watercourses).
Terrestrial (or vegetation) GDEs	Ecosystems (including riparian vegetation) dependent on the subsurface presence of groundwater (i.e. plants accessing shallow groundwater or the capillary fringe, or deeper-rooted vegetation accessing deeper groundwater).
Subterranean GDEs	Ecosystems that are present within pore spaces, fractures or caves within an aquifer.
Aquatic Ecosystems	Aquatic ecosystems dependent on surface water resources that are maintained by groundwater levels, but not groundwater-fed (i.e. connected but losing streams).

The level of dependency is not implied in these definitions, and such ecosystems may be wholly or partially dependent on the water resources. They may also rely on the water resource only periodically (e.g. greater vegetation reliance on groundwater during drought periods).

1.3. Summary of SGP Stage 1 CSG WMMP GDE and aquatic ecosystem impact assessment

1.3.1. Objective and approach

The SGP was approved by the Australian Government under the EPBC Act 1999 decision 2010/5344. Conditions 13 to 25 of the approval outline requirements for the Stage 1 and subsequent CSG WMMPs. The approval conditions concerning stream connectivity and GDEs for the SGP Stage 1 CSG WMMP include Approval Condition 13(c) and 13(p), as described in Section 1.1.

The findings of the Stage 1 CSG WMMP GDE and aquatic ecosystem impact assessment is presented in the Stage 1 CSG WMMP, which was reviewed and endorsed by the appointed independent peer reviewer for the SGP WMMP.

With reference to terrestrial GDEs, the following risk assessment was undertaken:

- Identification of potential GDEs in the vicinity of the SGP.
- Use of numerical groundwater modelling to predict areas of potential groundwater level drawdown.
- Correlation of potential GDEs with areas of potential impact (drawdown) to identify potentially at risk GDEs in consideration of:
    - Direct observation during site visits to confirm the presence or otherwise of groundwater dependent vegetation.
    - Site conceptualisation, including stratigraphy, depth to groundwater (including current and historical variability), characteristics of vegetation present and position in landscape.
    - Interpreted GDE source aquifer.
    - Ecosystem resilience and adaptability.

Key inputs to the GDE risk assessment and the corresponding findings are summarised in Section 1.3.2.

Consideration of project related risks to Long Swamp and Lake Broadwater and aquatic ecology and aquatic ecosystems were assessed in accordance with Approval Condition 13(c) as part of the Stage 1 CSG WMMP, the findings of which are summarised in Section 1.3.3 and Section 1.3.4, respectively.

The second component to Approval Condition 13(p) required demonstrating Arrow’s contribution to ongoing OGIA research projects and investigation programs. This approval condition was addressed by describing Arrow’s contribution to such projects and programs to date and a commitment and proposal for ongoing involvement (refer Section 1.3.5).

1.3.2. Terrestrial GDE risk assessment

Key inputs to impact assessment

The Stage 1 CSG WMMP GDE risk assessment relied on key data and information sources that were available at the time of the study. These inputs are listed and described in Table 1-2. The assessment of impacts to the identified terrestrial GDE landscapes was based on those present in the area where greater than 1 m of drawdown was predicted in the watertable aquifer. As presented in Appendix D of the Stage 1 CSG WMMP, a range of factors have been considered when assessing the appropriateness of adopting the area within the 1 m or greater drawdown prediction in the watertable aquifer for the assessment of potential impact to terrestrial GDEs, including:

- Current and historical groundwater level fluctuations in the watertable.

- The predicted maximum rate of change in groundwater levels in areas beyond the 1 m drawdown contour in the watertable.

- Likely ecosystem water sources.

- Ecosystem resilience and adaptability.

The following discussion provides a basis for selecting the 1 m drawdown level for the assessment of potential impacts to terrestrial GDEs.

Observed groundwater level fluctuations in the watertable aquifer vary by >1 m annually in a number of locations (refer to hydrographs in Appendix D, Stage 1 CSG WMMP, Attachment 3: RN160193A, RN123130A, RN160518A, RN41620043A, RN42231411A, RN42230210A and Figure 5.4 for bore locations). A significant baseline of data is available to assess fluctuations with many records commencing in 2011 and some monitoring bore records across the Condamine Alluvium dating back to the 1960s. In these areas there is a well documented seasonal response to non-CSG groundwater abstraction, and historically, groundwater levels have steadily declined in the order of tens of metres as a result. These antecedent conditions indicate that where terrestrial GDEs remain present, they are likely to have been established in or adapted to fluctuating and/or declining groundwater levels and be less sensitive to small declines in groundwater levels (Shafroth et al. 2000).

The rate of drawdown where <1 m total modelled drawdown occurs (i.e. the outer extent of the drawdown predictions) is low as the total drawdown from the Action is not predicted to occur in a single year. The low rate of change of groundwater level is demonstrated in CDM Smith (2016) for the Condamine Alluvium where the rate of change of watertable elevation is predicted to be 1 to 2 mm per year (0.001 – 0.002 m/year). In consolidated aquifers, as reported in Appendix E of GHD (2013), the maximum rate of change of watertable elevation in areas of <1 m total drawdown due to the Action (i.e. Arrow only impact) is estimated to be low (refer to Appendix D, Stage 1 CSG WMMP, Attachment 4 for model hydrographs):

- Springbok Sandstone: <0.06 m/year (refer hydrographs in HH_1, IJ_1, JK_1, VW_1, WX_1 and U131_1).

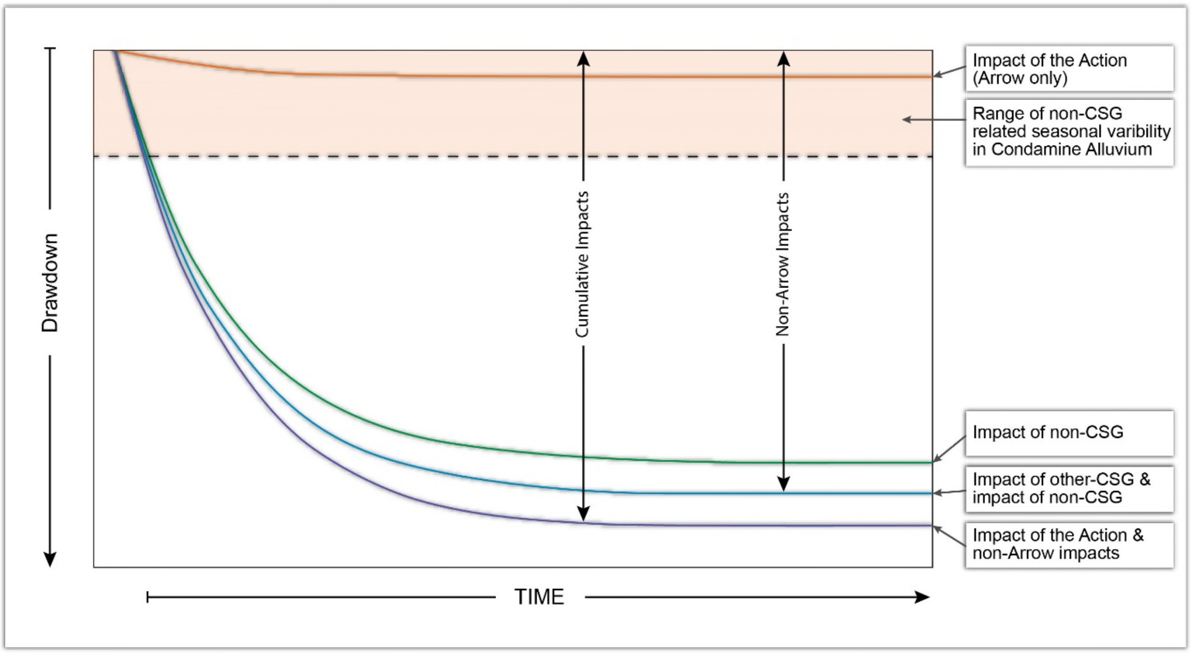
- WCMs: <0.09 m/year (refer hydrographs KI_1 and MJ_1 noting there are limited extracted hydrograph locations in areas of <1 m drawdown in the WCM, however there is also limited areas of <1m drawdown in the WCM where the WCM is inferred to be the watertable aquifer).

- Hutton Sandstone: <0.02 m/year (refer hydrographs PM_2, OP_1, QP_1 and UZ_1).

- Precipice Sandstone: <0.0001 m/year (refer hydrograph TR_1).

More typically the rate of drawdown in areas where less than 1 m of drawdown is predicted in the watertable is much less than these maximum estimated rates of change. Accordingly, the magnitude of total drawdown along with the rate of change that would be experienced in these areas is substantially less than existing variability in watertable levels induced as a result of seasonal fluctuation and/or non-CSG abstraction. It is therefore reasonable to assume that in these areas vegetation is either adapted to the variability in groundwater levels or disconnected from the watertable and not reliant on groundwater.

Schematic 2.1 presents a conceptual representation of the relative change in groundwater level as a result of various factors across the Project area. The schematic demonstrates that the potential influence of CSG activities on watertable levels in areas of <1 m drawdown prediction is negligible in comparison to historical and current non-CSG influences.



Schematic 2.1: Conceptual representation of drawdown contribution

These small and gradual reductions in groundwater levels provide a greater opportunity for natural recharge processes to mitigate the effects of water stress and allow terrestrial GDEs (i.e. deep rooted vegetation) to adapt to longer-term changes (Froend and Sommer 2009; Shafroth 2000).

The concept of ecological resilience is one of natural systems being in a state of change, rather than equilibrium (Sommer and Froend 2011). As a result, GDEs are necessarily adapted to some degree of groundwater level fluctuations and the terrestrial vegetation community composition will progressively respond to the prevailing conditions. It is reasonable to assume that vegetation would adapt to the very gradual changes that may eventuate over a long period of time in the areas beyond the 1 m watertable drawdown contour interval, as evidenced by adaptation to the historical change in levels.

Flood plain eucalypts, most notably Eucalyptus camaldulensis which are the key species of interest across the SGP with regards to potential groundwater reliance, are an adaptable species able to extract water from multiple sources including shallow soil moisture, river water and groundwater, dependent on availability (Mensforth et al. 1994), affording this species resilience to small and gradual changes in groundwater availability.

This is supported by Zolfaghar (2013) who indicates that Eucalyptus species more broadly, which dominate the SGP study area, have an ability to adapt to decreased groundwater availability and are adept at utilising both groundwater, surface water and soil moisture, depending on their availability.

Many riparian trees have dimorphic root systems which include shallow roots to improve stability, nutrient uptake, and rapid uptake of surface soil water after rainfall events, with deeper sinker roots that can access the capillary fringe of groundwater (Eamus et al. 2006; Pinto et al. 2014). Small fluctuations in the availability of soil moisture from one source (e.g. groundwater) is therefore unlikely to impart any significant ecological response.

Shafroth et al (2000, 2002) also propose that terrestrial vegetation that has established in an area of variable groundwater levels, which is reflective of the Condamine River Floodplain environment, will be less sensitive to very small declines in groundwater level than species that have established in an environment with a shallow stable groundwater resource.

The review of literature has demonstrated that it is reasonable to assume vegetation will be able to adapt to the relatively low rate and magnitude of total drawdown predicted in areas of watertable drawdown <1 m over the life of the project. Potential GDEs in this area are considered to be at low to no risk of impact as a result of the Action and therefore attention and effort regarding further assessment and management is focussed on higher risk areas where predicted drawdown in the watertable aquifer is greater than 1 m over the life of the project.

It is noted that terrestrial GDEs differ significantly in their ecohydrological function and response from spring GDEs, where a 0.2 m drawdown limit in the source aquifer is adopted as the impact threshold. The adoption of the 0.2 m drawdown trigger for spring GDEs is defined in the Water Act (2000) based on this being the smallest quantifiable drawdown that essentially is reflective of no impact. For some springs, even small reductions in groundwater pressure may have a bearing on the flow rates and the ecosystems supported by this groundwater.

Terrestrial GDEs, however, are fundamentally adapted to some variability in groundwater levels given natural variability, and they also play a part in controlling groundwater levels, as described above. Adoption of a 1 m drawdown contour is therefore considered to be an appropriate and pragmatic position for the ongoing assessment of potential impacts to terrestrial GDEs.

Table 1-2 Key inputs to the GDE risk assessment

Key inputs	Description
Potential GDE landscapes	The Queensland Department of Science, Information Technology and Innovation (DSITI) developed spatial datasets of potential GDE landscapes (WetlandInfo 2015), to provide a baseline mapping product at catchment scale. The mapping built on existing information, including the BoM GDE Atlas and Queensland regional ecosystem (RE) mapping. The mapping process included the establishment of conceptual GDE models that underpin GDE landscape identification, and the mapping products were reviewed and rationalised by a range of industry experts prior to public release. The product reflects the existing effects on groundwater levels in the Condamine Alluvium where significant drawdown has already occurred due to agricultural activities, resulting in a watertable largely below plant rooting depth in these areas. Furthermore, it excludes potential GDE landscapes in pastoral / agricultural areas with known salinisation issues as these are considered to represent “anthropogenic GDEs” that are a function of land clearing and associated groundwater level rise. At the time of preparing the SGP Stage 1 CSG WMMP, the WetlandInfo (2015) product was considered to provide the best available catchment-scale GDE mapping and was adopted to address Approval Conditions 13(c) and 13(p). Other studies also assisted in refining the location of the potential non-spring GDEs, and the potential for impact to these, including: AGEs GDE risk assessment (AGE 2013a), CDM Smith’s Condamine Alluvium surface water-groundwater modelling (CDM Smith 2016), NRAs aquatic ecology study (NRA 2016), 3D Environmental/Earth Search desktop assessment and field work (3D Environmental/Earth Search 2017), together with other relevant studies and research papers.
Predicted groundwater level drawdowns in the source aquifer	For terrestrial GDEs, the source aquifer is represented by the watertable. Detailed numerical groundwater modelling underpins the prediction of drawdown in the watertable aquifers. The basis for numerical modelling to address Approval Condition 13(c) and 13(p) is described in the SGP Stage 1 CSG WMMP. The modelling approach adopted the Stage 1 CSG WMMP Field Development Plan (FDP) and the 2012 version of the OGIA’s regional groundwater model for the Surat CMA. To address Condition 13(c), the 1 m predicted drawdown contour for the watetable aquifer was adopted in the consideration of identifying potential GDEs at risk of impact. Justification for this assessment criteria is provided above.

Key inputs	Description
	Approval Condition 13(p) has been addressed by adopting the impact assessment approach defined for Condition 13(c), including use of the 1 m drawdown contours for cumulative drawdown predictions (based on outputs of the 2012 OGIA model) and review of where terrestrial GDEs may be at risk of impact from drawdown in the watertable aquifer. The spatial extent considered for cumulative impact assessment of non-spring GDEs to address Condition 13(p) includes: 1 m drawdown of relevant aquifers predicted within Arrow tenements and 1 m drawdown of relevant aquifers predicted within Arrow's off-tenement area of responsibility (i.e. the extent of the Arrow-only drawdown predictions, where this does not fall on another proponent's tenements).
Sub-crop of solid geology	The numerical modelling platform employed for the assessment of drawdown generates drawdown predictions for individual model layers. Therefore, in defining areas of > 1.0 m drawdown in the watertable aquifer, correlation of drawdown in individual model layers with the spatial extent of the corresponding solid sub-cropping geology was undertaken. At the time of the assessment, the source of surface geology mapping in the Surat CMA was GeoSciences Australia (2011).
Supporting information on likelihood for ecosystem dependence on groundwater	Review of additional sources of information supported the assessment of the likelihood for GDE landscapes identified as at risk, to actually be dependent on groundwater. This included consideration for: • Depth to groundwater with data sourced from a range of State and Arrow held databases. • Borehole logs. • Regional ecosystem mapping and direct site observation on vegetation presence. • Landscape position, including geomorphology and hydrology.

Summary of findings

The Stage 1 CSG WMMP terrestrial GDE risk assessment concluded the following:

- Ecosystems in Risk Area 1 are not dependent on groundwater and therefore not at risk from Project-related drawdown.
- Ecosystems in Risk Area 2, 3a and the northern parts of 3b are not dependent on a watertable aquifer in the Springbok Sandstone and are therefore not at risk from Project-related drawdown.
- Ecosystems to the south-west of Cecil Plains along the western slopes of the Kumbarilla Ridge (southern part of designated Risk Area 3b) may be dependent on groundwater in the Springbok Sandstone and may be impacted by Project (Arrow only) related groundwater drawdown (Figure 1).
- Ecosystems in the southern part of Risk Area 4 are either not groundwater dependent or not dependent on a watertable aquifer in the Walloon Coal Measures and are therefore not at risk from Project-related drawdown.
- Ecosystems in the northern parts of designated Risk Area 4 near Wandoan may be dependent on shallow groundwater in the Walloon Coal Measures (WCM) and may be impacted by Project (Arrow only) related groundwater drawdown (Figure 2).
- Ecosystems in Cumulative Risk Areas 1 and 2 are unlikely to be groundwater dependent.

- Ecosystems in Cumulative Risk Areas 3, 4 and 5 are unlikely to be dependent on a waterable aquifer hosted in the Springbok Sandstone and are therefore not expected to be impacted by SGP development.
- Ecosystems in designated Cumulative Risk Area 6 (south of designated Risk Area 3b) may be dependent on groundwater in the Springbok Sandstone and may be impacted by cumulative groundwater drawdown (Figure 3).

Based on these assessment results, potential terrestrial GDEs associated within the southern part of Risk Area 3b and the northern parts of Risk Area 4 were further investigated via detailed field studies in Stage 2; 3D Environmental/Earth Search 2018 (Section 5) and Arrow Energy 2018 (Section 6) to refine the conceptual understanding of the potential for ecosystem interaction with groundwater at these sites.

Whilst the Stage 1 CSG WMMP GDE and aquatic ecosystem impact assessment included assessment of cumulative risk and identification of cumulative impact areas on Arrow tenure, the focus of further detailed assessment to refine the conceptual understanding of potentially at risk GDEs and inform the need for impact management was on the Arrow-only impact areas. A function of the OGIA is to assess and administer responsibilities concerning the management of cumulative impact, therefore it is appropriate that further assessment of cumulative impacts be guided by this process. This is also consistent with the requirements of Condition 13(p), which requires Arrow to assess cumulative impact and then contribute to investigations coordinated through the OGIA.

1.3.3. Long Swamp and Lake Broadwater

Lake Broadwater is situated on a sequence of massive clays overlying a deeply weathered regolith of the Westbourne Formation, comprising predominantly plastic clays, sandy clays and clayey sands. The lake is described as a perched depositional feature on a claypan, with potential for a deep wetting profile below the regolith. Long Swamp is situated on a thick layer of clay to loamy clay (3D Environmental/Earth Search 2017).

The groundwater connectivity and potential dependence of these surface water features on groundwater required further investigation to adequately characterise the potential risk of the Action. While these features were not predicted to be impacted by the Action, in accordance with Approval Condition 13(f), further assessment has been conducted to support development of the Stage 2 CSG WMMP (3D Environmental/Earth Search 2018 and Arrow Energy 2018). Specifically, ecological and hydrogeological investigations have been conducted at both Lake Broadwater and Long Swamp to further characterise the potential for the surface water features to interact with groundwater systems that may be impacted by the Action. The results of these investigations are described in Section 5 (3D Environmental/Earth Search 2018) and Section 6 (Arrow Energy 2018) of this memorandum, for incorporation in the SGP Stage 2 CSG WMMP in accordance with Approval Condition 17(g) and 17(e).

1.3.4. Aquatic ecology and aquatic ecosystems

Across the SGP area, no significant impacts to aquatic ecology and aquatic ecosystems were predicted as a result of the Action. As set out in the SGP EIS/SREIS and the SGP Stage 1 CSG WMMP - GDE and Aquatic Ecosystem technical memorandum (Coffey 2017a), environmental conditions with regards to aquatic ecology and aquatic ecosystems were assessed as being highly disturbed, and there is not likely to be significant impacts to aquatic ecosystems as a result of the Action.

The impact to surface water flows in the Condamine River as a consequence of flux changes in the Condamine Alluvium were considered to be negligible on the basis of the following:

- Where surface water systems are connected to groundwater, and flows are in regulated surface water systems, negligible change to surface water flow regimes were predicted therefore it was concluded that negligible impact to aquatic ecosystems and surface expression GDEs would occur.

- Where surface water systems are connected to groundwater, and flows are not regulated by allocations, very limited to no impact was predicted to aquatic ecosystems and surface expression GDEs based on negligible altered leakage rates over a period of hundreds of years.

An assessment of changes to stream connectivity due to groundwater drawdown and the implications for GDEs is a requirement of Approval Condition 17(f) in the SGP Stage 2 CSG WMMP. This condition is addressed in Section 3 with the outputs of the CDM Smith (2018) Stage 2 groundwater modelling which relies on the Stage 2 CSG WMMP FDP and the 2016 version of the OGIA's Surat CMA numerical groundwater model.

1.3.5. Contribution to OGIA investigations

Arrow currently has no assigned spring monitoring or investigation obligations under the 2016 Surat CMA UWIR. Should this change in future revisions of the Surat CMA UWIR (based on new data), Arrow will contribute to investigations as required by the SIMS and/or other GDE management requirements that may be included in future versions of the UWIR.

Arrow's industry investigation project contributions have included:

- The provision of the results of prior spring / GDE assessment work, including remote sensing data, geochemical investigations and GDE impact modelling.
- The Condamine Interconnectivity Research Project (CIRP), which aimed to improve understanding around the connectivity between the Walloon Coal Measures and the Condamine Alluvium. Arrow provided key contributions including the completion of groundwater monitoring bore installations and aquifer pumping tests.

Arrow makes a commitment to make available the results of any ongoing and future investigations to the OGIA.

2. Approach to addressing conditions

This memorandum addresses Approval Conditions 17(f) and 17(g) and partially addresses the requirements of 17(a), which requires all matters in the Stage 1 CSG WMMP to be included as well as a discussion on how the Stage 1 CSG WMMP is informing the adaptive management for the Stage 2 CSG WMMP. The relevant matters from the Stage 1 CSG WMMP include the assessment completed to address Approval Conditions 13(c) and 13(p).

The approach adopted to address matters concerning stream connectivity and GDEs as set out in Approval Conditions 13(c) and 13(p) for the Stage 1 CSG WMMP and 17(f) and 17(g) for the Stage 2 CSG WMMP is described in Table 2-1.

The Stage 1 CSG WMMP addressed Approval Conditions 13(c) and 13(p) (in full) and this assessment is summarised in Sections 1.3.1 to 1.3.5.

All outstanding stream connectivity and GDE matters to address Approval Conditions 13(c), 17(f) and 17(g) are responded to in the Stage 2 CSG WMMP and described in detail in this memorandum.

Table 2-1 Approach to addressing Approval Conditions relating to stream connectivity and GDEs (SGP Stage 1 and 2 CSG WMMPs)

Approval Condition	Approach to addressing Approval Conditions
Approval Condition 13(c): *An assessment of potential impacts from the action on non-spring based groundwater dependent ecosystems through potential changes to surface-groundwater connectivity and interactions with the sub-surface expression of groundwater.*	• Arrow only terrestrial GDE risk assessment conducted in the Stage 1 CSG WMMP (Section 1.3.2) and Stage 2 CSG WMMP (Section 4). • Desktop assessment of potential groundwater connectivity and dependence of Long Swamp and Lake Broadwater in the Stage 1 CSG WMMP and proposal for further investigations to characterise the risk to these features from the Action (Section 1.3.3). • Desktop assessment of risks to aquatic ecology and aquatic ecosystems in Stage 1 CSG WMMP (Section 1.3.4). • The field based investigations of four sites at risk of predicted project related drawdown conducted by: (i) 3D Environmental/Earth Search (2018) (Section 5) to assess the potential groundwater dependency of ecosystems and (ii) Arrow Energy (2018) to assess the potential level of connectivity between formations overlying the WCM (Section 6), whilst principally addressing Approval Condition 17(g), also informs and responds to Approval Condition 13(c).
Approval Condition 13(p): *A cumulative impact assessment based on the outputs of the OGIA model which integrates groundwater model outputs with known and potential groundwater dependent ecosystems and presents the outputs in map form. Contribute to investigations coordinated through the OGIA to assess hydrological and ecological*	• Cumulative case terrestrial GDE risk assessment conducted in the Stage 1 CSG WMMP (Section 1.3.2) and Stage 2 CSG WMMP (Section 4). • Arrow's contributions to OGIA investigations are described in Section 1.3.5.

Approval Condition	Approach to addressing Approval Conditions
characteristics of impacted groundwater dependent ecosystems.	
Approval Condition 17(f): *Identify any predicted changes in stream connectivity due to groundwater drawdown from the action and assess potential impacts to groundwater dependent ecosystems due to any predicted changes in stream connectivity, including to water quality, quantity and ecology.*	• Numerical modelling conducted as part of the Stage 2 CSG WMMP by CDM Smith (2018) which utilises the 2016 UWIR model and Arrow's current FDP to assess the significance of predicted changes in stream connectivity from the Action and subsequent potential impacts to GDEs (Section 3).
Approval Condition 17(g): *Address any uncertainty in the groundwater dependency of ecosystems and springs with supporting evidence from field-based investigations for any groundwater-dependent ecosystems and springs confirmed in the OGIA model.*	• Field based investigations conducted by 3D Environmental/Earth Search (2018) to assess the potential groundwater dependency of ecosystems at four selected sites (Section 5). • Field based investigations conducted by Arrow Energy (2018) to assess the potential level of connectivity between formations overlying the WCM within the four sites subject to the 3D Environmental/Earth Search (2018) study (Section 6).

3. SGP Stage 2 CSG WMMP Groundwater Modelling

3.1. Introduction and objectives

The CDM Smith (2018) Stage 2 groundwater modelling study utilises Arrow's Stage 2 CSG WMMP FDP and the 2016 version of the OGIA's regional groundwater model for the Surat CMA (hereafter referred to as the 2016 UWIR model). The earlier modelling for the Stage 1 CSG WMMP employed Arrow's Stage 1 CSG WMMP FDP and the 2012 version of the OGIA's regional groundwater model.

Two other models used for the Stage 1 and 2 WMMPs; the Central Condamine Alluvium Model (CCAM) and the Integrated Quantity and Quality Model (IQQM) for the middle Condamine River, are unchanged in model structure and parameterisation between the 2012 and 2018 model iterations. Accordingly, any differences in model results between Stage 1 and 2 are due to changes between the 2012 and 2016 OGIA model versions and the simulated FDPs for Arrow (Stage 1 and Stage 2) and other CSG operators used in these simulations.

With reference to presenting model outputs, while the 2012 UWIR model version was run with three realisations: P5, P50 and P95, the 2016 UWIR model version was run as a single predictive simulation for CSG development.

The CDM Smith (2018) model development and outputs are reviewed and summarised in a separate technical memorandum (Coffey 2018) in response to addressing Approval Conditions 17(b), 17(c), 17(d) and 23.

A key component of the CDM Smith (2018) modelling report of relevance to the assessment of potential impact to GDEs and stream connectivity is the prediction of impacts to the Condamine River from the Action which directly addresses Approval Condition 17(f) (Table 2-1). Key findings in relation to this impact assessment are described in Section 3.4. Preceding this section is a description of the updated geological model integrated into 2016 UWIR model (Section 3.2) and the approach to representing groundwater-surface water connectivity in the CCAM (Section 3.3), as used by CDM Smith (2018).

3.2. Revised geological and hydrogeological conceptualisation

Additional information has become available since the 2012 UWIR model was developed which has enhanced the understanding and conceptualisation of geology and hydrogeology in the Surat CMA. These developments have enabled the construction of an updated geological model by OGIA for integration into the 2016 UWIR model. It is understood that the regional scale geological model will continue to be revised as new data becomes available to support future UWIR updates and water resource management activities in the area. Key updates incorporated into the new geological model include (OGIA 2016a):

- Interpretation by OGIA of substantial additional primary data including the interrogation of more than 4,800 CSG wells that informed the extent and elevation of the revised geological modelled surfaces, including the Westbourne Formation, separating the Gubberamunda Sandstone from the underlying Springbok Sandstone.
- A systematic compilation, review and interpretation of geophysical wireline logs. Lithostratigraphic packages were correlated from consistent and recognisable wireline log characteristics.
- A revised stratigraphic division between the Westbourne Formation and the Springbok Sandstone which is transitional and has been inconsistently divided in the past. OGIA has divided this into three consistent units: an upper siltstone/mudstone-dominated Westbourne Formation, a middle interbedded sandstone/siltstone/coal-dominated upper Springbok Sandstone, and a sandstone-dominated lower Springbok Sandstone (OGIA 2016b). Throughout the remainder of the geological sequence, the recognised lithostratigraphic divisions have been used.

- Additional lithostratigraphic subdivisions including a consistent subdivision of the Springbok Sandstone, Hutton Sandstone and Walloon Coal Measures.
- More accurate representation of surficial sediments, including the Condamine Alluvium and the Main Range Volcanics, defined from primary interpretation of thousands of water bore lithological descriptions.
- The inclusion of a number of the major geologic faults.

It is noted that the joint Department of Natural Resources, Mines and Energy (DNRME) and Geological Survey of Queensland (GSQ) Surat Basin CSG reservoir units mapping project (Cranfield 2017) was developed in parallel with the OGIA (2016) geological model and relies on many of the same data and information sources. The project focused on identifying sub-crop boundaries between Cainozoic age cover (including alluvial and colluvial units of the ‘Condamine Basin’) and duricrust above the stratigraphic section from the upper Hutton Sandstone / upper Marburg Subgroup to the top of the Springbok Sandstone. The outputs for the project include two 1:500 000 scale map products. The DNRME mapping products (Cranfield 2017) have been reviewed and adopted for the revised Stage 2 CSG WMMP GDE risk mapping exercise (Section 4).

3.3. Representation of groundwater – surface water connectivity

The CCAM, as used in the CDM Smith (2018) model study, predicts impacts to the Condamine River only at locations where the river is represented by a river boundary condition (i.e. at river cells) and only in river cells where the assigned value of the river bed elevation is below the simulated elevation of the watertable. In these circumstances, the MODFLOW River package considers the river and aquifer to be ‘connected’ and computes a rate of flux between the alluvium and the river that is based on the difference in elevation between the river level and water table.

Activities that may potentially change the watertable elevation, such as change in vertical flux at the base of the alluvium, also have a potential to change the rate at which groundwater is exchanged between the alluvium and river at these locations by affecting the elevation of the water table. The direction of flow between the alluvium and river in these river cells is controlled by the relative elevations of the river level and watertable, with flow occurring in the direction from highest to lowest elevation. The direction of flow can change dynamically during a simulation in response to changes in the assigned river level and computed water table elevation; thus, the river can, on occasion, gain groundwater from the alluvium (gaining condition) and at other times during the simulation, lose water to the alluvium (losing condition).

In contrast, where river cells are assigned a river bed elevation above the simulated elevation of the watertable (i.e. at locations where there is a zone of unsaturated soil between the river bed and underlying water table), the MODFLOW River package considers the river and aquifer to be ‘disconnected’ and computes a rate of flux from the river to groundwater that is solely based on the depth of river water above the river bed and the value assigned to the river-bed conductance. In this case, the computed rate of flow between the river and alluvium is independent of the simulated water table elevation, such that activities with potential to change the elevation of the water table do not affect the rate at which groundwater is exchanged at these locations.

Figure 4 illustrates the depth of the water table below the assigned values of river bed elevation in river cells of the CCAM. Negative values of depth (blue tones in the legend) signify that the watertable is above the river bed and the river cells are ‘connected’. Positive values of depth (red tones) signify that the watertable elevation is below the river bed and the river cells are ‘disconnected’ and the river in this area is a losing stream feature. As indicated in Figure 4, the Condamine River is dominantly represented by disconnected and losing conditions in the CCAM. Three localised areas (northwest, central and southeast in the CCAM) are indicated to be connected river reaches and where drawdown of the water table may result in impact to the river. Over the simulation period, the transient recharge and river boundary conditions (the cycle of 29.5 years repeated) can potentially influence and slightly change the connection between the river and water table shown in Figure 4.

3.4. Predicted impacts to Condamine River

As discussed in Section 3.3, predicted impacts to the Condamine River from CSG water extraction are only assessed where river cells are ‘connected’ to groundwater and where potential drawdown is predicted. The predicted magnitude and timing of impacts to the river is therefore dependent on the location of ‘connected’ river cells and the drawdown induced by the simulated water production.

Figure 5 illustrates the predicted distributions of the all-time maximum changes in groundwater flux in river cells due to Arrow’s forecast water production. Approximately 80% of river cells experience no discernible change in groundwater flux over the simulation period having been nominated as ‘disconnected’ from groundwater in model development. The rates of leakage from these river cells during model operation are constant and independent of the water table elevation.

Most of the predicted impact on the Condamine River due to water production by Arrow occurs in river cells located between Warra Town Weir and Chinchilla Weir, with maximum changes in groundwater flux of between 0.001 ML/d and 0.005 ML/d. Maximum changes of less than 0.001 ML/d are also predicted immediately upstream of Cecil Plains Weir. The predicted maximum change in the total groundwater flux to the Condamine River due to Arrow’s water production is 0.148 ML/d. Over the simulation period (up to 811 years after the start of simulated water production) the predicted total change in volumetric flux between the Condamine River and Condamine Alluvium is 33.7 GL.

These predicted cell flux changes are small (maximum of 0.1 L/s for a cell 500 m x 500 m in size along the alignment of the river) and considered beyond the expected accuracy of the CCAM. Accordingly, for all practical purposes the predicted impacts of groundwater flux changes to the connected reaches in the Condamine River from the Action are considered negligible.

Changes to groundwater – surface water connectivity have the potential to affect water quality in river systems with sustained and significant changes to water quality having the potential to impact habitats of aquatic ecosystems in river and riparian zones. The predicted magnitude of the groundwater flux changes (of up to 0.1 L/s per cell 500 m × 500 m in size) however, imply any associated changes to water quality in the Condamine River are likely to be immeasurably small.

From both a river water quantity and quality perspective, potential changes are predicted to be negligible and hence, the potential impacts to existing aquatic ecosystems and surface expression GDEs dependent on the Condamine River are also expected to be negligible.

A network of surface water and aquatic ecology monitoring locations was established as part of the SGP EIS/SREIS process (Arrow Energy 2012 & 2013). These included surface water quality, flow and aquatic ecology monitoring locations. Locations were selected to provide baseline data across representative conditions for the different surface water systems and land uses within the SGP area, at the time of the EIS/SREIS. Ongoing monitoring is carried out by the Queensland Government and also tenure holders assigned responsibilities under the Surat CMA UWIR in relation to watercourse springs. Arrow are not the responsible tenure holder for any identified watercourse springs, and no monitoring sites nominated by the OGIA are located within relevant areas for the SGP.

Identification of further baseline and ongoing monitoring locations will occur, where relevant, should future project requirements and/or future revision of the FDP result in the potential for impact to surface water systems and aquatic ecology. Monitoring activities will commence in advance of the potential for impact to occur, to enable the establishment of baseline conditions and development of WQOs where required.

4. SGP Stage 2 CSG WMMP terrestrial GDE risk mapping

The terrestrial GDE risk mapping exercise conducted in the SGP Stage 1 CSG WMMP (Section 1.3.2) has been reviewed and updated in Stage 2 taking into account the CDM Smith (2018) groundwater modelling outputs which adopts Arrow's Stage 2 CSG WMMP FDP, the 2016 version of the OGIA's regional groundwater model for the Surat CMA, current surface and subsurface geological mapping (Cranfield 2017, Section 3.2) and updates to the GDE mapping (Department of Environment and Science (DES) 2018). The outcomes of the field based GDE investigations (3D Environmental/Earth Search 2018, Section 5) and hydraulic connectivity investigations (Arrow Energy 2018, Section 6) have also assisted in conceptualising the local scale hydrogeological regime in comparable settings and in the assignment of risks.

A comparison of the Stage 1 and 2 WMMP risk mapping outputs provides a measure of the sensitivity of the risk assessment to the modelling and mapping inputs employed between the two stages. The Stage 2 CSG WMMP GDE risk mapping exercise also aims to address (in part) Approval Condition 17(g) which seeks to identify any uncertainty in the groundwater dependency of ecosystems that may be subject to potential impacts as a consequence of the Action.

4.1. Input data

The assessment of potential risk to terrestrial GDEs due to Arrow-only and cumulative drawdown adopted the same approach as set out in the Stage 1 methodology (Section 1.3.2). For the Stage 2 assessment, the key inputs included:

- CDM Smith (2018) groundwater modelling outputs which adopt Arrow's Stage 2 CSG WMMP FDP and the 2016 version of the OGIA's regional groundwater model.
- Potential GDE landscapes as per the Stage 1 GDE risk assessment, current DES mapping (2018) (formerly DSITI), and findings of field based investigations undertaken by 3D Environmental (2018) and Arrow Energy (2018).
- The solid geology mapping (Cranfield, 2017).
- Depth to groundwater and borehole information from various Arrow Energy and publicly available datasets (Natural Resources, Mines and Energy 2018).

4.2. Potentially affected terrestrial GDEs

Figure 6 to Figure 24 present the predicted drawdown in the key aquifer systems together with mapped subcrop of the relevant geological units and potential terrestrial GDE landscapes. A multi-criteria GIS analysis of these three components assisted in identifying GDE areas at risk of predicted drawdown that were then subject to more detailed assessment of the likelihood of the actual risk arising.

Table 4-1 summarises the outcomes of the Stage 2 CSG WMMP GDE risk area mapping exercise, including a comparison of the outputs generated in the Stage 1 CSG WMMP GDE risk assessment. The difference in assessment outcomes between the WMMP Stages relates to the adoption of different modelled drawdown predictions, geological interpretation and more recent terrestrial GDE mapping published by DES (2018). Further detail on specific GDE risk areas identified in Stage 2 is provided in the following sections.

Table 4-1 Stage 2 CSG WMMP terrestrial GDE risk mapping outputs and comparison with the Stage 1 CSG WMMP

Watertable aquifer	Arrow only drawdown	Cumulative drawdown
Condamine Alluvium	In Stage 1 and 2, the maximum predicted drawdown in the Condamine Alluvium is < 1.0 m. Accordingly, no risk areas were identified in either stage (Figure 6) and further assessment is not required.	No terrestrial GDE risk areas were identified in the Stage 1 assessment. A small area (designated as Cumulative Risk Area 7) has been identified between Dalby and Chinchilla in Stage 2 with a predicted drawdown of up to 1.5 m (Figure 7). This area is discussed further in Section 4.2.1.
Gubberamunda Sandstone	In Stage 1 and 2, no drawdown > 1.0 m is predicted to occur in this aquifer (or the Mooga Sandstone) for the Arrow-only scenario. No further assessment is required.	In Stage 1, Cumulative Risk Areas 1 and 2 were eliminated as being potentially groundwater dependent based on an interrogation of field data and landscape and vegetation mapping. These cumulative risk areas were not identified in the Stage 2 assessment. No further assessment is required.
Springbok Sandstone	Predicted risk areas in the Springbok Sandstone have been influenced by revised subcrop extent, modelled drawdown predictions and potential GDE mapping in Stage 2 (Figure 9). Stage 1 Risk Areas 1, 3a and 3b were not identified in the Stage 2 assessment. Risk area 2, which is reflected in the Stage 2 assessment, was assessed in Stage 1 as not being dependent on a watertable aquifer hosted in the Springbok Sandstone and is therefore not considered at risk from Project-related drawdown. Additional areas of potential risk to GDEs are identified in Stage 2: • Due east of Miles (Risk Area 5). • South of Chinchilla (Risk Area 6 north-west of Risk Area 2). • Small areas to east of Risk Area 3a (Risk Area 7). These areas are discussed further in Section 4.2.2.	Predicted cumulative risk areas in the Springbok Sandstone have been influenced by revised subcrop extent, modelled drawdown predictions and potential GDE mapping in Stage 2 (Figure 11). Stage 1 Cumulative Risk Areas 3 and 6 were not identified in the Stage 2 assessment. The Stage 2 assessment does however indicate: • Slightly revised areas potentially at risk around Cumulative Risk Area 4. • Revised areas potentially at risk to the south-east of Cumulative Risk Area 5. These partly overlap with Risk Area 2. • A small area potentially at risk to the south of Cecil Plains (Cumulative Risk Area 8). These areas are discussed further in Section 4.2.2.

Watertable aquifer	Arrow only drawdown	Cumulative drawdown
Walloon Coal Measures	The DNRM (2017) solid geology map provides additional detail concerning the subcropping extent of the WCM across Arrow's tenure for the Stage 2 assessment. The Stage 1 Risk Area 4 was not identified in the Stage 2 assessment due to the reduced extent of predicted drawdown in the area of revised WCM subcrop/outcrop (Figure 15). A range of additional risk areas are identified in the Stage 2 assessment located between Wandoan and Chinchilla, south of Chinchilla and north-west of Millmerran (Risk Areas 8, 9, 10 and 11). These areas are discussed further in Section 4.2.3.	No cumulative risk areas (in addition to the Arrow only assessment) were identified as part of the Stage 1 and 2 assessments (Figure 20). No further assessment is required.
Hutton Sandstone	The Hutton Sandstone does not subcrop or outcrop in areas of Arrow only modelled drawdown > 1m predicted for Stage 1 or 2 (Figure 21). No further assessment is required.	No cumulative risk areas were identified in the Stage 1 assessment. For the Stage 2 assessment, a small area of predicted cumulative drawdown > 1m in the Hutton Sandstone coincides with Hutton Sandstone subcrop in the north of Arrow's tenure, south-west of Wandoan (Figure 22). This area is discussed further in Section 4.2.4.
Precipice Sandstone	The Precipice Sandstone does not subcrop or outcrop in areas of Arrow only modelled drawdown > 1m predicted for Stage 1 or 2 (Figure 24). No further assessment is required.	The Precipice Sandstone does not subcrop or outcrop in areas of cumulative modelled drawdown > 1m predicted for Stage 1 or 2. No further assessment is required.

4.2.1. Condamine Alluvium

Arrow only impact

As for Stage 1, no risk areas associated with Arrow-only impact have been identified in the Stage 2 assessment.

Cumulative impact

A small area of potential terrestrial GDEs are present overlying predicted drawdown of > 1.0 m mid-way between Chinchilla and Dalby (Cumulative Risk Area 7 (CRA7), Figure 7).

Available depth to groundwater data in this area (present on Figure 8) indicates the watertable is typically 10 m to 20 m below ground surface. This is generally beyond the rooting depth of trees (<10 m; Yee Yet and Silburn 2003), however it may be within the rooting depth of species such as Eucalyptus camaldulensis (River Red Gum).

The dominant Regional Ecosystem (RE) types present in this area are 11.3.2, 11.3.4 and 11.3.25, all of which have variable potential to contain vegetation types that may be reliant upon groundwater, in particular, River Red Gum. The presence of River Red Gum in this reach is consistent with field observations during recent field surveys. The inferred depth to groundwater of < 20 m bgl is within the potential rooting depth of River Red Gum, however the ecohydrological conceptualisation of this area is that of vegetation with relatively shallow rooting depth accessing water sourced from shallow stream leakage and not deeper groundwater present below 10 m. This is consistent with the findings of the 3D Environmental/Earth Search (2018) study at target sites in the project area that identified shallow maximum tree rooting depths (with the deepest rooting depth across all sites investigated being 7.6 m bgl), as well as other indictors (such as leaf water potential) supporting the conceptualisation that vegetation is accessing shallow soil moisture and not groundwater (refer Section 5 for further detail). This was observed to be true even for riparian environments.

The cumulative drawdown in this area is predicted to be less than 2 m. Review of the modelling outputs indicates a maximum rate of change of groundwater level of 0.03 m/year, with the timing of maximum drawdown occurring around 2120.

Historical fluctuations in the watertable, due to significant abstraction associated with agricultural practices, are typically in excess of 2 m on a seasonal basis, which has resulted in sustained and significant drawdown of the watertable across the Condamine Alluvium. As shown in Figure 4, in the vicinity of CRA7, the watertable is indicated to be > 5 m below the base of the Condamine River. This further supports the conceptualisation that vegetation in CRA7 access shallow soil moisture, including leakage from the Condamine River, as it is seasonally available.

Based on this conceptualisation, vegetation present in Cumulative Risk Area 7 is considered to source water from the shallow soil profile in the alluvial system and is not dependent on deeper groundwater. No further assessment is therefore considered necessary.

4.2.2. Springbok Sandstone

Arrow only impact

Risk Area 5 – east of Miles

This area coincides with the Stage 1 CSG WMMP Cumulative Risk Area 3, and the conceptualisation from the Stage 1 risk assessment that there is a significant depth of Westbourne Formation overlying the Springbok Sandstone in this area still applies in Stage 2. Terrestrial GDEs in this area are therefore not considered further in this Stage 2 assessment with regards to potential risk of drawdown impact.

Risk Area 6 - South of Chinchilla (north-west of Risk Area 2)

Risk Area 6 coincides with the Stage 1 CSG WMMP Cumulative Risk Area 5 and the conceptualisation from the Stage 1 risk assessment that there is a significant depth of Westbourne Formation overlying the Springbok Sandstone in this area as well as vegetation types that are generally not considered to be groundwater dependent and a landscape setting that is supportive of this remains valid. Terrestrial GDEs in this area are therefore not considered further with regards to potential risk of drawdown impact.

Risk Area 7- East of Risk Area 3a

Risk area 7 is defined by small areas of potential terrestrial GDEs immediately west of the inferred western extent of the Condamine Alluvium where the Springbok Sandstone is indicated to subcrop/outcrop and > 1.0 m of modelled drawdown in the Springbok Sandstone is predicted (Figure 10). The risk area partly overlaps the eastern edge of Stage 1 Risk area 3a.

The REs mapped across the risk area are largely classified as 11.5.1, which are dominated by Ironbark species that are not associated as being groundwater dependent due to their shallow rooting depth and tendency to rely on soil moisture in the upper soil profile. Small areas of REs that contain vegetation that has an established association with groundwater (RE 11.3.25 and to a lesser degree 11.3.2) are located within the relatively cleared areas immediately west of the inferred extent of the Condamine River Alluvium on the eastern slopes of the Kumbarilla Ridge.

Further review of available bore reports and depth to groundwater records in and immediately surrounding Risk area 7 indicate the Condamine River Alluvium is generally present, and is likely to host the watertable aquifer:

- Borehole geology for RN160732 (southwest of the risk area) indicates 16 m of Condamine River Alluvium underlain by 10 m of Westbourne Formation.
- RN42230091 (west of the risk area) is logged with Condamine River Alluvium to a depth of >50 m, while RN107689 (also west of the risk area) is interpreted as having Condamine River Alluvium to a depth of 27m.
- The borehole log of RN42231216 (north of the risk area), reports the presence of 8 m of Condamine River Alluvium, directly underlain by WCM, thereby indicating the Springbok Sandstone aquifer is absent. Depth to groundwater is measured at approximately 22.5 m bgl. RN42230110 (east of the risk area), indicates the presence of 50 m of Condamine River Alluvium, and depth to groundwater is measured as approximately 9.0 m bgl.
- The borehole log for RN22377 (east of the risk area, in close proximity to RN42230091), indicates Kumbarilla Beds from near surface to 112 m depth bgl, overlying Walloon Coal Measures. The water level depth for this bore is measured at between 18 m and 27 m bgl.

On the basis of the interrogation of bore logs and water level data in and around Risk Area 7, the watertable aquifer is not considered to be hosted in the Springbok Sandstone. If terrestrial GDEs are present in the area, including the likely riparian GDE landscape observed from the 3D Environmental/Earth Search 2017 desk top assessment and field survey in the southern extent of Risk area 7 (Figure 9), their source of water is considered to be the Condamine Alluvium. Risk area 7 is likely a consequence of modelling artefacts at the boundary of the defined extent of the Condamine Alluvium.

Given the limited predicted drawdown under the Arrow only scenario for the whole of the Condamine Alluvium, it is reasonable to expect that drawdown propagation from the Springbok Sandstone to the overlying Condamine Alluvium in this area would also be < 1.0 m and therefore not represent a risk to terrestrial GDEs that may be present. Local scale groundwater modelling of CSG extraction at the Lake Broadwater site (approximately 25 km north of Cecil Plains), by AGE (2018) as part of the Arrow Energy (2018) connectivity studies (Section 6), provides further semi-quantitative support to this interpretation. The calibrated steady state model comprised four layers representing key geological units including Alluvium, Westbourne Formation, Springbok Sandstone and WCM. The model simulation indicated that the perched system associated with Lake Broadwater, overlying the alluvium, is unlikely to be affected by CSG pumping from the WCM. The low vertical hydraulic conductivity of the intervening WCM mudstones and sandstones layers above the target coal seam were considered to be limiting drawdown extending to the overlying Alluvium. Furthermore, sensitivity analyses demonstrated that increasing the vertical hydraulic conductivities of the units beneath the Alluvium by one and two orders of magnitude still contributed to negligible propagation of drawdown to the watertable in the Alluvium unit.

Cumulative impact

Revised Cumulative Risk Area 4

Cumulative Risk Area 4 was defined during the Stage 1 CSG WMMP assessment. This Stage 2 assessment has identified some localised additional potential risk areas immediately northwest of the Stage 1 assessment area, directly west of Chinchilla (Figure 12).

Few potential terrestrial GDEs are mapped in this area, which is consistent with the Stage 1 assessment of Cumulative Risk Area 4. The revised area comprises RE types dominated by 11.5.1 and 11.7.4. Some minor inclusion (< 10%) of 11.3.4 is also listed, which may contain a variable proportion of River Red Gum. On the basis of the risk area's position in the landscape (e.g. elevated terrain and not alluvial plains which are the typical landscape setting for River Red Gums), and as per the assessment made in Stage 1; that the RE types present are not usually associated with the potential for groundwater interaction, this area is considered unlikely to contain ecosystems that are reliant on a watertable hosted in the Springbok Sandstone.

Revised Cumulative Risk Area 5 / Risk Area 2

An area between Chinchilla and Dalby that was assessed in the Stage 1 CSG WMMP is indicated as a Cumulative Risk Area in the Stage 2 assessment (Figure 13). The area, designated Revised Cumulative Risk Area 5, partly overlaps with the Stage 1 Arrow-only Risk Area 2 and is situated to the southeast of the Stage 1 Cumulative Risk Area 5.

Consistent with the Stage 1 assessment, this area is generally not likely to support ecosystems potentially dependent on a watertable hosted in the Springbok Sandstone based on:

- The presence of a thinner sequence of Westbourne Formation and up to 15 m of clayey lithology in the upper soil profile to the east. Combined with the presence of RE types dominated by 11.7.4, 11.7.7, 11.7.5 and 11.5.1 (which are not usually associated with the potential for groundwater interaction given their shallow rooting depths) and the position in the landscape (which is on the side of the Kumbarilla Ridge, but does not extend on to the alluvial plain) these ecosystems are considered to be more reliant on soil moisture than the watertable.

- Borehole RN42231258 located on the eastern boundary of the risk area indicates the presence of a thin layer of clay, underlain by mudstone and sandstone. Carbonaceous mudstone and coal are intersected at a depth of 24 m bgl and the groundwater level is recorded at 38 m bgl. This lithology is not typical of supporting ecosystems reliant on groundwater as is difficult for vegetation to establish extensive or deep rooting system through clays, mudstone and sandstone.

- Borehole RN160730, located approximately 2.5 km to the north of this risk area, indicates the absence of Springbok Sandstone, with the Condamine Alluvium (18 m in thickness) directly underlain by the WCM.

- A single gully is present at the southern end of this risk area that contains RE types of 11.3.2 and 11.3.25 and overlies an area of predicted drawdown of up to 3 m. It is unlikely that River Red Gums or other deeper-rooted vegetation are present along this gully, based on the inferred outcrop geology.

- Borehole RN42231257 is located approximately 1 km south and indicates outcropping sandstone, and a depth to groundwater of 37.5 m bgl. Whilst this is considered to be representative of depth to groundwater in the Springbok Sandstone in this area, there is the potential for shallower groundwater levels in the immediate vicinity of the drainage feature.

The available information in proximity to the risk area indicates a low likelihood that the landscape settings hosts a watertable aquifer in the Springbok Sandstone or which support terrestrial GDEs. As a function of the OGIA is to assess and administer responsibilities concerning the management of cumulative scale impacts, any further assessment of risks to GDEs in this area will be guided by this process.

Cecil Plains Cumulative Risk Area (Cumulative Risk Area 8)

A small area to the south of Cecil Plains (Figure 14) is indicated as a cumulative risk area. This is east of the Westbourne Formation subcrop extent, and on the western boundary of the Condamine Alluvium. Groundwater drawdown of less than 2 m is predicted.

Borehole RN42231210 which is located immediately south of this risk area indicates the presence of 12 m of Condamine Alluvium directly underlain by the WCM. The mapped REs present in this risk area include 11.5.1 and 11.5.4, which are not associated with a groundwater dependence due to their shallow rooting structure. This is consistent with the landscape setting of being on the lower elevations of the Kumbarilla Ridge.

It is therefore concluded that the ecosystems associated with Cumulative Risk Area 8 are not likely to be groundwater dependent, nor dependent on a watertable aquifer hosted in the Springbok Sandstone.

4.2.3. Walloon Coal Measures

Arrow only impact

Risk Area 8

Risk Area 8 comprises significant areas of potential GDE landscapes between Wandoan and Chinchilla, associated with the Barakula State Forest (Figure 16). There is no depth to groundwater information available in the vicinity of these areas. Borehole Kedron-570 (RN160348) located to the west of Risk Area 8, indicates a regional groundwater elevation in the shallowest monitored WCM interval of approximately 297 m AHD; 60 m bgl. In addition, Castledean-18 (RN160687) indicates a depth to groundwater in the Juandah Coal Measures of approximately 40 m (groundwater elevation of around 273 m AHD). Whilst these boreholes are some distance from Risk Area 8, they are indicative of regional groundwater elevation in the WCM. The depth to groundwater in these bores (of between 40 m bgl and 60 m bgl) is well beyond the rooting depth of terrestrial GDE species.

The dominant RE types are 11.5.1, 11.5.1a, 11.5.4, 11.5.21, 11.7.7, 11.7.5 and 11.7.4 (Figure 16). As previously discussed in Stage 1, these RE types are dominated by Ironbark species with shallow rooting depth that have limited potential to tap deeper groundwater sources, with the species relying on soil moisture in the upper soil profile. This is supported by the description of the landscape setting provided in 3D Environmental/Earth Search (2017), that describes this general area as comprising colluvial outwash, decomposed sandstone and indurated sandstone jump-ups, that are not supportive of deep rooted vegetation.

Based on the conceptualised landscape setting, assessment of dominant RE types present and regional understanding of groundwater elevation in the WCM, the potential terrestrial GDEs in Risk Area 8 are not considered to be dependent on a watertable hosted in the WCM and are therefore not at risk of drawdown impact.

Risk Area 9

Risk Area 9 is located to the north-west of Chinchilla (Figure 17). There is limited depth to groundwater information available in this area.

Borehole report for RN172269 (located on the eastern edge of the collective risk area) indicates the presence of clayey lithology in the top 20 m. Across most of Risk Area 9, the dominant RE types include 11.7.7, 11.5.1 and 11.7.5. As previously discussed, these RE types are not known to contain vegetation with an established reliance on groundwater due to their shallow rooting depth and more typical reliance on shallow soil moisture. This is consistent with the clayey upper lithology indicated in borehole RN172269, and these potential terrestrial GDEs are therefore not considered further in this assessment.

In the south of Risk Area 9, there is an area of mapped potential terrestrial GDEs with dominant RE types being reported as 11.3.4 and 11.3.25. These coincide with a reach of Rocky Creek, a tributary of Charley's Creek. The mapped RE types are typically present along alluvial plains with sandy lithology. Whilst detailed site-specific information is not available in this area, it is reasonable to conceptualise that these potential terrestrial GDEs are associated with localised alluvial deposits along this drainage line, and not outcropping WCM.

This is consistent with the findings of the detailed site investigations for Stage 1 Risk Area 4 (Burunga Lane) (3D Environmental/Earth Search 2018, Section 5), where similar RE types were mapped as being present along subcropping WCM. The study found that the River Red Gums present along the fringes of Juandah Creek were likely to be dependent on soil moisture in the upper 6.5 m, not preferentially accessing deeper groundwater in the coal measures.

Accordingly, these potential terrestrial GDEs are considered likely to be dependent primarily on soil moisture in the upper soil profile, and potentially a watertable hosted in the shallow river alluvium. They are not considered to be dependent on a regional watertable hosted in the WCM.

Risk Area 10

Risk Area 10 is located to the south-east of Chinchilla with areas of potential terrestrial GDEs scattered along the length of the Condamine River, as well as some further west on the lower slopes of the Kumbarilla Ridge (Figure 18).

Along the lower slopes of the Kumbarilla Ridge the dominant RE types are 11.5.1 and 11.7.4. As previously discussed, these REs are not known to contain vegetation with an established reliance on groundwater due to their shallow rooting depth and more typical reliance on shallow soil moisture. As such, these risk areas are not considered further in this assessment.

The mapped risk areas along the Condamine River are considered to be an artefact of the defined model boundary of the Condamine River Alluvium. The areas lie immediately west of the inferred boundary, however available borehole reports for Wyalla-16 (central to Risk Area 10), RN42231475, RN42231471, RN42231473 and RN42231474 (in the north of Risk Area 10) indicate the presence of more than 10 m of Condamine River Alluvium and a watertable hosted in the alluvium. Therefore, the terrestrial GDEs potentially present in these areas are considered to be reliant on a watertable present in the Condamine Alluvium, not the WCM.

As the risk areas along the Condamine River are interpreted to be a model artefact it is reasonable to assume propagation of drawdown to the Condamine Alluvium in this area, as a consequence of CSG pumping from WCM, is likely to be of a similar magnitude to that predicted for the Condamine Alluvium areas immediately surrounding Risk Area 10 (Figure 6), that is, less than adopted 1 m drawdown level for the assessment of potential impacts to terrestrial GDEs.

Risk Area 11

Risk Area 11 is located immediately east of the Stage 1 CSG WMMP Risk Area 3b (noting Risk Area 3b was defined based on potential impact arising from drawdown in the Springbok Sandstone), south of Cecil Plains on the western slopes of the Kumbarilla Ridge (Figure 19). Modelled groundwater drawdown in the WCM of up to 10 m is predicted in the northern parts of this risk area.

Limited depth to groundwater data is available in this area, however DNRME investigation bore RN42231208 (originally drilled as exploration borehole PCP 24) is located in close proximity to the eastern boundary of Risk Area 11. Drillers logs for RN42231208 report the presence of 8 m of Condamine River Alluvium, underlain by WCM, with a groundwater level of 17 m bgl. The construction record indicates the bore is perforated from 39.6 m bgl and open from 45.6 m bgl with a gravel pack from surface to the borehole depth of 158 m bgl. Given the absence of a bore seal, the measured groundwater level of 17 m bgl cannot be considered representative of any particular units intersected by the borehole. Interrogation of the original drilling record for exploration borehole PCP 24 and accompanying exploration report for the Authority to Prospect 234C (Peabody Australia 1981) provides a comprehensive stratigraphic interpretation for the area of interest that contrasts with the drillers log. Specifically, for exploration borehole PCP 24, Quaternary age sediments are indicated to 22 m bgl, underlain by Kumbarilla Beds (inferred to be Springbok Sandstone) to 55 m bgl at which depth the WCM is intersected. A similar stratigraphic profile is indicated further west in exploration borehole PCP41.

The model boundary of the Condamine Alluvium is present immediately to the east of Risk Area 11 (Figure 19). Arrow's UWIR monitoring bore Mt Haystack 5, located around 4 km east of Risk Area 11, was logged with Condamine Alluvium from surface to 26 m bgl, underlain by undifferentiated basal alluvial clays and palaeoregolith between 26 and 30 m bgl and then by WCM. The bore is screened within the Condamine Alluvium with a recorded water level of 11.7 m bgl.

Risk Area 11 is located in the vicinity of the boundary of Westbourne Formation subcrop. Approximately 3.5 km northwest of this designated area borehole RN160941 is logged with 10 m of Condamine River Alluvium, underlain by 47 m of Westbourne Formation, consistent with this area being west of the Westbourne Formation inferred subcrop extent. The WCM is therefore not expected to represent the watertable aquifer in this area to the northwest.

These three boreholes demonstrate the variable subsurface conditions with regards to the presence of the Westbourne Formation and Condamine Alluvium across Risk Area 11.

The dominant RE types within Risk Area 11 include 11.5.1 and 11.5.1a on the slopes of the Kumbarilla Ridge, and 11.3.2, 11.3.25 and 11.3.4 further east on the alluvial plains, mapped along local drainage lines (Figure 19). RE types 11.5.1 and 11.5.1a are dominated by Ironbark species that are not associated with being groundwater dependent due to their shallow rooting depth and tendency to rely on soil moisture in the upper soil profile. RE types 11.3.2, 11.3.25 and 11.3.4 contain vegetation that has a potential association with groundwater and is therefore defined in Figure 19 as a sub-risk area.

Based on the results of the Stage 1 CSG WMMP GDE impact assessment, detailed field investigations (3D Environmental/Earth Search 2018, Section 5 and Arrow Energy 2018, Section 6) were carried out within Risk Area 3b (Glenburnie, 12 km southwest of Risk Area 11) to assess the presence and potential groundwater connectivity of deeper rooted vegetation along drainage lines. The investigations encountered a sub-artesian aquifer at 27 m depth bgl within the WCM, with groundwater rising to approximately 14.4 m bgl. The WCM is considered to represent the regional aquifer, with a shallow saturated seepage zone (perched aquifer) present from between 11 and 18 m bgl within the overlying weathered Springbok Sandstone. The maximum observed tree rooting depth was recorded at 7.6 m bgl and leaf water potential and soil moisture potential measurements indicated plant moisture being sourced from a zone of soil moisture between 9.0 and 11.5 m bgl. Stable isotope signatures indicate however, shallow evaporatively enriched surface moisture is the pre-dominant source of plant water.

The regional geology in and around Risk Area 11 is expected to be variable. The WCM is present at depth across the area; to the west and southwest the Westbourne Formation and Springbok Sandstone subcrop and to the east the subcropping unit is defined as the Kumbarilla Beds (inferred to be Springbok Sandstone). The mapped vegetation in the risk area has the potential to be deep-rooted and possibly dependent on groundwater up to 20 m in depth. However, examination of drilling records indicates the WCM does not outcrop or subcrop in or around Risk Area 11. The WCM is demonstrated to be present at considerable depth (> 30 m bgl) and as such will not host the watertable aquifer in this area. Accordingly, any terrestrial GDEs present are not considered at risk of impact from drawdown in the WCM associated with the Action.

Cumulative impact

No additional risk areas associated with predicted cumulative drawdown have been identified in the Stage 2 assessment for the WCM.

4.2.4. Hutton Sandstone

Arrow only impact

As for Stage 1, no risk areas associated with Arrow-only impact have been identified in the Hutton Sandstone in the Stage 2 assessment.

Cumulative impact

A small cumulative impact risk area for the Hutton Sandstone is present in the north east of the project area (Cumulative Risk Area 9, Figure 22 and Figure 23). The area is at the eastern most extent of the 1.0 m modelled drawdown prediction and likely to be an artefact of the modelling grid size. Regardless, further assessment of this area has been undertaken.

There is no depth to watertable information available in the vicinity of this location. As described in the GDE mapping database used to identify these potential landscapes, the potential GDE landscapes are conceptualised as comprising deep rooted regional ecosystems intermittently connected to aquifers with brackish salinity in sandy plains.

The risk area is located on the western extent of the Barakula State Forest at an elevation of approximately 20 m above Dogwood Creek therefore depth to groundwater would be expected to be within 20 m to 30 m (but greater than 10 m) of ground surface. The landscape is characterised by extensive stands of Ironbark forest (REs 11.5.1, 11.5.21, 11.7.5 and 11.7.7), typical of vegetation present on the side of elevated areas in the north of project land. These RE types comprise species that are not associated with being groundwater dependent due to their shallow rooting depth and tendency to rely on soil moisture in the upper soil profile.

Based on this landscape assessment, review of present REs and inferred depth to groundwater (> 10 m below ground surface), this small area of potential cumulative risk to terrestrial GDEs is considered unlikely to be at risk from cumulative CSG related drawdown.

4.3. Conclusions

Table 4-2 presents a summary of the assessed potential risk to terrestrial GDEs, combining the Stage 1 and Stage 2 assessments to the review of where further investigations may be required to characterise the potential for groundwater dependence.

Table 4-2 Comparison of Stage 1 and Stage 2 assessment areas of terrestrial GDEs potentially at risk

Risk Area	Outcropping aquifer (Cranfield 2017 and UWIR 2016)	Assessed as potentially at risk of drawdown impact		Requirement for further assessment
		Stage 1 CSG WMMP	Stage 2 CSG WMMP	
Risk Area 1	Springbok Sandstone	×	Not present	No
Risk Area 2	Springbok Sandstone	×	×	No
Risk Area 3a	Springbok Sandstone	×	Not present	No
Risk Area 3b – north	Springbok Sandstone	×	Not present	No
Risk Area 3b – south	Springbok Sandstone	✓	Not present	No (1)
Risk Area 4 – north	WCM	✓	Not present	
Risk Area 4 – south	WCM	×	Not present	No
Risk Area 5	Springbok Sandstone	Not present	×	No
Risk Area 6	Springbok Sandstone	Not present	×	No

Risk Area	Outcropping aquifer (Cranfield 2017 and UWIR 2016)	Assessed as potentially at risk of drawdown impact		Requirement for further assessment
		Stage 1 CSG WMMP	Stage 2 CSG WMMP	
Risk Area 7	Springbok Sandstone	Not present	✕	No
Risk Area 8	WCM	Not present	✕	No
Risk Area 9	WCM	Not present	✕	No
Risk Area 10	WCM	Not present	✕	No
Risk Area 11	WCM	Not present	✕	No
Cumulative Risk Area 1	Gubberamunda Sandstone	✕	Not present	No
Cumulative Risk Area 2	Gubberamunda Sandstone	✕	Not present	No
Cumulative Risk Area 3	Springbok Sandstone	✕	Not present	No
Cumulative Risk Area 4	Springbok Sandstone	✕	✕	No
Cumulative Risk Area 5	Springbok Sandstone	✕	✕	No
Cumulative Risk Area 6	Springbok Sandstone	✓	Not present	No (2)
Cumulative Risk Area 7	Condamine Alluvium	Not present	✕	No
Cumulative Risk Area 8	Springbok Sandstone	Not present	✕	No
Cumulative Risk Area 9	Hutton Sandstone	Not present	✕	No

Notes:

✕: The risk assessment concludes that the ecosystems are not likely to be reliant on groundwater or that the potential terrestrial GDEs are not at risk of impact from Arrow only or cumulative drawdowns.

✓: Further assessment is recommended to define the potential risk of Arrow of drawdowns to terrestrial GDEs.

(1) Risk Area 3b and Risk Area 4 have been the subject of detailed field investigations by 3D Environmental/Earth Search (2018) and Arrow Energy (2018), the outcomes of which are described in Sections 5 and 6 of the memorandum, respectively. Multiple lines of evidence from these field investigations demonstrated that the terrestrial ecosystems at both sites are unlikely to be reliant on any regional aquifer system, including the Springbok Sandstone and WCM.

(2) As a function of the OGIA is to assess and administer responsibilities concerning the management of cumulative scale impacts, any further assessment of risks to GDEs in this area will be guided by this process.

5. Phase 3 GDE assessment and monitoring program

5.1. Objectives and scope

The objectives of the Phase 3 GDE assessment and monitoring program conducted by 3D Environmental/Earth Search 2018 are as follows:

- Identify if vegetation accesses groundwater (permanently or intermittently) to verify assumptions used in previous desktop GDE assessments.
- Identify the degree of connection between aquifer units (including coal formations) to verify if propagation of drawdown in deeper coal measures will impact shallow formations.
- Identify stratigraphy to confirm geological mapping at monitoring sites.

The scope of work adopted to complete these objectives are as follows:

- Field ecological and hydrogeological characterisation of potential GDE sites.
- Installation of monitoring infrastructure.
- Data collation and reporting.

The assessment required clarification as to whether each site meets the definition of a GDE. To facilitate this process, a GDE Decision Matrix (Appendix J of the 3D Environmental/Earth Search 2018 report) was developed as a measure of confidence in the GDE assessment.

The complete report is provided as an attachment to this memorandum in Appendix 1 for further information or detail concerning the study.

5.2. Site selection

Subsequent to the SGP Stage 1 CSG WMMP GDE risk assessment (Coffey 2017a, 2017b) four sites were chosen for further Phase 3 investigations (Figure 25):

- Risk Area 4 - GDE Investigation Site within Arrow's Burunga Lane field (BL182, northern portion of Arrows Tenements between Miles and Wandoan).
- Risk Area 3b - GDE Investigation Site within Arrow's Glenburnie field (GB20, northwest of Millmerran).
- Long Swamp GDE investigation site (LS35).
- Lake Broadwater GDE investigation site (LS31).

The initial two sites were chosen to satisfy Approval Condition 13(c) whilst monitoring of Lake Broadwater and Long Swamp areas is a requirement of Approval Condition 13(f). A description of the setting of each study area is presented in Table 5-1.

Table 5-1 Description of Site Settings (3D Environmental/Earth Search 2018)

Study Site	Setting
Burunga Lane (BL182)	The Burunga Lane site is located between the townships of Wandoan and Miles and is situated to the immediate west of the main channel of Juandah Creek. The study site lies on a broad flat to gently undulating partially confined alluvial terrace that extends for approximately 530 m on the western side of the creek, separated from gently undulating sandstone foot-slopes by a narrow overflow channel.

Study Site	Setting
Glenburnie (GB20)	The Glenburnie (GB20) study site is located to the west of Millmerran adjacent to Western Creek. Western Creek at this location presents as a dry sandy creek channel with a narrow sinuous overflow flood terrace that has only limited alluvial development. The channel is moderately confined by deeply weathered Springbok Sandstone that variably outcrops in stream benches and along the channel floor with the sandy bedload overlying a weathered sandstone regolith.
Long Swamp (LS35)	Long Swamp is a broad sinuous overland flow path that extends for approximately 30 km on the Condamine Alluvium. The feature comprises a broad drainage depression, with the central portion underlain by highly vertic surface soils with a strong shrink-swell structure of hummocks and deep cracks.
Lake Broadwater (LS31)	Lake Broadwater is a naturally occurring, seasonal/intermittent, shallow, freshwater wetland which covers approximately 350 hectares. It is a highly significant ecological feature that is mapped as a Wetland of High Ecological Significance (DEHP 2014) and is listed in the Australian Directory of Important Wetlands (Australian Government 2010).

5.3. Approach

A comprehensive description of the methods employed in the GDE field investigations is provided in 3D Environmental/Earth Search 2018 (Appendix 1). A concise summary is provided herein (Table 5-2).

Broadly, the synthesised ecological and hydrogeological information obtained from the methods summarised in Table 5-2 has provided multiple lines of evidence for the assessment of GDE status and potential for impacts from the Action.

Table 5-2 Summary of methods adopted in the GDE field investigations (3D Environmental/Earth Search 2018)

Approach	Description
Coring to root depth	Sites investigated for coring root depth included: Longswamp 31 and 35, Burunga Lane 182 and Glenburnie 20. A Commachio MC900 sonic rig was employed to advance a 175 mm diameter hole, collection of a 150 mm core, and installation of 100 mm diameter groundwater monitoring bores. At most sites, three to four core holes were drilled at each site around the target tree to a maximum depth of 30 m (12 m below the maximum anticipated tree rooting depth), including one angled hole targeting root material directly beneath the tree. Detailed drilling and root material logging were recorded on site. Drill core was transported to an off-site laboratory for further testing.
Groundwater monitoring bore installation and sampling	Groundwater monitoring bores were installed within the saturated geological horizon most likely to contain water that could be accessible to deeper rooted trees in each study area. In 3 of the 4 study areas (Longswamp, Lake Broadwater and Glenburnie) a deeper (regional) aquifer was encountered below the maximum anticipated, and well below the maximum observed tree root depth. The deeper aquifer at all of these sites (18-30 m) was considered of little relevance to the objectives of the study as these units were considered inaccessible for tree water uptake. Accordingly, groundwater monitoring bores were installed in shallower "perched" saturated zones.

Approach	Description
	Groundwater monitoring bores were instrumented with pressure transducers and groundwater sampling and laboratory analysis was undertaken following bore development. Laboratory analyses included the following parameters: pH, EC, Alkalinity, Major ions, SAR, TDS and Hardness, Dissolved Silica, Dissolved Metals, Dissolved C_1-C_4 gases (Methane, Ethylene, Ethane, Propylene, Propane, 1 -Butene, Butane), Stable isotopes of oxygen and deuterium, $^{87}Sr/^{86}Sr$ isotopes and $^{13}C/^{14}C$ isotopes.
Soil moisture potential measurement	The measurement soil moisture potential and leaf water potential (below) was used to assess the interaction between tree roots and soil moisture / groundwater. Measurements were undertaken at all groundwater monitoring bore localities: LS31, LS35, BL182 and GB20 which were placed adjacent to potentially deeper-rooted river red gums at each site, specifically to assess these interactions. Samples collected for measurement of soil moisture potential were taken from consistent 0.5 m intervals down the soil profile with the initial sample being taken within the soil A horizon (approximately 20 cm depth). Sample collection continued down the core hole to the depth of the watertable, or 18 m (the maximum inferred rooting depth). The measurement of soil moisture potential was completed in the laboratory with the aid of a portable Dew Point PotentiaMeter (WP4C) (Meter Group Inc. 2017) which uses the chilled mirror dew point technique to measure water potential with the sample being equilibrated with the headspace of a sealed chamber that contains a mirror and a means of detecting condensation on the mirror. The WP4C unit measures soil moisture potential with a 7 ml soil sample inserted into a plastic measuring tray with a stainless-steel base. The WP4C unit measured soil moisture potential in MPa (and also pF), which was then converted to PSI for comparison with leaf water potential readings.
Leaf water potential measurement	Leaf water potential was measured pre-dawn as per standard protocol. Survey localities were visited during pre-dawn periods with collection of leaves taken from the canopy with the aid of a 7.5 m extension pole fitted with a lopping head. Canopy leaves were collected from the GDE assessment target tree at each investigation area, plus a selection of adjacent trees for varying size class and species with an aim to determine the variability of leaf water potential between tree size classes and species. Collected branches were harvested for suitable leaf material which was trimmed with a fine blade and inserted into an appropriate grommet for sealing within a Model 3115 Plant Water Status Console (Soil Moisture Equipment Corp 2007). The chamber was sealed and gradually pressurised with Nitrogen until the first drop of leaf water emerged from the petiole. For the target tree at each GDE site, three readings were taken for completeness with an average taken from the three readings. Readings were taken in PSI which is converted to a negative value for direct comparison to soil moisture potential measurements.
Stable isotope analysis	**Soil Moisture Isotopes**: Sampling was undertaken at regular intervals along retrieved soil and rock core to capture signatures for possible isotopic end points (groundwater and surface water) and a range of potential plant moisture sources from the upper soil surface to the top of the phreatic zone. The sampling intervals for soil moisture isotope analyses mirrors that of sampling for soil moisture potential. Approximately 200 mg of soil was collected for isotope analysis from the central portion of the drill core to minimise chances for contamination with water introduced during drilling of some core holes. Where possible, sampling was not undertaken from core holes where water was utilised during the drilling process.

Approach	Description
	Xylem Water Isotopes: Twigs were collected from the outer branches of the target tree during sampling of trees for leaf water potential. Up to four twig samples were collected from individual trees directly adjacent to the assessment locality.
Baseline characterisation	The assessment aimed to establish ecological and hydrogeological conditions at each of the potential GDE sites as a baseline for ongoing monitoring, as required. Ecological and hydrogeological characterisation aimed to establish the robustness of vegetation at each GDE site including assessment of specific parameters to measure the health of canopy trees and foliage in response to changes in groundwater availability: **Ecological characterisation**: A transect approach was employed whereby a single survey transect was chosen for each GDE assessment ensuring that a representative sample of deep rooted vegetation was assessed. The survey plot was extended 5m either side of the centreline to provide a 50 m x 10 m survey transect (0.05 ha). Specific details collected at each transect included: canopy intercept of woody species separated into the T1 (canopy), T2 (sub-canopy) and S1 (shrub) structural layers; tree and shrub species for all structural layers and identification of applicable regional ecosystem based on species composition; counts of woody species within height classes (Trees T1 & T2; Shrubs S1); groundcover of plants within 10 x 1 m^2 quadrats placed at 10 m intervals; average canopy heights and canopy height ranges and geomorphic attributes including soil type and position relative to the river channel. In addition, a foliage cover assessment was undertaken according to a modified version of that applied by Reardon-Smith (2011) to provide a measure of Foliage Index (FI), being percentage of living leaf cover relative to total canopy cover for all species in the T1 and T2 structural layers. This was aided with the use of a digital camera retro-fitted with a bullseye level to assist horizontal camera alignment. Canopy photographs were taken from the transect start point at 5 m intervals to the transect end point with the assessment techniques employed: the total projected canopy cover (PCC%1) within each photo point was estimated using a 1500 dot point matrix (0.5 cm centres) with the photos expanded full screen (235 x 175 mm); projected foliage cover (PFC%) estimated for the portions of each canopy cover photograph; total foliage cover for each canopy photograph was calculated (% canopy cover x % foliage cover) and Foliage Index (FI) calculated being total PFC / PCC x 100. PCC values from the July 2016 survey were adopted for subsequent survey events unless evidence from canopy photographs indicated a significant change. Where there was evidence of canopy dieback in the photographs that had occurred, subsequent to the original assessment, the dead canopy portion was also included in the calculation of PFC and FI. **Hydrogeological characterisation**: approaches included geological logging and observations of soil/rock moisture and saturated horizons that may form horizons for tree water use, baseline measurement of standing water levels, and baseline groundwater chemistry characterisation (as described above). The outcomes have been integrated into a baseline ecological/hydrogeological data set and the conceptual site model described in the report. A future integrated ecological/hydrogeological monitoring program will assess trends in vegetation response to groundwater availability.

5.4. Key Findings

Use of numerous complementary assessment methods, as described in Section 5.3, has provided multiple lines of evidence to support the assessment findings with a strong degree of confidence. The outcomes of this assessment, with reference to the GDE Decision Matrix is summarised below for each study site.

For reference, the conceptual site models developed in the study for each site are illustrated in Figure 26 (Burunda Lane), Figure 27 (Glenburnie) Figure 28 (Long Swamp) and Figure 29 (Lake Broadwater).

5.4.1. Burunga Lane

Key findings of the Burunga Lane (BL182) site assessment were:

- A sub-artesian aquifer was intersected at 13.5 m depth within a thin coal seam and surrounding sandstone.
- Presence of high moisture content approaching saturation within and above a conglomerate band at 5.8 m depth during drilling. Groundwater was however not present within a monitoring bore installed to a depth of 7.1 m during the sampling event, completed almost 3 months following drilling.
- Drill coring identified tree root material to a maximum depth of 6 m; well above the depth of the regional aquifer.
- Leaf water potential and soil moisture potential measurements at the site suggests that larger river red gums are predominantly sourcing soil moisture from a zone between 4.5 m bgl and 6.5 m bgl which is consistent with observations of tree rooting depth.

Based on the considerable depth to the regional aquifer and evidence for a shallower source of soil moisture for river red gums on the fringes of Juandah Creek, the site is considered unlikely to represent a GDE.. There is a possibility that shallow seasonal groundwater may be present following significant rainfall events causing recharge to the creek alluvium, particularly when the creek is in a state of high flow.

It’s not clear whether the groundwater observed to be present at 13.5 m bgl in sandstone and a coal seam at Burunga Lane and observed rising to 7.5 m bgl represents the upper horizons of a regional aquifer within the WCM, or if this zone is receiving some localised pressure support due to a recharge feature. In any case, based on the observations of tree rooting depth and a likely shallower zone of preferred soil moisture uptake, it is not considered likely that tree roots will be preferentially tapping water at 13.5 m bgl.

5.4.2. Glenburnie

Key findings of the Glenburnie (GB20) site assessment were:

- A sub-artesian aquifer was intersected at 27 m depth in GB20 with groundwater rising to approximately 14.4 m bgl. The aquifer is well below the observed maximum tree rooting depth of 7.6 m.
- There was only a shallow profile of alluvial soil of approximately 2.5 m overlying weathered bedrock (Springbok Sandstone) with zones of higher soil moisture availability at approximately 9-11.5 m bgl and also at 14.5-17 m bgl.
- A shallow saturated seepage zone was noted during drilling of between 13.5 m bgl and 18 m bgl.

- Leaf water potential and soil moisture potential measurements indicate moisture being sourced from a zone of soil moisture between 9.0 m bgl and 11.5 m bgl; slightly deeper than the observed maximum tree rooting depth.
- Stable isotope signatures are considerably enriched above those where trees are predicted to be sourcing their soil moisture from. While this may indicate a significant contribution of shallow evaporatively enriched surface moisture, it may also indicate potential isotopic fractionation within the tree xylem, or confounding errors associated with the sampling process. There is however no indication that a deeper groundwater source is contributing significantly to the water usage of trees at the locality.

Based on the considerable depth to the regional aquifer, observations of tree rooting depth and evidence for a shallower source of soil moisture from leaf water potential and soil moisture potential analysis, the site is considered unlikely to represent a GDE.

5.4.3. Long Swamp

Key findings of the Long Swamp (LS182) site assessment were:

- The regional aquifer was intersected at a depth of 26.5 m within a basalt sand of the Westbourne Formation, well below the observed tree rooting depth of 7.1m.
- A thick sand sequence between depths of 10.8 m to 17.4 m (within the Condamine Alluvium) is interpreted to be a depleted aquifer, which transitions from dry at the top to saturated at the base of the sequence. The upper 5 m of this sand was dry to slightly moist, presenting a deterrent for the possible downward growth of recent tree roots, and a potential zone of root desiccation and embolism for any existing mature tree roots.
- Leaf water potential, soil moisture potential measurements indicate larger river red gums are predominantly sourcing soil moisture from a zone between 11.5 m bgl and soil surface (based on an enrichment of stable isotopes in twig water) broadly consistent with observations of tree rooting depth. Stable isotope signatures obtained from sampled twig xylem are enriched above all soil samples except at the soil surface. Although additional is required to fully elucidate the significance and behaviour of xylem isotopes in relation to season and climatic conditions, there is no apparent suggestion of a deeper groundwater source.

Historic and current declining groundwater level trends in bores monitoring the Condamine Alluvium in proximity to Long Swamp is ascribed to groundwater abstraction and harvesting of surface water and overland flow (reducing natural recharge rates for non-CSG uses). The consequence of these activities has been a decline in water levels to below the lower root depth threshold zone where severe decline in vegetation condition may occur. These findings are consistent with those of Kath et al (2014), Reardon Smith (2011) and Dafny and Silburne (2014) which all identify significant declines in groundwater levels across the Condamine Alluvium prior to CSG activities.

Based on the considerable depth to the saturated zone and evidence of a shallower source of soil moisture for river red gums in Long Swamp, the site is considered unlikely to represent a GDE .

5.4.4. Lake Broadwater

Key findings of the Lake Broadwater (LS31) site assessment were:

- Lake Broadwater is fringed by a low sand ridge on its northern and western margins which overlies a thick plastic clay layer between depths of approximately 3 m and 11.3 m. The interface between the plastic clay and sand hosts a shallow perched aquifer within which groundwater levels would fluctuate dependent largely upon the water levels in the lake, as well as recharge directly to the sand mass fringing the lake.
- Drill coring identified abundant tree root material within the shallow perched aquifer, with deeper roots penetrating heavy clays to a depth of 4 m. This indicates trees are utilising shallow perched water to satisfy all or a portion of their water budget requirements. The

deeper roots penetrating into the upper fringe of the underlying heavy clays is interpreted to be both an anchor mechanism and an alternative source of moisture during periods of drought and aquifer depletion.

- Leaf water potential and soil moisture potential measurements at the site support the interpretation that canopy trees are extracting moisture from a saturated zone coinciding with the interface between clay and sand.

Based largely on the identification of tree root material within the perched saturated zone, and supported by measurement of soil moisture, leaf water potential and stable isotopes, Lake Broadwater is considered to represent a GDE. The shallow perched aquifer overlies a 7.8 m thick sequence of massive plastic clays and further clay-rich deeply weathered regolith of the Westbourne Formation which comprises a thick separation barrier between the perched aquifer and the underlying formations potentially subject to CSG depressurisation.

5.4.5. Concluding comments

The 3D Environmental/Earth Search (2018) study concluded that the deeper-rooted trees at all of the GDE sites, with the exception of Lake Broadwater (LS31), are considered likely to be tapping downward-percolating water moving under gravity through a near-saturated vadose zone. This vadose water likely exists in a transient state of near-saturation to saturation and is moving within a permanent wetting front associated with the adjacent ephemeral surface water bodies which temporarily channel and hold water for extended periods. Trees such as river red gum which require a high soil moisture potential appear to be tapping the near permanent sources of moisture described above which is available in horizons containing a balanced matrix of sand and fines which provide enough permeability for the high transpiration rates required for such trees, but also enough fine material to slow and hold water between wetting events (recharge), and hence buffer the effects of tree stress that would be caused by pronounced droughts.

A key finding of the assessment is that the depth to the regional aquifer (potentially subject to CSG depressurisation) at each site is considerably deeper than:

- the deepest observed rooting depth;
- the inferred likely zone of predominant soil moisture uptake by trees (both from water potential and stable isotope measurements); and
- with the possible exception of Burunga Lane (BL182), the likely maximum tree rooting depth for deeper rooted potential GDE species (such as river red gums) of 18 m.

Another key finding of this assessment was the relatively shallow maximum tree root depths observed compared with the maximum anticipated depth threshold of 18 m based on literature studies. The deepest observed root depth across all the study sites was 7.6 m in sandstone at Glenburnie 20.

The key parameters measured in the assessment for each study site are summarised in Table 5-3.

Table 5-3 Summary of assessment outcomes (3D Environmental/Earth Search 2018)

Study Site	Maximum observed root depth	Inferred zone of soil moisture uptake	Observed zone of shallow saturation / perched aquifer	Stable isotope analysis – indicated zone of water uptake (m)	Observed depth to regional aquifer
Burunga Lane (BL182)	6 m	4.5 m – 6.5 m	4.9 m – 6 m	0 m – 3.0 m	13.5 m – WCM
Glenburnie (GB20)	7.6 m	9 m – 11.5 m	13.5 m – 18 m	0 m – 0.2 m	27 m – WCM
Long Swamp (LS35)	7.1 m	7.5 m – 11.5 m	14.7 m - 17.4 m	0 m – 7.5 m	26.5 m – Westbourne Formation
Lake Broadwater (LS31)	4 m	1.8 m – 3 m	1.8 m – 3 m	2.6 m	18 m - Westbourne Formation

6. GDE connectivity studies

6.1. Objectives and scope

The objective of the GDE connectivity investigations completed by Arrow Energy (2018) was to assemble and interrogate field and laboratory data to establish, using multiple lines of evidence, the degree of inter-aquifer connectivity between the WCM and overlying formations within each of the four selected study sites (Figure 25).

The outcomes of the study are intended to be considered in conjunction with the results of the site specific GDE assessments conducted by 3D Environmental/Earth Search (2018) (Section 5). Both studies seek to address Approval Conditions 13(c), 13(f) and 17(g).

The complete report is provided as an attachment to this memorandum in Appendix 2 and the reader is referred to this document should further information or detail concerning the study be required.

6.2. Site selection

Site selection for the GDE connectivity study was informed by the outcomes of the Stage 1 CSG WMMP GDE risk assessment (summarised in Section 1.3 of the current memorandum) which identified two areas that may potentially host ecosystems dependent on groundwater that are at risk of project related groundwater drawdown. These included:

- The southern part of designated Risk Area 3b (south west of Cecil Plains), and
- The northern part of designated Risk Area 4 (near Wandoan).

These areas, coupled with Approval Condition 13(f) which require connectivity studies at Lake Broadwater and Long Swamp, formed the focus for the Arrow Energy connectivity study. The locations of the four investigation sites is presented in Figure 25. Further detail regarding the location of individual monitoring bores at each site is provided in the report attached as Appendix 2.

6.3. Approach

Each site consisted of the drilling and construction of multiple bores to enable the monitoring of selected formations from surface to within the WCM unit. A summary of the monitoring bores, their monitored formation and field investigations and laboratory analyses conducted at each site is provided in Table 6-1. The monitoring bores installed and monitored as part of the 3D Environmental/Earth Search (2018), which complement the connectivity study, are also summarised in Table 6-1.

Field investigations commenced in December 2017 and were completed in April 2018. A summary of the drilling approach and construction and development details of each bore is provided in the report attached as Appendix 2.

Field data were collected and analysed to assist in the hydrogeological conceptualisation and characterisation of hydraulic connectivity according to the following approaches:

- Hydrograph analysis of groundwater level data collected both manually and by way of pressure transducers.
- Field and laboratory analysis of groundwater samples (major ion and trace metals) and major ion water type analysis with representation by Piper and Schoeller plots.
- Laboratory permeability testing (using a Hassler cell permeameter) of selected core samples targeting the lower permeability lithologies. It is acknowledged that such tests generally provide lower values compared to field scale tests for reasons including sampling bias, the small scale of measurement and sample alteration during both the drilling process and laboratory testing. Despite the limitations, laboratory estimates can provide useful data for low permeability formations where larger scale field testing may be challenging.

- Hydraulic (slug) testing (both rising and falling) was undertaken on selected monitoring bores during the week of 9 April 2018 utilising a PVC slug filled with sand to determine the hydraulic conductivity of the screened aquifer. Slug test data analyses were performed using Aqtesolv software and the analysis approach adopted was the Bouwer-Rice solution for an unconfined aquifer.

- Numerical modelling to assess the potential vertical hydraulic conductivity in target formations at the four study sites. The scope of the modelling exercise involved: review of site data for development of a conceptual model, analysis of observed data, model design and preparation and model calibration and uncertainty assessment:

    - A simple "sandpit" model was adopted in the modelling exercise and in the absence of significant transient variability in the water pressures/levels a steady state model was employed. The model domain was assigned 1 km around the site and consisted of layers representing the hydrogeological conceptualisation. Constant head boundaries were applied on the eastern and western boundaries of the model domain. No recharge or evapotranspiration was applied in the model and it was operated in confined mode with the aim of assessing vertical hydraulic conductivity in the consolidated aquifers.

    - The modelling strategy included a steady state run with manual calibration to assess the potential hydraulic parameters and assess sensitivity of the parameters in the model domain. Parameter Estimation software (PEST) utilities were applied to assess the potential parameter ranges that could accommodate the water pressures/levels observed. It is acknowledged that the absence of transient, variable and contemporaneous water pressure data limits the ability of the model to constrain potential parameter variability. When contemporaneous and variable pressure data are available modelling may be revisited to assess whether parameter values can be further constrained.

    - An additional numerical modelling exercise was undertaken by AGE (2018) for the Lake Broadwater site to quantify the potential for groundwater level drawdown in the Alluvium as a consequence of groundwater production in association with CSG extraction from the WCM. A description of the model construction, calibration, sensitivity analyses and outputs is provided in Section 6.4.4 and Arrow Energy (2018) (Appendix 2).

Table 6-1 Monitoring bores installed and accompanying field investigations conducted at each site (Arrow Energy 2018)

Site	Bores and target aquifers	Site investigations					
		Coring	Geophysical logging	Laboratory permeability tests (core samples)	Slug testing	Groundwater sampling	Data logger / pressure transducer installed
Burunga Lane (Northern part of Risk Area 4)	Burunga Lane 183: Walloon Coal Measures	Conducted for Burunga Lane 184			✓	✓	✓
	Burunga Lane 184: Walloon Coal Measures	✓	✓	✓	✗	✓	✓
	Burunga Lane 185: Walloon Coal Measures	Conducted for Burunga Lane 184			✓	✓	✓
	Burunga Lane 182: Alluvium (1)						
Glenburnie (Southern part of Risk Area 3)	Glenburnie 21: Walloon Coal Measures	Conducted for Glenburnie 22			✗	✓	✓
	Glenburnie 22: Walloon Coal Measures	✓	✗	✓	✗	✓	✓
	Glenburnie 20: Springbok Sandstone (1)						
Long Swamp	Longswamp 32: Westbourne Formation	Conducted for Longswamp 34			✓	✓	✓
	Longswamp 33: Springbok Sandstone	Conducted for Longswamp 34			✓	✓	✓
	Longswamp 34: Walloon Coal Measures	✓	✓	✓	✗	✓	✓
	Longswamp 35: Condamine Alluvium (1)						
Lake Broadwater	Longswamp 28: Westbourne Formation	Conducted for Longswamp 30R			✓	✓	✓
	Longswamp 29: Springbok Sandstone	Conducted for Longswamp 30R			✓	✓	✓

<table>
<tr><th rowspan="2">Site</th><th rowspan="2">Bores and target aquifers</th><th colspan="6">Site investigations</th></tr>
<tr><th>Coring</th><th>Geophysical logging</th><th>Laboratory permeability tests (core samples)</th><th>Slug testing</th><th>Groundwater sampling</th><th>Data logger / pressure transducer installed</th></tr>
<tr><td rowspan="2"></td><td>Longswamp 30R: Walloon Coal Measures</td><td>✓</td><td>✓</td><td>✓</td><td>✗</td><td>✓</td><td>✓</td></tr>
<tr><td colspan="7">Longswamp 31: Perched Alluvium (1)</td></tr>
</table>

Notes:

✓: Site investigation conducted.

✗: Site investigation not conducted.

(1) Longswamp 35, Longswamp 31, Glenburnie 20 and Burunga Lane 182 were installed as part of the 3D Environmental/Earth Search (2018) study. Investigations conducted in association with the bores/sites included: coring to identify rooting depth, groundwater monitoring and sampling and stable isotope, soil water and leaf water potential analysis.

6.4. Key findings

The field (drilling and bore construction logs, geophysical logs, core sample photographs, slug tests, groundwater monitoring) and laboratory (groundwater and permeability) results and their interpretation for each site are documented in the report attached as Appendix 2.

The key findings of the connectivity study are summarised below for each of the four sites. Broadly, the findings from the drilling and field program are consistent with the regional stratigraphy applied in the desk-top Stage 1 CSG WMMP GDE risk mapping exercise (Coffey 2017), supporting the outcomes of the risk assessment.

6.4.1. Burunga Lane

The drilling program at the Burunga Lane site involved the installation of three groundwater monitoring bores: Burunga Lane 183 and Burunga Lane 185 (Macalister Seams of the WCM) and Burunga Lane 184 (Wambo Seam of the WCM). Based on drilling investigations at the site, the WCM is confirmed to subcrop in the area with a thin alluvial cover (approximately 7 m in thickness) at surface; a local scale feature believed to be associated with Juandah Creek.

A graphical representation of the geological sequence recorded at the site illustrating the depth and screened intervals of the three monitoring bores, and potentiometric surface for each formation is provided in Figure 30.

Lower permeable lithology types (e.g. well cemented fine-grained sandstones, hard blocky siltstones and carbonaceous mudstones) are well represented in the interburden at depth, separating the more permeable coal seams. Such profiles are expected to significantly impede the vertical movement of groundwater.

The hydrographs of groundwater level data collected from the monitoring bores at Burunga Lane is presented in Figure 31. Burunga Lane 182, screening the Alluvium, was consistently recorded as dry during each monitoring event, indicating this alluvial feature associated with Juandah Creek is not a permanent aquifer and possibly only stores water, on a temporary basis, following recharge events. The groundwater levels confirm the confining conditions of the WCM and while the water level record is not always contemporaneous, hydraulic head differences between the three WCM bores implies an upward vertical hydraulic gradient. The deepest monitored interval (Burunga Lane 184, screening the Wambo Seam at 62.3 m bgl to 73.0 m bgl) is recorded at an almost artesian pressure.

Major ion analysis demonstrates the groundwater at the site is characterised by Na-Cl type water. A difference in chemical composition between the Macalister Seam (Burunga Lane 183 and Burunga Lane 185) and the deeper Wambo Seam (Burunga Lane 184) was observed, with greater concentrations of Na and Cl in Burunga Lane 184.

The hydraulic conductivity results derived from the laboratory testing of core samples, hydraulic (slug) testing of monitoring bores and the numerical modelling exercise are summarised in Table 6-2, along with (for comparative purposes) the horizontal and vertical hydraulic conductivities adopted in the calibrated the 2016 UWIR model (OGIA 2016).

Table 6-2 Hydraulic conductivity results - Burunga Lane

Formation	Sample / Testing Depth (m bgl)	Hydraulic Conductivity (m/d)			
		Laboratory testing of core samples	Hydraulic (slug) testing (average)	Arrow (2018) Modelling	2016 UWIR Model (arithmetic mean) (1)
Alluvium	0.0 – 7.0	-	-	-	22.9 (other Alluvium) (H) 3.34 (other Alluvium) (V)
WCM	15.3 (Interburden)	1.7×10^{-7} (V) 1.7×10^{-6} (H)	-	9.4×10^{-2} to 1.5×10^{-8} (V)	1.49×10^{-2} (non-productive zone) (H) 1.28×10^{-6} (non-productive zone) (V)
	20.0 – 26.0 (Coals)	-	3.0×10^{-1} (H)	2.1×10^{-2} to 9.0×10^{-3} (V)	2.16×10^{-2} (Upper WCM) (H) 7.82×10^{-7} (Upper WCM) (V)
	34.0 – 40.0 (Interburden)	-	$5.5 \text{ X } 10^{-3}$ (H)	9.4×10^{-2} to 1.5×10^{-8} (V)	1.49×10^{-2} (non-productive zone) (H) 1.28×10^{-6} (non-productive zone) (V)
	50.3 (Interburden)	2.2×10^{-5} (H)		9.4×10^{-2} to 1.5×10^{-8} (V)	1.49×10^{-2} (non-productive zone) (H) 1.28×10^{-6} (non-productive zone) (V)
	62.3 – 73.0 (Coals)	-	-	-	2.16×10^{-2} (Upper WCM) (H) 7.82×10^{-7} (Upper WCM) (V)

Notes:
V: Vertical hydraulic permeability.
H: Horizontal hydraulic permeability.
(1) Source: 2016 UWIR Model (OGIA 2016c), Appendix I - Table I17-1 Statistical summary for pre-calibrated and calibrated horizontal hydraulic conductivity (Kh) and Table I19-1 Statistical summary for pre-calibrated and calibrated vertical hydraulic conductivity (Kv).

The hydraulic (slug) testing derived horizontal hydraulic conductivities for the coal intervals align well with the calibrated 2016 UWIR model values. The permeability testing of core samples from the interburden at depths of 15.3 m and 50.3 m however returned horizontal hydraulic conductivities value some 4 and 3 orders of magnitude less, respectively, than the corresponding 2016 UWIR model calibrated values. The targeting of lower permeability core samples for this analysis along with other factors described in Section 6.3 are likely to be contributing to this inconsistency. Arrow's modelling for the current study captures the vertical hydraulic conductivity range measured in the laboratory testing of an interburden core sample from 15.3 m depth.

The findings of the hydraulic slug testing indicate the WCM coal seams are more permeable zones relative to the interburden which returned horizontal hydraulic conductivities some two orders of magnitude lower.

In summary, the field investigations and desk-top studies of the Burunga Lane site support the conceptualisation of a shallow and generally unsaturated Alluvium unit overlying the confined WCM aquifer with limited potential for vertical movement of groundwater. Multiple lines of evidence from the study demonstrate a limited potential for interconnectivity between the formations.

6.4.2. Glenburnie

The drilling program at the Glenburnie site involved the installation of two groundwater monitoring bores: Glenburnie 21 (Wambo Seam of the WCM) and Glenburnie 22 (Argyle Seam of the WCM). A third bore (Glenburnie 20) installed in the perched zone of the Springbok Sandstone unit by 3D Environmental/Earth Search (2018) was accessed for monitoring purposes in the current study.

The drilling program demonstrated the site consists of a thin layer of Alluvium (up to 2.5 m in depth) at surface, underlain by the Springbok Sandstone unit to 21.1 m bgl. The 3D Environmental/Earth Search study (2018) observed a perched seepage zone in the Springbok Sandstone at 11 m bgl to 18 m bgl, while the regional aquifer was intersected deeper within the WCM.

The WCM was intersected from 21.1 m bgl; the Wambo Seam at 21.1 m bgl and the Argyle Seam at 57.03 m bgl. The WCM aquifer is considered to be confined at the site due to its depth, the low permeable overburden and interburden between coal seams and observed hydraulic heads in Glenburnie 21 and Glenburnie 22.

A graphical representation of the geological sequence recorded at the site illustrating the depth and screened intervals of the three monitoring bores, and potentiometric surface for each formation is provided in Figure 32. Lower permeable lithology types (e.g. well cemented fine-grained sandstones, carbonaceous siltstones and weathered mudstones) are well represented as interburden at depth, separating the more permeable coal seams. Such profiles are expected to significantly impede the vertical movement of groundwater.

The hydrographs of groundwater level data collected from the three monitoring bores at Glenburnie is presented in Figure 33. Within the confined WCM aquifer, groundwater pressure increases with depth indicating an upward potential for vertical movement of groundwater between the screened zones. The low permeability of the interburden limits the potential for vertical groundwater movement and mixing, as demonstrated by the significant difference in hydraulic head (approximately 10 m) between Glenburnie 21 and Glenburnie 22.

Major ions analysis demonstrates varying chemical compositions between the three monitoring bores:

- Na is consistently recorded as the dominant cation with no appreciable concentrations of other cations.
- Differing anion components -
    - Glenburnie 20 (perched aquifer within the Springbok Sandstone): CO_3 and HCO_3 is the dominant anion with minor SO_4 and Cl components;
    - Glenburnie 21 (Wambo Seam in WCM aquifer): Cl is the dominant anion with a moderate CO_3 and HCO_3 component; and
    - Glenburnie 22 (Argyle Seam in WCM aquifer): Cl is the dominant anion with a minor CO_3 and HCO_3 component.

The major ions analysis demonstrates a level of separation between the three monitoring bores, most notably between the deeper monitoring bores of the confined WCM aquifer (Glenburnie 21 and Glenburnie 22) and the shallow monitoring bore in the perched Springbok Sandstone unit (Glenburnie 20). An increasing chloride component with depth is also indicated. The data support the conceptualisation that appreciable exchange of groundwater between formations at the Glenburnie site is unlikely to be occurring.

The hydraulic conductivity results derived from the laboratory testing of core samples, hydraulic (slug) testing of monitoring bores and the numerical modelling exercise are summarised in Table 6-3, along with (for comparative purposes) the horizontal and vertical hydraulic conductivities adopted in the 2016 UWIR model.

Table 6-3 Hydraulic conductivity results - Glenburnie

Formation	**Sample / Testing Depth (m bgl)**	**Hydraulic Conductivity (m/d)**			
		Laboratory testing of core samples	**Hydraulic (slug) testing (average)**	**Arrow (2018) Modelling**	**2016 UWIR Model (1)**
Alluvium	0.0 – 2.5	-	-	-	22.9 (other Alluvium) (H)
Springbok Sandstone	2.5 – 21.1	-	-	5.00×10^{-3} (V)	8.46×10^{-3} (H)
WCM	21.1 – 57.0	-	-	1.00×10^{-7} (V)	2.44×10^{-2} (Lower WCM) (H) 3.24×10^{-7} (Lower WCM) (V)
	38.55	2.6×10^{-6} (V) 9.4×10^{-6} (H)	-	-	$1.49 \text{ x } 10^{-2}$ (non-productive zone) (H) $1.28 \text{ x } 10^{-6}$ (non-productive zone) (V)
	57.0 – 58.9	-	-	5.00×10^{-3} (V)	2.44×10^{-2} (Lower WCM) (H) 3.24×10^{-7} (Lower WCM) (V)
	58.9 – 92.4	-	-	1.00×10^{-8} (V)	$1.49 \text{ x } 10^{-2}$ (non-productive zone) (H) $1.28 \text{ x } 10^{-6}$ (non-productive zone) (V)

Notes:
V: Vertical hydraulic permeability.
H: Horizontal hydraulic permeability.
(1) Source: 2016 UWIR Model (OGIA 2016c), Appendix I - Table I17-1 Statistical summary for pre-calibrated and calibrated horizontal hydraulic conductivity (Kh) and Table I19-1 - Statistical summary for pre-calibrated and calibrated vertical hydraulic conductivity (Kv).

Hydraulic (slug) testing of monitoring Glenburnie 21 and Glenburnie 22 was not possible due to the access constraints associated with their steel pressure wellheads construction. Nonetheless, the laboratory horizontal hydraulic testing results for the WCM are significantly lower (up to four magnitudes) than the UWIR (2016) model values which is likely due to the core sample depth of Glenburnie 22 correlating with interburden. The vertical hydraulic conductivity value derived from the laboratory testing is however, consistent with the 2016 UWIR model value.

The modelled vertical hydraulic conductivity values for the WCM generally exhibit a greater level of differentiation between the coal seam and non-productive zone intervals, varying by 5 orders of magnitude, in comparison to the 2016 UWIR model values with variations of 1 order of magnitude.

In summary, the field investigations and desk-top studies of the Glenburnie site provide multiple lines of evidence to support the conceptualisation of a regional watertable within the WCM aquifer. Overlying the WCM is a perched seepage zone within the Springbok Sandstone and a thin unsaturated Alluvium unit. The field data indicate limited potential for interconnectivity between the formations. Within the confined WCM aquifer, the substantial thickness of interburden is of low permeability, significantly limiting the potential for vertical groundwater movement and connectivity between the coal seams and overlying formations.

6.4.3. Long Swamp

Field investigations at the Long Swamp site, comprising three monitoring bores, confirms the stratigraphy encompasses Condamine Alluvium (Longswamp 35, 3D Environmental/Earth Search 2018) from surface, underlain in succession by the Westbourne Formation (Longswamp 32), Springbok Sandstone (Longswamp 33) and the Macalister Seam of the WCM (Longswamp 34). The stratigraphy at the site is classified according to geophysical logging as follows:

- Condamine Alluvium: 0 m bgl to 18 m bgl.
- Westbourne Formation: 18 m bgl to 52.94 m bgl.
- Springbok Sandstone: 52.94 m bgl to 82.05 m bgl.
- WCM: Kogan Seam from 82.05 m bgl to 107.97 m bgl and the Macalister Seam from 107.97 m bgl to total bore depth of 128.3 m bgl.

The WCM aquifer is considered to be confined at the site due to its depth, the low permeable overburden and interburden between coal seams and observed hydraulic heads.

A graphical representation of the geological sequence recorded at the site illustrating the depth and screened intervals of the four monitoring bores, and potentiometric surface for each formation is provided in Figure 34.

The hydrographs of groundwater level data collected from the monitoring bores at Long Swamp is presented in Figure 35. It is noted that water levels recorded in Longswamp 35 declined by 4 m metres between the period of installation (December 2017) to development and sampling (March 2018), possibly due to water injection during bore installation. Following bore development and sampling in March 2018, the groundwater level dropped to below the pressure gauge in the bore and, as a result, no hourly pressure data are available from March 2018. Of significance is the distinct difference in hydraulic head levels between the four screened formations, although noting that the pressure transducer data for Longswamp 34 (WCM) is not contemporaneous with the other monitored bores. The declining hydraulic pressures with depth implies a downward potential for vertical movement of groundwater and limited hydraulic connection between the formations.

Major ion analysis demonstrates groundwater within the monitored bores at the site is characterised by Na-Cl type water with:

- Na as the dominant cation with minor Ca and Mg components in all monitoring bores with the exception of WCM bore Longswamp 34; and
- Cl as the dominant anion with a minor CO_3 and HCO_3.

The water quality data show variation in the ratio of major ions between the water samples collected from the four monitoring bores, represented by decreasing Ca and Mg contributions with depth across Longswamp 32, Longswamp 33 and Longswamp 34.

The hydraulic conductivity results derived from the laboratory testing of core samples, hydraulic (slug) testing of monitoring bores and the numerical modelling exercise are summarised in Table 6-4, along with (for comparative purposes) the horizontal and vertical hydraulic conductivities adopted in the calibrated the 2016 UWIR model (OGIA 2016).

Table 6-4 Hydraulic conductivity results – Long Swamp

Formation	Sample / Testing Depth (m bgl)	Hydraulic Conductivity (m/d)			
		Laboratory testing of core samples	Hydraulic (slug) testing (average)	Arrow (2018) Modelling	2016 UWIR Model (1)
Condamine Alluvium	0.0 – 18.0	-	-	-	11.30 (H) 11.10 (V)
Westbourne Formation	32.0 – 38.0	-	5.28 (H)	1.12 to 0.50 (V)	1.44×10^{-3} (H) 1.78×10^{-6} (V)
Springbok Sandstone	64.4	1.00×10^{-4} (H)	-	1.00×10^{-4} to 7.90×10^{-3} (V)	8.64×10^{-3} (H) 3.33×10^{-5} (V)
	73.0 – 79.0	-	1.10×10^{-2} (H)		
WCM	83.9	1.70×10^{-6} (H)	-	2.50×10^{-3} (V)	2.16×10^{-2} (Upper WCM) (H) 7.82×10^{-7} (Upper WCM) (V)

Notes:

V: Vertical hydraulic permeability

H: Horizontal hydraulic permeability

(1) Source: 2016 UWIR Model (OGIA 2016c), Appendix I - Table I17-1 Statistical summary for pre-calibrated and calibrated horizontal hydraulic conductivity (Kh) and Table I19-1 Statistical summary for pre-calibrated and calibrated vertical hydraulic conductivity (Kv)

The derived horizontal hydraulic conductivity value for the Westbourne Formation (Longswamp 32) from slug testing are greater than what would be expected for the Westbourne Formation (i.e. some 3 orders of magnitude greater than the calibrated 2016 UWIR model value). It is possible that the atypical sand content in the Westbourne Formation at this bore location are contributing to the comparatively elevated hydraulic conductivity. The field tested horizontal hydraulic conductivity values for the Springbok Sandstone (derived from slug testing and laboratory permeability testing of core samples) aligned with the calibrated 2016 UWIR model value. The horizontal hydraulic conductivity value for the WCM (derived from laboratory permeability testing of core samples) are however two orders of magnitude lower than that adopted in the calibrated 2016 UWIR model. As noted for the Burunga Lane site, the targeting of lower permeability core samples for this analysis along with other factors described in Section 6.3 are likely to be contributing to this inconsistency.

The derived horizontal hydraulic conductivity data indicates the Springbok Sandstone and WCM are of low permeability at the Long Swamp site. The finding further supports the conceptualisation of a significantly limited potential for hydraulic connection between the Westbourne Formation, Springbok Sandstone and WCM formations.

In summary, the field investigations and desk-top studies of the Long Swamp site indicates a hydrogeological conceptualisation comprising an unconfined Condamine Alluvium aquifer, underlain by an aquitard represented by the Westbourne Formation and thereafter the confined aquifers of the Springbok Sandstone and WCM. The findings from this study imply there is very limited potential for hydraulic connection between each aquifer at the site. These conclusions are primarily based on:

- Substantial intervals of low permeable interburden throughout all three formations restricting vertical movement of groundwater; and
- Distinct difference in hydraulic heads between the formations (including Longswamp 35) with a declining aquifer pressure with depth indicating a downward potential for vertical movement of groundwater and limited hydraulic connection between the formations.

6.4.4. Lake Broadwater

Field investigations at the Lake Broadwater site, comprising three monitoring bores, confirms the stratigraphy encompasses Alluvium from surface overlying the Westbourne Formation (Longswamp 28), followed by the Springbok Sandstone (Longswamp 29) and the Kogan Seam of the WCM (Longswamp 30R). The stratigraphy at the site is classified according to geophysical logging as follows:

- Alluvium: 0 m bgl to 30.78 m bgl.
- Westbourne Formation: 30.78 m bgl to 94.50 m bgl.
- Springbok Sandstone: 94.50 m bgl to 178.28 m bgl.
- WCM: Kogan Seam from 178.28 m bgl to total bore depth of 204.0 m bgl.

The highly weathered intervals of the Westbourne Formation generally result in the formation being regarded as a regional aquitard and not a productive aquifer. The observed highly weathered lithology, poor yield recorded during airlift development of Longswamp 28 and the hydraulic conductivity value derived from hydraulic testing (discussed below) are typical of the Westbourne Formation and its classification at the site as an aquitard.

The Springbok Sandstone aquifer within the vicinity of site is low yielding (due to the presence of very well cemented sandstones and hard blocky siltstone) and likely confined with the overlying low permeable lithology of the Westbourne Formation acting as the confining layer.

The WCM lithology consisted of weathered, dull, thin coal seams interbedded with fresh very well cemented fine to medium grained sandstone, fresh siltstone and weathered carbonaceous mudstone (generally regarded as aquitards). The WCM aquifer is considered to be confined at this site due to its depth and the low permeable overburden and interburden between coal seams. The observed overlying lithology (within Westbourne Formation and Springbok Sandstone) and the recorded hydraulic heads in Longswamp 30R lends support to the WCM aquifer in the vicinity of Lake Broadwater being classified as confined. A graphical representation of the geological sequence recorded at the site illustrating the depth and screened intervals of the three monitoring bores, and potentiometric surface for each formation is provided in Figure 36.

The hydrographs of groundwater level data collected from the monitoring bores at Lake Broadwater is presented in Figure 37. In general, a distinct difference in hydraulic head between the perched system at Longswamp 31 and the underlying Westbourne Formation, Springbok Sandstone and WCM units is recorded indicating its hydraulic separation from the underlying formations. The Westbourne Formation displays a greater hydraulic pressure than the Springbok Sandstone and WCM formations (inferred from non-contemporaneous monitoring data) indicating a downward potential for movement of groundwater between the Westbourne Formation and the underlying formations. The comparative hydraulic pressures recorded for the Springbok Sandstone and WCM may imply a potential hydraulic connection between the two formations.

Major ion analysis demonstrates groundwater within the monitored bores at the site is characterised by Na-Cl type water with:

- Na as the dominant cation with no appreciable concentrations of other cations; and
- Cl as the dominant anion with a minor CO_3 and HCO_3 component in all monitoring bores, while the Lake Broadwater surface water is close to displaying no dominant anion.

While the Lake Broadwater surface water is reasonably fresh (at 290 mg/L TDS), groundwater in all monitoring bores is recorded as brackish (3,110 to 3,930 mg/L TDS) with no trend in salinity concentration with formation depth.

The water quality data exhibit variation in the ratio of major ions between the water samples collected from the four sampling points (three monitoring bores and Lake Broadwater surface water) however there is no clear pattern in the ratio of major ions with depth.

The hydraulic conductivity results derived from the laboratory testing of core samples, hydraulic (slug) testing of monitoring bores and the numerical modelling exercise are summarised in Table 6-5 along with (for comparative purposes) the horizontal and vertical hydraulic conductivities adopted in the calibrated the 2016 UWIR model (OGIA 2016).

Table 6-5 Hydraulic conductivity results – Lake Broadwater

Formation	**Sample / Testing Depth (m bgl)**	**Hydraulic Conductivity (m/d)**			
		Laboratory testing of core samples	**Hydraulic (slug) testing (average)**	**Arrow (2018) Modelling**	**2016 UWIR Model (1)**
Alluvium	17.44	9.40 × 10^{-6} (V) 7.70 × 10^{-6} (H)	-	1.93 × 10^{-2} (V)	22.9 (other Alluvium) (H) 3.34 (other Alluvium) (V)
Westbourne Formation	34.0 – 40.0	-	2.53 × 10^{-3} (H)	1.67 × 10^{-6} (V)	1.44 × 10^{-3} (H) 1.78 × 10^{-6} (V)
	74.37	5.10 × 10^{-6} (H)	-		
Springbok Sandstone	104.0 – 111.0	-	8.52 × 10^{-4} (H)	3.01 × 10^{-7} (V)	8.46 × 10^{-3} (H) 3.33 × 10^{-5} (V)
	177.6	1.70 × 10^{-7} (V) 1.30 × 10^{-5} (H)	-	3.01 × 10^{-7} (V)	8.46 × 10^{-3} (H) 3.33 × 10^{-5} (V)
WCM	178.2 – 204.0	-	-	1.11 × 10^{-3} (V)	2.16 × 10^{-2} (Upper WCM) (H) 7.82 × 10^{-7} (Upper WCM) (V)

Notes:
V: Vertical hydraulic permeability
H: Horizontal hydraulic permeability
(1) Source: 2016 UWIR Model (OGIA 2016c), Appendix I - Table I17-1 Statistical summary for pre-calibrated and calibrated horizontal hydraulic conductivity (Kh) and Table I19-1 Statistical summary for pre-calibrated and calibrated vertical hydraulic conductivity (Kv).

The hydraulic (slug) testing values for horizontal hydraulic conductivity and the calibrated 2016 UWIR model values are broadly aligned. The laboratory vertical permeability testing of deeper core samples from the Springbok Sandstone correspond with the derived vertical hydraulic conductivity value in the Arrow modelling. Whereas the laboratory vertical permeability testing of the Alluvium is significantly lower (4 and 7 orders of magnitude respectively) than that derived in the Arrow model and the 2016 UWIR model. Similarly, the laboratory horizontal permeability testing of the Alluvium, Westbourne Formation and Springbok Sandstone are 2 to 8 orders of magnitude lower than the calibrated values of the 2016 UWIR model. As noted for the Burunga Lane and Long Swamp sites, the targeting of lower permeability core samples for this analysis along with other factors described in Section 6.3 are likely to be contributing to this inconsistency.

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) (2018) assessed potential impacts to Lake Broadwater from CSG extraction in the WCM. AGE constructed a sandpit groundwater model to simulate the pressure/pressure differences between the Lake Broadwater monitoring bores and assess when the well drawdown extends into the surface.

The model consisted of a simple square measuring ~5 km by 5 km at a cell resolution of 250 m, with four layers representing the key geological units including Alluvium, Westbourne Formation, Springbok Sandstone and WCM. A steady-state simulation was deemed suitable as the monitoring data exhibited no significant variations over time. Constant head boundaries were assigned to the four sides of the model based on monitoring data. Model calibration was achieved in a steady state simulation.

The calibrated model was used in steady state to assess the rate at which pumping from the WCM (Kogan seam, Longswamp 30R) has the potential to induce groundwater level drawdown in the Alluvium. The modelling approach indicated a maximum pumpable rate from the coal seam of 10 ML/day. These elevated pumping rates were predicted to have nil drawdown in the Alluvium. Such predictions are expected given that the vertical hydraulic conductivity in layers above the Kogan seam are demonstrated to be low, limiting drawdown extending to the overlying Alluvium. Furthermore, a sensitivity analysis of the vertical hydraulic conductivities applied in the model indicated that increasing the vertical hydraulic conductivities of the units beneath the Alluvium by one and two orders of magnitude still contributed to nil drawdown in the Alluvium unit.

AGE (2018) note that due to the significant upscaling of the horizontal hydraulic conductivity of the WCM, the maximum sustainable pumping rate adopted in the modelling exercise of 10 ML/day is likely to be highly conservative. The WCM consists of interbedded mudstones and sandstones, with hydraulic conductivity values orders of magnitudes lower than the calibrated rate. Accordingly, determining the maximum pumping rate from LS30 requires developing a model that separates the coal seam layers from the less permeable units.

In summary, the field investigations and desk-top studies of the site indicates a hydrogeological conceptualisation comprising a perched system associated with Lake Broadwater within the Alluvium, underlain by an aquitard represented by the Westbourne Formation and thereafter the confined aquifers of the Springbok Sandstone and WCM. The findings from this study infer that there is limited potential for hydraulic connection between the upper units at the Site. These conclusions are based on:

- A distinct difference in hydraulic head between the perched system at Lake Broadwater and the underlying Westbourne Formation, Springbok Sandstone and WCM;
- The Westbourne Formation displays a greater hydraulic pressure than the Springbok Sandstone and WCM formations indicating a downward potential for vertical movement of groundwater between the Westbourne Formation and the underlying formations;
- Substantial intervals of low permeable interburden are logged throughout all formations underlying the perched system at Lake Broadwater and with a lack of perceived permeable zones, vertical movement of groundwater is likely to be limited;
- Low laboratory values of hydraulic conductivity in Longswamp 28 (Westbourne Formation) and Longswamp 29 (Springbok Sandstone); and
- The results of the simulated pumping scenario indicate that the perched system associated with Lake Broadwater, overlying the alluvium, is unlikely to be affected by CSG pumping from the WCM.

Hydraulic connection between the Springbok Sandstone and the WCM at the site is considered possible based on the comparative hydraulic pressures recorded for the Springbok Sandstone and WCM.

6.4.5. Concluding comments

The outcomes of the Arrow Energy GDE connectivity study (2018) have assisted the conceptualisation and understanding of inter-aquifer connectivity between the WCM and overlying formations at four selected locations within Arrow Energy’s Surat Basin tenure. The findings of the study broadly indicate limited potential for hydraulic connection between the formations at each of the sites, the exception being potential connectivity between the Springbok Sandstone and WCM in the vicinity of the Lake Broadwater site. Numerical modelling has demonstrated, however, that groundwater extraction from the WCM in association with CSG development in this area, is unlikely to contribute to discernible drawdown in the shallow Alluvium unit which hosts the perched system associated with Lake Broadwater.

7. Summary of findings

The Stage 2 CSG WMMP stream connectivity and GDE assessment, inclusive of risk mapping, numerical modelling and field investigations, has addressed Approval Conditions 17(f) and 17(g) and fulfilled the relevant commitments made in the Stage 1 CSG WMMP. The assessments conducted in Stage 2 utilise Arrow's Stage 2 CSG WMMP FDP and the 2016 UWIR model. Updates to the sub-crop geological mapping (Cranfield 2017) and GDE mapping (DES 2018) have also informed the Stage 2 assessment.

In response to Approval Condition 17(f), numerical modelling was conducted by CDM Smith (2018) utilising the 2016 UWIR model and Arrow's Stage 2 CSG WMMP FDP, to assess the potential impacts to the Condamine River from the Action. The modelling exercise predicted that the maximum change in the total groundwater flux to the Condamine River due to Arrow's water production is 0.148 ML/d. Over the simulation period (of over 800 years) the predicted total change in volumetric flux between the Condamine River and Condamine Alluvium is 33.7 GL. The predicted cell flux changes are small and beyond the expected accuracy of the CCAM, and accordingly, for all practical purposes are considered negligible. On the basis of the predicted negligible change to leakage rates over periods of hundreds of years, it was concluded that any potential impacts to water quality and existing aquatic ecosystems and surface expression GDEs dependent on the Condamine River are also likely to be negligible.

The terrestrial GDE risk mapping exercise conducted in the SGP Stage 1 CSG WMMP was updated in Stage 2 with the CDM Smith (2018) groundwater modelling outputs and updates to the geological and GDE mapping of the Surat CMA. This desk-top study aimed to address (in part) Approval Condition 17(g) which seeks to identify any uncertainty in the groundwater dependency of ecosystems that may be subject to potential impacts as a consequence of the Action. The Stage 2 assessment did not identify any areas of terrestrial GDEs at potential risk of impact from groundwater drawdown associated with CSG extraction from the Action, and in turn, no additional site-specific field investigations were considered necessary.

To satisfy the commitments made in the Stage 1 CSG WMMP and to address Approval Condition 17(g), comprehensive field investigations were conducted at four sites: Burunga Lane, Glenburnie, Long Swamp and Lake Broadwater. The field investigations, conducted in two parts, aimed to: characterise GDEs and their reliance on groundwater (3D Environmental/Earth Search 2018) and quantify the degree of inter-aquifer connectivity between the WCM and overlying formations (Arrow Energy 2018), at each of the four sites.

Multiple lines of evidence from the joint field investigations conducted in Stage 2 demonstrated that ecosystems at each of the selected sites are unlikely to be at risk of impact from groundwater extraction associated with cumulative CSG development in the Surat CMA according to the following findings:

- The deeper-rooted trees at all four sites, with the exception of Lake Broadwater, are considered likely to be tapping downward-percolating water moving under gravity through a near-saturated vadose zone.
- The depth to the regional aquifer (potentially subject to CSG depressurisation) at each site is considerably deeper than: (i) the deepest observed rooting depth; (ii) the inferred likely zone of predominant soil moisture uptake by trees and (iii) with the possible exception of Burunga Lane, the likely maximum tree rooting depth for deeper rooted potential GDE species (such as river red gums) of 18 m.
- The relatively shallow maximum tree root depths observed (maximum of 7.6 m at Glenburnie) in comparison to the maximum anticipated depth threshold of 18 m based on literature studies.
- Limited potential for hydraulic connection between the WCM and overlying aquifers at each of the sites, the exception being potential connectivity between the Springbok Sandstone and WCM at Lake Broadwater. Numerical modelling has demonstrated, however, that groundwater extraction from the WCM in association with CSG development at Lake

> Broadwater, is unlikely to contribute to discernible drawdown in the shallow Alluvium unit, which hosts the perched system associated with Lake Broadwater. Accordingly, ecosystems dependent on the shallow perched groundwater at Lake Broadwater are not considered at risk of impact from cumulative CSG production in the Surat CMA.

It is anticipated that the findings of the field investigations across different landscape and geological settings, in particular, the characterisation of GDEs (including shallow rooting depths and dependency on downward-percolating water and/or perched water) and the limited potential for inter-connectivity between the WCM and overlying formations will serve as useful conceptualisations for any future assessment of risks to terrestrial GDEs from cumulative CSG production in the Surat CMA. Such risk assessment of cumulative impacts to terrestrial GDEs, and any assigned responsibilities regarding the management of potentially affected ecosystems, are expected to be incorporated into the next iteration of the UWIR.

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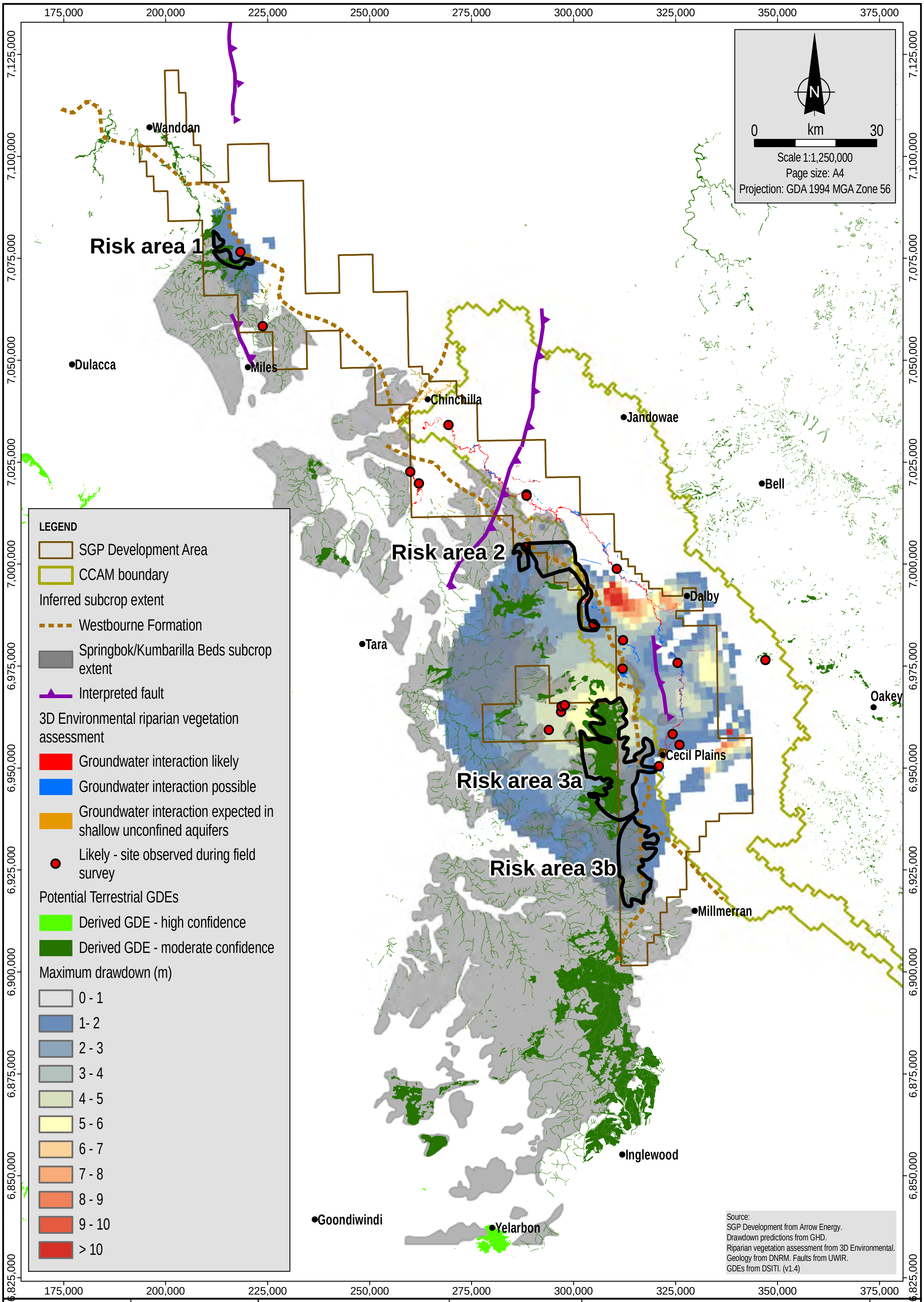
Figures



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Drawdown predictions from GHD.
Riparian vegetation assessment from 3D Environmental.
Geology from DNRM. Faults from UWIR.
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MXD Reference: 20484AB_M03_GIS021_v0_Sr1_SS_1

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Potential terrestrial GDE Risk Area 3b
(Springbok Sandstone source aquifer)
at risk from predicted impacts from
Arrow only CSG activities (SGP Stage 1 WMMP)

Figure No:
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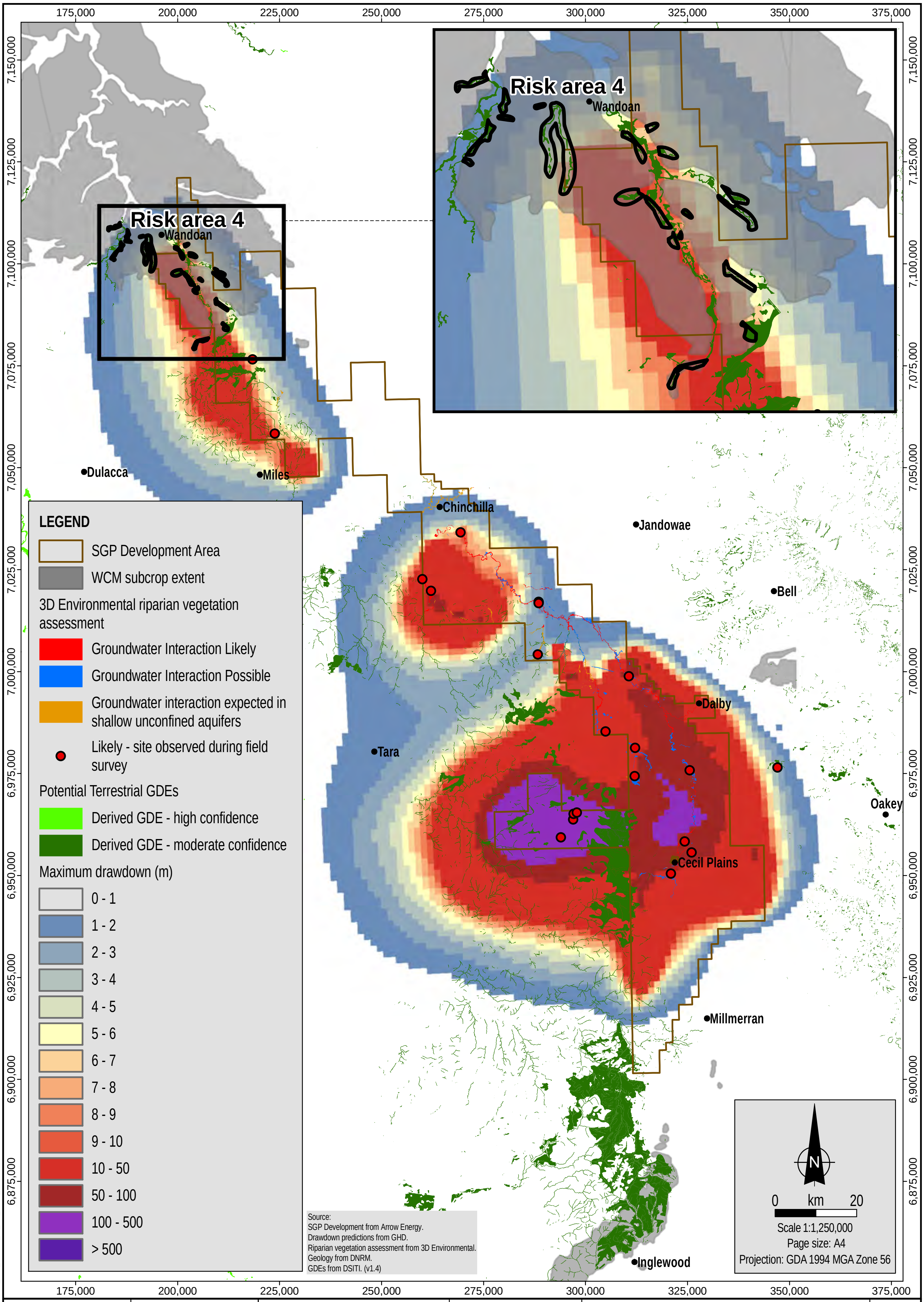

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Potential terrestrial GDE Risk Area 4
(WCM source aquifer) at risk from predicted
impacts from Arrow only CSG activities
(SGP Stage 1 WMMP)

Figure No:
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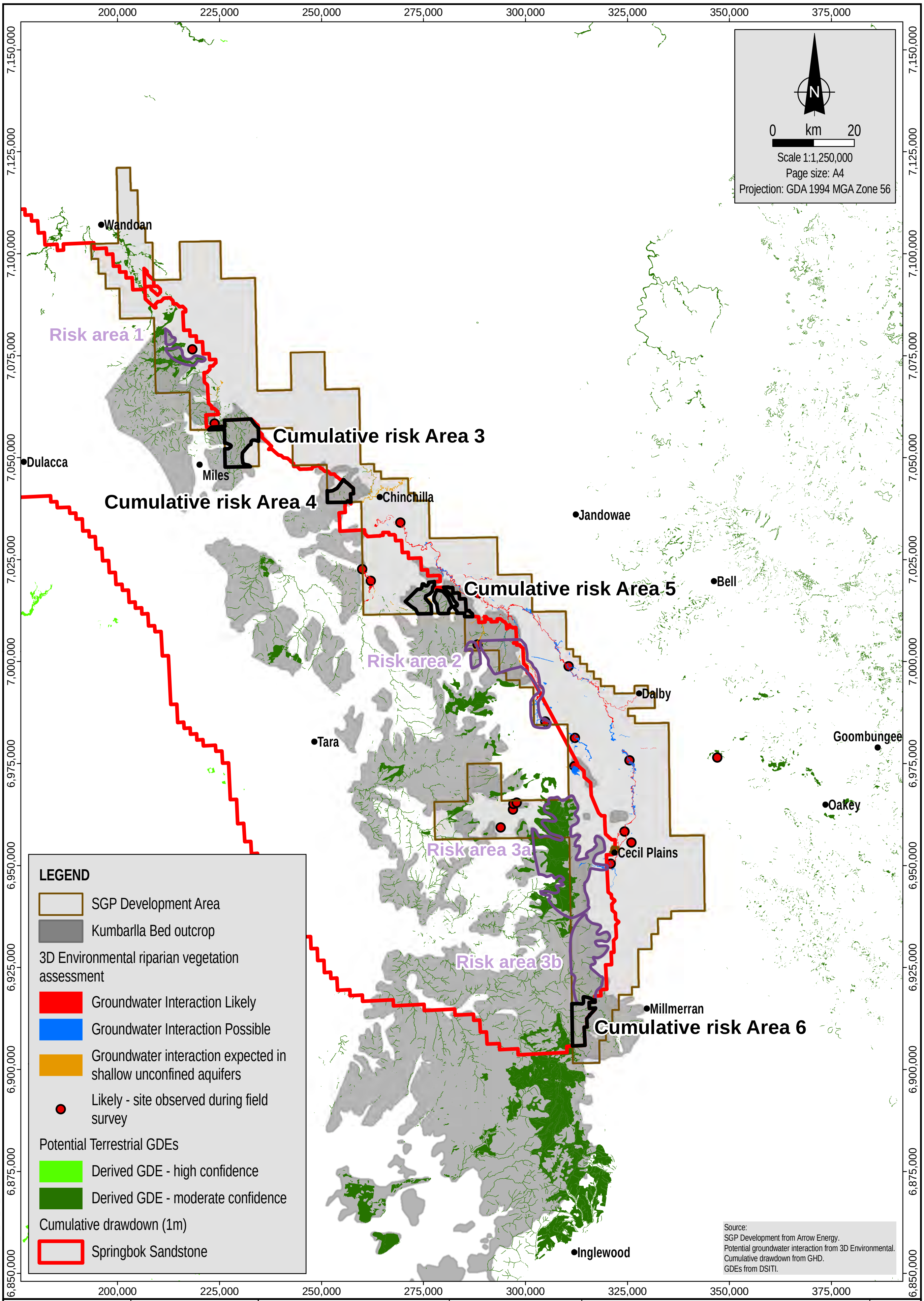

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Potential terrestrial GDE Cumulative Risk Area 6 (Springbok Sandstone source aquifer) at risk from predicted impacts from cumulative CSG activities (SGP Stage 1 WMMP)

Figure No:
3

Figure 4 Representation of river connectivity in the CCAM at initial conditions in 1980 (sourced from CDM Smith 2018)

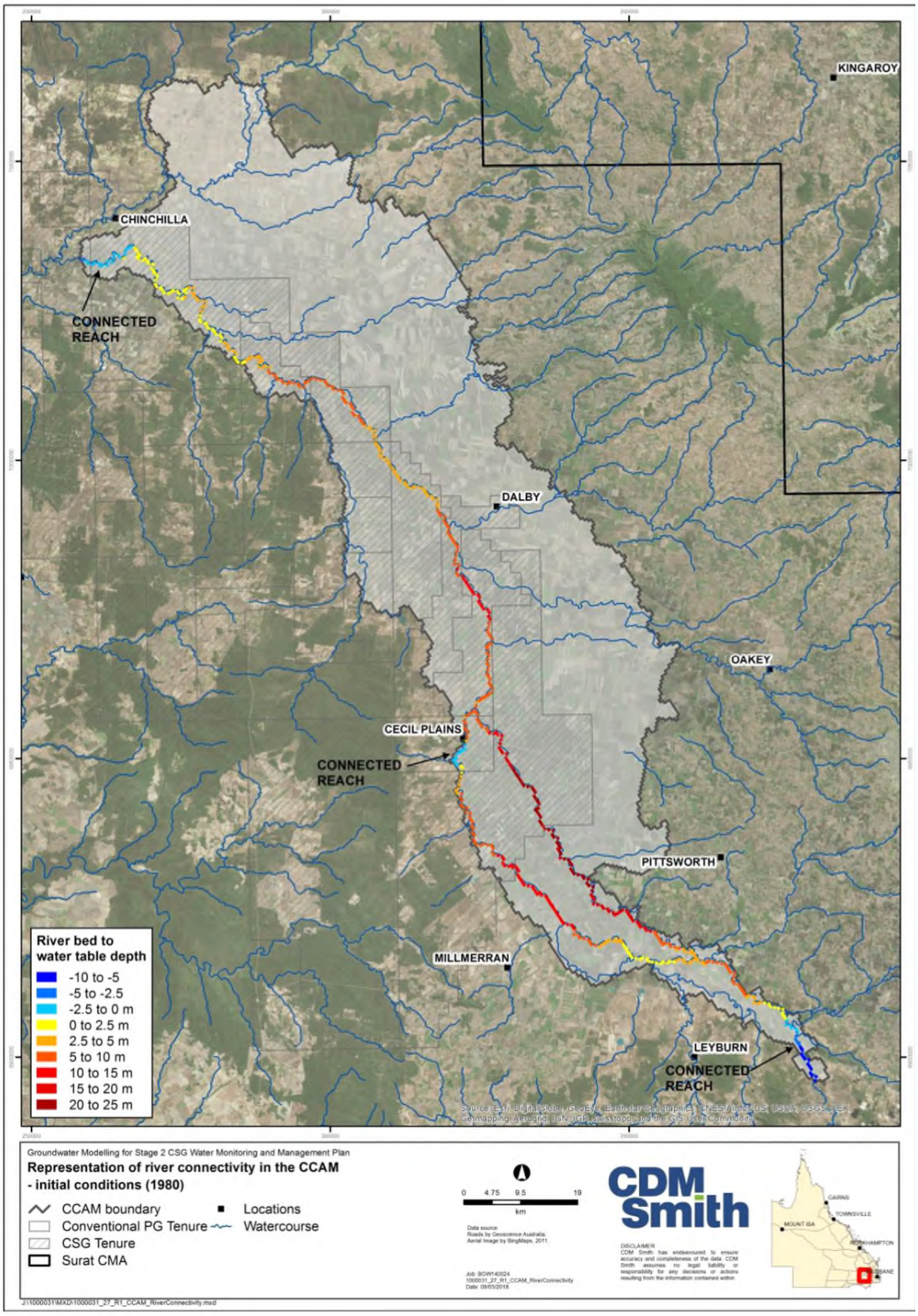
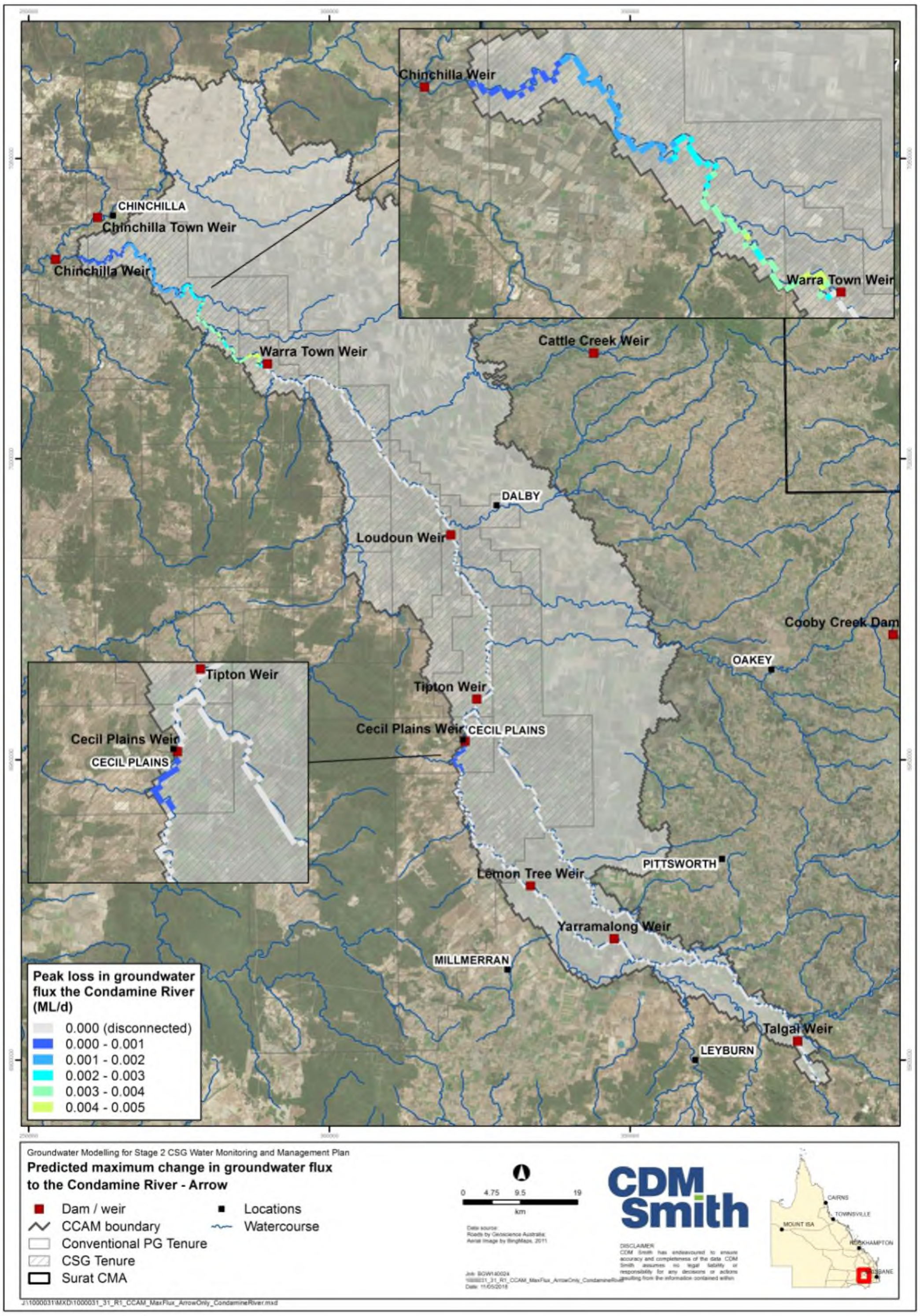
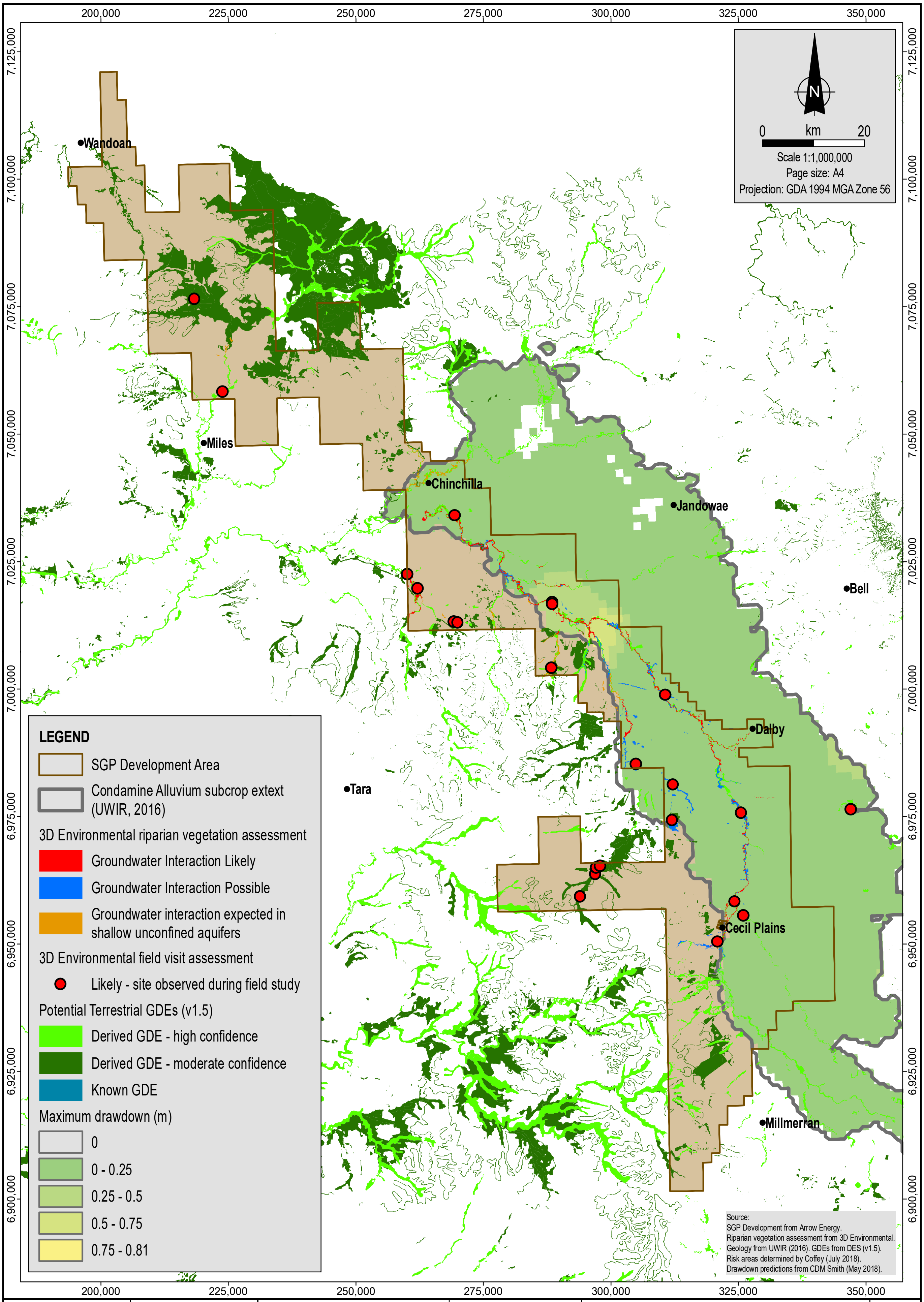


Figure 5 Predicted maximum change in groundwater flux to the Condamine River due to Arrow only production (sourced from CDM Smith 2018)





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Drawdown predictions from CDM Smith (May 2018).

MXD Reference: 20484AB_M03_GIS005_v0_Condamine_2

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Project: ENAUABTF20484AA
File Name: 20484AB_M03_F006_GIS

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Condamine Alluvium terrestrial GDE risk assessment, Arrow only CSG activities (SGP Stage 2 WMMP)

Figure No:
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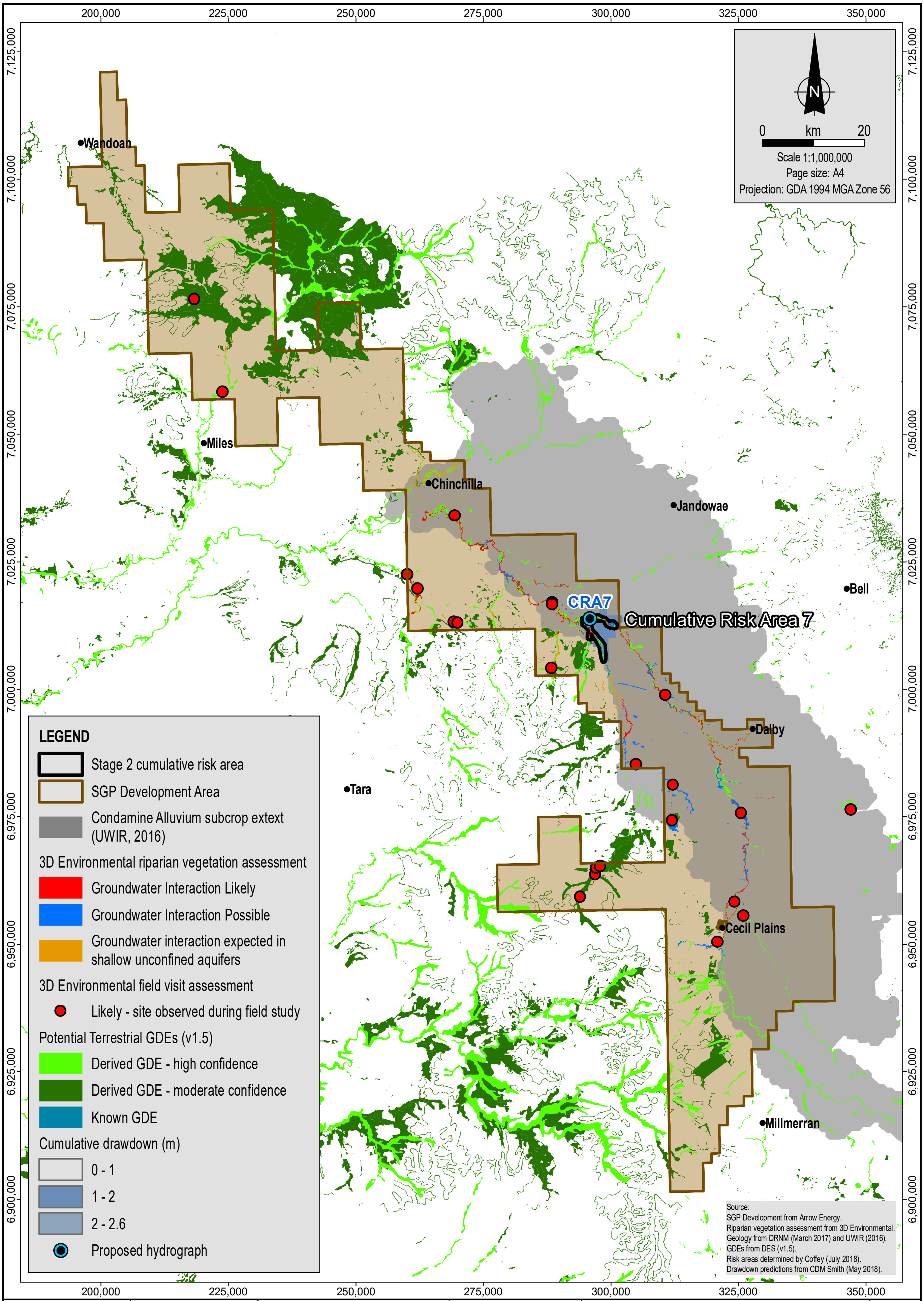

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Riparian vegetation assessment from 3D Environmental.
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Drawdown predictions from CDM Smith (May 2018).

MXD Reference: 20484AB_M03_GIS009_v0_Condamine_CRA_4

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Condamine Alluvium terrestrial GDE risk assessment,
Cumulative CSG Activities
(SGP Stage 2 WMMP)

Figure No:
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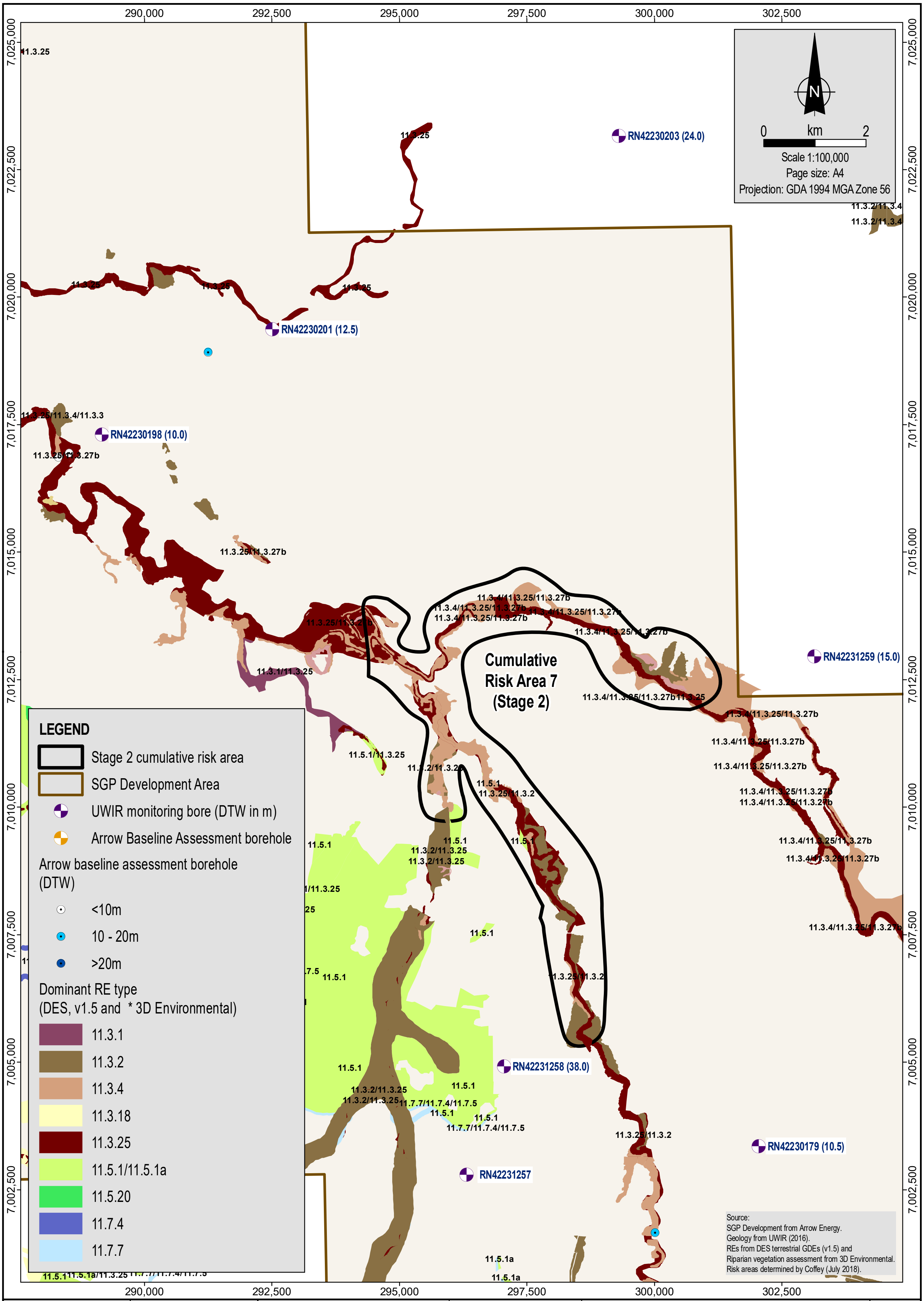

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MXD Reference: 20484AB_M03_GIS011_v0_CRA7_4

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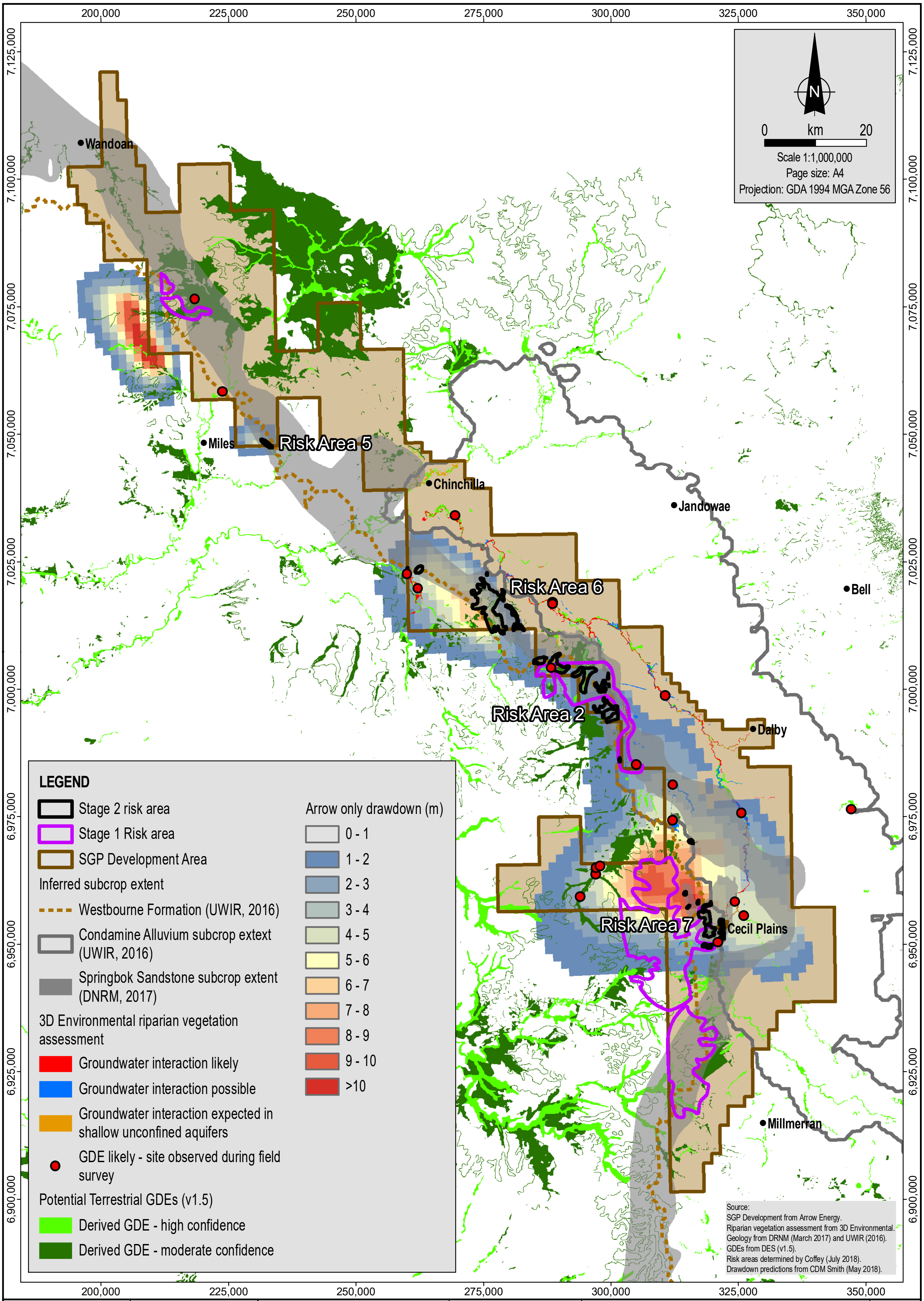

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Springbok Sandstone terrestrial GDE risk assessment,
Arrow only CSG Activities
(SGP Stage 2 WMMP)

Figure No:
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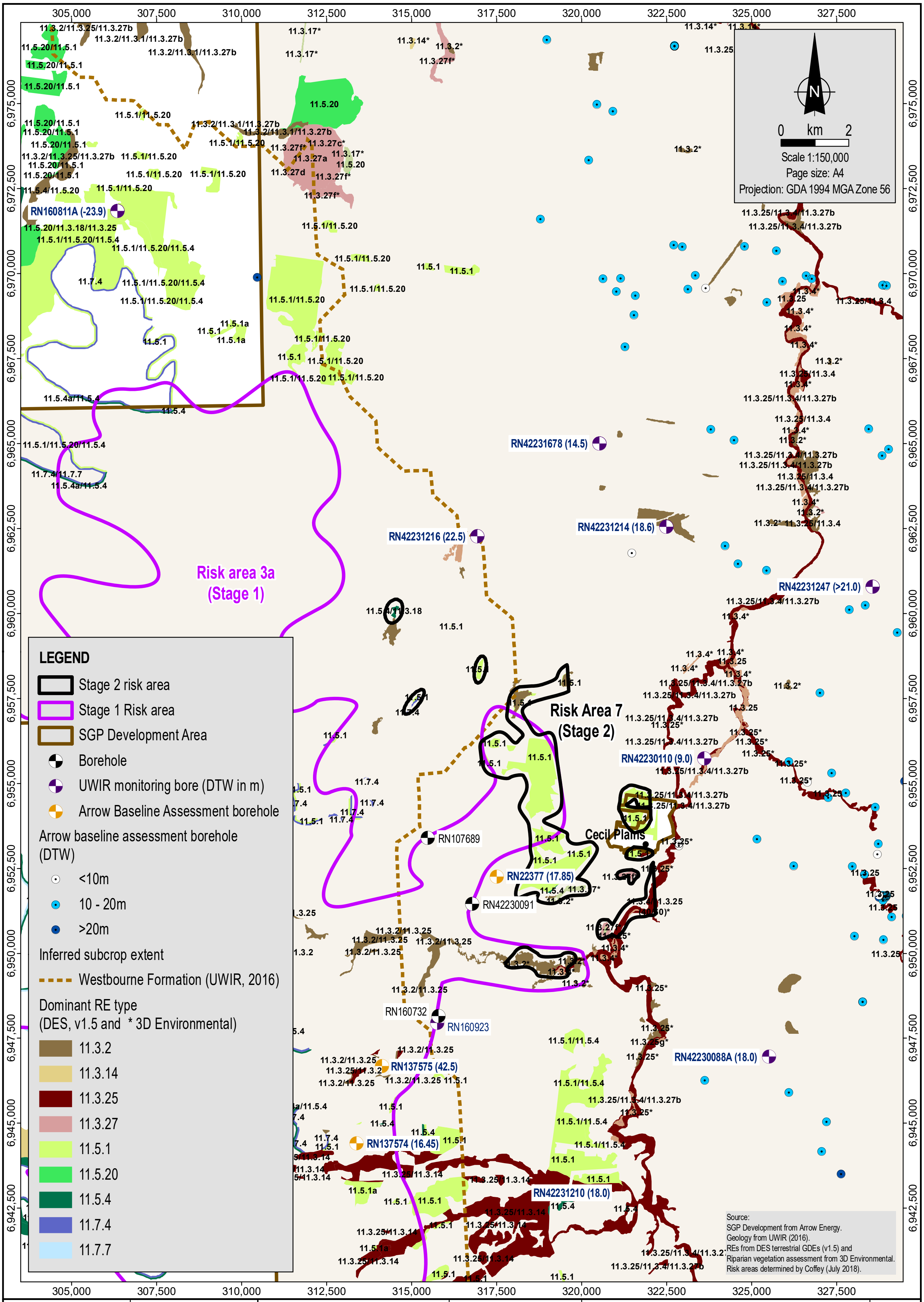

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Springbok Sandstone terrestrial GDE risk assessment,
Arrow only CSG Activities (SGP Stage 2 WMMP),
Risk Area 7

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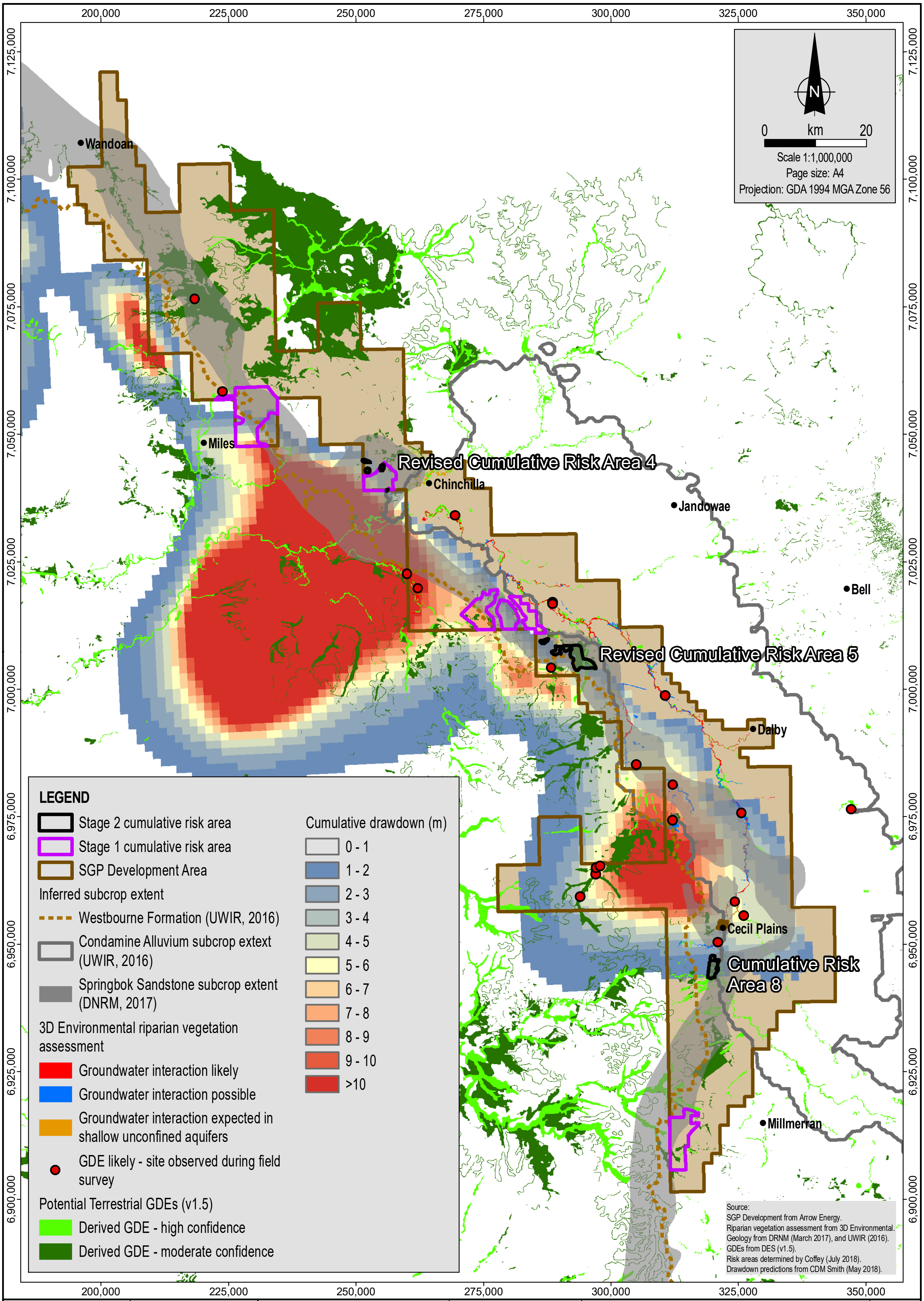

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Springbok Sandstone terrestrial GDE risk assessment,
Cumulative CSG Activities
(SGP Stage 2 WMMP)

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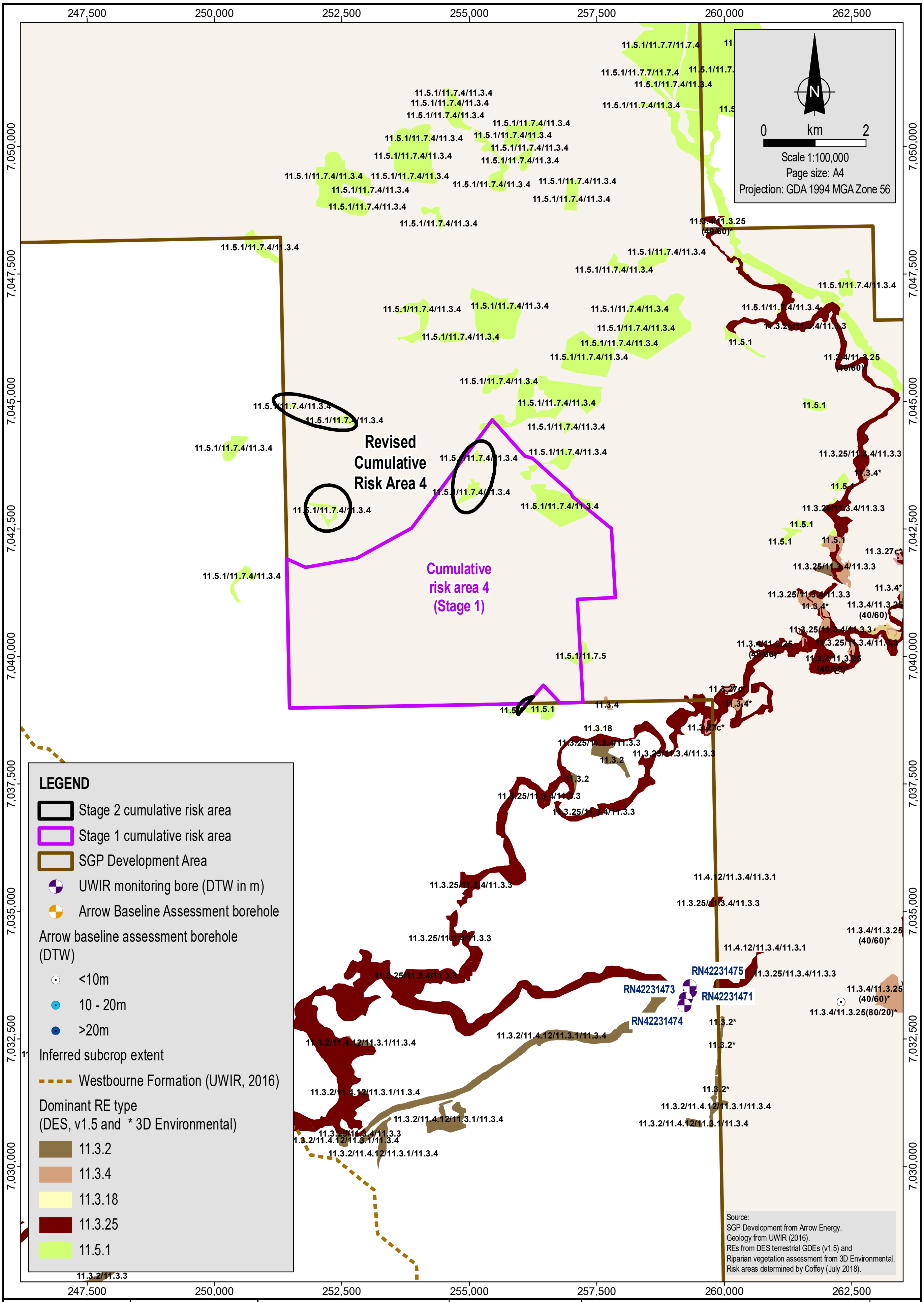

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Springbok Sandstone terrestrial GDE risk assessment, Cumulative CSG Activities (SGP Stage 2 WMMP), Revised Cumulative Risk Area 4

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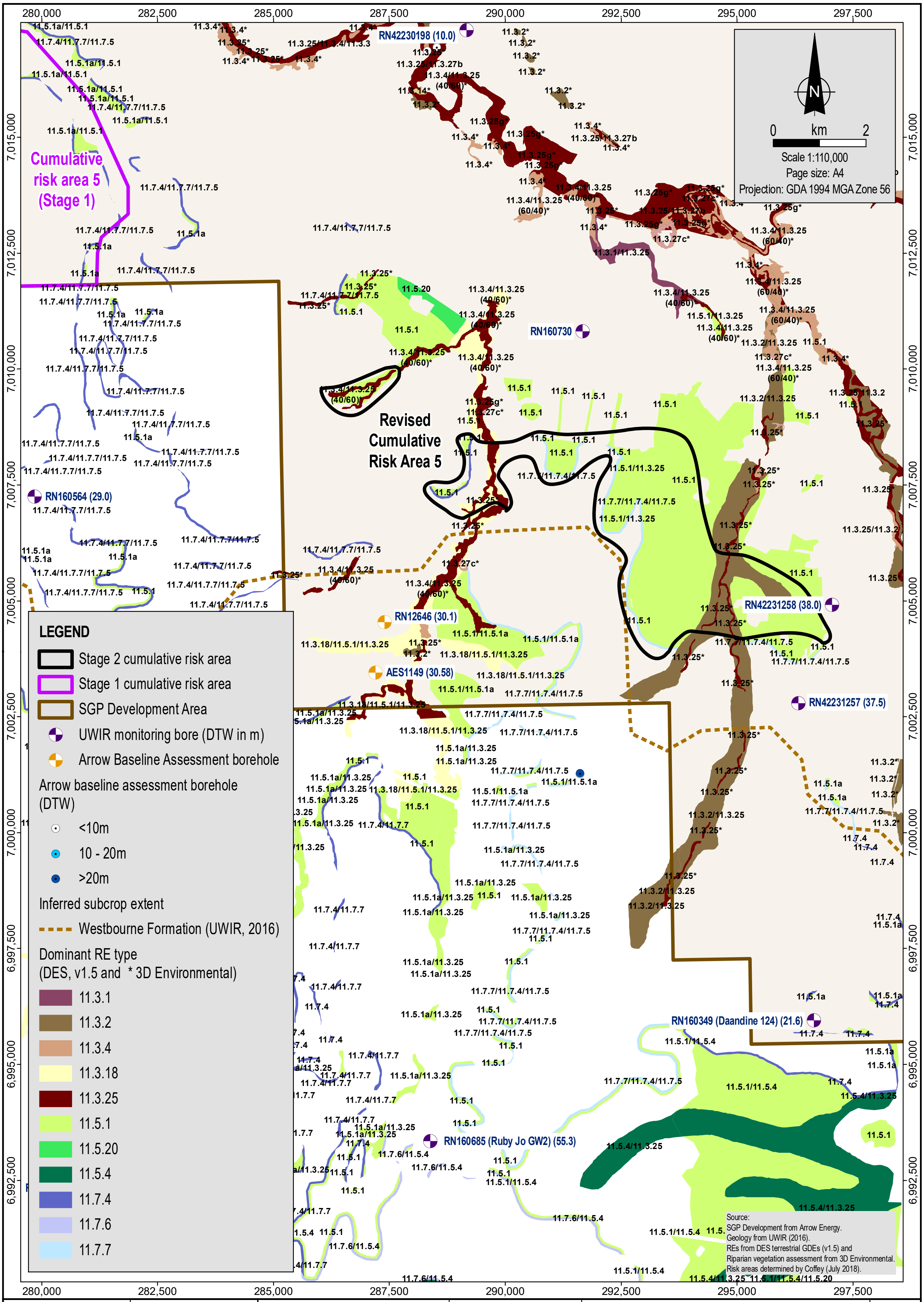

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Springbok Sandstone terrestrial GDE risk assessment, Cumulative CSG Activities (SGP Stage 2 WMMP), Revised Cumulative Risk Area 5 / Risk Area 2

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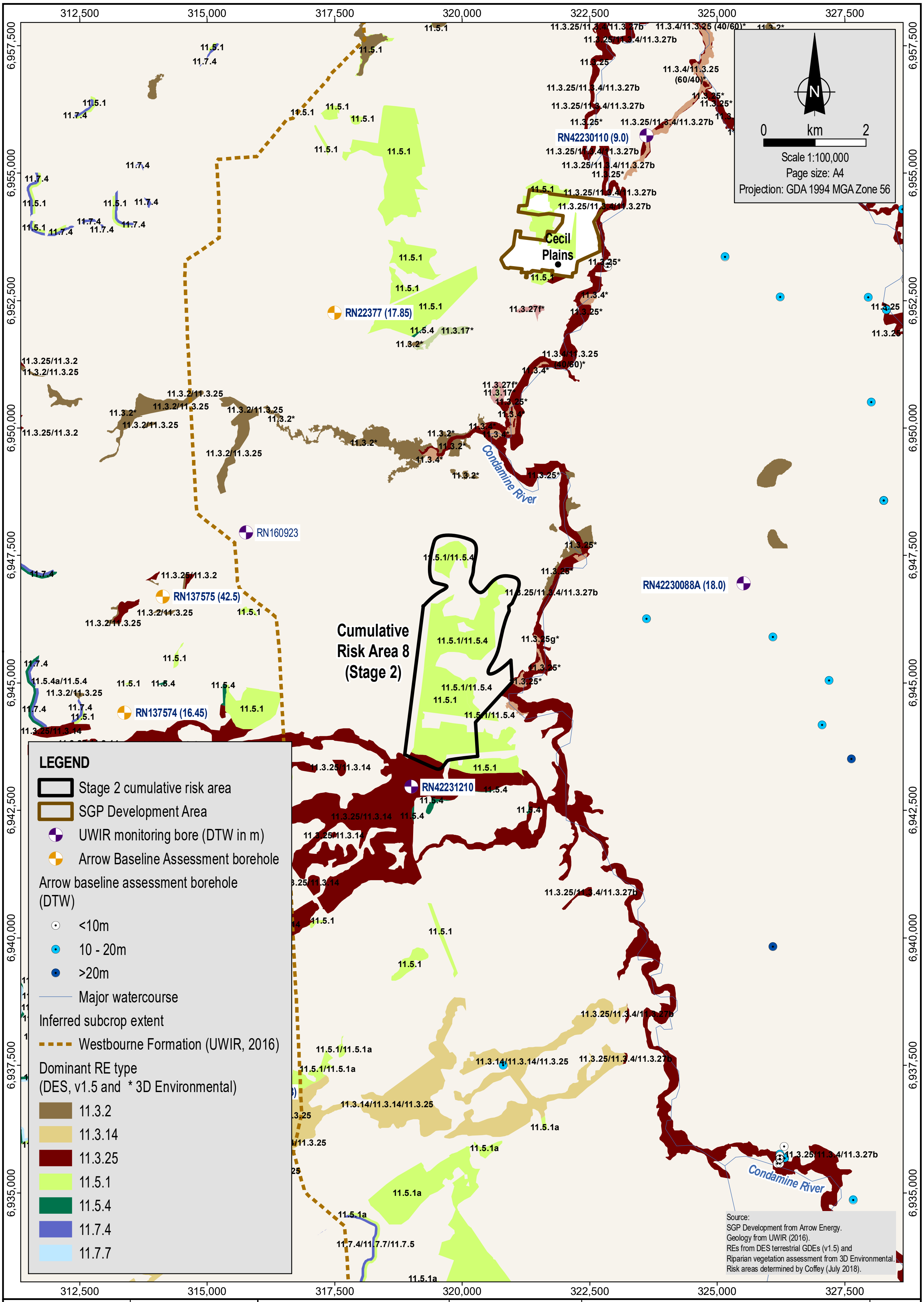

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Springbok Sandstone terrestrial GDE risk assessment, Cumulative CSG Activities (SGP Stage 2 WMMP), Cumulative Risk Area 8

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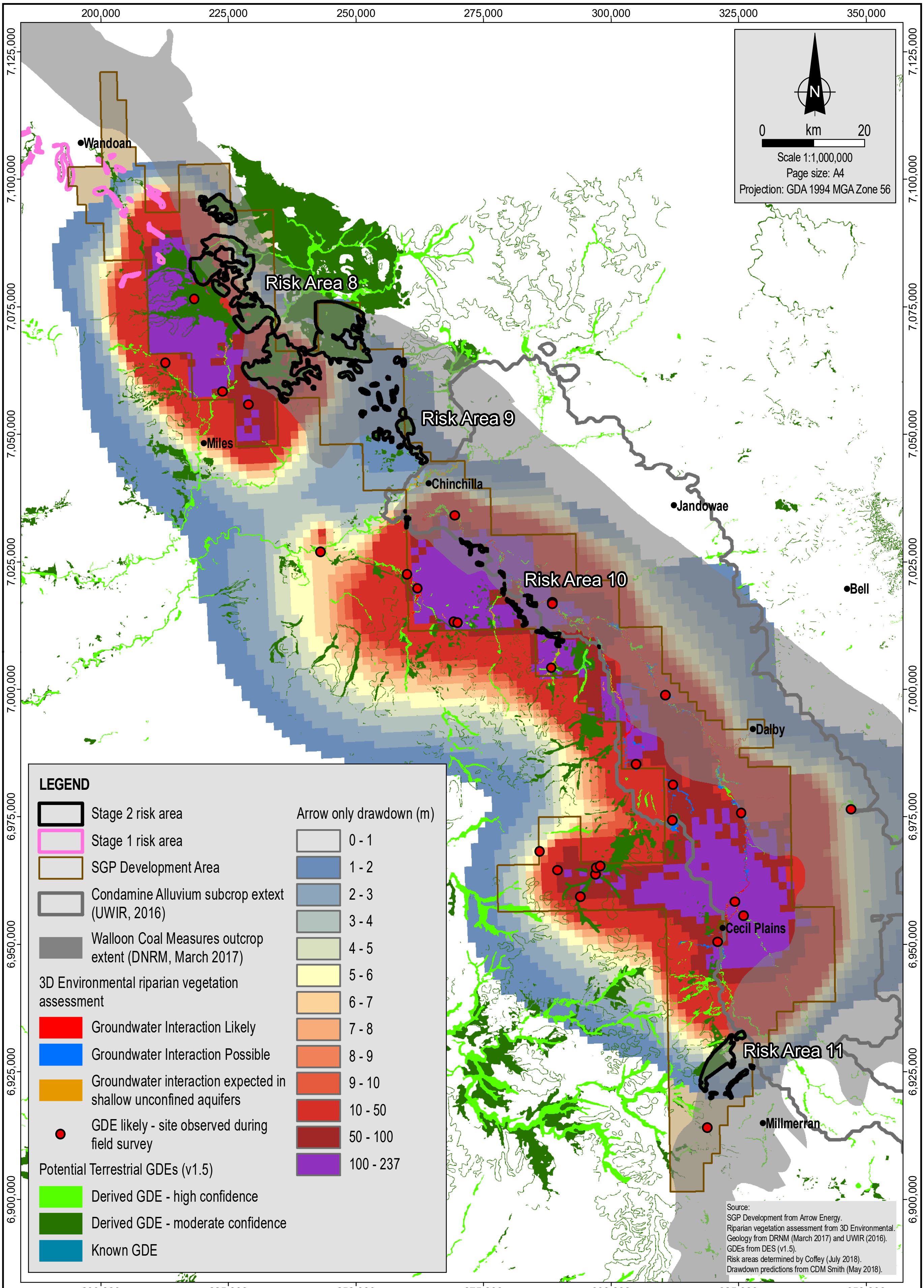

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MXD Reference: 20484AB_M03_GIS002_v0_WCM_5

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WCM terrestrial GDE risk assessment, Arrow only CSG Activities (SGP Stage 2 WMMP)

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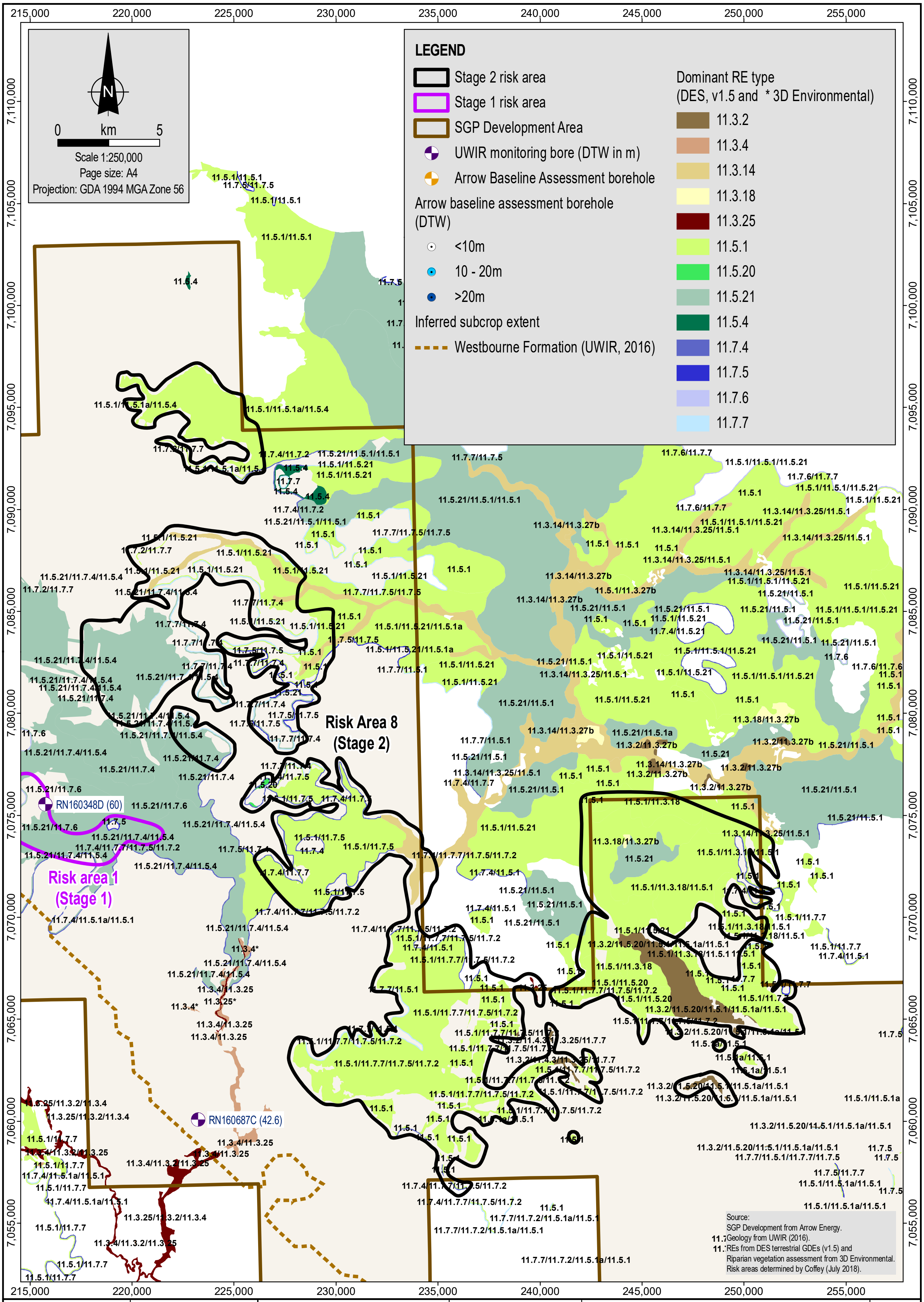

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WCM terrestrial GDE risk assessment,
Arrow only CSG Activities (SGP Stage 2 WMMP),
Risk Area 8

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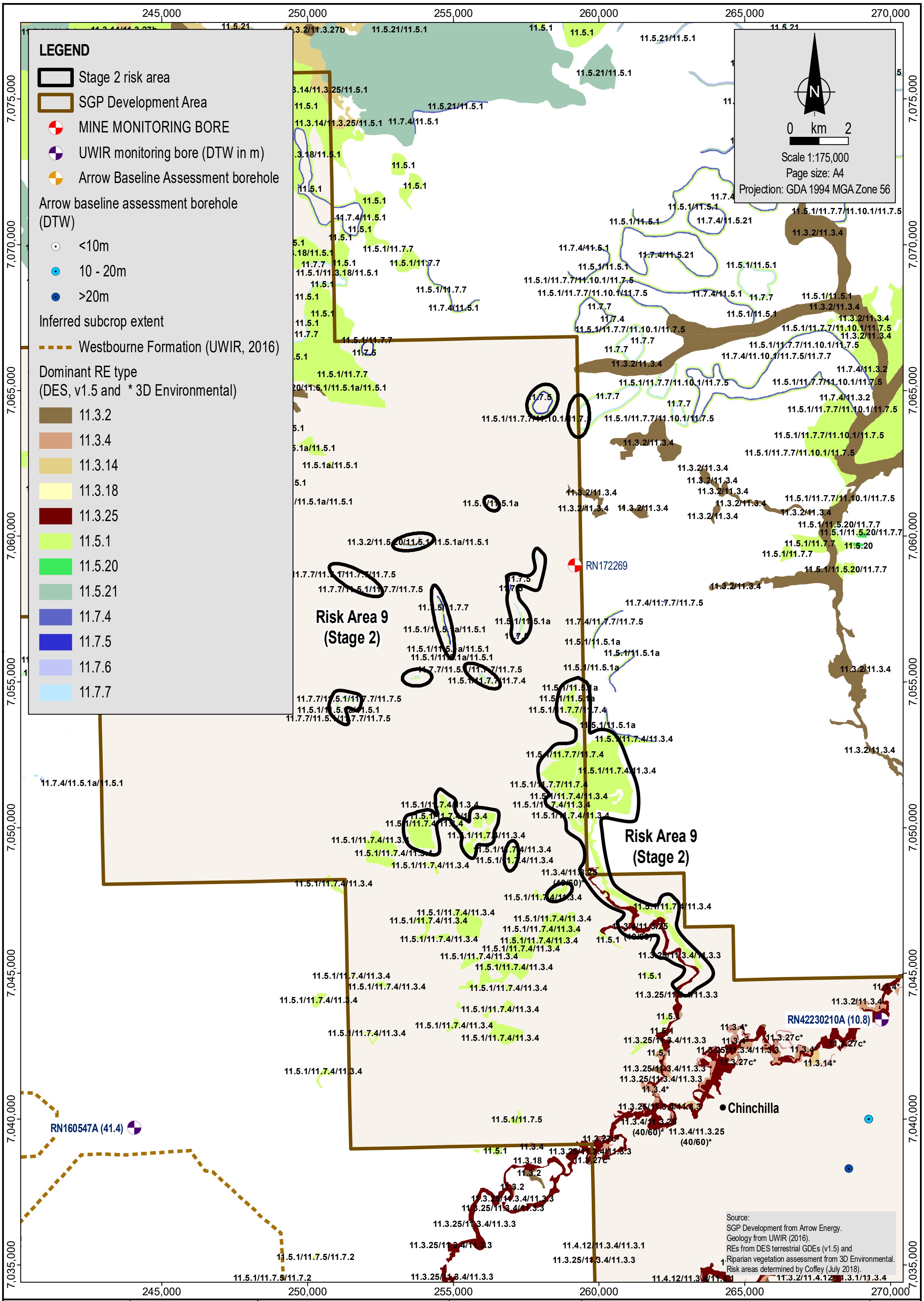

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MXD Reference: 20484AB_M03_GIS017_v0_RA9_4

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WCM terrestrial GDE risk assessment, Arrow only CSG Activities (SGP Stage 2 WMMP), Risk Area 9

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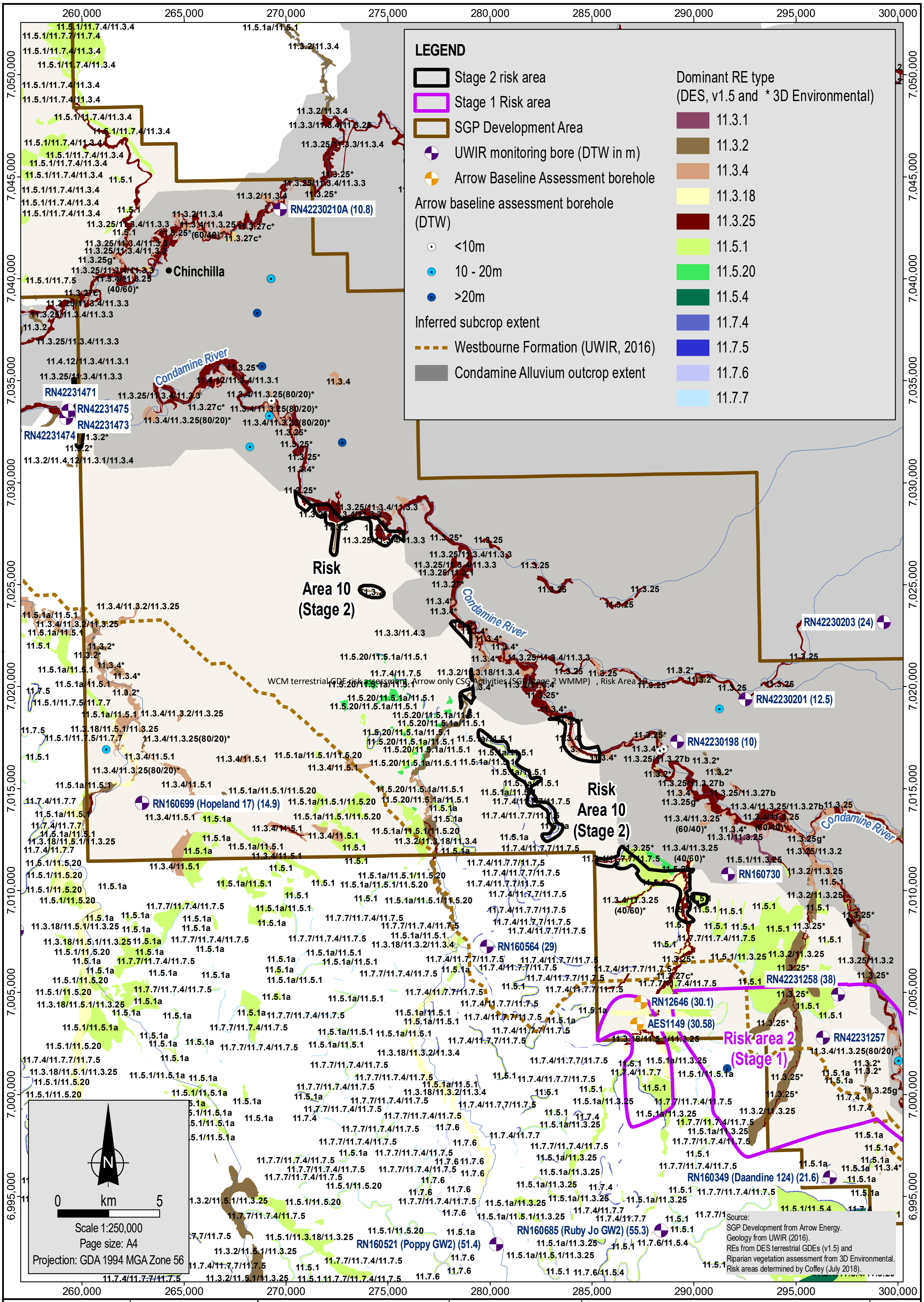

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REs from DES terrestrial GDEs (v1.5) and Riparian vegetation assessment from 3D Environmental.
Risk areas determined by Coffey (July 2018).

MXD Reference: 20484AB_M03_GIS018_v0_RA10_3

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Date: 12.11.2018
Project: ENAUABTF20484AA
File Name: 20484AB_M03_F018_GIS

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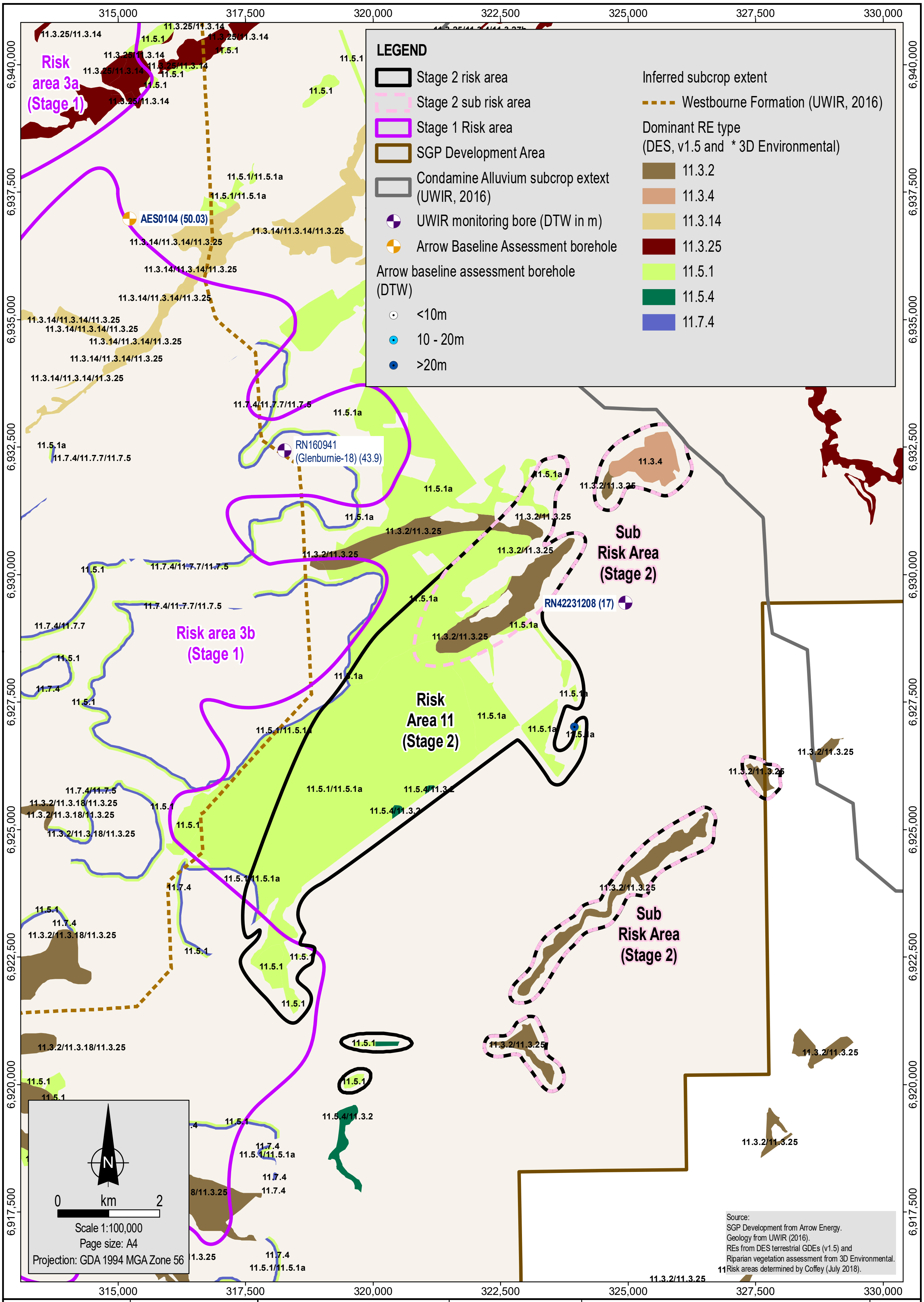
WCM terrestrial GDE risk assessment, Arrow only CSG Activities (SGP Stage 2 WMMP), Risk Area 10

Figure No: 18



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Riparian vegetation assessment from 3D Environmental.
Risk areas determined by Coffey (July 2018).

MXD Reference: 20484AB_M03_GIS019_v0_RA11_4

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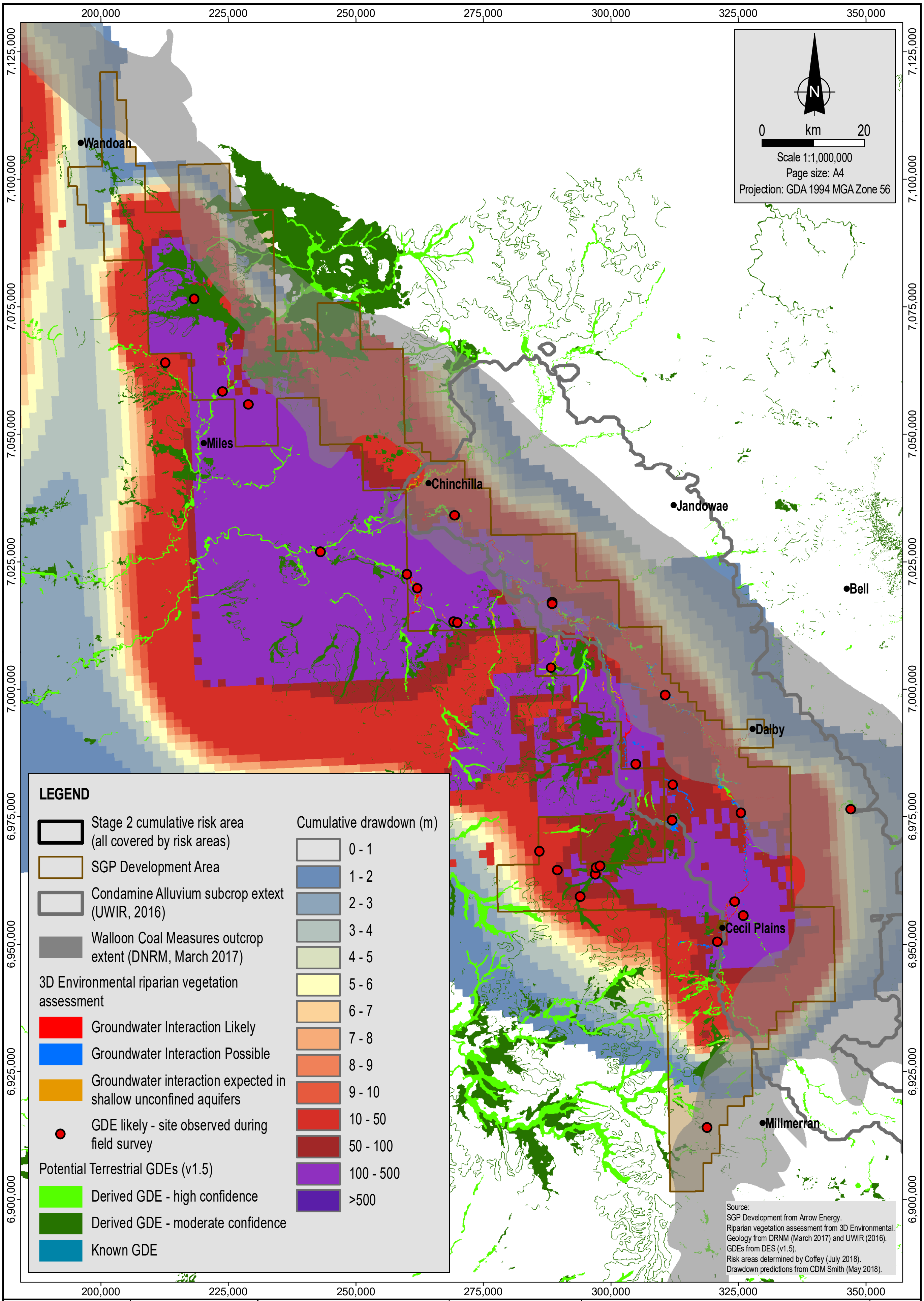
Date: 12.11.2018 Project: ENAUABTF20484AA File Name: 20484AB_M03_F019_GIS	Arrow Energy Surat Gas Project WMMP	arrow energy go further	WCM terrestrial GDE risk assessment, Arrow only CSG Activities (SGP Stage 2 WMMP), Risk Area 11	Figure No: 19



Source:
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Riparian vegetation assessment from 3D Environmental.
Geology from DRNM (March 2017) and UWIR (2016).
GDEs from DES (v1.5).
Risk areas determined by Coffey (July 2018).
Drawdown predictions from CDM Smith (May 2018).

MXD Reference: 20484AB_M03_GIS007_v0_WCM_CRA_3

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Project:
ENAUABTF20484AA
File Name:
20484AB_M03_F020_GIS

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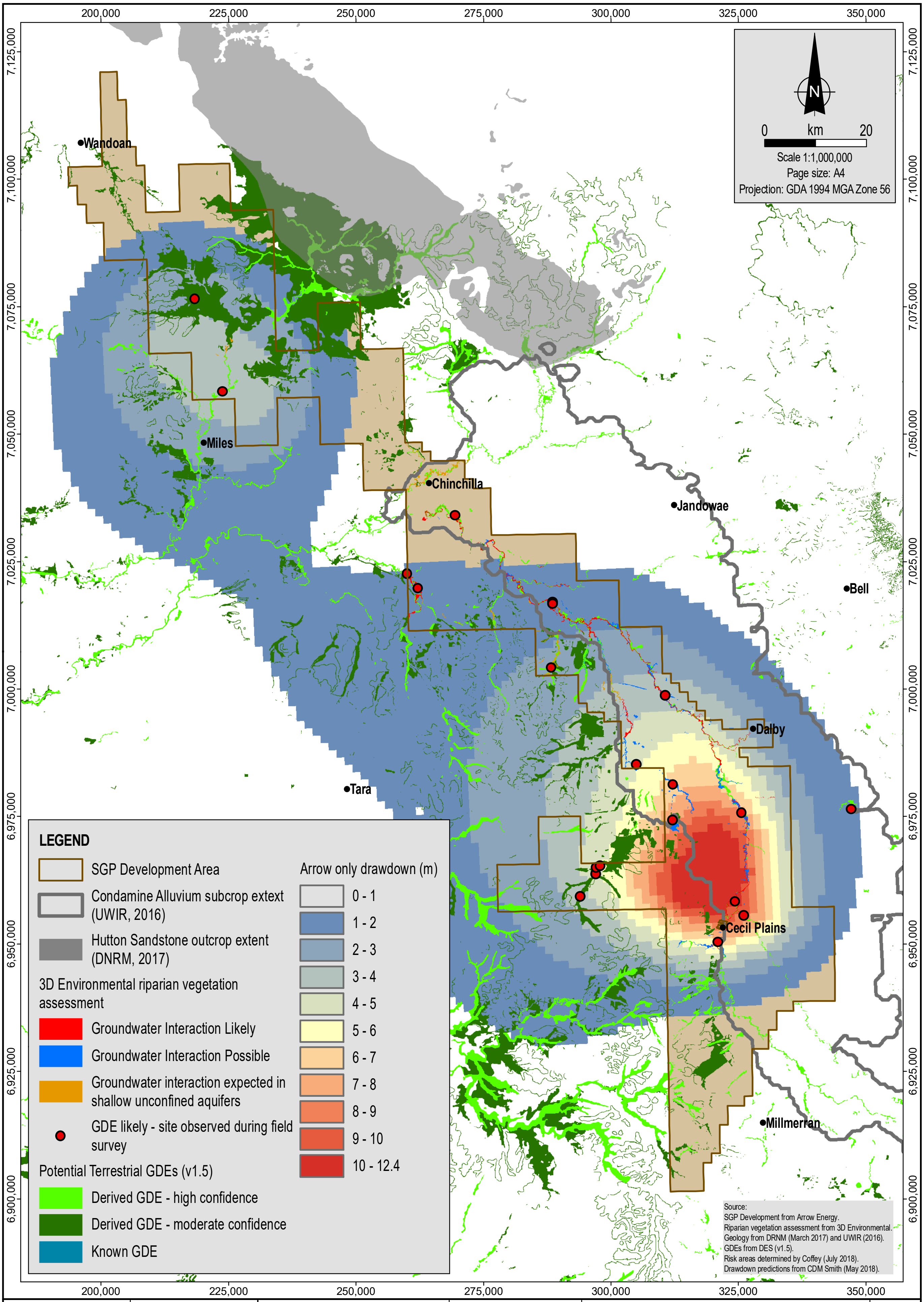
**WCM terrestrial GDE risk assessment,
Cumulative CSG Activities
(SGP Stage 2 WMMP)**

Figure No:
20



Source:
SGP Development from Arrow Energy.
Riparian vegetation assessment from 3D Environmental.
Geology from DRNM (March 2017) and UWIR (2016).
GDEs from DES (v1.5).
Risk areas determined by Coffey (July 2018).
Drawdown predictions from CDM Smith (May 2018).

MXD Reference: 20484AB_M03_GIS003_v0_Hutton_5

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Date:
13.11.2018
Project:
ENAUABTF20484AA
File Name:
20484AB_M03_F021_GIS

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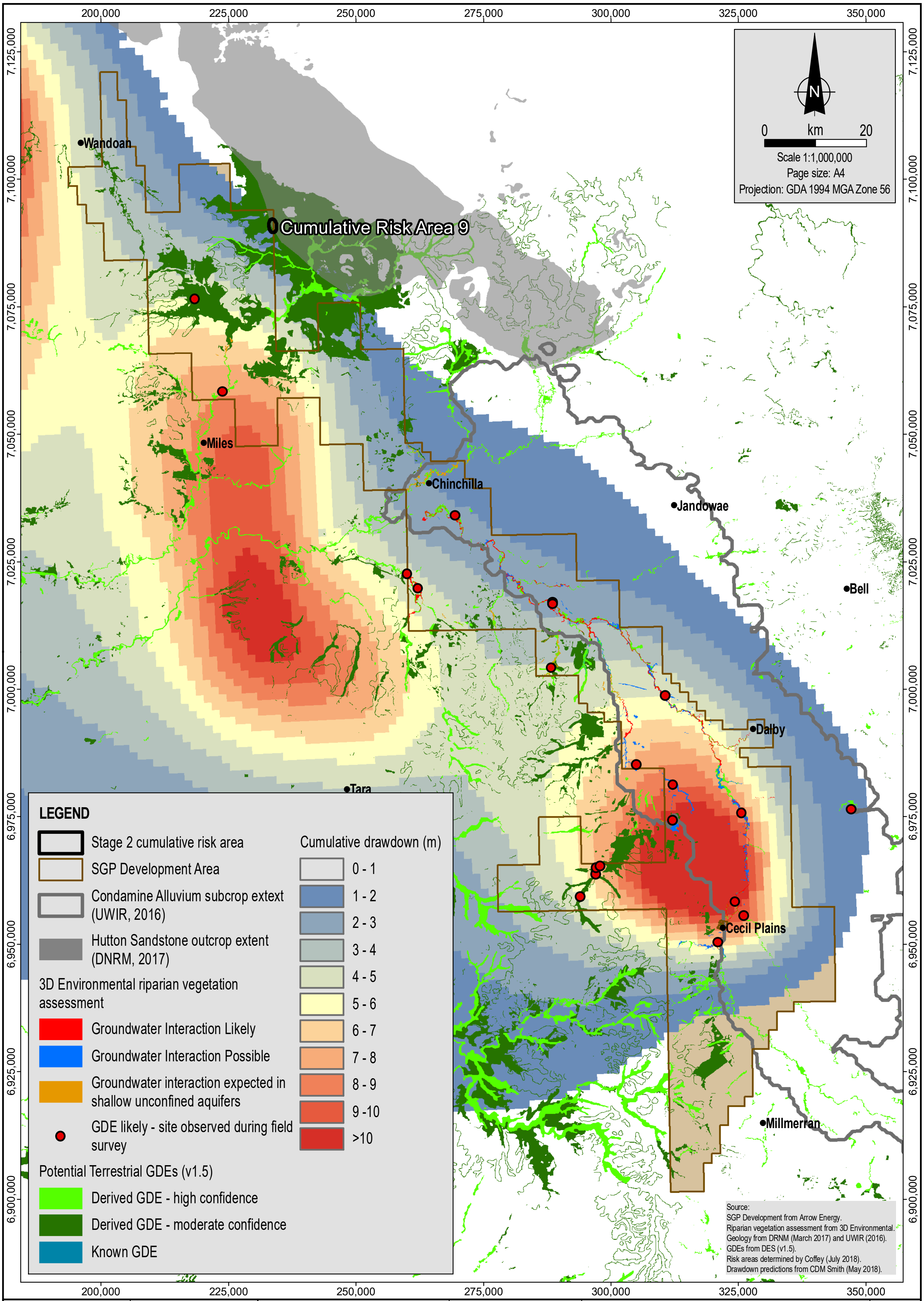
Hutton Sandstone terrestrial GDE risk assessment, Arrow only CSG Activities (SGP Stage 2 WMMP)

Figure No:
21



Source:
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Riparian vegetation assessment from 3D Environmental.
Geology from DRNM (March 2017) and UWIR (2016).
GDEs from DES (v1.5).
Risk areas determined by Coffey (July 2018).
Drawdown predictions from CDM Smith (May 2018).

MXD Reference: 20484AB_M03_GIS008_v0_Hutton_CRA_3

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Date: 12.11.2018
Project: ENAUABTF20484AA
File Name: 20484AB_M03_F022_GIS

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Surat Gas Project WMMP

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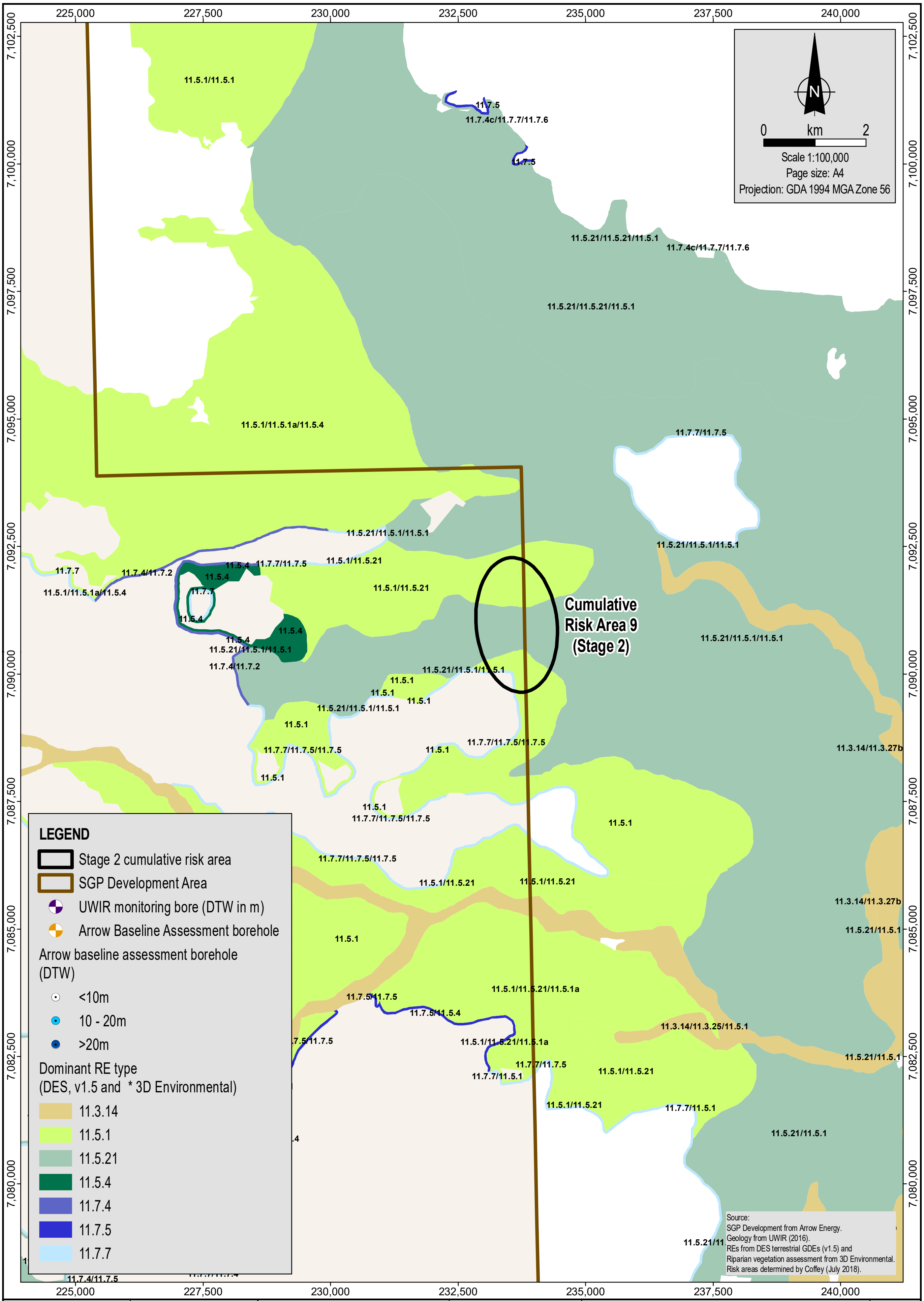
Hutton Sandstone terrestrial GDE risk assessment, Cumulative CSG Activities (SGP Stage 2 WMMP)

Figure No: **22**



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Geology from UWIR (2016).
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MXD Reference: 20484AB_M03_GIS020_v0_CRA9_3

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Project:
ENAUABTF20484AA

File Name:
20484AB_M03_F023_GIS

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Surat Gas Project WMMP

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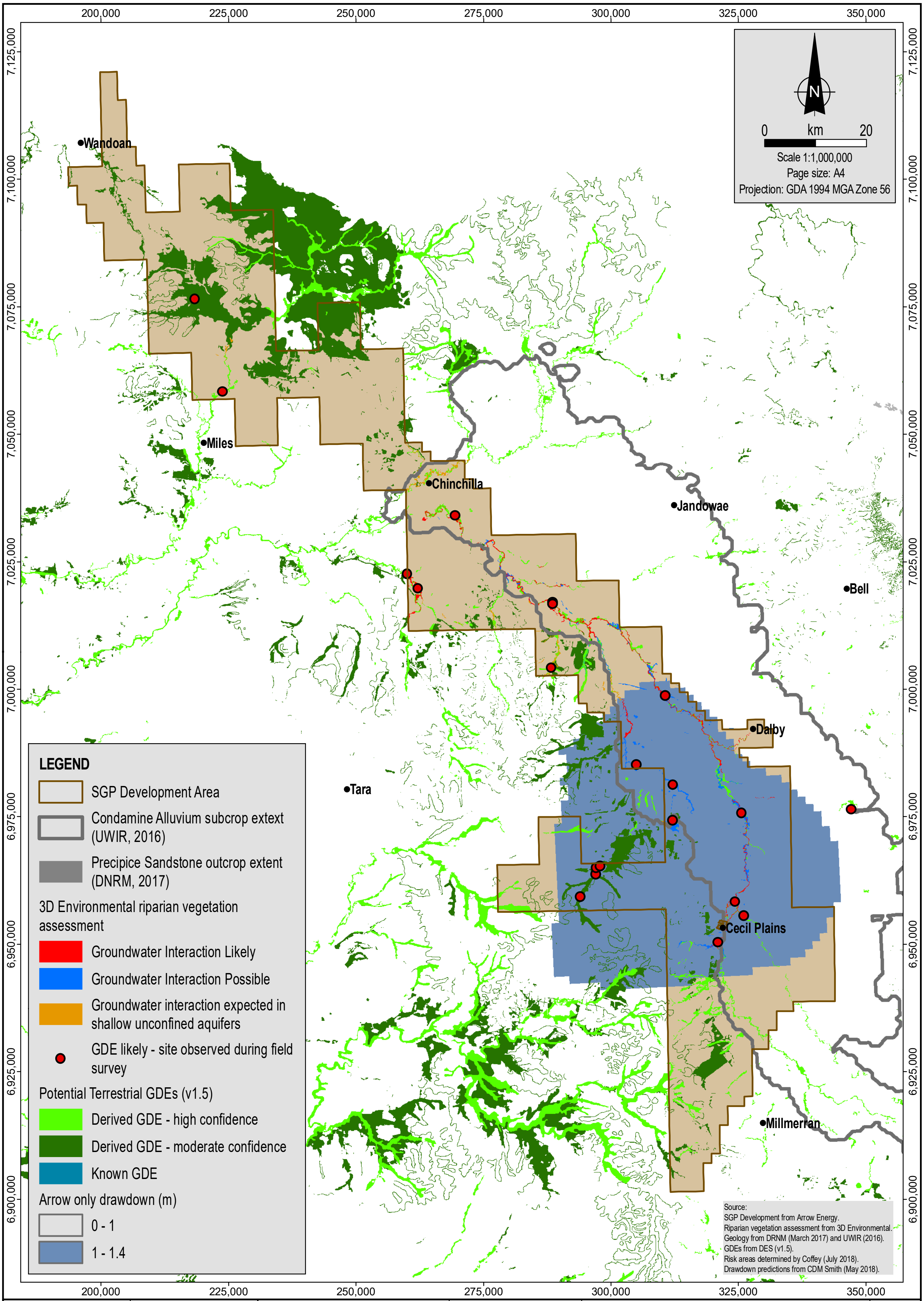
Hutton Sandstone terrestrial GDE risk assessment, Cumulative CSG Activities (SGP Stage 2 WMMP), Cumulative Risk Area 9

Figure No:
23



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Riparian vegetation assessment from 3D Environmental.
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GDEs from DES (v1.5).
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Drawdown predictions from CDM Smith (May 2018).

MXD Reference: 20484AB_M03_GIS004_v0_Precipice_4

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Date:
13.11.2018
Project:
ENAUABTF20484AA
File Name:
20484AB_M03_F024_GIS

Arrow Energy

Surat Gas Project WMMP

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Precipice Sandstone terrestrial GDE risk assessment, Arrow only CSG Activities (SGP Stage 2 WMMP)

Figure No:
24

Figure 25 Distribution of GDE assessment areas, 3D Environmental/Earth Search (2018) and Arrow Energy (2018) (sourced from 3D Environmental/Earth Search 2018)

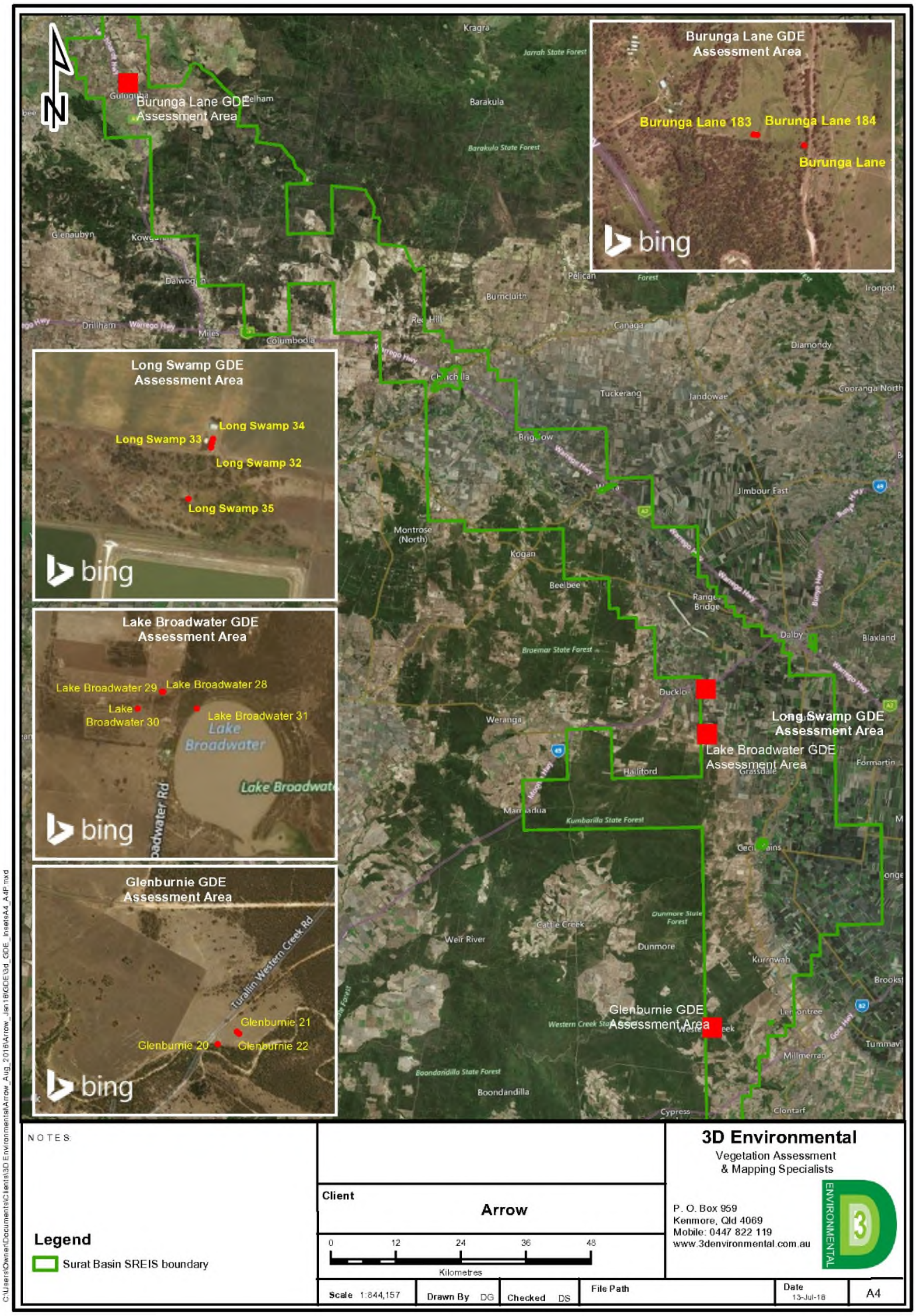


Figure 26 Conceptual site model for the Buruna Lane study site (sourced from 3D Environmental/Earth Search 2018)

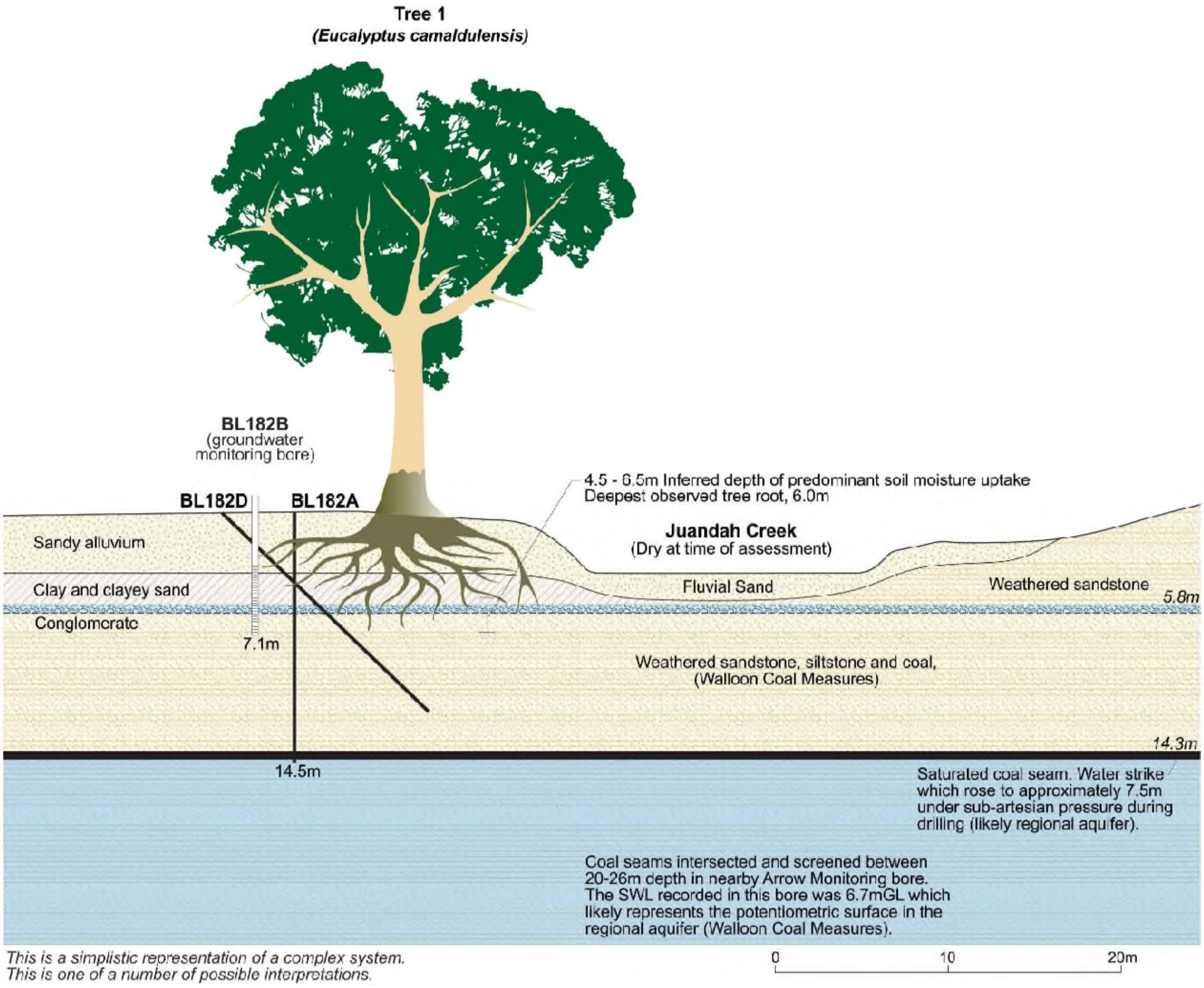


Figure 27 Conceptual site model for the Glenburnie study site (sourced from 3D Environmental/Earth Search 2018)

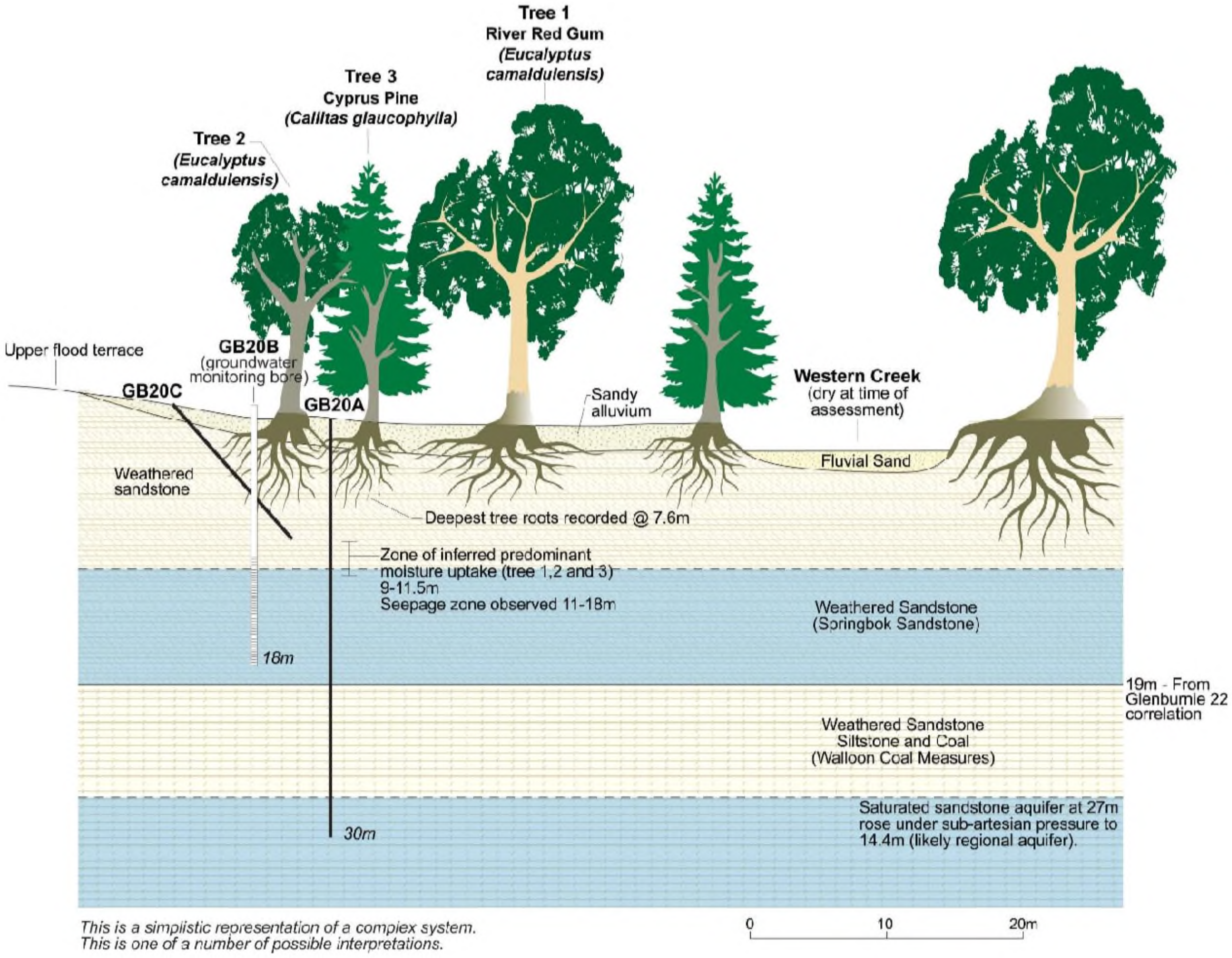


Figure 28 Conceptual site model for the Long Swamp study site (sourced from 3D Environmental/Earth Search 2018)

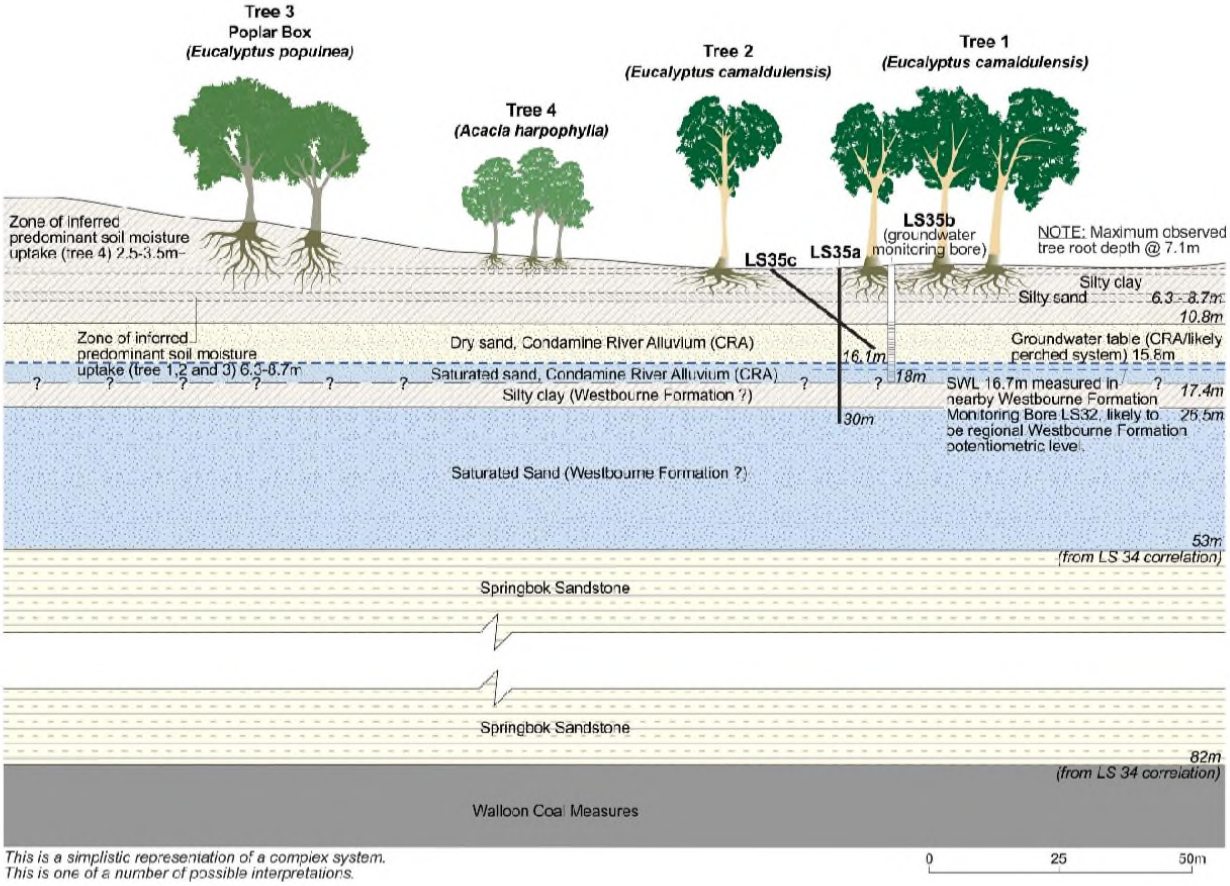
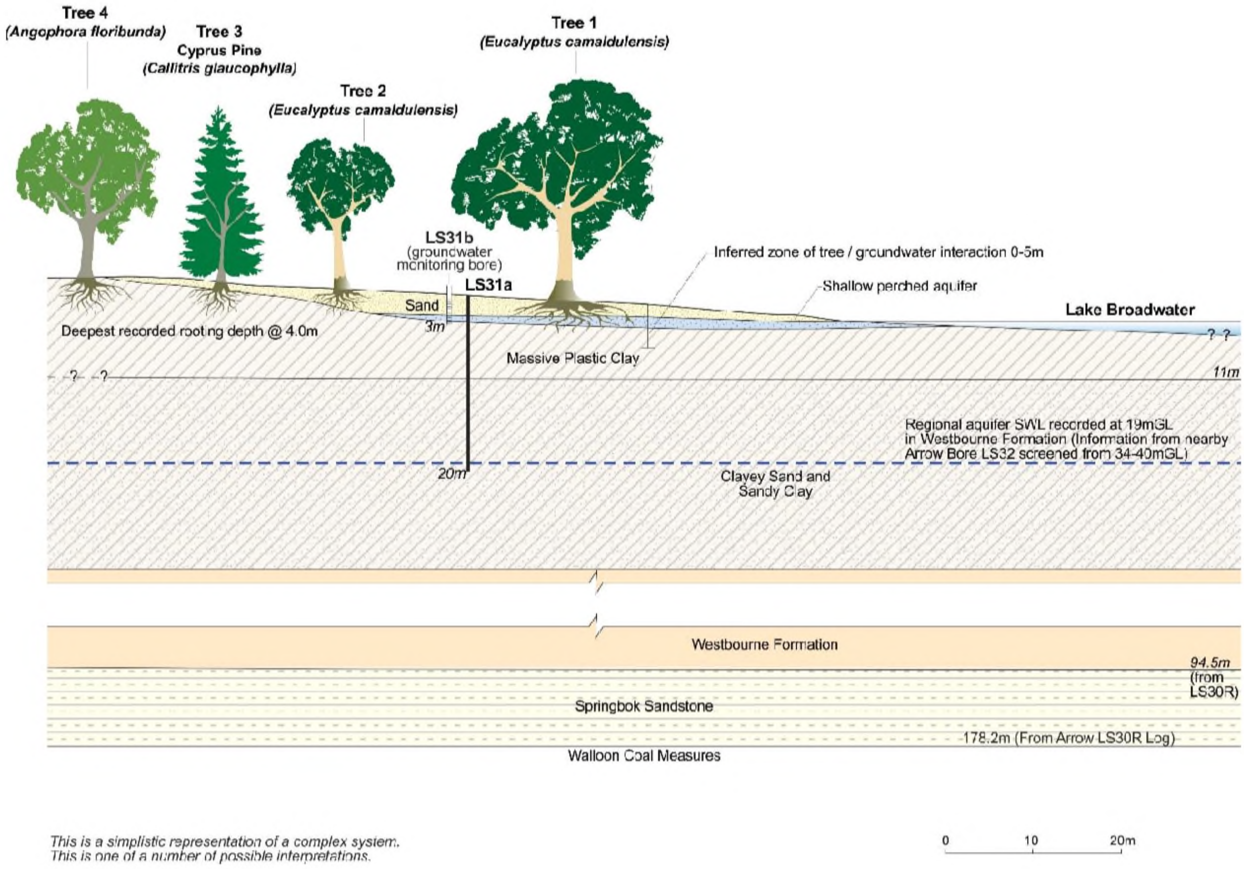


Figure 29 Conceptual site model for the Lake Broadwater study site (sourced from 3D Environmental/Earth Search 2018)



This is a simplistic representation of a complex system.
This is one of a number of possible interpretations.

Figure 30 Burunga Lane geological and hydrogeological conceptualisation (sourced from Arrow Energy 2018)

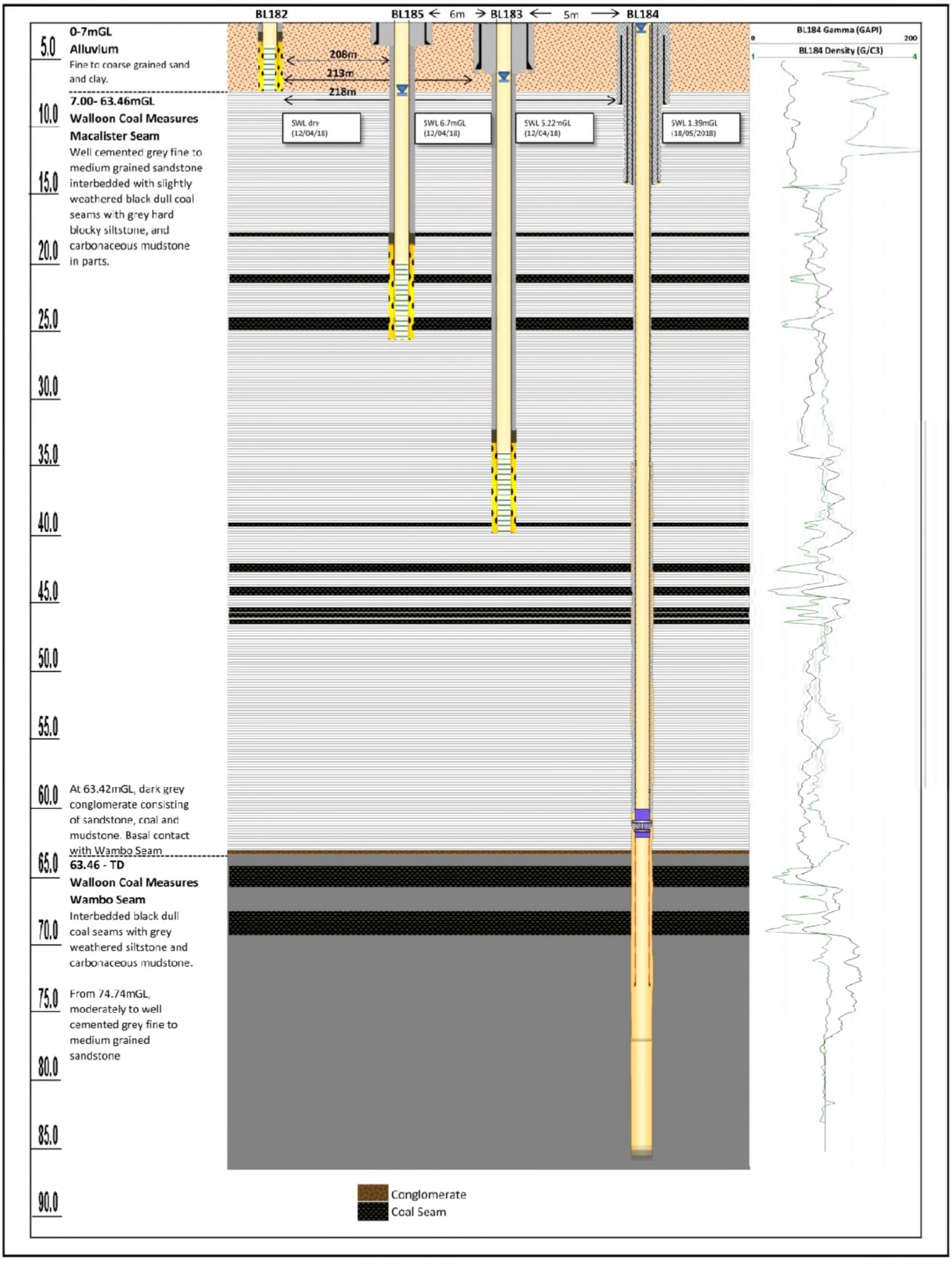


Figure 31 Burunga Lane hydrographs (sourced from Arrow Energy 2018)

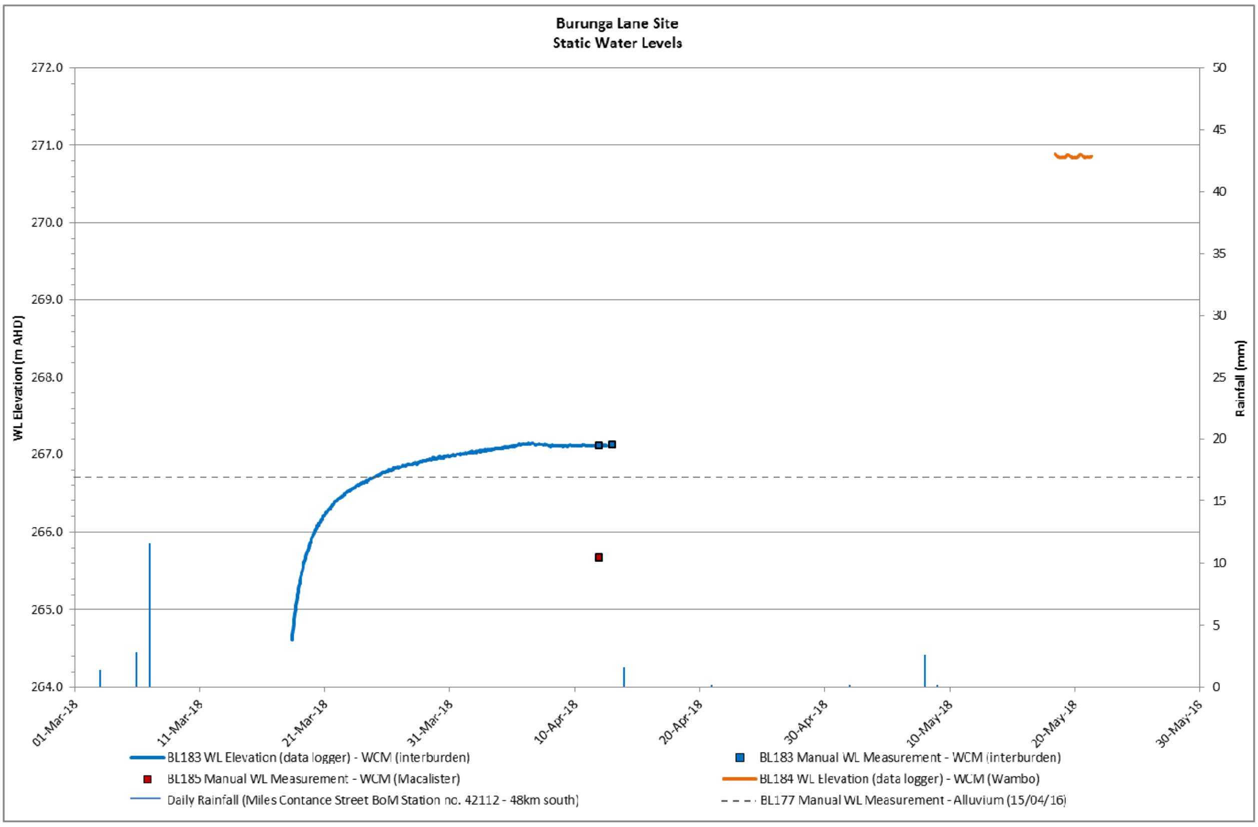


Figure 32 Glenburnie geological and hydrogeological conceptualisation (sourced from Arrow Energy 2018)

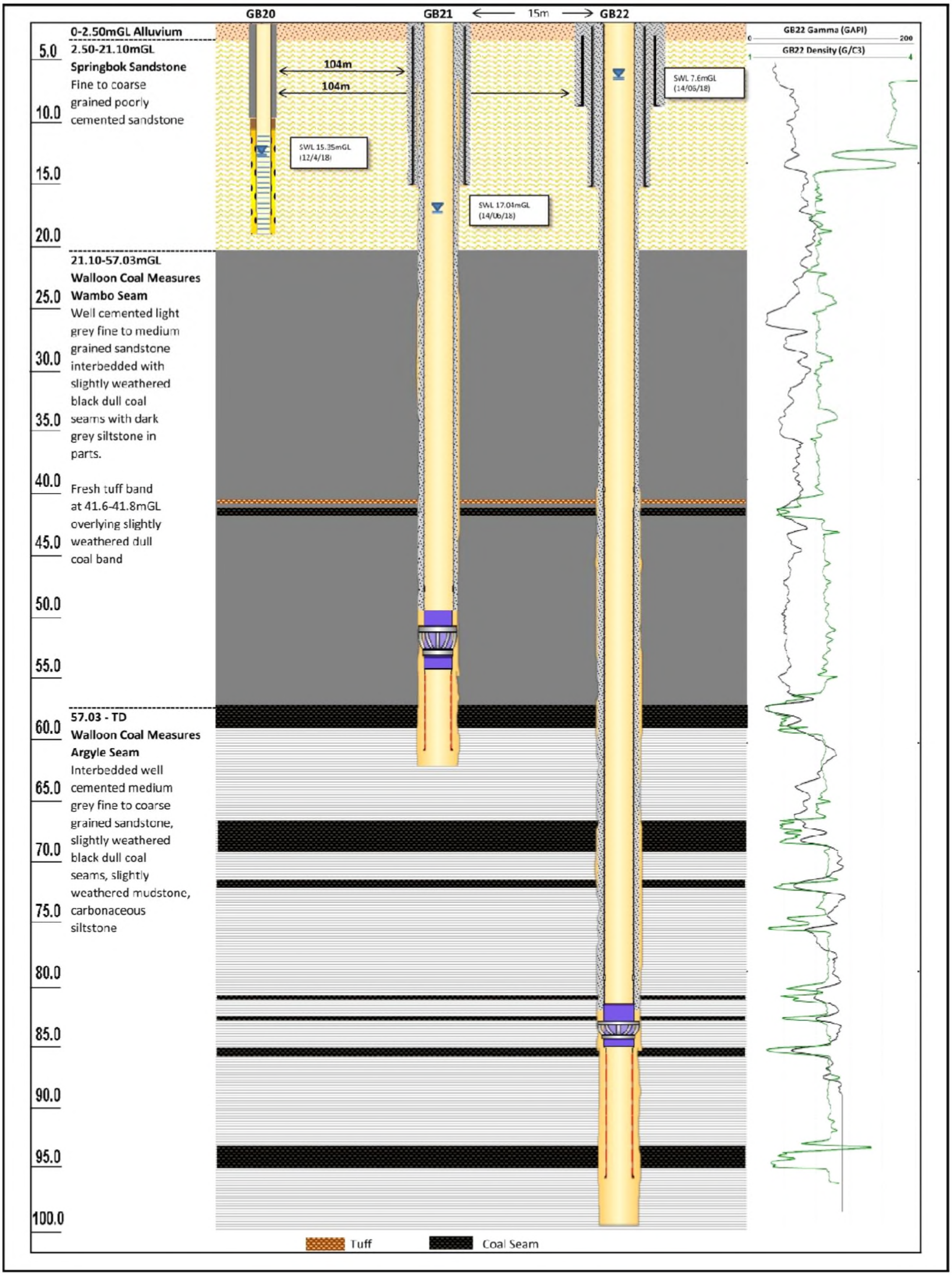


Figure 33 Glenburnie hydrographs (sourced from Arrow Energy 2018)

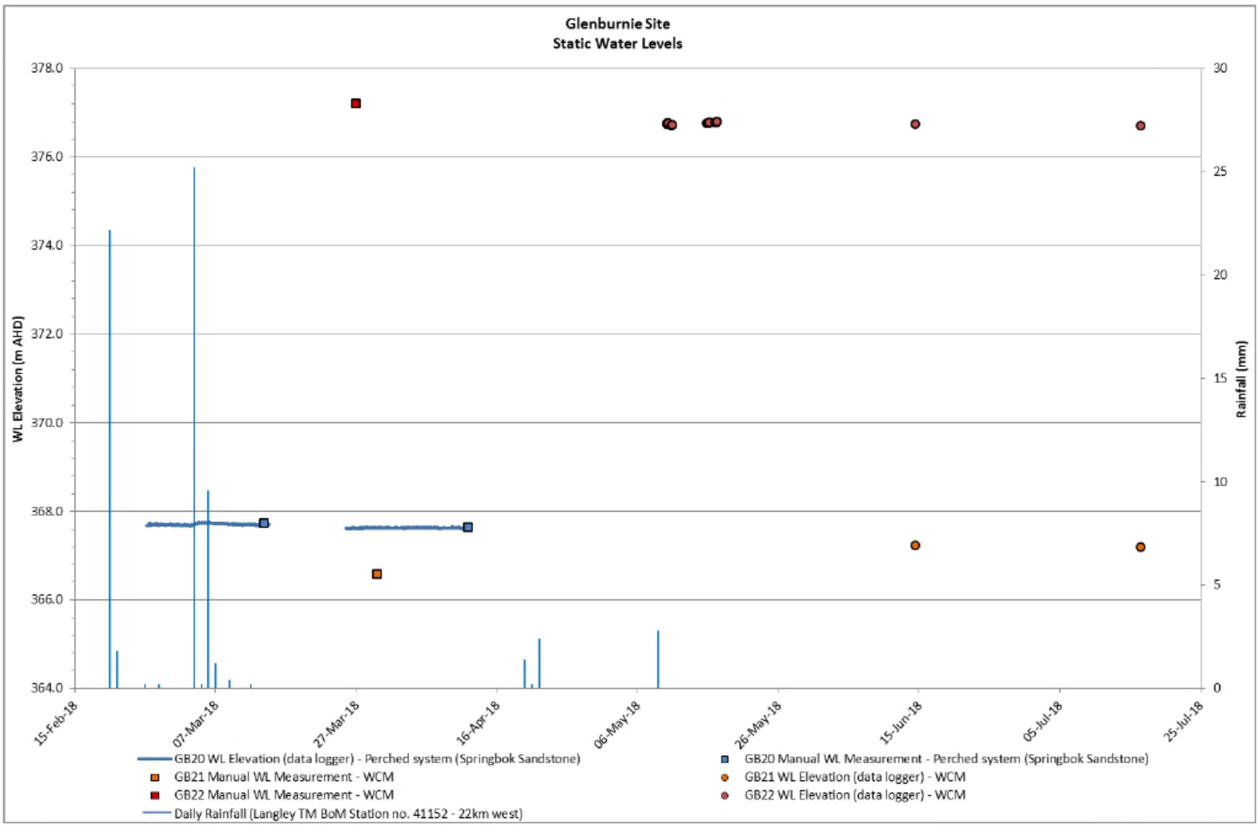


Figure 34 Long Swamp geological and hydrogeological conceptualisation (sourced from Arrow Energy 2018)

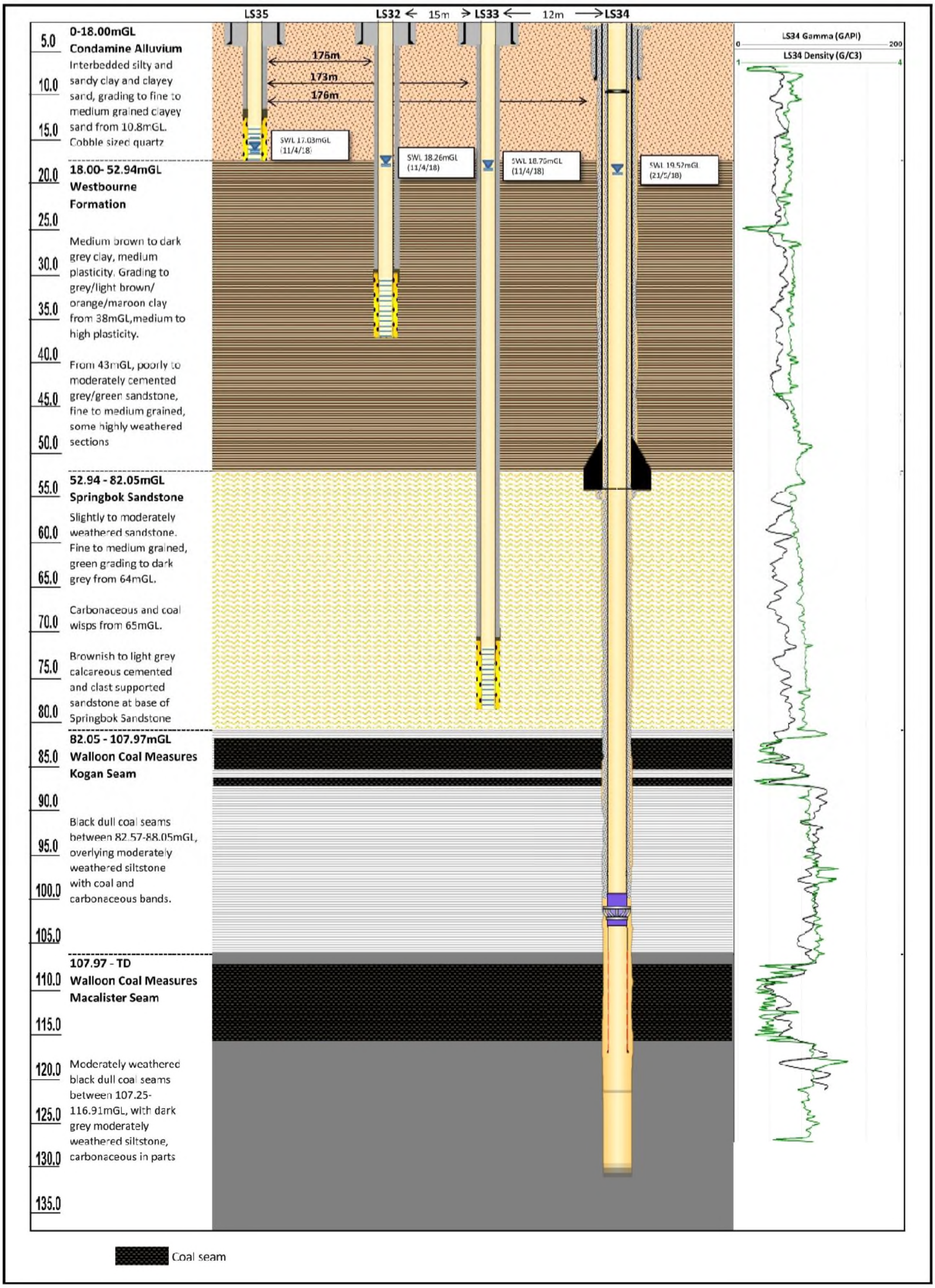


Figure 35 Long Swamp hydrographs (sourced from Arrow Energy 2018)

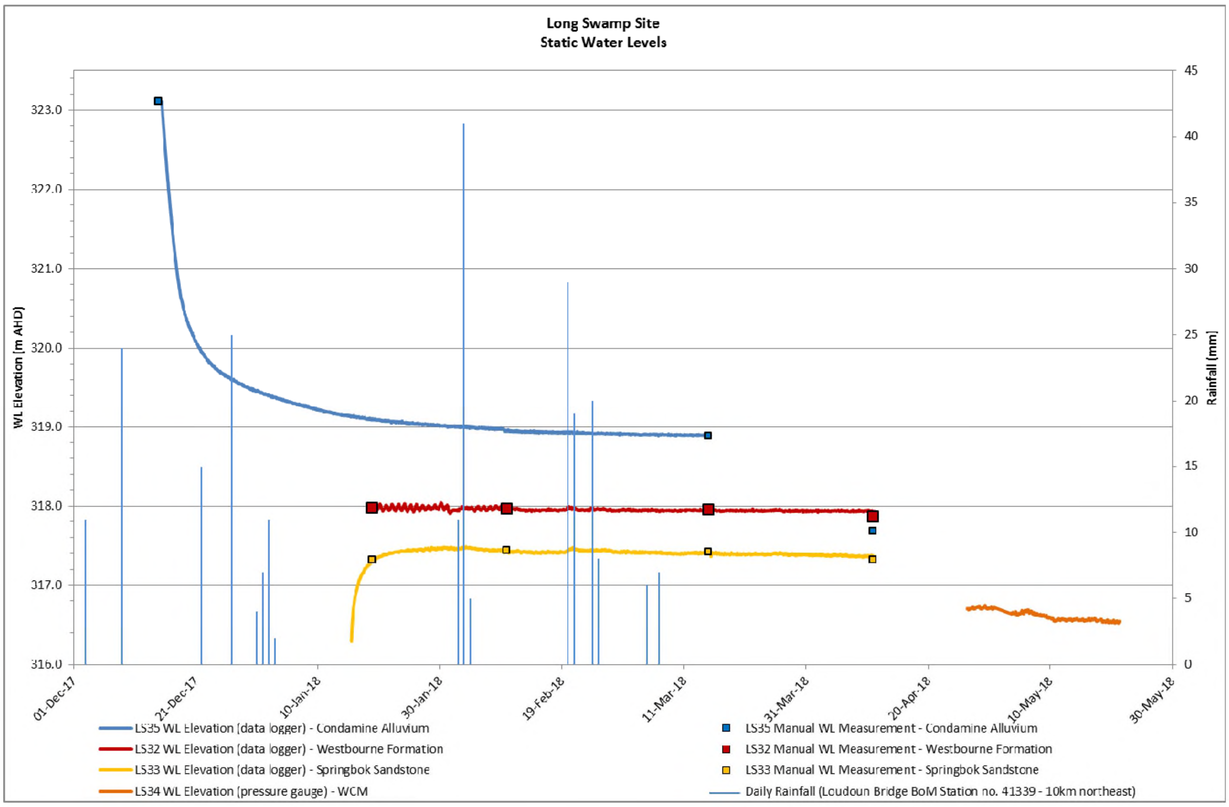


Figure 36 Lake Broadwater geological and hydrogeological conceptualisation (sourced from Arrow Energy 2018)

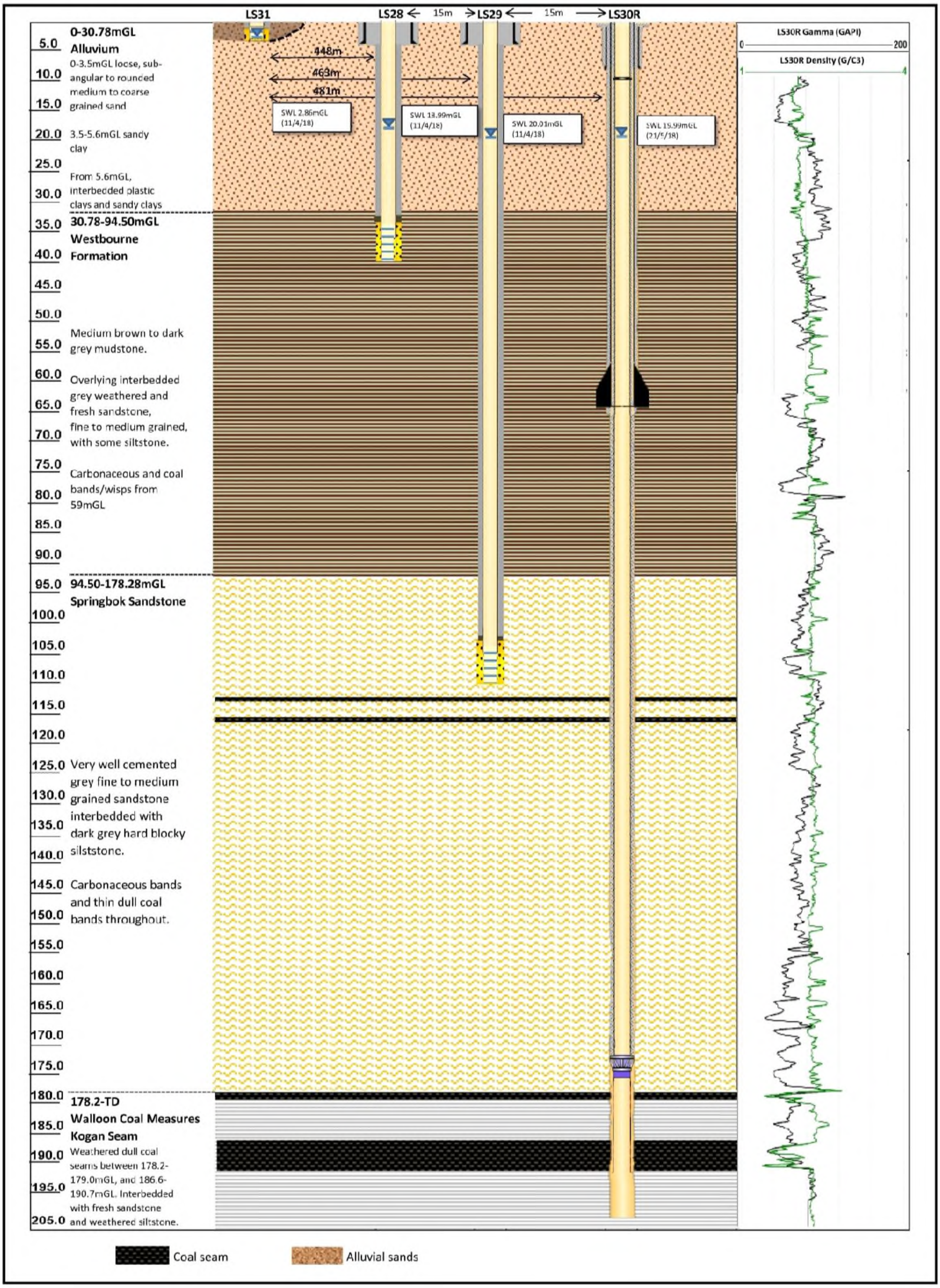
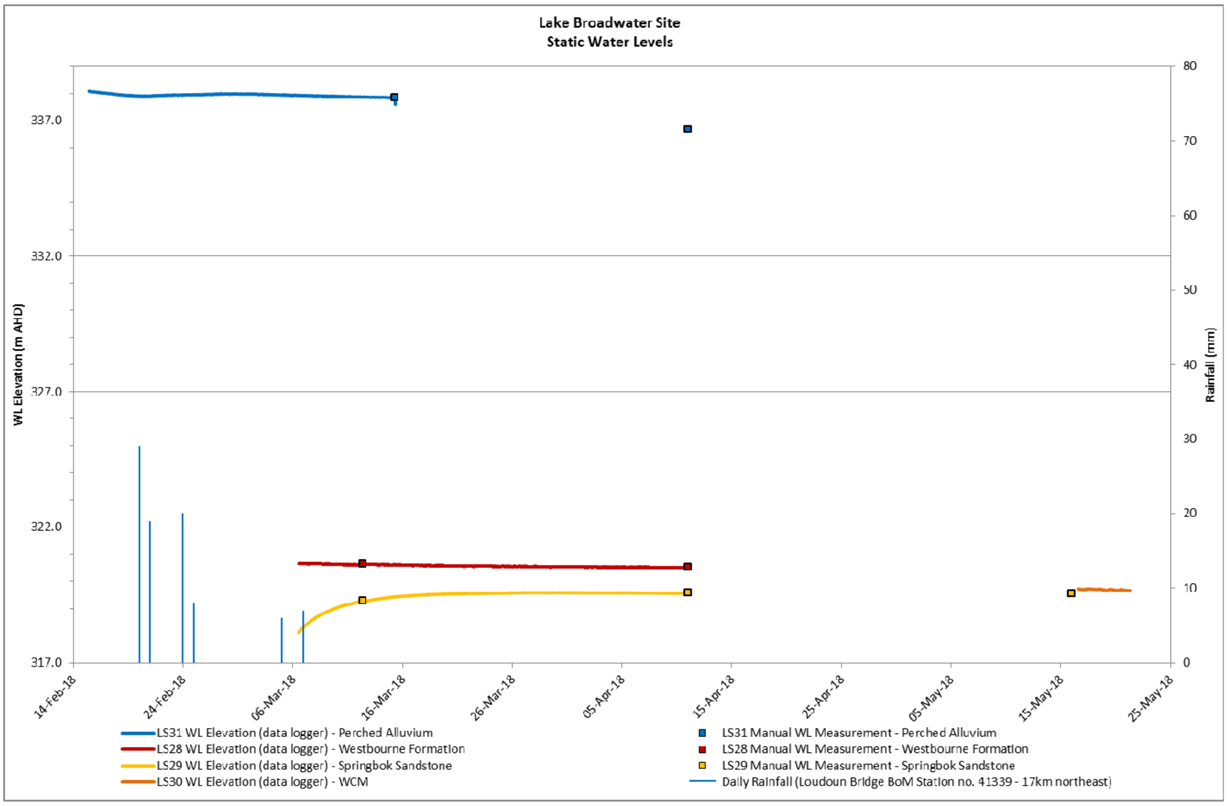
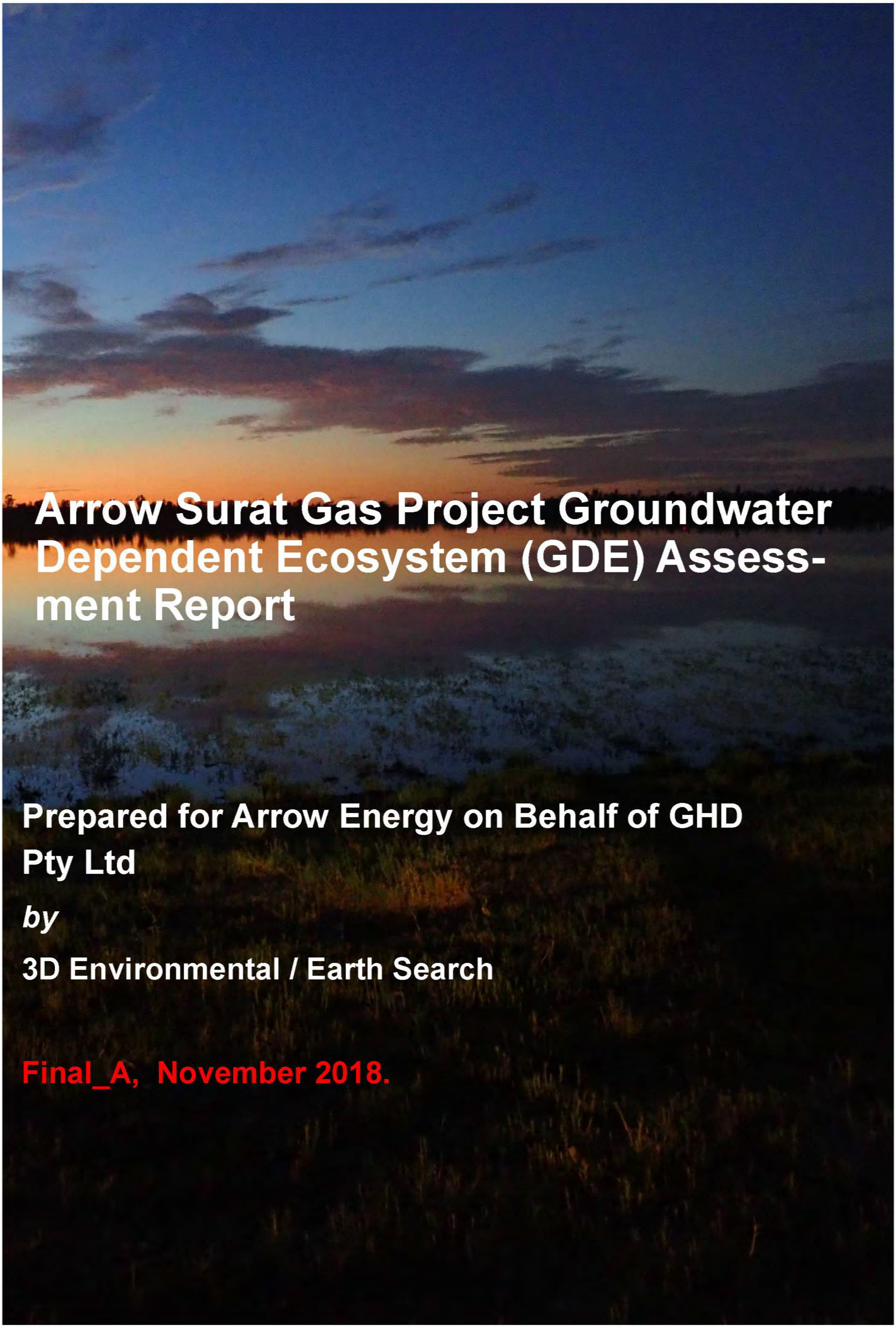


Figure 37 Lake Broadwater hydrographs (sourced from Arrow Energy 2018)



Appendices

Appendix 1 Phase 3 GDE assessment and monitoring program (3D Environmental/Earth Search 2018)



Arrow Surat Gas Project Groundwater Dependent Ecosystem (GDE) Assessment Report

Prepared for Arrow Energy on Behalf of GHD Pty Ltd

by

3D Environmental / Earth Search

Final_A, November 2018.

Project No. 2017_203B
Project Manager: David Stanton
Client: Arrow Energy
Purpose: Surat Gas Project GDE Characterisation and Monitoring Assessment

Draft	**Date Issued**	**Issued By.**	**Purpose**
Draft 1	4 April 2018	David Stanton/ Ned Hamer	First Draft GDE Assessment Report minus stable isotope results
Draft 2	02 May 2018	David Stanton/ Ned Hamer	Second draft addressing first round comments. Stable Isotope data outstanding and expected in several days
Draft 3	29 June 2018	David Stanton/ Ned Hamer	Third draft following the inclusion of stable isotope results
Final Draft	31 July 2018	David Stanton/ Ned Hamer	AE and GH review of Draft 3 Report. Report updates
Final	11 September 2018	David Stanton/ Ned Hamer	Final document
Final _A	11 November 2018	David Stanton/ Ned Hamer	Updated stable isotope results and interpretation following peer review comments.

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Contents

List of Figures

Executive Summary

Arrow Energy's Surat Gas Expansion Project's Federal Environmental Approval Conditions require the development of a Stage 2 Coal Seam Gas (CSG) Water Monitoring and Management Plan (WMMP). This report provides information necessary to address the following obligation:

- *"Condition 17g: address any uncertainty in the groundwater-dependency of ecosystems and springs with supporting evidence from field-based investigations for any groundwater-dependent ecosystems and springs confirmed in the OGIA model."*

Prior assessments undertaken as part of the Stage 1 CSG WMMP resulted in the identification of four sites for assessment to characterise ecological / hydrogeological relationships and determine whether these sites meet the definition of a GDE. Sites include the Burunga Lane GDE Assessment Site (BL182) near Wandoan, the Long Swamp GDE Assessment Site (LS35) near Ducklo south-west of Dalby, The Lake Broadwater GDE Assessment Site (Long Swamp 31) approximately 25km south-west of Dalby and the Glenburnie GDE Assessment Site (Glenburnie 20) in the southern portion of Arrow's exploration tenements approximately 20km west of Millmerran.

Use of numerous complementary assessment methods including coring using a sonic drilling rig to observe rooting depth, and assess hydrogeological conditions, assessment of soil moisture and leaf water potential, and stable isotope analysis of soil moisture, groundwater and xylem water has resulted in data and observations providing multiple lines of evidence supporting assessment findings. Consequently, it has been possible to hypothesise with a strong degree of confidence whether vegetation at each assessment site is likely to fit the definition of a GDE, or whether further information is required. The outcomes for each study site are summarised below.

The Lake Broadwater site is considered to represent a GDE based largely on the observed depths of tree root material compared with the depth of the saturated zone and supported by measurements of soil moisture and leaf water potential. This assessment is strongly supported by analysis of stable isotope values in both the soil and twig xylem moisture. The shallow perched aquifer overlies a 7.8m thick sequence of massive plastic clays and further clay-rich deeply weathered regolith of the Westbourne Formation which comprises a thick separation barrier between the perched aquifer and the underlying formations potentially subject to CSG depressurisation.

The Long Swamp site is considered unlikely to represent a GDE based on the depth to the saturated zone (15.8m), a maximum recorded rooting depth of 7.1m and evidence of a shallow source of soil moisture for river red gums of between 7.5 and 11.5mGL. Stable isotope data is inconclusive although due to the considerable enrichment of xylem water samples over soils, there is no indication that groundwater provides any significant contribution to tree water sources.

The Burunga Lane site is considered unlikely to represent a GDE based on the considerable depth to the regional aquifer at 13.5m, the observed shallow maximum rooting depth of 6m and evidence for a shallower source of soil moisture for river red gums of between 4.5 and 6.5m depth. Stable isotopes data, although inconclusive in terms of the depth of the soil moisture source for trees, does not support a groundwater source due to the considerable enrichment of stable isotope signatures measured in xylem water. There is a possibility that shallow seasonal groundwater may be present after significant rainfall events causing recharge to the creek alluvium, particularly when the creek is in a state of flow or flood. Ongoing monitoring is recommended to identify the presence of a seasonal shallow groundwater which may result in revision of the site's GDE status.

The Glenburnie site is considered unlikely to represent a GDE based on the considerable depth to the first observed saturated zone (perched seepage) at 13.5m, a maximum observed tree rooting depth at 7.6m, and evidence that trees in the vicinity of the site were utilising a shallow source of soil moisture between 9.0 and 11.5mGL. Similar to the Burunga Lane GDE investigation site, the considerable enrichment of xylem moisture over the isotope signature of soils suggests that groundwater is unlikely to provide any significant contribution to tree water resources.

Deeper rooted trees at all of the GDE investigation sites except Long Swamp 31 (Lake Broadwater) are considered likely to be tapping downward-percolating water moving under gravity through a near-saturated vadose zone. This vadose water likely exists in a transient state of near-saturation to saturation and is moving within a permanent wetting front associated with the adjacent ephemeral surface water bodies which temporarily channel and hold water for extended periods. Trees such as river red gum which require a high soil moisture potential appear to be tapping the near permanent sources of moisture described above which is available in horizons containing a balanced matrix of sand and fines which provide enough permeability for the high transpiration rates required for such trees, but also enough fine material to slow and hold water between wetting events (recharge), and hence buffer the effects of tree stress that would be caused by pronounced droughts. A key finding of the assessment is that the depth to the regional aquifer (potentially subject to CSG depressurisation) at each site is considerably deeper than:

- the deepest observed rooting depth,
- the inferred likely zone of predominant soil moisture uptake by trees, and
- the likely maximum tree rooting depth for deeper rooted potential GDE species (such as river red gums) of 18m. The exception is Burunga Lane (BL 182) where the regional aquifer was intersected at 13.5m, although the maximum observed tree rooting depth was at 6mGL.

Another key finding of this assessment was the relatively shallow maximum tree root depths observed compared with the maximum anticipated depth threshold of 18m based on literature studies. The deepest observed root depth across all of the study sites was 7.6m in sandstone at Glenburnie 20.

1.0 Introduction

Arrow Energy (Arrow) have commenced the development of the Stage 2 Coal Seam Gas (CSG) Water Monitoring and Management Plan (WMMP) which requires addressing any uncertainty in the groundwater-dependency of ecosystems and springs with supporting evidence from field-based investigations for any GDEs and springs confirmed in the OGIA model. A GDE assessment and monitoring program was developed to provide information necessary to address this requirement as part of a 3 phase program. This builds on the GDE investigations completed to date as part of the Stage 1 CSG WMMP. This document provides the initial results and analysis of the Phase 3 assessment.

This report follows two prior phases of work being:

1. Phase 1 which included a review of potential GDE assessment and monitoring methodology proposed by Arrow Energy (completed June 2017).
2. Phase 2 which required the development of a GDE study execution plan based on the outcome of the Phase 1 review (final execution plan submitted in January 2018). The execution plan, provided by 3d Environmental (2018a) involves a detailed description of methods to be employed during the baseline GDE assessment and installation of monitoring infrastructure. A summary of this information is provided in the methods section of this report.

Phase 3 assessment (study execution phase) commenced in December 2017. Details of the Phase 3 assessment within include a concise summary of project implementation including a description of methods employed, data collection protocols, analysis and interpretation, plus rationale for the GDE assessment and decision-making process.

1.1 Project Background

Arrow's Surat Gas Expansion Project's (SGP) Federal Environmental Approval Conditions require the development of a Stage 1 and Stage 2 CSGWMMP. The Stage 1 CSG WMMP was submitted to the Minister in December 2017 which included addressing three conditions relating to groundwater dependent ecosystems (GDEs), namely:

- Condition 13c: An assessment of potential impacts on non-spring based GDEs through potential changes to surface-groundwater connectivity and interactions with the sub-surface expression of groundwater.
- Condition 13f: A baseline monitoring network that will enable the identification of spatial and temporal changes to surface water and groundwater. This must include a proposal for aquifer connectivity studies and monitoring of relevant aquifers to determine hydraulic connectivity (including potential groundwater dependence of Long Swamp and Lake Broadwater) and must also enable monitoring of all aquatic ecosystems that may be impacted.
- Condition 13p: A cumulative impact assessment based on the outputs of the OGIA model which integrates groundwater model outputs with known and potential GDEs. Contribute to investigations coordinated through the OGIA to assess hydrological and ecological characteristics of impacted GDEs.

As part of the Stage 1 CSG WMMP, Arrow has previously commissioned and completed multiple phases of investigation and assessment aimed at gaining an understanding of the project's potential impact on GDEs. Previous studies which have dealt specifically with GDEs within Arrow tenements and surrounding areas include:

1. Assessment of potential spring GDEs undertaken by AGE (2015)
2. A characterisation of GDE types and distribution throughout Arrow Energy Tenements undertaken by 3d Environmental and Earth Search (2017) (Identification and Assessment of Groundwater Dependent Ecosystems – Surat Gas Project). Preliminary recommendations for monitoring of GDEs were made within this document.
3. Additional risk assessment of GDEs was provided within the SGP Stage 1 CSG WWMP (Coffey Environments 2017). A primary aim of the assessment was to screen potential GDEs to identify those at higher risk of impact through CSG related groundwater drawdown.

The findings from this body of work has identified discrete geographic areas of higher risk requiring further assessment and has informed Arrow's development of a method for further studies of risk to GDEs from CSG depressurisation. The assessment to identify the monitoring sites was carried out by Coffey Environments within the SGP Stage 1 - CSG WMMP (Coffey Environments 2017).

Coffey Environments (2017) relied on groundwater modelling undertaken by CDM Smith (2016) for Condamine River Alluvium (CRA) Aquifers and GHD (2013) for non-alluvial aquifers for its assessment to identify 'High Risk GDE Areas', which were defined as aquifers where >1m drawdown is predicted to occur over the life of the project. These areas were targeted for further assessment and numerous risk factors were evaluated which included:

- Species identified at the site do not typically utilise groundwater.
- Groundwater is too deep to be accessed by plants.
- Shallow lithology does not allow root penetration to groundwater level.
- Modelled drawdown impacts are unlikely to propagate to the groundwater table due to intervening aquitard lithologies.
- Rate of modelled drawdown change is sufficiently slow to allow plant adaptation.
- Background fluctuations in groundwater level would render modelled changes as insignificant or immeasurable.

From the risk assessment completed by Coffey Environments (2017), four areas within Arrow's tenements were identified for potential future monitoring purposes. These, as shown in **Figure 1** are:

1. Risk Area 4 GDE Investigation Site within the Burunga Lane Tenement (northern portion of Arrows Tenements between Miles and Wandoan).
2. Risk Area 3b GDE Investigation Site within the Glenburnie Tenement (northwest of Millmerran);.
3. Long Swamp GDE investigation site.
4. Lake Broadwater GDE investigation site.

The initial two sites were chosen to satisfy Condition 13c whilst monitoring of Lake Broadwater and Long Swamp areas is a requirement of Condition 13f.

The refinement process completed by Coffey Environments (2017) removed several previously identified risk areas based on one or more mitigating factors. The rationale provided for carrying through the two Risk Areas to be included in the Study scope, in addition to Lake Broadwater and Long Swamp, is summarised below:

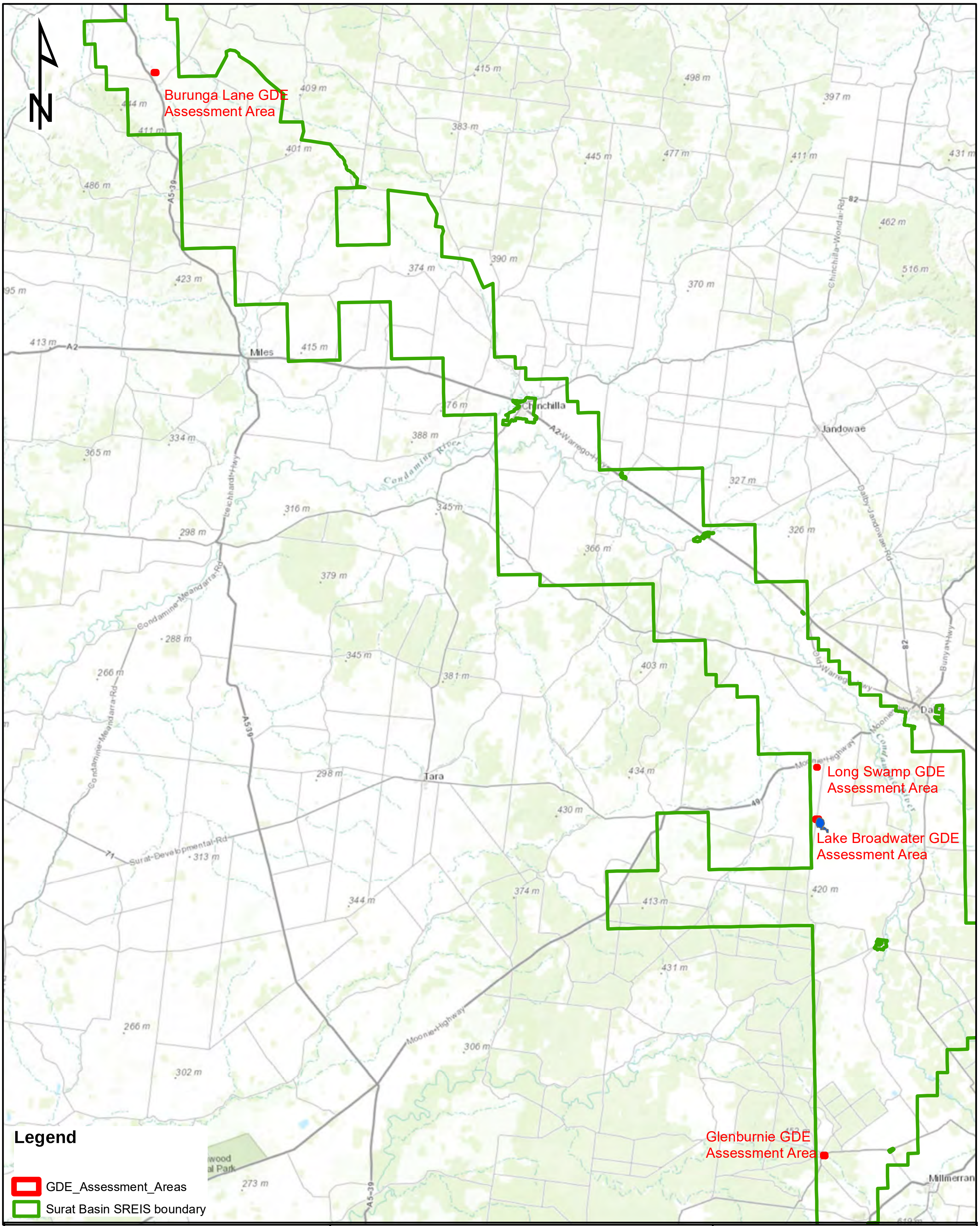
Risk Area 3b is located south-west of Cecil Plains on the western slopes of the Kumbarilla Range. Limited depth to groundwater data is available for the area, and where Red River Gums (*Eucalyptus camaldulensis)* are present they may access groundwater in the Springbok Sandstone. In the southern part of Risk Area 3b the maximum predicted drawdown is 3.9 m with a rate of change of groundwater drawdown estimated to range between 0.07 to 0.3 m/yr based on hydrograph analysis. The predicted rate of change is within the historical range of variability. However, the overall drawdown of almost 4 m in this southern part of Risk Area 3b may result in vegetation stress if critical groundwater access thresholds are exceeded. Therefore, terrestrial GDEs in the southern part of Risk Area 3b are considered potentially at risk from groundwater drawdown.

Risk Area 4 is located to the south and west of Wandoan where potential areas of shallow Walloon Coal Measures outcrop and subcrop beneath alluvium along some creek drainage areas. Maximum predicted drawdown in the Walloon Coal Measures in Risk Area 4 ranges from 1.5 to 10 m. The rate of groundwater drawdown in the Walloon Coal Measures in this area may be up to 4 m/yr early in the project life. Given this potential rate of change, and the presence of River Red Gums and other deeper-rooted trees growing within outcrop and subcrop areas, GDEs in the northern parts of Risk Area 4 may be at risk of impact from groundwater drawdown in the Walloon Coal Measures.

Arrow have since commenced the development of the Stage 2 Coal Seam Gas (CSG) Water Monitoring and Management Plan (WMMP) which includes addressing the following condition in relation to GDEs:

- *"Condition 17g: address any uncertainty in the groundwater-dependency of ecosystems and springs with supporting evidence from field-based investigations for any groundwater-dependent ecosystems and springs confirmed in the OGIA model."*

Further review of ecological and hydrogeological factors at each of the proposed monitoring localities in the Stage 1 CSG WMMP was undertaken by 3d Environmental/Earth Search during Phase 1 of this assessment to identify potential site conditions and constraints that may inform or direct GDE assessment methods. This information is provided in **Section 2.**



NOTES:

Figure 1. Distribution of GDE Assessment Areas

Client

Arrow

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1.2 Objectives

Objectives of Phase 3 assessment of the GDE Study, as provided by Arrow Energy are:

- Identify if vegetation accesses groundwater (permanently or intermittently) to verify assumptions used in previous desktop GDE assessments.
- Identify the degree of connection between aquifer units (including coal formations) to verify if propagation of drawdown in deeper coal measures will impact shallow formations.
- Identify stratigraphy to confirm geological mapping at monitoring sites.

1.3 Scope

The scope of work required to complete Phase 3 objectives is as follows:

- Field ecological and hydrogeological characterisation of potential GDE sites,
- Installation of monitoring infrastructure.
- Data collation and reporting.

Table 1 below provides a summary of the field testing scope undertaken. The location of these bores are shown in **Figure 2**.

Table 1. Field testing scope with summary of proposed boreholes.

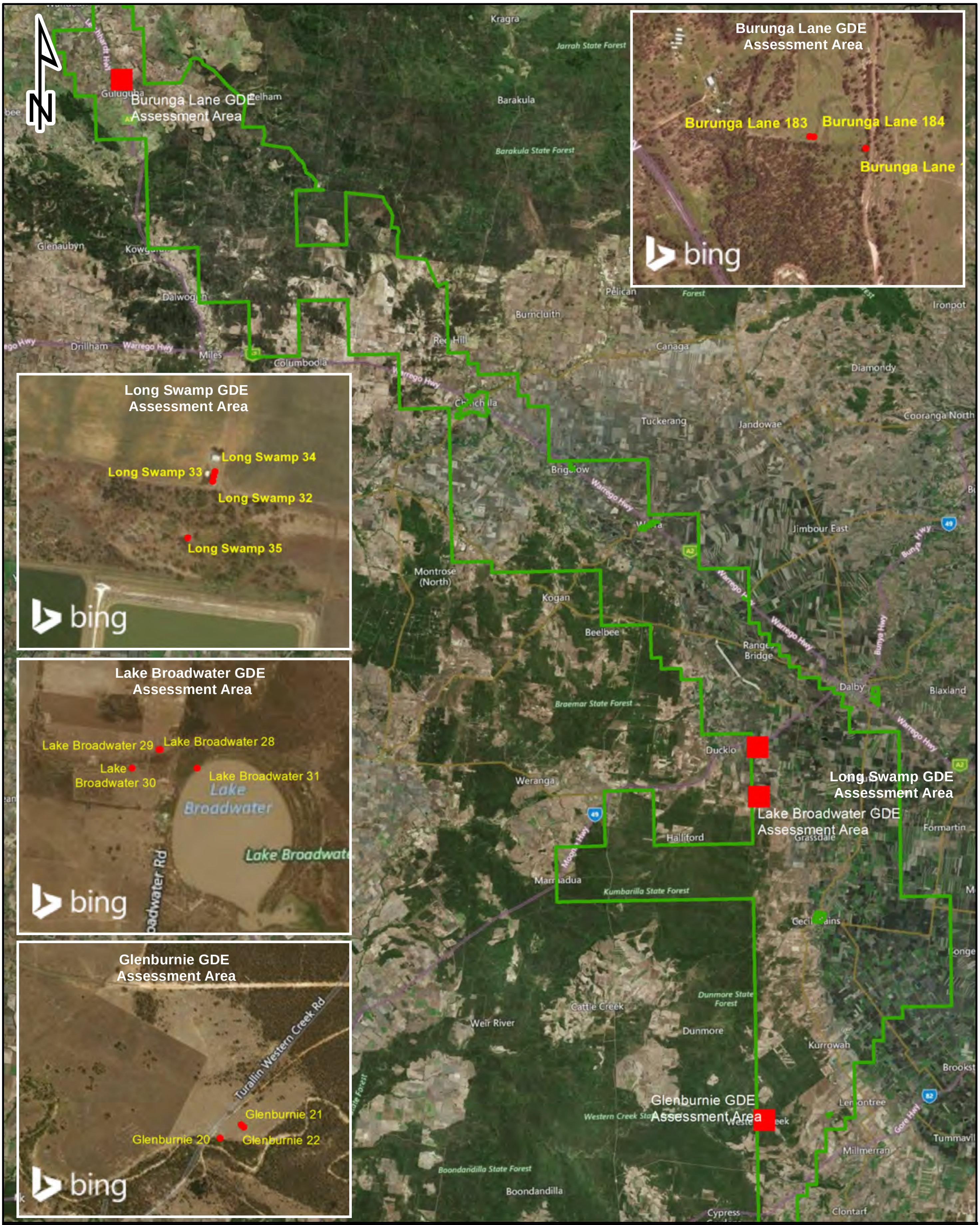
Site	**Bores and target aquifers for each site**	**Field testing scope**
Site 1 Long Swamp	Long Swamp 32: Westbourne Formation*	- **Groundwater monitoring** using data loggers to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy
	Long Swamp 33: Springbok Sandstone*	
	Long Swamp 34: Walloon Coal Measures*	
	Long Swamp 35: Alluvium (tree rooting depth hole)	- **Coring to identify rooting depth** of target plant species known to access shallow groundwater (i.e. <20m) and confirm stratigraphy - **Groundwater monitoring** using data loggers to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy - **Stable isotopes** (deuterium and oxygen-18) collected from the groundwater, soil water and plant xylem water to potentially identify the single or most dominant source of water - **Leaf water potential** of target plant species to identify the level of water stress experienced by the plant during dry periods and therefore if it relies only on rainfall/surface water flows
Site 2 Lake Broadwater	Long Swamp 28: Westbourne Formation*	- **Groundwater monitoring** using data loggers to collect information on:

Site	Bores and target aquifers for each site	Field testing scope
		• Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy
	Long Swamp 29: Springbok Sandstone*	
	Long Swamp 30: Walloon Coal Measures*	
	Long Swamp 31: Alluvium (tree rooting depth hole)**	- **Coring to identify rooting depth** of target plant species known to access shallow groundwater (i.e. <20m) and confirm stratigraphy - **Groundwater monitoring** using data loggers to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy - **Stable isotopes** (deuterium and oxygen-18) collected from the groundwater, soil water and plant xylem water to potentially identify the single or most dominant source of water - **Leaf water potential** of target plant species to identify the level of water stress experienced by the plant during dry periods and therefore if it relies only on rainfall/surface
Site 3 Southern part of Risk area 3b	Glenburnie 21: Walloon Coal Measures*	- **Groundwater monitoring** using data loggers to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy
	Glenburnie 22: Walloon Coal Measures*	
	Glenburnie 20: Springbok Sandstone (tree rooting depth hole)**	- **Coring to identify rooting depth** of target plant species known to access shallow groundwater (i.e. <20m) and confirm stratigraphy - **Groundwater monitoring** using data loggers to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy - **Stable isotopes** (deuterium and oxygen-18) collected from the groundwater, soil water and plant xylem water to potentially identify the single or most dominant source of water - **Leaf water potential** of target plant species to identify the level of water stress experienced by the plant during dry periods and therefore if it relies only on rainfall/surface
Site 4 Northern part of Risk Area 4	Burunga Lane 183: Walloon Coal Measures*	- **Groundwater monitoring** using data loggers to collect information on: • Local connectivity of shallow aquifer units (including coal formations)

Site	Bores and target aquifers for each site	Field testing scope
	Burunga Lane 184: Walloon Coal Measures*	• Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy
	Burunga Lane 182: Alluvium (tree rooting depth hole)*	- **Coring to identify rooting depth** of target plant species known to access shallow groundwater (i.e. <20m) and confirm stratigraphy - **Groundwater monitoring** using data loggers to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy - **Stable isotopes** (deuterium and oxygen-18) collected from the groundwater, soil water and plant xylem water to potentially identify the single or most dominant source of water - **Leaf water potential** of target plant species to identify the level of water stress experienced by the plant during dry periods and therefore if it relies only on rainfall/surface

* Addressed by AE connectivity report; **Addressed in this study.

A GDE Decision Matrix was developed to facilitate an informed decision as to whether an ecosystem is expected to be reliant on the presence of groundwater. The method considers Phase 3 assessment data which collectively provide confidence in the ecological and hydrogeological conceptual site model (CSM) to characterise whether each assessment site does or does not meet the definition of a GDE.



NOTES:

Figure 2. Proposed groundwater and GDE assessment wells.

3D Environmental

Vegetation Assessment
& Mapping Specialists

Client

Arrow

0 12 24 36 48

Kilometres

P. O. Box 959
Kenmore, Qld 4069
Mobile: 0447 822 119
www.3denvironmental.com.au

Legend

🟩 Surat Basin SREIS boundary

Scale 1:844,157	Drawn By DG	Checked DS	File Path	Date 13-Jul-18	A4

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1.4 GDE Definition Used for Assessment

The definition of a GDE applied to this assessment is provided in the *Supplementary Assessment – Arrow Energy Surat Gas Project – Supplementary Report to the EIS* (Coffey 2013):

- *Ecosystems dependent on the surface expression of groundwater including:*
    - *Springs, spring wetlands, spring fed watercourses.*
    - *Groundwater discharge to rivers and wetlands.*
- *Ecosystems dependent on the subsurface presence of groundwater, including plant roots accessing shallow groundwater. These are termed Vegetation GDEs.*

This is broadly consistent with the definition of GDEs provided in the guidance document *Modelling water-related ecological responses to coal seam gas extraction and coal mining* prepared by Commonwealth of Australia (2015) on the advice from the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC). This definition is described below: *Groundwater dependent ecosystems (GDEs): Natural ecosystems which require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services (Richardson et al. 2011). The broad types of GDE are (*from *Eamus et al. 2006):*

- *Ecosystems dependent on surface expression of groundwater*
- *Ecosystems dependent on subsurface presence of groundwater*
- *Subterranean ecosystems*

1.5 The Definition of Groundwater Used in this Assessment

Eamus (2006) defines groundwater (when related to GDEs) as;

'all water in the saturated sub-surface; water that flows or seeps downwards and saturates soil or rock, supplying springs and wells, water stored underground in rock crevices and in the pores of geological material'.

For this assessment, the term groundwater refers to those areas in the sub-surface where all soil or rock interstitial porosity is saturated with water. It is assumed that in the overlying unsaturated zone, water may be present in varying amounts over time although saturation is rarely reached during infiltration or percolation of rainfall, stream water or other surface sources of groundwater recharge moving under gravity. The definition of groundwater excludes:

- Water within wetting fronts, being the boundary between soil that is wet through the downward percolation of rainfall, or leakage from stream, lake or other surface sources of water and the dryer soil/rock in the unsaturated zone through which it is passing.
- Ephemeral zones of near-saturation created when the infiltration rate approaches the saturated hydraulic conductivity of a subsurface soil horizon or geological layer.

It should also be noted that potential impacts to groundwater created by Arrow's CSG depressurisation activities would only be expected in permanent aquifers that have capacity to store or transmit significant quantities of water under natural pressure gradients. Hence any vegetation dependent on water stored in the saturated zone of such aquifers would be subject to the greatest risk of impact from depressurisation.

1.6 Hydrogeological / Ecological Setting

The following sections provide a brief overview of the ecological and hydrological setting of the four chosen GDE Investigation Sites.

1.6.1 Lake Broadwater

Lake Broadwater is a naturally occurring, seasonal/intermittent, shallow, freshwater wetland which covers approximately 350 hectares within the 1212 hectares Lake Broadwater Conservation Park (DEHP 2012). Lake Broadwater is a highly significant ecological feature that is mapped as a Wetland of High Ecological Significance (DEHP 2014) and is listed in the Australian Directory of Important Wetlands (Australian Government 2010). Lake Broadwater's catchment is approximately 6000 hectares with inlet streams located to the south and west.

Figure 3. View north to south across Lake Broadwater from study site.

The groundwater monitoring site is located on a shallow sandy mantle of stranded shoreline deposits that fringes Lake Broadwater. The sandy apron forms a series of concentric sand ridges, which have geomorphic similarities to coastal beach ridges. The sandy feature is at its narrowest in this locality and broadens considerably toward the north-east where it forms a fringe around the lake that is approximately 250m wide. The site is located within fringing wetland woodland to open forest dominated by River Red Gum (RE11.3.27d) with the broad, seasonally fluctuating area of open water mapped as RE11.3.27a.

The lake goes through cycles of wetting and drying, occasionally overflowing. Only minor inflows of water occurred during a prolonged period of lower than average annual rainfall years between 2003 and March 2010 when it refilled. Further inflows have been recorded since 2010 during a number of major flooding events.

DEHP (2012) describes the lake as lying within a broad alluvial plain, deriving its water supply principally from rainfall entering the lake via two ephemeral streams—Surveyor's Gully to the south-east and Broadwater Gully from the south-west, and from low energy overland flow (run-off) from the surrounding flat area. The lake overflows to the north-west through the Broadwater Overflow into Wilkie Creek which drains northwards into the Condamine River. Queensland Government GDE mapping (DES 2017) identifies Lake Broadwater as a Derived Terrestrial GDE (with High-Confidence).
There are very few literature descriptions of the hydrogeological setting of the lake and potential groundwater-surface water interactions. An existing Ecological Conceptual Model has been developed by the QLD Government (DEHP 2012) but does not describe the geological setting or connectivity.
A preliminary hydrogeological/ecological Conceptual Site Model (CSM) for Lake Broadwater is presented in *Identification and Assessment of Groundwater Dependent Ecosystems*; Arrow Surat Gas Project (3d Environmental/Earth Search, 2017). This preliminary integrated ecological and hydrogeological model local has been refined further through this further phase of assessment and described in later chapters of this report.

Lake Broadwater sits within a transitional landscape of Jurassic-age Westbourne Formation colluvium overlying lower Westbourne regolith, and drains to the Condamine River Floodplain to the north (see **Figure 5**). The lower Westbourne Formation pinches out to the east of the Broadwater area, and the Condamine River alluvium to the east and north is underlain in the area by deeply weathered Jurassic age Springbok sandstone. Geological information from numerous groundwater bores drilled in the area suggests that there is a deep weathering profile, likely laterised in places through deep leaching. Underlying Westbourne Formation siltstone and claystone has weathered to a series of clay-rich horizons. Lake Broadwater is a perched depositional feature on this claypan, likely receiving further infilling lacustrine sedimentation as wash from local colluvium. There is likely a deep wetting front extending downwards into the regolith.

Hand auger sampling conducted during preliminary assessment (3d Environmental/Earth Search, 2017) indicated that the layer of friable sand is relatively thin before it passes into a sequence of indurated sand and clay with bands of Fe-oxide. This partially cemented horizon was relatively consistent down to a depth of 2.3m where hand augering encountered tight clay. Taylor and Eggeleton (2001) identified similar Fe Oxide bands in sand dunes surrounding Lake George (Central NSW), thought to be formed by the illuviation of clay material into bands which act as a permeability barrier leading to precipitation of Fe-oxides in ephemeral perched water tables. While no groundwater was encountered during the previous assessment, the presence of an indurated sand layer above the underlying clays (suggesting a zone of fluctuating groundwater levels), indicates that perched groundwater may be seasonally present.

There was no indication of a permanent shallow perched groundwater table in this locality, either through assessment of nearby groundwater bore logs, and also through hand augering undertaken to a depth of 2.3m. While there is no shallow saturated sands encountered beneath the immediate lake fringe, including at a depth well below the lake bed, This suggests that the red-gum forest is either sustained by deeper groundwater sources, or alternatively was extracting residual groundwater moisture held within the sand and upper clay horizons following capture of rainfall or retreat of the lake margins.

Most bores in the area are drilled to 40-140m depth into the deeper, less weathered Springbok Sandstone aquifer, and historical groundwater levels stand at around 9-16m below ground level (bgl). Groundwater levels in the Walloon Coal Measures (>140m depth) are generally >40mGL. Historical groundwater yields from bores in the area are relatively low <0.5l/sec), and brackish (>1000ppm total dissolved solids (TDS)). A number of bores in the area are listed in the DNRM Groundwater Database as tapping the Condamine River Alluvium aquifer. Based on a review of the available stratigraphy and bore logs, these are in fact likely tapping the upper weathered Springbok Sandstone or lower Westbourne Formation.There are no registered groundwater bores located within the shallow sand deposits fringing Lake Broadwater.

During previous Lake sampling ((3d Environmental/Earth Search, 2017), Radon presence of 0.12 Bq/L in the lake surface water sample almost certainly indicated some recent groundwater inflow around the time of that monitoring event conducted during a low lake level in November 2016. High dD and d18O isotope results as well as brackish salinity (3570ppm Total Dissolved Solids (TDS)), indicated a water chemistry that had undergone evaporative enrichment.

At the time of the previous field survey, the lake had recently received overland flow run-off from the south due to rainfall events in the catchment but was not approaching flooding levels. Previous higher-level shore strand lines were exposed. Poorly developed shallow outlet drainage channels to the north east (to Long Swamp) and to the north west (to Wilkie Creek) suggest that these features are only active during flooding due to high evaporation rates compared with inflow rates.

The source of possible recent groundwater discharge indicated by Radon levels is unclear. Hand augering at the time of that event in a localised area suggested that the thin sand body located at the lake fringe was dry at the time of assessment. This suggests that there may be some other potential areas of groundwater connectivity to the Lake. Only a relatively small area of the shallow lake margin geology was assessed by hand augering and groundwater may be present within the surrounding sandy foreshore sediments elsewhere within the lake margin, or some other source of connected groundwater may exist.

Observations from hand augering during previous assessment, and a review of bore logs support the likelihood that the lake is perched on a relatively low permeability clay pan associated with a weathered surface of the Westbourne Formation. Regardless, relatively shallow (9-16mGL for SWL) in the underlying Springbok Sandstone groundwater on the western margins of the lake, and the presence of Radon in the surface water suggests that the subsurface conceptualisation would be enhanced through further shallow geological investigations to assess the potential for hydraulic connectivity and allow further refinement of the conceptual site model previously developed. This has been undertaken and is described within this report.

Figure 4. Lake Broadwater with a fringing sandy mantle. The large River Red Gum is the tree targeted for assessment.

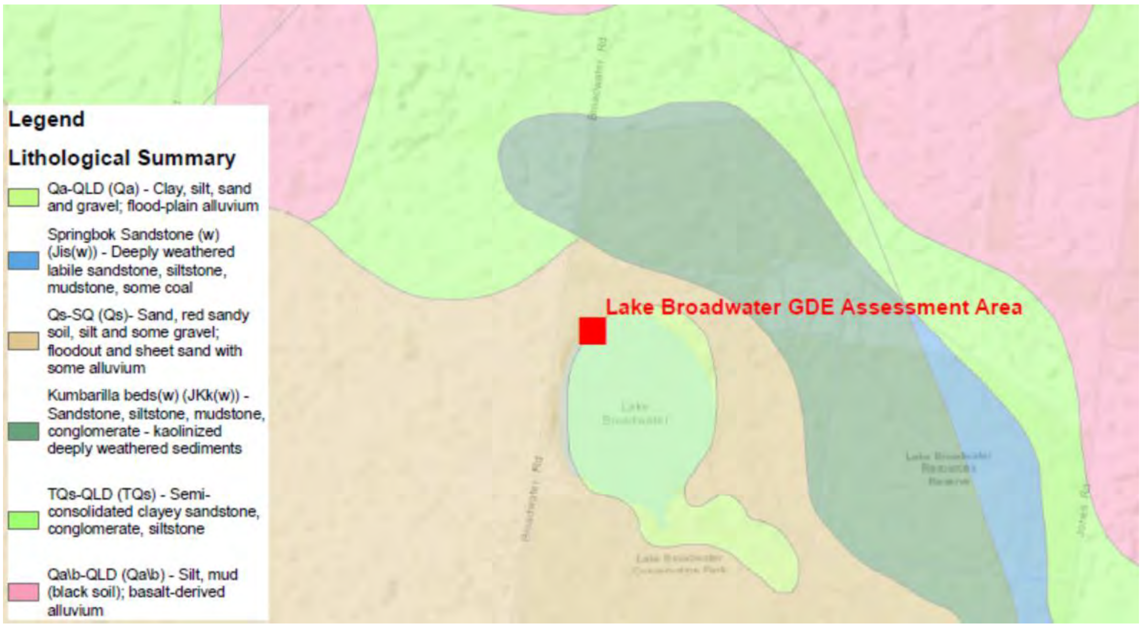


Figure 5. Surface geology of the Lake Broadwater Area (DNRM, 2018).

1.6.2 Long Swamp

Long Swamp is a broad sinuous overland flow path that extends for a distance of approximately 30 km on the Condamine Alluvium. When in flood, the swamp flows in a north-westerly direction to the east and north of Lake Broadwater, before joining Wilkie Creek to the west. The feature comprises a broad drainage depression, with the central portion underlain by highly vertic surface soils with a strong shrink-swell structure of hummocks and deep cracks. There was no flow, nor significant pooled water within Long Swamp during previous field visits, despite heavy recent rains. These observations together with the observations of deep, open cracks in the central swamp channel soil surface confirmed that the feature is only active during flooding.

Long Swamp is a palustrine wetland (tree swamp) and the vegetation is largely native with the canopy formed by tall, broadly spaced River Red Gum at approximately 50% cover. The canopy is significantly stressed in some areas with signs of senescence and foliage loss. Groundcover consists of Water Chestnut (*Eleocharis dulcis),* Nardoo (*Marsillea drummondii)* and patch covering of the exotic Condamine Couch (*Phylla canescens).* The Queensland Government maps Long Swamp as Wetland of High Ecological Significance (DEHP 2014)

Queensland Groundwater Dependent Ecosystems Mapping (DES 2017) identifies Long Swamp as a Derived Terrestrial GDE (with Low-Confidence). The system is described as a '*Deep rooted regional ecosystems intermittently connected to aquifers with saline salinity and neutral pH in unconsolidated Quaternary alluvia in the Condamine River drainage basin sub-area'.*
Surface geology mapping (DNRM 2018) indicates Long Swamp is formed on a broad depression associated with basalt derived alluvium (Qa-b) amongst low rises of Tertiary age semi-consolidated sediments (TQs – QLD) (see **Figure 7**). 3d Environmental/Earth Search interpret the surface geology to consist locally of quaternary clays, silts, sands and gravels of the Condamine River Alluvium (CRA) with subcropping tertiary sands and gravels of the Chinchilla Sands or equivalents which subcrops under the CRA in the study area as a coarse basal weakly consolidated sand unit and occasionally outcrops above the CRA flood plain as low sandy rises.

Stratigraphy from water bore data (Bore RN#30670, 24332, 24329 & 24853) indicates a thick layer of clay to loamy clay to a depth of 13-15m before passing into a variably thick basal sand horizon with clay interbeds to depths of 25mGL. The upper surface of the sandy horizon likely indicates the original SWL of the undisturbed aquifer. Several groundwater bores (e.g. RN 24332, 30670) in vicinity of Long Swamp had SWLs of around 15mGL in the 1950s-60s, and current water levels show relatively little change (SWL of 16 to 18mGL when baselined recently by Arrow Energy) compared to drawdown trends elsewhere in the CRA (discussed further in this report). DNRM monitoring bore 42230155 located in Long Swamp has recorded a clear but relatively modest decline in SWL from 16.01mGL in 1965 to 18.68mGL in Jan 2017.

A preliminary hydrogeological/ecological CSM for Long Swamp and other smaller overland flow paths on the Condamine River Alluvium (CRA) was previously presented in 3d Environmental/Earth Search (2017). Due to the thick layer of heavy clay which is likely to provide significant resistance to tree root penetration, it was considered unclear as to whether mature canopy trees have historically had capacity to tap groundwater sources as deep as 15mGL, and it was noted that the current standing water levels hover around the lower threshold range for Vegetation GDE impact. The senescence of mature canopy trees may also be partly or wholly related to changes in surface flow volumes, as a result of observed nearby large-scale surface water extraction for irrigation. Further shallow geological investigations and the installation of monitoring sites were recommended to better define this preliminary conceptualisation. This has been undertaken and is described within this report.

Figure 6. Vegetation at the Long Swamp 35 GDE assessment site.

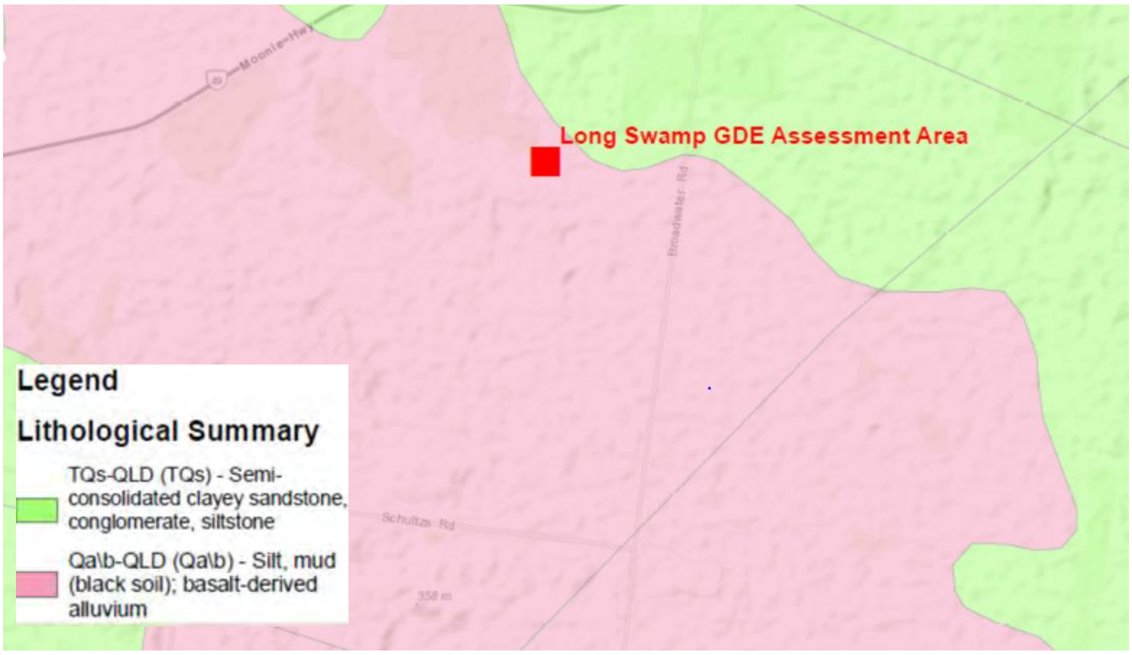


Figure 7. Surface geology mapping in vicinity of the Long Swamp assessment area as produced by DNRM (2018).

1.6.3 Burunga Lane

The Burunga Lane monitoring site is located between the townships of Wandoan and Miles and is situated to the immediate west of the main channel of Juandah Creek. The study site lies on a broad flat to gently undulating partially confined alluvial terrace that extends for approximately 530m on the western side of the creek, separated from gently undulating sandstone foot-slopes by a narrow overflow channel. The alluvial landform on the eastern side of the creek is much narrower and passes rapidly into colluvium on low foothills. The creek presents as a sandy drainage channel of approximately 20m wide, incised to a depth of approximately 3m below the floodplain (see **Figure 8**). The channel benches are fringed by a line of mature river-red gum, which are targeted for GDE assessment. The vegetation is considered non-remnant in Queensland Government databases on account of its fragmented nature. Ground covers are typically exotic pasture grasses of which buffel grass (*Cenchris ciliaris)* is most abundant.

Surface geology mapping (DNRM 2018) identifies the Burunga Lane site as being located on a sinuous band of Quaternary Age alluvium (Qa) associated with Juandah Creek, between confining colluvium and foot slopes of outcropping Springbok Sandstone (Jis) (**Figure 9**).

The Juandah Creek channel adjacent to the study site was dry during the assessment period, despite some recent moderate rainfall events. Queensland Groundwater Dependent Ecosystems Mapping (DES 2017) identifies Juandah Creek as a Terrestrial GDE – Low Confidence.

A Hydrogeological/ecological CSM for was developed for streams, including Juandah Creek and is included in the Shallow Drainage Subsurface GDE System CSM as proposed by 3d Environmental/Earth Search (2017). Streams that fit within the model are perennial streams that are shallowly incised into basement rock with localised alluvial development restricted to the margins of the watercourse and associated flood pockets. The drilling and detailed subsurface characterization undertaken in this assessment allowed a comprehensive assessment of an example site within one of these systems and the development of a more detailed site-specific hydrogeological/ecological CSM. The major questions in relation to streams within this CSM type is whether associated riparian vegetation is supported by shallow alluvial aquifers or whether tree roots are accessing groundwater in confined aquifers. The installation of monitoring sites were recommended to better define this preliminary conceptualisation.

Figure 8. Sandy reach of Juandah Creek adjacent to Burunga Lane GDE Assessment Area.

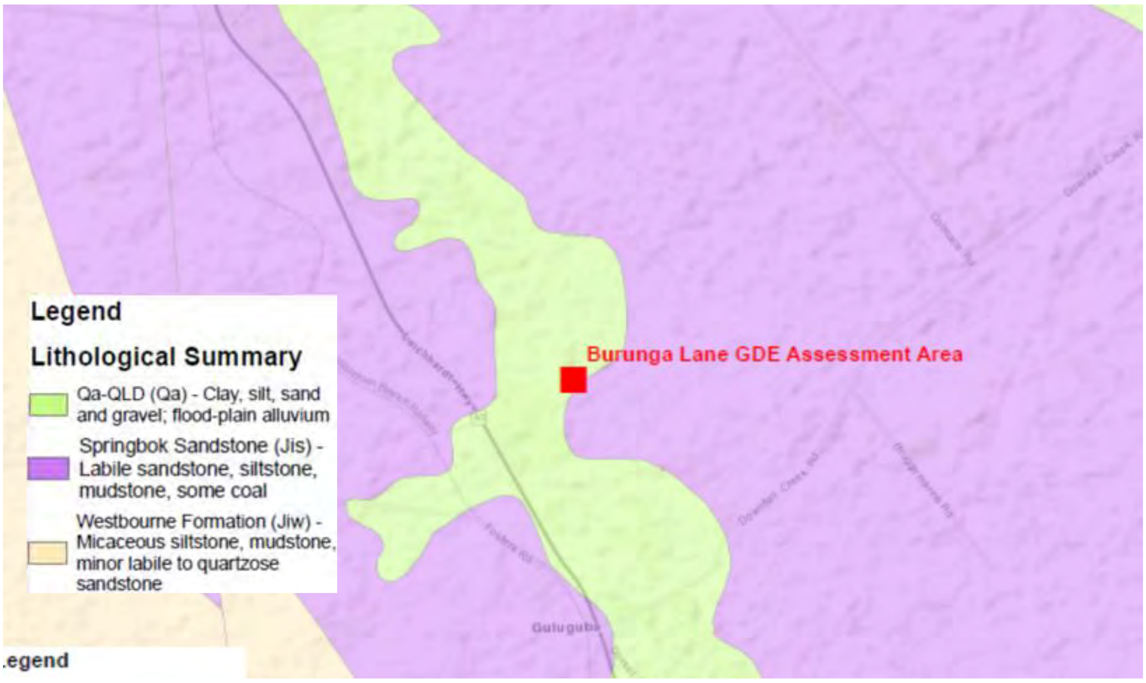


Figure 9. Surface geology at Burunga Lane as produce by DNRM (2018).

1.6.4 Glenburnie

The Glenburnie site is located on Western Creek which presents as a sandy creek channel with a narrow sinuous overflow flood terrace that has only limited alluvial development. The channel is moderately confined by deeply weathered Springbok Sandstone that variably outcrops in stream benches and along the channel floor with the sandy bedload overlying a weathered sandstone regolith (**Figure 10**). The Western Creek channel adjacent to the study site was dry during the assessment period, despite some recent moderate rainfall events.

Vegetation along the creek is lesser developed than other GDE localities with considerable dieback of the larger canopy trees including river red-gum and rough-barked apple (*Angophora leiocarpa*) and a large number of trees representative of 15 to 30yo regrowth. White cypress pine (*Callitris glaucophylla)* is also an abundant sub-canopy tree on and adjacent to the Western Creek floodplain, generally indicative of shallow basement rock. Ground covers generally comprise native grasses.

Surface geology mapping produced by (DNRM 2018) indicates the Glenburnie assessment area is located on Springbok Sandstone (Jis) (**Figure 11**). In the Arrow Energy tenement study areas, most of the tributary systems typically meander through and are variably incised into the low colluvial slopes of the Westbourne and Springbok Sandstone Formations before flowing out onto the southern margins of the Condamine River floodplain or the Fitzroy Catchment in the northern section of Arrow's tenements. Outside of the CRA a lack of groundwater dependent vegetation away from the immediate riparian corridor suggests an absence of shallow permanent soil moisture and alluvium-hosted groundwater. Registered groundwater bore RN#32726A located approximately 1km to the west of the study site indicates groundwater levels in the underlying Walloon Coal Measures were 14.6m in 1969 and had dropped to 23.5m in 1983. During drilling of this bore in 1969, both the sandstone and coal seams encountered were noted to be water-bearing. It should also be noted that this bore was deepened in 1983 from 67 to 97m.

A preliminary hydrogeological/ecological CSM for Shallow Alluvium Systems such as the Glenburnie and Burunga Lane sites was previously presented in 3d Environmental/Earth Search (2017). Previous field examination of these watercourses noted that underlying bedrock often formed low permeability base to pools which hold water for extended periods. Deeper GAB aquifer standing water levels are typically well below the base of the alluvium suggesting that any connection is likely to be associated with a deep "wetting front" where, in areas of reasonable bedrock permeability, the shallow "losing" alluvial systems can provide an important source of downward percolating recharge water to underling GAB formations. Further refinement of these CSMs local to the study sites has been reported in subsequent chapters of this report.

Figure 10. Sandy channel of Western Creek with a narrow confined alluvial floodplain.

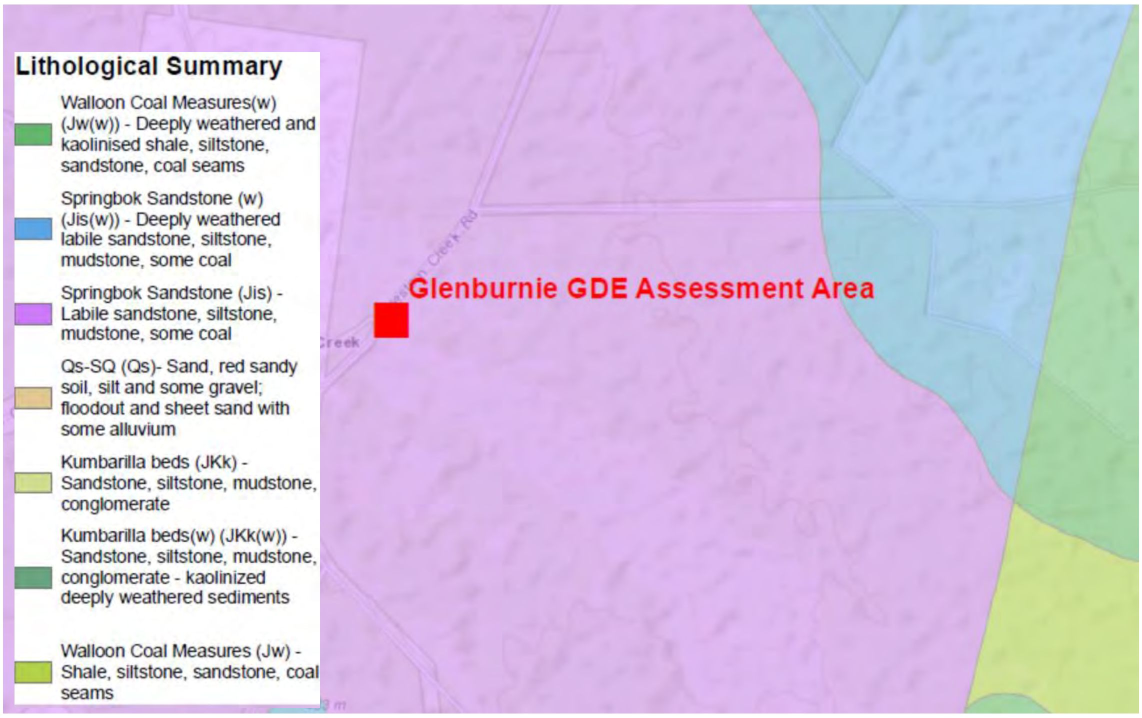


Figure 11. Surface geology at the Glenburnie GDE Assessment Area as produced by DNRM (2018).

2.0 Methods

The following section provides an overview of methods utilised during the Phase 3 assessment. It follows methods detailed within the *Arrow Surat Gas Project Groundwater Dependent Ecosystem Characterisation and Monitoring Study – Study Execution Plan* which is included in **Appendix K**. Where there were any significant deviations from this plan, due to unidentified constraints or process requirements, these are identified and discussed. The synthesised ecological and hydrogeological information obtained from the following methods has provided multiple lines of evidence for assessment of GDE status and potential impacts:

- Coring to root depth
- Groundwater monitoring
- Soil moisture potential measurement
- Leaf water potential measurement
- Stable isotope analysis
- Leaf area index measurement (and ecological characterisation)

2.1 Assessment Timing and Conditions

The GDE assessments and installation of groundwater monitoring bores was completed in two separate mobilisations. Long Swamp 35 and Burunga Lane 182 assessments were completed from the 8th to 15th December 2017 and Long Swamp 31 and Glenburnie 20 completed from the 14th to 18th February 2018. Data from the nearest reliable weather recording stations to each GDE assessment site are included to as context to the prevailing climatic conditions at the time of assessment. Climatic data has been sourced from the Bureau of Meteorology website (http://www.bom.gov.au/climate/data/?ref=ftr).

The weather station at the Dalby Airport (20km NE of the Long Swamp 35 assessment site) recorded slightly above average rainfall for 2017 with 622mm falling compared to a long term average of 603 mm. The month of October 2017 was extremely wet with 120.6 mm recorded compared to a long term monthly average of 63.1 mm. November recorded well below average rainfall with 10.6 mm falling compared to a long term average of 71.0 mm. Prior to drilling Long Swamp 35, 21.4 mm of rainfall fell in a storm on the 3rd of December. A further 20.6 mm fell on 9th December the day before drilling commenced. Maximum temperatures recorded during the drilling of Long Swamp 35 ranged from 30.0°C on the 11th December to 32.6°C on the 9th with a relative humidity of 31% at 3 pm.

The weather station for Miles Post Office (47km south of the Burunga Lane GDE assessment site) recorded well below average rainfall for 2017 with 464.6 mm falling compared to a long term average rainfall of 648.8mm. Prior to installation of the Burunga Lane 182 monitoring well, 79.1 mm of rainfall fell in October, which was above the long term average for the month of 53.6 mm while 56.6 mm fell in November compared to a long term average of 64.4 mm. Rainfall of 12 mm was recorded on December 9th three days prior to well installation. Maximum temperatures during the assessment ranged from 32°C on the 11th December to 36.0°C on the 15th.

Prior to installation of Long Swamp 31 monitoring well on the 14th – 15th February, 34.4 mm of rainfall was recorded at the Dalby Airport (26 km NE of the assessment site) in January, well below the long term average of 76.1 mm for the month. A total of 48.8 mm fell in storms on the 2nd, 3rd and 4th of

February several days prior to well installation. The highest temperature recorded during the assessment reached 34.9°C on the 14th February coupled with a low relative humidity of 39.7% at 3 pm.

There are no reliable weather stations in close proximity to the Glen Burnie GDE assessment site. The Dalby Airport Site 76 km north of the site recorded maximum temperatures of 33.6°C on the 18th of February with a humidity of 27% at 3pm. An estimated 15 - 25 mm of rainfall fell at the site which temporarily saturated soils at the surface, although there was limited evidence in drill core of any significant percolation of rainfall and ground conditions dried rapidly.

2.2 Coring to Root Depth

The drilling rig used for both events was a Commachio MC900 sonic rig which combines rotation and high-frequency vibration for drill bit penetration. This method was successful in the recovery of an almost continuous, relatively undisturbed core in both consolidated rock and unconsolidated soils at all four study sites. The sonic drilling method was chosen for this study due to rapid drilling rates (minimising time spent in sensitive environments), recovery of a continuous core for detailed descriptions and observations of lithology and tree root material, relatively minimal amounts of waste generated, and the ability to minimise the disturbance footprints within sensitive GDE environments. No tree removal, or vegetation disturbance (apart from grass cover which has since recovered) was required. The sonic coring system utilised the drilling of a 175mm diameter hole, collection of a 150mm core, and installation of 100mm diameter groundwater monitoring bores. Drilling was conducted in accordance with the methods described in detail within the Study Execution Plan (**Appendix K**), apart for a few minor exceptions as noted within this report.

At most sites, three holes were drilled at each site around the target tree to a maximum depth of 30m (12m below the maximum anticipated tree rooting depth), including 1 angled hole targeting root material directly beneath the tree. The only exception to this scope was Long Swamp 31 (Lake Broadwater) where limited access for the support truck around mature trees meant that the automatic rod handler could not be mobilised into the site for drilling of the angled core hole. Therefore only two core holes were drilled at this site. An additional hole was also drilled at the Burunga Lane site solely to determine the depth to the regional aquifer bringing the total of holes drilled at this site to four. The additional hole was drilled dry (without injection of water) to a depth of 15m and core was not retained for detailed logging.

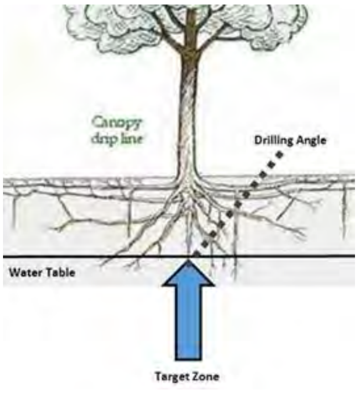
The following sequence of coring and related activities was generally followed in order to maintain sample integrity and minimise drilling down-time while sampling was undertaken. Some alteration to this schedule was required to adapt to field conditions encountered:

1) **Core 1:** 30m vertically cored bore to allow detailed geological logging which will inform subsequent sample collection, and design of groundwater monitoring bore/s to be constructed in the second corehole (Core 2). The following analysis and activities will occur on this core hole:
    a) Detailed geological logging.
    b) Photograph core.
    c) Field inspection for tree root material.

  d) Preservation of core for transport to 3d/Earth Search laboratory for further inspection for tree root material; and collection, weighing (to determine any loss of moisture), and bagging of samples for potential future permeability analyses.
  e) Grouted upon completion.

Figure 12. Commachio MC900 Sonic Drilling Rig operating at the Lake Broadwater Study Site.

2) **Core 2:** Maximum 18m (maximum anticipated tree root depth) vertically cored bore for comprehensive field and lab sampling program and construction of groundwater monitoring bore.
  a) Geological logging.
  b) Soil moisture sampling (dispatch to laboratory).
  c) Soil moisture potential testing (field).
  d) Soil moisture isotope analysis sampling (dispatch to laboratory).
  e) Field inspection for tree root material.
  f) Preservation of core for transport to 3d/Earth Search laboratory for further inspection for tree root material.
  g) Construction of groundwater monitoring bore.



3) **Core 3:** Maximum 18m depth (longer linear drilled length) angled core to increase the chance of encountering tree root material. The rig head and coring string was angled to intersect the tree root zone directly below the tree at the projected depth of the water table / capillary fringe. This was required to maximise chances of tree root intersection. In addition, the following activities will be implemented:
    a) Geological logging.
    b) Field inspection for tree root material.
    c) Preservation of core for transport to 3d/Earth Search laboratory for further inspection for tree root material.
    d) Grouted upon completion.

Upon completion of the core holes at each site that were not converted into a groundwater monitoring bore, these were properly abandoned in compliance with the Minimum Construction Requirements for Water Bores in Australia – Version 3 (National Uniform Drillers Licensing Committee, 2012), by filling the bore hole from TD to surface with a bentonite/cement grout mix.

Figure 13. Angled core hole being drilled at the Glenburnie Study Site.

2.2.1 Geological and Hydrogeological Logging

Detailed drilling logs were recorded on site by a qualified geologist and are presented in **Appendix D**. Drilling logs include descriptions of the lithology encountered, presence and description of tree roots, moisture and groundwater observations, depths of all samples collected, soil moisture potential measurements, and gas concentrations. Core material was wrapped in thick PE plastic, sealed, and placed into steel core trays for transport back to an off-site laboratory. Further detailed stereo microscope logging and photography, and collection and preservation of samples for potential future permeability testing was undertaken in the off-site laboratory.

2.2.2 Root Material Logging

Observations and sampling of root materials were undertaken on site during drilling by a qualified botanist with the aid of a hand lens. Drill core was transported to an offsite laboratory where further detailed examination for tree root material was undertaken. Where root material was recorded, rooting depth, diameter and other root structural observations were noted. This data was then recorded on detailed drilling logs for future reference (**Appendix D**).

2.3 Groundwater Monitoring Bore Installation and Sampling

2.3.1 Groundwater Monitoring Bore Construction

Groundwater monitoring bores were installed within the saturated geological horizon most likely to contain water that could be accessible to deeper rooted trees in each study area. A single monitoring bore was installed at each GDE investigation sites which includes Long Swamp 35, Long Swamp 31, Burunga Lane182 and Glenburnie 20 bringing the total number of monitoring bores installed to four (see **Figure 2**, **Section 1.3**).

At all sites, 100mm diameter groundwater monitoring bores were installed except at Glenburnie 20 where a 50mm diameter monitoring bore was installed to negate the requirement for adding drilling water for running 175mm temporary casing prior to monitoring bore installation.
Groundwater monitoring bores were typically constructed in accordance with the design shown in Figure 14. Details of the groundwater monitoring bore drilling and construction methods followed are provided in the *Study Execution Plan* (see **Appendix K**).

Groundwater bores were designed and constructed in accordance with *Minimum Construction Requirements for Water Bores in Australia – Version 3* (National Uniform Drillers Licensing Committee, 2012), the Australian Drilling Industry Manual (5th Edition, revised 1995)", and where intersecting Great Artesian Basin (GAB) formations: *Minimum standards for the construction and reconditioning of water bores that intersect the sediments of artesian basins in Queensland*, (Queensland Government Department of Natural Resources and Mines (DNRM), 2014). All groundwater monitoring bores were drilled and constructed by a Class 2 Licensed Water Bore Driller. Bores were registered with QLD Government DNRM as Groundwater Monitoring Bores.

Significant care and time was taken during drilling to observe for the presence of shallow saturated zones within the potential rooting depth of trees (<18m). Efforts to allow detection of subtle changes in moisture and the possibility of free water draining into the core hole included:

- Drilling without water wherever possible, even where this resulted in significant delays drilling and retrieving core material.
- Regular drilling breaks were taken during drilling of the upper 18m to observe for the presence of free water in the core hole, using an electronic dip meter. In some cases holes were left for several hours, or overnight before monitoring bores were constructed (if water entered), or drilling continued
- Compressed air was not used during drilling as this can result in drying of the bore hole skin and displacement of water with pressurised air in a zone around the bore.

- Drilling mud was not added to stabilise the bore hole as this could lead to development of a mud cake around the bore hole, therefore suppressing the inflow of formation water.

Drilling of groundwater monitoring bores without any water (such as Glenburnie 20) meant that development activities could be minimised and groundwater samples collected with complete confidence that they represented true formation water. Many of these actions and observations are recorded on the drilling logs (**Appendix D**).

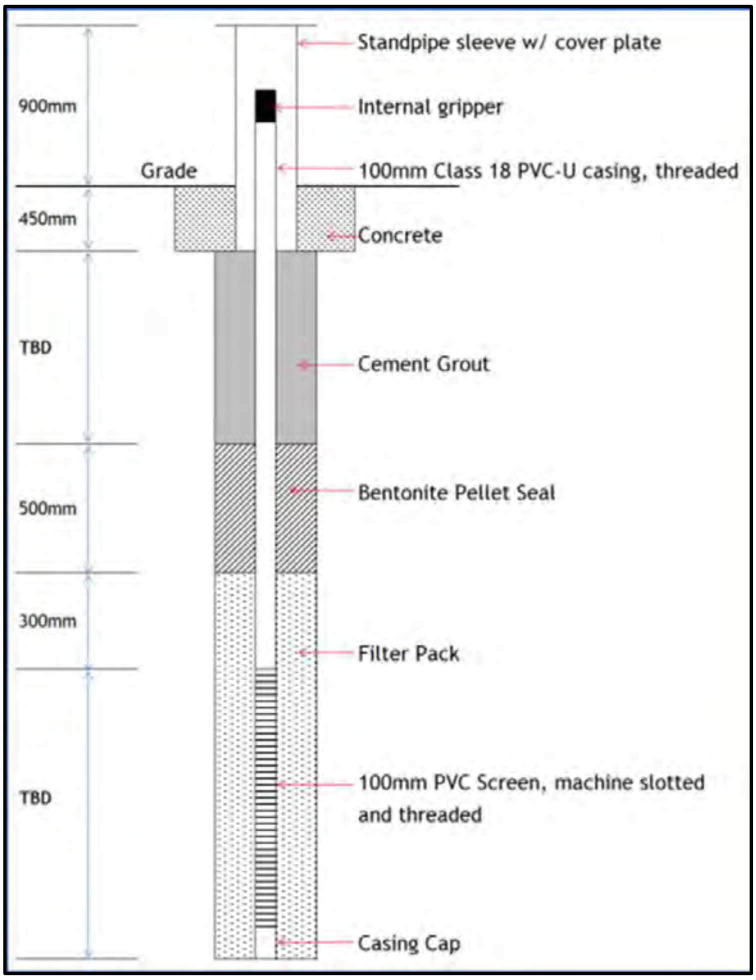


Figure 14. Groundwater Monitoring Bore Design

Figure 15. Construction of groundwater monitoring bore at Long Swamp 35.

Figure 16. Completed groundwater monitoring bores with protective monument covers at Long Swamp 35 next to target River Red Gum and Long Swamp 31 (Lake Broadwater).

In 3 of the 4 study areas (Long Swamp, Lake Broadwater and Glenburnie) a deeper (regional) aquifer was encountered below the maximum anticipated, and well below the maximum observed, tree root depth. The deeper aquifer at all of these sites (18-30m) was considered of little relevance to the objectives of this study, as these units were considered inaccessible for tree water uptake. Therefore groundwater monitoring bores were installed in shallower "perched" saturated zones. At Burunga Lane a deeper (likely regional) aquifer was also encountered below a perched groundwater horizon, but in this case was also at a depth (13.5m) that could conceivably be accessible to tree roots. It should be noted that tree roots were not observed below 6m.

Underlying deeper formations and regional aquifers were targeted by the drilling and construction of deeper aquifer groundwater monitoring bores within a related and complementary drilling campaign managed directly by Arrow Energy. This deeper programme allowed further coring and assessment of geological conditions and potential interconnectivity within intervening geological horizons, and the installation of groundwater monitoring bores within underlying aquitards and aquifers potentially subject to depressurisation. All groundwater monitoring bores will comprise the GDE groundwater monitoring network.

Due to the possibility of encountering coal seam gas, the deeper drilling programme was undertaken with a larger drilling rig equipped with gas diversion or blow out protectors (BOPs). Due to the larger drilling footprint of this rig, drilling sites were not able to be located immediately adjacent to the shallow GDE study sites, and were typically located 50-475m distant. Further details of the deeper groundwater monitoring bore drilling programme is reported under separate cover (Arrow, in press).

Figure 17. Nested deeper aquifer groundwater monitoring bores near Long Swamp 35 (Long Swamp 32, 33, and 34).

2.3.2 Groundwater Monitoring Bore Development

Development of groundwater monitoring bores was undertaken by a qualified hydrogeologist approximately 4 weeks after completion of the monitoring bore drilling programme between 14-15 March 2018. Development was undertaken by removal of 5-7 bore volumes by hand bailing until field groundwater quality parameters stabilised. Air-displacement and submersible pumps were mobilised to the site for development. However due to the very low recovery rates (<1L/minute) observed after evacuation of the initial bore volume, pumping was not considered feasible.

Burunga Lane contained insufficient groundwater (<1l of sediment-laden liquid removed) at the time for development to occur. This bore is installed in a seasonal perched aquifer and would require a significant rainfall event and subsequent inundation of the river alluvium before development and sampling could occur.

2.3.3 Groundwater Monitoring Bore Instrumentation

Groundwater monitoring bores were instrumented with unvented insitu Inc. Level Troll 400 pressure transducer/loggers. Transducers were suspended approximately 0.5m from the bottom of each monitoring bore on stainless steel cable or Kevlar braid connected to a D-ring within the internal bore cap “gripper”. Caps were fitted with brass ports for sampling and measurement of internal gas concentrations.

2.3.4 Groundwater Monitoring Bore Sampling

Baseline sampling of groundwater monitoring bores was undertaken by a qualified hydrogeologist approximately 48 hours after monitoring bore development and approximately 4 weeks after completion of the monitoring bore drilling programme, between 16-17 March 2018. Groundwater samples were collected from each groundwater monitoring bore using disposable bailers dedicated to each monitoring bore. Samples were transferred directly from the bailer into laboratory supplied bottles and placed immediately on ice until transfer to the laboratories. Groundwater sampling followed methods described in the Study Execution Plan (see **Appendix K**) and the Geosciences Australia *Groundwater Sampling and Analysis – A Field Guide* (Sundaram, et al., 2009).

Prior to both development and sampling, depth to the standing water level was measured with a 9 volt electrical water level meter in each bore. Standing water levels were also recorded on the drilling logs (**Appendix D**).

The following field water quality parameters stabilised and were measured with a calibrated water quality meter prior to the collection of samples for laboratory analyses:

- pH,
- Redox potential (Eh),
- Electrical Conductivity (EC),
- Total Dissolved Solids (TDS),
- Temperature, and
- Dissolved Oxygen (DO).

Groundwater samples were dispatched to ALS Laboratories for analyses of:

- pH, EC, Alkalinity,
- Ions: Ca, Mg, Na, K, F, Cl, SO4,
- Ionic balance
- SAR, TDS and Hardness
- Dissolved Silica
- Dissolved metals Al, As, B, Ba, Be, Cd, Co,Cr, Cu, Fe, Hg, Mo, Mn, Ni, Pb, Se, Sr, V, Zn + Bromide
- Dissolved C_1-C_4 gases (Methane, Ethylene, Ethane, Propylene, Propane, 1-Butene, Butane)

- Stable isotopes of oxygen and deuterium
- $^{87}Sr/^{86}Sr$ isotopes
- ^{13}C and ^{14}C isotopes

Samples for isotope analysis were sent to:

- Rafter Radiocarbon Laboratories (NZ): ^{13}C and ^{14}C isotopes
- Australian National University (ANU): Stable isotopes of oxygen and deuterium
- Adelaide University: $^{87}Sr/^{86}Sr$ isotopes.

2.4 Moisture Potential Measurements

The measurement of leaf water potential and soil moisture potential was applied to assess the interaction between tree roots and soil moisture / groundwater. Measurements were undertaken at all groundwater monitoring bore localities Long Swamp 31, Long Swamp 35, Burunga Lane182 and Glenburnie 20 which were placed adjacent to potentially deeper-rooted river red gums at each site, specifically to assess these interactions.

2.4.1 Soil Moisture Potential

The ability or tendency of soil/rock water to move, or capacity to be extracted from soil/rock is expressed as the soil moisture potential (Ψ). It is defined as the work water needs to do to move it from its present state to an elevation defined as zero. The total water potential of a soil/rock is defined in four components being 1) gravitational or the position of the water within the gravitational field; 2) matrix potential or the adhesive forces binding water to soil particles; 3) osmotic potential or the concentration of dissolved substances in the water; 4) pressure potential or the hydrostatic potential on the water.

Soil moisture potential is expressed as a negative force (suction). The maximum suction roots can apply to a soil/rock before a plant wilts due to negative water supply is approximately -15 bars or -1.5 MPa (or -217.55 PSI). This wilting point is relatively consistent between all plant species (Mackenzie et al, 2004). At saturation, when all soil pores are filled with water, the water potential is nominally zero and as soil dries out soil moisture potential becomes increasingly negative.

Samples collected for measurement of soil moisture potential were taken from consistent 0.5m intervals down the soil profile as shown in **Figure 18** below with the initial sample being taken within the soil A horizon (approximately 20cm depth). Sample collection continued down the core hole to the depth of the water table, or 18m (the maximum inferred rooting depth).

The measurement of soil moisture potential was completed in the laboratory with the aid of a portable Dew Point PotentiaMeter (WP4C) (Meter Group Inc, 2017) which uses the chilled mirror dew point technique to measure water potential with the sample being equilibrated with the headspace of a sealed chamber that contains a mirror and a means of detecting condensation on the mirror. The WP4C unit measures soil moisture potential with a 7ml soil sample inserted into a plastic measuring tray with a stainless-steel base. The WP4C unit measured soil moisture potential in MPa (and also pF), which was then converted to PSI for comparison with leaf water potential readings.

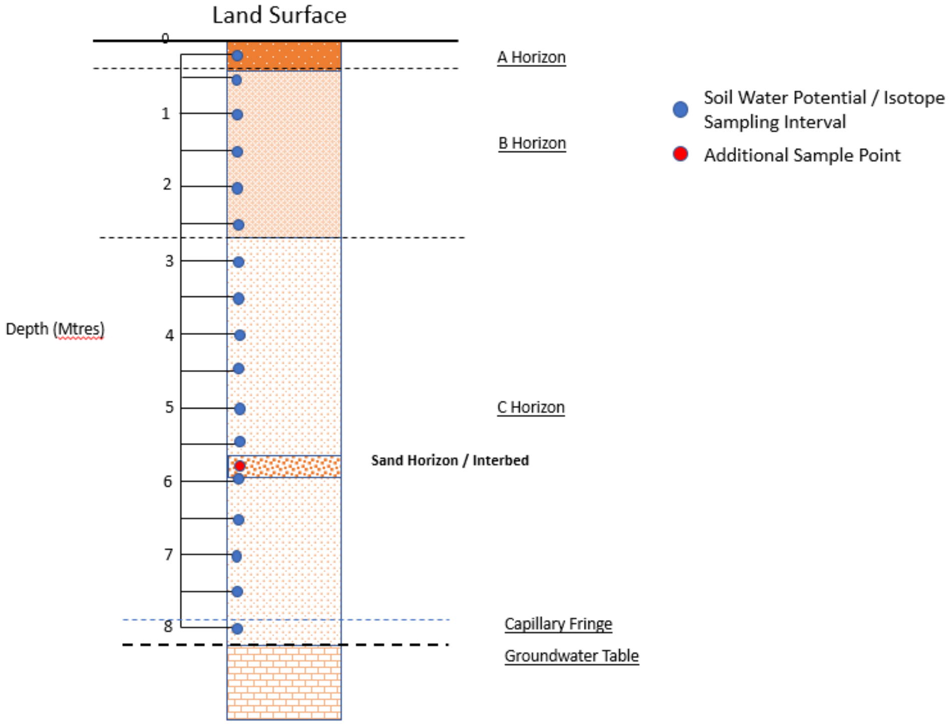


Figure 18. Sampling interval for soil moisture potential along drillcore .

2.4.2 Leaf Water Potential

Leaf Water Potential is the total potential for water in a leaf consisting of the balance between osmotic potential, turgor pressure and matric potential. It is defined as the amount of work that must be done per unit quantity of water to transport that water from the moisture held in soil to leaf stomata. It is a function of soil water availability, evaporative demand and soil conductivity.

Leaf water potential was measured pre-dawn (prior to sunrise) as per standard protocol. Due to lack of transpiration, leaf water potential will equilibrate with the wettest portion of the soil that contains a significant amount of root material. Pre-dawn leaf water potential will shift to a lower status as soil dries out on a seasonal basis (Eamus 2006a). Hence contemporaneous measurement of both pre-dawn leaf water potential from a canopy tree at a chosen monitoring locality and soil water potential from selected depth intervals down a co-located borehole will provide an indication of the predominant source of water (soil moisture or groundwater) being utilised by trees at the time of survey.

Survey localities were visited during pre-dawn periods (prior to sunrise) with collection of leaves taken from the canopy with the aid of a 7.5m extension pole fitted with a lopping head. Canopy leaves were collected from the GDE assessment target tree at each investigation area, plus a selection of adjacent trees for varying size class and species with an aim to determine if there is variation in leaf water potential between tree size classes and species.   Collected branches were harvested for suitable leaf material which was trimmed with a fine blade and inserted into an appropriate grommet for sealing within a Model 3115 Plant Water Status Console (Soil Moisture Equipment Corp, 2007). The chamber was sealed and gradually pressurised with Nitrogen until the first drop of leaf water emerged from the petiole. For the target tree at each GDE site, 3 readings were taken for completeness with an average taken from the three readings. Readings were taken in PSI which is converted to a negative value for direct comparison to soil moisture potential measurements.

Figure 19. Leaf collection, insertion of the leaf petiole into the grommet for sealing in the pressure chamber and measurement of water potential.

2.5 Stable Isotope Sampling and Analyses

Trees may utilise water from a range of sources including the phreatic zone, the vadose zone and surface water. The stable isotopes of water, oxygen 18 (18O) and deuterium (2H) may be a useful tool to help define the predominant source of water used by terrestrial vegetation. The method relies on a comparison between the stable isotope ratios of water contained in plant xylem (from a twig or xylem core) with stable isotope ratios in the various sources of water including potential sub-artesian aquifer water sources, and shallow soil moisture. Methods of assessment are detailed below.

2.5.1 Soil Moisture Isotopes

Sampling was undertaken at regular intervals along retrieved soil and rock core to capture signatures for possible isotopic end points (ground water and surface water) and a range of potential plant moisture sources from the upper soil surface to the top of the phreatic zone. The sampling intervals for soil moisture isotope analyses mirrors that of sampling for soil moisture potential with the intervals provided in **Figure 17** (**Section 2.3.1**). The sampling protocols applied were as follows:

1. Initial soil sample taken within the top 10cm of the soil profile.
2. Subsequent soil sampled taken at 0.5m intervals down borehole to the top of the phreatic zone.
3. Additional soil samples were taken whenever there is a noted change is soil texture within the soil core.
4. Where homogenous bedrock was intersected, the sampling interval was increased to 1m intervals except where significant changes in lithology occur.

Approximately 200mg of soil was collected for isotope analysis, collected from the central portion of the drill core to minimise chances for contamination with water introduced during drilling of some core holes. Where possible, sampling was not undertaken from coreholes where water was utilised during the drilling process. Upon collection, samples were double sleaved in click-seal plastic bags and placed on ice for storage prior to immediate dispatch to ANU Stable Isotope Laboratory for analysis where they were snap frozen until analysis was complete. An inventory of soil samples dispatched to ANU for stable isotope (δ18O and δ2H) is provided in **Appendix A**.

2.5.2 Xylem Water Isotopes

Twigs were collected from the outer branches of the target tree during sampling of trees for leaf water potential. Up to 4 twig samples were collected from individual trees directly adjacent to the assessment locality. The following sampling procedure, as per the study execution plan, was followed:

1. Outer branches trees of the GDE target tree were harvested for twig material. Two duplicate samples were prepared from each branch / limb for analysis.
2. The position of trees subject to assessment were marked with a GPS and structural measurements recorded (i.e height and diameter at breast height (dbh)) with a GPS device.
3. Outer branches from each tree were harvested with an extendable aluminium pole.
4. Stem material equivalent to one joint length of the small finger was sourced using clean stainless-steel secateurs.
5. Stems were sealed in wide mouth sample containers with leakproof polypropylene closure (approx. 125ml sample size) and immediately labelled with the tree number and placed in an iced storage vessel prior to dispatch to the ANU stable isotope laboratory.
6. Upon receipt of samples at the ANU stable isotope laboratory, samples were snap frozen (-18°C) until analysis.
7. For all twigs, samples were taken from xylem as close to the centre of twig as possible. For both xylem and soil samples, extracted water was analysed using a Picarro L2140i cavity ring-down spectrometer.

For the purpose of xylem water analysis, multiple samples were taken from a single branch sample at all localities. From each branch sampled, the value of the lowest (least enriched) sample was used as the reference. This is because there may be considerable partitioning of isotope ratios across a twig section (moving from xylem to phloem) and it is not always possible to sample the same region of a twig consistently when multiple samples are analysed. As there is potential for fractionation of stable isotope values, particularly 2H, during movement of water through the xylem from roots to leaves (Evaristo et al 2017, Petit and Froend 2018). As fractionation will likely result in isotopic enrichment rather than depletion, the least enrich sample from each tree is considered most likely to be representative of the soil moisture or groundwater source. An inventory of twig samples dispatched to ANU for stable isotope analysis is provided in **Appendix A**.

2.6 Baseline Characterisation

The assessment aimed to establish ecological and hydrogeological conditions at each of the GDE assessment sites as a baseline for ongoing monitoring as required. Ecological and hydrogeological characterisation aimed to establish the robustness of vegetation at each GDE site including assessment of specific parameters to measure the health of canopy trees and foliage in response to changes in groundwater availability. Methods applied to characterise ecological condition are detailed in **Section 2.5.1**.

2.6.1 Ecological Characterisation

Transect Methods: A single survey transect was chosen for each GDE assessment ensuring that a representative sample of deep rooted vegetation was assessed. A 50m tape measure stretched tightly and end points marked with a GPS to indicate the start and end of the transect. The survey plot was extended 5m either side of the centreline to provide a 50 m x 10 m survey transect (0.05ha). Specific details collected at each transect were:

- Canopy intercept of woody species over the tape marking the centre line, from 0 to 50m separated into the T1 (canopy), T2 (sub-canopy) and S1 (shrub) structural layers.
- Tree and shrub species for all structural layers and identification of applicable regional ecosystem based on species composition.
- Counts of woody species within the survey plots within height classes (Trees T1 & T2; Shrubs S1).
- Groundcover of plants within 10 x 1m^2 quadrats placed at 10m intervals along the tape measure with the initial quadrat position (Q1) at the 4 – 5m interval on the left side of the tape measure and flipped to measure Q2 on the right. The final quadrats Q9 and Q10 were positioned at 44 – 45m on the left and right side of the transect respectively.
- Average canopy heights and canopy height range were recorded for all canopy intercepts in the T1, T2 and S1 structural layers.
- Geomorphic attributes including soil type and position relative to the river channel.

GPS localities of start and end points were recorded in the field and photographs were taken along the quadrat centreline.

Foliage Cover Assessments: Assessment of foliage cover followed a modified version of that applied by Reardon-Smith (2011) to provide a measure of Foliage Index (FI), being % living leaf cover relative to total canopy cover for all species in the T1 and T2 structural layers. This was aided with the use of a digital camera (Olympus Stylus Tough -TG4, 35mm lense) retro-fitted with a bullseye level to assist horizontal camera alignment (see **Figure 20**). Canopy photographs were taken from the transect start point at 5m intervals to the transect end point (11 photos in total), taken 1m off the ground directly above the tape measure marking with camera positioned horizontally. This process resulted in approximately 30% overlap between photo points. The following methods were then applied in the office:

1. The total projected canopy cover (PCC%[1]) within each photo point was estimated using a 1500 dot point matrix (0.5 cm centres) with the photos expanded full screen (235 x 175mm) (see **Figure 21**).
2. Projected foliage cover (PFC%) estimated for the portions of each canopy cover photograph.
3. Total foliage cover for each canopy photograph was calculated (%canopy cover x %foliage cover).
4. Foliage Index (FI) calculated being total PFC / PCC x 100.

Calculation of FI provides a measure of the robustness of canopy cover, or the proportion of the tree canopy with living foliage. PCC values from the July 2016 survey were adopted for subsequent survey events unless evidence from canopy photographs indicated a significant change. Where there was evidence of canopy dieback in the photographs that had occurred subsequent to the original assessment, the dead canopy portion was also included in the calculation of PFC and FI.

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[1] PCC calculated from digital photography will always be lower that calculations using a line transect as it provides increased capacity to exclude minor canopy gaps and openings.

Figure 20. Camera mounted with a bullseye level for canopy photography.

Figure 21. A typical canopy photograph illustrating estimation of total canopy cover. Based on estimates assisted with dot matrix, this photograph illustrates 65% canopy cover (PCC) with 60% PFC within the portion covered by canopy.

2.6.2 Hydrogeological Characterisation

Hydrogeological characterisation included geological logging and observations of soil/rock moisture and saturated horizons that may form horizons for tree water use, baseline measurement of standing water levels, and baseline groundwater chemistry characterisation including analysis of 87/86Sr ratios and δ13C for age dating purposes. These methods have been described above and integrated into a baseline ecological/hydrogeological data set and conceptual site model described in **Section 4.0**. Any future integrated ecological/hydrogeological monitoring programme will assess trends in vegetation response to groundwater availability.

2.7 Limitations and Other Information Relevant to the Assessment

The assessment provides a snapshot of eco-hydrological process at each of four pre-determined GDE assessment localities identified during prior desktop assessment exercises. The major limitations of the process are:

1. Due to land access conditions, there was no scope to adjust the location of the rig prior to drilling if an opportunity to provide a more robust assessment was identified at the site.
2. Where possible, drilling was completed without the use of introduced water. In some cases, particularly at the Longwamp 35, Long Swamp 31 and Burunga Lane sites, introduction of drilling water limited the ability to collect representative core moisture samples. Sampling for isotopic analysis was largely restricted to those holes that were drilled dry which included

   a. BL182b (0 – 7m)
   b. LS31a (Lake Broadwater).
   c. GB20b.
3. Where sampling was completed in bores drilled with introduced water, efforts were made to extract samples for isotopic analysis from the central portion of the core where the impact of introduced drilling water would have been moderated.
4. An isolated heavy storm interrupted drilling at the Glenburnie GDE site on the afternoon of the 16th February 2018. It is estimated that up to 25mm of rainfall fell and surface conditions were saturated, although soil was observed to be dry at >20cm depth from surface indicating limited infiltration. This may have influenced results of the leaf water potential and stable isotope analyses for this site.
5. Ecological and hydrogeological conditions encountered are complex and transient. Interpretations and conceptualisations presented here are based upon multiple lines of evidence. However, sources of uncertainty remain and other interpretations are possible.
6. The GDE assessment undertaken here provides only a snapshot of the ecohydrological conditions at one locality in what are otherwise extensive systems. The findings of this assessment are specific to each of the study sites and do not necessarily reflect conditions at other locations. It should be noted that Long Swamp extends for in excess of 30 km over broad expanses of Condamine River Alluvium and Lake Broadwater covers 350 hectares.
7. The potential influence of evapotranspiration on soil moisture potential measurements has not been considered in any detail in this assessment. Soil moisture potential will be affected by evapotranspiration to varying degrees with the greatest effects noted in zones of high root density during periods of maximum transpiration, with some expected lag in response. The amount of drying around the root zone caused by evapotranspiration will also be influenced by soil matric potential with very dry soils (i.e. low soil moisture potential) unlikely to be significantly affected while wetter soils with high matric potential more likely to be subject to changes in soil moisture content as a result of evapotranspiration, although these soils are also more likely to replenish soil moisture rapidly from surrounding areas. There are also complexities introduced by hydraulic redistribution of moisture facilitated by some trees which have ability to shift soil moisture via roots from depth to upper parts of the soil profile when the upper soil profile is dry and the reverse may also occur when upper soil layers are moist and zones within the deeper functional root zone are dry. *Eucalyptus camaldulensis* is known to facilitate this process (Eamus 2006). Due to the low rooting densities recorded in most drill core sampled, it is not expected that evapotranspiration would have significantly influenced soil moisture potential results at any of the GDE assessment sites. An exception might be the upper soil profile where it was typical to encounter a high density of both coarse and fine roots. This zone however has little relevance in the determination of groundwater dependence of a tree or ecosystem.

3.0 Results

In **Section 3**, assessment observations and measured parameters are reported separately for each study site. For ease of presentation and to allow comparisons between study sites, groundwater chemistry results are presented in a single section below. The results are interpreted and discussed in **Section 4.0**.

3.1 Groundwater chemistry

Groundwater samples were collected from groundwater monitoring bores Long Swamp 31 (Lake Broadwater), Long Swamp 35, and Glenburnie 20, and a surface water sample collected from Lake Broadwater between the 16 and 17 March 2018. As noted in **Section 2**, the Burunga Lane 182 bore was dry at the time of sampling. A duplicate sample was also collected for QA/QC purposes from Glenburnie 20. Sampling was conducted in accordance with the methodologies described in **Section 2.**

Groundwater and surface water sample results are summarised in **Table 2** below. Major ion chemistry for all samples have been plotted in a single piper plot as shown in **Figure 22**, and water types summarised in **Table 3**. Piper plots have also been prepared for individual bores. These are included along with Stiff Diagrams, Radial Plots, and Schoeller Diagrams in **Appendix B**. The results of $^{87}Sr/^{86}Sr$ isotopes and δ13C are reported in **Table 4** and **Table 5** respectively. Laboratory analytical reports are also included in **Appendix C**.

All water samples displayed Na-Cl major ion water chemistry types except for Glenburnie 20 which presented as a sodium bicarbonate water type. The salinity of groundwater in the Long Swamp 31 (Lake Broadwater) monitoring bore is significantly higher (3930ppm Total Dissolved Solids (TDS)) compared with the sample collected from Lake Broadwater (290). The major ion water types are the same (Na-Cl) for both the Lake Broadwater groundwater and surface water samples.

Another notable observation from review of the water chemistry data is the presence of relatively high concentrations of dissolved silica (as SiO_2) in the Lake Broadwater surface water sample. Hem (1985) notes the strong correlation between silica solubility and temperature. The shallow lake water temperature was 32^0C during sampling at the end of a heat wave period where there were numerous days with temperatures exceeding 40^0C. The $^{87}Sr/^{86}Sr$ ratios identified in bore samples GB20, LS31 and LS35 are considered low, consistent with values identified in aquifers of the GAB and the Murray Basin (Collerson et al., 1988; Dogramaci et al 1998 sited in Harrington et al 2003). It is also noteworthy that δ13C **for** both the lake surface water and shallow groundwater sample from LS31 indicate a similar 'Modern' age (see **Table 5**).

A discussion of groundwater and surface water chemistry results is provided in **Section 4**. Results of analysis of stable isotopes of oxygen and deuterium are reported in those sections relevant to each individual GDE assessment site.

Table 2. Groundwater and surface water samples analytical summary table

		Sample Date:	16/03/2018	16/03/2018	16/03/2018	17/03/2018	16/03/2018
		Sample ID:	**Glenburnie 20**	**Glenburnie 20 Dup**	**Longswamp 31**	**Longswamp 35**	**Lake Broadwater**
Analyte grouping/Analyte	**Unit**	**Limit of reporting**					
pH Value	pH Unit	0.01	**8.36**	**8.34**	**8.31**	**7.80**	**8.45**
Electrical Conductivity @ 25°C	µS/cm	1	**1860**	**1840**	**6050**	**4480**	**446**
Total Dissolved Solids (Calc.)	mg/L	1	**1210**	**1200**	**3930**	**2910**	**290**
Total Hardness as CaCO3	mg/L	1	**77**	**90**	**277**	**556**	**36**
Bromide	mg/L	0.010	**0.335**	**0.340**	**4.20**	**3.40**	**0.309**
Hydroxide Alkalinity as CaCO3	mg/L	1	<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3	mg/L	1	**22**	**18**	**9**	<1	**12**
Bicarbonate Alkalinity as CaCO3	mg/L	1	**741**	**732**	**670**	**523**	**65**
Total Alkalinity as CaCO3	mg/L	1	**763**	**751**	**680**	**523**	**77**
Silicon	mg/L	0.05	**11.0**	**11.0**	**8.16**	**8.95**	**27.7**
Chloride	mg/L	1	**69**	**71**	**1440**	**1150**	**85**
Calcium	mg/L	1	**16**	**18**	**45**	**119**	**8**
Magnesium	mg/L	1	**9**	**11**	**40**	**63**	**4**
Sodium	mg/L	1	**398**	**417**	**1170**	**609**	**71**
Potassium	mg/L	1	**4**	**4**	**30**	**5**	**15**
Sodium Adsorption Ratio		0.01	**19.7**	**19.1**	**30.6**	**11.2**	**5.12**
Silicon as SiO2	mg/L	0.1	**23.6**	**23.6**	**17.5**	**19.2**	**59.4**
Fluoride	mg/L	0.1	**0.2**	**0.2**	**0.6**	**0.1**	**0.2**
Total Anions	meq/L	0.01	**20.1**	**20.0**	**58.6**	**44.0**	**4.42**
Total Cations	meq/L	0.01	**19.0**	**20.0**	**57.2**	**37.7**	**4.20**
Ionic Balance	%	0.01	**3.05**	**0.10**	**1.19**	**7.70**	**2.49**
Dissolved Metals							
Aluminium	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Arsenic	mg/L	0.001	<0.001	**0.001**	**0.001**	**0.001**	**0.002**
Beryllium	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium	mg/L	0.001	**0.058**	**0.068**	**0.267**	**5.21**	**0.015**
Cadmium	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	<0.001	<0.001	<0.001	**0.001**	<0.001
Cobalt	mg/L	0.001	**0.001**	**0.002**	**0.004**	**0.007**	<0.001
Copper	mg/L	0.001	**0.001**	<0.001	<0.001	<0.001	**0.002**
Lead	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	mg/L	0.001	**0.269**	**0.308**	**0.533**	**6.23**	<0.001
Molybdenum	mg/L	0.001	**0.024**	**0.040**	**0.027**	**0.013**	**0.001**
Nickel	mg/L	0.001	**0.002**	**0.001**	**0.003**	**0.009**	**0.002**
Selenium	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium	mg/L	0.001	**0.450**	**0.527**	**1.08**	**2.53**	**0.109**
Vanadium	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	**0.03**
Zinc	mg/L	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Boron	mg/L	0.05	**0.09**	**0.08**	**0.34**	<0.05	**0.16**
Iron	mg/L	0.05	<0.05	<0.05	<0.05	**10.4**	<0.05
Mercury	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
C1 - C4 Hydrocarbon Gases							
Methane	µg/L	10	<10	<10	<10	**1000**	<10
Ethene	µg/L	10	<10	<10	<10	<10	<10
Ethane	µg/L	10	<10	<10	<10	<10	<10
Propene	µg/L	10	<10	<10	<10	<10	<10
Propane	µg/L	10	<10	<10	<10	<10	<10
Butene	µg/L	10	<10	<10	<10	<10	<10
Butane	µg/L	10	<10	<10	<10	<10	<10

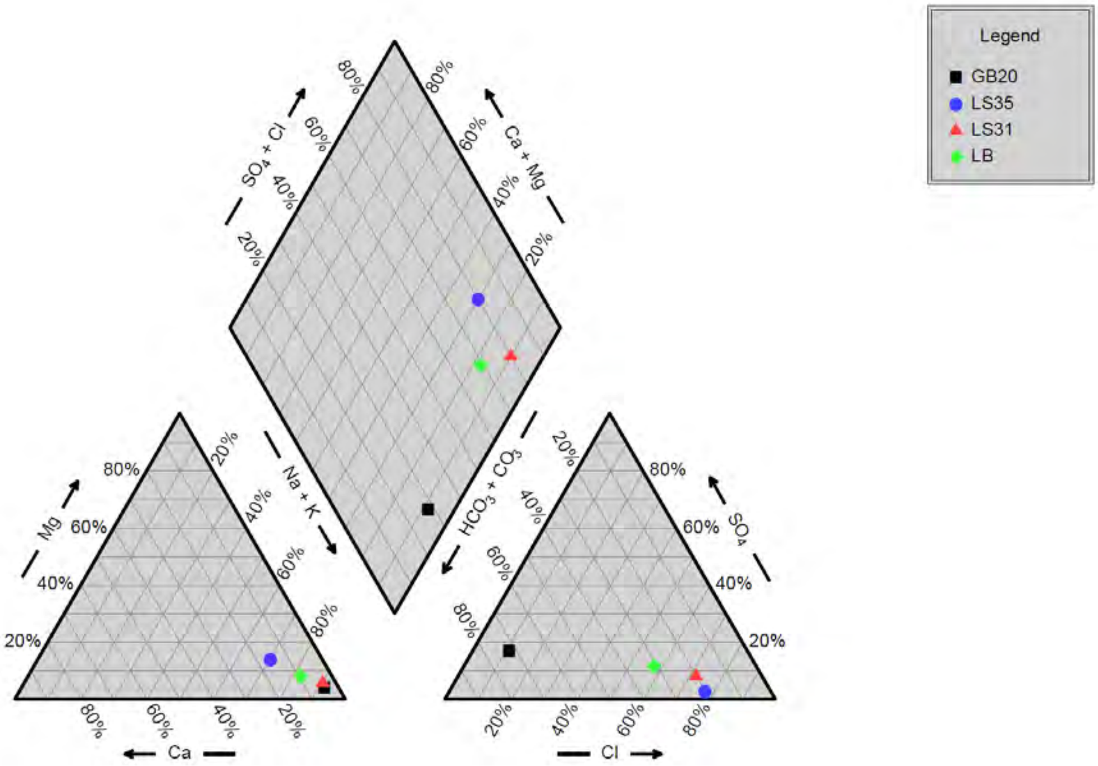

Figure 22. Water chemistry Piper Plot (GB = Glenburnie; LS = Long Swamp, LB = Lake Broadwater surface water sample)

Table 3. Groundwater and surface water major ion chemistry types

	Glenburnie (GB20)	**Long Swamp (LS35)**	**Lake Broadwater (LS31)**	**Lake Broadwater**
Source	Bore	Bore	Bore	Lake
Date	16 March	17 March	16 March	16 March
Water Type	Na-HCO3	Na-Cl	Na-Cl	Na-Cl (if Si ignored)

Table 4. ^{87}Sr/^{86}Sr isotope results for groundwater samples at relevant well sites.

Sample Locality	**Sample Name**	**Sample Type**	**Sample Date**	**87/86Sr**
Lake Broadwater	LS31	Bore	16 March	.707427
Long Swamp	LS35	Bore	17 March	.705474
Glenburnie	GB20	Bore	16 March	.705169
Lake Broadwater	Lake Broadwater	Lake	16 March	.707048

Table 5. δ13C isotope results for groundwater samples at relevant well sites.

Sample Locality	**Sample Name**	**Sample Type**	**Sample Date**	**δ13C [‰]**	**Age (yrs bp).**
Lake Broadwater	LS31	Bore	16 March	-8.2	Modern
Long Swamp	LS35	Bore	17 March	-13.5	421 ± 26
Glenburnie	GB20	Bore	16 March	-14.8	4752 ± 47
Lake Broadwater	Lake Broadwater	Lake	16 March	-14.0	Modern

3.2 Lake Broadwater

Figure 23 shows features applicable to assessment at the Lake Broadwater (Long Swamp 31) GDE assessment area. This includes;

1. Five trees measured for leaf water potential including the target tree and four trees in the vicinity at varying distances from the lake edge.
2. Two sonic core holes targeted to assess shallow hydrogeology and the presence of groundwater / aquifers, observing rooting depth of trees and collection of soil/rock samples for analysis of soil moisture potential and stable isotope analysis. Core holes include:
    a. LS31a drilled to a depth of 21m as close as possible to the target river red gum for geological characterisation, soil moisture and soil isotope sampling and assessment of tree rooting depth.
    b. LS31b drilled to a depth of 3m for construction of a permanent shallow groundwater monitoring bore.
3. A permanent vegetation monitoring transect as a baseline for ongoing monitoring of vegetation health if required.

3.2.1 Coring to Root Depth

3.2.1.1 Geological and Hydrogeological Logging

Descriptions of the lithology encountered, presence and description of tree roots, moisture and groundwater observations, depths of all samples collected, soil moisture potential measurements, and gas concentrations are presented in the drilling logs (**Appendix D**).

In summary, approximately 3m of loose sandy lacustrine alluvium was intersected above a sequence of massive clays (interpreted by Arrow from the nearby LS30 monitoring bore to be alluvium) and a deeply weathered regolith of the Westbourne Formation, comprising predominantly of plastic clays, sandy clays and clayey sands. Shallow groundwater (1.8m below ground level (BGL)) was perched within the shoreline sands above an abrupt change into the weathered clay-dominated alluvium and Westbourne Formation regolith present to the maximum extent of drilling (21m). The recovered core transitioned from moist to saturated at approximately 18m depth at a change from sandy clay to clayey sand. This transition was best described as a seepage horizon rather than a significant water strike. Very little free groundwater was noted entering the core hole during drilling beyond 3m.

Formation top picks from the nearby Arrow Monitoring bore LS30 are:

- Alluvium: 0 - 31mGL
- Westbourne Formation: 31-94.5mGL
- Springbok Sandstone Formation: 94.5mGL - 178.2mGL
- Walloon Coal Measures: 178.2 - 204mGL (Total Depth reached in LS30).

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Figure 23. Lake Broadwater GDE Investigation site

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0 10 20 30 40
Metres

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File Path

Date 28-Mar-18

A4

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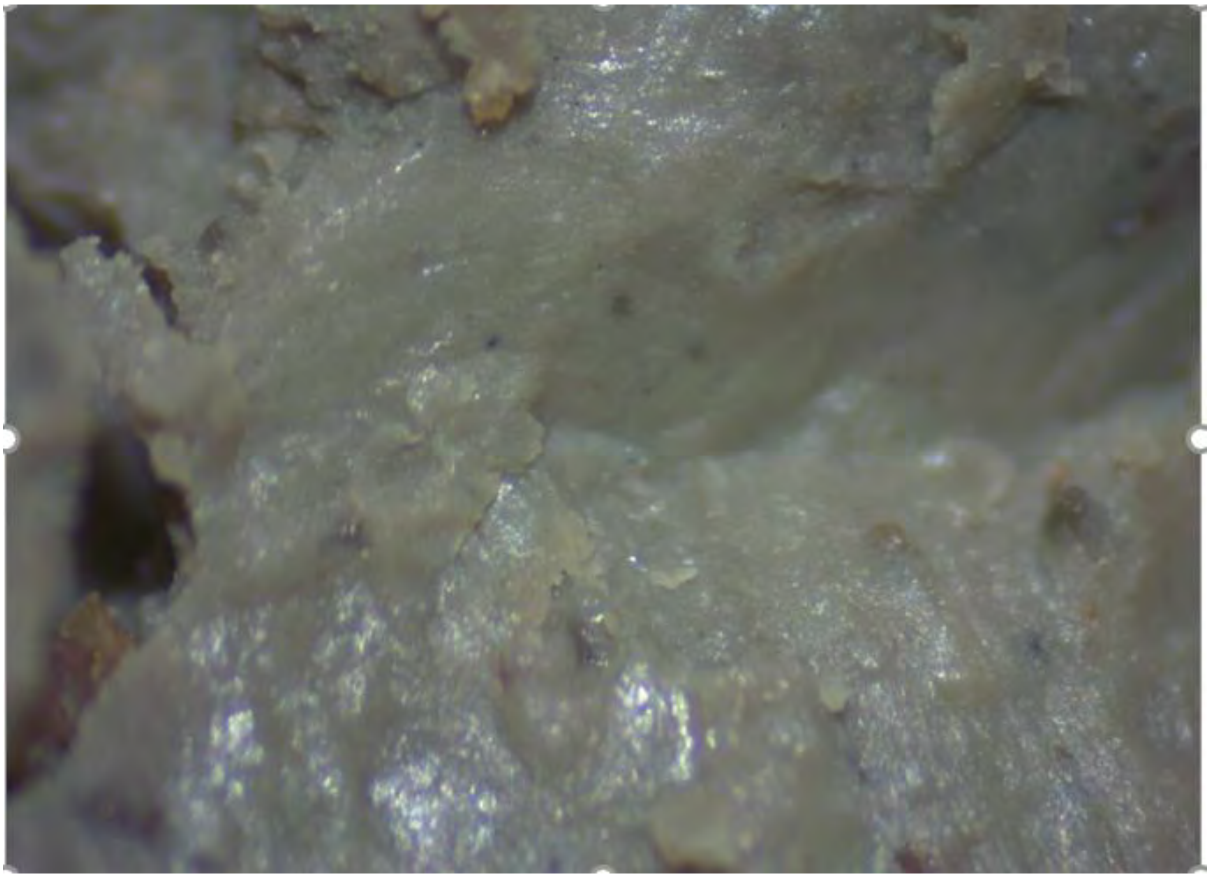

Figure 24. High plasticity clay magnified under microscope (2mm diameter view shown) from sample collected at 14.5m depth in LS31a (Lake Broadwater)

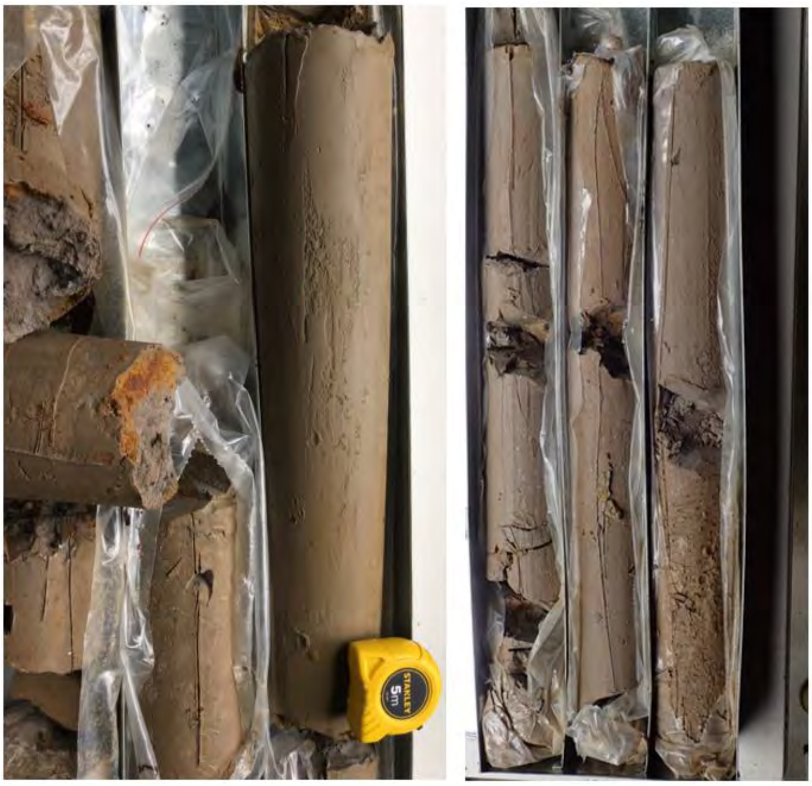

Figure 25. Massive sequences of high plasticity clays and sandy clays encountered during drilling Long Swamp 31 (Lake Broadwater). Note that incisions into the clay core are where samples have been collected for soil moisture and isotope sample analyses.

3.2.1.2 Root Material Logging

The intervals in which root material was identified during core examination is recorded in the core hole log for LS31a which provided within **Appendix D**. Fine fibrous root material was recorded throughout much of the upper 2.6m of the core hole with the greatest concentration of fibrous root material recorded at the interface between wet sand and clay (2.6mGL) (**Figure 26**), the location of an identified shallow perched aquifer. Occasional tree roots were also recorded in sandy clay to depth of 4mGL (**Figure 27**).

Figure 26. Fine (1mm) tree roots in sand/clay interface at 2.9m depth in LS31a.

Figure 27. Fibrous tree roots to 3mm thickness in fissured sandy clay at 4m depth in LB31a

3.2.2 Groundwater Monitoring Bore Construction

A 100mm diameter groundwater monitoring bore was constructed at 3m depth, screened across groundwater perched in sandy alluvium above the sandy clays. Bore construction details are shown on the drilling log LS31b in **Appendix D**. It is highly likely that this bore could be dry as the lake water levels recede and level drops in the hydraulically connected alluvium.
Hand augering undertaken during previous assessment in December 2016 during a period of low lake level did not encounter any groundwater in the shallow fringing lake sands but did intersect indurated and mottled iron-stained sand indicative of a seasonally present and fluctuating groundwater level.

Figure 28. Low lake levels and river red gum tree stress after a low rainfall period.

At the time of drilling. the groundwater level in the alluvium was slightly higher than the lake surface water level, suggesting a slight fall on the groundwater piezometric surface towards the lake. This could be indicative of a drying stage as evaporation dominates lake levels and groundwater drains towards the falling lake level. At the time of groundwater bore sampling approximately 1 month later, groundwater levels were lower than the Lake which had recently received direct rainfall and runoff from some significant rainfall events. At this time the lake level was noticeably higher than during drilling which could reflect a lake level rising stage where the lake was likely flowing into and charging the adjacent shallow aquifer.

Figure 29. Relatively high lake level during ecology scouting of the GDE study site by Arrow Energy in June 2017 (note flooding of lake water up into the river red gum woodland in background).

Figure 30. Lower lake level shown in photograph taken from the same location as the photograph above immediately prior to the drilling at the GDE study site in February 2018

3.2.3 Stable Isotope Sampling and Analyses

Water stable isotopes of oxygen and deuterium (δ18O and δ2H) have been measured at regular intervals in the soil profile, groundwater and twig xylem in an attempt to correlate the dominant source of water utilised by riparian vegetation on the fringes of Lake Broadwater. The two trees sampled for xylem water were located directly on the margins of Lake Broadwater (Tree 1) and a second tree located approximately 100m from the margins of the lake (Tree 2) (see **Section 3.2.4**). The results of these analyses are provided within **Table 6** with raw data provided in **Appendix F**.

Table 6. δ18O and δ2H isotope values for soil moisture, twig xylem and surface / groundwater at the Lake Broadwater GDE assessment site.

Metres below ground	Raw 2H	δ2H VSMOW	Raw 18O	δ18O
		Soil Moisture		
0.2	-17.57	-19.58	-1.43	-2.8
2.6	-5.11	-7.12	0.62	-0.75
3	-14.85	-16.86	-1.38	-2.75
3.5	-24.44	-26.45	-3.67	-5.04
4	-24.59	-26.6	-2.68	-4.05
4.5	-23.37	-25.38	-2.65	-4.02
5	-24.92	-26.93	-1.95	-3.32
5.5	-25.18	-27.19	-2.44	-3.81
6	-23.47	-25.48	-1.69	-3.06
6.5	-24.73	-26.74	-2.59	-3.96
7	-21.64	-26.35	-2.53	-3.9
7.5	-23.36	-25.37	-2.03	-3.4
8	-23.79	-25.8	-3.08	-4.45
8.5	-23.93	-25.94	-2.78	-4.15
9	-22.75	-24.76	-1.63	-3
9.5	-23.48	-25.49	-2.93	-4.3
10	-24.85	-26.86	-1.85	-3.22
10.5	-25.24	-27.25	-2.41	-3.78
11	-24.75	-26.76	-2.41	-3.78
11.5	-22.21	-24.22	-1.84	-3.21
12	-21.96	-23.97	-2.29	-3.66
12.5	-21.19	-23.2	-1.43	-2.8
13	-18.22	-20.23	-1.60	-2.97
13.5	-20.80	-22.81	-1.60	-2.97
14	-22.53	-24.54	-0.76	-2.13
14.5	-20.76	-22.77	-1.47	-2.84
15	-20.38	-22.39	-0.87	-2.24
15.5	-21.36	-23.37	-1.09	-2.46
16	-22.60	-24.61	-2.18	-3.55
16.5	-20.91	-22.92	-2.38	-3.75
17	-20.49	-22.5	-1.18	-2.55
17.5	-19.14	-21.15	-0.73	-2.1
18	-20.40	-22.41	-1.91	-3.28

Metres below ground	Raw 2H	δ2H VSMOW	Raw 18O	δ18O
3	-20.10	-22.11	-2.72	-4.09
Twig Xylem Analysis				
Tree 1	-5.3	-7.31	0.42	-0.95
Tree 2	-11.88	-13.89	-1.72	-3.09
Groundwater / Surface water Analysis				
Lake Broadwater	-22.74	32.2	6.79	6.55
LS31_Well	-17.57	-20.16	-2.59	-3.01

VSMOW = Vienna Standard Mean Ocean Water

3.2.3.1 Soil Moisture Isotopes

The isotopic composition of extracted soil moisture is plotted against sample depth in **Figure 31.** The profile indicates moderate enrichment in δ2H and δ18O in the upper soil profile to a depth of approximately 3m where a sharp transition to a depleted isotopic signature occurs, corresponding with the sharp boundary between loose sand and plastic clay (see Appendix D). The depleted signature is relatively consistent throughout the thick unit of heavy plastic clay with a slight enrichment occurring at approximately 11m, at the lithological change from clay to sandy clay. The enriched isotopic signature in the top 2.6m of the soil profile can be attributed to evaporation of rainfall at the surface with moderate infiltration of enriched water into the sandy soil profile.

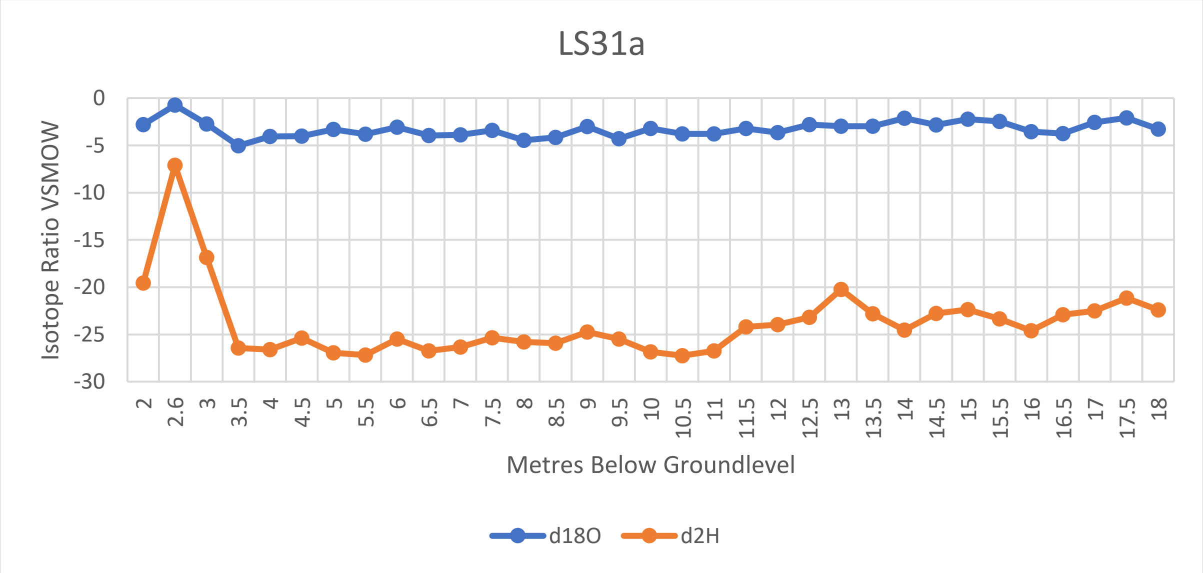

Figure 31. Isotopic composition of soil moisture plotted down hole in GDE investigation bore LS31a.

3.2.3.2 Xylem Water Isotopes

Figure 32 plots the relationship between δ18O and δ2H for soil moisture samples collected from borehole LS31a, with comparison to isotopic composition of xylem water (Tree 1 and Tree 2), a sample of surface water from Lake Broadwater and groundwater extracted from the monitoring well LS31a. The Lake Broadwater surface water sample demonstrates strong evaporative enrichment of the lake water as would be expected in the light of extreme temperatures which preceded the assessment and the lack of any significant rainfall prior to the sampling event. Xylem water extracted from T1 overlaps with the isotopic signature for soil moisture at 2.6mGL. This corresponds to an area of observed high rooting density above the sharp boundary between loose sand and plastic clay (see **Section 3.2.1**; **Appendix D**). T2, located away from the lake margin overlaps with isotopic signatures recorded in the clay and sandy clay moisture that lies below the sand / clay interface. It is noted that the groundwater sample taken from borehole LS31 (LS31_Well) has an isotopic fingerprint of the clay rather than the overlying sandy material and could also be a potential source of moisture for T2

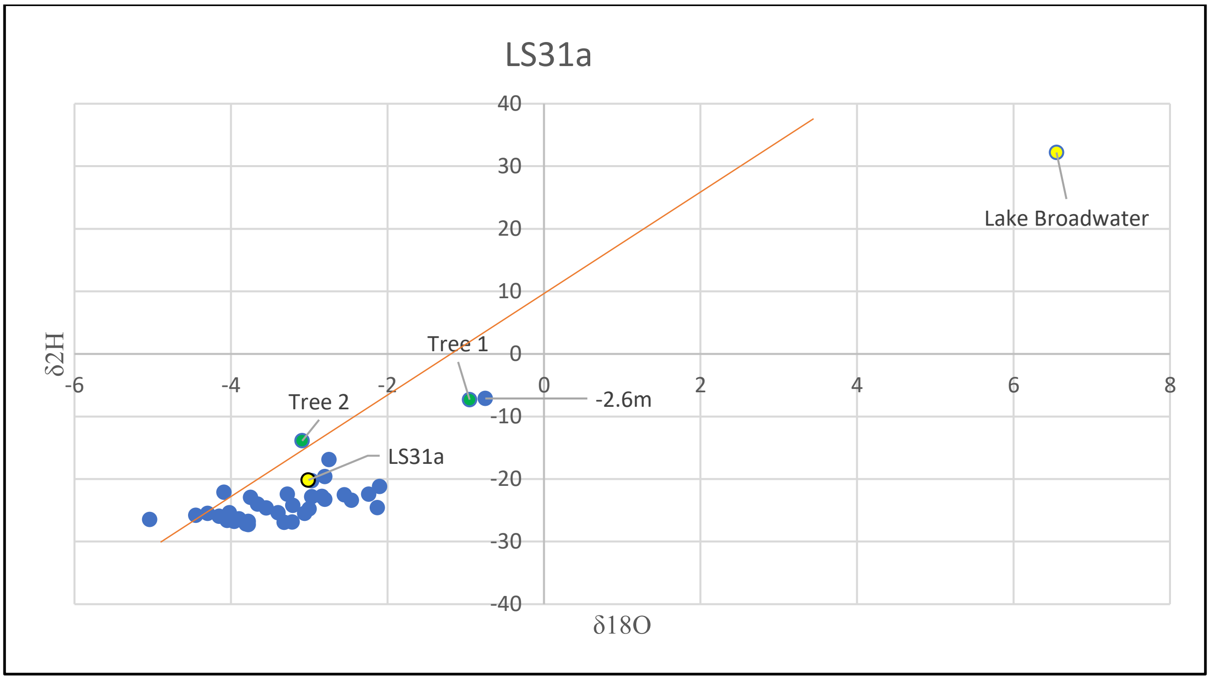

Figure 32. Biplot showing the relationship of stable isotope signatures (δO18 and δ2H) of water extracted from soil samples, twig xylem and surface / groundwater samples at the LS31 GDE assessment site. The red line indicates the Global Meteoric Water Line (GMWL) for reference, in the absence of a local standard.

3.2.4 Moisture Potential Measurements

The results of soil moisture and leaf water potential analyses for the Lake Broadwater (Long Swamp 31) GDE assessment area are discussed in the following sections.

3.2.4.1 Soil Moisture Potential

The results of soil moisture potential analysis completed on soil and bedrock material samples from drill hole LS31a are represented in **Figure 33** with drill logs presented in **Appendix D** and raw data provided in **Appendix E**. It is apparent that the 2.7 m of the profile, which comprises medium to coarse quartz sand, has an extremely high water potential approaching saturation (-14.5 psi) and corresponds to a shallow perched water table. Soil moisture potential diminishes abruptly between 2.5 and 3m coinciding with a sharp change from sand to clayey sand and sandy clay, with heavy clay forming the profile from 4m depth to approximately 11m. The entirety of this clay horizon has an extremely low soil moisture potential (at or near wilting point). There would be no benefit in terms of moisture availability for tree roots to penetrate these clays deeply. Although the bulk of tree root material identified was located in the upper 3m of the soil profile (see **Section 3.3.1**), tree roots were recorded to a depth of 4m in heavy clay and this is inferred to be acting as an anchor to offset any instability in the upper sandy profile.

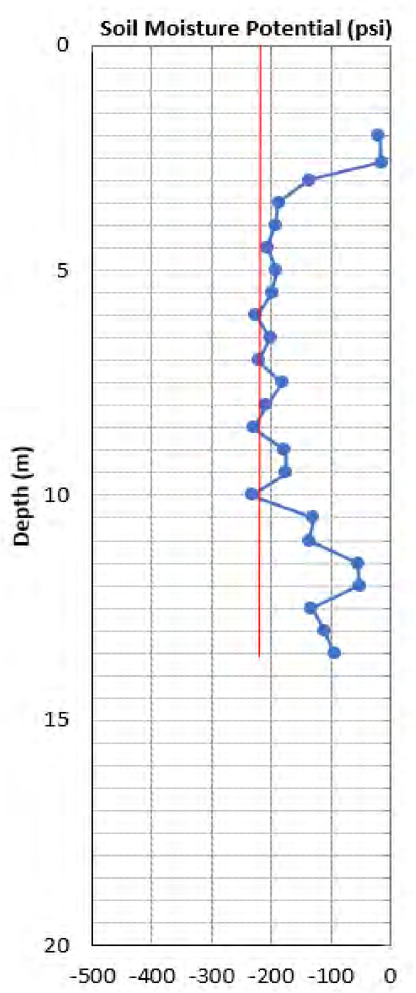

Figure 33 . Soil Moisture Potential profile in LS31a showing high availability in the upper 3m of the profile.

3.2.4.2 Leaf Water Potential

The average Leaf water potential for all measured trees is presented below in **Table 7**. The two mature river red gum on the margins of Lake Broadwater (Tree 1 and Tree 5) demonstrate the highest leaf water potential indicating that the predominant source of water for these trees is soil that is saturated or approaching saturation and uptake of water for these species is inferred to be occurring at the interface of sand at clay (2.6m depth). The other trees, in particular the cypress pine (*Callitris glaucophylla)* and the rough barked apple (*Angophora floribunda)* have a much lower leaf water potential suggesting that they are sourcing water from deeper in the profile. Due to their position away from the lake margins, it is probable that the perched groundwater table is not influencing water uptake in these trees.

Table 7. Leaf water potential measurements for canopy trees in vicinity of Long Swamp 31.

Tree ID	Species	Height	DBH	X	Y	M1_PSI	M2_PSI	M3_PSI	Average
Tree 1	E. camaldulensis	28	105	-27.3434	151.0957	30	30	25	**28.3**
Tree 2	E. camaldulensis	19	50	-27.3432	151.0956	40	45		**42.5**
Tree 3	Callitris glaucophylla	17	45	-27.3432	151.0955	170			**170**
Tree 4	Angophora floribunda	21	68	-27.343	151.0955	125			**170**
Tree 5	E. camaldulensis	27	110	-27.3434	151.0957	20			**20**

3.2.5 Baseline Characterisation

3.2.5.1 Ecological Characterisation

Raw vegetation transect data from the Long Swamp 31 GDE Assessment Area is provided in **Appendix H**. The vegetation on the site consists of a tall open forest dominated by river red gum forming a fringe to the lake edge. At the transect, the canopy has an average canopy height of 21m and 38% cover. The shrub layer is sparse (almost non-existent) comprising mostly of wattles (*Acacia leiocalyx)* at 2 -3m height and less <10% cover. The ground cover is formed by 11% cover of native grasses and forbs with mat-rush (*Lomandra longifolia)* being prominent and the Paspalum distichum forming relatively dense mats on the lakes fringe within the zone where the lake water level fluctuates. Over a 50m measured transect with a measured canopy cover of 53.6%, a foliage index of 0.71 (76%) is calculated from canopy photography. This suggests a robust and healthy canopy, particularly when compared to Long Swamp (35a) where foliage index was considerably lower at 0.56.

Figure 34. Typical vegetation along the Lake Broadwater Monitoring Transect (Long Swamp 31) with photograph on right indicative of robust canopy foliage.

3.3 Long Swamp

Features applicable to GDE assessment at the Long Swamp GDE assessment area are indicated in **Figure 35** below. The figure shows;

1. Four trees measured for leaf water potential including the target tree and three adjacent trees.
2. Three Sonic core holes targeted to assess shallow hydrogeology and the presence of groundwater / aquifers, determine rooting depth of trees and collect soil samples for analysis of soil moisture potential and stable isotope analysis. Core holes include:
    a. LS35a cored to a depth of 30m for the purpose of geological characterisation.
    b. LS35b cored to a depth of 18m for stable isotope and soil moisture potential sampling (drilled without introduction of water) and construction of a permanent shallow monitoring bore.
    c. LS35c cored without introduced water to a depth of 18m to assess tree rooting depth. (-60° toward 180°)
3. A permanent vegetation monitoring transect as a baseline to facilitate ongoing monitoring of vegetation health if required.

NOTES:

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Figure 35. Long Swamp GDE Investigation site

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Arrow

0 30 60 90 120

Metres

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Kenmore, Qld 4069
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3.3.1 Coring to Root Depth

3.3.1.1 Geological and Hydrogeological Logging

Descriptions of the lithology encountered, presence and description of tree roots, moisture and groundwater observations, depths of all samples collected, soil moisture potential measurements, and gas concentrations are presented in the drilling logs (**Appendix D**).

The surficial geology encountered comprised of plastic clays underlain by sandy clays and clayey sands. Open fissures to a depth of at least 2.4m provided a pathway for surface water infiltration into a moist clay-bound sand (see **Figure 36**), with the sand content increasing with depth, and thus representing a noticeably moist vadose zone, approaching saturation. A feature of these open fissures (often also containing tree root material) was the presence of rounded clay pebbles (see **Figure 36**), likely due to the tumbling of surface clays down the open fissures during surface water infiltration. This may ultimately result in the illuviation of clays into lower sandy horizons.

An abrupt change into a dry loose sand (becoming gravelly at the base) was observed at 10.8m (**Figure 37**). This unit became moist to wet towards the base at approximately 15.1m, with water possibly perched above the underlying low permeability clays and silts. Groundwater (Likely to be the regional aquifer) was intersected at the base of the clay-rich sequences upon penetration into a loose to medium dense, very weakly consolidated sand at 26.5m which was present to the total drilling depth of 30m. **Figure 38** shows a microscope photo of the sand unit. This sand unit was picked by Arrow from the nearby Arrow Monitoring Bore LS34 log and other off-set wells in the area to be the top of the Westbourne Formation. This sand is possibly the same coarse sand described in many water bore drilling logs in the area and identified as Condamine River Alluvium within the QLD Government Groundwater Database.

3.3.2 Groundwater Monitoring Bore Construction

A 100mm diameter groundwater monitoring bore was constructed at 18m depth, screened from 15-18m across a predominantly dry sand unit with minor groundwater perched above the underlying clays and silts. This was the only zone observed to contain free water (saturated) above the maximum likely tree rooting depth (18m). The partially drilled core hole was left suspended overnight at 14.8m depth, and was noted to be dry the next morning. Upon intersection of the wet sand lower in this sequence, groundwater did not flow rapidly into the bore during drilling, but rather entered slowly as seepage at 15.74m (rose 3mm in 15 mins before stabilising). Based on soil moisture potential measurements, the inferred zone of moisture uptake by trees was 7.6-11.5m. However it is conceivable, although considered unlikely, that trees may be accessing observed groundwater within the base of the underlying sand unit between 15 and 18m.

Figure 36. Clay pebbles in open fissures at 2m; and underlying clayey sand comprising a very moist vadose zone inferred to be the horizon of predominant soil moisture uptake by trees.

Figure 37. Dry gravelly sand alluvium at 18m along the angle core (15mGL)

Figure 38. Poorly sorted sand unit encountered in Long Swamp 35 (Photo of sample collected at 30m depth).

3.2.1.2 Root Material Logging

A concise record of where root material was recorded in the soil/rock profile during core examination is recorded in the core hole log for LS35 attached to **Appendix D**. Whilst tree roots were recorded throughout the upper 3.5 m of the soil profile in vertic clays (see **Figure 39** below), the deepest root material was recorded at 7.1mGL in LS35c (10.2 m downhole in the angle hole). This position corresponds with an increase in soil moisture potential which suggests tree roots are tapping these zones of available soil moisture within the sandy clay horizon described in the previous **Section 3.2.1.1**.

Figure 39. Large tree roots in vertic clay at 2.5m depth in LS35a and fine tree roots (approx. 1.5mm) recorded in 5.5mGL in clayey sand (LS35a).

Although the main regional aquifer was encountered at 26.5m (and rose during drilling to 14.72m), this aquifer (picked by Arrow to be the Westbourne Formation) was considered to be well below the maximum likely tree rooting depth (18m), and well below the maximum observed tree rooting depth (7.1m). Therefore this aquifer zone was not considered highly relevant to assessing potential groundwater uptake by trees in Long Swamp, and a groundwater monitoring bore was not installed.

Groundwater monitoring bores drilled to assess and monitor deeper aquifers were installed at a nearby drilling pad by Arrow Energy and reported under separate cover. Bore construction details are shown on the drilling log LS35b in **Appendix D**.

3.3.3 Stable Isotope Sampling and Analyses

The results of stable isotope analyses are provided within **Table 8** with raw data provided in **Appendix F**. Water stable isotopes of oxygen and deuterium (δ18O and δ2H) were measured at regular intervals in the soil profile, and twig xylem samples were taken from 2 representative trees in an attempt to correlate the dominant source of water utilised river red gum located within the swamp.

Table 8. δ18O and δ2H isotope values for soil moisture, twig xylem and surface / groundwater at the Long Swamp GDE assessment site (LS35).

Metres below ground	Raw 2H	δ2H VSMOW	Raw 18O	δ18O
Soil Moisture				
0.2	-14.77	-16.78	-0.99	-2.36
0.5	-18.50	-20.51	-2.85	-4.22
1	-18.32	-20.33	-2.65	-4.02
1.5	-20.35	-22.36	-3.09	-4.46
2	-17.27	-19.28	-1.83	-3.20
2.5	-20.81	-22.82	-1.62	-2.99
3	-20.87	-22.88	-1.18	-2.55
3.5	-19.44	-21.45	-1.48	-2.85
4	-18.23	-20.24	-1.74	-3.11
4	-19.44	-21.45	-2.03	-3.85
5	-23.00	-25.01	-2.10	-3.47
5.5	-21.40	-23.41	-2.48	-3.85
6	-17.44	-19.45	-1.47	-2.84
6.5	-22.84	-24.85	-2.94	-4.31
7	-26.85	-28.86	-3.00	-4.37
7.5	-18.68	-20.69	-1.43	-2.80
8	-21.37	-23.38	-1.50	-2.87
8.5	-24.87	-26.88	-3.02	-4.39
9	-26.10	-28.11	-2.98	-4.35
9.5	-26.53	-28.54	-4.07	-5.44
10	-25.63	-27.64	-2.49	-3.86
10.5	-28.24	-30.25	-3.15	-4.52
11	-29.28	-31.29	-3.66	-5.03
11.5	-26.41	-28.42	-3.24	-4.61
12.5	-26.76	-28.77	-2.91	-4.28
13	-30.00	-32.01	-4.59	-5.96
13.5	-26.81	-28.82	-3.67	-5.04
14	-28.02	-30.03	-2.97	-4.34
14.5	-30.67	-32.68	-4.59	-5.96
15	-30.47	-32.48	-3.48	-4.85
17	-29.39	-31.40	-4.06	-5.43
Twig Xylem Analysis				

Metres below ground	Raw 2H	δ2H VSMOW	Raw 18O	δ18O
Tree 1	-10.39	-12.4	-1.34	-2.17
Tree 2	-13.23	-15.24	-1.93	-3.3
		Groundwater Analysis		
LS35_Well	-63.88	-10.62	-0.59	-0.99

VSMOW = Vienna Standard Mean Ocean Water

3.3.3.1 Soil Moisture Isotopes

The isotopic composition of extracted soil moisture is plotted against sample depth in **Figure 40.** The profile indicates minor enrichment in δ2H and δ18O in the upper soil profile to a depth of approximately 0.5m consistent with evaporative enrichment in the upper soil profile. There is then a gradual decline in isotopic ratios with depth, particularly for δ2H which declines more obviously than δ18O. The higher energy state of 2H increases its tendency to fractionate (Singer et al 2014) which may be enhanced by the migration of soil moisture through clays. The isotopic profile suggests some limited infiltration of enriched surface water downward into the soil profile, although infiltration of more significant quantities of surface water close to meteoric values may occur when the swamp is inundated.

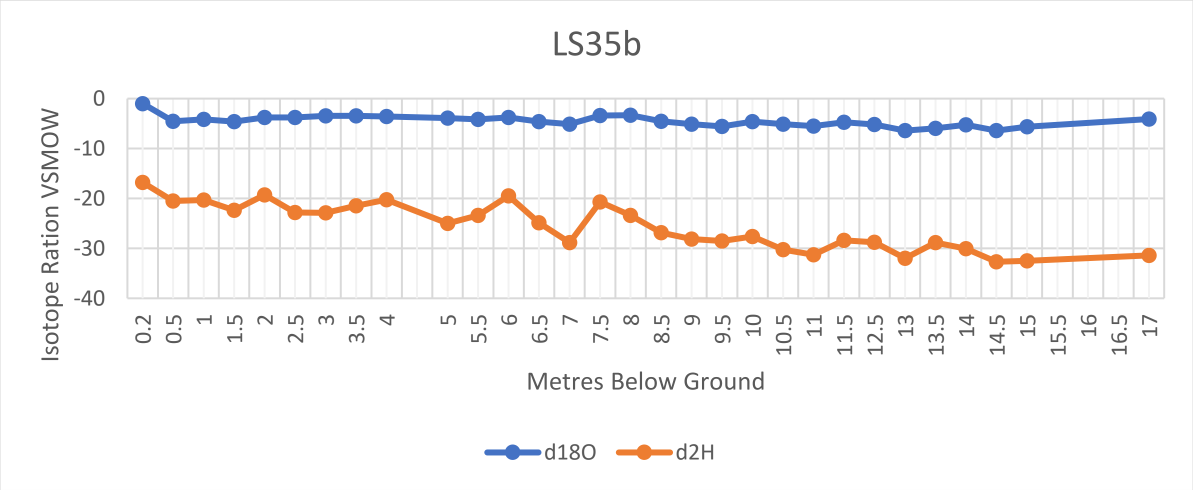

Figure 40. Isotopic composition of soil moisture plotted down hole in GDE investigation bore LS35b.

3.3.3.2 Xylem Water Isotopes

Figure 41 (overleaf) plots the relationship between δ18O and δ2H for soil moisture samples collected from borehole LS35b with comparison to isotopic composition of xylem water (Tree 1 and Tree 2) and a sample of water collected from the monitoring well at LS35. The groundwater sample (Well LS35b) shows isotopic enrichment above any of the soil samples suggesting that it may be erroneous, possibly influenced by residual water introduced to the well during the drilling process (see **Section 2.6**). Isotopic signatures of both Tree 1 and Tree 2 are enriched above all soil samples with the exception of the sample taken at 0.2m depth. This could indicate that trees are sourcing moisture from a range of depths in the profile including enriched surface water sourced from recent rainfall in the upper (0.2m) soil profile, or other processes are influencing the isotopic ratios including fractionation of isotopes in tree xylem or problems inherent in the sampling method. A number of possible explanations for the relative enrichment of xylem water extracted from twigs over soils is provided in **Section 4.1**.

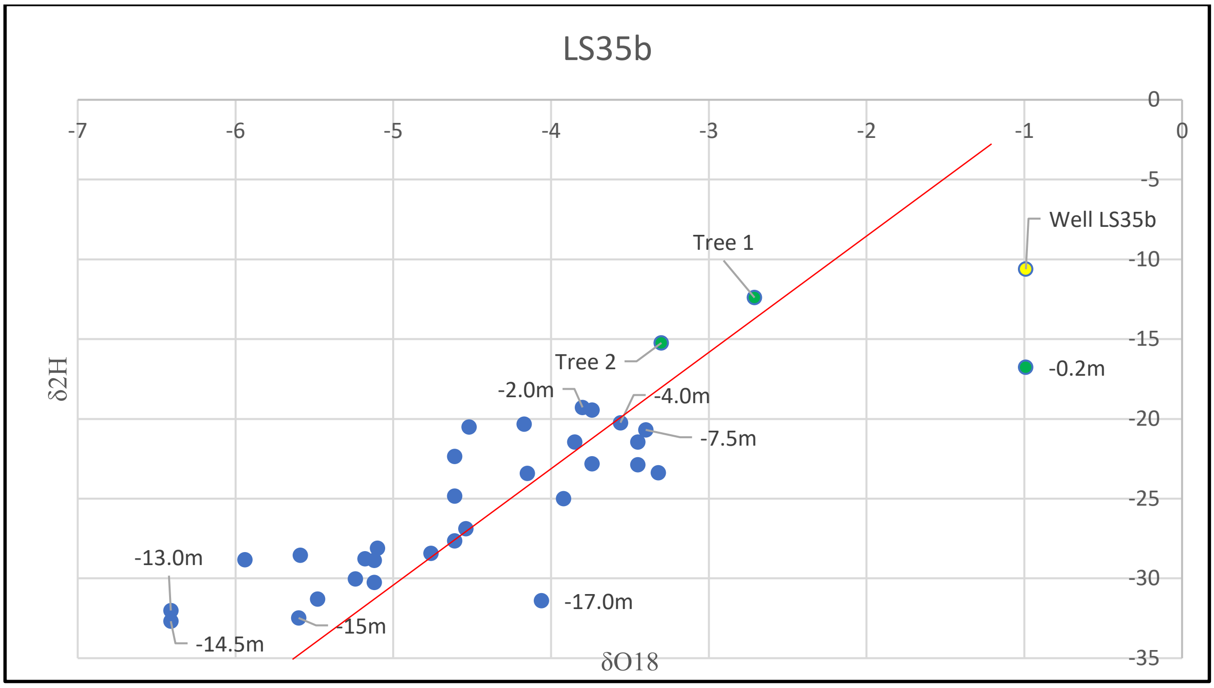

Figure 41. Biplot showing the relationship of stable isotope signatures (δO18 and δ2H) of water extracted from soil samples, twig xylem and surface / groundwater samples at the LS35 GDE assessment site. The red line indicates the Global Meteoric Water Line (GMWL) for reference, in the absence of a local standard.

3.3.4 Moisture Potential Measurements

The results of soil moisture and leaf water potential analyses for the Long Swamp 35 GDE assessment area are discussed in the following sections.

3.3.4.1 Soil Moisture Potential

The results of soil moisture potential analysis completed on soil and bedrock material samples from drill hole LS35b are represented in **Figure 42** with raw data provided in **Appendix E** and drill logs presented in **Appendix D**. The vertic clay in the upper soil profile has a strongly negative soil moisture potential to approximately 0.5m which would be a strong limiting factor in recruitment of shrubs. Between 2m and 6.5m depth, the constituent silty clays also have extremely low soil moisture availability falling well below standard wilting point. This suggests that the canopy red-gums in Long Swamp would unlikely be dependent on the upper 6.5m of the soil profile as a soil moisture source and any trees with a significant proportion of their root mass within this soil interval would be considerably stressed. Soil moisture availability increases between 7 and 8m depth (-105.9 psi at 7.5m) in wet to moist Clayey, Silty Sand (see lithological log – **Appendix D**) and then again at 10.5m (-88.5 psi). It should be noted from **Section 3.3.1** that deepest tree roots were recorded at 7.1m in LS35c (angle hole) corresponding with the zone of comparatively high soil moisture availability.

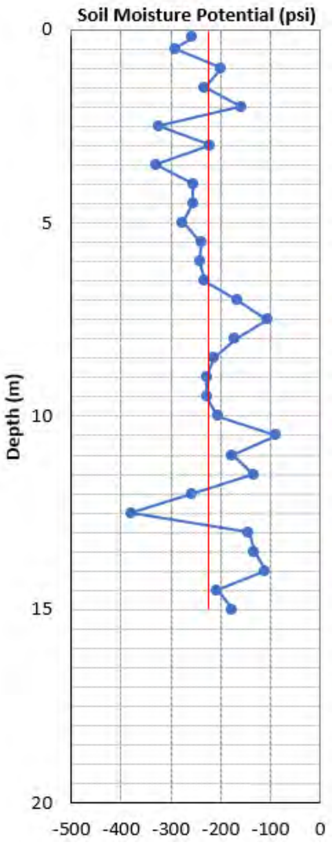

Figure 42. Soil moisture potential plotted downhole for LS35b with standard wilting point indicated by a red line.

3.3.4.2 Leaf Water Potential

The average Leaf water potential for all measured trees is presented below in **Table 9**. It is noted that Tree 2, being a considerably larger and more mature red gum that Tree 1 has a higher leaf water potential and is likely to be accessing water from a zone in the soil where there is greater soil moisture availability. The leaf water potential for Tree 1, Tree 2 and Tree 3 (poplar box) correspond with soil moisture potential measurements at depths between 7 and 10.5mGL. The brigalow (Tree 4) has an extremely low leaf water potential indicating that the species is adapted to survive under considerable moisture stress. It is anticipated that brigalow would be sourcing its soil moisture from the upper 2 -4m in the soil profile where moisture availability in the heavy clay is extremely low.

Table 9. Measured leaf water potential for trees at GDE Assessment Site LS35b.

Tree ID	Species	Height	DBH	X	Y	M1_PSI	M2_PSI	M3_PSI	Average
Tree 1	E.camaldulensis	19	55	-27.26999	151.09462	160	160	116	**-145.3**
Tree 2	E.camaldulensis	24	80	-27.26988	151.09492	116	44	58	**-72.6**
Tree 3	E.populnea	19	60	-27.2695	151.09541	145	145	145	**-145**
Tree 4	A.harpophylla	12	26	-27.2691	151.09376	333			**-333**

3.3.5 Baseline Characterisation

3.3.5.1 Ecological Characterisation

Raw vegetation transect data from the Long Swamp GDE Assessment Area is provided in **Appendix H**. The vegetation on the site consists of a woodland although canopy cover is variable and patchy across large areas and numerous dead trees are scattered throughout the broader woodland habitat. At the transect, the canopy is formed by river red gum with an average canopy height of 20m and 40% cover. The shrub layer is extremely sparse (almost non-existent) indicative of low levels of canopy recruitment. Ground comprises 17% cover of native grasses with *Panicum queenslandicum* the most prominent and scattered native sedges and forbs including *Eleocharis plana* which was desiccated at the time of assessment. It is expected that the contribution of native forbs would increase dramatically during wetter seasonal periods. Over a 50m measured transect with a measured canopy cover of 40.9%, a foliage index of 0.56 (56%) is calculated from canopy photography. Canopy observations while on site suggest that canopy foliage is suffering from stress and this is probably reflected in a relatively low foliage index score (**Appendix I**).

Figure 43. Typical vegetation along the Long Swamp Monitoring Transect (LS35b) with photograph on right showing stressed foliage cover.

3.4 Burunga Lane

Burunga lane is the most northern of all GDE Assessment Areas. The general features applicable to GDE assessment are indicated in **Figure 44**. This includes;

1. Two trees measured for leaf water potential.
2. Three Sonic drill holes targeted to assess shallow hydrogeology and the presence of groundwater / aquifers, determine rooting depth of trees and collect soil samples for analysis of soil moisture potential and stable isotope analysis. Drill holes constructed include:
    a. BL182a drilled to a depth of 14m for the purpose of geological characterisation.
    b. BL182b drilled to a depth of 7.1m for stable isotope and soil moisture potential sampling (drilled without introduction of water) and construction of a permanent shallow monitoring bore.
    c. BL182c duplication of BL182a drilled without introduction water to a depth of 15.5m with a sole aim of confirming the depth of the regional aquifer suspected to be associated with a coal seam.The drill hole was not sampled and core was not collected,
    d. BL182d drilled on an angle (-56° toward 090) to a depth of 13mGL (16.1m drilled length) with an aim to confirm tree rooting depth.
3. A permanent vegetation monitoring transect baseline to facilitate ongoing monitoring of vegetation health if required.

3.4.1 Coring to Root Depth

3.4.1.1 Geological and Hydrogeological Logging

Descriptions of the lithology encountered, presence and description of tree roots, moisture and groundwater observations, depths of all samples collected, soil moisture potential measurements, and gas concentrations are presented in the drilling logs (**Appendix D**).

The surficial geology encountered comprised of alluvial sands, silty sands and clays becoming more indurated towards a basal conglomerate at 4.9-6m (variable depths noted between the bore holes). The alluvium and conglomerate (**Figure 45**) overlay a sequence of highly to completely weathered sandstones (**Figure 46**), siltstones and coals (**Figure 47**) of the Walloon Coal Measures present to the total drilled depth of 14.5m.

Figure 44. Burunga Lane GDE Investigation site

NOTES:

Data Sources:
Regional Ecosystem Mapping from DNRM,
Version 10.1

Client

Arrow

0 30 60 90 120
Metres

Scale 1:2,000

Drawn By DG

Checked DS

File Path

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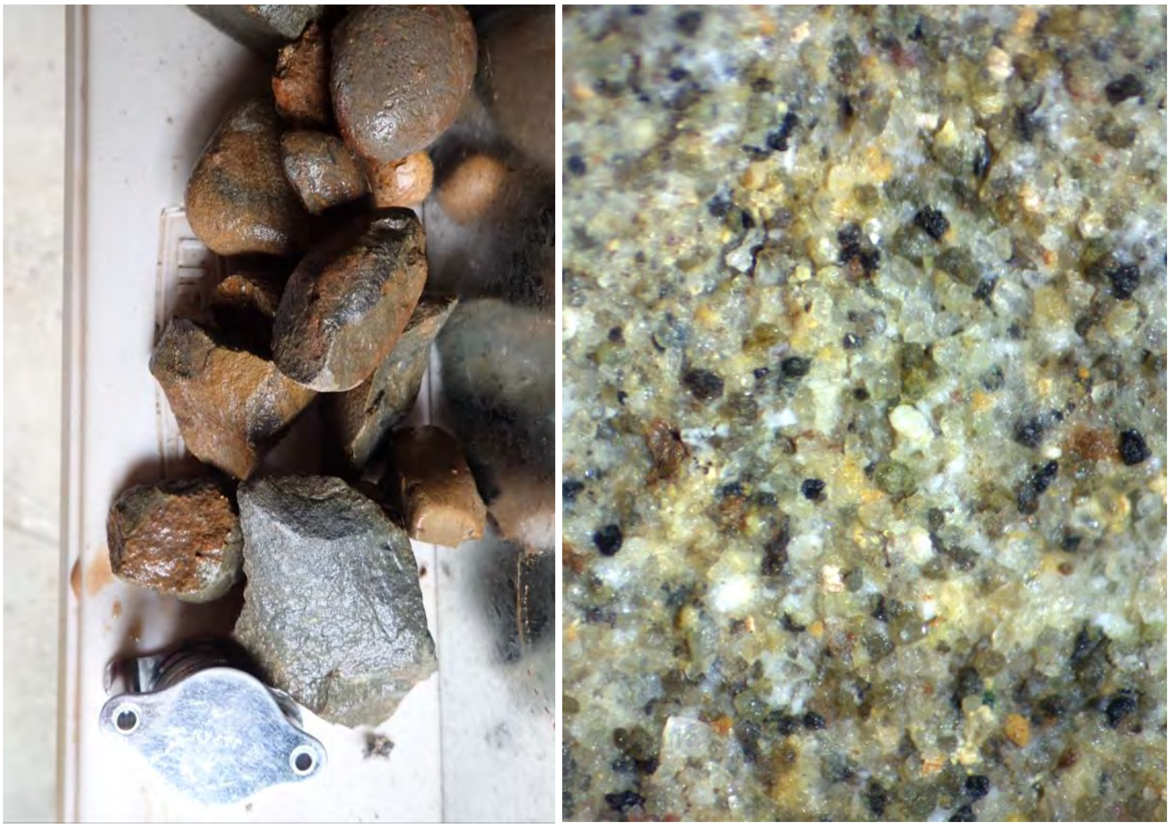

Figure 45. Clasts from weakly cemented and highly weathered conglomerate at 5.8m and well cemented sandstone with very little visible porosity at 10m

Figure 46. Coal seam at 13.8m depth in BL182a.

Figure 47. Coal seam and dull and bright coal samples (20mm thickness) collected from BL182A at 13.8m depth

Minor perched water was present within the conglomerate. The first noticeable true groundwater strike occurred at 13.5m within a thin coal seam, the inferred position of the regional aquifer. This groundwater rose under sub-artesian pressure to approximately 7.5mGL .

3.4.1.2 Root Material Logging

Root material was intersected in the upper 0.5 m of the soil profile with concentrations of tree roots recorded between 3.8 and 4.5mGL. Maximum tree rooting depth recorded was 6mGL in drill core BL182b where a 1.5mm tree root was recorded in a fractured conglomerate band (see **Figure 48**). This depth corresponds with a zone of relatively high soil water potential and represents a likely source of soil moisture for transpiration.

Figure 48. Fine (1.5mm thick) tree roots recorded in conglomerate at 5.7mGL in BL182a. Note iron oxidation and calcite dissolution “halo”, possibly representing a zone of locally enhanced permeability.

3.4.2 Groundwater Monitoring Bore Construction

A 100mm diameter groundwater monitoring bore was constructed at 7.1m depth, screened from 4.1-7.1m across the interface between the unconsolidated alluvium, conglomerate and the highly weathered upper fringe of weathered fine sandstone regolith. The core from this zone appeared to contain moisture approaching saturation, and coincided with the deepest observed tree roots noted at 6m depth, and also a zone of higher soil moisture potential. Based on the competent nature of the underlying sandstone and lack of saturation above 13.5m, it was considered unlikely that tree roots would penetrate deeper than the upper perched water.

The underlying Walloon Coal Measures Formation has been targeted for assessment through a series of deeper groundwater monitoring bores drilled during the concurrent and complementary drilling programme managed by Arrow Energy which is reported on separately. The Burunga Lane 182 groundwater monitoring bore contained insufficient groundwater (<1l of sediment-laden liquid removed) at the time for development to occur. This bore is considered to be screened across a seasonal perched aquifer and would require a significant rainfall event and subsequent inundation of the river alluvium to recharge the perched aquifer before development and sampling could occur. Bore construction details are shown on the drilling log BL182b in **Appendix D**.

3.4.3 Stable Isotope Sampling and Analyses

The results of stable isotope analyses for the Burunga Lane GDE investigation site are provided in **Table 10** with raw data provided in **Appendix F**. Similar to previous investigation sites, water stable isotopes of oxygen and deuterium (δ18O and δ2H) were analysed from soils collected at regular intervals in the soil profile, twig xylem samples were taken from 2 representative trees. There was insufficient water in the monitoring well BL182 to allow well development and collect a water sample. The results of these analyses are provided in **Table 10** with raw data provided in **Appendix F**.

Table 10. δ18O and δ2H isotope values for soil moisture, twig xylem and surface / groundwater at the Burunga Lane GDE assessment site.

Metres below ground	Raw 2H	δ2H VSMOW	Raw 18O	δ18O
Soil Moisture				
0.2	-2.57	-4.58	0.78	-0.59
1	-8.71	-10.72	-2.34	-3.71
1.5	-18.60	-20.61	-2.53	-3.90
2	-11.39	-13.40	-2.81	-4.18
2.5	-7.67	-9.68	-3.24	-4.61
3	-0.72	-2.73	1.43	0.06
3.5	-23.79	-25.80	-3.82	-5.19
4	-23.79	-25.80	-3.82	-5.19
4.5	-20.45	-22.46	-2.55	-3.92
4.8	-18.55	-20.56	-2.75	-4.12
5	-23.18	-25.19	-2.49	-3.86
5.5	-25.19	-27.20	-3.06	-4.43
6	-23.31	-25.32	-2.70	-4.07
6.5	-26.06	-28.07	-3.32	-4.69
7	-34.07	-36.08	-5.13	-6.50

Metres below ground	Raw 2H	δ2H VSMOW	Raw 18O	δ18O
8[1]	-25.63	-27.64	-4.11	-5.48
10[1]	-30.66	-32.67	-4.68	-6.05
12[1]	-30.35	-32.36	-4.42	-5.79
13.8[2]	-33.68	-35.69	-3.60	-4.97
Twig Xylem Analysis				
Tree 1	-7.22	-9.23	3.01	1.64
Tree 2	-9.67	-11.68	5.56	4.19

VSMOW = Vienna Standard Mean Ocean Water; [1] sample taken from BL182A; [2] sample taken from BL182C.

3.4.3.1 Soil Moisture Isotopes

The isotopic composition of extracted soil moisture is plotted against sample depth for borehole BL182b in **Figure 49.** The profile indicates relative isotopic enrichment at the surface (0.2mGL) with an enriched horizon also located at 3.0mGL corresponding with a change in lithology from silty sand to sandy clay. The profile suggests infiltration of evaporatively enriched soil moisture from the surface with a zone of moisture accumulation corresponding to the interface between sand and clay in the upper soil profile.

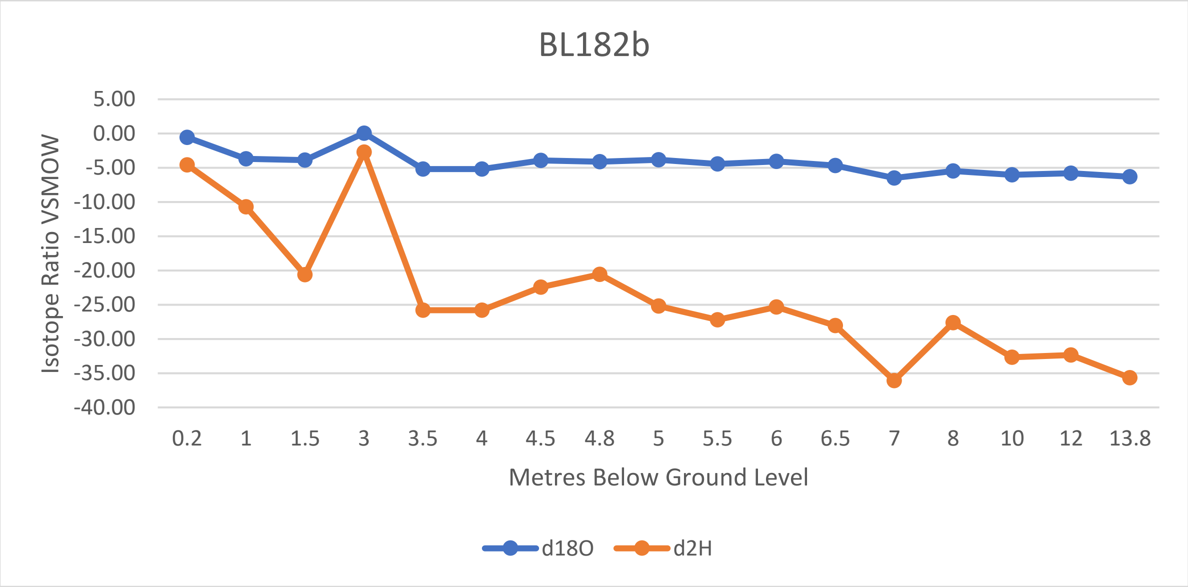

Figure 49. Isotopic composition of soil moisture plotted down hole in GDE investigation bore BL182b.

3.4.3.2 Xylem Water Isotopes

Figure 50 plots the relationship between δ18O and δ2H for soil moisture samples collected from borehole BL182b, with comparison to isotopic composition of xylem water (Tree 1 and Tree 2). Isotopic signatures of both Tree 1 and Tree 2 align more closely with the enriched soil moisture samples taken at the surface (0.2mGL) and 3.0mGL although demonstrate a greater degree of δ18O enrichment with δ2H has falling below trend. Potential reasons for the isotopic differences between xylem water and soil moisture are discussed in **Section 4.1**.

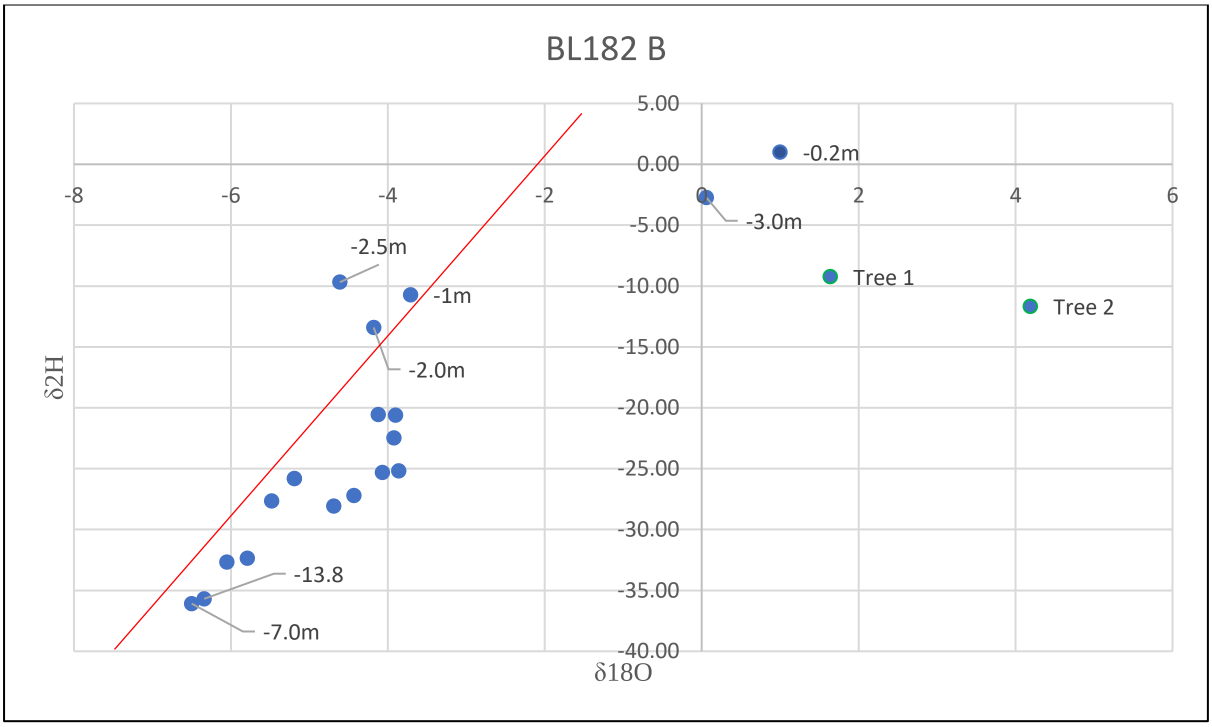

Figure 50. Biplot showing the relationship of stable isotope signatures (δO18 and δ2H) from water extracted from soil samples and twig xylem and surface / groundwater samples at the Burunga Lane GDE assessment site. The red line indicates the Global Meteoric Water Line (GMWL)

3.4.4 Moisture Potential Measurements

The results of soil moisture and leaf water potential analyses for the Burunga Lane GDE assessment area are discussed in the following sections.

3.4.4.1 Soil Moisture Potential

The results of soil moisture potential analysis completed on soil and bedrock material samples from core hole BL182b are represented in **Figure 51** with raw data provided in **Appendix E**. The approximate soil moisture potential at tree wilting point (217 Psi) is shown on the figure for reference. It is apparent that there is an extremely dry sub-surface profile between 0.5m and 2.0m depth corresponding with unconsolidated silty sand (alluvial) where soil moisture potential falls considerably below standard wilting point. It is unlikely that river red gum would derive any significant quantities of water from this drier zone and infiltration events initiated by heavy rainfall or overbank flow would be required to prompt the initial growth of roots through drier layers into deeper layers where soil moisture content is higher (Kramer, 1983; Eaumus 2006). The zone where soil moisture is most available in the profile occurs between approximately 4.5m and 6.5m depth corresponding with a horizon of moist sand which sits above a conglomerate band surface of weathered basement rock (see lithological log – **Appendix D**).

3.4.4.2 Leaf Water Potential

Leaf water potential sampling was undertaken on two trees in the Burunga Lane GDE Assessment area. This includes a mature river red gum (Tree 1) with a canopy height of 24m and 'diameter at breast height (DBH) at 120cm, plus a smaller regrowth tree which was located in an open paddock 20m to the east of Tree 1. At Tree 1, the measured soil moisture potential was -63psi (based on an average of 3 readings) and for Tree 2 relatively consistent at 72psi.

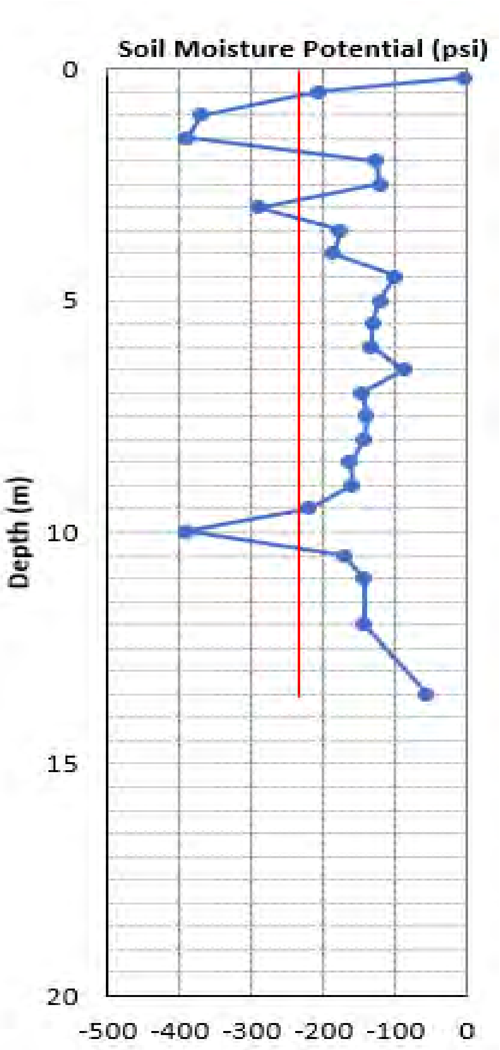

Figure 51. Soil moisture potential plotted downhole for BL182b with standard wilting point indicated by the red line.

3.4.5 Baseline Characterisation

3.4.5.1 Ecological Characterisation

Raw vegetation transect data from the Burunga Lane assessment area is provided in **Appendix H**. Due to the heavy modification of riparian vegetation in this locality, the transect was shortened to cover only the target tree (Tree 1) and groundcover composition was not recorded systematically due to the heavy grazing regime. Transect data indicates a disturbed riparian woodland habitat which has been largely cleared to the margins of Juandah Creek with only a few scattered mature canopy trees remaining. These remnant trees are located in a paddock which is otherwise covered in dense pasture of exotic buffel grass (*Cenchrus ciliaris).* The immediate upper bank of Juandah Creek is occupied by a fringe of sally wattle (*Acacia salicinia)* and river myall (*Acacia stenophylla)* although these are located outside the immediate transect. The only consistently repeatable measure of ecological health that could be made at this site relates the foliage index of the target tree. Over a 30m measured transect with a measured canopy cover of 53%, a foliage index of 65% is calculated indicating canopy health is relatively robust. Comparison with other GDE Assessment Areas is provided in following discussions.

Figure 52. The photograph on the left is view looking south along transect towards the target tree (Tree 1) with photograph on right indicating relatively robust foliage cover.

3.5 Glenburnie

Glenburnie is the most southern of the GDE Assessment Areas lying to the west of Millmerran on the fringes of Western Creek. The general features applicable to GDE assessment are indicated in **Figure 53** below. This includes;

1. Four trees measured for leaf water potential.
2. Three sonic core holes targeted to assess shallow hydrogeology and the presence of groundwater / aquifers, determine rooting depth of trees and collection of soil samples for analysis of soil moisture potential and stable isotopes. Core holes constructed include:
    a. GB20a drilled to a depth of 30m for the purpose of geological characterisation.
    b. GB20b drilled to a depth of 18m for stable isotope and soil moisture potential sampling (drilled without introduction of water) and construction of a permanent groundwater monitoring bore.
    c. GB20c drilled on an angle (-50° toward 180°) to a depth of 11mGL (14.2m drilled length), with an aim to assess tree rooting depth.
3. Hand auger hole GB20HA drilled to a depth of 1.1m through the base of the dry sandy creek bed into the underlying weathered bedrock.
4. A permanent vegetation monitoring transect baseline to facilitate ongoing monitoring of vegetation health if required.

NOTES:

Data Sources:
Regional Ecosystem Mapping from DNRM,
Version 10.1

Figure 53. Glenburnie GDE Investigation site

Client Arrow

0 10 20 30 40
Metres

Scale 1:970

Drawn By DG

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File Path

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3.5.1 Coring to Root Depth

3.5.1.1 Geological and Hydrogeological Logging

Descriptions of lithology, presence and description of tree roots, moisture and groundwater observations, depths of all samples collected, soil moisture potential measurements, and gas concentrations are presented in the drilling logs (**Appendix D**). The surface geology comprised loose, alluvial sands to 2.5m depth which overlay increasingly carbonaceous and less weathered sequences of fine to coarse sandstones which were present to the total depth of drilling (30m). The shallow depth to sandstone bedrock was confirmed through the presence of nearby outcrop (see **Figure 54**), and through hand augering Glenburnie 20HA within the dry sandy bed of Western Creek adjacent to the drilling site. Weathered sandstone was present at 0.7m depth, demonstrating a very thin drape of alluvium bed and a shallow bedrock base which may temporarily support the perched flow and pooling of groundwater after significant rainfall events.

Figure 54. Weathered sandstone outcrop within the nearby road (drilling site visible in background across the dry creek bed) and adjacent to the road in a low cutting.

A seepage zone was noted between 11-18m above a transition into a carbonaceous sandstone rich in re-worked coal fragments and other carbonaceous clasts (**Figure 55**, **Figure 56** below) as well as dark grey siltstone lenses likely to represent over-bank slump deposits. This depth (21mGL in the adjacent Glenburnie 22, equivalent to approximately 19mGL in Glenburnie 20) is considered by Arrow geologists to represent the top of the Walloon Coal Measures (see **Figure 57)** . Therefore Glenburnie 20 is considered to be tapping a perched groundwater zone within the basal Springbok Sandstone. The regional aquifer was encountered at a depth of approximately 27m in a fine to medium quartzose sandstone which became stronger, less weathered from 28.9m. The groundwater level from this water strike rose under sub-artesian pressure to approximately 14.4m. This aquifer was considered to be much deeper than the maximum likely tree rooting depth (18m) and was well below the maximum observed tree rooting depth (7.1m).

Figure 55 . Coal fragments in sandstone core from Glenburnie 20 at 22.5-24m.

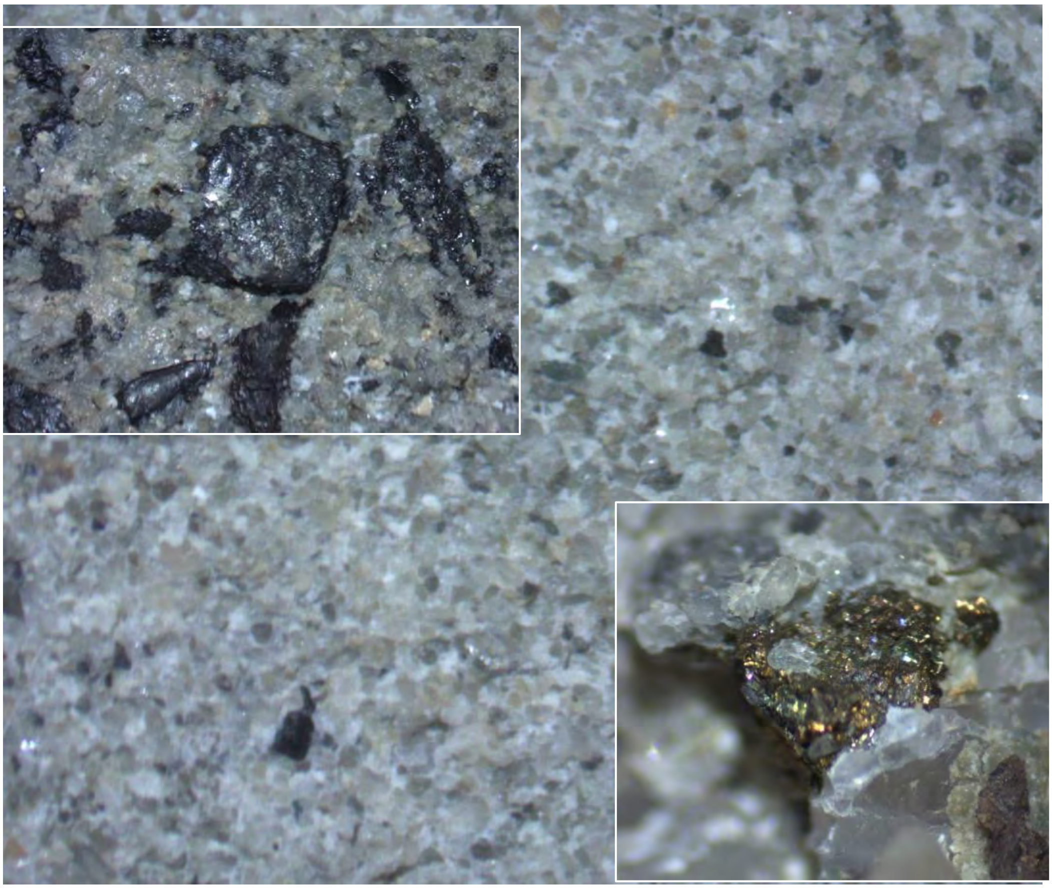

Figure 56. Coal (1-5mm) and (likely) chalcopyrite (2mm) fragments in coarse sandstone at 20.3m

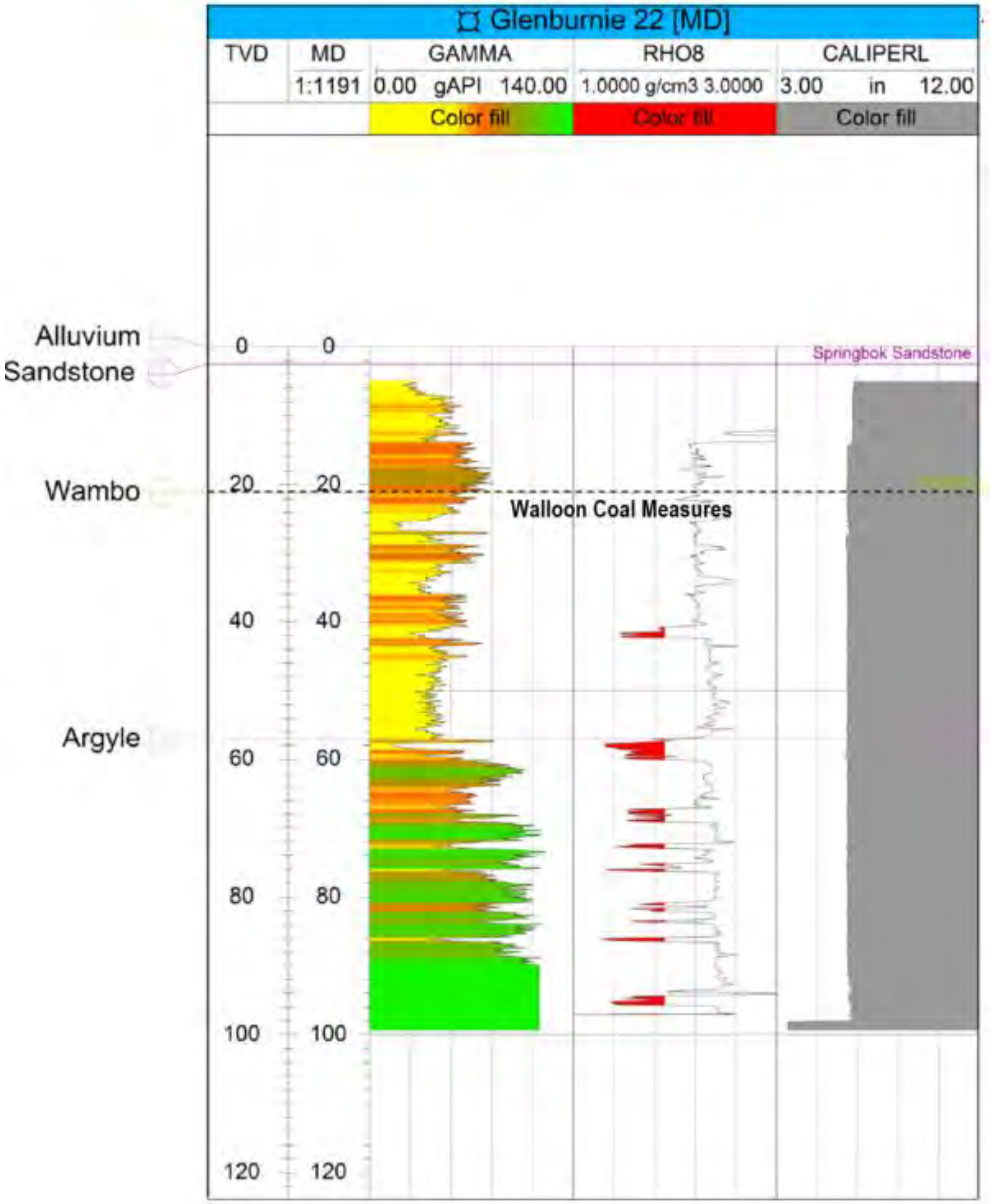

Figure 57. Combined geophysical log with formation tops provided by Arrow Energy for Glenburnie 22 located approximately 100m to the north of Glenburnie 20. Note that the surface elevation for Glenburnie 22 is approximately 2.1m higher in elevation than Glenburnie 20.

3.5.1.2 Root Material Logging

The Glenburnie assessment site was geologically different to other GDE assessment sites in that weathered bedrock was intersected within 1.5m of the ground surface. Root material was recorded at several positions in the soil profile with a large (1cm wide) tree root recorded along bedding at 4.5m depth and an extremely fragile example recorded at 7.6m depth in the angle hole (GB20c). This latter example, which had penetrated the rock matrix, had an extremely open vessel structure which would require a seasonally consistent supply of soil moisture to prevent root embolism (Santini et al 2017, Orellana 2012).

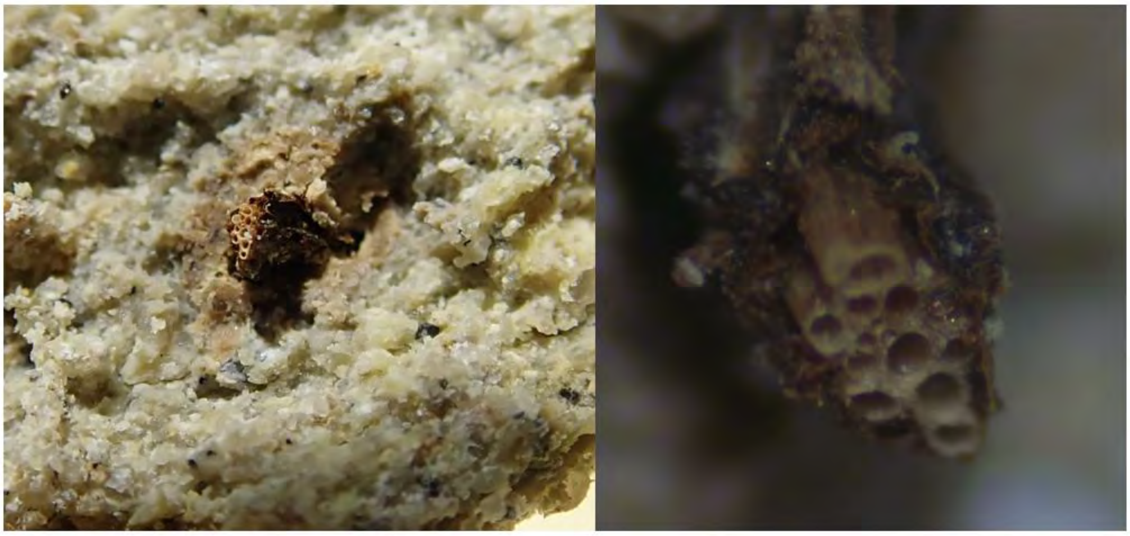

Figure 58. Open vessel structure of tree roots recorded at 7.6m in weathered Springbok Sandstone. Note water or resin droplets present within xylem in the photograph on the right.

Figure 59. Large tree roots recorded penetrating along bedding in sandstone at 4.5mGL in GB20a.

3.5.2 Groundwater Monitoring Bore Construction

A 50mm diameter groundwater monitoring bore was constructed at 18m depth, screened from 10-18m across a seepage zone within fine to coarse grained sandstones. This was the only zone observed to contain free water (saturated) above the maximum likely tree rooting depth (18m). The partially drilled core hole was left for 35 minutes and 1 hour respectively at 6m and 12.3m, and each time noted to be dry before drilling commenced. Groundwater noted at 11-18m did not flow rapidly into the bore during drilling, but rather entered slowly overnight as seepage (rose 0.3m in 13 hours) from 18m. The hydrograph shown below in **Figure 60** from the pressure transducer installed into Glenburnie 20 after drilling shows that the bore took approximately 4 days to reach 90% recovery (3.25m).

Based on soil moisture potential measurements, the inferred zone of moisture uptake by trees was 9-11.5m, potentially tapping the very upper limit (capillary fringe) of this seepage zone.

Although the main regional aquifer (inferred to be the Walloon Coal Measures) was encountered at approximately 27m (and rose under sub-artesian pressure to 14.4m), this aquifer was considered to be well below the maximum likely tree rooting depth (18m), and well below the maximum observed tree rooting depth (7.6m). Therefore this aquifer zone was not considered highly relevant to assessing potential uptake by trees at Glenburnie. Groundwater monitoring bores drilled to assess and monitor deeper horizons within the Walloon Coal Measures were installed at a nearby drilling pad by Arrow Energy and reported under separate cover. Bore construction details are shown on the drilling log Glenburnie 20B in **Appendix D**.

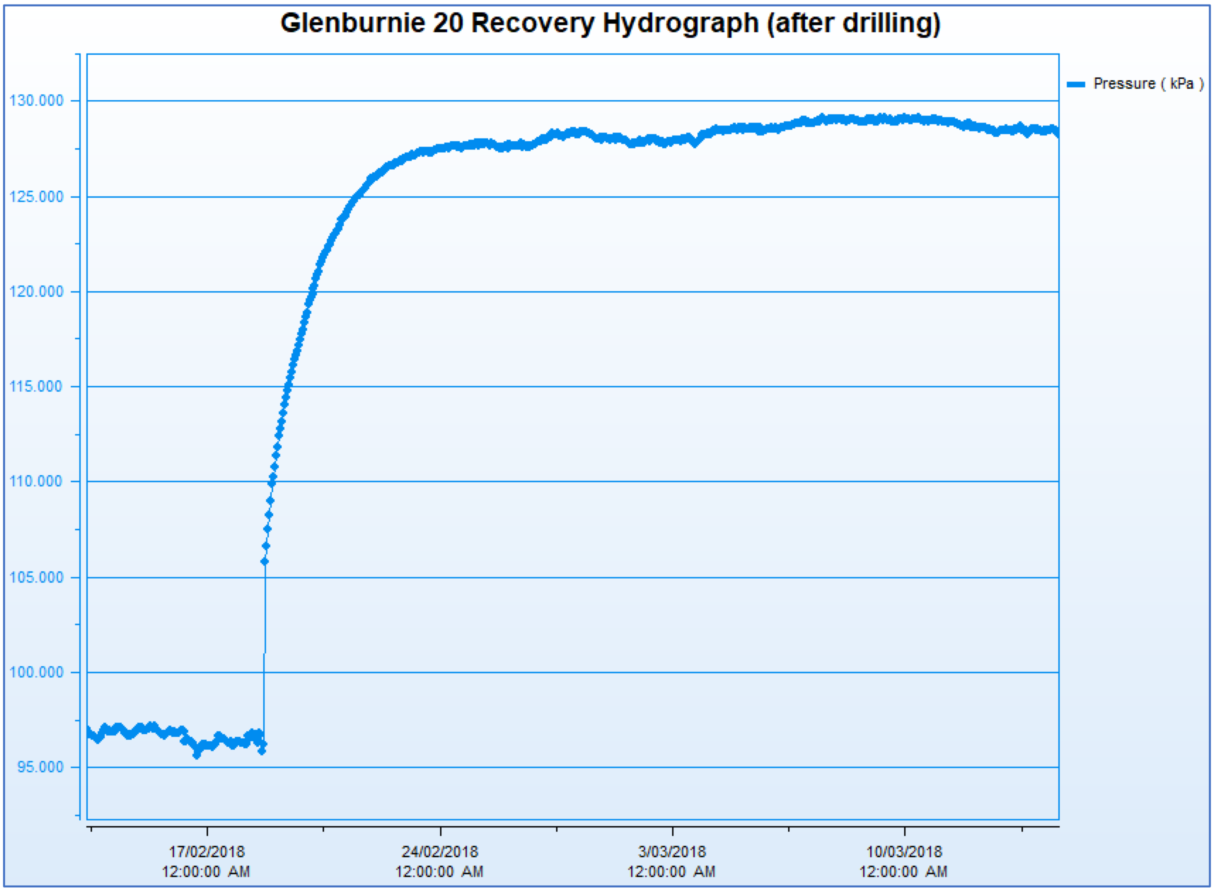

Figure 60. Glenburnie 20 recovery hydrograph showing relatively slow recovery after drilling

3.5.3 Stable Isotope Sampling and Analyses

Consistent with other assessment sites, water stable isotopes of oxygen and deuterium (δ18O and δ2H) were analysed from soils collected at regular intervals in the soil profile and twig xylem samples were taken from 2 representative trees. The results of stable isotope analyses for the Glenburnie GDE investigation site are provided in **Table 11** with raw data provided in **Appendix F**.

Table 11. δ18O and δ2H isotope values for soil moisture, twig xylem and surface / groundwater at the Glenburnie GDE assessment site.

Metres below ground	Raw 2H	δ2H VSMOW	Raw 18O	δ18O
		Soil Moisture		
0.2	5.94	3.93	2.83	1.46
0.5	-17.71	-19.72	-2.35	-3.72
1	1.55	-0.46	-2.47	-3.84
1.5	-16.23	-18.24	-3.20	-4.57
2	-21.19	-23.20	-2.42	-3.79
2.5	-22.16	-24.17	-3.52	-4.89
3	-24.90	-26.91	-2.83	-4.20
3.5	-24.84	-26.85	-3.88	-5.25
4	-22.42	-24.43	-2.55	-3.92
4.5	-23.08	-25.09	-2.93	-4.30
5	-23.30	-25.31	-3.39	-4.76
5.5	-23.69	-25.70	-3.39	-4.76
6	-25.54	-27.55	-3.54	-4.91
6.5	-26.58	-28.59	-3.96	-5.33
7	-23.90	-25.91	-2.42	-3.79
7.5	-24.19	-26.20	-1.95	-3.32
8	-24.19	-26.20	-2.09	-3.46
8.5	-24.91	-26.92	-2.12	-3.49
9	-24.30	-26.31	-2.00	-3.37
9.5	-25.06	-27.07	-1.98	-3.35
10	-25.76	-27.77	-2.25	-3.62
10.5	-24.11	-26.12	-1.69	-3.06
11	-23.94	-25.95	-2.72	-4.09
11.5	-22.47	-24.48	-1.03	-2.40
12	-22.97	-24.98	-1.67	-3.04
12.5	-24.85	-26.86	-1.55	-2.92
13	-25.21	-27.22	-1.92	-3.29
13.5	-27.43	-29.44	-1.39	-2.76
14	-24.19	-26.20	-2.96	-4.33
14.5	-26.74	-28.75	-2.34	-3.71
15	-23.01	-25.02	-1.79	-3.16
15.5	-21.46	-23.47	-1.27	-2.64
16	-27.40	-29.41	-2.11	-3.48
16.5	-23.51	-25.52	-2.66	-4.03
17	-24.70	-26.71	-1.90	-3.27
17.5	-31.15	-33.16	-3.90	-5.27
18	-25.54	-27.55	-2.31	-3.68

Metres below ground	Raw 2H	δ2H VSMOW	Raw 18O	δ18O
Aug1 - 0.5	-5.77	-7.78	-0.63	-2.00
Aug1 - 0.75	-10.47	-10.47	-1.46	-2.83
Twig Xylem Analysis				
Tree 1	4.98	2.97	8.53	7.16
Tree 2	-3.25	-5.26	2.70	1.33
Groundwater Analysis				
LS35_Well	-74.36	-21.51	-2.37	-2.79

3.5.3.1 Soil Moisture Isotopes

The isotopic composition of extracted soil moisture is plotted against sample depth for borehole GB20b in **Figure 61.** The trend indicates strong evaporative enrichment at the soil surface (0.2m) with minimal infiltration of enriched surface moisture below approximately 1m depth in the soil profile. Differences in the degree of fractionation of δ18O and δ2H at 1m may reflect noise in the analysis process due to the higher sensitivity of deuterium (Singer et al, 2014).

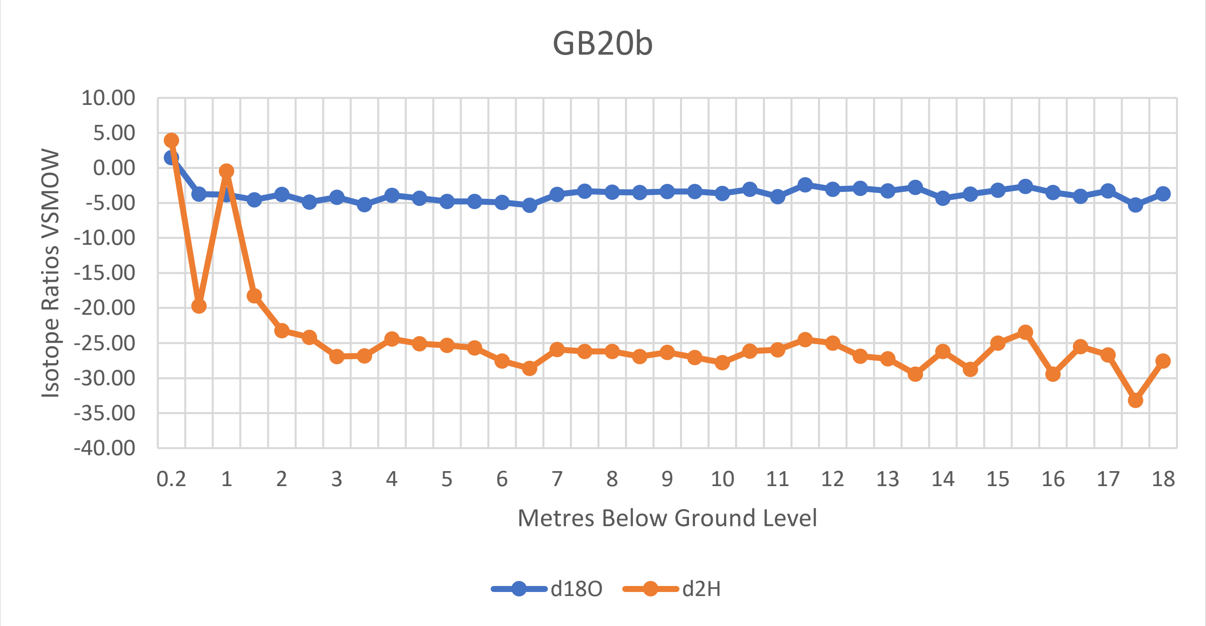

Figure 61. Isotopic composition of soil moisture plotted down hole in GDE investigation bore GB20b.

3.5.3.2 Xylem Water Isotopes

Figure 62 plots the relationship between δ18O and δ2H for soil moisture samples collected from borehole GB20b, compared to isotopic composition of xylem water (Tree 1 and Tree 2) and groundwater from sampling of monitoring well GB20. Isotopic signatures of both Tree 1 and Tree 2 demonstrate isotopic signatures that are significantly enriched above the majority of soil samples with the exception of Tree 2 where the isotopic signature is closer to the soil sample from the upper soil profile (0.2m) than samples taken at greater depth. Tree 1 has an isotopic signature that shows strong enrichment in δ18O above the upper soil profile, with δ2H lying below trend . Potential causal factors for enrichment are discussed in **Section 4.1** although may be an artefact of the sampling process or possibly isotopic fractionation within tree xylem. The heavy rainfall episode that occurred two days prior to the sampling effort has also possibly influenced the sampling results (see **Section 2.6**).

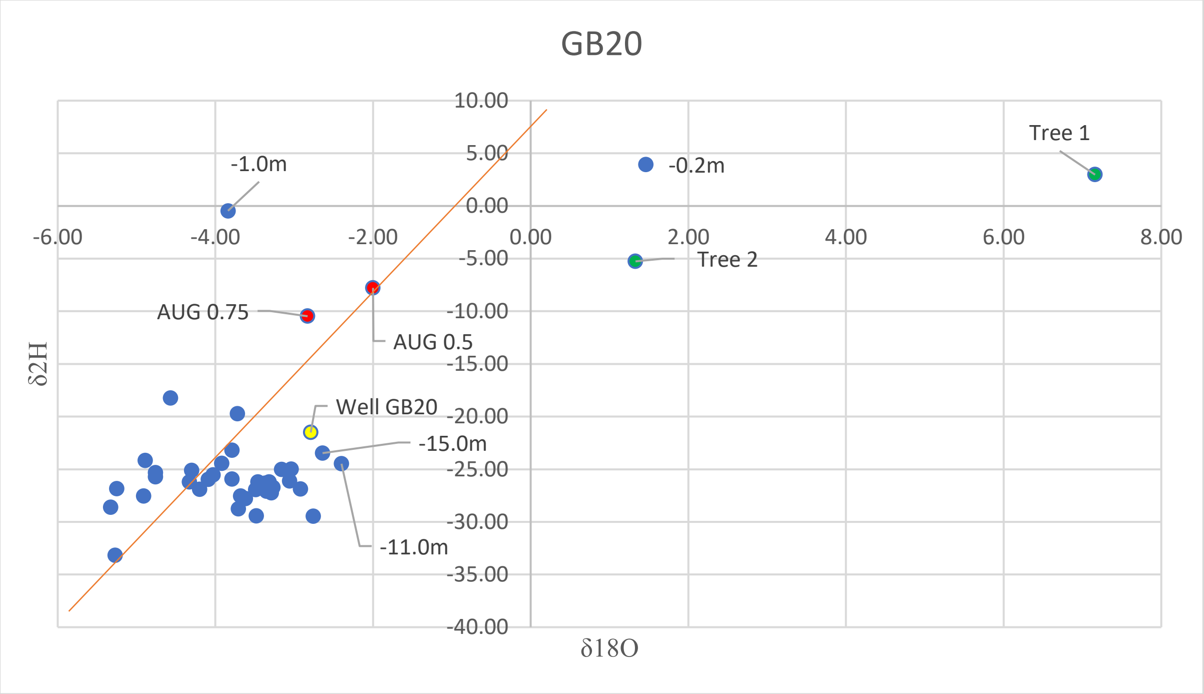

Figure 62. Biplot showing the relationship of stable isotope signatures (δO18 and δ2H) of water extracted from soil samples, twig xylem and surface / groundwater samples at the Glenburnie GDE assessment site. The red line indicates the Global Meteoric Water Line (GMWL)

3.5.4 Moisture Potential Measurements

The results of soil moisture and leaf water potential analyses for Glenburnie 20 GDE assessment area are discussed in the following sections.

3.4.4.1 Soil Moisture Potential

The results of soil moisture potential analysis completed on soil and weathered bedrock samples from drill hole GB20b are represented in **Figure 63** with drill logs presented in **Appendix D** and raw data provided in **Appendix E**. Soil moisture potential is extremely low for the top 8m of the hole within weathered sandstone, much lower than standard wilting point for considerable depths. The major rise in available soil moisture occurs between 9 and 11.5m. Soil moisture potential rises to -7.25 psi (at 10.5m) within a wet zone where the soil approaches saturation. Another zone of extremely high water potential occurs from 14.5m depth down to the base of the bore hole at 18m. It is noted in Section 3.4.1 that deepest tree roots are recorded at 7.6m depth within weathered sandstone, occurring immediately above the initial zone of high soil moisture potential.

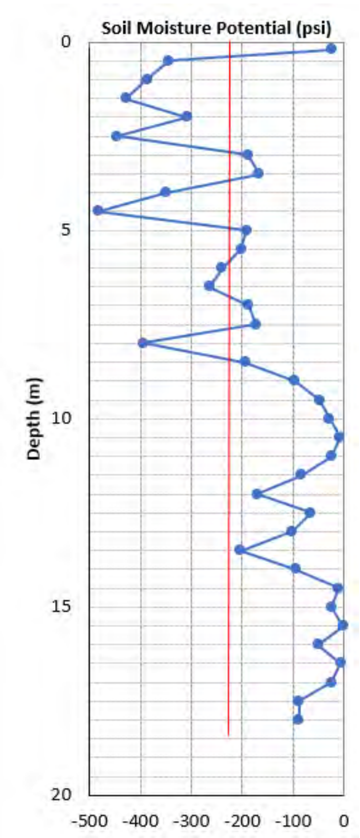

Figure 63. Soil Moisture Potential profile in GB20a showing extremely low moisture availability between 0.5 and 3.5mGL. Standard tree wilting point is shown by the red line.

3.4.4.2 Leaf Water Potential

The average Leaf water potential for all measured trees is presented below in **Table 12**. Tree 2, the mature river red gum located on the alluvial flat of Western Creek has a lower Leaf Water Potential than the target tree (Tree 2) which is located off the river flat on shallow colluvium. This result suggests that the Leaf Water Potential measurements may have been influenced by the preceding rainfall event (see **Section 2.6**) and soil moisture may have been harvested from wet horizons in the upper soil profile. The leaf water potential for the three eucalypts measured (Tree 1, Tree 2, Tree 4) all suggest that the trees have equilibrated with soil moisture below depths of 8m in the profile, consistent with the deepest recorded tree roots at 7.6m depth. The cypress pine has a much lower leaf water potential than the eucalypts which may indicate that the predominant zone of moisture extraction is at relatively shallower depths.

Table 12. Leaf water potential measurements for canopy trees in vicinity of Glenburnie 20.

Tree ID	Species	Height	DBH	X	Y	M1_PSI	M2_PSI	M3_PSI	Average
Tree 1	E.camaldulensis	24	80	27.83313	151.097	110	75	90	**91.6**
Tree 2	E.camaldulensis	19	40	-27.8331	151.0972	58	43	51	**50.6**
Tree 3	Callitris glaucophylla	17	45	-27.8331	151.0971	180	130	195	**168.3**
Tree 4	Corymbia tessellaris	21	55	-27.833	151.0955	58	90		**74**

3.5.5 Baseline Characterisation

3.5.5.1 Ecological Characterisation

Raw vegetation transect data from the Glenburnie 20 GDE Assessment Area is provided in **Appendix H.** The vegetation on the site is a disturbed riparian woodland (RE11.3.25) with a canopy that has been variably disturbed through timber extraction and unexplained canopy dieback. Many of the canopy trees represent mature regrowth. At the transect, the canopy is formed by river red gum and rough barked apple (*Angophora floribunda)* with a mid-dense sub-canopy of cypress pine. The predominant canopy forms a cover of 50% - 60% with an average canopy height of 21m with the sub-canopy and upper shrub layers formed by mid-dense cover (17%) of cypress pine at an average height of 14m. Ground cover is sparse with only 10% living native cover comprising grasses and graminoids, 44% leaf litter and a balance of bare sandy ground (45%) and 1% cover of exotic forbs. Over a 50m measured transect with a measured canopy cover of 63%, a foliage index of 0.62 (62%) is calculated from canopy photography (**see Appendix I**).

Figure 64. Riparian vegetation at the Glenburnie Monitoring Transect with photograph on right showing typical structure and canopy foliage on the right from canopy photography sequence.

4.0 Discussion and Refined Conceptual Site Models (CSMs)

4.1. Interpretation of Soil and Twig Moisture Isotope Results

While analysis of δ18O and δ2H in twig, soil and groundwater samples supports a shallow groundwater source of moisture for trees at the Lake Broadwater (LS31) GDE assessment site, the results at other assessment localities are less definitive. In particular, the strong enrichment of δ18O in xylem samples above soil moisture samples requires further consideration. There are several factors that may have influenced the results from twig sampling which may include the following:

1. Isotopic fractionation may occur in the xylem which has potential to confounding the isotopic results (Petit and Froend, 2018).
2. Water in the phloem is isotopically enriched carrying photosynthate back to the roots and potential exists for isotopic transfer to take place between the semi-permeable barriers of the phloem and xylem, especially in stored samples. There is also diffusion of enriched water from the site of enrichment against the physical flow of water (Peclet effect) and this may also enrich the xylem without the need for diffusion through the wood (Dr Hilary Stuart-Williams, Farquhar Laboratory, pers.comm).
3. The highly variable results of δ2H analyses are often attributed to evaporative enrichment and δ18O is a more reliable indicator of potential water source. There is evidence of δ2H fractionation occurring in a number of plant species (Singer et al, 2014, Petit and Froend, 2018).
4. Confounding sources of error which include sampling in conditions of extreme heat which may have facilitated isotopic fractionation in the xylem water and soil, plus the fact that any handling of samples during extremely hot conditions will exacerbate the tendency for fractionation due to evaporative loss (Petit. And Froend, 2018). It is noted that all sampling events were completed under hot to hot conditions (see **Section 2.1**).

While Petit and Froend (2018) consider stable isotope analysis a powerful tool, they state that it is often not enough to disentangle complex ecological interactions. Due to a variability in the isotopic composition of xylem water which responds to climatic variables, they recommend isotopic sampling over an extended time frame which considers all seasons. Hence the one-off sampling event undertaken during this study may not have provided sufficient temporal context to allow the results of isotopic sampling to be interpreted with confidence. It should be stated however that for the Burunga Lane, Long Swamp and Glenburnie GDE assessment sites, there is no suggestion of a deeper isotopically depleted source of water contributing significantly to the water uptake of trees in any of the isotopic analyses undertaken.

4.2. Zone of Water Uptake for GDE Assessment Areas

Figure 65 shows the inferred zone of dominant root water uptake for each of the individual GDE assessment areas based on direct comparison between leaf water potential and soil moisture potential. The maximum recorded depth of tree roots from drill core is also indicated. The results of the stable isotope analysis largely support the assessments made from measurement leaf and soil water potential and observations of rooting depth with further elaboration provided in the following sections. Integrated ecological and hydrogeological preliminary Conceptual Site Models (CSMs) have been prepared based on observations and measurements made during this assessment. In the case of Lake Broadwater and Long Swamp, these conceptualisations represent a refinement from preliminary models prepared during previous reporting (3d Environmental/Earth Search, 2017). Figures depicting key elements of the CSMs are presented and described below (see **Figures 66** to **69**).

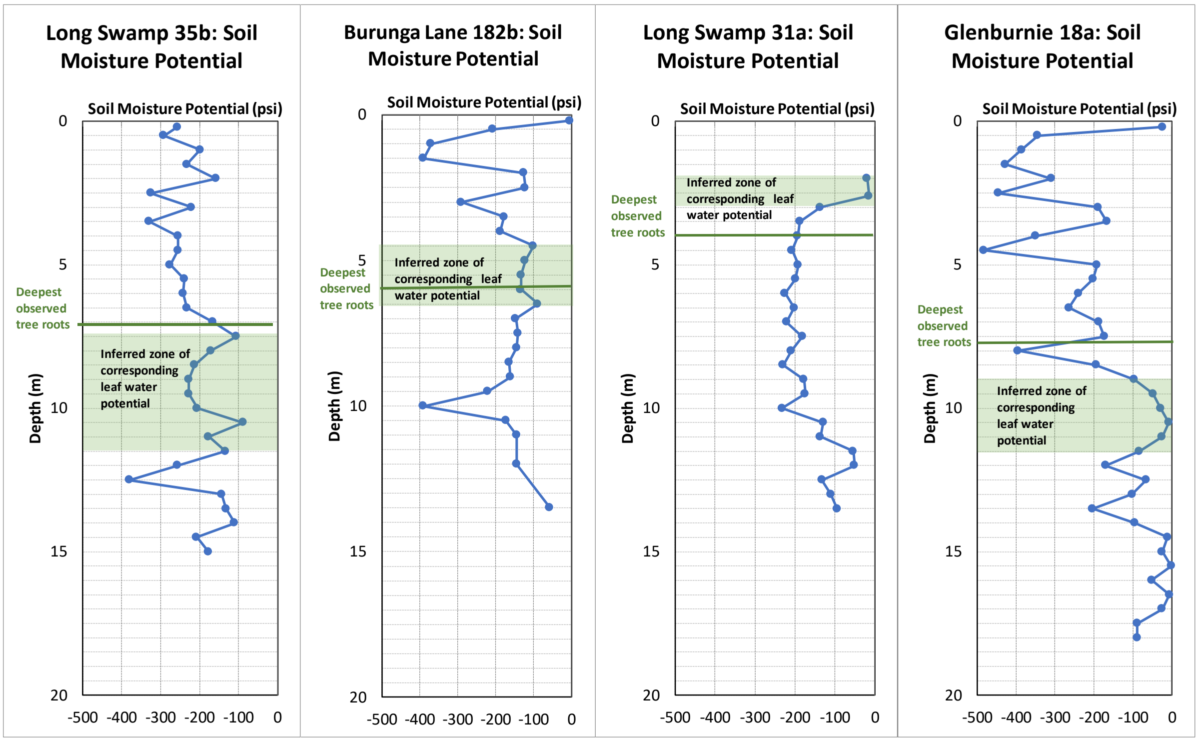

Figure 65. Inferred zone of predominant soil moisture uptake by river red gums at the 4 GDE investigation sites. Maximum recorded tree root depth at each of the sites is indicated by the green line.

Lake Broadwater: For Lake Broadwater (Long Swamp 31) (see Figure 66) an analysis Leaf Water Potential indicates soil water uptake from a saturated zone with high soil moisture potential. The soil profile from 2 to 3m with a very high soil moisture potential is considered to be the primary source of water which was largely confirmed through the analysis of stable isotope data. Below the shallow loose sand perched aquifer, the clay-dominated cored profile was not noted to be saturated until a depth of 18m in a clayey sand, with limited visible permeability, and at the maximum likely river red gum rooting depth threshold (18m). Although tree roots were recorded to depths of 4m, this is interpreted to be:

1. An anchorage adaptation. The loose unconsolidated sand in the upper 3m of the soil profile would not have capacity to support the wind load on a tall spreading red gum, and tree roots must penetrate a portion of the profile with greater mechanical strength to maintain structural integrity. Hence tree roots have penetrated the upper portion of the sandy clay profile.
2. A potential source of soil moisture during periods of drought stress when the shallow groundwater at the interface between sand and clay has been depleted.

It should be noted that for Lake Broadwater, no regional aquifer with a significant inflow during drilling (water strike) was intersected in the core hole that was drilled to 21mGL. It is also noted that the heavy plastic clay that extends to 11.3m depth has extremely low soil moisture potential and would present a major physical barrier to tree root penetration.

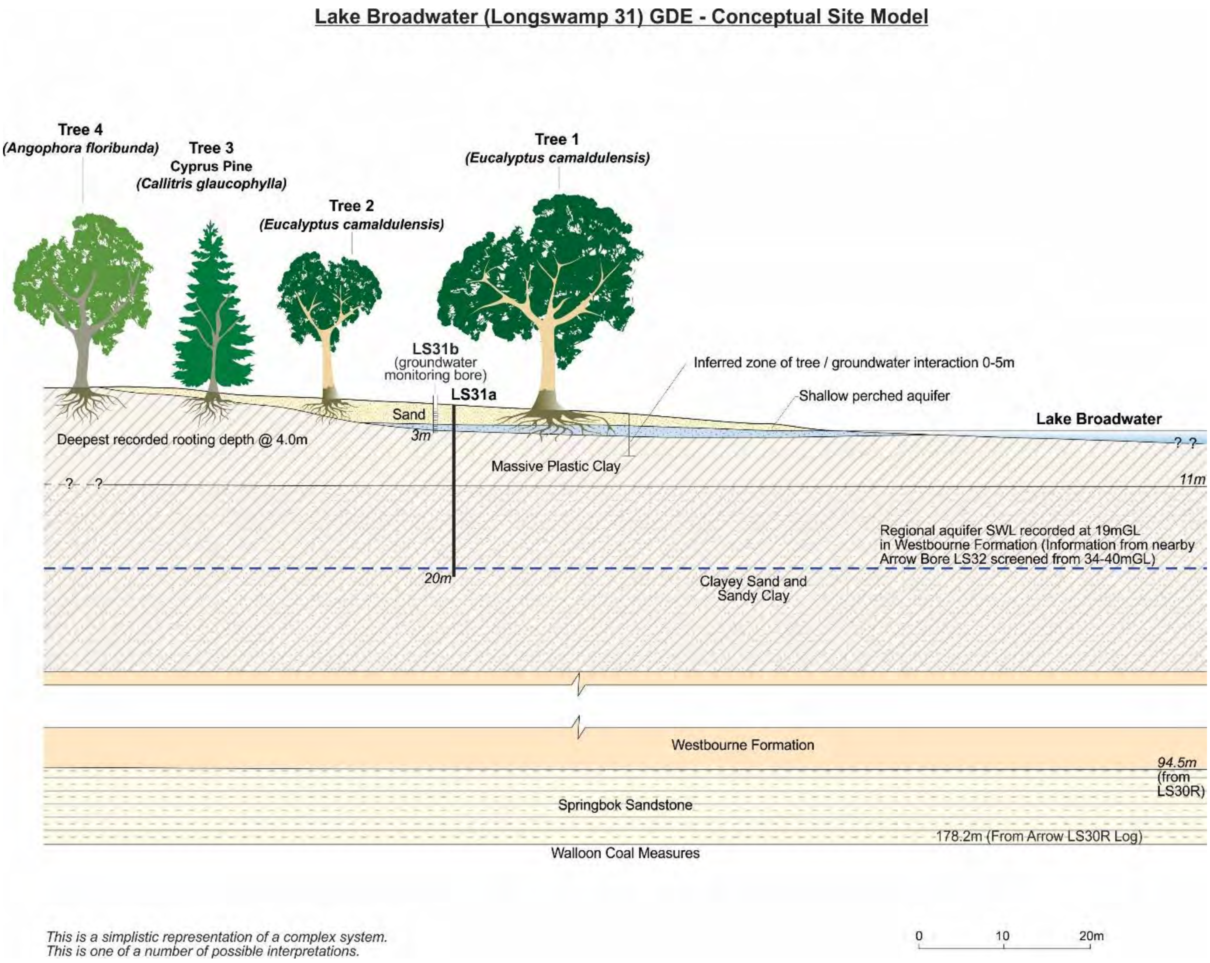

Figure 66. Conceptual site model of the Lake Broadwater GDE Assessment Area.

Long Swamp: For the Long Swamp GDE investigation site (LS35a) (**Figure 67**), the hole remained dry during coring to a depth >14m, which is beyond the maximum inferred tree root depth (determined from soil moisture potential data) and also well below the maximum observed tree root depth of 7.1m. The multiple lines of evidence utlilised in this assessment suggest reliance on shallower sources of soil moisture with sources lying in a depth range from -11.5 mGL and the soil surface. Leaf water potential for river red gum (Tree 1 and Tree 2) corresponds to a moist zone in the soil profile between 8 and 11.5mGL from where larger canopy trees are inferred to be accessing soil moisture while stable isotope data suggests a mixed source of soil moisture for canopy trees influenced by evaporatively enriched surface moisture.

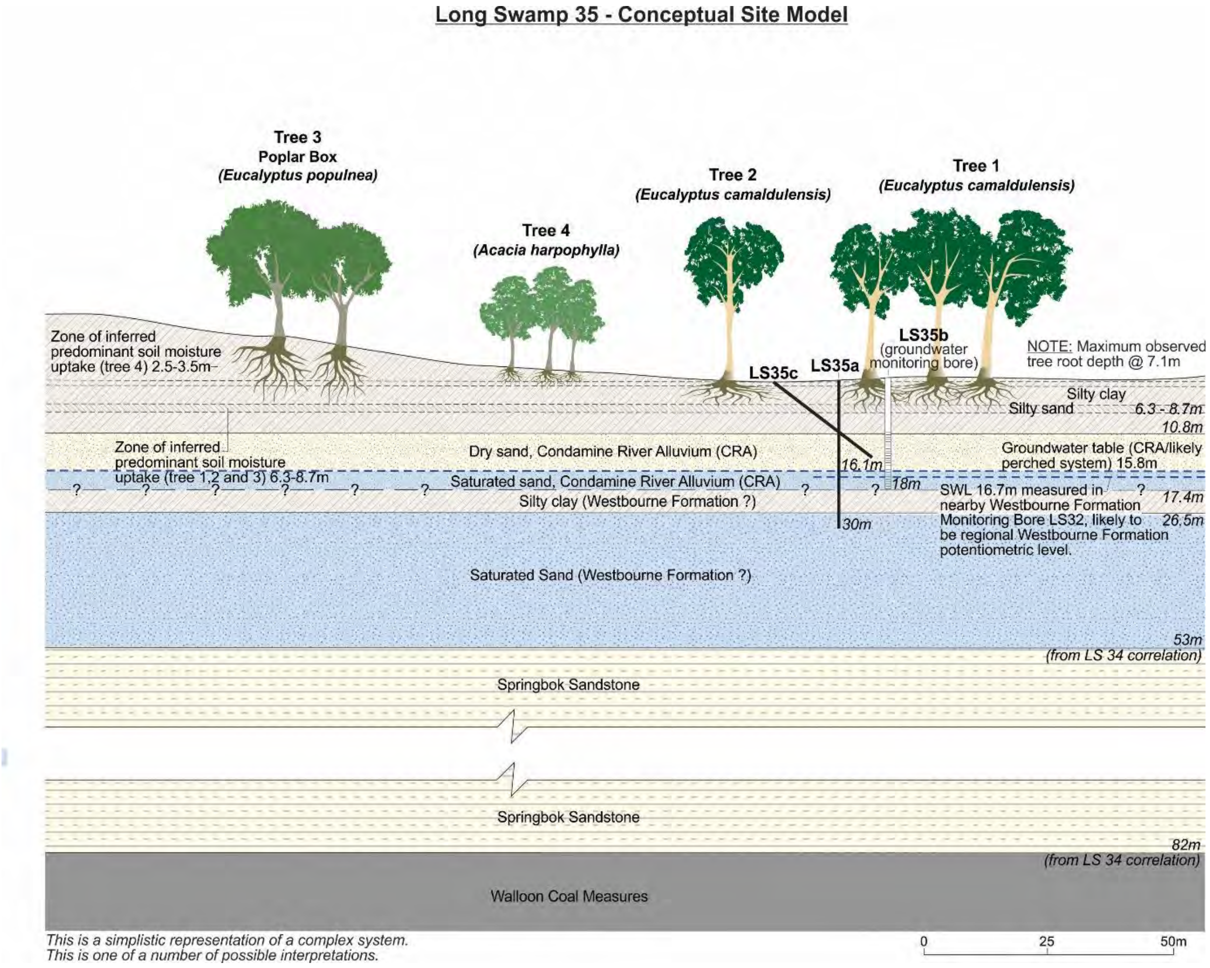

Figure 67. Conceptual site model for the Long Swamp GDE Assessment Area.

Burunga Lane: At Burunga Lane (BL182) (see **Figure 68**), tree roots were identified to 6m depth which corresponds with the inferred zone of soil moisture uptake between 4.5 and 6.5mGL indicated through measurement of leaf and soil moisture potential. Stable isotopic data indicates a shallower source of soil moisture from 3mGL to the soil surface, which gives a high degree of confidence that deeper sources of groundwater are not being utilised. It is noted that an aquifer intersected at 13.5mGL in underlying sandstone and coal seams is well below the depth of inferred water uptake.

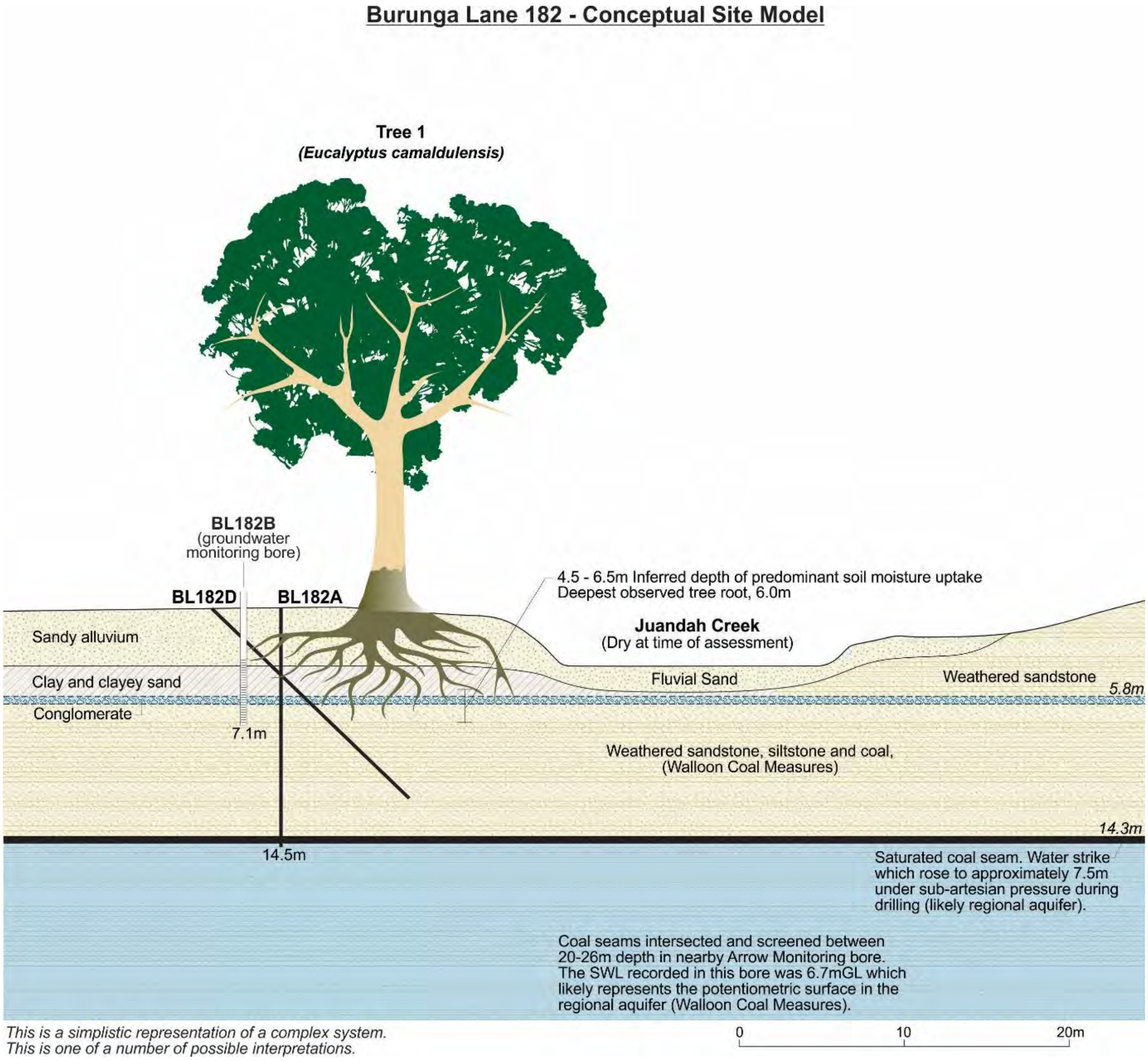

Figure 68. Conceptual site model for the Burunga Lane GDE Assessment Area

Glenburnie: For the measurement of soil moisture and leaf water potential, the interpreted zone of predominant water uptake at the Glenburnie GDE assessment (see **Figure 69**) site falls between 9 and 11.5mGL where soil moisture potential ranges from -100 to -7.5psi (-7.5 psi). The deepest root material identified in the Glenburnie drill core was at 7.6m depth which adds confidence to this interpretation. Although stable isotope data indicates that trees are accessing shallow evaporatively enriched soil moisture sources, there is a possibility that results were influenced by a preceding rainfall event or fractionation of stable isotopes in the xylem. There is no evidence from any of the assessed parameters that trees are utilising

deeper soil moisture sources which includes a saturated seepage zone that lies between 11m and 18m depth or the deeper sub-artesian aquifer intersected at approximately 27m in GB20a.

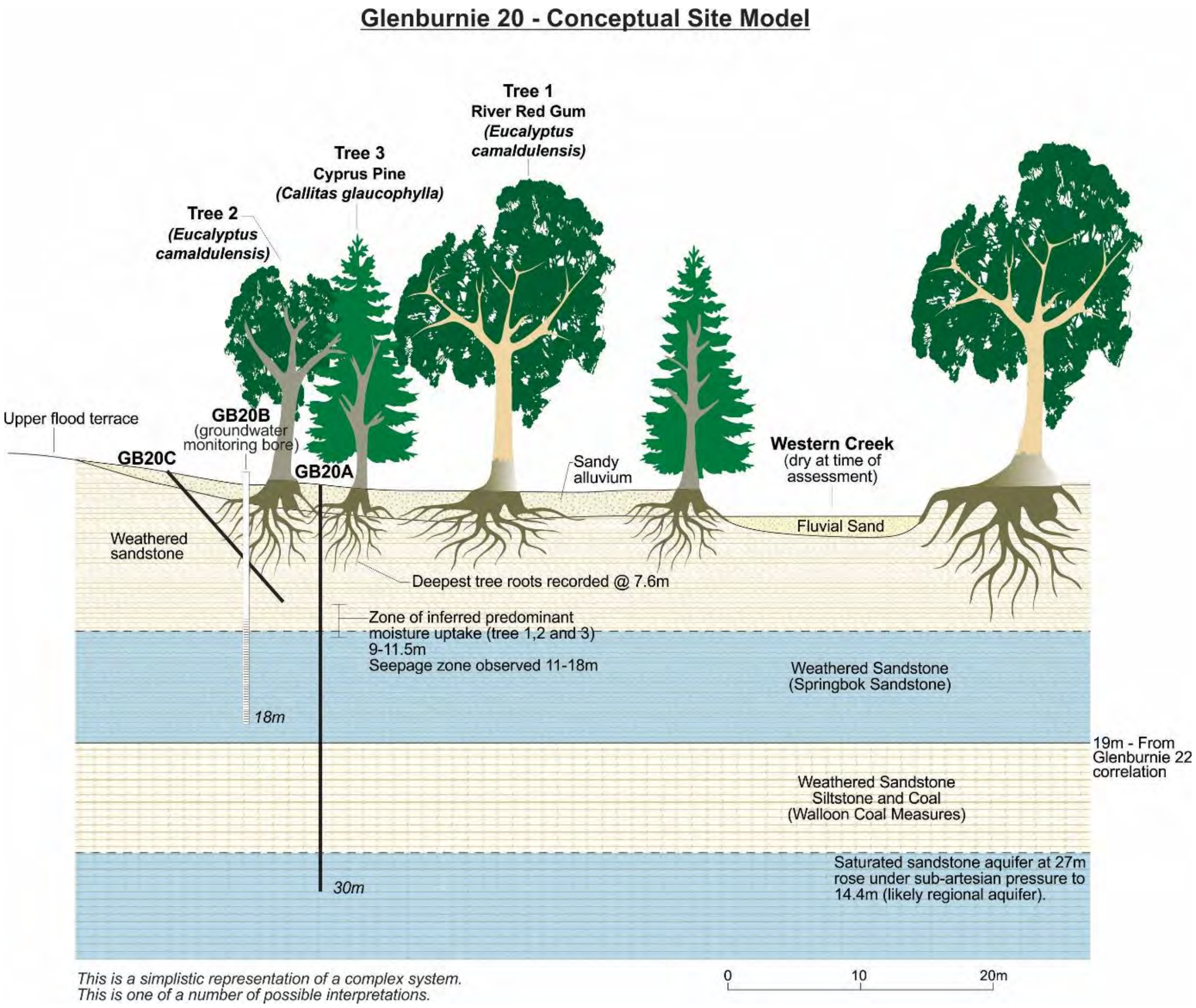

Figure 69. Conceptual site model for the Glenburnie GDE Assessment Area.

Deeper rooted trees at all of the GDE sites except Long Swamp 31 (Lake Broadwater) and possibly Glenburnie are considered likely to be tapping downward-percolating water moving under gravity through a near-saturated vadose zone. This vadose water would likely exist in a transient state of near-saturation to saturation, and is moving within a permanent wetting front associated with the adjacent ephemeral surface water bodies which temporarily channel and hold water for extended periods. Trees such as river red gum which require a high soil moisture potential appear to be tapping the near permanent sources of moisture described above which is available in horizons containing a balanced matrix of sand and fines which provide enough permeability for the high transpiration rates required for such trees, but also enough fine material to slow and hold water between wetting events (recharge), and hence buffer the effects of tree stress that would be caused by pronounced drought. A lack of river red gums (and other species considered to be groundwater dependant) located away from the major river channels supports the above concept which requires both sources of seasonal surface water infiltration and underlying zones of high moisture potential within the tree rooting depths.

4.3 Groundwater chemistry

A preliminary review of water chemistry results for groundwater samples collected from monitoring bores at the GDE study sites, and a surface water sample from Lake Broadwater does not provide any clear line of evidence for tree-groundwater interaction zones, nor is the chemistry data supportive of any hypotheses on whether the study sites are GDEs.

Cartwright et al (2007) suggest low $^{87}Sr/^{86}Sr$ ratios in the SE Murray Basin reflect an aquifer mineralogy that has a low abundance of K-rich minerals (K-feldspar and biotite) coupled with exchange of Sr on clays derived from the weathering of silicate rich minerals within the aquifer. Similar host material is considered likely for water sampled in monitoring bores at all GDE investigation site, whilst a low $^{87}Sr/^{86}Sr$ ratio in the Lake Broadwater surface water sample probably reflects a meteoric water source. Results of the carbon isotope (δ13C) analysis reflect the residence time of soil moisture or groundwater with both Lake Broadwater sampling localities (i.e. Well_LS31 and surface water body) suggesting a modern meteoric water source for both the lake and shallow groundwater associated with the sandy apron. The 4.7K years determined for the Glenburnie groundwater sample (GB20) confers with the postulated low infiltration rates (**Section 3.5.3**) at that site while the Long Swamp groundwater sample remains suspicious due to potential contamination.

4.4 Relationship Between Leaf Water Potential and Canopy Vigour

From the four GDE assessment sites, there is strong evidence that access to soil moisture has considerable bearing on the health and vigour of foliage in the canopy of river red gums. The Long Swamp GDE Assessment Site (LS35) recorded the lowest leaf water potential of all sites and commensurately the lowest foliage index (see **Section 3.2.4** and **3.2.5**). In contrast, the river red gums at the Lake Broadwater Assessment area (Long Swamp 31) with access to shallow groundwater, recorded the highest of both parameters supporting the assessment of Zolfagher et al (2014) that access to groundwater is a major influence on the productivity of eucalyptus dominant ecosystems. The general trend is illustrated in **Figure 70** which shows the relationship between plant water stress (expressed as leaf water potential) and foliage index. The trend clearly illustrates the potential for any activity which diminishes a plants access to groundwater or soil moisture to manifest as an ecological impact.

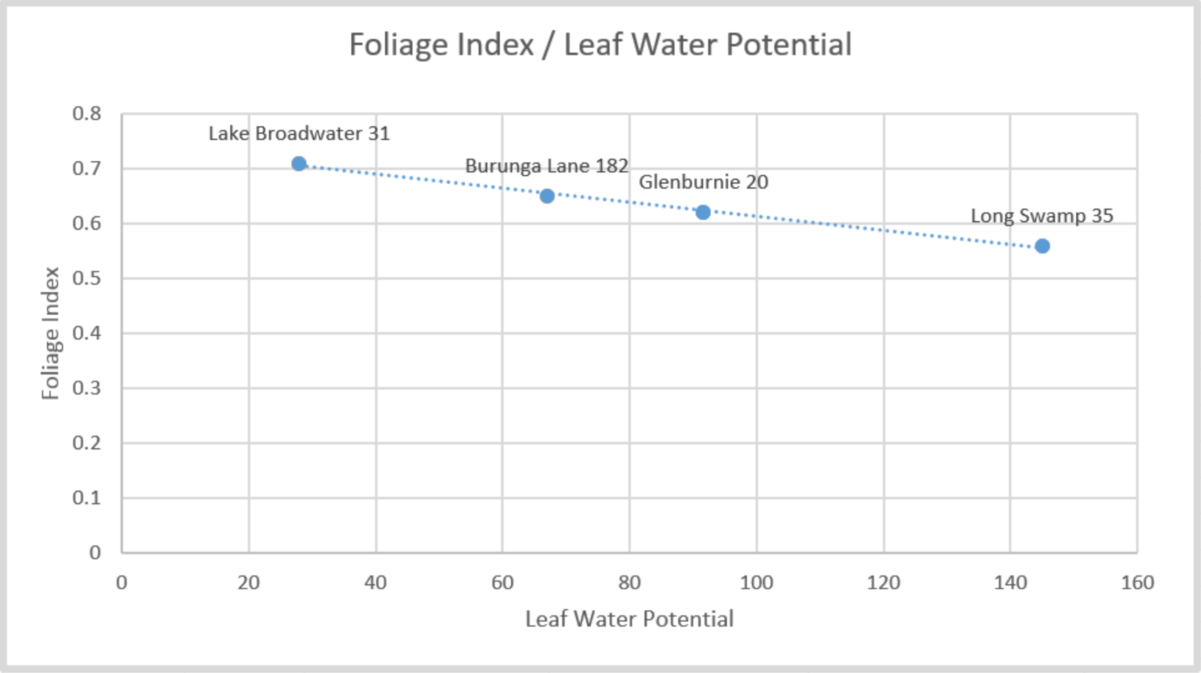

Figure 70. Relationship between measured foliage index and leaf water potential.

5.0 Conclusions and GDE Decision Matrix

Through review of multiple lines of evidence including drill coring to observe rooting depth, and assess hydrogeological conditions, assessment of soil moisture and leaf water potential, and stable isotope analysis of soil moisture, groundwater and xylem water, it has been possible to hypothesise with a strong degree of confidence whether vegetation at each assessment site is likely to fit the definition of a GDE. The following **Table 13** has been prepared to summarise the key parameters measured in this assessment for each study site.

Table 13. Key parameters for GDE Assessment for each GDE assessment area.

Study Site	Maximum observed root depth (m)	Inferred zone of soil moisture uptake (m)	Observed zone of shallow saturation/ perched aquifer (m)	Stable Isotope Analysis – Indicated Zone of Water Uptake (m)	Observed depth to regional aquifer (m)
Lake Broadwater	4	1.8 - 3	1.8 - 3	2.6	>18 (Westbourne)
Long Swamp	7.1	7.5 – 11.5	14.7- 17.4	0 – 7.5	26.5 (Westbourne)
Burunga Lane	6	4.5 – 6.5	4.9 - 6	0 – 3.0	13.5 (WCM)
Glenburnie	7.6	9 – 11.5	13.5 - 18	0 – 0.2m	27 (WCM)

As inferred from **Table 13,** a key finding of the assessment is that the depth to the regional aquifer (potentially subject to CSG depressurisation) at each site is considerably deeper than:

- the deepest observed rooting depth,
- the inferred likely zone of predominant soil moisture uptake by trees (both from water potential and stable isotope measurements, and
- the likely maximum tree rooting depth for deeper rooted potential GDE species (such as river red gums) of 18m. Although the regional aquifer was intersected at 13.5mGL at Burunga Lane (BL182) the maximum observed tree rooting depth was 6mGL. There is no evidence from either isotope analysis or soil and leaf water potential that tree roots are accessing water that is deeper than the maximum observed rooting depth.

Another key finding of this assessment is the relatively shallow maximum tree root depths observed compared with the maximum anticipated depth threshold of 18m based on literature studies. The deepest observed root depth across all of the study sites was 7.6m in sandstone at Glenburnie 20. The largest number and deepest intersections of root material at each site was conclusively in the angled core holes, justifying the rationale for angling the core hole beneath the tree canopy and trunk to maximise the likelihood of intersecting root material. Sonic coring proved to be a highly effective means of intersecting and sampling well preserved intact tree roots in situ within both a relatively undisturbed unconsolidated soil or rock core.

A GDE Decision Matrix was developed during development of the Study Execution Plan (**Appendix K**) to assess the likelihood of the various study sites representing GDEs. The outcomes of this assessment, with reference to the Decision Matrix (**Appendix J**) is provided for individual assessment areas below:

Lake Broadwater (Longwamp 31): Lake Broadwater is a naturally occurring, seasonal/intermittent, shallow, freshwater wetland which covers approximately 350 hectares. It is a highly significant ecological feature that is mapped as a Wetland of High Ecological Significance (DEHP 2014) and is listed in the Australian Directory of Important Wetlands (Australian Government 2010). Two core holes were drilled at the assessment locality including a 21m core hole to assist interpretation of the local geology, and a 3m deep bore to allow installation of a shallow groundwater monitoring bore. The assessment concluded:

1. Lake Broadwater is fringed by a low sand ridge on its northern and western margins which overlies a thick plastic clay layer between depths of approximately 3 and 11.3m. The interface between the plastic clay and sand hosts a shallow perched aquifer within which groundwater levels would fluctuate dependent largely upon the water levels in the lake, as well as recharge directly to the sand mass fringing the lake.
2. Drill coring identified abundant tree root material within the shallow water table, with deeper roots penetrating heavy clays to a depth of 4m. This indicates trees are utilising shallow groundwater to satisfy all or a portion of their water budget requirements. The deeper roots penetrating into the upper fringe of the underlying heavy clays is interpreted to be both an anchor mechanism and an alternative source of moisture during periods of drought and aquifer depletion.
3. Leaf water potential, soil moisture potential and stable isotope measurements at the site all support the interpretation that canopy trees are extracting moisture from a saturated zone coinciding with the interface between clay and sand.

Based largely on the identification of tree root material within the saturated zone, and supported by measurement of soil moisture, leaf water potential and stable isotopes, Lake Broadwater is considered to represent a GDE (Confidence of 1 in the Decision Matrix, **Appendix J**). The shallow perched aquifer overlies a 7.8m thick sequence of massive plastic alluvial clays and further clay-rich deeply weathered regolith of the Westbourne Formation which comprises a thick separation barrier between the perched aquifer and the underlying formations potentially subject to CSG depressurisation.

Long Swamp (LS35): Long Swamp is a broad sinuous overland flow path that extends for a distance of approximately 30 km on the Condamine Alluvium. The feature comprises a broad drainage depression, with the central portion underlain by highly vertic surface soils with a strong shrink-swell structure of hummocks and deep cracks. Three core holes were drilled at the investigation site including a 30m deep bore to assist interpretation of the local geology (LS35a), an 18m deep bore for the purpose of groundwater monitoring bore installation and soils sampling (LS35b) and an 15.5m deep (18.3m drilled length) angle hole to assess tree rooting depth.

The assessment concluded:

1. The regional alluvial aquifer at the location of the Long Swamp GDE investigation site was intersected at a depth of 25.6m within a basal sand, well below the observed tree rooting depth (7.1m).

2. A thick sand sequence between depths of 10.8 to 17.4m is interpreted to be a depleted aquifer (discussed further below), which transitions from dry at the top to saturated at the base of the sequence. The upper 5m of this sand was dry to slightly moist, presenting a deterrent for the possible downward growth of recent tree roots, and a potential zone of root desiccation and embolism for any existing mature tree roots.
3. Leaf water potential, soil moisture potential measurements indicate larger river red gums are predominantly sourcing soil moisture from a zone between 11.5mGL and soil surface (based on an enrichment of stable isotopes in twig water) broadly consistent with observations of tree rooting depth. Stable isotope signatures obtained from sampled twig xylem are enriched above all soil samples except at the soil surface. Although additional is required to fully elucidate the significance and behaviour of xylem isotopes in relation to season and climatic conditions, there is no apparent suggestion of a deeper groundwater source.

Figure 71 shows a clear historical declining trend in standing water levels within registered Condamine River Alluvium groundwater bores within Arrow tenements that have been baselined by Arrow in recent years, and had a recorded historical standing water level. Below this is a graph showing standing water levels in a subset of the above CRA bores which are located within a 3km radius of the Long Swamp 35 study site. While the decline in the study area is relatively modest compared with the overall trend, it is conceivable that the declining trend may have resulted in a drop of groundwater head in the upper CRA sand of 4-5m required to result in the observed unsaturated sand mass described in Point 2 above. If tree roots were historically present within the upper sand mass, then a drop below the 18m root depth lower threshold would likely have resulted in significant tree stress or mortality.

As noted in previous assessments (3d Environmental/Earth Search 2017), this declining trend is likely to be due mostly to groundwater abstraction as well as harvesting of surface water and overland flow (reduction in natural recharge rates). This has resulted in a general fall in SWLs across most of the study area to below the lower root depth threshold zone where severe decline in vegetation condition would be expected. These findings are consistent with those of Kath et al (2014), Reardon Smith (2011) and Dafny and Silburne (2014) which all identify significant declines in groundwater levels across the CRA prior to CSG activities.These multiple lines of evidence suggest reliance on shallower sources of soil moisture.

Based on the considerable depth to the saturated zone and evidence of a shallower source of soil moisture for river red gums in Long Swamp, the site is considered unlikely to represent a GDE (Confidence of 14 in the Decision Matrix, Appendix J).

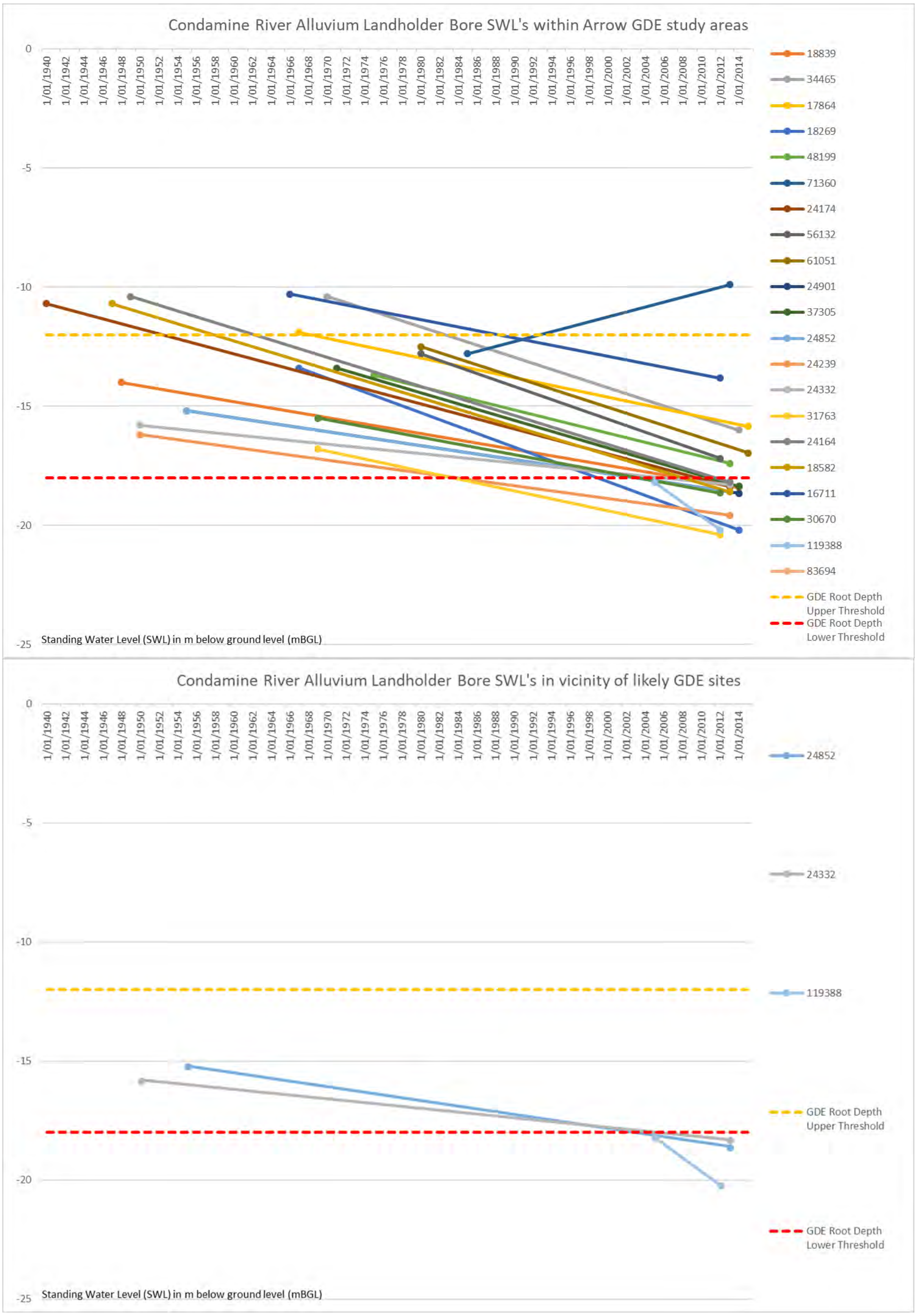

Figure 71. Hydrographs for CRA bores baselined by Arrow shows declines in SWLs relative to vegetation response thresholds; The second graph shows a subset of bores within a 3km radius of Long Swamp 35

Burunga Lane (Burunga Lane 182): The Burunga Lane monitoring site is located between the townships of Wandoan and Miles and is situated to the immediate west of the main channel of Juandah Creek. The study site lies on a broad flat to gently undulating partially confined alluvial terrace that extends for approximately 530m on the western side of the creek, separated from gently undulating sandstone foot-slopes by a narrow overflow channel. Three core holes, plus an additional hole drilled exlusively to confirm the regional aquifer depth, were drilled at the locality including two vertical core holes completed to maximum depth of 14.5m, a shallower 7.1m core hole for construction of a permanent groundwater monitoring bore and a 13m deep angle hole (16.1m lineal length) to assist determination of maximum tree rooting depth.

The assessment at Burunga Lane concluded:

1. A sub-artesian aquifer was intersected at 13.5m depth within a thin coal seam and surrounding sandstone.
2. There was presence of high moisture content approaching saturation within and above a conglomerate band at 5.8m depth during drilling. However, groundwater was not present within the groundwater monitoring bore installed to a depth of 7.1m during the sampling event completed almost 3 months after drilling.
3. Drill coring identified tree root material to a maximum depth of 6m which is well above the depth of the regional aquifer.
4. Leaf water potential and soil moisture potential measurements at the site suggests that larger river red gums are predominantly sourcing soil moisture from a zone between 4.5 and 6.5mGL which is consistent with observations of tree rooting depth.
5. Stable isotope analysis indicates considerable enrichment in the stable isotope signature of twig xylem water above those of the soil where water extraction in predicted to be occurring. Additional sampling is required to fully understand the significance of stable isotope signatures in regard to seasonality.

Based on the considerable depth to the regional aquifer and evidence for a shallower source of soil moisture for river red gums on the fringes of Juandah Creek, the site is considered unlikely to represent a GDE (Confidence of 14 in the Decision Matrix , **Appendix J**).although there it is possibile that shallow seasonal groundwater may be present after significant rainfall events when the creek is in a state of high flow.

It is not clear whether the groundwater observed to be present at 13.5m in sandstone and a coal seam at Burunga Lane, and observed rising to 7.5mGL represents the upper horizons of a regional aquifer within the Walloon Coal Measures, or if this zone is receiving some localised pressure support due to a recharge feature. In any case, based on the observations of tree rooting depth and a likely shallower zone of preferred soil moisture uptake, it is not considered likely that tree roots will be preferentially tapping water at 13.5m.

Glenburnie (Glenburnie 20): The Glenburnie GDE Assessment site is located to the west of Millmerran adjacent to Western Creek. Western Creek at the location presents as a dry sandy creek channel with a narrow sinuous overflow flood terrace that has only limited alluvial development. The channel is moderately confined by deeply weathered Springbok Sandstone that variably outcrops in stream benches and along the channel floor with the sandy bedload overlying a weathered sandstone regolith (**Figure 8**). Three core holes were drilled at the assessment site including a 30m deep hole for the purpose of geological characterization (GB20a), an 18m deep hole for construction of a permanent groundwater monitoring bore and a 11m deep angled hole (13.5m lineal length) to confirm tree rooting depth.

The assessment at Glenburnie concluded the following:

1. A sub-artesian aquifer was intersected at 27m depth in Glenburnie 20 with the groundwater rising to approximately 14.4 m.
2. There was only a shallow profile of alluvial soil of approximately 2.5m overlying weathered bedrock (Springbok Sandstone) with zones of higher soil moisture availability at approximately 9-11.5mGL and also at 14.5-17mGL.
3. A shallow saturated seepage zone was noted between 11 and 18mGL in the groundwater monitoring bore with a SWL of 13.54mGL measured during well development in March 2018. .
4. Drill coring identified tree root material to a maximum depth of 7.6m.
5. Leaf water potential and soil moisture potential measurements indicate soil moisture being sourced from a zone of soil moisture between 9.0 and 11.5mGL slightly deeper than the observed maximum tree rooting depth.
6. Stable isotope signatures are considerably enriched above those where trees are predicted to be sourcing their soil moisture from. While this may indicate a significant contribution of shallow evaporatively enriched surface moisture, it may also indicate potential isotopic fractionation within the tree xylem, or confounding errors associated with the sampling process. There is however no indication that a deeper groundwater source is contributing significantly to the water usage of trees at the locality. .

Based on the considerable depth to the regional aquifer, observations of tree rooting depth and evidence for a shallower source of soil moisture from leaf water potential and soil moisture potential analysis, the site is considered unlikely to represent a GDE (Confidence of 14 in the Decision Matrix excluding soil isotope results, **Appendix J**).

6.0 References

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7.0 Appendices

Appendix A – Soil and Twig Samples Despatched to ANU for Stable Isotope Analysis

Location_Drillhole	Sample	Depth	Type	δ18O and δ2H	Date Sampled	Date Dispatched
Longswamp 35b	LS35b-IS-0.2	0.2m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-0.5	0.5m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-1.0	1.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-1.5	1.5m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-2.0	2.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-2.5	2.5m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-3.0	3.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-3.5	3.5m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-4.0	4.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-4.5	4.5m	Soil	No Sample	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-5.0	5.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-5.5	5.5m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-6.0	6.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-6.5	6.5m	Soil	No Sample	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-7.0	7.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-7.5	7.5m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-8.0	8.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-8.5	8.5m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-9.0	9.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-9.5	9.5m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-10.0	10.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-10.5	10.5m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-11.0	11.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-11.5	11.5m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-12.0	12.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-12.5	12.5m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-13.0	13.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-13.5	13.5m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-14.0	14.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-14.5	14.5m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-15.0	15.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-15.5	15.5m	Soil	No Sample	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-16.0	16.0m	Soil	No Sample	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-16.5	16.5m	Soil	No Sample	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-17.0	17.0m	Soil	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	LS35b-IS-17.5	17.5m	Soil	No Sample	10-Dec-17	13-Dec-17
Longswamp 35b	Tree 1	NA	Twig	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	Tree 1	NA	Twig	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	Tree 3	NA	Twig	Yes	10-Dec-17	13-Dec-17
Longswamp 35b	Tree 4	NA	Twig	Yes	10-Dec-17	13-Dec-17
Burunga Lane 182a	BL182A-IS-7.0	7.0m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182a	BL182A-IS-8.0	8.0m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182a	BL182A-IS-10.0	10.0m	Soil	Yes	12-Dec-17	18-Dec-18

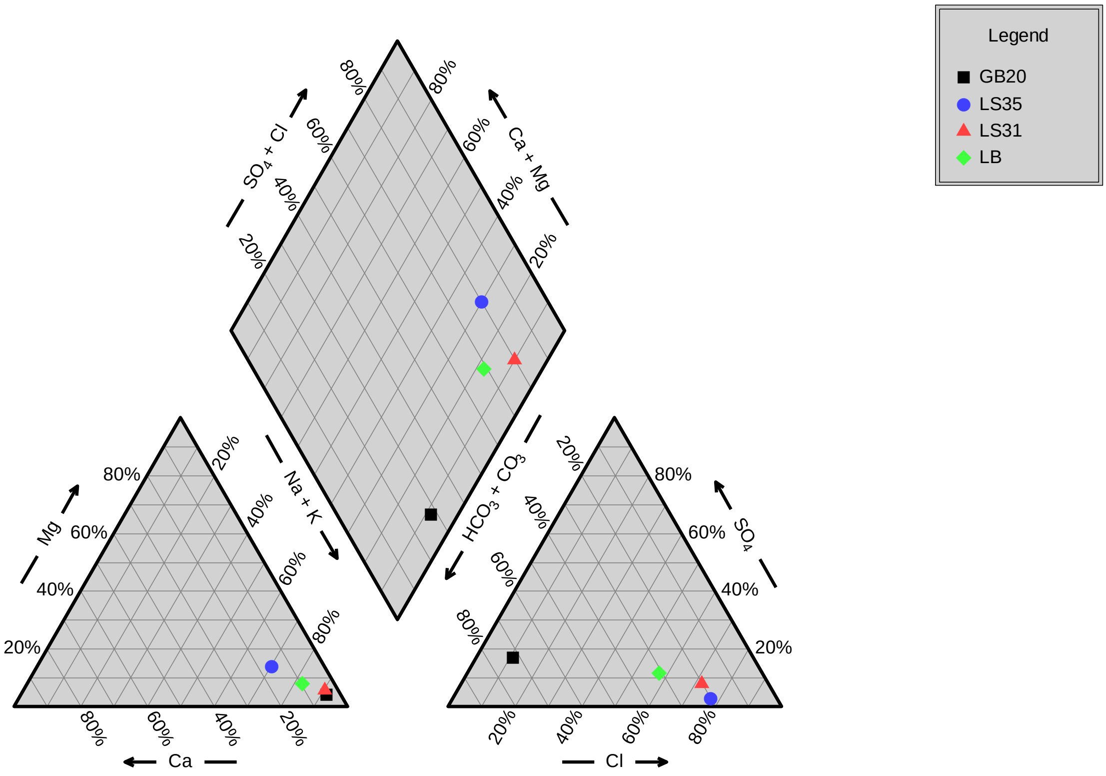
Location_Drillhole	Sample	Depth	Type	δ18O and δ2H	Date Sampled	Date Dispatched
Burunga Lane 182a	BL182A-IS-12.0	12.0m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-0.2	0.2m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-1.0	1.0m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-1.5	1.5m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-2.0	2.0m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-3.0	3.0m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-3.5	3.5m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-4.0	4.0m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-4.5	4.5m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-4.8	4.8m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-5.0	5.0m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-5.5	5.5m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-6.0	6.0m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-6.5	6.5m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182b	BL182B-IS-7.0	7.0m	Soil	Yes	12-Dec-17	18-Dec-18
Burunga Lane 182c	BL182C-IS-13.8	13.8m	Soil	Yes	13-Dec-17	18-Dec-18
Burunga Lane 182d	BL182D-IS-9.2	9.2m	Soil	Yes	13-Dec-17	18-Dec-18
Burunga Lane 182d	BL182D-IS-12.0	12.0m	Soil	Yes	13-Dec-17	18-Dec-18
Burunga Lane 182d	BL182D-IS-12.5	12.5m	Soil	Yes	13-Dec-17	18-Dec-18
Burunga Lane 182b	BL182-T1	NA	Twig	Yes	13-Dec-17	18-Dec-18
Burunga Lane 182b	BL182-T1	NA	Twig	Yes	13-Dec-17	18-Dec-18
Glenburnie 20b	GB_IS_0.2	0.2m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_0.5	0.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_1.0	1.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_1.5	1.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_2.0	2.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_2.5	2.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_3.0	3.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_3.5	3.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_4.0	4.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_4.5	4.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_5.0	5.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_5.5	5.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_6.0	6.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_6.5	6.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_7.0	7.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_7.5	7.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_8.0	8.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_8.5	8.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_9.0	9.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_9.5	9.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_10.0	10.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_10.5	10.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_11.0	11.0m	Soil	Yes	17-Feb-18	21-Dec-18

Location_Drillhole	Sample	Depth	Type	δ18O and δ2H	Date Sampled	Date Dispatched
Glenburnie 20b	GB_IS_11.5	11.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_12.0	12.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_12.5	12.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_13.0	13.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_13.5	13.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_14.0	14.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_14.5	14.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_15.0	15.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_15.5	15.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_16.0	16.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_16.5	16.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_17.0	17.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_17.5	17.5m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB_IS_18.0	18.0m	Soil	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB20_T1	NA	Twig	Yes	17-Feb-18	21-Dec-18
Glenburnie 20b	GB20_T2	NA	Twig	Yes	17-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_2.6+	2.6m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_3.0	3.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_3.5	3.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_4.0	4.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_4.5	4.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_5.0	5.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_5.5	5.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_6.0	6.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_6.5	6.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_7.0	7.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_7.5	7.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_8.0	8.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_8.5	8.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_9.0	9.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_9.5	9.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_10.0	10.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_10.5	10.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_11.0	11.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_11.5	11.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_12.0	12.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_12.5	12.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_13.0	13.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_13.5	13.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_14.0	14.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_14.5	14.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_15.0	15.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_15.5	15.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_16.0	16.0m	Soil	Yes	14-Feb-18	21-Dec-18

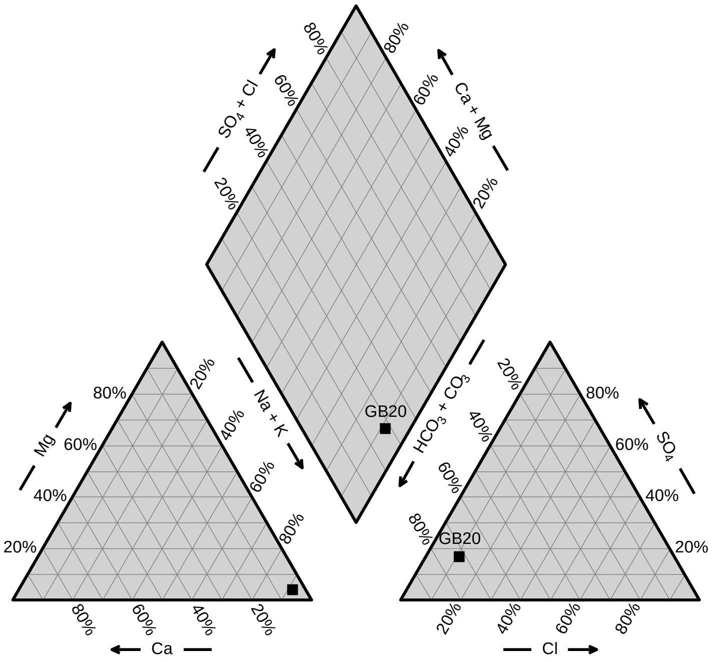
Location_Drillhole	Sample	Depth	Type	δ18O and δ2H	Date Sampled	Date Dispatched
Longswamp 31a	LS31a_IS_16.5	16.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_17.0	17.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_17.5	17.5m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31a_IS_18.0	18.0m	Soil	Yes	14-Feb-18	21-Dec-18
Long Swamp 31b	LS31b_PMB_3.0	3.0m	Soil	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31-T1a	NA	Twig	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31-T1b	NA	Twig	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31-T2a	NA	Twig	Yes	14-Feb-18	21-Dec-18
Longswamp 31a	LS31-T2b	NA	Twig	Yes	14-Feb-18	21-Dec-18
Glenburnie 20	Glenburnie 20b	NA	Water	Yes	16-Mar-18	19-Mar-18
Longswamp 31	Longswamp 31b	NA	Water	Yes	16-Mar-18	19-Mar-18
Lake Broadwater	Lake Broadwater_Surface Water	NA	Water	Yes	16-Mar-18	19-Mar-18
Longswamp 35	Longswamp 35b	NA	Water	Yes	17-Mar-18	19-Mar-18

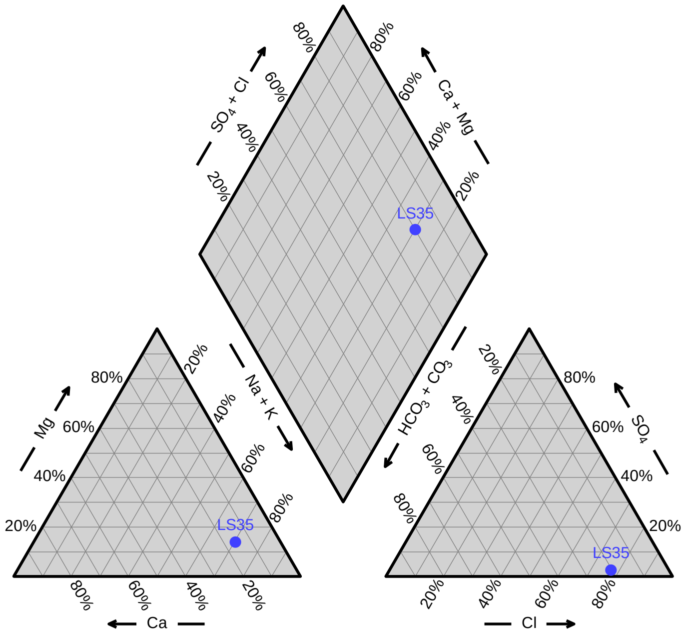
Appendix B. Stiff Diagrammes, Radial Plots, and Schoeller Diagrams

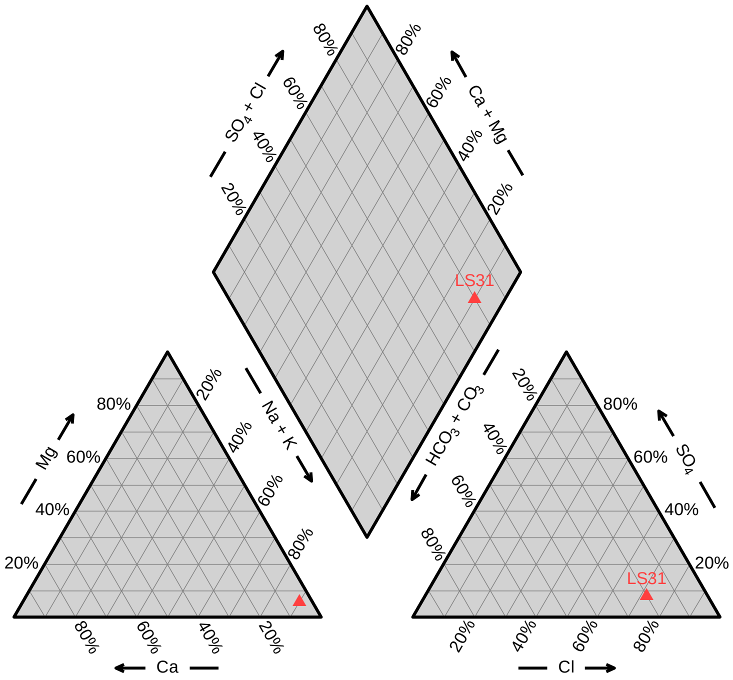
Combined Piper plot of samples:



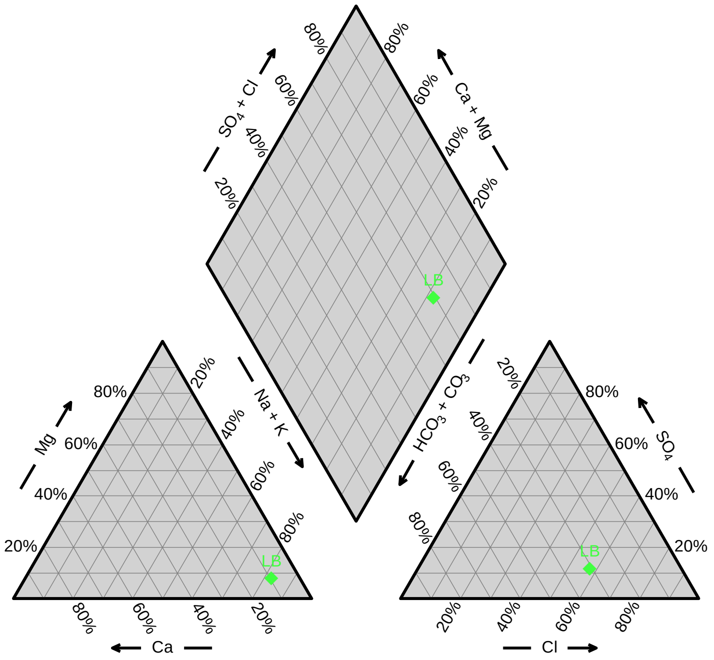
Individual Piper Plots







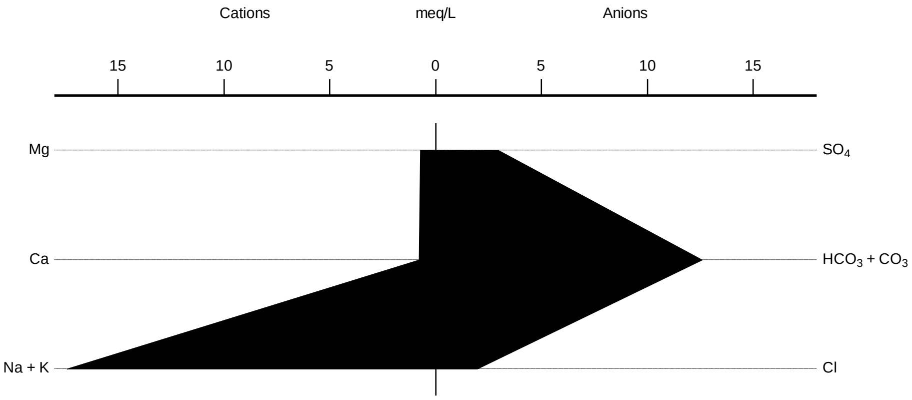
SO4 + Cl
Ca + Mg
80%
60%
40%
20%
LS31
Mg
Na + K
HCO3 + CO3
SO4
Ca
Cl



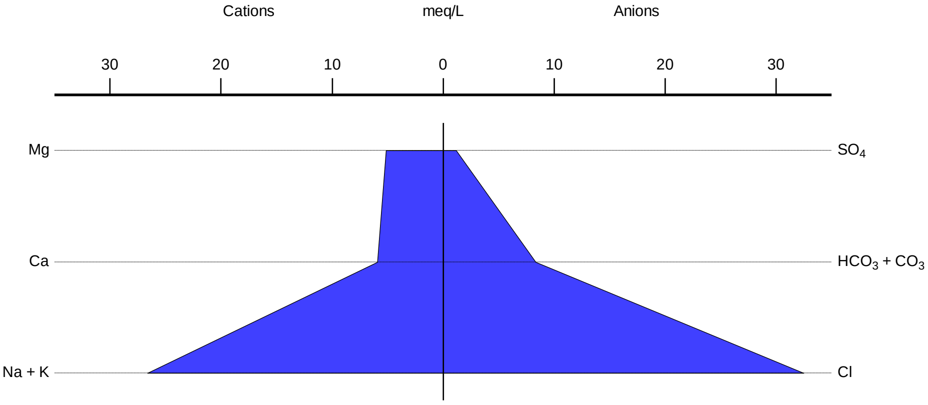
SO4 + Cl
Ca + Mg
80%
60%
40%
20%
LB
Mg
Na + K
HCO3 + CO3
SO4
Ca
Cl

Stiff diagrams:

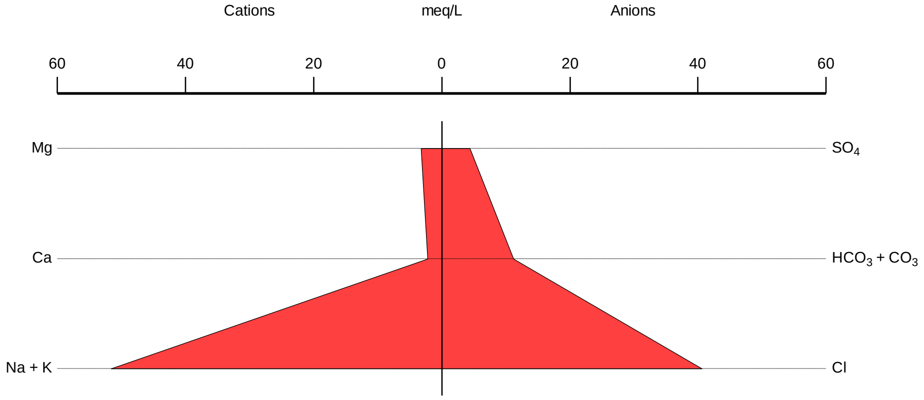
Glenburnie 20



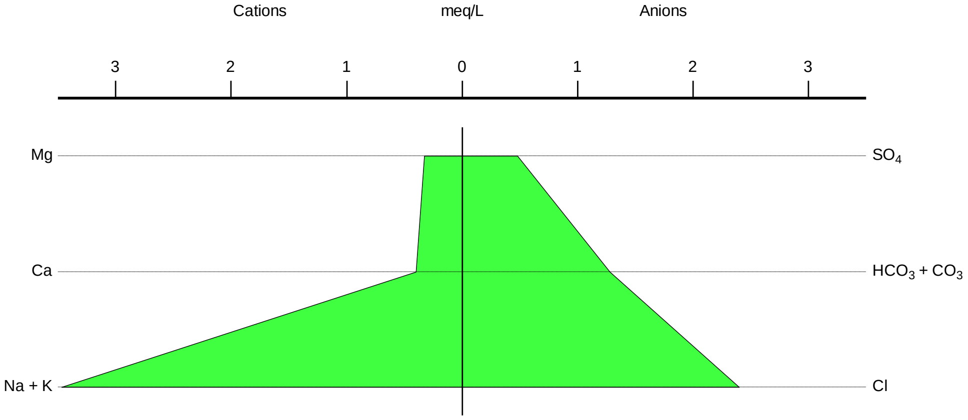
Longswamp 35



Longswamp 31

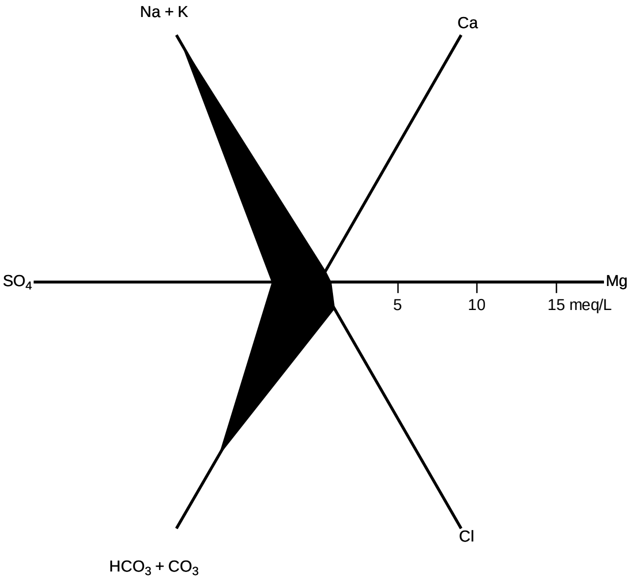


Lake Broadwater

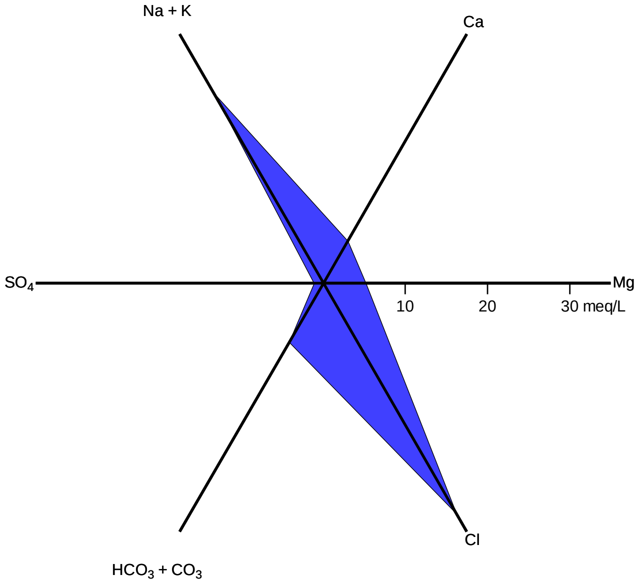


Radial Plots

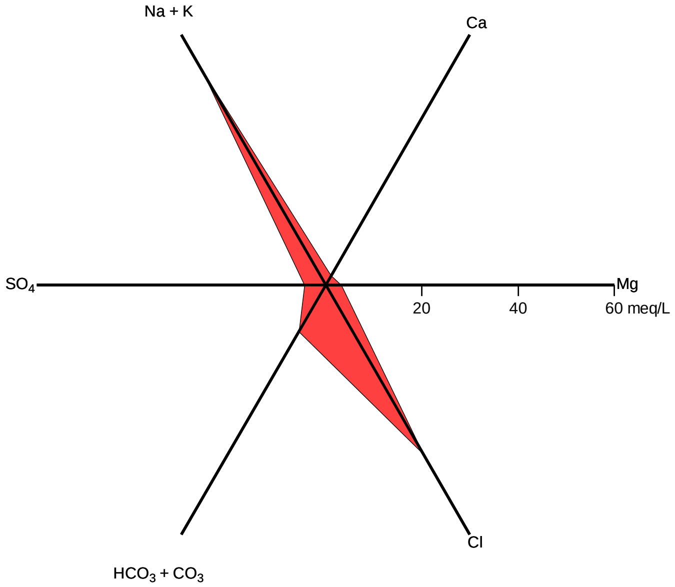
Glenburnie 20



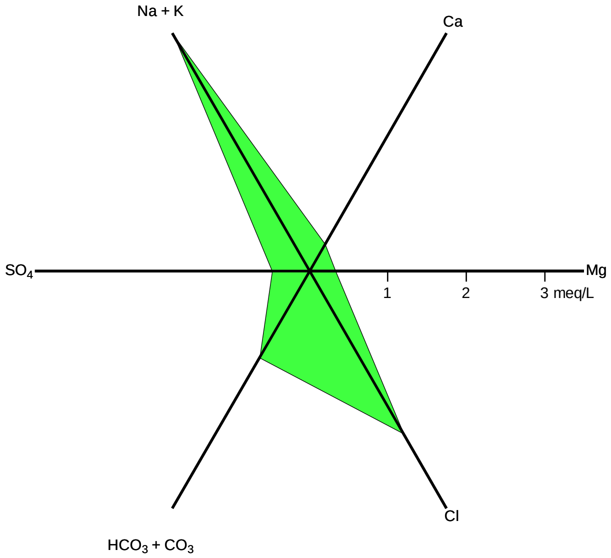
Longswamp 35

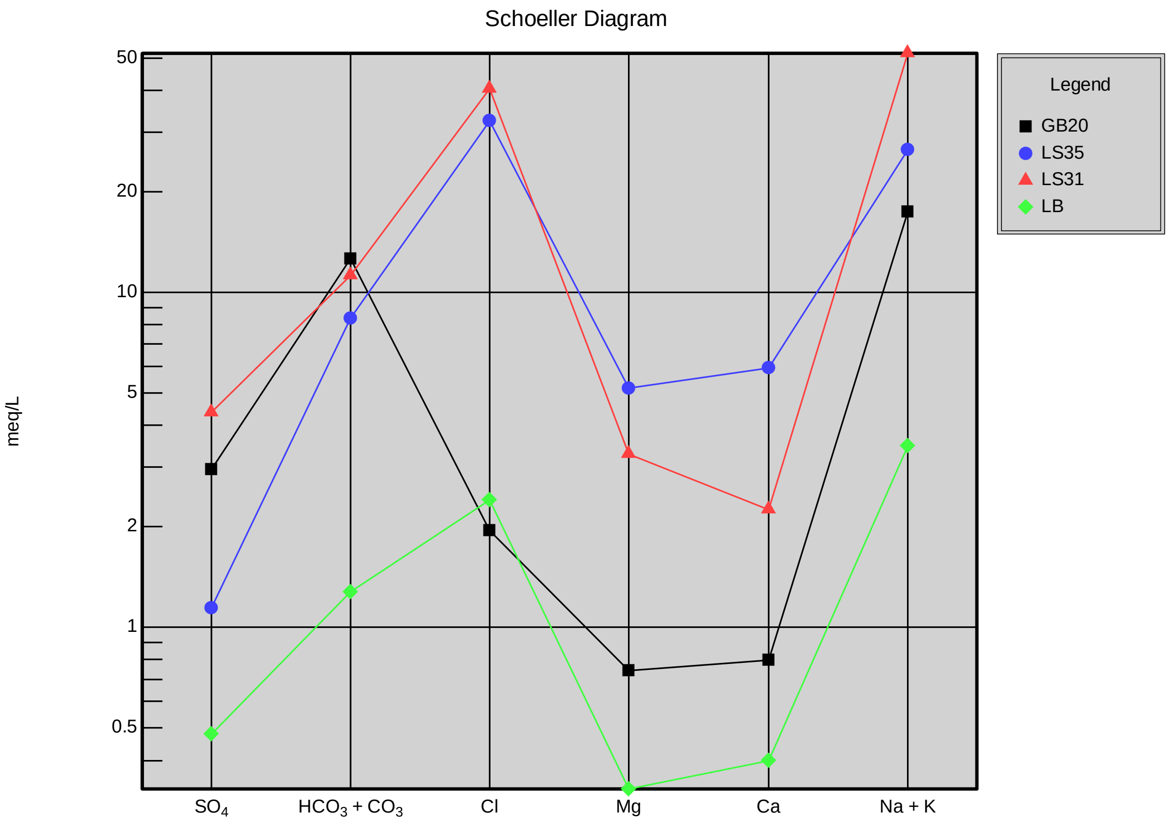


Longswamp 35



Lake Broadwater




Schoeller Diagram
meq/L
50
20
10
5
2
1
0.5
SO$_4$
HCO$_3$ + CO$_3$
Cl
Mg
Ca
Na + K
Legend
GB20
LS35
LS31
LB

Appendix C. Groundwater and surface water laboratory reports, QA/QC documentation, and water chemistry plots.

ALS Environmental

CERTIFICATE OF ARALYSIS

Work Order	: **EB1807088**	Page	: 1 of 4
Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Contact	: Customer Services EB
Address	: 15 HAMPSON STREET KELVIN GROVE QUEENSLAND 4059	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: ----	Telephone	: +61-7-3243 7222
Project	: GDE Study	Date Samples Received	: 19-Mar-2018 13:30
Order number	:	Date Analysis Commenced	: 20-Mar-2018
C-O-C number	: ----	Issue Date	: 26-Mar-2018 15:13
Sampler	: NED HAMER		
Site	: ----		
Quote number	: BNBQ/101/16		
No. of samples received	: 5		
No. of samples analysed	: 5		

NATA
Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Andrew Epps	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Edwandy Fadjar	Organic Coordinator	Sydney Organics, Smithfield, NSW
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	WB Water Lab Brisbane, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key :
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- **Dissolved C1-C4 gases analysis will be conducted by ALS Environmental, Sydney, NATA accreditation no. 825, Site No. 10911 (Micro site no. 14913).**
- EA016: Calculated TDS is determined from Electrical conductivity using a conversion factor of 0.65.

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**Glenburnie 20**	**Longswamp 31**	**Longswamp 35**	**Lake Broadwater**	**Glenburnie 20 Dup**
			Client sampling date / time	16-Mar-2018 12:00	16-Mar-2018 15:45	17-Mar-2018 08:00	16-Mar-2018 16:30	16-Mar-2018 12:30
Compound	*CAS Number*	*LOR*	*Unit*	**EB1807088-001**	**EB1807088-002**	**EB1807088-003**	**EB1807088-004**	**EB1807088-005**
				Result	Result	Result	Result	Result
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	**8.36**	**8.31**	**7.80**	**8.45**	**8.34**
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**1860**	**6050**	**4480**	**446**	**1840**
EA016: Calculated TDS (from Electrical Conductivity)								
Total Dissolved Solids (Calc.)	----	1	mg/L	**1210**	**3930**	**2910**	**290**	**1200**
EA065: Total Hardness as CaCO3								
Total Hardness as CaCO3	----	1	mg/L	**77**	**277**	**556**	**36**	**90**
ED009: Anions								
Bromide	24959-67-9	0.010	mg/L	**0.335**	**4.20**	**3.40**	**0.309**	**0.340**
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	**22**	**9**	<1	**12**	**18**
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**741**	**670**	**523**	**65**	**732**
Total Alkalinity as CaCO3	----	1	mg/L	**763**	**680**	**523**	**77**	**751**
ED040F: Dissolved Major Anions								
Silicon	7440-21-3	0.05	mg/L	**11.0**	**8.16**	**8.95**	**27.7**	**11.0**
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**142**	**210**	**55**	**23**	**144**
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	**69**	**1440**	**1150**	**85**	**71**
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**16**	**45**	**119**	**8**	**18**
Magnesium	7439-95-4	1	mg/L	**9**	**40**	**63**	**4**	**11**
Sodium	7440-23-5	1	mg/L	**398**	**1170**	**609**	**71**	**417**
Potassium	7440-09-7	1	mg/L	**4**	**30**	**5**	**15**	**4**
ED093F: SAR and Hardness Calculations								
^ **Sodium Adsorption Ratio**	----	0.01	-	**19.7**	**30.6**	**11.2**	**5.12**	**19.1**
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Arsenic	7440-38-2	0.001	mg/L	<0.001	**0.001**	**0.001**	**0.002**	**0.001**
Beryllium	7440-41-7	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Barium	7440-39-3	0.001	mg/L	**0.058**	**0.267**	**5.21**	**0.015**	**0.068**
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)			*Client sample ID*	**Glenburnie 20**	**Longswamp 31**	**Longswamp 35**	**Lake Broadwater**	**Glenburnie 20 Dup**
			Client sampling date / time	16-Mar-2018 12:00	16-Mar-2018 15:45	17-Mar-2018 08:00	16-Mar-2018 16:30	16-Mar-2018 12:30
Compound	*CAS Number*	*LOR*	*Unit*	**EB1807088-001**	**EB1807088-002**	**EB1807088-003**	**EB1807088-004**	**EB1807088-005**
				Result	Result	Result	Result	Result
EG020F: Dissolved Metals by ICP-MS - Continued								
Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	**0.001**	<0.001	<0.001
Copper	7440-50-8	0.001	mg/L	**0.001**	<0.001	<0.001	**0.002**	<0.001
Cobalt	7440-48-4	0.001	mg/L	**0.001**	**0.004**	**0.007**	<0.001	**0.002**
Nickel	7440-02-0	0.001	mg/L	**0.002**	**0.003**	**0.009**	**0.002**	**0.001**
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc	7440-66-6	0.005	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005
Manganese	7439-96-5	0.001	mg/L	**0.269**	**0.533**	**6.23**	<0.001	**0.308**
Molybdenum	7439-98-7	0.001	mg/L	**0.024**	**0.027**	**0.013**	**0.001**	**0.040**
Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium	7440-24-6	0.001	mg/L	**0.450**	**1.08**	**2.53**	**0.109**	**0.527**
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	**0.03**	<0.01
Boron	7440-42-8	0.05	mg/L	**0.09**	**0.34**	<0.05	**0.16**	**0.08**
Iron	7439-89-6	0.05	mg/L	<0.05	<0.05	**10.4**	<0.05	<0.05
EG035F: Dissolved Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
EG052F: Dissolved Silica by ICPAES								
Silicon as SiO2	14464-46-1	0.1	mg/L	**23.6**	**17.5**	**19.2**	**59.4**	**23.6**
EK040P: Fluoride by PC Titrator								
Fluoride	16984-48-8	0.1	mg/L	**0.2**	**0.6**	**0.1**	**0.2**	**0.2**
EN055: Ionic Balance								
Total Anions	----	0.01	meq/L	**20.1**	**58.6**	**44.0**	**4.42**	**20.0**
Total Cations	----	0.01	meq/L	**19.0**	**57.2**	**37.7**	**4.20**	**20.0**
Ionic Balance	----	0.01	%	**3.05**	**1.19**	**7.70**	**2.49**	**0.10**
EP033: C1 - C4 Hydrocarbon Gases								
Methane	74-82-8	10	µg/L	<10	<10	**1000**	<10	<10
Ethene	74-85-1	10	µg/L	<10	<10	<10	<10	<10
Ethane	74-84-0	10	µg/L	<10	<10	<10	<10	<10
Propene	115-07-1	10	µg/L	<10	<10	<10	<10	<10
Propane	74-98-6	10	µg/L	<10	<10	<10	<10	<10
Butene	25167-67-3	10	µg/L	<10	<10	<10	<10	<10
Butane	106-97-8	10	µg/L	<10	<10	<10	<10	<10

QUALITY CONTROL REPORT

Work Order	: **EB1807088**	Page	: 1 of 7
Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Contact	: Customer Services EB
Address	: 15 HAMPSON STREET KELVIN GROVE QUEENSLAND 4059	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: ----	Telephone	: +61-7-3243 7222
Project	: GDE Study	Date Samples Received	: 19-Mar-2018
Order number	:	Date Analysis Commenced	: 20-Mar-2018
C-O-C number	: ----	Issue Date	: 26-Mar-2018
Sampler	: NED HAMER		
Site	: ----		
Quote number	: BNBQ/101/16		
No. of samples received	: 5		
No. of samples analysed	: 5		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Quality Control Report contains the following information:

- Laboratory Duplicate (DUP) Report; Relative Percentage Difference (RPD) and Acceptance Limits
- Method Blank (MB) and Laboratory Control Spike (LCS) Report; Recovery and Acceptance Limits
- Matrix Spike (MS) Report; Recovery and Acceptance Limits

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Andrew Epps	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Edwandy Fadjar	Organic Coordinator	Sydney Organics, Smithfield, NSW
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics, Stafford, QLD
Kim McCabe	Senior Inorganic Chemist	WB Water Lab Brisbane, Stafford, QLD

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis. Where the LOR of a reported result differs from standard LOR, this may be due to hig

Key :
Anonymous = Refers to samples which are not specifically part of this work order but formed part of the QC process lot
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
RPD = Relative Percentage Difference
# = Indicates failed QC

Laboratory Duplicate (DUP) Report

The quality control term Laboratory Duplicate refers to a randomly selected intralaboratory split. Laboratory duplicates provide information regarding method precision and sample heterogeneity. The permitted ranges for the Relative Percent Deviation (RPD) of Laboratory Duplicates are specified in ALS Method QWI-EN/38 and are dependent on the magnitude of results in comparison to the level of reporting: Result < 10 times LOR: No Limit; Result between 10 and 20 times LOR: 0% - 50%; Result > 20 times LOR: 0% - 20%.

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	*Client sample ID*	*Method: Compound*	*CAS Number*	*LOR*	*Unit*	*Original Result*	*Duplicate Result*	*RPD (%)*	*Recovery Limits (%)*
EA005P: pH by PC Titrator (QC Lot: 1506475)									
EB1806987-001	Anonymous	EA005-P: pH Value	----	0.01	pH Unit	8.55	8.58	0.350	0% - 20%
EB1807088-004	Lake Broadwater	EA005-P: pH Value	----	0.01	pH Unit	8.45	8.42	0.356	0% - 20%
EA010P: Conductivity by PC Titrator (QC Lot: 1506478)									
EB1806987-001	Anonymous	EA010-P: Electrical Conductivity @ 25°C	----	1	µS/cm	10500	10500	0.0962	0% - 20%
EB1807088-004	Lake Broadwater	EA010-P: Electrical Conductivity @ 25°C	----	1	µS/cm	446	446	0.00	0% - 20%
ED009: Anions (QC Lot: 1507955)									
EB1806788-001	Anonymous	ED009-X: Bromide	24959-67-9	0.01	mg/L	1.83	1.80	1.65	0% - 20%
ED037P: Alkalinity by PC Titrator (QC Lot: 1506477)									
EB1806987-001	Anonymous	ED037-P: Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	75	68	9.65	0% - 20%
		ED037-P: Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	604	609	0.798	0% - 20%
		ED037-P: Total Alkalinity as CaCO3	----	1	mg/L	679	677	0.301	0% - 20%
EB1807088-004	Lake Broadwater	ED037-P: Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	0.00	No Limit
		ED037-P: Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	12	8	35.5	0% - 50%
		ED037-P: Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	65	64	0.00	0% - 20%
		ED037-P: Total Alkalinity as CaCO3	----	1	mg/L	77	72	5.71	0% - 20%
ED040F: Dissolved Major Anions (QC Lot: 1514738)									
EB1806788-001	Anonymous	ED040F: Silicon	7440-21-3	0.05	mg/L	18.5	18.8	1.29	0% - 20%
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA (QC Lot: 1514737)									
EB1807088-004	Lake Broadwater	ED041G: Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	23	23	0.00	0% - 20%
EB1806788-001	Anonymous	ED041G: Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	8	7	0.00	No Limit
ED045G: Chloride by Discrete Analyser (QC Lot: 1514739)									
EB1807088-004	Lake Broadwater	ED045G: Chloride	16887-00-6	1	mg/L	85	86	0.00	0% - 20%
EB1806788-001	Anonymous	ED045G: Chloride	16887-00-6	1	mg/L	642	640	0.385	0% - 20%

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	*Client sample ID*	*Method: Compound*	*CAS Number*	*LOR*	*Unit*	*Original Result*	*Duplicate Result*	*RPD (%)*	*Recovery Limits (%)*
ED093F: Dissolved Major Cations (QC Lot: 1510865)									
EB1807088-005	Glenburnie 20 Dup	ED093F: Calcium	7440-70-2	1	mg/L	18	18	0.00	0% - 50%
		ED093F: Magnesium	7439-95-4	1	mg/L	11	11	0.00	0% - 50%
		ED093F: Sodium	7440-23-5	1	mg/L	417	415	0.646	0% - 20%
		ED093F: Potassium	7440-09-7	1	mg/L	4	4	0.00	No Limit
EB1807042-002	Anonymous	ED093F: Calcium	7440-70-2	1	mg/L	12	12	0.00	0% - 50%
		ED093F: Magnesium	7439-95-4	1	mg/L	3	3	0.00	No Limit
		ED093F: Sodium	7440-23-5	1	mg/L	12	11	0.00	0% - 50%
		ED093F: Potassium	7440-09-7	1	mg/L	7	7	0.00	No Limit
EG020F: Dissolved Metals by ICP-MS (QC Lot: 1510867)									
EB1807088-005	Glenburnie 20 Dup	EG020A-F: Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	0.00	No Limit
		EG020A-F: Arsenic	7440-38-2	0.001	mg/L	0.001	0.001	0.00	No Limit
		EG020A-F: Beryllium	7440-41-7	0.001	mg/L	<0.001	<0.001	0.00	No Limit
		EG020A-F: Barium	7440-39-3	0.001	mg/L	0.068	0.066	3.01	0% - 20%
		EG020A-F: Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	0.00	No Limit
		EG020A-F: Cobalt	7440-48-4	0.001	mg/L	0.002	0.002	0.00	No Limit
		EG020A-F: Copper	7440-50-8	0.001	mg/L	<0.001	<0.001	0.00	No Limit
		EG020A-F: Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	0.00	No Limit
		EG020A-F: Manganese	7439-96-5	0.001	mg/L	0.308	0.305	0.835	0% - 20%
		EG020A-F: Molybdenum	7439-98-7	0.001	mg/L	0.040	0.040	0.00	0% - 20%
		EG020A-F: Nickel	7440-02-0	0.001	mg/L	0.001	0.001	0.00	No Limit
		EG020A-F: Zinc	7440-66-6	0.005	mg/L	<0.005	<0.005	0.00	No Limit
		EG020A-F: Aluminium	7429-90-5	0.01	mg/L	<0.01	<0.01	0.00	No Limit
		EG020A-F: Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	0.00	No Limit
		EG020A-F: Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	0.00	No Limit
		EG020A-F: Boron	7440-42-8	0.05	mg/L	0.08	0.08	0.00	No Limit
		EG020A-F: Iron	7439-89-6	0.05	mg/L	<0.05	<0.05	0.00	No Limit
EB1807042-002	Anonymous	EG020A-F: Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	0.00	No Limit
		EG020A-F: Arsenic	7440-38-2	0.001	mg/L	0.002	0.002	0.00	No Limit
		EG020A-F: Beryllium	7440-41-7	0.001	mg/L	<0.001	<0.001	0.00	No Limit
		EG020A-F: Barium	7440-39-3	0.001	mg/L	0.071	0.072	1.66	0% - 20%
		EG020A-F: Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	0.00	No Limit
		EG020A-F: Cobalt	7440-48-4	0.001	mg/L	<0.001	<0.001	0.00	No Limit
		EG020A-F: Copper	7440-50-8	0.001	mg/L	0.002	0.003	0.00	No Limit
		EG020A-F: Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	0.00	No Limit
		EG020A-F: Manganese	7439-96-5	0.001	mg/L	<0.001	<0.001	0.00	No Limit
		EG020A-F: Molybdenum	7439-98-7	0.001	mg/L	<0.001	<0.001	0.00	No Limit
		EG020A-F: Nickel	7440-02-0	0.001	mg/L	0.002	0.002	0.00	No Limit
		EG020A-F: Zinc	7440-66-6	0.005	mg/L	<0.005	<0.005	0.00	No Limit
		EG020A-F: Aluminium	7429-90-5	0.01	mg/L	0.11	0.10	0.00	0% - 50%
		EG020A-F: Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	0.00	No Limit

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	*Client sample ID*	*Method: Compound*	*CAS Number*	*LOR*	*Unit*	*Original Result*	*Duplicate Result*	*RPD (%)*	*Recovery Limits (%)*
EG020F: Dissolved Metals by ICP-MS (QC Lot: 1510867) - continued									
EB1807042-002	Anonymous	EG020A-F: Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	0.00	No Limit
		EG020A-F: Boron	7440-42-8	0.05	mg/L	<0.05	<0.05	0.00	No Limit
		EG020A-F: Iron	7439-89-6	0.05	mg/L	0.11	0.10	0.00	No Limit
EG020F: Dissolved Metals by ICP-MS (QC Lot: 1510868)									
EB1807088-005	Glenburnie 20 Dup	EG020B-F: Strontium	7440-24-6	0.001	mg/L	0.527	0.510	3.28	0% - 20%
EB1807042-002	Anonymous	EG020B-F: Strontium	7440-24-6	0.001	mg/L	0.248	0.248	0.00	0% - 20%
EG035F: Dissolved Mercury by FIMS (QC Lot: 1510866)									
EB1807088-003	Longswamp 35	EG035F: Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	0.00	No Limit
EB1807042-002	Anonymous	EG035F: Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	0.00	No Limit
EK040P: Fluoride by PC Titrator (QC Lot: 1506476)									
EB1806987-001	Anonymous	EK040P: Fluoride	16984-48-8	0.1	mg/L	1.2	1.2	0.00	0% - 50%
EB1807088-004	Lake Broadwater	EK040P: Fluoride	16984-48-8	0.1	mg/L	0.2	0.2	0.00	No Limit
EP033: C1 - C4 Hydrocarbon Gases (QC Lot: 1512249)									
EB1807088-001	Glenburnie 20	EP033: Methane	74-82-8	10	µg/L	<10	<10	0.00	No Limit
		EP033: Ethene	74-85-1	10	µg/L	<10	<10	0.00	No Limit
		EP033: Ethane	74-84-0	10	µg/L	<10	<10	0.00	No Limit
		EP033: Propene	115-07-1	10	µg/L	<10	<10	0.00	No Limit
		EP033: Propane	74-98-6	10	µg/L	<10	<10	0.00	No Limit
		EP033: Butene	25167-67-3	10	µg/L	<10	<10	0.00	No Limit
		EP033: Butane	106-97-8	10	µg/L	<10	<10	0.00	No Limit
EW1801204-002	Anonymous	EP033: Methane	74-82-8	10	µg/L	11	11	0.00	No Limit
		EP033: Ethene	74-85-1	10	µg/L	<10	<10	0.00	No Limit
		EP033: Ethane	74-84-0	10	µg/L	<10	<10	0.00	No Limit
		EP033: Propene	115-07-1	10	µg/L	<10	<10	0.00	No Limit
		EP033: Propane	74-98-6	10	µg/L	<10	<10	0.00	No Limit
		EP033: Butene	25167-67-3	10	µg/L	<10	<10	0.00	No Limit
		EP033: Butane	106-97-8	10	µg/L	<10	<10	0.00	No Limit

Method Blank (MB) and Laboratory Control Spike (LCS) Report

The quality control term Method / Laboratory Blank refers to an analyte free matrix to which all reagents are added in the same volumes or proportions as used in standard sample preparation. The purpose of this QC parameter is to monitor potential laboratory contamination. The quality control term Laboratory Control Spike (LCS) refers to a certified reference material, or a known interference free matrix spiked with target analytes. The purpose of this QC parameter is to monitor method precision and accuracy independent of sample matrix. Dynamic Recovery Limits are based on statistical evaluation of processed LCS.

Sub-Matrix: **WATER**

				Method Blank (MB) Report	Laboratory Control Spike (LCS) Report			
					Spike	Spike Recovery (%)	Recovery Limits (%)	
Method: Compound	CAS Number	LOR	Unit	Result	Concentration	LCS	Low	High
EA005P: pH by PC Titrator (QCLot: 1506475)								
EA005-P: pH Value	----	----	pH Unit	----	4 pH Unit	100	98	102
				----	7 pH Unit	100	98	102
EA010P: Conductivity by PC Titrator (QCLot: 1506478)								
EA010-P: Electrical Conductivity @ 25°C	----	1	µS/cm	<1	2000 µS/cm	103	91	107
				<1	24800 µS/cm	96.7	91	107
ED009: Anions (QCLot: 1507955)								
ED009-X: Bromide	24959-67-9	0.01	mg/L	<0.010	0.2 mg/L	89.0	80	115
ED037P: Alkalinity by PC Titrator (QCLot: 1506477)								
ED037-P: Total Alkalinity as CaCO3	----	----	mg/L	----	50 mg/L	106	80	120
ED040F: Dissolved Major Anions (QCLot: 1514738)								
ED040F: Silicon	7440-21-3	0.05	mg/L	<0.05	----	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA (QCLot: 1514737)								
ED041G: Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	<1	25 mg/L	99.6	85	118
				<1	100 mg/L	96.0	85	118
ED045G: Chloride by Discrete Analyser (QCLot: 1514739)								
ED045G: Chloride	16887-00-6	1	mg/L	<1	10 mg/L	100	90	115
				<1	1000 mg/L	103	90	115
ED093F: Dissolved Major Cations (QCLot: 1510865)								
ED093F: Calcium	7440-70-2	1	mg/L	<1	----	----	----	----
ED093F: Magnesium	7439-95-4	1	mg/L	<1	----	----	----	----
ED093F: Sodium	7440-23-5	1	mg/L	<1	----	----	----	----
ED093F: Potassium	7440-09-7	1	mg/L	<1	----	----	----	----
EG020F: Dissolved Metals by ICP-MS (QCLot: 1510867)								
EG020A-F: Aluminium	7429-90-5	0.01	mg/L	<0.01	0.5 mg/L	99.1	79	118
EG020A-F: Arsenic	7440-38-2	0.001	mg/L	<0.001	0.1 mg/L	101	88	116
EG020A-F: Beryllium	7440-41-7	0.001	mg/L	<0.001	0.1 mg/L	95.2	81	117
EG020A-F: Barium	7440-39-3	0.001	mg/L	<0.001	0.5 mg/L	96.7	70	130
EG020A-F: Cadmium	7440-43-9	0.0001	mg/L	<0.0001	0.1 mg/L	102	88	108
EG020A-F: Chromium	7440-47-3	0.001	mg/L	<0.001	0.1 mg/L	100	87	113
EG020A-F: Cobalt	7440-48-4	0.001	mg/L	<0.001	0.1 mg/L	96.4	86	112
EG020A-F: Copper	7440-50-8	0.001	mg/L	<0.001	0.2 mg/L	102	88	114
EG020A-F: Lead	7439-92-1	0.001	mg/L	<0.001	0.1 mg/L	95.9	89	110
EG020A-F: Manganese	7439-96-5	0.001	mg/L	<0.001	0.1 mg/L	99.9	89	120

Sub-Matrix: **WATER**

				Method Blank (MB) Report	Laboratory Control Spike (LCS) Report			
					Spike	Spike Recovery (%)	Recovery Limits (%)	
Method: Compound	*CAS Number*	*LOR*	*Unit*	*Result*	*Concentration*	*LCS*	*Low*	*High*
EG020F: Dissolved Metals by ICP-MS (QCLot: 1510867) - continued								
EG020A-F: Molybdenum	7439-98-7	0.001	mg/L	<0.001	0.1 mg/L	97.0	89	112
EG020A-F: Nickel	7440-02-0	0.001	mg/L	<0.001	0.1 mg/L	103	89	113
EG020A-F: Selenium	7782-49-2	0.01	mg/L	<0.01	0.1 mg/L	99.4	83	112
EG020A-F: Vanadium	7440-62-2	0.01	mg/L	<0.01	0.1 mg/L	105	88	114
EG020A-F: Zinc	7440-66-6	0.005	mg/L	<0.005	0.2 mg/L	98.6	87	113
EG020A-F: Boron	7440-42-8	0.05	mg/L	<0.05	0.5 mg/L	104	81	125
EG020A-F: Iron	7439-89-6	0.05	mg/L	<0.05	0.5 mg/L	99.1	82	114
EG020F: Dissolved Metals by ICP-MS (QCLot: 1510868)								
EG020B-F: Strontium	7440-24-6	0.001	mg/L	<0.001	0.5 mg/L	107	86	111
EG035F: Dissolved Mercury by FIMS (QCLot: 1510866)								
EG035F: Mercury	7439-97-6	0.0001	mg/L	<0.0001	0.01 mg/L	84.6	84	118
EK040P: Fluoride by PC Titrator (QCLot: 1506476)								
EK040P: Fluoride	16984-48-8	0.1	mg/L	<0.1	5 mg/L	102	80	117
EP033: C1 - C4 Hydrocarbon Gases (QCLot: 1512249)								
EP033: Methane	74-82-8	10	µg/L	<10	28.48 µg/L	96.2	86	114
EP033: Ethene	74-85-1	10	µg/L	<10	50.29 µg/L	97.1	87	111
EP033: Ethane	74-84-0	10	µg/L	<10	54.43 µg/L	97.1	87	111
EP033: Propene	115-07-1	10	µg/L	<10	73.97 µg/L	96.0	85	113
EP033: Propane	74-98-6	10	µg/L	<10	78.28 µg/L	96.8	84	112
EP033: Butene	25167-67-3	10	µg/L	<10	99.61 µg/L	95.0	83	115
EP033: Butane	106-97-8	10	µg/L	<10	102.18 µg/L	94.9	85	115

Matrix Spike (MS) Report

The quality control term Matrix Spike (MS) refers to an intralaboratory split sample spiked with a representative set of target analytes. The purpose of this QC parameter is to monitor potential matrix effects on analyte recoveries. Static Recovery Limits as per laboratory Data Quality Objectives (DQOs). Ideal recovery ranges stated may be waived in the event of sample matrix interference.

Sub-Matrix: **WATER**

				Matrix Spike (MS) Report			
				Spike	SpikeRecovery(%)	Recovery Limits (%)	
Laboratory sample ID	*Client sample ID*	*Method: Compound*	*CAS Number*	*Concentration*	*MS*	*Low*	*High*
ED009: Anions (QCLot: 1507955)							
EB1806789-001	Anonymous	ED009-X: Bromide	24959-67-9	0.5 mg/L	# Not Determined	70	130
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA (QCLot: 1514737)							
EB1806789-001	Anonymous	ED041G: Sulfate as SO4 - Turbidimetric	14808-79-8	20 mg/L	# Not Determined	70	130
ED045G: Chloride by Discrete Analyser (QCLot: 1514739)							
EB1806789-001	Anonymous	ED045G: Chloride	16887-00-6	400 mg/L	84.8	70	130

Sub-Matrix: **WATER**

Laboratory sample ID	Client sample ID	Method: Compound	CAS Number	Matrix Spike (MS) Report Spike Concentration	SpikeRecovery(%) MS	Recovery Limits (%) Low	High
EG020F: Dissolved Metals by ICP-MS (QCLot: 1510867)							
EB1807042-001	Anonymous	EG020A-F: Aluminium	7429-90-5	0.5 mg/L	99.8	70	130
		EG020A-F: Arsenic	7440-38-2	0.1 mg/L	101	70	130
		EG020A-F: Beryllium	7440-41-7	0.1 mg/L	98.7	70	130
		EG020A-F: Barium	7440-39-3	0.5 mg/L	100	70	130
		EG020A-F: Cadmium	7440-43-9	0.1 mg/L	104	70	130
		EG020A-F: Chromium	7440-47-3	0.1 mg/L	103	70	130
		EG020A-F: Cobalt	7440-48-4	0.1 mg/L	96.0	70	130
		EG020A-F: Copper	7440-50-8	0.2 mg/L	103	70	130
		EG020A-F: Lead	7439-92-1	0.1 mg/L	99.9	70	130
		EG020A-F: Manganese	7439-96-5	0.1 mg/L	102	70	130
		EG020A-F: Molybdenum	7439-98-7	0.1 mg/L	95.3	70	130
		EG020A-F: Nickel	7440-02-0	0.1 mg/L	103	70	130
		EG020A-F: Selenium	7782-49-2	0.1 mg/L	108	70	130
		EG020A-F: Vanadium	7440-62-2	0.1 mg/L	104	70	130
		EG020A-F: Zinc	7440-66-6	0.2 mg/L	104	70	130
		EG020A-F: Boron	7440-42-8	0.5 mg/L	97.6	70	130
EG035F: Dissolved Mercury by FIMS (QCLot: 1510866)							
EB1807042-001	Anonymous	EG035F: Mercury	7439-97-6	0.01 mg/L	78.2	70	130
EK040P: Fluoride by PC Titrator (QCLot: 1506476)							
EB1807021-001	Anonymous	EK040P: Fluoride	16984-48-8	5 mg/L	97.0	70	130
EP033: C1 - C4 Hydrocarbon Gases (QCLot: 1512249)							
EB1807088-002	Longswamp 31	EP033: Methane	74-82-8	28.48 µg/L	92.4	70	130
		EP033: Ethene	74-85-1	50.29 µg/L	96.6	70	130
		EP033: Ethane	74-84-0	54.43 µg/L	96.3	70	130
		EP033: Propene	115-07-1	73.97 µg/L	95.5	70	130
		EP033: Propane	74-98-6	78.28 µg/L	95.2	70	130
		EP033: Butene	25167-67-3	99.61 µg/L	94.6	70	130
		EP033: Butane	106-97-8	102.18 µg/L	94.3	70	130

QA/QC Compliance Assessment to assist with Quality Review

Work Order	: **EB1807088**	Page	: 1 of 8
Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Telephone	: +61-7-3243 7222
Project	: GDE Study	Date Samples Received	: 19-Mar-2018
Site	: ----	Issue Date	: 26-Mar-2018
Sampler	: NED HAMER	No. of samples received	: 5
Order number	:	No. of samples analysed	: 5

This report is automatically generated by the ALS LIMS through interpretation of the ALS Quality Control Report and several Quality Assurance parameters measured by ALS. This automated reporting highlights any non-conformances, facilitates faster and more accurate data validation and is designed to assist internal expert and external Auditor review. Many components of this report contribute to the overall DQO assessment and reporting for guideline compliance.

Brief method summaries and references are also provided to assist in traceability.

Summary of Outliers

Outliers : Quality Control Samples

This report highlights outliers flagged in the Quality Control (QC) Report.

- **NO Method Blank value outliers occur.**
- **NO Duplicate outliers occur.**
- **NO Laboratory Control outliers occur.**
- **Matrix Spike outliers exist - please see following pages for full details.**
- **For all regular sample matrices, NO surrogate recovery outliers occur.**

Outliers : Analysis Holding Time Compliance

- **Analysis Holding Time Outliers exist - please see following pages for full details.**

Outliers : Frequency of Quality Control Samples

- **NO Quality Control Sample Frequency Outliers exist.**

Outliers : Quality Control Samples

Duplicates, Method Blanks, Laboratory Control Samples and Matrix Spikes

Matrix: **WATER**

Compound Group Name	Laboratory Sample ID	Client Sample ID	**Analyte**	CAS Number	Data	Limits	**Comment**
Matrix Spike (MS) Recoveries							
ED009: Anions	EB1806789--001	Anonymous	**Bromide**	24959-67-9	Not Determined	----	**MS recovery not determined, background level greater than or equal to 4x spike level.**
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA	EB1806789--001	Anonymous	**Sulfate as SO4 - Turbidimetric**	14808-79-8	Not Determined	----	**MS recovery not determined, background level greater than or equal to 4x spike level.**

Outliers : Analysis Holding Time Compliance

Matrix: **WATER**

Method	*Extraction / Preparation*			*Analysis*		
Container / Client Sample ID(s)	*Date extracted*	*Due for extraction*	***Days overdue***	*Date analysed*	*Due for analysis*	***Days overdue***
EA005P: pH by PC Titrator						
Clear Plastic Bottle - Natural Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	----	----	----	20-Mar-2018	16-Mar-2018	**4**
Clear Plastic Bottle - Natural Longswamp 35	----	----	----	20-Mar-2018	17-Mar-2018	**3**

Analysis Holding Time Compliance

If samples are identified below as having been analysed or extracted outside of recommended holding times, this should be taken into consideration when interpreting results.

This report summarizes extraction / preparation and analysis times and compares each with ALS recommended holding times (referencing USEPA SW 846, APHA, AS and NEPM) based on the sample container provided. Dates reported represent first date of extraction or analysis and preclude subsequent dilutions and reruns. A listing of breaches (if any) is provided herein.

Holding time for leachate methods (e.g. TCLP) vary according to the analytes reported. Assessment compares the leach date with the shortest analyte holding time for the equivalent soil method. These are: organics 14 days, mercury 28 days & other metals 180 days. A recorded breach does not guarantee a breach for all non-volatile parameters.

Holding times for ***VOC in soils*** vary according to analytes of interest. Vinyl Chloride and Styrene holding time is 7 days; others 14 days. A recorded breach does not guarantee a breach for all VOC analytes and should be verified in case the reported breach is a false positive or Vinyl Chloride and Styrene are not key analytes of interest/concern.

Matrix: **WATER**

Evaluation: ✗ = Holding time breach ; ✓ = Within holding time.

Method	***Sample Date***	*Extraction / Preparation*			*Analysis*		
***Container** / Client Sample ID(s)*		***Date extracted***	*Due for extraction*	*Evaluation*	***Date analysed***	*Due for analysis*	*Evaluation*
EA005P: pH by PC Titrator							
Clear Plastic Bottle - Natural (EA005-P) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**20-Mar-2018**	16-Mar-2018	✗
Clear Plastic Bottle - Natural (EA005-P) Longswamp 35	**17-Mar-2018**	**----**	----	----	**20-Mar-2018**	17-Mar-2018	✗

Matrix: **WATER**

Evaluation: × = Holding time breach ; ✓ = Within holding time.

Method	*Sample Date*	*Extraction / Preparation*			*Analysis*		
Container / Client Sample ID(s)		*Date extracted*	*Due for extraction*	*Evaluation*	*Date analysed*	*Due for analysis*	*Evaluation*
EA010P: Conductivity by PC Titrator							
Clear Plastic Bottle - Natural (EA010-P) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**20-Mar-2018**	13-Apr-2018	✓
Clear Plastic Bottle - Natural (EA010-P) Longswamp 35	**17-Mar-2018**	**----**	----	----	**20-Mar-2018**	14-Apr-2018	✓
EA065: Total Hardness as CaCO3							
Clear Plastic Bottle - Nitric Acid; Filtered (ED093F) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**22-Mar-2018**	13-Apr-2018	✓
Clear Plastic Bottle - Nitric Acid; Filtered (ED093F) Longswamp 35	**17-Mar-2018**	**----**	----	----	**22-Mar-2018**	14-Apr-2018	✓
ED009: Anions							
Clear Plastic Bottle - Natural (ED009-X) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**20-Mar-2018**	13-Apr-2018	✓
Clear Plastic Bottle - Natural (ED009-X) Longswamp 35	**17-Mar-2018**	**----**	----	----	**20-Mar-2018**	14-Apr-2018	✓
ED037P: Alkalinity by PC Titrator							
Clear Plastic Bottle - Natural (ED037-P) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**20-Mar-2018**	30-Mar-2018	✓
Clear Plastic Bottle - Natural (ED037-P) Longswamp 35	**17-Mar-2018**	**----**	----	----	**20-Mar-2018**	31-Mar-2018	✓
ED040F: Dissolved Major Anions							
Clear Plastic Bottle - Natural (ED040F) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**22-Mar-2018**	13-Apr-2018	✓
Clear Plastic Bottle - Natural (ED040F) Longswamp 35	**17-Mar-2018**	**----**	----	----	**22-Mar-2018**	14-Apr-2018	✓
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA							
Clear Plastic Bottle - Natural (ED041G) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**22-Mar-2018**	13-Apr-2018	✓
Clear Plastic Bottle - Natural (ED041G) Longswamp 35	**17-Mar-2018**	**----**	----	----	**22-Mar-2018**	14-Apr-2018	✓
ED045G: Chloride by Discrete Analyser							
Clear Plastic Bottle - Natural (ED045G) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**22-Mar-2018**	13-Apr-2018	✓
Clear Plastic Bottle - Natural (ED045G) Longswamp 35	**17-Mar-2018**	**----**	----	----	**22-Mar-2018**	14-Apr-2018	✓

Matrix: **WATER**

Evaluation: × = Holding time breach ; ✓ = Within holding time.

Method *Container / Client Sample ID(s)*	*Sample Date*	*Extraction / Preparation*			*Analysis*		
		Date extracted	*Due for extraction*	*Evaluation*	*Date analysed*	*Due for analysis*	*Evaluation*
ED093F: Dissolved Major Cations							
Clear Plastic Bottle - Nitric Acid; Filtered (ED093F) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**22-Mar-2018**	13-Apr-2018	✓
Clear Plastic Bottle - Nitric Acid; Filtered (ED093F) Longswamp 35	**17-Mar-2018**	**----**	----	----	**22-Mar-2018**	14-Apr-2018	✓
ED093F: SAR and Hardness Calculations							
Clear Plastic Bottle - Nitric Acid; Filtered (ED093F) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**22-Mar-2018**	13-Apr-2018	✓
Clear Plastic Bottle - Nitric Acid; Filtered (ED093F) Longswamp 35	**17-Mar-2018**	**----**	----	----	**22-Mar-2018**	14-Apr-2018	✓
EG020F: Dissolved Metals by ICP-MS							
Clear Plastic Bottle - Nitric Acid; Filtered (EG020B-F) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**22-Mar-2018**	12-Sep-2018	✓
Clear Plastic Bottle - Nitric Acid; Filtered (EG020B-F) Longswamp 35	**17-Mar-2018**	**----**	----	----	**22-Mar-2018**	13-Sep-2018	✓
EG035F: Dissolved Mercury by FIMS							
Clear Plastic Bottle - Nitric Acid; Filtered (EG035F) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**26-Mar-2018**	13-Apr-2018	✓
Clear Plastic Bottle - Nitric Acid; Filtered (EG035F) Longswamp 35	**17-Mar-2018**	**----**	----	----	**26-Mar-2018**	14-Apr-2018	✓
EK040P: Fluoride by PC Titrator							
Clear Plastic Bottle - Natural (EK040P) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**20-Mar-2018**	13-Apr-2018	✓
Clear Plastic Bottle - Natural (EK040P) Longswamp 35	**17-Mar-2018**	**----**	----	----	**20-Mar-2018**	14-Apr-2018	✓
EP033: C1 - C4 Hydrocarbon Gases							
Amber VOC Vial - Sulfuric Acid (EP033) Glenburnie 20, Longswamp 31, Lake Broadwater, Glenburnie 20 Dup	**16-Mar-2018**	**----**	----	----	**21-Mar-2018**	30-Mar-2018	✓
Amber VOC Vial - Sulfuric Acid (EP033) Longswamp 35	**17-Mar-2018**	**----**	----	----	**21-Mar-2018**	31-Mar-2018	✓

Quality Control Parameter Frequency Compliance

The following report summarises the frequency of laboratory QC samples analysed within the analytical lot(s) in which the submitted sample(s) was(were) processed. Actual rate should be greater than or equal to the expected rate. A listing of breaches is provided in the Summary of Outliers.

Matrix: **WATER**

Evaluation: × = Quality Control frequency not within specification ; ✓ = Quality Control frequency within specification.

Quality Control Sample Type		Count		Rate (%)			Quality Control Specification
Analytical Methods	*Method*	*QC*	*Regular*	***Actual***	***Expected***	*Evaluation*	
Laboratory Duplicates (DUP)							
Alkalinity by PC Titrator	ED037-P	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
C1 - C4 Gases	EP033	2	12	**16.67**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Chloride by Discrete Analyser	ED045G	2	13	**15.38**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Conductivity by PC Titrator	EA010-P	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Mercury by FIMS	EG035F	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Metals by ICP-MS - Suite A	EG020A-F	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Metals by ICP-MS - Suite B	EG020B-F	2	13	**15.38**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Anions - Dissolved	ED040F	1	5	**20.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Cations - Dissolved	ED093F	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
pH by PC Titrator	EA005-P	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	1	9	**11.11**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Sulfate (Turbidimetric) as SO4 2- by Discrete Analyser	ED041G	2	18	**11.11**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Laboratory Control Samples (LCS)							
Alkalinity by PC Titrator	ED037-P	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
C1 - C4 Gases	EP033	1	12	**8.33**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Chloride by Discrete Analyser	ED045G	2	13	**15.38**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Conductivity by PC Titrator	EA010-P	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Mercury by FIMS	EG035F	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Metals by ICP-MS - Suite A	EG020A-F	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Metals by ICP-MS - Suite B	EG020B-F	1	13	**7.69**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
pH by PC Titrator	EA005-P	2	20	**10.00**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	1	9	**11.11**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Sulfate (Turbidimetric) as SO4 2- by Discrete Analyser	ED041G	2	18	**11.11**	**10.00**	✓	NEPM 2013 B3 & ALS QC Standard
Method Blanks (MB)							
C1 - C4 Gases	EP033	1	12	**8.33**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Chloride by Discrete Analyser	ED045G	1	13	**7.69**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Conductivity by PC Titrator	EA010-P	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Mercury by FIMS	EG035F	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Metals by ICP-MS - Suite A	EG020A-F	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Metals by ICP-MS - Suite B	EG020B-F	1	13	**7.69**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Anions - Dissolved	ED040F	1	5	**20.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Major Cations - Dissolved	ED093F	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	1	9	**11.11**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard

Matrix: **WATER**

Evaluation: × = Quality Control frequency not within specification ; ✓ = Quality Control frequency within specification.

Quality Control Sample Type		Count		Rate (%)			Quality Control Specification
Analytical Methods	*Method*	*QC*	*Regular*	***Actual***	***Expected***	*Evaluation*	
Method Blanks (MB) - Continued							
Sulfate (Turbidimetric) as SO4 2- by Discrete Analyser	ED041G	1	18	**5.56**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Matrix Spikes (MS)							
C1 - C4 Gases	EP033	1	12	**8.33**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Chloride by Discrete Analyser	ED045G	1	13	**7.69**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Mercury by FIMS	EG035F	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Dissolved Metals by ICP-MS - Suite A	EG020A-F	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Fluoride by PC Titrator	EK040P	1	20	**5.00**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Standard Anions -by IC (Extended Method)	ED009-X	1	9	**11.11**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard
Sulfate (Turbidimetric) as SO4 2- by Discrete Analyser	ED041G	1	18	**5.56**	**5.00**	✓	NEPM 2013 B3 & ALS QC Standard

Brief Method Summaries

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the US EPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request. The following report provides brief descriptions of the analytical procedures employed for results reported in the Certificate of Analysis. Sources from which ALS methods have been developed are provided within the Method Descriptions.

Analytical Methods	*Method*	*Matrix*	*Method Descriptions*
pH by PC Titrator	EA005-P	WATER	In house: Referenced to APHA 4500 H+ B. This procedure determines pH of water samples by automated ISE. This method is compliant with NEPM (2013) Schedule B(3)
Conductivity by PC Titrator	EA010-P	WATER	In house: Referenced to APHA 2510 B. This procedure determines conductivity by automated ISE. This method is compliant with NEPM (2013) Schedule B(3)
Calculated TDS (from Electrical Conductivity)	EA016	WATER	In house: Calculation from Electrical Conductivity (APHA 2510 B) using a conversion factor specified in the analytical report. This method is compliant with NEPM (2013) Schedule B(3)
Standard Anions -by IC (Extended Method)	ED009-X	WATER	In house: Referenced to APHA 4110B. This method is compliant with NEPM (2013) Schedule B(3)
Alkalinity by PC Titrator	ED037-P	WATER	In house: Referenced to APHA 2320 B This procedure determines alkalinity by automated measurement (e.g. PC Titrate) using pH 4.5 for indicating the total alkalinity end-point. This method is compliant with NEPM (2013) Schedule B(3)
Major Anions - Dissolved	ED040F	WATER	In house: Referenced to APHA 3120. The 0.45µm filtered samples are determined by ICP/AES for Sulfur and/or Silcon content and reported as Sulfate and/or Silica after conversion by gravimetric factor.
Sulfate (Turbidimetric) as SO4 2- by Discrete Analyser	ED041G	WATER	In house: Referenced to APHA 4500-SO4. Dissolved sulfate is determined in a 0.45um filtered sample. Sulfate ions are converted to a barium sulfate suspension in an acetic acid medium with barium chloride. Light absorbance of the BaSO4 suspension is measured by a photometer and the SO4-2 concentration is determined by comparison of the reading with a standard curve. This method is compliant with NEPM (2013) Schedule B(3)
Chloride by Discrete Analyser	ED045G	WATER	In house: Referenced to APHA 4500 Cl - G.The thiocyanate ion is liberated from mercuric thiocyanate through sequestration of mercury by the chloride ion to form non-ionised mercuric chloride.in the presence of ferric ions the librated thiocyanate forms highly-coloured ferric thiocyanate which is measured at 480 nm APHA 21st edition seal method 2 017-1-L april 2003
Major Cations - Dissolved	ED093F	WATER	In house: Referenced to APHA 3120 and 3125; USEPA SW 846 - 6010 and 6020; Cations are determined by either ICP-AES or ICP-MS techniques. This method is compliant with NEPM (2013) Schedule B(3) Sodium Adsorption Ratio is calculated from Ca, Mg and Na which determined by ALS in house method QWI-EN/ED093F. This method is compliant with NEPM (2013) Schedule B(3) Hardness parameters are calculated based on APHA 2340 B. This method is compliant with NEPM (2013) Schedule B(3)
Dissolved Metals by ICP-MS - Suite A	EG020A-F	WATER	In house: Referenced to APHA 3125; USEPA SW846 - 6020, ALS QWI-EN/EG020. Samples are 0.45µm filtered prior to analysis. The ICPMS technique utilizes a highly efficient argon plasma to ionize selected elements. Ions are then passed into a high vacuum mass spectrometer, which separates the analytes based on their distinct mass to charge ratios prior to their measurement by a discrete dynode ion detector.
Dissolved Metals by ICP-MS - Suite B	EG020B-F	WATER	In house: Referenced to APHA 3125; USEPA SW846 - 6020, ALS QWI-EN/EG020. Samples are 0.45µm filtered prior to analysis. The ICPMS technique utilizes a highly efficient argon plasma to ionize selected elements. Ions are then passed into a high vacuum mass spectrometer, which separates the analytes based on their distinct mass to charge ratios prior to their measurement by a discrete dynode ion detector.

Analytical Methods	*Method*	*Matrix*	*Method Descriptions*
Dissolved Mercury by FIMS	EG035F	WATER	In house: Referenced to AS 3550, APHA 3112 Hg - B (Flow-injection (SnCl2)(Cold Vapour generation) AAS) Samples are 0.45µm filtered prior to analysis. FIM-AAS is an automated flameless atomic absorption technique. A bromate/bromide reagent is used to oxidise any organic mercury compounds in the filtered sample. The ionic mercury is reduced online to atomic mercury vapour by SnCl2 which is then purged into a heated quartz cell. Quantification is by comparing absorbance against a calibration curve. This method is compliant with NEPM (2013) Schedule B(3)
Silica (Total Dissolved) by ICPAES	EG052F	WATER	In house: Referenced to APHA 4500-SiO2. Silica (Total) determined by calculation from Silicon by ICPAES.
Fluoride by PC Titrator	EK040P	WATER	In house: Referenced to APHA 4500-F C: CDTA is added to the sample to provide a uniform ionic strength background, adjust pH, and break up complexes. Fluoride concentration is determined by either manual or automatic ISE measurement. This method is compliant with NEPM (2013) Schedule B(3)
Ionic Balance by PCT DA and Turbi SO4 DA	EN055 - PG	WATER	In house: Referenced to APHA 1030F. This method is compliant with NEPM (2013) Schedule B(3)
C1 - C4 Gases	EP033	WATER	Technical Guidance for the Natural Attenuation Indicators: Methane, Ethane, and Ethene, US EPA - Region 1, EPA New England, July 2001. Automated static headspace, dual column GC/FID. A 12 mL sample is pipetted into a 20 mL headspace vial containing 3g of sodium chloride and sealed. Each sample is equilibrated with shaking at 40 degrees C for 10 minutes prior to analysis by GC/FID using a pair of PLOT columns of different polarity.

SAMPLE RECEIPT NOTIFICATION (SRN)

Work Order : **EB1807088**

Client	: **EARTH SEARCH**	Laboratory	: Environmental Division Brisbane
Contact	: MR NED HAMER	Contact	: Customer Services EB
Address	: 15 HAMPSON STREET KELVIN GROVE QUEENSLAND 4059	Address	: 2 Byth Street Stafford QLD Australia 4053
E-mail	: ned@earthsearch.com.au	E-mail	: ALSEnviro.Brisbane@alsglobal.com
Telephone	: ----	Telephone	: +61-7-3243 7222
Facsimile	: ----	Facsimile	: +61-7-3243 7218
Project	: GDE Study	Page	: 1 of 2
Order number	:	Quote number	: EB2016EARSEA0001 (BNBQ/101/16)
C-O-C number	: ----	QC Level	: NEPM 2013 B3 & ALS QC Standard
Site	: ----		
Sampler	: NED HAMER		

Dates

Date Samples Received	: 19-Mar-2018 13:30	Issue Date	: 19-Mar-2018
Client Requested Due Date	: 26-Mar-2018	Scheduled Reporting Date	: **26-Mar-2018**

Delivery Details

Mode of Delivery	: Client Drop Off	Security Seal	: Intact.
No. of coolers/boxes	: 1	Temperature	: 25.0°C - Ice Bricks present
Receipt Detail	: MEDIUM ESKY	No. of samples received / analysed	: 5 / 5

General Comments

- This report contains the following information:
  - Sample Container(s)/Preservation Non-Compliances
  - Summary of Sample(s) and Requested Analysis
  - Proactive Holding Time Report
  - Requested Deliverables
- **Please be advised that the 3 eskies sent with this work order have been forwarded to the respective destinations as requested. Please note that this will incur a freight forwarding charge.**
- Discounted Package Prices apply only when specific ALS Group Codes ('W', 'S', 'NT' suites) are referenced on COCs.
- **Dissolved C1-C4 gases analysis will be conducted by ALS Environmental, Sydney, NATA accreditation no. 825, Site No. 10911 (Micro site no. 14913).**
- Please direct any turn around / technical queries to the laboratory contact designated above.
- Sample Disposal - Aqueous (3 weeks), Solid (2 months) from receipt of samples.
- Analysis will be conducted by ALS Environmental, Brisbane, NATA accreditation no. 825, Site No. 818 (Micro site no. 18958).
- **Sample(s) requiring volatile organic compound analysis received in airtight containers (ZHE).**
- **Breaches in recommended extraction / analysis holding times (if any) are displayed overleaf in the Proactive Holding Time Report table.**

Sample Container(s)/Preservation Non-Compliances

All comparisons are made against pretreatment/preservation AS, APHA, USEPA standards.

- **No sample container / preservation non-compliance exists.**

Summary of Sample(s) and Requested Analysis

Some items described below may be part of a laboratory process necessary for the execution of client requested tasks. Packages may contain additional analyses, such as the determination of moisture content and preparation tasks, that are included in the package.

If no sampling time is provided, the sampling time will default 00:00 on the date of sampling. If no sampling date is provided, the sampling date will be assumed by the laboratory and displayed in brackets without a time component

Matrix: **WATER**

Laboratory sample ID	*Client sampling date / time*	*Client sample ID*	WATER - ED009-X Standard Anions (Extended method	WATER - EG020F Dissolved Metals by ICP/MS	WATER - EG052 Silica (Total Dissolved) by ICPAES	WATER - EP033 C1 - C4 Gases in Water	WATER - NT-12 General Water Suite	WATER - W-02 8 Metals
EB1807088-001	16-Mar-2018 12:00	Glenburnie 20	✓	✓	✓	✓	✓	✓
EB1807088-002	16-Mar-2018 15:45	Longswamp 31	✓	✓	✓	✓	✓	✓
EB1807088-003	17-Mar-2018 08:00	Longswamp 35	✓	✓	✓	✓	✓	✓
EB1807088-004	16-Mar-2018 16:30	Lake Broadwater	✓	✓	✓	✓	✓	✓
EB1807088-005	16-Mar-2018 12:30	Glenburnie 20 Dup	✓	✓	✓	✓	✓	✓

Proactive Holding Time Report

The following table summarises breaches of recommended holding times that have occurred prior to samples/instructions being received at the laboratory.

Matrix: **WATER**

Evaluation: × = Holding time breach ; ✓ = Within holding time.

Method **Client Sample ID(s)**	**Container**	**Due for extraction**	**Due for analysis**	**Samples Received**		**Instructions Received**	
				Date	**Evaluation**	**Date**	**Evaluation**
EA005-P: pH by PC Titrator							
Glenburnie 20 Dup	Clear Plastic Bottle - Natural	----	16-Mar-2018	19-Mar-2018	×	----	----
Glenburnie 20	Clear Plastic Bottle - Natural	----	16-Mar-2018	19-Mar-2018	×	----	----
Lake Broadwater	Clear Plastic Bottle - Natural	----	16-Mar-2018	19-Mar-2018	×	----	----
Longswamp 31	Clear Plastic Bottle - Natural	----	16-Mar-2018	19-Mar-2018	×	----	----
Longswamp 35	Clear Plastic Bottle - Natural	----	17-Mar-2018	19-Mar-2018	×	----	----

Requested Deliverables

NED HAMER

- *AU Certificate of Analysis - NATA (COA)	Email	ned@earthsearch.com.au
- *AU Interpretive QC Report - DEFAULT (Anon QCI Rep) (QCI)	Email	ned@earthsearch.com.au
- *AU QC Report - DEFAULT (Anon QC Rep) - NATA (QC)	Email	ned@earthsearch.com.au
- A4 - AU Sample Receipt Notification - Environmental HT (SRN)	Email	ned@earthsearch.com.au
- A4 - AU Tax Invoice (INV)	Email	ned@earthsearch.com.au
- Chain of Custody (CoC) (COC)	Email	ned@earthsearch.com.au
- EDI Format - XTab (XTAB)	Email	ned@earthsearch.com.au

CHAIN OF CUSTODY

ALS Laboratory: please tick →

☐ADELAIDE 2/1 Burma Road Pooraka SA 5095 Ph: 08 8162 5130 E: adelaide@alsglobal.com
☐BRISBANE 2 Byth Street Stafford QLD 4053 Ph: 07 3243 7222 E: samples.brisbane@alsglobal.com
☐GLADSTONE 46 Callemondah Drive Clinton QLD 4680 Ph: 07 4978 7944 E: ALSEnviro.Gladstone@alsglobal.com
☐MACKAY Unit 2/20 Caterpillar Drive Paget QLD 4740 Ph: 07 4952 5795 E: ALSEnviro.Mackay@alsglobal.com
☐MELBOURNE 2-4 Westall Road Springvale VIC 3171 Ph: 03 8549 9600 E: samples.melbourne@alsglobal.com
☐MUDGEE 1/29 Sydney Road Mudgee NSW 2850 Ph: 02 6372 6735 E: mudgee.mail@alsglobal.com
☐NEWCASTLE 5/585 Maitland Road Mayfield West NSW 2304 Ph: 02 4014 2500 E: samples.newcastle@alsglobal.com
☐NOWRA 4/13 Geary Place North Nowra NSW 2541 Ph: 02 4423 2063 E: nowra@alsglobal.com
☐PERTH 10 Hod Way Malaga WA 6090 Ph: 08 9209 7655 E: samples.perth@alsglobal.com
☐SYDNEY 277-289 Woodpark Road Smithfield NSW 2164 Ph: 02 8784 8555 E: samples.sydney@alsglobal.com
☐TOWNSVILLE 14-15 Desma Court Bohle QLD 4818 Ph: 07 4796 0600 E: ALSEnviro.Townsville@alsglobal.com
☐WOLLONGONG 1/19-21 Ralph Black Drive, Nth Wollongong NSW 2500 Ph: 02 4225 3125 E: wollongong@alsglobal.com

CLIENT: Earth Search
OFFICE: Brisbane
PROJECT: GDE Study
PROJECT NO.:
ORDER NUMBER: ✓
PURCHASE ORDER NO.:
PROJECT MANAGER: Ned Hamer
CONTACT PH: 0429 049 154
SAMPLER: Ned Hamer
SAMPLER MOBILE: 0429049154
COC Emailed to ALS? (YES / [✓ NO])
EDD FORMAT (or default):
Email Reports to (will default to PM if no other addresses are listed): ~~ned-hame~~ ned@earthsearch.com.au
Email Invoice to (will default to PM if no other addresses are listed): ned@earthsearch.com.au
COMMENTS/SPECIAL HANDLING/STORAGE OR DISPOSAL:

TURNAROUND REQUIREMENTS : (Standard TAT may be longer for some tests e.g.. Ultra Trace Organics)
☑ Standard TAT (List due date):
☐ Non Standard or urgent TAT (List due date):
ALS QUOTE NO.: BNBQ/101/16
COUNTRY OF ORIGIN: Australia

COC SEQUENCE NUMBER (Circle)
COC: [✓ 1] 2 3 4 5 6 7
OF: [✓ 1] 2 3 4 5 6 7

FOR LABORATORY USE ONLY (Circle)
Custody Seal Intact? Yes No N/A
Free ice / frozen ice bricks present upon receipt? Yes No N/A
Random Sample Temperature on Receipt: °C
Other comment:

RELINQUISHED BY:	RECEIVED BY:	RELINQUISHED BY:	RECEIVED BY:
	Justine		
DATE/TIME: 19/3/18 12:15	DATE/TIME: 1-30 19-3-18	DATE/TIME:	DATE/TIME:

ALS USE ONLY LAB ID	SAMPLE DETAILS MATRIX: Solid(S) Water(W) SAMPLE ID	DATE / TIME	MATRIX	CONTAINER INFORMATION TYPE & PRESERVATIVE (refer to codes below)	TOTAL BOTTLES	pH, EC, Alkalinity, TDS, SAR, Hardness, Dissolved Silica	Ionic: Ca, Mg, Na, K, F, Cl, SO4; Ionic Balance	Dissolved metals * See list	Dissolved CH4 Gases						Additional Information Comments on likely contaminant levels, dilutions, or samples requiring specific QC analysis etc.
1	Glenburnie 20	16/3/18 12:00	W	2xP; 2xVS; 1xN	~~4~~ 5	X	X	X	X						Dissolved * Metals to include: Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Mo, Mn, Ni, Pb, Se, Sr, V, Zn + Bromide
2	Longswamp 31	16/3/18 15:45	W	1xP; 1xAG; 2xVS; 1xN	5	↓	↓	↓	↓						
3	Longswamp 35	17/3/18 8:00	W	1xP; 2xVS; 1xN	4	↓	↓	↓	↓						
4	Lake Broadwater	16/3/18 16:30	W	1xP; 2xVS; 1xN	4	↓	↓	↓	↓						
5	Glenburnie 20 Dup	16/3/18 12:30	W	1xP; 2xVS; 1xN; 1xAG	5	↓	↓	↓	↓						
				TOTAL											

Environmental Division
Brisbane
Work Order Reference
EB1807088

Telephone : + 61-7-3243 7222

Water Container Codes: P = Unpreserved Plastic; N = Nitric Preserved Plastic; ORC = Nitric Preserved ORC; SH = Sodium Hydroxide/Cd Preserved; S = Sodium Hydroxide Preserved Plastic; AG = Amber Glass Unpreserved; AP - Airfreight Unpreserved Plastic
V = VOA Vial HCl Preserved; VB = VOA Vial Sodium Bisulphate Preserved; VS = VOA Vial Sulfuric Preserved; AV = Airfreight Unpreserved Vial SG = Sulfuric Preserved Amber Glass; H = HCl preserved Plastic; HS = HCl preserved Speciation bottle; SP = Sulfuric Preserved Plastic; F = Formaldehyde Preserved Glass;
Z = Zinc Acetate Preserved Bottle; E = EDTA Preserved Bottles; ST = Sterile Bottle; ASS = Plastic Bag for Acid Sulphate Soils; B = Unpreserved Bag; LI = Lugols Iodine Preserved Bottles; STT = Sterile Sodium Thiosulfate Preserved Bottles.

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Equipment Report – Eagle Multi-Gas Monitor

This Gas Meter has been performance checked and calibrated as follows:

Gas Channel	Cal Value	Zero (Filtered Fresh Air)	Span	Traceability Lot # Tolerance ± 5%
CH4	50 % LEL	0 % LEL	51 % LEL	863947
O2	18.0 % vol	20.9 % vol	18.0 % vol	
H2S	25 ppm	0.0 ppm	25.0 ppm	
CO	100 ppm	0 ppm	100 ppm	
CO2 (if fitted)	2.0 % vol	NF % vol	% vol	

☐ Battery Status ______________
☑ 10 minutes test complete
☑ ~~Electrical Safety Tag attached (AS/NZS 3760)~~

☑ In-Line filters checked
☑ Data cleared

Tag No: 000300 Valid to: 25/4/18

Date: 9/3/18 Checked by: Nat Brower

Signed:

Please check that the following items are received and that all items are cleaned and decontaminated before return. A minimum cleaning / service / repair charge may be applied to any unclean or damaged items. Items not returned will be billed for at the full replacement cost.

Sent	Returned	Item
☑	☐	Eagle Multi Gas detector Ops check
☑	☐	Liquid Inhibiting Probe with In-Line Filter
☐	☐	CO₂ Scrubber (When CO₂ channel fitted, use for zero calibration)
☑	☐	Carry Strap
☑	☐	Power Supply (Optional)
☑	☐	Spare Alkaline Batteries Qty 4
☐	☐	Spare In Line Filters Qty ____
☑	☐	Operating Manual
☐	☐	Quick Guide
☑	☐	Carry Case
☐	☐	______________________________

Date: 9/3/18 Signed:

TFS Reference		Return Date: / /
Customer Reference		Return Time:
Equipment ID	EAGSD	Condition on return:
Equipment Serial No.	E2B047	

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Phone: (Free Call) 1300 735 295		Fax: (Free Call) 1800 675 123		Email: RentalsAU@Thermofisher.com
Melbourne Branch 5 Caribbean Drive, Scoresby 3179	Sydney Branch Level 1, 4 Talavera Road, North Ryde 2113	Adelaide Branch 27 Beulah Road, Norwood, South Australia 5067	Brisbane Branch Unit 2/5 Ross St Newstead 4006	Perth Branch 121 Beringarra Ave Malaga WA 6090

RENTALS

Equipment Certification Report – TPS 90FLMV Water Quality Meter

This Water Quality Meter has been performance checked and calibrated as follows:

Sensor	Concentration	Span 1	Span 2	Traceability Lot #	Pass?
pH	pH 7.00 / pH 4.00	7.01 pH	4.00 pH	310933/312725	☑
Conductivity	12.88 mS/cm	12.91 µS/cm	mS/cm	306044	☑
Dissolved Oxygen	Sodium Sulphite / Air	0.01 ppm in Sodium Sulphite	8.91 ppm Saturation in Air	1705243881	☑

Check only

Redox (ORP) *	Zobell's Solution	229mV @25°C	235 mV	305343/310585	☑

* This meter uses an Ag/AgCl ORP electrode. To convert readings to SHE (Standard Hydrogen Electrode), add 199mV to the mV reading.

☑ Battery Status 8.0 (min 7.2V)
☐ Electrical Safety Tag attached (AS/NZS 3760)

☑ Temperature 21.0 °C
☑ Electrodes Cleaned and checked

Tag No: 006337

Valid to: 9/6/18

Date: 9/3/18

Signed:

Please check that the following items are received and that all items are cleaned and decontaminated before return. A minimum $30 cleaning / service / repair charge may be applied to any unclean or damaged items. Items not returned will be billed for at the full replacement cost.

Sent	Returned	Item
☑	☐	90FLMV Unit. Ops check/Battery status: 100%
☑	☐	pH sensor with wetting cap, 5m
☑	☐	Conductivity/TDS/Temperature K=10 sensor, 5m
☑	☐	Dissolved oxygen YSI5739 sensor with wetting cap, 5m
☑	☐	Redox (ORP) sensor with wetting cap, 5m
☑	☐	Power supply 240V to 12V DC 200mA
☑	☐	Instruction Manual
☑	☐	Quick Guide
☑	☐	Storage solution for pH and ORP sensors
☑	☐	Carry Case
☑	☐	Check to confirm electrical safety (tag must be valid)

Date: 9/3/18

Signed:

TFS Reference		Return Date: / /
Customer Reference		Return Time:
Equipment ID	90FLMVBM	Condition on return:
Equipment Serial No.		

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Equipment Report – Eagle Multi-Gas Monitor

This Gas Meter has been performance checked and calibrated as follows:

Gas Channel	Cal Value	Zero (Filtered Fresh Air)	Span	Traceability Lot # Tolerance ± 5%	Pass?
CH_4	50 % LEL 25 000 ppm	0.0 % LEL ppm	50 % LEL ppm	455051	☑
O_2	18.0 % vol	0.0 % vol	% vol		☑
CO	100 ppm	0.0 ppm	100 ppm	455051	☑
H_2S	25 ppm	0.0 ppm	25.5 ppm	808093	☑
CO_2 (if fitted)	4.0 % vol	% vol	% vol		☐

☑ Battery Status 5.4V

☑ 10 minutes test complete

☐ Electrical Safety Tag attached (AS/NZS 3760)

Tag No: ____________

Valid to: ____________

☑ In-Line filters checked

☐ Data cleared

Date: 12/2/18 Checked by: ROBERT

Signed: RB

Please check that the following items are received and that all items are cleaned and decontaminated before return. A minimum $30 cleaning / service / repair charge may be applied to any unclean or damaged items. Items not returned will be billed for at the full replacement cost.

Sent	Returned	Item
☑	☐	Eagle Multi Gas detector Ops check
☑	☐	Liquid Inhibiting Probe with In-Line Filter
☐	☐	CO_2 Scrubber (When CO_2 channel fitted, use for zero calibration)
☑	☐	Carry Strap
☐	☐	Power Supply (Optional)
☑	☐	Spare Alkaline Batteries Qty 8
☑	☐	Spare In Line Filters Qty 4
☑	☐	Operating Manual
☑	☐	Quick Guide
☑	☐	Carry Case
☐	☐	

Processors Signature ____________

Quote Reference		Condition on return
Customer Ref		
Equipment ID	EAGBA	
Equipment serial no.	E47029	
Return Date & Time	/ /	

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Equipment Certification Report - Impact Pro Multi-Gas Detector

This Gas Meter has been performance checked and calibrated as follows:

Sensor	Concentration	Zero	Span	Traceability Lot #	Pass?
O_2	Fresh Air	0.0 %	— %		☑
CO	100 ppm	0.0 ppm	100 ppm	198582	☑
H_2S	40 ppm	0.0 ppm	40 ppm	198582	☑
LEL	50 % CH_4	0.0 %	50 %	198582	☑

☑ Battery Status 100 %
☑ 10 minute test complete
☑ Electrical Safety Tag attached (AS/NZS 3760)

☑ Filters checked
☑ Spare Battery (Min 4.2 volts)
☑ Pump test

Tag No: 000318

Valid to: 18/4/18

Date: 7/2/18

Signed: RBLT

Please check that the following items are received and that all items are cleaned and decontaminated before return. A minimum $30 cleaning / service / repair charge may be applied to any unclean or damaged items. Items not returned will be billed for at the full replacement cost.

Sent	Returned	Item
☑	☐	Impact Pro Gas Detector
☑	☐	Performance check / Battery 100 %
☑	☐	Monitor setup for (Correction Factor) CH_4
☑	☐	Power supply 240/12v with base station
☑	☐	Flow adaptor (Grey) for calibration with hose
☑	☐	Pump adaptor (Black) with hose and Inline filter
☑	☐	Battery Cases with 4 Alkaline Batteries
☑	☐	Allen Key located back of Instrument to open battery
☑	☐	Spare inline filters 2
☑	☐	Instruction Manual behind foam on the lid of case
☑	☐	Quick Use Guide behind foam on the lid of case
☑	☐	Carry Case
☑	☐	Check to confirm electrical safety (tag must be valid)

Date: 7/2/8

Signed: RBLT

TFS Reference		Return Date: / /
Customer Reference		Return Time:
Equipment ID	IMPPRO-21	Condition on return:
Equipment Serial No.	ZEL1403839	

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Equipment Report – Eagle Multi-Gas Monitor

This Gas Meter has been performance checked and calibrated as follows:

Gas Channel	Cal Value	Zero (Filtered Fresh Air)	Span	Traceability Lot # Tolerance ± 5%	Pass?
CH_4	50% LEL 25000 ppm	0 % LEL ppm	51 % LEL ppm	845171	☑
O_2	18.0 % vol	0.0 % vol	18.0 % vol	845171	☑
H_2S	25 ppm	0 ppm	25.0 ppm	845171	☑
CO	100 ppm	0 ppm	98 ppm	845171	☑
CO_2 (if fitted)	2.0 % vol	% vol	% vol		☐

☑ Battery Status 5.4V
☑ 10 minutes test complete
☑ Electrical Safety Tag attached (AS/NZS 3760)

☑ In-Line filters checked
☐ Data cleared

Tag No: 000175/6

Valid to: 24/1/18

Date: 5/12/17 Checked by: ROBERT

Signed: RBLF

Please check that the following items are received and that all items are cleaned and decontaminated before return. A minimum $30 cleaning / service / repair charge may be applied to any unclean or damaged items. Items not returned will be billed for at the full replacement cost.

Sent	Returned	Item
☑	☐	Eagle Multi Gas detector Ops check
☑	☐	Liquid Inhibiting Probe with In-Line Filter
☐	☐	CO_2 Scrubber (When CO_2 channel fitted, use for zero calibration)
☑	☐	Carry Strap
☑	☐	Power Supply (Optional)
☑	☐	Spare Alkaline Batteries Qty 8
☑	☐	Spare In Line Filters Qty 3
☑	☐	Operating Manual
☑	☐	Quick Guide
☑	☐	Carry Case
☐	☐	

Processors Signature

Quote Reference		Condition on return
Customer Ref		
Equipment ID	EAGBB	
Equipment serial no.	E2A813	
Return Date & Time	/ /	

RENTALS

Equipment Certification Report - Impact Pro Multi-Gas Detector

This Gas Meter has been performance checked and calibrated as follows:

Sensor	Concentration	Zero	Span	Traceability Lot #	Pass?
O_2	Fresh Air	0.0 %	— %	198582	☐
CO	100 ppm	0 ppm	100 ppm	198582	☑
H_2S	40 ppm	0 ppm	40 ppm	198582	☑
LEL	50 % CH_4	0 %	50 %	198582	☑

☑ Battery Status 100 %
☐ 10 minute test complete
☑ Electrical Safety Tag attached (AS/NZS 3760)

☑ Filters checked
☑ Spare Battery (Min 4.2 volts)
☐ Pump test

Tag No: 000160

Valid to: 17/1/18

Date: 6/12/17

Signed: RB

Please check that the following items are received and that all items are cleaned and decontaminated before return. A minimum $30 cleaning / service / repair charge may be applied to any unclean or damaged items. Items not returned will be billed for at the full replacement cost.

Sent	Returned	Item
☑	☐	Impact Pro Gas Detector
☑	☐	Performance check / Battery 100 %
☑	☐	Monitor setup for (Correction Factor) CH_4
☑	☐	Power supply 240/12v with base station
☑	☐	Flow adaptor (Grey) for calibration with hose
☑	☐	Pump adaptor (Black) with hose and Inline filter
☑	☐	Battery Cases with 4 Alkaline Batteries
☑	☐	Allen Key located back of Instrument to open battery
☑	☐	Spare inline filters 2
☑	☐	Instruction Manual behind foam on the lid of case
☑	☐	Quick Use Guide behind foam on the lid of case
☑	☐	Carry Case
☑	☐	Check to confirm electrical safety (tag must be valid)

Date: 6/12/17

Signed: RB

TFS Reference		Return Date: / /
Customer Reference		Return Time:
Equipment ID	IMPPRO-21	Condition on return:
Equipment Serial No.	ZEL1403839	

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Rafter Radiocarbon

NZA 64884

R 41165/1

Job No: 209636

Report issued: 28 May 2018

Accelerator Mass Spectrometry Result

This result for the sample submitted is for the exclusive use of the submitter. All liability whatsoever to any third party is excluded.

Sample ID	Glenburnie 20
Description	Groundwater from monitoring bore
Fraction dated	Groundwater
Submitter	Ned Hamer Earth Search

Conventional Radiocarbon Age	**4752**	±	**41**	(years BP)
$\delta^{13}C$ (‰)	-14.8	±	0.2	from IRMS
Fraction modern	0.5534	±	0.0029	
$\Delta^{14}C$ (‰) and collection date	-451.1	±	2.8	16 Mar 2018

Measurement Comment

AMS measurement of this sample was performed at the Australian National University AMS facility. All preparation (pretreatment, combustion, graphitisation, target packing) and data reduction was performed at the Rafter facility in our usual way. The data quality meets our usual high standard, indicated by standard materials that agree with previous measurements of the same material made in our lab within one standard deviation.

Sample Treatment Details

The sample was submitted in a plastic frosted bottle with a white screw cap lid that was sealed with black tape. There was some dark sediment on the bottom of the bottle with no head space. Sample colour: colourless and odourless. CO2 was generated by phosphoric acid evolution, and carbonate content was 181.6 mgC/kgH2O, total dissolved inorganic carbon (TDIC) 15.1 mmol/kgH2O. Sample carbon dioxide was converted to graphite by reduction with hydrogen over iron catalyst.

Conventional Radiocarbon Age and $\Delta^{14}C$ are reported as defined by Stuiver and Polach (*Radiocarbon 19*:355-363, 1977). $\Delta^{14}C$ is reported only if collection date was supplied and is decay corrected to that date. Fraction modern (F) is the blank corrected fraction modern normalized to $\delta^{13}C$ of -25‰, defined by Donahue et al. (*Radiocarbon, 32*(2):135-142, 1990). $\delta^{13}C$ normalization is always performed using $\delta^{13}C$ measured by AMS, thus accounting for AMS fractionation. Although not used in the ^{14}C calculations, the environmental $\delta^{13}C$ measured offline by IRMS is reported if sufficient sample material was available. The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error based on the analysis of an ongoing series of measurements of standard materials. Further details of pretreatment and analysis are available on request.

Rafter Radiocarbon

Accelerator Mass Spectrometry Result

This result for the sample submitted is for the exclusive use of the submitter. All liability whatsoever to any third party is excluded.

NZA 64885

R 41165/2

Job No: 209637

Report issued: 28 May 2018

Sample ID	Longswamp 31
Description	Groundwater from monitoring bore
Fraction dated	Groundwater
Submitter	Ned Hamer Earth Search

Conventional Radiocarbon Age	**Modern**	±		(years BP)
$\delta^{13}C$ (‰)	-13.5	±	0.2	from IRMS
Fraction modern	1.0084	±	0.0032	
$\Delta^{14}C$ (‰) and collection date	0.2	±	3.2	16 Mar 2018

Measurement Comment

AMS measurement of this sample was performed at the Australian National University AMS facility. All preparation (pretreatment, combustion, graphitisation, target packing) and data reduction was performed at the Rafter facility in our usual way. The data quality meets our usual high standard, indicated by standard materials that agree with previous measurements of the same material made in our lab within one standard deviation.

Sample Treatment Details

The sample was submitted in a plastic frosted bottle with a white screw cap lid that was sealed with black tape. There was some dark sediment on the bottom of the bottle with no head space. Sample colour: colourless and odourless. CO2 was generated by phosphoric acid evolution, and carbonate content was 165.9 mgC/kgH2O, total dissolved inorganic carbon (TDIC) 13.8 mmol/kgH2O. Sample carbon dioxide was converted to graphite by reduction with hydrogen over iron catalyst.

Conventional Radiocarbon Age and $\Delta^{14}C$ are reported as defined by Stuiver and Polach (*Radiocarbon 19*:355-363, 1977). $\Delta^{14}C$ is reported only if collection date was supplied and is decay corrected to that date. Fraction modern (F) is the blank corrected fraction modern normalized to $\delta^{13}C$ of -25‰, defined by Donahue et al. (*Radiocarbon, 32*(2):135-142, 1990). $\delta^{13}C$ normalization is always performed using $\delta^{13}C$ measured by AMS, thus accounting for AMS fractionation. Although not used in the ^{14}C calculations, the environmental $\delta^{13}C$ measured offline by IRMS is reported if sufficient sample material was available. The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error based on the analysis of an ongoing series of measurements of standard materials. Further details of pretreatment and analysis are available on request.

Rafter Radiocarbon

NZA 64886

R 41165/3

Job No: 209638

Report issued: 28 May 2018

Accelerator Mass Spectrometry Result

This result for the sample submitted is for the exclusive use of the submitter. All liability whatsoever to any third party is excluded.

Sample ID	Lake Broadwater
Description	Surface water from Lake
Fraction dated	Water
Submitter	Ned Hamer Earth Search

Conventional Radiocarbon Age	**Modern**	±		(years BP)
$\delta^{13}C$ (‰)	-8.2	±	0.2	from IRMS
Fraction modern	1.0477	±	0.0034	
$\Delta^{14}C$ (‰) and collection date	39.1	±	3.4	16 Mar 2018

Measurement Comment

AMS measurement of this sample was performed at the Australian National University AMS facility. All preparation (pretreatment, combustion, graphitisation, target packing) and data reduction was performed at the Rafter facility in our usual way. The data quality meets our usual high standard, indicated by standard materials that agree with previous measurements of the same material made in our lab within one standard deviation.

Sample Treatment Details

The sample was submitted in a plastic frosted bottle with a white screw cap lid that was sealed with black tape. There was some dark sediment on the bottom of the bottle with no head space. Sample colour: pale cloudy brown and odourless. CO2 was generated by phosphoric acid evolution, and carbonate content was 13.2 mgC/kgH2O, total dissolved inorganic carbon (TDIC) 1.1 mmol/kgH2O. Sample carbon dioxide was converted to graphite by reduction with hydrogen over iron catalyst.

Conventional Radiocarbon Age and $\Delta^{14}C$ are reported as defined by Stuiver and Polach (*Radiocarbon 19*:355-363, 1977). $\Delta^{14}C$ is reported only if collection date was supplied and is decay corrected to that date. Fraction modern (F) is the blank corrected fraction modern normalized to $\delta^{13}C$ of -25‰, defined by Donahue et al. (*Radiocarbon, 32*(2):135-142, 1990). $\delta^{13}C$ normalization is always performed using $\delta^{13}C$ measured by AMS, thus accounting for AMS fractionation. Although not used in the ^{14}C calculations, the environmental $\delta^{13}C$ measured offline by IRMS is reported if sufficient sample material was available. The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error based on the analysis of an ongoing series of measurements of standard materials. Further details of pretreatment and analysis are available on request.

Rafter Radiocarbon

NZA 64887

R 41165/4

Job No: 209639

Report issued: 28 May 2018

Accelerator Mass Spectrometry Result

This result for the sample submitted is for the exclusive use of the submitter. All liability whatsoever to any third party is excluded.

Sample ID	Longswamp 35
Description	Groundwater from monitoring bore
Fraction dated	Groundwater
Submitter	Ned Hamer Earth Search

Conventional Radiocarbon Age	**421**	±	**26**	(years BP)
$\delta^{13}C$ (‰)	-14.0	±	0.2	from IRMS
Fraction modern	0.9490	±	0.0031	
$\Delta^{14}C$ (‰) and collection date	-58.8	±	3.1	17 Mar 2018

Measurement Comment

AMS measurement of this sample was performed at the Australian National University AMS facility. All preparation (pretreatment, combustion, graphitisation, target packing) and data reduction was performed at the Rafter facility in our usual way. The data quality meets our usual high standard, indicated by standard materials that agree with previous measurements of the same material made in our lab within one standard deviation.

Sample Treatment Details

The sample was submitted in a plastic frosted bottle stained a pale orange from sediment filled to about the 125 ml mark with head space. Head space comment: The bottle was half empty before the sampling was started. Sample colour: colourless and smells of dirt. CO2 was generated by phosphoric acid evolution, and carbonate content was 105.6 mgC/kgH2O, total dissolved inorganic carbon (TDIC) 8.8 mmol/kgH2O. Sample carbon dioxide was converted to graphite by reduction with hydrogen over iron catalyst.

Conventional Radiocarbon Age and $\Delta^{14}C$ are reported as defined by Stuiver and Polach (*Radiocarbon 19*:355-363, 1977). $\Delta^{14}C$ is reported only if collection date was supplied and is decay corrected to that date. Fraction modern (F) is the blank corrected fraction modern normalized to $\delta^{13}C$ of -25‰, defined by Donahue et al. (*Radiocarbon, 32*(2):135-142, 1990). $\delta^{13}C$ normalization is always performed using $\delta^{13}C$ measured by AMS, thus accounting for AMS fractionation. Although not used in the ^{14}C calculations, the environmental $\delta^{13}C$ measured offline by IRMS is reported if sufficient sample material was available. The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error based on the analysis of an ongoing series of measurements of standard materials. Further details of pretreatment and analysis are available on request.

Appendix D - Drilling Logs, Monitoring Bore Construction, and Core Photos

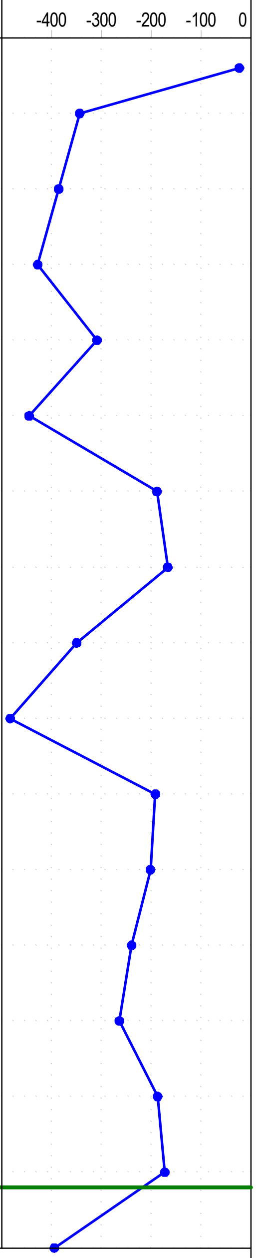
VERTICAL CORE HOLE LOG

Hole ID. **Glenburnie 20A**

Hole Depth: **30.00 m**
Sheet: **1 of 4**
Ground Level : **N/A**
Top of Casing : **N/A**
Easting: **312607**
Northing: **6919839**
Zone: **56J**
Checked By: **Ned Hamer 3/04/2018**

Project Name: **Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site: **on alluvial terrace above dry sandy creek, 2m North of immature River Red Gum**
Client: **Arrow Energy**
Drilling Company: **Numac Drilling**
Drill Method: **Sonic Drilling**
Logged By: **Ned Hamer 16/02/2018**

Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeabilty Sample Depth (m)	Soil Moisture Potential (psi)
			Silty SAND (SM) - light brown, fine to medium grained sand, poorly sorted, sub-angular to rounded, loose, dry. trace organic content. Less silt and organic content from 0.7m.				
		0.9	**SAND (SP)** - light brown, fine to medium grained sand, poorly sorted, sub-angular to rounded, loose, dry. <10% fines, collapsing hole.				
		1.5	**SAND (SP)** - medium brown with dark brown / orange iron oxide staining, fine to medium grained sand, poorly sorted, sub-angular to rounded, loose, moist. Very weakly indurated, seasonal water table fluctuation zone. Becoming dense, more indurated from 1.8m.				
		2.5	**SANDSTONE** - orange (iron stained), fine to coarse grained sand, poorly sorted, sub-angular to rounded quartz, moist. Very weak, alternating grey leached horizons and orange oxide-stained horizons, increasing grain size. Very moist to wet from 3.5m.		3.0m 0ppm (O2 20.9%) (H2S 0ppm) (CO 0ppm)		
		4.1	**Gravelly SANDSTONE** - cream to orange, fine to coarse grained sand, poorly sorted, sub-angular to rounded, moist to wet. 15% rounded siliceous gravel. Coarse grain dominating (80%), very weak (almost loose / friable).	Tree root in healed horizontal fracture or bedding plane at 5.4m. White clay rich halo around healed zone.			
		6.0	**SANDSTONE** - oxidised zones ranging from light orange to dark red / brown, fine to coarse grained sand, poorly sorted, sub-angular to rounded, moist. Becoming less gravelly, coarse grain dominating (80%), very weak to weak, rounded gravel clasts (<5%).	*CB20C: Fine tree root (1mm diameter) present at 10m lineal depth (7.6mbgl) in weathered sandstone. Very open xylem vessels apparent, with resin noted to be intact in some vessels.*	6.0m 0ppm		
				Maximum tree root depth observed at 7.6m.			



Water Level

▽ First Noted

▼ Stabilised

Notes

Vertical Core hole within pegged lease area 2m North of an immature River Red Gum on alluvial terrace above dry sandy creek. Suspended drilling at 27m, pumped water (drilling water or groundwater) from hole down to 10m SWL. Waited 30 minutes. Started at 9.58m, dipped 9.94m after 15 minutes, dipped 10.03 after after 30 minutes. Next run (27-28.5m) drilled without water, using water in hole already. Water evacuated when running out of hole. SWL 18mbgl after pull out of hole. Next run (28.5-30m) drilled without water. Water evacuated when running out of hole. SWL 18mbgl after reaching 30m TD. SWL 15mbgl 1.5 hours after drilling (rose from 18mbgl at end of drilling). SWL 14.8mbgl 3.5hours after drilling. SWL 14.4mbgl 21 hours after drilling (confined sub-artesian aquifer). From 22-30m the core was too broken during transport for permeability sample collection.

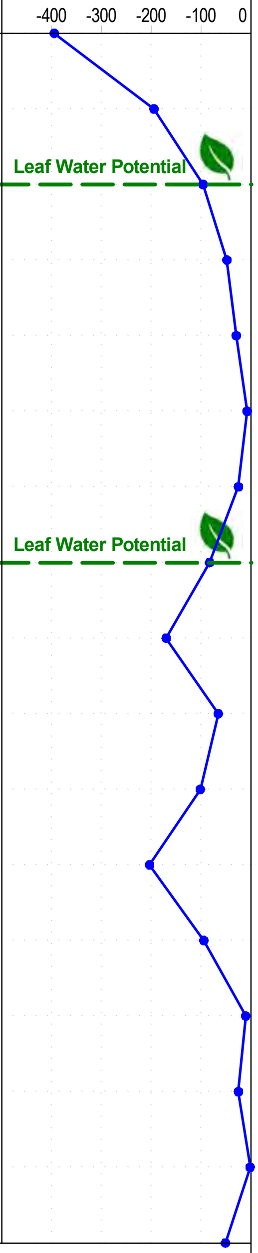
VERTICAL CORE HOLE LOG

Earth Search

Hole ID.	**Glenburnie 20A**
Hole Depth:	**30.00 m**
Sheet:	**2 of 4**
Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on alluvial terrace above dry sandy creek, 2m North of immature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 16/02/2018**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**312607**
Northing:	**6919839**
Zone:	**56J**
Checked By:	**Ned Hamer 3/04/2018**

Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeabilty Sample Depth (m)
		8.5	**SANDSTONE** - oxidised zones ranging from light orange to dark red / brown, fine to coarse grained sand, poorly sorted, sub-angular to rounded, moist. Becoming less gravelly, coarse grain dominating (80%), very weak to weak, rounded gravel clasts (<5%). Fining down and transitional change.			
		9.0	**SANDSTONE** - cream to light brown, fine to coarse grained sand, poorly sorted, sub-angular to rounded, moist. With moist brown siltstone interbeds.			
14.4m (from deep aquifer, rose for approx. 27m initial water strike)		11.5	**SANDSTONE** - light grey to dark grey, very fine to fine grained sand, moist to wet. Laminated, organic and lithic rich, 10% carbonaceous, 5% lithic grains, weak, 1mm to 150mm dark grey siltstone interbeds. Highly interbedded zone of siltstone to medium grained sandstone from 11.9 to 12.3m.		12.0m 0ppm (O2 20.9%) (H2S 0ppm) (CO 0ppm)	
		15.0	**SANDSTONE** - grey to light yellow (iron oxidised zone), very fine to medium grained sand, poorly sorted, sub-angular to rounded, moist. Abrupt increase in grain size, weak, some dark grey siltstone lenses (over-bank slump deposits).			15.5 - 15.7

Soil Moisture Potential (psi)



Water Level

▽ First Noted

▼ Stabilised

Notes

Vertical Core hole within pegged lease area 2m North of an immature River Red Gum on alluvial terrace above dry sandy creek. Suspended drilling at 27m, pumped water (drilling water or groundwater) from hole down to 10m SWL. Waited 30 minutes. Started at 9.58m, dipped 9.94m after 15 minutes, dipped 10.03 after after 30 minutes. Next run (27-28.5m) drilled without water, using water in hole already. Water evacuated when running out of hole. SWL 18mbgl after pull out of hole. Next run (28.5-30m) drilled without water. Water evacuated when running out of hole. SWL 18mbgl after reaching 30m TD. SWL 15mbgl 1.5 hours after drilling (rose from 18mbgl at end of drilling). SWL 14.8mbgl 3.5hours after drilling. SWL 14.4mbgl 21 hours after drilling (confined sub-artesian aquifer). From 22-30m the core was too broken during transport for permeability sample collection.

Earth Search

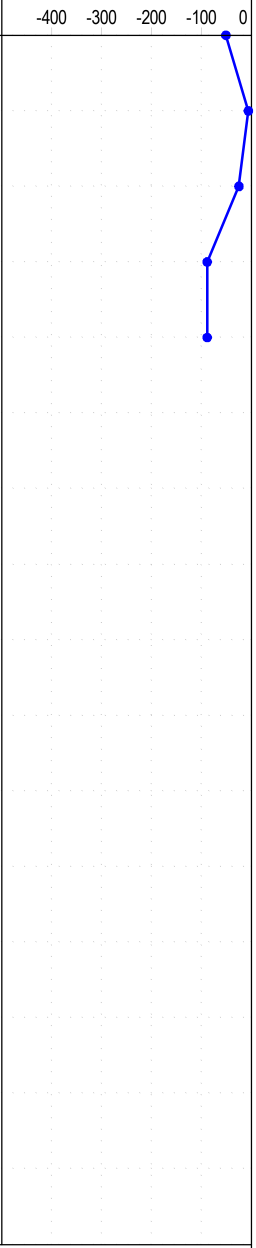
VERTICAL CORE HOLE LOG

Hole ID.	**Glenburnie 20A**
Hole Depth:	**30.00 m**
Sheet:	**3 of 4**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**312607**
Northing:	**6919839**
Zone:	**56J**
Checked By:	**Ned Hamer 3/04/2018**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on alluvial terrace above dry sandy creek, 2m North of immature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 16/02/2018**

Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeabilty Sample Depth (m)
			SANDSTONE - grey to light yellow (iron oxidised zone), very fine to medium grained sand, poorly sorted, sub-angular to rounded, moist. Abrupt increase in grain size, weak, some dark grey siltstone lenses (over-bank slump deposits).			
		17.1	**SANDSTONE** - grey, fine to medium grained sand, poorly sorted, sub-angular to rounded, moist. Predominantly quartzite, increase in organic content to a coal rich sandstone. Assortment of re-worked coal fragments and carbonaceous sandstone, up to 50% coal in some bands to 150mm thick, 15% lithics. Reduction in carbonaceous material lense from 18.9 to 19.2m.		18.0m 340ppm within coal 290ppm in hole	
		19.2	**SANDSTONE** - grey, wet. Massive, very limited core breaks.			
		22.3	**CONGLOMERATE** - grey, poorly sorted, sub-rounded to rounded. Sand and gravel (predominantly quartz to 15mm), weak, <5% coal fragments.			
		22.5	**SANDSTONE** - grey, fine to medium grained sand, poorly sorted, sub-angular to rounded, moist. Predominantly quartzose, increase in organic content to a coal rich sandstone. Assortment of re-worked coal fragments and carbonaceous sandstone, up to 50% coal in some bands to 150mm thick, 15% lithics, 5mm coal seam at 22.6m, thin discontinuous coal stringers to 3mm in sandstone. Decrease in grain size to silty sandstone, grey, weathered, clay rich, hard band of grey / green sandstone at 23.9m, very fine to fine		23.0m 0ppm (O2 20.9%) (H2S 0ppm) (CO 0ppm)	

Soil Moisture Potential (psi)



Water Level

▽	First Noted
▼	Stabilised

Notes

Vertical Core hole within pegged lease area 2m North of an immature River Red Gum on alluvial terrace above dry sandy creek. Suspended drilling at 27m, pumped water (drilling water or groundwater) from hole down to 10m SWL. Waited 30 minutes. Started at 9.58m, dipped 9.94m after 15 minutes, dipped 10.03 after after 30 minutes. Next run (27-28.5m) drilled without water, using water in hole already. Water evacuated when running out of hole. SWL 18mbgl after pull out of hole. Next run (28.5-30m) drilled without water. Water evacuated when running out of hole. SWL 18mbgl after reaching 30m TD. SWL 15mbgl 1.5 hours after drilling (rose from 18mbgl at end of drilling). SWL 14.8mbgl 3.5hours after drilling. SWL 14.4mbgl 21 hours after drilling (confined sub-artesian aquifer). From 22-30m the core was too broken during transport for permeability sample collection.

VERTICAL CORE HOLE LOG

Hole ID. **Glenburnie 20A**

Hole Depth: **30.00 m**
Sheet: **4 of 4**
Ground Level : **N/A**
Top of Casing : **N/A**
Easting: **312607**
Northing: **6919839**
Zone: **56J**
Checked By: **Ned Hamer 3/04/2018**

Project Name: **Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site: **on alluvial terrace above dry sandy creek, 2m North of immature River Red Gum**
Client: **Arrow Energy**
Drilling Company: **Numac Drilling**
Drill Method: **Sonic Drilling**
Logged By: **Ned Hamer 16/02/2018**

Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeabilty Sample Depth (m)	Soil Moisture Potential (psi) -400 -300 -200 -100 0
		24.0	grained.				
			SANDSTONE - grey, very fine to medium grained sand, poorly sorted, sub-angular to rounded. Massive, weak, inter-granular cement weathered to clay. Loss of core recovery between 24 & 27m (1.5m). Band of coal fines and black colour of water, likely coal loss..				
		25.0	**Gravelly SANDSTONE** - fine to medium grained sand, poorly sorted, sub-angular to rounded. Increase in grain size to coarse sandstone, 10% gravel to 40mm clasts, conglomerate bands with large bright coal fragments (to 15mm thickness). Given high energy setting, fragments are likely to be log inclusions in alluvium rather than coal seams.		26.0m 5ppm (O2 20.9%) (H2S 0ppm) (CO 0ppm)		
▽ 27m (approx. initial water strike in deeper aquifer, rose to 14.4m)		26.3	**SANDSTONE** - grey, very fine to medium grained sand, poorly sorted, sub-angular to rounded. Massive, weak, inter-granular cement weathered to clay.				
		27.3	**Carbonaceous SILTSTONE band** - brown. With some bright coal fragments and quartz sand.				
		27.5	**SANDSTONE** - grey, very fine to medium grained sand, poorly sorted, sub-angular to rounded. Massive, weak, inter-granular cement weathered to clay, medium grain dominates (<15%). Carbonaceous bands to 30mm thick from 28.1m, grey, softer, weaker. Stronger (less weathered) from 28.9m.		28.0m 20ppm (O2 20.9%) (H2S 0ppm) (CO 0ppm)		
		30.0	**SANDSTONE** - grey. Medium to high strength, quartzose, tightly cemented sandstone. **Terminated at 30.00 m** Target depth.		30.0m 70ppm		

Depth scale: 24.5, 25.0, 25.5, 26.0, 26.5, 27.0, 27.5, 28.0, 28.5, 29.0, 29.5, 30.0, 30.5, 31.0, 31.5, 32.0

Water Level

▽ First Noted

▼ Stabilised

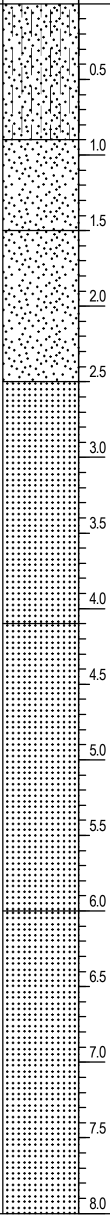
Notes

Vertical Core hole within pegged lease area 2m North of an immature River Red Gum on alluvial terrace above dry sandy creek. Suspended drilling at 27m, pumped water (drilling water or groundwater) from hole down to 10m SWL. Waited 30 minutes. Started at 9.58m, dipped 9.94m after 15 minutes, dipped 10.03 after after 30 minutes. Next run (27-28.5m) drilled without water, using water in hole already. Water evacuated when running out of hole. SWL 18mbgl after pull out of hole. Next run (28.5-30m) drilled without water. Water evacuated when running out of hole. SWL 18mbgl after reaching 30m TD. SWL 15mbgl 1.5 hours after drilling (rose from 18mbgl at end of drilling). SWL 14.8mbgl 3.5hours after drilling. SWL 14.4mbgl 21 hours after drilling (confined sub-artesian aquifer). From 22-30m the core was too broken during transport for permeability sample collection.

GROUNDWATER MONITORING BORE LOG

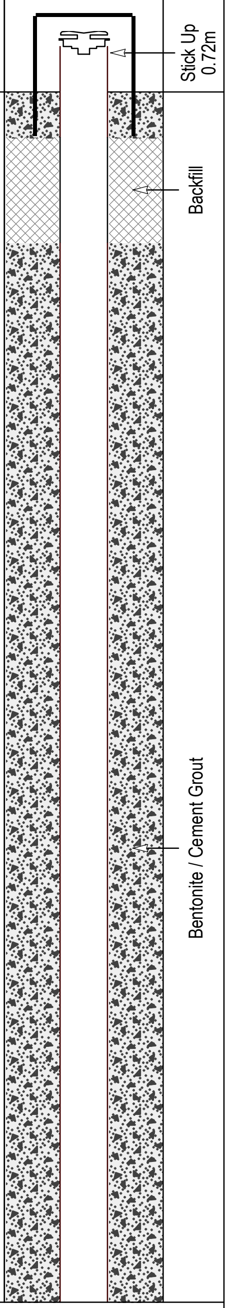
Earth Search

		Hole ID.	**Glenburnie 20B**
		Hole Depth:	**18.00 m**
		Sheet:	**1 of 3**
Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**	Ground Level :	**N/A**
Location / Site:	**on alluvial terrace above dry sandy creek, 2m North of immature River Red Gum**	Top of Casing :	**N/A**
Client:	**Arrow Energy**	Easting:	**312613**
Drilling Company:	**Numac Drilling**	Northing:	**6919838**
Drill Method:	**Sonic Drilling**	Zone:	**56J**
Logged By:	**Ned Hamer 17/02/2018**	Checked By:	**Ned Hamer 28/03/2018**



Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Methane Gas Log
			Silty SAND (SM) - light brown, fine to medium grained sand, poorly sorted, sub-angular to rounded, loose, dry. trace organic content. Less silt and organic content from 0.7m.	
		0.9	**SAND (SP)** - light brown, fine to medium grained sand, poorly sorted, sub-angular to rounded, loose, dry. <10% fines, collapsing hole.	
		1.5	**SAND (SP)** - medium brown with dark brown / orange iron oxide staining, fine to medium grained sand, poorly sorted, sub-angular to rounded, loose, moist. Very weakly indurated, seasonal water table fluctuation zone. Becoming dense, more indurated from 1.8m.	
		2.5	**SANDSTONE** - orange (iron stained), fine to coarse grained sand, poorly sorted, sub-angular to rounded quartz, moist. Very weak, alternating grey leached horizons and orange oxide-stained horizons, increasing grain size. Very moist to wet from 3.5m.	
		4.1	**Gravelly SANDSTONE** - cream to orange, fine to coarse grained sand, poorly sorted, sub-angular to rounded, moist to wet. 15% rounded siliceous gravel. Coarse grain dominating (80%), very weak (almost loose / friable).	6.0m 460ppm (O2 20.9%) (H2S 0ppm) (CO 0ppm)
		6.0	**SANDSTONE** - oxidised zones ranging from light orange to dark red / brown, fine to coarse grained sand, poorly sorted, sub-angular to rounded, moist. Becoming less gravelly, coarse grain dominating (80%), very weak to weak, rounded gravel clasts (<5%).	

Bore with Lockable Monument



Water Level

▽ First Noted

▼ Stabilised

Notes

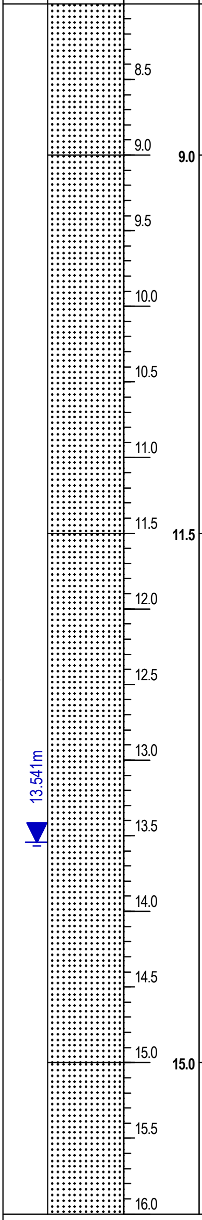
Vertical Core hole within pegged lease area 2m North of an immature River Red Gum on alluvial terrace above dry sandy creek.
Drilled without water. Drilled to 6m collected samples for soil moisture and isotope analysis. Stopped drilling at 6m. Left hole open for 35 minutes, dry. Dry prior to recommencing. Drilled further to 12.3m. Stopped and left for 1 hour, measured dry. Drilled to 18m (maximum tree rooting depth) left overnight. Next day 18/2/18 SWL measured at 17.7m. 0.3m of water in open bore. Tape 'flick' test suggested seepage at 11-18m which matched soil moisture potential measurements.
50mm Ø Class 18 PVC with 1mm factory slotted screen. Graded and wash 2mm filter pack.

GROUNDWATER MONITORING BORE LOG

Hole ID. **Glenburnie 20B**

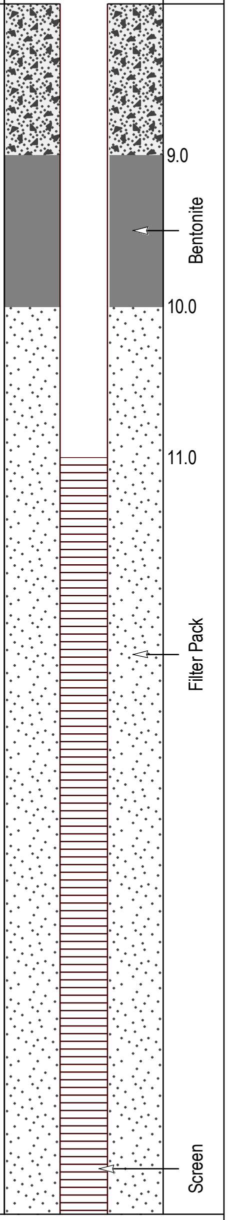
Hole Depth:	**18.00 m**
Sheet:	**2 of 3**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**312613**
Northing:	**6919838**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on alluvial terrace above dry sandy creek, 2m North of immature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 17/02/2018**



Depth (mbgl)	Material Description	Methane Gas Log
	SANDSTONE - oxidised zones ranging from light orange to dark red / brown, fine to coarse grained sand, poorly sorted, sub-angular to rounded, moist. Becoming less gravelly, coarse grain dominating (80%), very weak to weak, rounded gravel clasts (<5%). Fining down and transitional change.	
9.0	**SANDSTONE** - cream to light brown, fine to coarse grained sand, poorly sorted, sub-angular to rounded, moist. With moist brown siltstone interbeds.	
11.5	**SANDSTONE** - light grey to dark grey, very fine to fine grained sand, moist to wet. Laminated, organic and lithic rich, 10% carbonaceous, 5% lithic grains, weak, 1mm to 150mm dark grey siltstone interbeds. Highly interbedded zone of siltstone to medium grained sandstone from 11.9 to 12.3m.	12.3m 750ppm (O_2 20.9%) (H_2S 0ppm) (CO 0ppm)
15.0	**SANDSTONE** - grey to light yellow (iron oxidised zone), very fine to medium grained sand, poorly sorted, sub-angular to rounded, moist. Abrupt increase in grain size, weak, some dark grey siltstone lenses (over-bank slump deposits).	

Bore with Lockable Monument



Water Level

- ▽ First Noted
- ▼ Stabilised

Notes

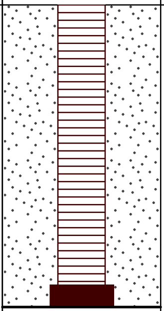
Vertical Core hole within pegged lease area 2m North of an immature River Red Gum on alluvial terrace above dry sandy creek.
Drilled without water. Drilled to 6m collected samples for soil moisture and isotope analysis. Stopped drilling at 6m. Left hole open for 35 minutes, dry. Dry prior to recommencing. Drilled further to 12.3m. Stopped and left for 1 hour, measured dry. Drilled to 18m (maximum tree rooting depth) left overnight. Next day 18/2/18 SWL measured at 17.7m. 0.3m of water in open bore. Tape 'flick' test suggested seepage at 11-18m which matched soil moisture potential measurements.
50mm Ø Class 18 PVC with 1mm factory slotted screen. Graded and wash 2mm filter pack.

GROUNDWATER MONITORING BORE LOG

Hole ID.	**Glenburnie 20B**
Hole Depth:	**18.00 m**
Sheet:	**3 of 3**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**312613**
Northing:	**6919838**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on alluvial terrace above dry sandy creek, 2m North of immature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 17/02/2018**

Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Methane Gas Log	Bore with Lockable Monument
▽ 17.7m (Initial water observation)	▨	16.5 17.0 17.1	**SANDSTONE** - grey to light yellow (iron oxidised zone), very fine to medium grained sand, poorly sorted, sub-angular to rounded, moist. Abrupt increase in grain size, weak, some dark grey siltstone lenses (over-bank slump deposits).		
	▨	17.5 18.0	**SANDSTONE** - grey, fine to medium grained sand, poorly sorted, sub-angular to rounded, moist. Predominantly quartzite, increase in organic content to a coal rich sandstone. Assortment of re-worked coal fragments and carbonaceous sandstone, up to 50% coal in some bands to 150mm thick, 15% lithics.		
		18.5 19.0 19.5 20.0 20.5 21.0 21.5 22.0 22.5 23.0 23.5 24.0	**Terminated at 18.00 m** Target depth.		



Water Level

▽ First Noted

▼ Stabilised

Notes

Vertical Core hole within pegged lease area 2m North of an immature River Red Gum on alluvial terrace above dry sandy creek.
Drilled without water. Drilled to 6m collected samples for soil moisture and isotope analysis. Stopped drilling at 6m. Left hole open for 35 minutes, dry. Dry prior to recommencing. Drilled further to 12.3m. Stopped and left for 1 hour, measured dry. Drilled to 18m (maximum tree rooting depth) left overnight. Next day 18/2/18 SWL measured at 17.7m. 0.3m of water in open bore. Tape 'flick' test suggested seepage at 11-18m which matched soil moisture potential measurements.
50mm Ø Class 18 PVC with 1mm factory slotted screen. Graded and wash 2mm filter pack.

ANGLED CORE HOLE LOG

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**	Hole ID.	**Glenburnie 20C**
Location / Site:	**on alluvial terrace above dry sandy creek, 2m North of immature River Red Gum**	Hole Depth:	**13.50 m**
Client:	**Arrow Energy**	Sheet:	**1 of 1**
Drilling Company:	**Numac Drilling**	Ground Level :	**N/A**
Drill Method:	**Sonic Drilling**	Top of Casing :	**N/A**
Logged By:	**Ned Hamer 17/02/2018**	Easting:	**312611**
		Northing:	**6919845**
		Zone:	**56J**
		Checked By:	**Ned Hamer 28/03/2018**

Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Tree Root Observations
		1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0	**See Glenburnie 20A Log for lithology description**.	Fine tree root (1mm diameter) present at 10m lineal depth (7.6mbgl) in weathered sandstone. Very open xylem vessels apparent, with resin noted to be intact in some vessels.
		11.0 12.0 13.0		**Maximum tree root depth observed at 10m lineal depth.**
		14.0 15.0	**Terminated at 13.50 m** Target depth.	

Water Level	Notes
▽ First Noted ▼ Stabilised	Cored at 50° angle to intersect target depth of 11m depth beneath tree at 13.5m drilled length.

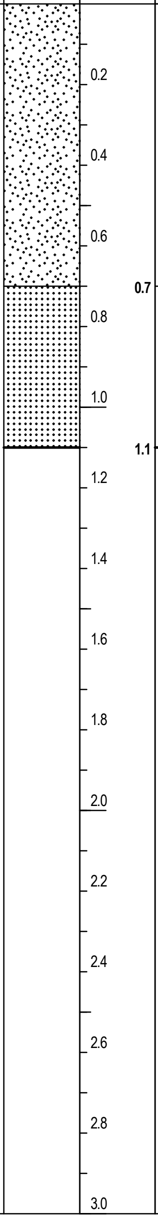
Earth Search

HAND AUGER LOG

Hole ID. **Glenburnie 20HA**

Hole Depth:	**1.10 m**
Sheet:	**1 of 1**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**312588**
Northing:	**6919816**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**in dry creek bed on cross section**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Hand Auger**
Logged By:	**Ned Hamer 18/02/2018**



Depth (mbgl)	Material Description
	SAND (SP) - light brown, medium to coarse grained, poorly sorted, sub-angular to rounded, loose, moist. With occasional rounded quartz gravel, approximate 10% fines. Moist from recent rainfall (was dry 2 days ago). ALLUVIUM.. Increasing grain size down hole from 0.4m, coarse grained dominant (75%), moist.
0.7	**SANDSTONE** - orange / brown mottled (iron stained), poorly sorted, sub-angular to rounded. Weakly cemented, becoming slightly stronger. Moist, seasonal perched water table zone. Dryer from 0.9m, more strongly cemented. Increase in fines content to 15%.
1.1	**Terminated at 1.10 m** Refusal in weathered sandstone bedrock.

Water Level

▽ First Noted

▼ Stabilised

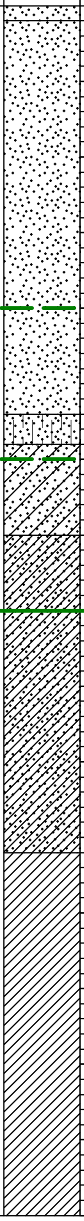
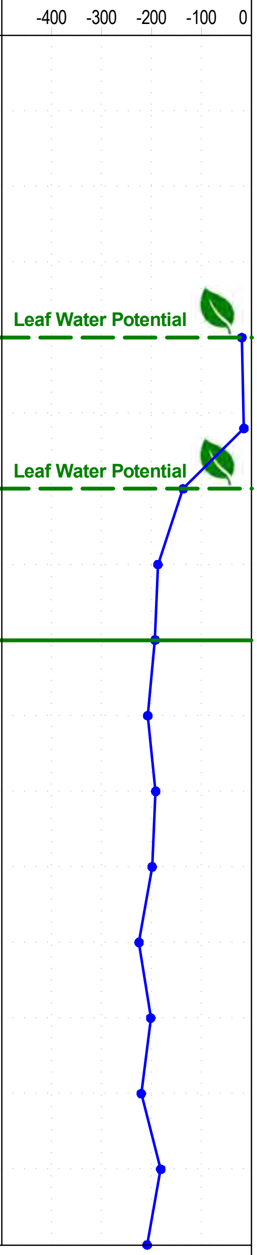
Notes

VERTICAL CORE HOLE LOG

Earth Search

Hole ID.	**Longswamp 31A**
Hole Depth:	**21.00 m**
Sheet:	**1 of 3**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**311629**
Northing:	**6974083**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on sandy shore of lake broadwater adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 14/02/2018**

Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeability Sample Depth (m)	Soil Moisture Potential (psi)
		0.1	**LEAF LITTER and SAND (SP)**. Organic rich.	*LS31B: Tree roots noted throughout upper 3m profile.*			
▽			**SAND (SP)** - cream to light brown, medium to coarse grained sand, poorly sorted, sub-angular to rounded, loose, dry. Predominantly quartz, moist from 0.2m. Wet becoming saturated at 1.8m. Abrupt change to....	Abundant fibrous root material recorded in loose sand at 2.6m. 1mm tree root on sand / clay interface at 2.9m.			
		2.7	**Silty SAND (SP)** - grey with green mottling, low plasticity, dense.				
		2.9	**Clayey SAND (SC)** - light orange (iron) mottling, medium plasticity, dense, moist.		3.0m 0ppm (O2 20.9%) (H2S 0ppm) (CO 0ppm)		
		3.5	**Sandy CLAY (CH)** - grey, orange mottling, high plasticity, moist. Reduction in sand content, transitional change to sandy clay. Iron nodule at 4m.	Thin (1-2mm) tree roots recorded in fissured sandy clay at 4m. **Maximum tree root depth observed at 4m.**		4.2 - 4.4	
		5.6	**CLAY (CL)** - grey, moist. Reduction in sand content to <15% (lean clay), some sandier horizons with depth (<10%).				

Water Level

▽ First Noted

▼ Stabilised

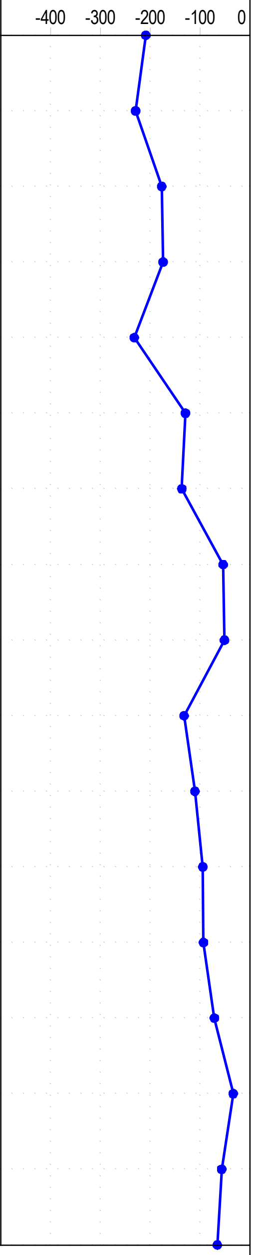
Notes

VERTICAL CORE HOLE LOG

Hole ID. **Longswamp 31A**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on sandy shore of lake broadwater adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 14/02/2018**

Hole Depth:	**21.00 m**
Sheet:	**2 of 3**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**311629**
Northing:	**6974083**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeability Sample Depth (m)	Soil Moisture Potential (psi)
	▨	8.5 9.0 9.5 10.0 10.5 11.0	**CLAY (CL)** - grey, moist. Reduction in sand content to <15% (lean clay), some sandier horizons with depth (<10%). Becoming sandier at 10.8m, medium brown, moist.		9.0m 0ppm (O2 20.9%) (H2S 0ppm) (CO 0ppm)	8.0 - 8.2 10.3 - 10.5	
	▨	11.3 11.5 12.0 12.5	**Clayey SAND (SC)** - fine to medium grained sand, poorly sorted, sub-angular to rounded, dense, moist. Transitional change to clayey sand, quartz sand. With thin (2-5mm) bands of very weathered coal or alluvial charcoal at 11.5-11.8m. Moist to wet at 11.8m.		12.0m 0ppm (O2 20.9%) (H2S 0ppm) (CO 0ppm)		
	▨	12.9 13.0 13.5 14.0	**Sandy CLAY (CL)** - grey, medium plasticity, fine to medium grained sand, poorly sorted, sub-rounded to sub-angular, moist. Transitions to clay at 14.1m.				
	▨	14.1 14.5	**CLAY (CH)** - grey, high plasticity, moist. <10% medium grained sand.				
	▨	14.9 15.0 15.5 16.0	**Sandy CLAY (CL)** - grey, medium plasticity, fine to medium grained sand, poorly sorted, sub-rounded to sub-angular, moist. Clayey sand bands with orange / brown (iron) mottling at 15.2m, some iron nodules (dark orange / red) rounded to 15mm diameter.				

Water Level

▽ First Noted

▼ Stabilised

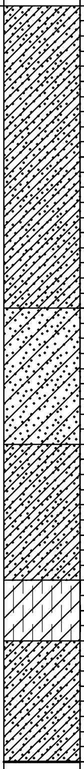
Notes

VERTICAL CORE HOLE LOG

Hole ID. **Longswamp 31A**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on sandy shore of lake broadwater adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 14/02/2018**

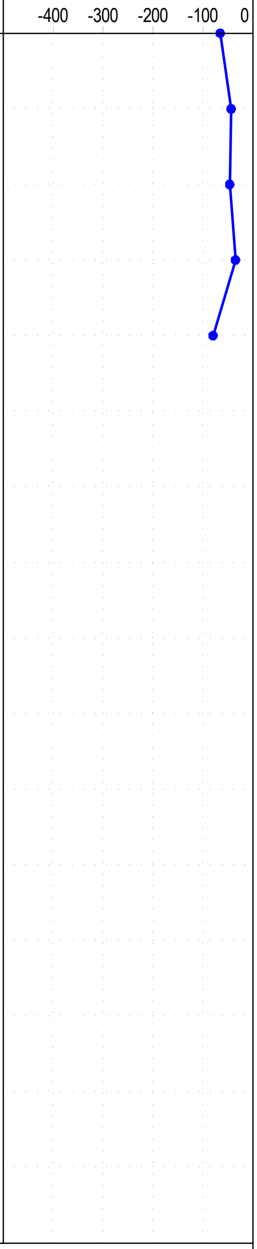
Hole Depth:	**21.00 m**
Sheet:	**3 of 3**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**311629**
Northing:	**6974083**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**



Water (mbgl)	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeability Sample Depth (m)
		Sandy CLAY (CL) - grey, medium plasticity, fine to medium grained sand, poorly sorted, sub-rounded to sub-angular, moist.			
▽	18.0	**Clayey SAND (SC)** - brown, fine to medium grained sand, poorly sorted, sub-rounded to sub-angular, dense, sat'd. Predominantly quartz.		18.0m 0ppm	
	18.9	**Sandy CLAY (CL)** - brown, with iron (orange) mottling, medium plasticity, fine to medium grained sand, poorly sorted, sub-rounded to sub-angular, moist.			
	19.8	**Sandy Clayey SILT (ML)** - orange / yellow / grey, low plasticity, moist.			
	20.2	**Sandy CLAY (CL)** - brown, with iron (orange) mottling, medium plasticity, fine to medium grained sand, poorly sorted, sub-rounded to sub-angular, moist.			20.4 - 20.6
	21.0	**Terminated at 21.00 m** Target depth.			

Depth scale: 16.5, 17.0, 17.5, 18.0, 18.5, 19.0, 19.5, 20.0, 20.5, 21.0, 21.5, 22.0, 22.5, 23.0, 23.5, 24.0

Soil Moisture Potential (psi)



Water Level

▽ First Noted

▼ Stabilised

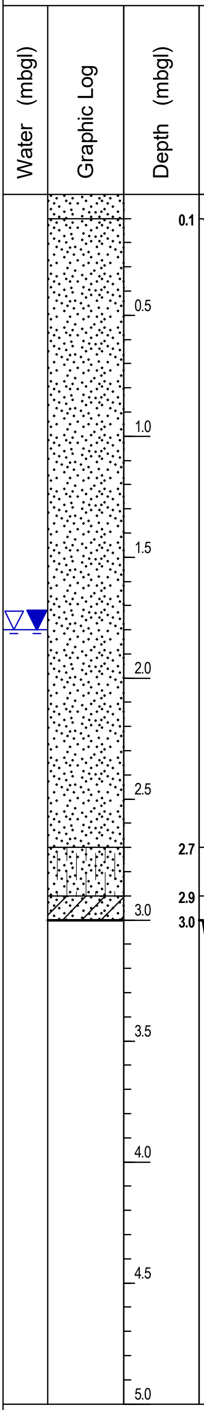
Notes

GROUNDWATER MONITORING BORE LOG

Hole ID. **Longswamp 31B**

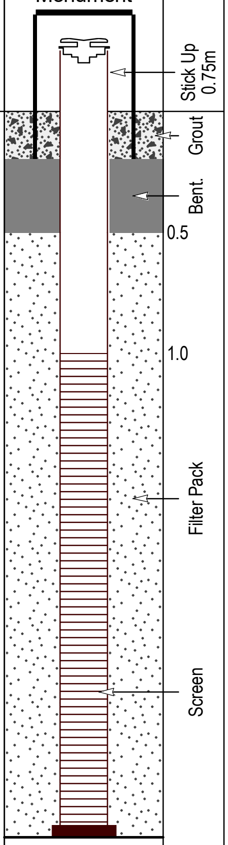
Hole Depth:	**3.00 m**
Sheet:	**1 of 1**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**311624**
Northing:	**6974081**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on sandy shore of lake broadwater approx. 5m West of mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 15/02/2018**



Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log
	LEAF LITTER and SAND (SP). Organic rich.		
0.1	**SAND (SP)** - cream to light brown, medium to coarse grained sand, poorly sorted, sub-angular to rounded, loose, dry. Predominantly quartz, moist from 0.2m. Wet becoming saturated at 1.8m. Abrupt change to....	Tree roots noted throughout upper 3m profile.	
2.7	**Silty SAND (SP)** - grey with green mottling, low plasticity, dense.		
2.9	**Clayey SAND (SC)** - light orange (iron) mottling, medium plasticity, dense, moist.		3.0m 0ppm
3.0	**Terminated at 3.00 m** Target depth.		

Bore with Lockable Monument



Water Level

▽ First Noted

▼ Stabilised

Notes

Located the 4 corners of lease from permit survey plan. Drilled at the location as determined in the survey plan, approximately 5m west of mature River Red Gum on the sandy shore of Lake Broadwater.

Hole initially drilled without water but repeatedly collapsed at 2-2.5m depth due to saturated sands. Therefore had to run in casing to clay at 3m.

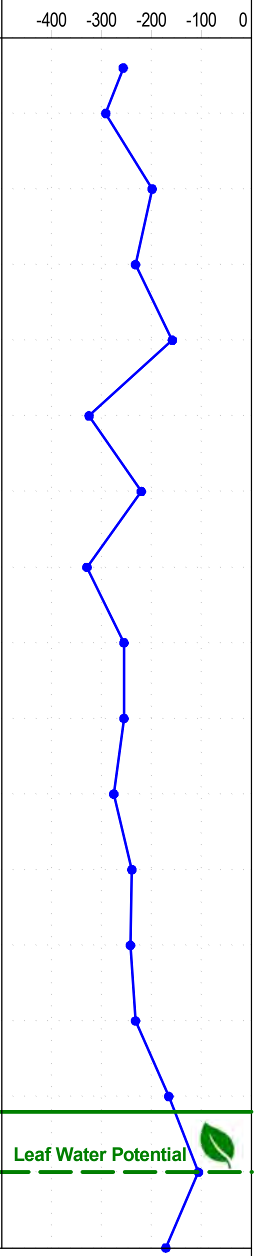
100mm Ø Class 18 PVC with 1mm factory slotted screen. Graded and wash 2mm filter pack.

VERTICAL CORE HOLE LOG

Hole ID. **Longswamp 35A**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**in Longswamp adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 9/12/2017 - 10/12/2017**
Hole Depth:	**30.00 m**
Sheet:	**1 of 4**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**311390**
Northing:	**6982223**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Water (mbgl)	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeabilty Sample Depth (m)
		Silty CLAY (CL) - dark grey, low to medium plasticity, firm. Highly fissured with open cavities filled with balls of rounded clay "clay pebbles" at 0.25-0.35m.	*LS35B: Tree roots noted throughout upper 3.5m profile.* Tree root occupied full diameter of core barrel (110mm) at 0.1-0.25m. *LS35C: 5mm trace root at 0.75m lineal depth (0.65mbgl)*		
	1.3	**Sandy Clayey SILT (ML)** - fine to medium grained sand, poorly sorted, sub-rounded to rounded, moist. Increasing sand content, less fissured.	1mm fine tree root at 1.2m. *LS35C: 1-3mm tree root at 1.9m lineal depth (1.6mbgl).* *LS35C: 1-3mm tree root at 2.3m lineal depth (2mbgl).*		
	2.1	**Clayey Silty SAND (SM)** - grey / brown, minor orange iron staining, fine to medium grained sand, poorly sorted, sub-angular to rounded quartz sand, non friable, moist. Dense sand in clay matrix. Clay lined fissured zone 20mm wide with "clay pebbles" at 2.1-2.4m.		3.0m 0ppm 13:15 0ppm	2.6 - 2.8
	3.8	**Clayey Silty SAND (SM)** - brown with grey / green mottling, fine to medium grained sand, poorly sorted, sub-angular to rounded quartz sand, moist. Dense sand in clay matrix.	1.5mm root with oxidised halo at 5.5m.		5.7 - 5.9
	5.8	**Sandy Clayey SILT (ML)** - brown with grey & orange mottling, low plasticity, stiff. Increasing sand content with depth.		6.0m 40ppm (0 upwind)	
	6.3	**Clayey Silty SAND (SM)** - grey / brown, fine to medium grained sand, poorly sorted, sub-angular to rounded, dense, moist to wet. Bands of medium dense to dense sub-rounded to rounded. Some gravelly sand bands moist to wet at 7.1-7.4m.	*LS35C: 1.5mm diameter tree root at 7.7m lineal depth (6.67mbgl).* *LS35C: Large fibrous root material in fissure at 8.2m lineal depth (7.1mbgl).*		
			Maximum tree root depth observed at 7.1m.	8.0m 20ppm	7.6 - 7.8



Water Level

▽ First Noted

▼ Stabilised

Notes

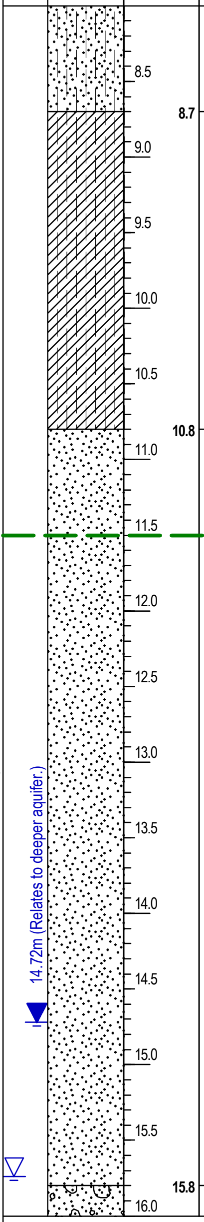
Day 1 end at 14.8m. Day 2 dipped bore at 14.7m prior to drilling ahead, no water.
Collapsed back to 16m after 1st run to 18m. Dipped bore immediately after removing barrel. Water strike at 15.74mbgl.
Waited 15 minutes at 17.8m. Water rose from 15.74m to 15.71m and stabilised.
Hole collapsed back to 16m.
Ran casing to 16m.
Lower hole (below 16m) drilled without water. Water struck at approximately 26.5m and rose to stabilised at 14.72mbgl.
Collapsed back to 23m. Drilled with casing to 30m.
EOH at 30m. SWL 14.72mbgl for deeper aquifer.

VERTICAL CORE HOLE LOG

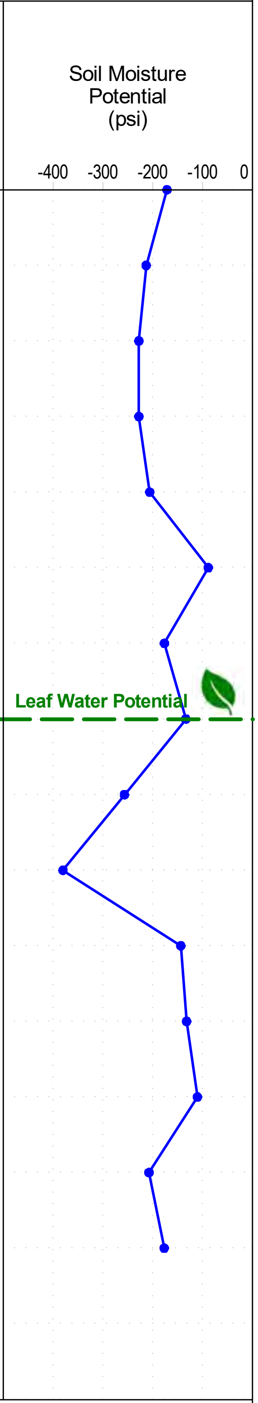
Earth Search

Hole ID.	**Longswamp 35A**
Hole Depth:	**30.00 m**
Sheet:	**2 of 4**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**311390**
Northing:	**6982223**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**in Longswamp adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 9/12/2017 - 10/12/2017**



Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeabilty Sample Depth (m)
			(0 upwind)	
8.7	**Bands of Sandy Silty CLAY & Sandy Clayey SILT (CL)** - grey with brown mottling, low plasticity. Inclusions of white powdery mineral.		10.0m 1200ppm (0 upwind)	
10.8	**SAND (SP)** - light brown with orange mottling, fine to medium grained, poorly sorted, sub-angular to rounded quartz sand, loose to medium dense. Lenses of stiff grey silty clay. Increasing sand grain size to fine to coarse. Medium dense at 11.7m. 5% sub-rounded to rounded gravel at 12.6m. Coarsening down hole, gravel 5-10% with some to 5mm. Increasing grain size and moisture content, moist to wet.		13.0m 1150ppm (40 upwind) 15.0m 0ppm	
15.8	*(see next page)*			



Water Level

▽	First Noted
▼	Stabilised

Notes

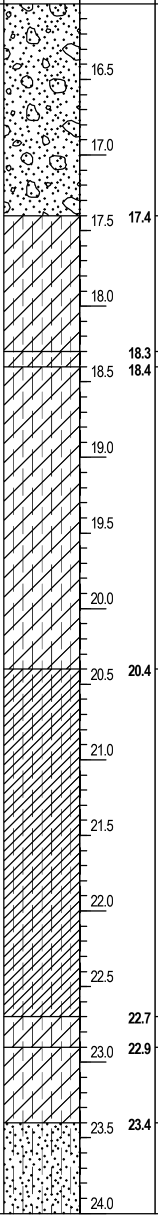
Day 1 end at 14.8m. Day 2 dipped bore at 14.7m prior to drilling ahead, no water.
Collapsed back to 16m after 1st run to 18m. Dipped bore immediately after removing barrel. Water strike at 15.74mbgl.
Waited 15 minutes at 17.8m. Water rose from 15.74m to 15.71m and stabilised.
Hole collapsed back to 16m.
Ran casing to 16m.
Lower hole (below 16m) drilled without water. Water struck at approximately 26.5m and rose to stabilised at 14.72mbgl.
Collapsed back to 23m. Drilled with casing to 30m.
EOH at 30m. SWL 14.72mbgl for deeper aquifer.

VERTICAL CORE HOLE LOG

Hole ID. **Longswamp 35A**

Hole Depth: **30.00 m**
Sheet: **3 of 4**
Ground Level : **N/A**
Top of Casing : **N/A**
Easting: **311390**
Northing: **6982223**
Zone: **56J**
Checked By: **Ned Hamer 28/03/2018**

Project Name: **Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site: **in Longswamp adjacent to mature River Red Gum**
Client: **Arrow Energy**
Drilling Company: **Numac Drilling**
Drill Method: **Sonic Drilling**
Logged By: **Ned Hamer 9/12/2017 - 10/12/2017**



Water (mbgl)	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeability Sample Depth (m)	Soil Moisture Potential (psi) -400 -300 -200 -100 0
		Silty Gravelly SAND (SP) - light brown, fine to coarse grained sand, poorly sorted, sub-angular to rounded, medium dense to dense. Gravel 5-10% up to 15mm clasts. Increasing fines content at 17.2m.		16.0m 15ppm		
	17.4	**Clayey SILT (ML)** - brown, medium plasticity, firm to stiff, wet to moist. Occasional fine sand interbedded with silty clay and sandy silty clay.		18.0m 480ppm	17.6 - 17.8	
	18.3	**Gravelly Clayey SILT (ML)** - brown, medium plasticity, stiff, moist to wet.				
	18.4	**Clayey SILT, trace Gravel (ML)** - brown, medium plasticity, stiff, moist to wet.			19.8 - 20.0	
	20.4	**Gravelly Silty CLAY (CL)** - brown, medium plasticity, sub-angular to sub-rounded gravel, poorly sorted, stiff, moist to wet.			22.6 - 22.8	
	22.7	**Clayey SILT, trace Gravel (ML)** - brown, medium plasticity, stiff, moist to wet.				
	22.9	**Sandy Clayey SILT (ML)** - brown, medium plasticity, very fine to fine grained sand, well sorted, sub-rounded to sub-angular quartz, stiff, moist to wet. Increasing sand content.			23.3 - 23.5	
	23.4	**Clayey Silty SAND (SM)** - brown, very fine to fine grained sand, well sorted, sub-angular to sub-rounded, dense, wet. Clay bound sand, 70% sand, 30% clay and silt, increasing				

Water Level
▽ First Noted
▼ Stabilised

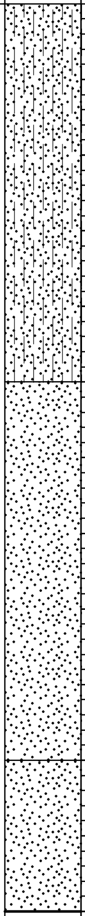
Notes
Day 1 end at 14.8m. Day 2 dipped bore at 14.7m prior to drilling ahead, no water.
Collapsed back to 16m after 1st run to 18m. Dipped bore immediately after removing barrel. Water strike at 15.74mbgl.
Waited 15 minutes at 17.8m. Water rose from 15.74m to 15.71m and stabilised.
Hole collapsed back to 16m.
Ran casing to 16m.
Lower hole (below 16m) drilled without water. Water struck at approximately 26.5m and rose to stabilised at 14.72mbgl.
Collapsed back to 23m. Drilled with casing to 30m.
EOH at 30m. SWL 14.72mbgl for deeper aquifer.

VERTICAL CORE HOLE LOG

Earth Search

Hole ID.	**Longswamp 35A**
Hole Depth:	**30.00 m**
Sheet:	**4 of 4**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**311390**
Northing:	**6982223**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**in Longswamp adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 9/12/2017 - 10/12/2017**



Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeabilty Sample Depth (m)	Soil Moisture Potential (psi) -400 -300 -200 -100 0
		24.5 25.0 25.5 26.0	grain size. Fine to medium grained sand from 23.9m, wet, uniform fine silt sand sequence. **Clayey Silty SAND (SM)** - brown, very fine to fine grained sand, well sorted, sub-angular to sub-rounded, dense, wet. Clay bound sand, 70% sand, 30% clay and silt, increasing grain size.		24.0m 140ppm		
▽ 26.5m (Deeper aquifer water strike. Rose to 14.72m)		**26.5** 27.0 27.5 28.0 28.5	**SAND (SP)** - brown, fine to medium grained sand, poorly sorted, sub-angular to sub-rounded, loose to medium dense, saturated. Decreasing fines, 5-10% silt. Pockets of silty clay, saturated.		27.0m 680ppm		
		29.0 29.5	**SAND (SP)** - brown, fine to coarse grained sand, poorly sorted, sub-angular to sub-rounded, medium dense, saturated. Increasing in grain size, some loose coarse beds.				
		30.0 30.5 31.0 31.5 32.0	**Terminated at 30.00 m** Target depth.		30.0m 1000ppm (CO 12ppm)		

Water Level

▽ First Noted

▼ Stabilised

Notes

Day 1 end at 14.8m. Day 2 dipped bore at 14.7m prior to drilling ahead, no water.
Collapsed back to 16m after 1st run to 18m. Dipped bore immediately after removing barrel. Water strike at 15.74mbgl.
Waited 15 minutes at 17.8m. Water rose from 15.74m to 15.71m and stabilised.
Hole collapsed back to 16m.
Ran casing to 16m.
Lower hole (below 16m) drilled without water. Water struck at approximately 26.5m and rose to stabilised at 14.72mbgl.
Collapsed back to 23m. Drilled with casing to 30m.
EOH at 30m. SWL 14.72mbgl for deeper aquifer.

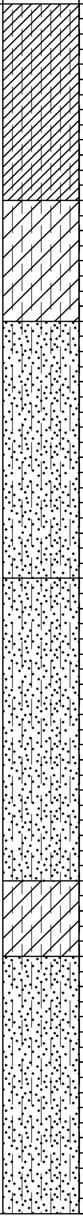
Earth Search

GROUNDWATER MONITORING BORE LOG

Hole ID. **Longswamp 35B**

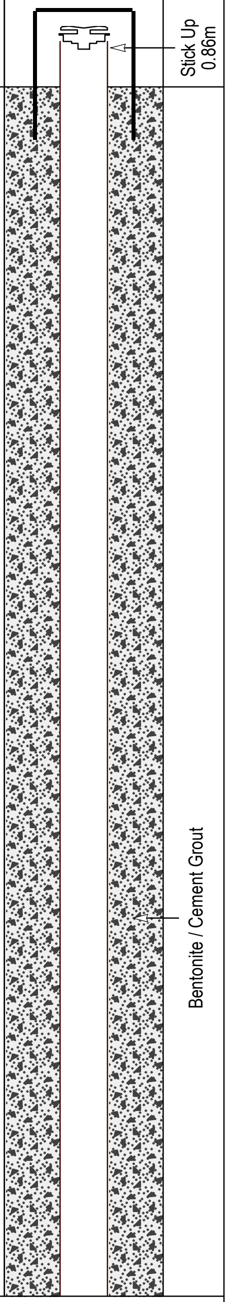
Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**in Longswamp adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 10/12/2017 - 11/12/2017**

Hole Depth:	**18.00 m**
Sheet:	**1 of 3**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**311388**
Northing:	**6982222**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**



Water (mbgl)	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log
		Silty CLAY (CL) - dark grey, low to medium plasticity, firm. Highly fissured with open cavities filled with balls of rounded clay "clay pebbles" at 0.25-0.35m.	Tree roots noted throughout upper 3.5m profile.	
	1.3	**Sandy Clayey SILT (ML)** - fine to medium grained sand, poorly sorted, sub-rounded to rounded, moist. Increasing sand content, less fissured.		
	2.1	**Clayey Silty SAND (SM)** - grey / brown, minor orange iron staining, fine to medium grained sand, poorly sorted, sub-angular to rounded quartz sand, non friable, moist. Dense sand in clay matrix. Clay lined fissured zone 20mm wide with "clay pebbles" at 2.1-2.4m.		
	3.8	**Clayey Silty SAND (SM)** - brown with grey / green mottling, fine to medium grained sand, poorly sorted, sub-angular to rounded quartz sand, moist. Dense sand in clay matrix.		
	5.8	**Sandy Clayey SILT (ML)** - brown with grey & orange mottling, low plasticity, stiff. Increasing sand content with depth.		6.0m 3800ppm (CO 147ppm)
	6.3	**Clayey Silty SAND (SM)** - grey / brown, fine to medium grained sand, poorly sorted, sub-angular to rounded, dense, moist to wet. Bands of medium dense to dense sub-rounded to rounded. Some gravelly sand bands moist to wet at 7.1-7.4m.		

Bore with Lockable Monument



Water Level

▽ First Noted

▼ Stabilised

Notes

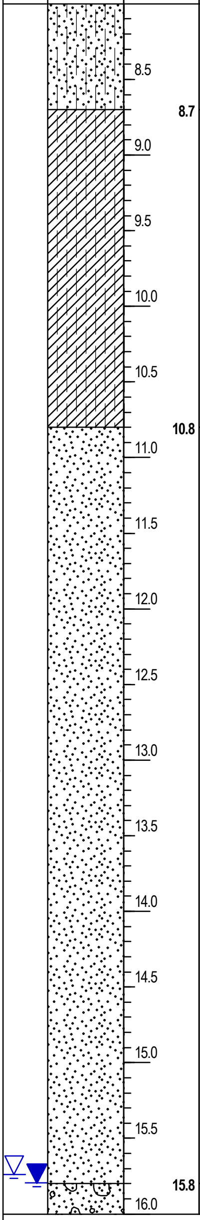
Set up on hole 14:00 10/12/2017.
11/12/2017 ran casing to 18m. Constructed Monitoring Bore.
100mm Ø Class 18 PVC with 1mm factory slotted screen. Graded and wash 2mm filter pack.

GROUNDWATER MONITORING BORE LOG

Earth Search

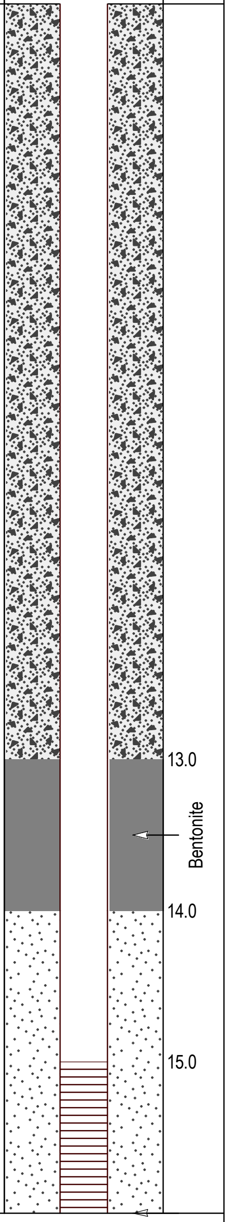
Hole ID.	**Longswamp 35B**
Hole Depth:	**18.00 m**
Sheet:	**2 of 3**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**311388**
Northing:	**6982222**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**in Longswamp adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 10/12/2017 - 11/12/2017**



Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log
	Clayey Silty SAND (SM) - grey / brown, fine to medium grained sand, poorly sorted, sub-angular to rounded, dense, moist to wet. Bands of medium dense to dense sub-rounded to rounded. Some gravelly sand bands moist to wet at 7.1-7.4m.		
8.7	**Bands of Sandy Silty CLAY & Sandy Clayey SILT (CL)** - grey with brown mottling, low plasticity. Inclusions of white powdery mineral.		9.0m (LEL 1%) (CO 21ppm)
10.8	**SAND (SP)** - light brown with orange mottling, fine to medium grained, poorly sorted, sub-angular to rounded quartz sand, loose to medium dense. Lenses of stiff grey silty clay.		
	Increasing sand grain size to fine to coarse. Medium dense at 11.7m.		
	5% sub-rounded to rounded gravel at 12.6m.		
	Coarsening down hole, gravel 5-10% with some to 5mm.		
	Increasing grain size and moisture content, moist to wet.		15.0m 760ppm (CO 0ppm)
15.8	*(see next page)*		

Bore with Lockable Monument



Water Level

▽ First Noted

▼ Stabilised

Notes

Set up on hole 14:00 10/12/2017.
11/12/2017 ran casing to 18m. Constructed Monitoring Bore.
100mm Ø Class 18 PVC with 1mm factory slotted screen. Graded and wash 2mm filter pack.

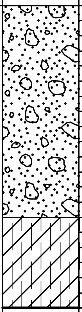
GROUNDWATER MONITORING BORE LOG

Earth Search

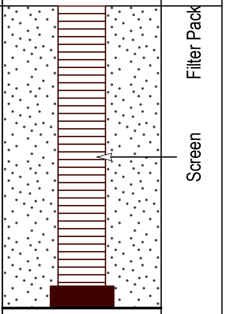
Hole ID. **Longswamp 35B**

Hole Depth:	**18.00 m**
Sheet:	**3 of 3**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**311388**
Northing:	**6982222**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**in Longswamp adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 10/12/2017 - 11/12/2017**



Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Bore with Lockable Monument
		16.5 17.0	**Silty Gravelly SAND (SP)** - light brown, fine to coarse grained sand, poorly sorted, sub-angular to rounded, medium dense to dense. Gravel 5-10% up to 15mm clasts. Increasing fines content at 17.2m.			
		17.4 17.5	**Clayey SILT (ML)** - brown, medium plasticity, firm to stiff, wet to moist. Occasional fine sand interbedded with silty clay and sandy silty clay.			
		18.0 18.5 19.0 19.5 20.0 20.5 21.0 21.5 22.0 22.5 23.0 23.5 24.0	**Terminated at 18.00 m** Target depth.			



Water Level

▽ First Noted

▼ Stabilised

Notes

Set up on hole 14:00 10/12/2017.
11/12/2017 ran casing to 18m. Constructed Monitoring Bore.
100mm Ø Class 18 PVC with 1mm factory slotted screen. Graded and wash 2mm filter pack.

ANGLED CORE HOLE LOG

Hole ID. **Longswamp 35C**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**in Longswamp adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 11/12/2017**

Hole Depth:	**18.30 m**
Sheet:	**1 of 2**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**311390**
Northing:	**6982229**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log
			Silty CLAY (CL) - dark grey, low to medium plasticity, firm, moist. Highly fissured with fissure openings to 30mmwith rounded clay balls.	5mm trace root at 0.75m lineal depth (0.65mbgl). 1-3mm tree root at 1.9m lineal depth (1.6mbgl).	1.0m 0ppm (CO 0ppm)
		1.9	**Sandy Clayey SILT (ML)** - green / brown mottling, moist. Increasing sand content to 40%. Brown from 2.8m, decrease in sand content (to 20%).	1-3mm tree root at 2.3m lineal depth (2mbgl).	840ppm in fissures within recovered core 3.0m 240ppm (CO 0ppm)
		4.7	**Clayey Silty SAND (SM)** - brown, 60% fine to medium grained sand, poorly sorted, sub-angular to sub-rounded, dense, moist. Interbeds of low plasticity firm clay and silt.		6.0m 250ppm (CO 0ppm)
		6.2	**Clayey Sandy SILT (ML)** - brown, low plasticity, 15% fine to medium grained sand, poorly sorted, sub-angular to sub-rounded quartz, stiff, moist.	1.5mm diameter tree root at 7.7m lineal depth (6.67mbgl).	
		6.9	**Clayey Silty SAND (SM)** - brown, light orange mottling, 75% fine to medium grained sand, poorly sorted, sub-angular to sub-rounded, dense, moist. Cemented with clay. Increased sand content to 85% at 7.4m, light brown, moist. Sand becoming loose and friable at 8m, increasing grained size with 10% coarse grains.	Large fibrous root material in fissure at 8.2m lineal depth (7.1mbgl).	
			Increased sand content to 85% at 8.5m, light brown, moist.	**Maximum tree root depth observed at 8.2m lineal depth.**	9.0m 1450ppm (CO 29ppm)
		10.9	**Clayey Sandy SILT (ML)** - brown, low plasticity, stiff, moist. Increasing silt content, decreasing sand content.		
		11.5	**Silty SAND (SM)** - brown, with bands of orange iron staining, fine to coarse grained sand, poorly sorted, sub-angular to sub-rounded quartz, dense. Bands of grey silt and clay.		

Water Level

▽ First Noted

▼ Stabilised

Notes

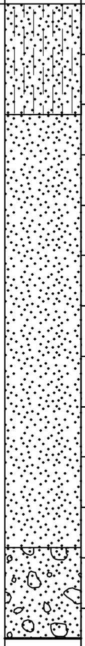
Cored at 60° angle to intersect target depth of 15.5m depth beneath tree at 17.3m drilled length.
Depths are along hole not true vertical depth.

ANGLED CORE HOLE LOG

Hole ID. **Longswamp 35C**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**in Longswamp adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Ned Hamer 11/12/2017**

Hole Depth:	**18.30 m**
Sheet:	**2 of 2**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**311390**
Northing:	**6982229**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**



Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log
			Silty SAND (SM) - brown, with bands of orange iron staining, fine to coarse grained sand, poorly sorted, sub-angular to sub-rounded quartz, dense. Bands of grey silt and clay.		
		13.0	Increasing sand content to 85% at 13.1m, no iron staining, occasional quartz gravel, loose to medium dense, 2-20mm bands of grey clayey silt, moist.		
		14.0			
		15.0	Increasing grain size, no clayey silt bands from 15.3m, sand is fine to coarse grained..		
		16.0			
		17.0			
		17.4	**Gravelly SAND (SP)** - brown, fine to coarse grained sand, poorly sorted, sub-angular to rounded, dense. Gravel to 20mm.		
		18.0	Lightly cemented at 18.3m.		18.0m 700ppm
		18.3	**Terminated at 18.30 m** Target depth beneath tree.		
		19.0			
		20.0			
		21.0			
		22.0			
		23.0			
		24.0			

Water Level

▽ First Noted

▼ Stabilised

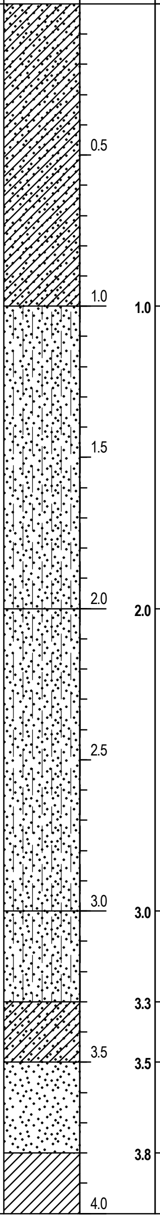
Notes

Cored at 60° angle to intersect target depth of 15.5m depth beneath tree at 17.3m drilled length.
Depths are along hole not true vertical depth.

VERTICAL CORE HOLE LOG

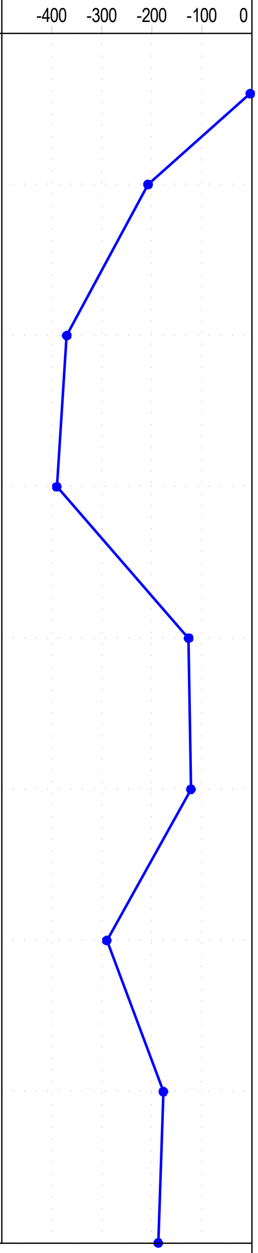
Hole ID. **Burunga Lane 182A**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on alluvial terrace above dry sandy creek, adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Grant Asser 13/12/2017**
Hole Depth:	**14.50 m**
Sheet:	**1 of 4**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**204875**
Northing:	**7094139**
Zone:	**56J**
Checked By:	**Ned Hamer 3/04/2018**



Water (mbgl)	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeabilty Sample Depth (m)
		Sandy CLAY / LOAM (CL) - dark brown, low plasticity, dry to moist. Clay, silt and very fine grained sand.			
	1.0	**Silty SAND / Sandy LOAM (SM)** - mid brown, medium dense, dry to moist. Silt and very fine grained sand.			
	2.0	**Silty SAND (SM)** - light brown, medium dense, dry to moist. Silt to fine grained sand grading to off white silty sand (silt to course grained sand, poorly sorted, sub-angular to sub-rounded) at 3m.			
	3.0	**Silty SAND (SM)** - mid brown, medium dense, dry to moist. Silt to medium grained sand, poorly sorted, sub-angular to sub-rounded.			
	3.3	**Sandy CLAY (CL)** - off white, low plasticity, moist. Clay-occasional course grains.			
	3.5	**SAND (SP)** - light brown, medium dense, dry to moist. Predominantly fine grained, poorly sorted, sub angular - sub rounded with occasional rounded gravels to 30mm.	*BL182C: occasional organic fragments (tree roots) 3.5-4m.*		3.5 - 3.7
	3.8	**CLAY (CL)** - grey and grey / brown, medium plasticity, moist. With occasional sandier lenses.	Abundant tree roots 3.8-4.5m.		

Soil Moisture Potential (psi)



Water Level

▽ First Noted

▼ Stabilised

Notes

Small amounts of water used to lubricate sonic barrel and for running casing.
Borehole was grouted to surface with a bentonite / cement grout mix.

VERTICAL CORE HOLE LOG

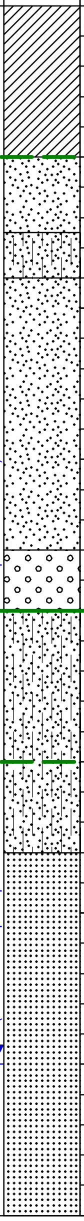
Hole ID. **Burunga Lane 182A**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on alluvial terrace above dry sandy creek, adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Grant Asser 13/12/2017**

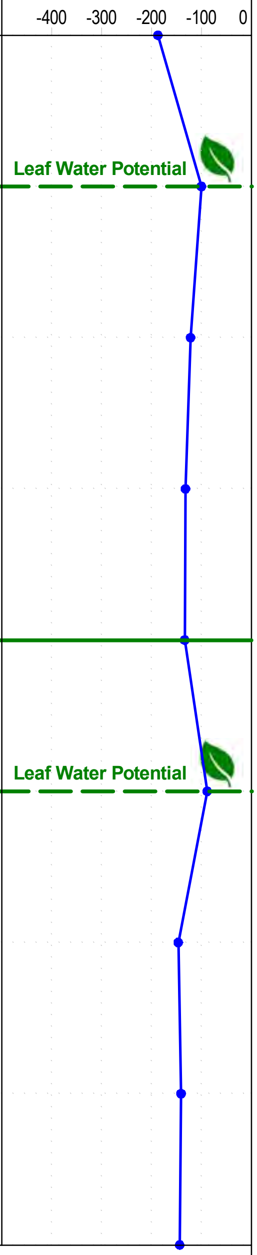
Hole Depth:	**14.50 m**
Sheet:	**2 of 4**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**204875**
Northing:	**7094139**
Zone:	**56J**
Checked By:	**Ned Hamer 3/04/2018**

Water (mbgl)	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeabilty Sample Depth (m)
		CLAY (CL) - grey and grey / brown, medium plasticity, moist. With occasional sandier lenses.	*BL182C: large fibrous root material (20mm width) in clay fissure at 4m.* Abundant tree roots 3.8-4.5m.		
	4.5	**SAND (SP)** - light brown, medium dense, moist. Quartz rich, sub-rounded to rounded, silt to medium grained, predominantly fine.		4.5m 660ppm	
	4.8	**Silty SAND (SM)** - light brown, medium dense, moist. Predominantly fine grained, but poorly sorted, sub-angular to sub-rounded.			
	4.9	**SAND (SP)** - light brown & light red, medium dense, moist. Silt to medium, predominantly fine, angular to sub-rounded. Occasional bands of more quartz rich coarser sand. Coarsening downhole and likely transitioning into completely weathered conglomerate.	*BL182C: 2mm tree root in moist clayey sand at 5m.* *BL182D: 2mm thick tree roots intersected at 6.5m lineal depth (5.7mbgl).*		
▽ (Possible water strike or seep)	5.8	**CONGLOMERATE** - grey / red. Conglomeratic mix of indurated sands, gravels and thin red clay layers. Sands and gravels fine to coarse quartz, poorly sorted, predominantly sub-rounded to rounded, occasional angular grains.	*BL182B: tree root at 6m.*		
	6.0	**Silty SAND (SM)** - light grey, dense, moist. Silt to fine grained, poorly sorted, sub-angular to sub-rounded, occasional grey and tan coloured mottling. Likely completely weathered sandstone.	**Maximum tree root depth observed at 6m.**	6.0m 880ppm	
	6.8	**SANDSTONE** - light grey. Silty sandstone (silt to fine grained, poorly sorted, sub-angular to sub-rounded). Occasional iron rich bands and off white and brown silt lenses, highly weathered, extremely low strength.			
▼ 7.5 (Relates to deeper aquifer water strike at 13.5m. Rose under sub-artesian pressure to 7.5m)					

Graphic Log



Soil Moisture Potential (psi)



Water Level

▽ First Noted

▼ Stabilised

Notes

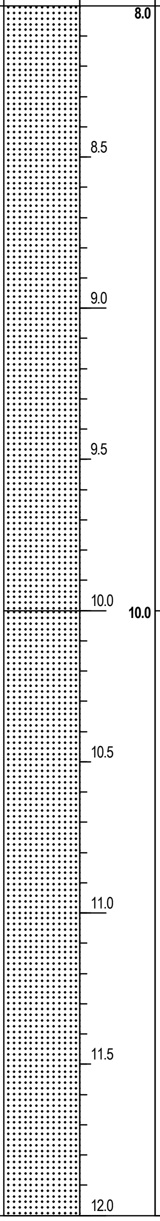
Small amounts of water used to lubricate sonic barrel and for running casing.
Borehole was grouted to surface with a bentonite / cement grout mix.

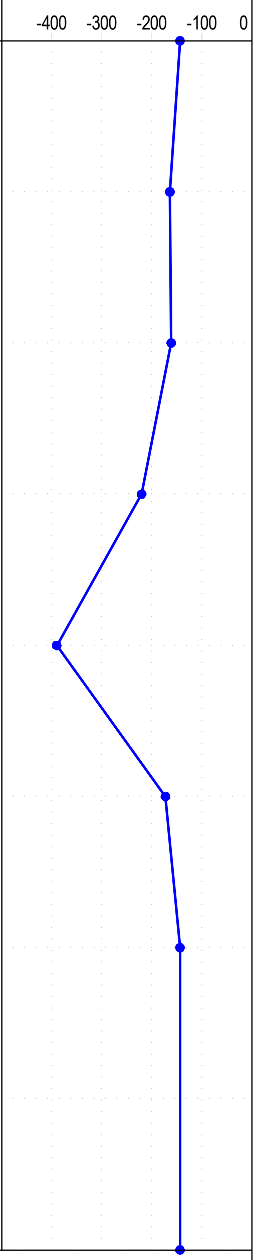
VERTICAL CORE HOLE LOG

Hole ID. **Burunga Lane 182A**

Hole Depth:	**14.50 m**
Sheet:	**3 of 4**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**204875**
Northing:	**7094139**
Zone:	**56J**
Checked By:	**Ned Hamer 3/04/2018**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on alluvial terrace above dry sandy creek, adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Grant Asser 13/12/2017**





Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeabilty Sample Depth (m)	Soil Moisture Potential (psi)
		8.0	**SANDSTONE** - light grey. Silty sandstone (silt to fine grained, poorly sorted, sub-angular to sub-rounded), highly weathered, extremely low strength.				
		8.5				8.4 - 8.6	
		9.0				9.2 - 9.0	
		10.0	**SANDSTONE** - light grey. Silty sandstone (silt to fine grained, poorly sorted). Increasing carbonaceous and weathered coal layers, highly weathered, extremely low strength.		10.0m 900ppm		
		10.5				10.4 - 10.6	
		11.5				11.6 - 11.7	

Water Level

▽ First Noted

▼ Stabilised

Notes

Small amounts of water used to lubricate sonic barrel and for running casing.
Borehole was grouted to surface with a bentonite / cement grout mix.

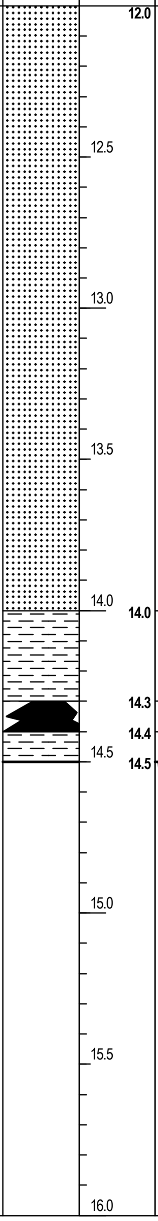
Earth Search

VERTICAL CORE HOLE LOG

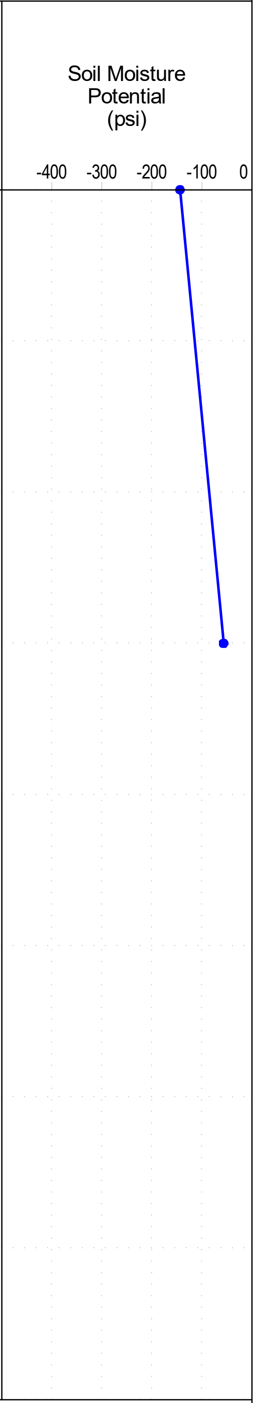
Hole ID. **Burunga Lane 182A**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on alluvial terrace above dry sandy creek, adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Grant Asser 13/12/2017**

Hole Depth:	**14.50 m**
Sheet:	**4 of 4**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**204875**
Northing:	**7094139**
Zone:	**56J**
Checked By:	**Ned Hamer 3/04/2018**



Water (mbgl)	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log	Permeability Sample Depth (m)
(Rose under sub-artesian pressure to 7.5m)	12.0	**SANDSTONE** - grey, moist to wet. silty sandstone (silt to fine, poorly sorted, sub-angular to sub-rounded) with thin weathered coal seams (to 40mm) and grey plastic clay layers, highly weathered, extremely low strength.			
▽	13.5	Becoming saturated at around 13.5m.			
	14.0	**SILTSTONE / CLAY** - grey. Highly weathered siltstone - weathered to a plastic clay.		14.0m 1000ppm	
	14.3	**COAL** - dark brown / black, saturated. Coal seam, weathered at boundaries, inferred low rank with high non-organic content.			
	14.4	**SILTSTONE / CLAY** - grey. Highly weathered siltstone - weathered to a plastic clay.			
	14.5	**Terminated at 14.50 m** Target depth.			



Water Level

▽ First Noted

▼ Stabilised

Notes

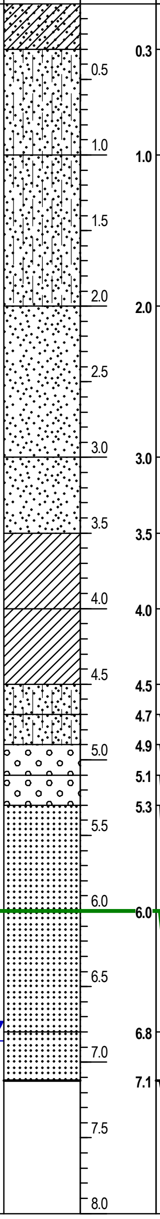
Small amounts of water used to lubricate sonic barrel and for running casing.
Borehole was grouted to surface with a bentonite / cement grout mix.

GROUNDWATER MONITORING BORE LOG

Hole ID. **Burunga Lane 182B**

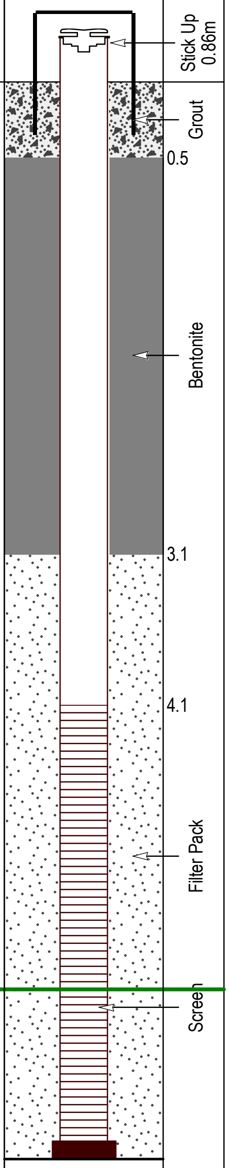
Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on alluvial terrace above dry sandy creek, adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Grant Asser 14/12/2017**

Hole Depth:	**7.12 m**
Sheet:	**1 of 1**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**204879**
Northing:	**7094137**
Zone:	**56J**
Checked By:	**Ned Hamer 3/04/2018**



Water (mbgl)	Depth (mbgl)	Material Description	Tree Root Observations	Methane Gas Log
		Sandy CLAY / LOAM (CL) - grey / brown. Clay, silt and very fine grained sand.		
	0.3	**Silty SAND / Sandy LOAM (SM)** - grey / brown. Silt - fine grained sand.		
	1.0	**Silty SAND (SM)** - light brown. Silt to fine grained sand. Increasing sand component and lighter in colour at 2m.		
	2.0	**SAND (SP)** - light brown. Silt to medium grained sand, predominately fine, with occasional gravel lenses (gravel 1mm-20mm angular to sub-rounded).		
	3.0	**SAND (SP)** - light brown. Silt to medium grained sand, predominantly fine. Grading to almost white at 3m.		
	3.5	**CLAY (CL)** - grey. With occasional organic fragments (tree roots).		
	4.0	**CLAY (CL)** - grey. With increasing organic fragments and some calcite?.		
	4.5	**Silty SAND (SM)** - grey / brown. Silt to fine grained, predominantly very fine grained.		
▽ (Possible water strike or seep)	4.7	**Silty SAND (SM)** - brown. Organic rich (silt - course, predominantly medium grained).		
	4.9	**CONGLOMERATE**. Rounded pebbles and siltstone fragments to 40mm in off white silty sandstone matrix.		
	5.1	**CONGLOMERATE**. Rounded pebbles and siltstone fragments to 40mm in iron rich poorly sorted medium-course grained sandstone.		
	5.3	**SANDSTONE** - off white to light brown. Silty sandstone (silt-fine grained, predominantly fine) with yellow fine grained sand lenses and white clay bands, highly weathered, extremely low strength.	Tree root at 6m.	
	6.0	**SANDSTONE** - light brown. Silty sandstone (silt-fine grained, predominantly fine), highly weathered, extremely low strength.	**Maximum tree root depth observed at 6m.**	
▼	6.8	**SANDSTONE** - light brown. Silty sandstone (silt-fine grained, predominantly fine) with yellow fine grained sand lenses, highly weathered, extremely low strength.		
	7.1	**Terminated at 7.12 m** Target depth.		7.1m 470ppm

Bore with Lockable Monument



Water Level

▽ First Noted

▼ Stabilised

Notes

Borehole was drilled as a shallow groundwater monitoring bore screened above the conglomerate layer to monitor the potential presence of perched groundwater.

Collapsed back to 3m. Re-drilled next day with water used for casing only.

Water bailed to depth of 6.6m from top of initial casing (approximately 0.1m above ground level).

After completing the bore, depth of bore is 7.92m from new top of casing (approximately 0.8m above ground level). Water level was 7.00m at 16:00 on 14/12/2017.

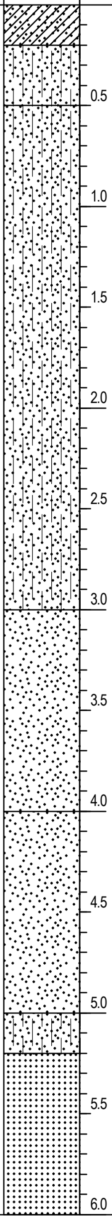
100mm Ø Class 18 PVC with 1mm factory slotted screen. Graded and wash 2mm filter pack.

ANGLED CORE HOLE LOG

Hole ID. **Burunga Lane 182D**

Hole Depth:	**16.10 m**
Sheet:	**1 of 3**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**204878**
Northing:	**7094138**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on alluvial terrace above dry sandy creek, adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Grant Asser 15/12/2017**

Water (mbgl)	Graphic Log	Depth (mbgl)	Material Description	Tree Root Observations
			**Sandy CLAY / LOAM (CL)** - dark brown. Clay, silt and very fine grained sand.	
		0.2	**Silty SAND / Sandy LOAM (SM)** - dark brown. Silt to fine grained sand, predominantly silt.	
		0.5	**Silty SAND (SM)** - light brown. Silt to fine grained, predominantly very fine.	
		3.0	**SAND (SP)** - light brown. Very fine to course grained, predominantly fine to medium, poorly sorted.	
		4.0	**SAND (SP)** - light brown. Very fine to medium grained, predominantly fine, poorly sorted.	
		5.0	**Silty SAND (SM)** - off white. Silt to fine grained, predominantly very fine grained.	
		5.2	**SANDSTONE** - light brown. Silty sandstone (silt - medium grained, predominantly fine), highly weathered, extremely low strength.	

Water Level

▽ First Noted

▼ Stabilised

Notes

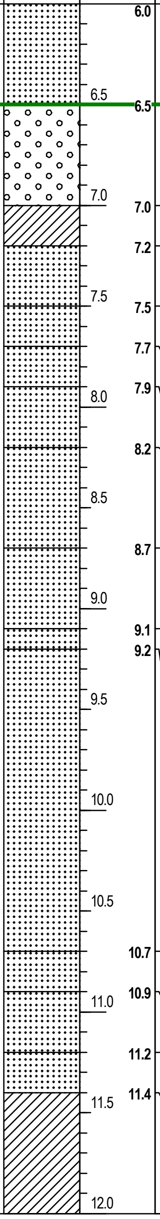
Cored at 56° angle to intersect target depth of 13m depth beneath tree at 16.1m drilled length.
Depths are along hole not true vertical depth.

ANGLED CORE HOLE LOG

Hole ID. **Burunga Lane 182D**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on alluvial terrace above dry sandy creek, adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Grant Asser 15/12/2017**

Hole Depth:	**16.10 m**
Sheet:	**2 of 3**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**204878**
Northing:	**7094138**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**



Water (mbgl)	Depth (mbgl)	Material Description	Tree Root Observations
	6.0	**SANDSTONE** - brown / yellow. Silty sandstone (silt - course grained, predominantly medium to course), highly weathered, extremely low strength.	2mm thick tree roots intersected at 6.5m lineal depth (5.7mbgl).
	6.5	**CONGLOMERATE**. Poorly sorted mix of silt to course grained sand plus rock fragments and rounded pebbles to 100mm.	**Maximum tree root depth observed at 6.5m lineal depth.**
	7.0	**CLAY (CL)** - grey. With occasional rounded pebbles and yellow clay lenses.	
	7.2	**SANDSTONE** - light brown / yellow. Silty sandstone (silt to fine grained, predominantly fine, poorly sorted), highly weathered, extremely low strength.	
	7.5	**SANDSTONE** - light brown / grey. Silty sandstone (silt to fine grained, predominantly fine, poorly sorted), highly weathered, extremely low strength.	
	7.7	**SANDSTONE** - light brown / yellow. Silty sandstone (silt to fine grained, predominantly fine, poorly sorted), highly weathered, extremely low strength.	
	7.9	**SANDSTONE** - light brown / grey. Silty sandstone (silt to fine grained, predominantly fine, poorly sorted), highly weathered, extremely low strength.	
	8.2	**SANDSTONE** - light grey. Silty sandstone (silt to fine grained, poorly sorted), highly weathered, extremely low strength.	
	8.7	**SANDSTONE** - interbedded layers of light grey, yellow and light brown / yellow. Silty sandstone (silt to fine grained, poorly sorted), highly weathered, extremely low strength.	
	9.1	**SANDSTONE** - light grey. Silty sandstone (silt to fine grained, poorly sorted) with occasional grey clay lenses, highly weathered, extremely low strength.	
	9.2	**SANDSTONE** - light grey. Silty sandstone (silt to fine grained, poorly sorted), highly weathered, extremely low strength.	
	10.7	**SANDSTONE** - light brown / yellow. Silty sandstone (silt to fine grained, poorly sorted), highly weathered, extremely low strength.	
	10.9	**SANDSTONE** - light grey. Silty sandstone (silt to fine grained, poorly sorted), highly weathered, extremely low strength.	
	11.2	**SANDSTONE** - light brown / yellow and light grey. Silty sandstone (silt to fine grained, poorly sorted), highly weathered, extremely low strength.	
	11.4	**CLAY (CL)** - black, dark brown, grey and yellow. Clay with occasional light grey sandstone.	

Water Level

▽ First Noted

▼ Stabilised

Notes

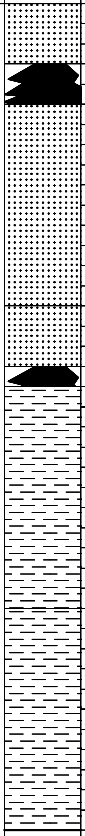
Cored at 56° angle to intersect target depth of 13m depth beneath tree at 16.1m drilled length.
Depths are along hole not true vertical depth.

ANGLED CORE HOLE LOG

Hole ID. **Burunga Lane 182D**

Hole Depth:	**16.10 m**
Sheet:	**3 of 3**
Ground Level :	**N/A**
Top of Casing :	**N/A**
Easting:	**204878**
Northing:	**7094138**
Zone:	**56J**
Checked By:	**Ned Hamer 28/03/2018**

Project Name:	**Arrow Surat Gas Project - Groundwater Dependent Ecosystem (GDE) Study**
Location / Site:	**on alluvial terrace above dry sandy creek, adjacent to mature River Red Gum**
Client:	**Arrow Energy**
Drilling Company:	**Numac Drilling**
Drill Method:	**Sonic Drilling**
Logged By:	**Grant Asser 15/12/2017**



Water (mbgl)	Depth (mbgl)	Material Description	Tree Root Observations
	12.0	**SANDSTONE** - grey. Silty sandstone (silt to fine grained, poorly sorted) and weathered coal, highly weathered, extremely low strength.	
	12.3	**Weathered COAL**. Inferred low maturity and high inorganic content.	
	12.5	**SANDSTONE** - grey. Silty sandstone (silt to fine grained, poorly sorted) and weathered coal, highly weathered, extremely low strength.	
	13.5	**SANDSTONE** - light grey. Silty sandstone (silt to fine grained, poorly sorted), highly weathered, extremely low strength.	
	13.8	**COAL & Weathered COAL**.	
	13.9	**SILTSTONE** - grey. Sandy siltstone with occasional light grey silty sandstone (silt to fine grained, poorly sorted), highly weathered, extremely low strength.	
	15.0	**SILTSTONE** - grey. Sandy siltstone, highly weathered, extremely low strength.	
	16.1	**Terminated at 16.10 m** Target depth beneath tree.	

Water Level

∇ First Noted

▼ Stabilised

Notes

Cored at 56° angle to intersect target depth of 13m depth beneath tree at 16.1m drilled length.
Depths are along hole not true vertical depth.

LS31A 0 – 4m

LS31A 4 – 6m

LS31A 6 – 9m

LS31A 9 – 12m

LS31A 12 – 15m

LS31A 15 – 18m

LS31A 18 – 21m

LS35A 0 - 3m

LS35A 3 – 6m

LS35A 6 – 8.2m

LS35A 8.2 - 11m

LS35A 11 – 14m

LS35A 14 – 17m

LS35A 17 – 20m

LS35A 20 – 23m

LS35A 23 – 26m

LS35A 26 – 29m

LS35A 29 – 30m

BL182B 0 - 4m

BL182A 3.5 – 6m

BL182A 6 - 8m

BL182A 8 - 10m

BL182A 10 – 12m

BL182A 12 – 14m

GB20A 0 – 2.5m

GB20A 2.5 – 4.5m

GB20A 4.5 – 7m

GB20A – 7 – 9m

GB20A 9 – 12m

GB20A 12 – 15m

GB20A 15 – 17m

GB20A 17 – 19m

GB20A 19 – 21m

GB20A 21 – 24m

GB20A 24 – 27m (1.5m core loss – likely coal)

GB20A 27 – 30m

Appendix E – Soil Moisture Potential Results

Drillhole	Depth (m)	Mpa	pF	Temp°C	Soil Moisture Potential - PSI	Notes - Tree Root Identification
Longswamp 35b	0.2	-1.77	4.26	28.7	-256.717	Large tree root >110mm occupied entire core barrel diameter in LS35A
Longswamp 35b	0.5	-2.01	4.32	29	-291.526	
Longswamp 35b	1	-1.37	4.15	28.6	-198.702	1mm fine tree root at 1.2m in LS35A
Longswamp 35b	1.5	-1.6	4.22	28.7	-232.06	1-3mm tree root at 1.9 and 2.3m depth in LS35C (angled bore)
Longswamp 35b	2	-1.09	4.05	28.8	-158.091	
Longswamp 35b	2.5	-2.24	4.37	28.6	-324.885	Thin fibrous (2mm) tree root intersected at 2.9m depth.
Longswamp 35b	3	-1.52	4.2	28.7	-220.457	
Longswamp 35b	3.5	-2.27	4.37	28.7	-329.236	
Longswamp 35b	4	-1.76	4.26	28.9	-255.266	
Longswamp 35b	4.5	-1.76	4.26	28.9	-255.266	
Longswamp 35b	5	-1.9	4.29	28.7	-275.572	
Longswamp 35b	5.5	-1.65	4.23	28.7	-239.312	1-2mm thick tree root observed in clayey sand at 5.5m
Longswamp 35b	6	-1.67	4.24	28.7	-242.213	
Longswamp 35b	6.5	-1.6	4.22	28.6	-232.06	1.5mm tree root at 7.7m (6.7m depth) in angle hole..
Longswamp 35b	7	-1.14	4.07	28.7	-165.343	Root matter @ 7.1m recorded in angle hole LS35c (8.2m down hole). Large fibrous root material in fissure.
Longswamp 35b	7.5	-0.73	3.88	28.6	-105.878	
Longswamp 35b	8	-1.18	4.09	28.7	-171.145	
Longswamp 35b	8.5	-1.47	4.18	28.8	-213.205	
Longswamp 35b	9	-1.57	4.21	28.8	-227.709	
Longswamp 35b	9.5	-1.57	4.21	28.8	-227.709	
Longswamp 35b	10	-1.42	4.17	28.7	-205.954	
Longswamp 35b	10.5	-0.61	3	28.6	-88.473	
Longswamp 35b	11	-1.23	4.1	29	-176.396	
Longswamp 35b	11.5	-0.92	3.98	28.7	-133.435	
Longswamp 35b	12	-1.77	4.26	28.7	-256.717	
Longswamp 35b	12.5	-2.62	4.43	28.7	-379.999	
Longswamp 35b	13	-0.99	4.01	28.8	-143.587	
Longswamp 35b	13.5	-0.91	3.98	28.7	-131.984	
Longswamp 35b	14	-0.76	3.89	28.7	-110.229	
Longswamp 35b	14.5	-1.43	4.17	28.8	-207.404	
Longswamp 35b	15	-1.22	4.1	28.8	-176.946	
Longswamp 35b	15.5					
Longswamp 35b	16					
Longswamp 35b	16.5					
Longswamp 35b	17	-0.76	3.9	28.7	-110.29	

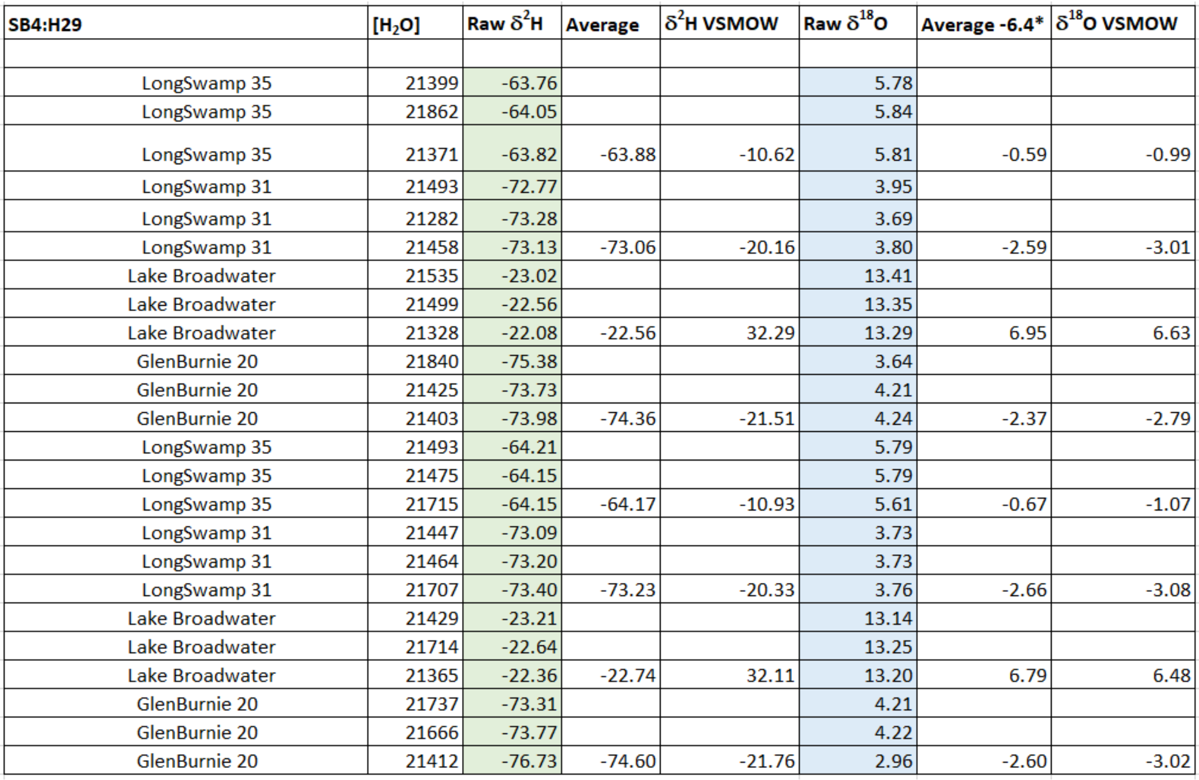
Drillhole	Depth (m)	Mpa	pF	Temp°C	Soil Moisture Potential - PSI	Notes - Tree Root Identification
Burunga Lane 182b	0.2	-0.02	1.71	28.8	-2.90075	
Burunga Lane 182b	0.5	-1.41	4.32	28.7	-207.404	
Burunga Lane 182b	1	-2.55	4.42	28.8	-369.846	
Burunga Lane 182b	1.5	-2.69	4.44	28.7	-390.152	
Burunga Lane 182b	2	-0.87	3.95	28.8	-126.183	
Burunga Lane 182b	2.5	-0.84	3.94	28.8	-121.832	
Burunga Lane 182b	3	-2	4.32	28.8	-290.075	
Burunga Lane 182b	3.5	-1.22	4.1	28.7	-176.946	
Burunga Lane 182b	4	-1.29	4.13	28.6	-187.099	Large fibrous root material (2cm width) in clay fissure.
Burunga Lane 182b	4.5	-0.69	3.85	28.6	-100.076	
Burunga Lane 182b	5	-0.84	3.94	28.8	-121.8317	2mm tree root in moist clayey sand
Burunga Lane 182b	5.5	-0.91	3.98	28.8	-131.984	2mm thick tree roots intersected at 5.4m depth in BL182d - Angle hole (6.5m depth along hole).
Burunga Lane 182b	6	-0.92	3.98	28.7	-133.435	2mm tree roots recorded in conglomerate band at 6m in BL182b
Burunga Lane 182b	6.5	-0.61	3.82	28.6	-88.473	
Burunga Lane 182b	7	-1.01	4.02	28.7	-146.488	
Burunga Lane 182b	7.5	-0.97	4.01	28.8	-140.687	
Burunga Lane 182b	8	-0.99	4.01	28.8	-143.587	
Burunga Lane 182b	8.5	-1.13	4.03	28.8	-163.893	
Burunga Lane 182b	9	-1.11	4.03	28.9	-160.992	
Burunga Lane 182b	9.5	-1.52	4.18	28.8	-220.457	
Burunga Lane 182b	10	-2.69	4.44	28.8	-390.152	
Burunga Lane 182b	10.5	-1.19	4.05	28.8	-172.595	
Burunga Lane 182b	11	-0.99	4	28.9	-143.587	
Burunga Lane 182b	11.5					
Burunga Lane 182b	12	-0.99	3.99	28.8	-143.587	
Burunga Lane 182b	12.5					
Burunga Lane 182b	13					
Burunga Lane 182b	13.5	-0.39	3.61	28.7	-56.5647	
Longswamp 31a	0.2					
Longswamp 31a	0.5					
Longswamp 31a	1					
Longswamp 31a	1.5					
Longswamp 31a	2	-0.13	1.71	29	-18.85490	
Longswamp 31a	2.6	-0.1	2.03	28.9	-14.50380	Abundant fibrous root material recorded in loose sand at 2.6m.
Longswamp 31a	3	-0.94	3.99	29.1	-136.33547	1mm tree root at 2.9 m on sand/clay interface
Longswamp 31a	3.5	-1.29	4.13	28.7	-187.09868	
Longswamp 31a	4	-1.33	4.14	28.7	-192.90019	Thin (1 - 2mm) tree roots recorded in fissured sandy clay at 4m depth. LS31a.

Drillhole	Depth (m)	Mpa	pF	Temp°C	Soil Moisture Potential - PSI	Notes - Tree Root Identification
Longswamp 31a	4.5	-1.43	4.17	28.7	-207.40396	
Longswamp 31a	5	-1.32	4.13	28.7	-191.44980	
Longswamp 31a	5.5	-1.37	4.15	28.8	-198.70170	
Longswamp 31a	6	-1.55	4.2	28.8	-224.80849	
Longswamp 31a	6.5	-1.39	4.16	28.7	-201.60245	
Longswamp 31a	7	-1.52	4.19	28.7	-220.45736	
Longswamp 31a	7.5	-1.25	4.11	28.7	-181.29717	
Longswamp 31a	8	-1.44	4.17	28.7	-208.85434	
Longswamp 31a	8.5	-1.58	4.21	28.7	-229.15960	
Longswamp 31a	9	-1.22	4.28	28.7	-176.94604	
Longswamp 31a	9.5	-1.2	4.09	27.2	-174.04528	
Longswamp 31a	10	-1.6	4.23	28.8	-232.06038	
Longswamp 31a	10.5	-0.89	3.89	28.7	-129.08350	
Longswamp 31a	11	0.94	3.99	28.7	-136.33547	
Longswamp 31a	11.5	-0.37	3.59	28.6	-53.66396	
Longswamp 31a	12	-0.35	3.56	28.7	-50.76320	
Longswamp 31a	12.5	-0.91	3.97	28.8	-131.98434	
Longswamp 31a	13	-0.76	3.89	28.7	-110.22868	
Longswamp 31a	13.5	-0.65	3.83	28.6	-94.27453	
Longswamp 31a	14	-0.64	3.82	28.7	-92.82415	
Longswamp 31a	14.5	-0.49	3.71	28.7	-71.06849	
Longswamp 31a	15	-0.23	3.37	28.9	-33.35868	
Longswamp 31a	15.5	-0.39	3.6	28.7	-56.56470	
Longswamp 31a	16	-0.45	3.66	28.7	-65.26698	
Longswamp 31a	16.5	-0.3	3.49	28.7	-43.51130	
Longswamp 31a	17	-0.32	3.52	28.7	-46.41207	
Longswamp 31a	17.5	-0.24	3.4	28.7	-34.80905	
Longswamp 31a	18	-0.55	3.76	28.6	-79.77076	
Glenburnie 20b	0.2	-0.16	3.21	28.9	-23.206	
Glenburnie 20b	0.5	-2.37	4.39	28.7	-343.7394	
Glenburnie 20b	1	-2.66	4.44	29	-385.80038	
Glenburnie 20b	1.5	-2.95	4.49	29.1	-427.8613	
Glenburnie 20b	2	-2.13	4.34	29.2	-308.930382	
Glenburnie 20b	2.5	-3.07	4.5	28.9	-445.2658	
Glenburnie 20b	3	-1.3	4.14	29	-188.54905	
Glenburnie 20b	3.5	-1.15	4.07	29.3	-166.79339	
Glenburnie 20b	4	-2.41	4.4	28.8	-349.5409	
Glenburnie 20b	4.5	-3.33	4.54	28.8	-482.97566	
Glenburnie 20b	5	-1.32	4.13	28.8	-191.4498142	
Glenburnie 20b	5.5	-1.39	4.16	28.8	-201.6024558	Large fibrous flattened tree roots within fissure zone recorded at 5.4m in GB182a
Glenburnie 20b	6	-1.65	4.23	29	-239.3122	
Glenburnie 20b	6.5	-1.82	4.27	28.8	-263.96868	

Drillhole	Depth (m)	Mpa	pF	Temp°C	Soil Moisture Potential - PSI	Notes - Tree Root Identification
Glenburnie 20b	7	-1.29	4.13	28.8	-187.09868	
Glenburnie 20b	7.5	-1.19	4.08	28.9	-172.5949	
Glenburnie 20b	8	-2.72	4.45	28.8	-394.50264	Fine tree roots (1mm) recorded at 7.6m in weathered Springbok Sandstone - 10m in Angle Hole GB182c
Glenburnie 20b	8.5	-1.34	4.14	29.1	-194.35056	
Glenburnie 20b	9	-0.66	3.83	29	-95.724907	
Glenburnie 20b	9.5	-0.33	3.53	28.8	-47.862453	
Glenburnie 20b	10	-0.2	3.32	29.1	-29.00754	
Glenburnie 20b	10.5	-0.05	2.68	28.8	-7.2518869	
Glenburnie 20b	11	-0.17	3.25	28.8	-24.656415	
Glenburnie 20b	11.5	-0.57	3.77	28.8	-82.67151	
Glenburnie 20b	12	-1.17	4.08	28.8	-169.6941	
Glenburnie 20b	12.5	-0.45	3.67	28.8	-65.26698	
Glenburnie 20b	13	-0.7	3.86	28.8	-101.5264	
Glenburnie 20b	13.5	-1.4	4.16	28.8	-203.0528332	
Glenburnie 20b	14	-0.65	3.83	28.9	-94.274529	
Glenburnie 20b	14.5	-0.07	2.86	28.8	-10.152641	
Glenburnie 20b	15	-0.17	3.25	28.8	-24.656415	
Glenburnie 20b	15.5	-0.01	2.03	28.8	-1.4503774	
Glenburnie 20b	16	-0.35	3.56	28.8	-50.763208	
Glenburnie 20b	16.5	-0.04	2.62	28.8	-5.801509	
Glenburnie 20b	17	-0.17	3.25	28.8	-24.656415	
Glenburnie 20b	17.5	-0.61	3.8	28.8	-88.47302	
Glenburnie 20b	18	-0.61	3.8	28.8	-88.4732018	

Appendix F – Tree Xylem and Soil Water Stable Isotope Analytical Reports

Groundwater Analysis



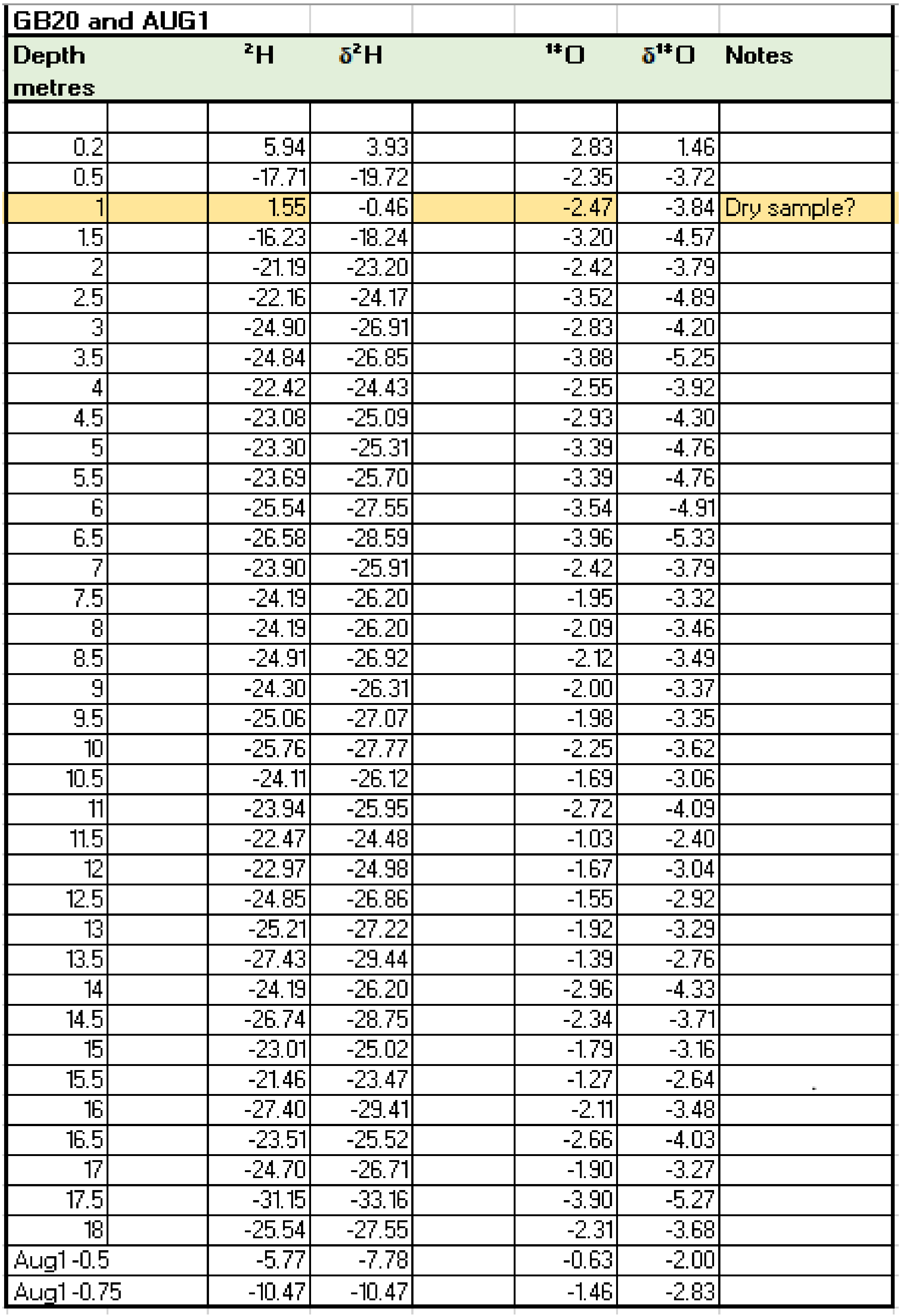
SB4:H29	[H_2O]	Raw δ^2H	Average	δ^2H VSMOW	Raw δ^{18}O	Average -6.4*	δ^{18}O VSMOW
LongSwamp 35	21399	-63.76			5.78		
LongSwamp 35	21862	-64.05			5.84		
LongSwamp 35	21371	-63.82	-63.88	-10.62	5.81	-0.59	-0.99
LongSwamp 31	21493	-72.77			3.95		
LongSwamp 31	21282	-73.28			3.69		
LongSwamp 31	21458	-73.13	-73.06	-20.16	3.80	-2.59	-3.01
Lake Broadwater	21535	-23.02			13.41		
Lake Broadwater	21499	-22.56			13.35		
Lake Broadwater	21328	-22.08	-22.56	32.29	13.29	6.95	6.63
GlenBurnie 20	21840	-75.38			3.64		
GlenBurnie 20	21425	-73.73			4.21		
GlenBurnie 20	21403	-73.98	-74.36	-21.51	4.24	-2.37	-2.79
LongSwamp 35	21493	-64.21			5.79		
LongSwamp 35	21475	-64.15			5.79		
LongSwamp 35	21715	-64.15	-64.17	-10.93	5.61	-0.67	-1.07
LongSwamp 31	21447	-73.09			3.73		
LongSwamp 31	21464	-73.20			3.73		
LongSwamp 31	21707	-73.40	-73.23	-20.33	3.76	-2.66	-3.08
Lake Broadwater	21429	-23.21			13.14		
Lake Broadwater	21714	-22.64			13.25		
Lake Broadwater	21365	-22.36	-22.74	32.11	13.20	6.79	6.48
GlenBurnie 20	21737	-73.31			4.21		
GlenBurnie 20	21666	-73.77			4.22		
GlenBurnie 20	21412	-76.73	-74.60	-21.76	2.96	-2.60	-3.02

Twig Xylem Measurements

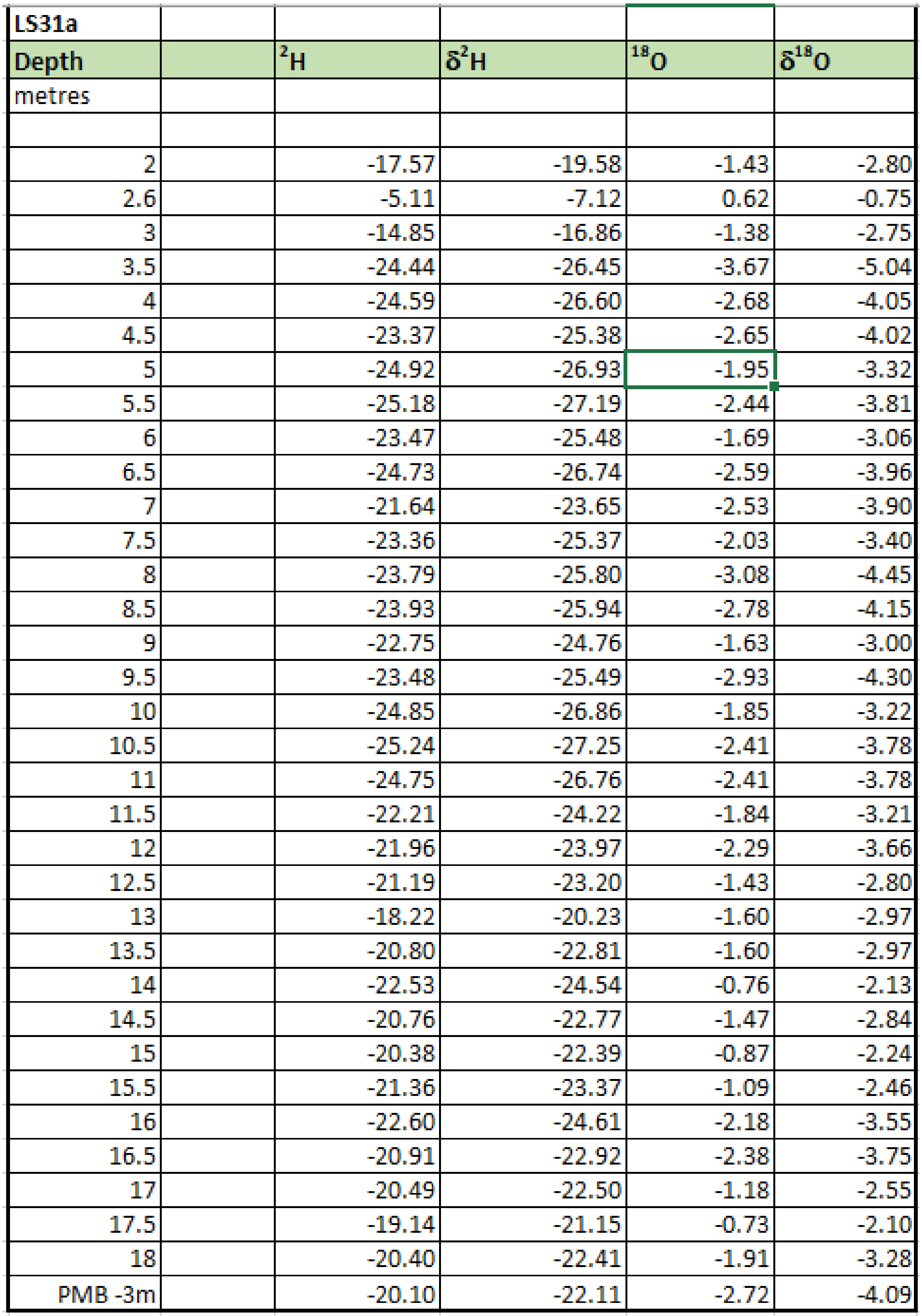
Xylem		All samples taken from near centre of Xylem						Notes
		^{2}H	δ^{2}H		^{18}O	δ^{18}O		
BL 182								
T1		-8.46	-10.47		2.86	1.49		
Jar 1		-7.22	-9.23		3.01	1.64		
T1		-6.11	-8.12		3.78	2.41		
Jar 2		-7.01	-9.02		3.67	2.30		
T2		-0.16	-2.17		11.58	10.21		
Jar 1		0.09	-1.92		12.04	10.67		
T 2		-8.67	-10.68		6.35	4.98		
Jar 2		-9.67	-11.68		5.56	4.19		
GB20								
T1		3.84	1.83		9.07	7.70		
		4.98	2.97		8.53	7.16		
T2		-10.07	-12.08		1.68	0.31		Twig
		-3.25	-5.26		2.70	1.33		
LS31								
T1A		-5.30	-7.31		0.42	-0.95		
		-4.74	-6.75		0.90	-0.47		
T1B		-3.82	-5.83		4.02	2.65		
		-7.90	-9.91		0.38	-0.99		
		-5.61	-7.62		0.98	-0.39		
T2A		-1.90	-3.91		3.99	2.62		
		-1.80	-3.81		4.10	2.73		
T2B		-11.88	-13.89		-1.72	-3.09		
		-8.65	-10.66		-0.66	-2.03		
LS 35B								
T1 Jar 1		-10.05	-12.06		-1.72	-3.09		Water condensed in jar
		-6.98	-8.99		-1.70	-3.07		Water condensed in jar
		-9.42	-11.43		-0.95	-2.32		Xylem
		-8.63	-10.64		-0.39	-1.76		Xylem
T1 Jar 2		-6.33	-8.34		-0.76	-2.13		Water condensed in jar
		-6.16	-8.17		-1.12	-2.49		Water condensed in jar
		-10.39	-12.40		-1.34	-2.71		Xylem
		-5.13	-7.14		0.52	-0.85		Xylem
T2 Jar 1		-12.92	-14.93		-1.96	-3.33		Water condensed in jar
		-5.10	-7.11		-0.68	-2.05		Xylem
T2 Jar 2		-9.41	-11.42		-0.41	-1.78		Water condensed in jar
		-13.23	-15.24		-1.93	-3.30		Xylem
T3 Jar 1		-4.62	-6.63		0.89	-0.48		Water condensed in jar
		-8.79	-10.80		0.06	-1.31		Xylem
T3 Jar 2		-1.53	-3.54		1.24	-0.13		Water condensed in jar
		-6.69	-8.70		0.70	-0.67		Xylem
		-13.49	-15.50		-0.06	-1.43		Bark
T4 Jar 1		-1.79	-3.80		0.89	-0.48		Water condensed in jar
		-11.17	-13.18		-0.90	-2.27		Xylem
T4 Jar 2		-3.02	-5.03		0.95	-0.42		Water condensed in jar
		0.14	-1.87		1.24	-0.13		Xylem

Soil Moisture Measurements

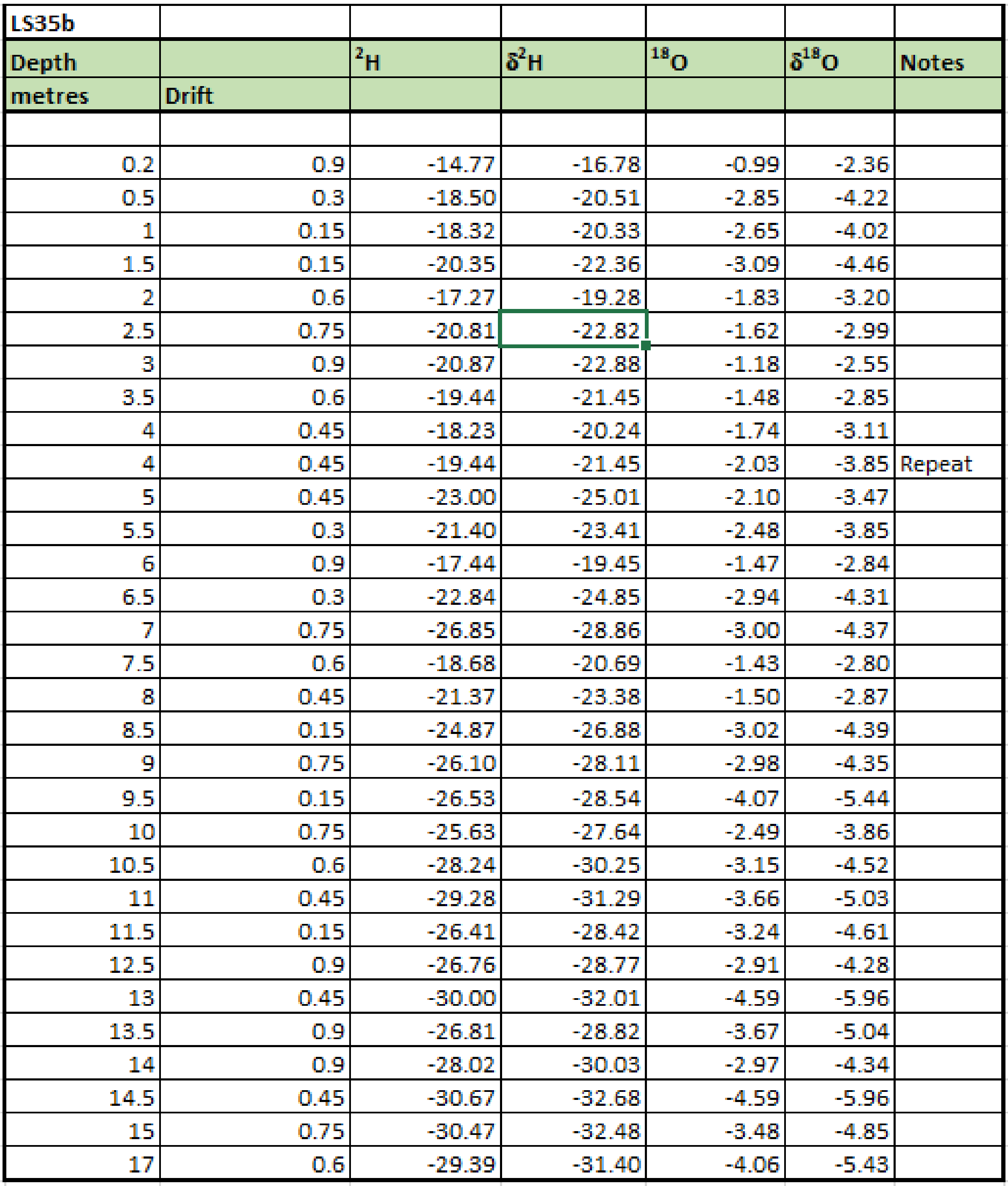
BL182b					
Depth	**^{2}H**	**δ^{2}H**	**^{18}O**	**δ^{18}O**	**Notes**
metres					
0.2	-2.57	-4.58	0.78	-0.59	Used as a QC material in early runs
0.2	-1.24	-3.25	0.79	-0.58	Ref
0.2	-2.42	-4.43	0.69	-0.68	Ref
1	-8.71	-10.72	-2.34	-3.71	
1.5	-18.60	-20.61	-2.53	-3.90	
2	-11.39	-13.40	-2.81	-4.18	
2.5	-7.67	-9.68	-3.24	-4.61	
3	-0.72	-2.73	1.43	0.06	Sample dried out?
3.5	-23.79	-25.80	-3.82	-5.19	
4	-23.79	-25.80	-3.82	-5.19	
4.5	-20.45	-22.46	-2.55	-3.92	
4.8	-18.55	-20.56	-2.75	-4.12	
5	-23.18	-25.19	-2.49	-3.86	
5.5	-25.19	-27.20	-3.06	-4.43	
6	-23.31	-25.32	-2.70	-4.07	
6.5	-26.06	-28.07	-3.32	-4.69	
7	-34.07	-36.08	-5.13	-6.50	
8	-25.63	-27.64	-4.11	-5.48	From BL182A
10	-30.66	-32.67	-4.68	-6.05	From BL182A
12	-30.35	-32.36	-4.42	-5.79	From BL182A
13.8	-33.68	-35.69	#REF!	#REF!	From BL182C



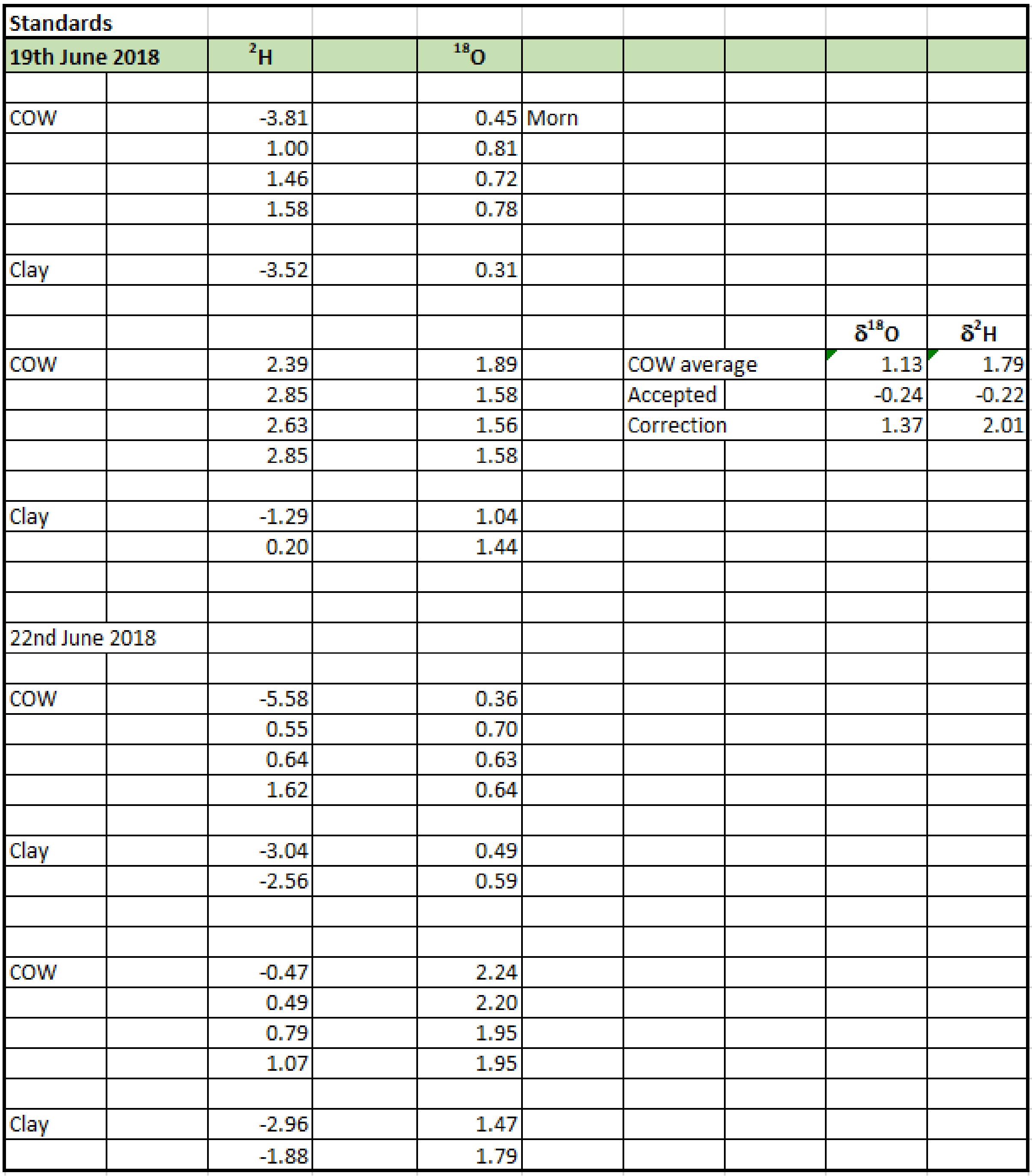
GB20 and AUG1							
Depth metres		^{2}H	δ^{2}H		^{18}O	δ^{18}O	Notes
0.2		5.94	3.93		2.83	1.46	
0.5		-17.71	-19.72		-2.35	-3.72	
1		1.55	-0.46		-2.47	-3.84	Dry sample?
1.5		-16.23	-18.24		-3.20	-4.57	
2		-21.19	-23.20		-2.42	-3.79	
2.5		-22.16	-24.17		-3.52	-4.89	
3		-24.90	-26.91		-2.83	-4.20	
3.5		-24.84	-26.85		-3.88	-5.25	
4		-22.42	-24.43		-2.55	-3.92	
4.5		-23.08	-25.09		-2.93	-4.30	
5		-23.30	-25.31		-3.39	-4.76	
5.5		-23.69	-25.70		-3.39	-4.76	
6		-25.54	-27.55		-3.54	-4.91	
6.5		-26.58	-28.59		-3.96	-5.33	
7		-23.90	-25.91		-2.42	-3.79	
7.5		-24.19	-26.20		-1.95	-3.32	
8		-24.19	-26.20		-2.09	-3.46	
8.5		-24.91	-26.92		-2.12	-3.49	
9		-24.30	-26.31		-2.00	-3.37	
9.5		-25.06	-27.07		-1.98	-3.35	
10		-25.76	-27.77		-2.25	-3.62	
10.5		-24.11	-26.12		-1.69	-3.06	
11		-23.94	-25.95		-2.72	-4.09	
11.5		-22.47	-24.48		-1.03	-2.40	
12		-22.97	-24.98		-1.67	-3.04	
12.5		-24.85	-26.86		-1.55	-2.92	
13		-25.21	-27.22		-1.92	-3.29	
13.5		-27.43	-29.44		-1.39	-2.76	
14		-24.19	-26.20		-2.96	-4.33	
14.5		-26.74	-28.75		-2.34	-3.71	
15		-23.01	-25.02		-1.79	-3.16	
15.5		-21.46	-23.47		-1.27	-2.64	
16		-27.40	-29.41		-2.11	-3.48	
16.5		-23.51	-25.52		-2.66	-4.03	
17		-24.70	-26.71		-1.90	-3.27	
17.5		-31.15	-33.16		-3.90	-5.27	
18		-25.54	-27.55		-2.31	-3.68	
Aug1 -0.5		-5.77	-7.78		-0.63	-2.00	
Aug1 -0.75		-10.47	-10.47		-1.46	-2.83	



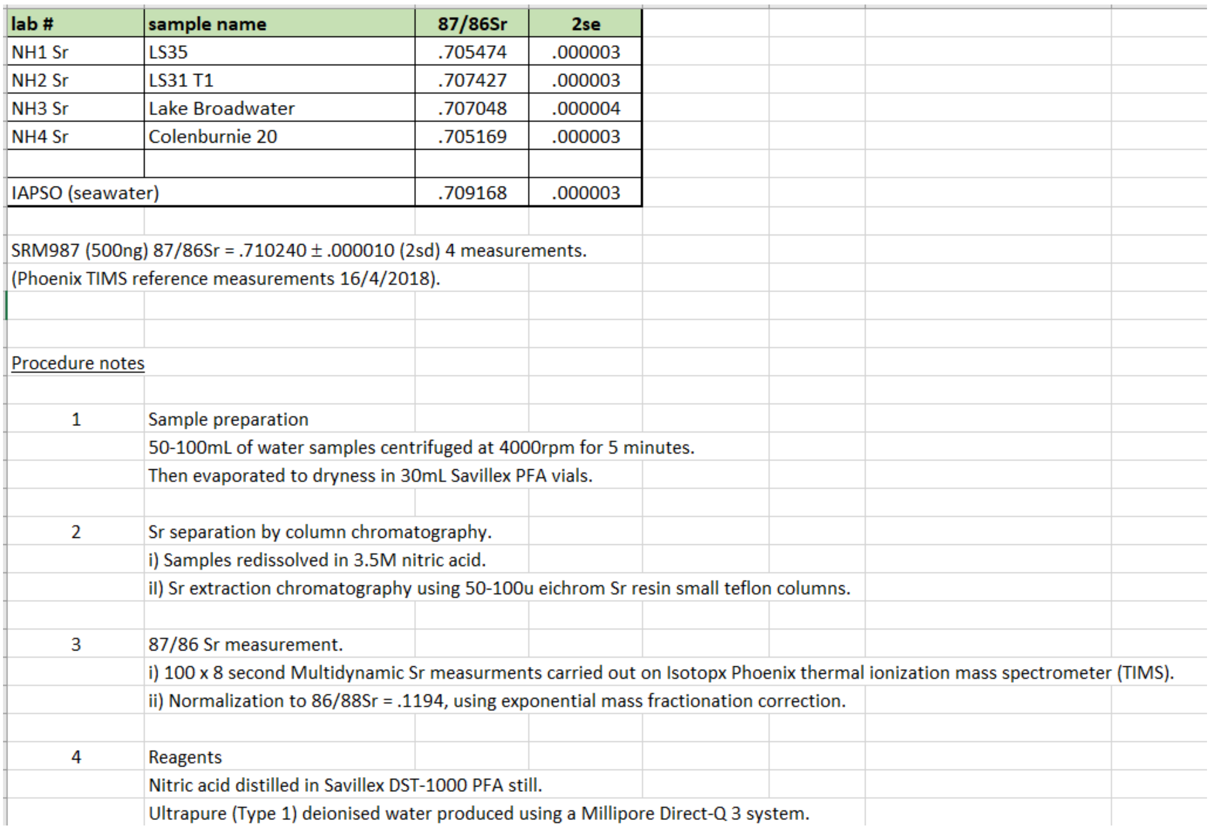
LS31a					
Depth		^{2}H	δ^{2}H	^{18}O	δ^{18}O
metres					
2		-17.57	-19.58	-1.43	-2.80
2.6		-5.11	-7.12	0.62	-0.75
3		-14.85	-16.86	-1.38	-2.75
3.5		-24.44	-26.45	-3.67	-5.04
4		-24.59	-26.60	-2.68	-4.05
4.5		-23.37	-25.38	-2.65	-4.02
5		-24.92	-26.93	-1.95	-3.32
5.5		-25.18	-27.19	-2.44	-3.81
6		-23.47	-25.48	-1.69	-3.06
6.5		-24.73	-26.74	-2.59	-3.96
7		-21.64	-23.65	-2.53	-3.90
7.5		-23.36	-25.37	-2.03	-3.40
8		-23.79	-25.80	-3.08	-4.45
8.5		-23.93	-25.94	-2.78	-4.15
9		-22.75	-24.76	-1.63	-3.00
9.5		-23.48	-25.49	-2.93	-4.30
10		-24.85	-26.86	-1.85	-3.22
10.5		-25.24	-27.25	-2.41	-3.78
11		-24.75	-26.76	-2.41	-3.78
11.5		-22.21	-24.22	-1.84	-3.21
12		-21.96	-23.97	-2.29	-3.66
12.5		-21.19	-23.20	-1.43	-2.80
13		-18.22	-20.23	-1.60	-2.97
13.5		-20.80	-22.81	-1.60	-2.97
14		-22.53	-24.54	-0.76	-2.13
14.5		-20.76	-22.77	-1.47	-2.84
15		-20.38	-22.39	-0.87	-2.24
15.5		-21.36	-23.37	-1.09	-2.46
16		-22.60	-24.61	-2.18	-3.55
16.5		-20.91	-22.92	-2.38	-3.75
17		-20.49	-22.50	-1.18	-2.55
17.5		-19.14	-21.15	-0.73	-2.10
18		-20.40	-22.41	-1.91	-3.28
PMB -3m		-20.10	-22.11	-2.72	-4.09



LS35b						
Depth		^{2}H	δ^{2}H	^{18}O	δ^{18}O	Notes
metres	Drift					
0.2	0.9	-14.77	-16.78	-0.99	-2.36	
0.5	0.3	-18.50	-20.51	-2.85	-4.22	
1	0.15	-18.32	-20.33	-2.65	-4.02	
1.5	0.15	-20.35	-22.36	-3.09	-4.46	
2	0.6	-17.27	-19.28	-1.83	-3.20	
2.5	0.75	-20.81	-22.82	-1.62	-2.99	
3	0.9	-20.87	-22.88	-1.18	-2.55	
3.5	0.6	-19.44	-21.45	-1.48	-2.85	
4	0.45	-18.23	-20.24	-1.74	-3.11	
4	0.45	-19.44	-21.45	-2.03	-3.85	Repeat
5	0.45	-23.00	-25.01	-2.10	-3.47	
5.5	0.3	-21.40	-23.41	-2.48	-3.85	
6	0.9	-17.44	-19.45	-1.47	-2.84	
6.5	0.3	-22.84	-24.85	-2.94	-4.31	
7	0.75	-26.85	-28.86	-3.00	-4.37	
7.5	0.6	-18.68	-20.69	-1.43	-2.80	
8	0.45	-21.37	-23.38	-1.50	-2.87	
8.5	0.15	-24.87	-26.88	-3.02	-4.39	
9	0.75	-26.10	-28.11	-2.98	-4.35	
9.5	0.15	-26.53	-28.54	-4.07	-5.44	
10	0.75	-25.63	-27.64	-2.49	-3.86	
10.5	0.6	-28.24	-30.25	-3.15	-4.52	
11	0.45	-29.28	-31.29	-3.66	-5.03	
11.5	0.15	-26.41	-28.42	-3.24	-4.61	
12.5	0.9	-26.76	-28.77	-2.91	-4.28	
13	0.45	-30.00	-32.01	-4.59	-5.96	
13.5	0.9	-26.81	-28.82	-3.67	-5.04	
14	0.9	-28.02	-30.03	-2.97	-4.34	
14.5	0.45	-30.67	-32.68	-4.59	-5.96	
15	0.75	-30.47	-32.48	-3.48	-4.85	
17	0.6	-29.39	-31.40	-4.06	-5.43	



Standards									
19th June 2018		^{2}H		^{18}O					
COW		-3.81		0.45	Morn				
		1.00		0.81					
		1.46		0.72					
		1.58		0.78					
Clay		-3.52		0.31					
								δ^{18}O	δ^{2}H
COW		2.39		1.89		COW average		1.13	1.79
		2.85		1.58		Accepted		-0.24	-0.22
		2.63		1.56		Correction		1.37	2.01
		2.85		1.58					
Clay		-1.29		1.04					
		0.20		1.44					
22nd June 2018									
COW		-5.58		0.36					
		0.55		0.70					
		0.64		0.63					
		1.62		0.64					
Clay		-3.04		0.49					
		-2.56		0.59					
COW		-0.47		2.24					
		0.49		2.20					
		0.79		1.95					
		1.07		1.95					
Clay		-2.96		1.47					
		-1.88		1.79					



lab #	sample name	87/86Sr	2se
NH1 Sr	LS35	.705474	.000003
NH2 Sr	LS31 T1	.707427	.000003
NH3 Sr	Lake Broadwater	.707048	.000004
NH4 Sr	Colenburnie 20	.705169	.000003
IAPSO (seawater)		.709168	.000003

SRM987 (500ng) 87/86Sr = .710240 ± .000010 (2sd) 4 measurements.
(Phoenix TIMS reference measurements 16/4/2018).

Procedure notes

1 Sample preparation
50-100mL of water samples centrifuged at 4000rpm for 5 minutes.
Then evaporated to dryness in 30mL Savillex PFA vials.

2 Sr separation by column chromatography.
i) Samples redissolved in 3.5M nitric acid.
iI) Sr extraction chromatography using 50-100u eichrom Sr resin small teflon columns.

3 87/86 Sr measurement.
i) 100 x 8 second Multidynamic Sr measurments carried out on Isotopx Phoenix thermal ionization mass spectrometer (TIMS).
ii) Normalization to 86/88Sr = .1194, using exponential mass fractionation correction.

4 Reagents
Nitric acid distilled in Savillex DST-1000 PFA still.
Ultrapure (Type 1) deionised water produced using a Millipore Direct-Q 3 system.

Appendix G – Leaf Water Potential Measurements

GDE Assessment Area	Leaf Water Potential	Species	Height	DBH	X	Y	M1_PSI	M2_PSI	M3_PSI	Average -PSI
Longswamp 35b	Tree 1	E.camaldulensis	19	55	-27.27	151.0946	160	160	116	**145**
Longswamp 35b	Tree 2	E.camaldulensis	24	80	-27.2699	151.0949	116	44	58	**73**
Longswamp 35b	Tree 3	E.populnea	19	60	-27.2695	151.0954	145	145	145	**145**
Longswamp 35b	Tree 4	A.harpophylla	12	26	-27.2691	151.0938	333			**333**
Burunga Lane 182b	Tree 1	E.camaldulensis	28	120	-26.242	150.0457	72	72	58	**67**
Burunga Lane 182b	Tree 2	E.camaldulensis	19	60	-27.2699	151.0949	72	72		**72**
Longswamp 31a	Tree 1	E.camaldulensis	28	105	-27.3434	151.0957	30	30	25	**28**
Longswamp 31a	Tree 2	E.camaldulensis	19	50	-27.3432	151.0956	40	45		**43**
Longswamp 31a	Tree 3	Callitris glaucophylla	17	45	-27.3432	151.0955	170			**170**
Longswamp 31a	Tree 4	Angophora floribunda	21	68	-27.343	151.0955	125			**170**
Longswamp 31a	Tree 5	E.camaldulensis	27	110	-27.3434	151.0957	20			**20**
Glenburne 20b	Tree 1	E.camaldulensis	24	80	27.83313	151.097	110	75	90	**92**
Glenburne 20b	Tree 2	E.camaldulensis	19	40	-27.8331	151.0972	58	43	51	**51**
Glenburne 20b	Tree 3	Callitris glaucophylla	17	45	-27.8331	151.0971	180	130	195	**168**
Glenburne 20b	Tree 4	Corymbia tessellaris	21	55	-27.833	151.0955	58	90		**74**

Appendix H – Vegetation Monitoring Transects

Transect T1 – Longswamp 35

Date of Assessment: 9 December 2017
Purpose of Assessment: Permanent Monitoring Site for Foliage Index.
Plot Size: 50 m linear transect (Canopy Cover); 50 x 10m transect for tree/ shrub counts; 10 x 1m x 1m quadrats for Ground Cover.
Location (Plot Centreline): *Start* -27.27003/ 151.09445; *Finish* - 27.27021 / 151.09489
Structure: Open Eucalypt forest with dominant *Eucalyptus camaldulensis*

Regional Ecosystem: 11.3.27d

Canopy Cover – Canopy Intercept (T1 / T2/ S1) (summarised 50 m transect)

Intercept (m)	Species	T1 - Canopy		T2 – Sub-canopy		S1 / S2 - Shrub	
		Intercept	Height	Intercept	Height	Intercept	Height
0 – 2.0	*E. camaldulensis*			2	10		
16.0 – 20.5	*E. camaldulensis*	4.5	17				
21.0 – 24.0	*E. camaldulensis*			3	8		
28.0 – 34.0	*E. camaldulensis*	6.0	22				
34.0 – 45.5	*E. coolibah*	9.5	22				
Total Cover		**20.0 (40.0*)**		**5.0 (10*)**			
Average Height			**20.0**		**9**		

* Projected over 100 m;

Stem Counts (50 x 10)

Species	50 m x 10 m Stems (50x4m)		
	T1	**T2**	**S1/S2**
E. camaldulensis	5	4	2
Totals	**8**	**2**	**2**

Ground Cover %- 1 x 1m Sub-plots

Ground Cover Type	Species	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Mean May 2017
Native perennial grass / sedges	*Panicum decompositum*	2		1								**17.4**
	Panicum queenslandicum	0	10	20	20	50	30	15	15	5	5	
	Ereochloa crebra	1	0	0	0	0	0	0	0	0	0	
Native forbs and other spp.	*Eleocharis sp.*	2	0	1	0	0	0	0	0	20	0	**4.4**
	Eleocharis plana	0	0	0	0	0	0	0	0	0	10	
	Muehlenbeckia florulenta	0	0	0	5	5	0	0	0	0	0	
	Brunoniella acaulis	0	0	0	0	0	1	0	0	0	0	
Native shrubs ,<1m	*0*											**0**

Ground Cover Type	Species	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Mean May 2017
Cryptogams	0											**0**
Bare Ground		7.5	5	4	10	10	20	10	15	0	30	**11.15**
Exotic Grass		0	0	0	0	0	0	0	0	0	0	**0**
Exotic Forbs	*Phyla canescens*	80	65	0	0	2.5	5	5	20	2.5	5	**18.5**
Leaf litter		7.5	20	74	65	32.5	44	70	50	72.5	30	**46.55**
Timber (>/= 10cm)		0	0	0	0	0	0	0	0	0	20	**2**
Total		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100%**

Additional Species: *Sida cordifolia*, Opuntia aurantiaca*,*

Structural / Floristic Summary

BioCondition Attribute		**May 2017**
Native Plant Species Richness	Tree:	1
	Shrub:	1
	Grass	3
	Forbs and other:	4
Native Trees	Canopy Height	20
	Projected Canopy Cover – T1 & T2 (%)###	40
	Projected Foliage Cover (%)##	
	Projected Canopy Cover – Shrubs S1 / S2 (%)	22.75
	Average Height >1m	0
Native Ground cover (%):	Native perennial grass / sedge cover (%):	17.4
	Native shrubs (%)	0
	Organic litter cover (%):	46.55
	Native forb cover	4.4
Non-native plant cover	Non-native Grasses	0
	Non-native shrubs / forbs	18.5

##Average measurements taken from canopy photographs 1 – 11

Transect LS35, Start to End (December 2017)

Transect T2 – Burunga Lane 182

Date of Assessment: 14 December 2017
Purpose of Assessment: Permanent Monitoring Site for Foliage Index.
Plot Size: 50 m linear transect (Canopy Cover); 30 x 10m transect** for tree/ shrub counts; 10 x 1m x 1m quadrats for Ground Cover.
Location (Plot Centreline): *Start* -26.24197/ 150.04587; *Finish* - 26.24224 / 150.04584
Structure: Disturbed riparian forest with dominant *Eucalyptus camaldulensis*

Regional Ecosystem: 11.3.25

Canopy Cover – Canopy Intercept (T1 / T2/ S1) (summarised 50 m transect)

Intercept (m)	Species	T1 - Canopy		T2 – Sub-canopy		S1 / S2 - Shrub	
		Intercept	Height	Intercept	Height	Intercept	Height
11 – 28.2	*E. camaldulensis*	17.2	24				
Total Cover		**17.2 (57.3*)**					
Average Height			**24.0**		**9**		

* Projected over 100 m;

Stem Counts (50 x 10)

Species	50 m x 10 m Stems (50x4m)		
	T1	T2	S1/S2
E. camaldulensis	1	1	0
Totals	**1**	**1**	**2**

Ground Cover %- 1 x 1m Sub-plots – Not Assessed

Ground Cover Type	Species	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Mean May 2017
Native perennial grass / sedges												
Native forbs and other spp.												
Native shrubs ,<1m												
Cryptogams												
Bare Ground												
Exotic Grass												

Ground Cover Type	Species	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Mean May 2017
Exotic Forbs												
Leaf litter												
Timber (>/= 10cm)												
Total												

Additional Species: *Sida cordifolia*, Opuntia aurantiaca*,*

Structural / Floristic Summary

BioCondition Attribute		**May 2017**
Native Plant Species Richness	Tree:	
	Shrub:	
	Grass	
	Forbs and other:	
Native Trees	Canopy Height	
	Projected Canopy Cover – T1 & T2 (%)###	57.3
	Projected Foliage Cover (%)##	34.5
	Projected Canopy Cover – Shrubs S1 / S2 (%)	
	Average Height >1m	
Native Ground cover (%):	Native perennial grass / sedge cover (%):	
	Native shrubs (%)	
	Organic litter cover (%):	46.55
	Native forb cover	4.4
Non-native plant cover	Non-native Grasses	0
	Non-native shrubs / forbs	18.5

##Average measurements taken from canopy photographs 1 – 11

Transect GB182 – Start to End (December 2017)

Transect T3 – Lake Broadwater 31

Date of Assessment: 14 February 2018
Purpose of Assessment: Permanent Monitoring Site for Foliage Index.
Plot Size: 50 m linear transect (Canopy Cover); 30 x 10m transect** for tree/ shrub counts; 10 x 1m x 1m quadrats for Ground Cover.
Location (Plot Centreline): *Start* -27.34358 / 151.09559; *Finish* -27.343267 / 151.095999
Structure: Intact open forest with dominant *Eucalyptus camaldulensis*
Regional Ecosystem: 11.3.27d

Canopy Cover – Canopy Intercept (T1 / T2/ S1) (summarised 50 m transect)

Intercept (m)	Species	T1 - Canopy		T2 – Sub-canopy		S1 / S2 - Shrub	
		Intercept	Height	Intercept	Height	Intercept	Height
7 - 20	*E. camaldulensis*	13	19				
23 - 26	*E.camaldulensis*			3	12		
26 - 35	*E.camaldulensis*			9	13		
44 - 50	*E. camaldulensis*	6	24				
Total Cover		**19.0 (38.0*)**		**12 (24*)**			
Average Height			**21.0**		**9**		

* Projected over 100 m;

Stem Counts (50 x 10)

Species	50 m x 10 m Stems (50x4m)		
	T1	T2	S1/S2
E. camaldulensis	3	1	1
Acacia leiocalyx			9
Totals	**1**	**1**	**10**

Ground Cover %- 1 x 1m Sub-plots

Ground Cover Type	Species	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Mean May 2017
Native perennial grass / sedges	*Digitaria sp.*		2.5							5		**4.25**
	Paspalum distichum					15	10	5			5	
Native forbs and other spp.	*Lomandra longifolia*	30										**6.75**
	Juncus continuus		10				20					
	Laxmannia gracilis									2.5	5	
Native shrubs ,<1m		0	0	0	0	0	0	0	0	0	0	
Cryptogams												
Bare Ground		60	80	85	70	75	40	85	35	77.5	67.5	**67.5**

Ground Cover Type	Species	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Mean May 2017
Exotic Grass												
Exotic Forbs	*Conyza sp.*										2.5	**0.25**
Leaf litter		10	7.5	15	15	10	30	10	5	15	20	**13.75**
Timber (>/= 10cm)					15				60			**7.5**
Total		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Additional Species: ,

Structural / Floristic Summary

BioCondition Attribute		**February 2018**
Native Plant Species Richness	Tree:	1
	Shrub:	1
	Grass	2
	Forbs and other:	2
Native Trees	Canopy Height	21
	Projected Canopy Cover – T1 & T2 (%)###	62
	Projected Foliage Cover (%)##	37.5
	Projected Canopy Cover – Shrubs S1 / S2 (%)	10
	Average Height >1m	
Native Ground cover (%):	Native perennial grass / sedge cover (%):	
	Native shrubs (%)	
	Organic litter cover (%):	46.55
	Native forb cover	4.4
Non-native plant cover	Non-native Grasses	0
	Non-native shrubs / forbs	18.5

##Average measurements taken from canopy photographs 1 – 11

Transect LB31 – Start to End (February 2018)

Transect T4 – Glenburnie 20

Date of Assessment: 16 February 2018
Purpose of Assessment: Permanent Monitoring Site for Foliage Index.
Plot Size: 50 m linear transect (Canopy Cover); 30 x 10m transect** for tree/ shrub counts; 10 x 1m x 1m quadrats for Ground Cover.
Location (Plot Centreline): *Start* - -27.343362/ 151.095634; *Finish* -27.343267/ 151.095999
Structure: Intact open forest with dominant *Eucalyptus camaldulensis*
Regional Ecosystem: 11.3.27d

Canopy Cover – Canopy Intercept (T1 / T2/ S1) (summarised 50 m transect)

Intercept (m)	Species	T1 - Canopy		T2 – Sub-canopy		S1 / S2 - Shrub	
		Intercept	Height	Intercept	Height	Intercept	Height
1.5 – 3.2	*Callitris glaucophylla*					1.7	8
6.5 – 14.2	*Callitris glaucophylla*			7.7	13		
14.2 – 29.0	*Eucalyptus tereticornis*	14.8	22				
20.0 - 26	*Callitris glaucophylla*			6	13		
29.0 – 33.0	*Acacia salicinia*					4	8
33.0 – 40.0	*Angophora floribunda*	7	17				
38.0 – 39.0	*Callitris glaucophylla*					1	5
40.5 – 47.0	*Corymbia tessellaris*	6.5	23				
45.0 – 49.0	*Callitris glaucophylla*			4	16		
Total Cover		**28.3 (56.6*)**		**17.3 (34.6*)**		**6.7 (13.4*)**	
Average Height			**21.0**		**14**		**6**

* Projected over 100 m;

Stem Counts (50 x 10)

Species	50 m x 10 m Stems (50x4m)		
	T1	T2	S1/S2
E. camaldulensis	2	1	1
Callitris glaucophylla		11	6
Angophora floribunda	1	1	1
Acacia salicinia			1
Corymbia tessellaris	1		
Totals	**4**	**13**	**8**

Ground Cover %- 1 x 1m Sub-plots

Ground Cover Type	Species	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Mean May 2017
Native perennial grass / sedges	*Arundinella nepalensis*	2.5	5			5	20					**6.95**
	Austrostipa stipoides	2						2.5	2.5	10	10	
	Aristida sp.			5								

Ground Cover Type	**Species**	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Mean May 2017**
Native forbs and other spp.	*Lomandra longifolia*			10	15							**2.95**
	Cyperus gracilis	2			2.5							
Native shrubs ,<1m												
Cryptogams												
Bare Ground		40	40	80	57.5	69	47.5	47.5	47.5	20	0	**44.9**
Exotic Grass												
Exotic Forbs	*Sida spinosa*					1						**1.85**
	Verbena aristigera	5	5			5	2.5					
Leaf litter		47.5	50	5	20	20	30	50	50	70	90	**43.35**
Timber (>/= 10cm)												
Total		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Additional Species: ,

Structural / Floristic Summary

BioCondition Attribute		**February 2018**
Native Plant Species Richness	Tree:	4
	Shrub:	1
	Grass	3
	Forbs and other:	2
Native Trees	Canopy Height	21
	Projected Canopy Cover – T1 & T2 (%)###	62
	Projected Foliage Cover (%)##	37.5
	Projected Canopy Cover – Shrubs S1 / S2 (%)	10
	Average Height >1m	
Native Ground cover (%):	Native perennial grass / sedge cover (%):	6.95
	Native shrubs (%)	
	Organic litter cover (%):	43.35
	Native forb cover	2.95
Non-native plant cover	Non-native Grasses	0
	Non-native shrubs / forbs	18.5

##Average measurements taken from canopy photographs 1 – 11

Transect GB20 – Start to End (February 2018)

Appendix I – Foliage Index Assessments

Burunga Lane 182				
Meters along Transect	**Canopy Cover**	**Foliage Cover**	**Total Foliage**	**Foliage Ratio**
0m	30	75	22.5	0.75
5m	35	70	24.5	0.70
10m	70	65	45.5	0.65
15m	80	65	52	0.65
20m	75	60	45	0.60
25m	55	60	33	0.60
30m	30	60	18	0.60
	53.57	**65.00**	**34.36**	**0.65**

Longswamp 35				
Meters along Transect	**Canopy Cover**	**Foliage Cover**	**Total Foliage**	**Foliage Ratio**
0m	40	55	22	0.55
5m	30	56	16.8	0.56
10m	30	60	18	0.60
15m	35	60	21	0.60
20m	50	60	30	0.60
25m	50	75	37.5	0.75
30m	50	50	25	0.50
35m	60	50	30	0.50
40m	60	45	27	0.45
45m	35	50	17.5	0.50
50m	10	55	5.5	0.55
	40.91	**56.00**	**22.75**	**0.56**

Longswamp 31				
Meters along Transect	**Canopy Cover**	**Foliage Cover**	**Total Foliage**	**Foliage Ratio**
0m	45	80	36	0.80
5m	50	65	32.5	0.65
10m	70	65	45.5	0.65
15m	70	65	45.5	0.65
20m	70	75	52.5	0.75
25m	60	65	39	0.65
30m	60	70	42	0.70
35m	60	70	42	0.70
40m	25	80	20	0.80
45m	30	75	22.5	0.75
50m	50	70	35	0.70
	53.64	**70.91**	**37.50**	**0.71**

Glenburnie 20

Meters along Transect	Canopy Cover	Foliage Cover	Total Foliage	Foliage Ratio
0m	25	70	17.5	0.70
5m	50	65	32.5	0.65
10m	65	70	45.5	0.70
15m	60	60	36	0.60
20m	55	60	33	0.60
25m	70	60	42	0.60
30m	75	60	45	0.60
35m	70	60	42	0.60
40m	85	55	46.75	0.55
45m	90	50	45	0.50
50m	55	70	38.5	0.70
	63.64	**61.82**	**38.52**	**0.62**

Appendix J – GDE Decision Matrix (Preliminary without Stable Isotope Results)

Decision Process to Identify Groundwater Dependant Ecosystems (GDEs)

This document aims to facilitate an informed decision as to whether an ecosystem is expected to be reliant on the presence of groundwater. The method considers several lines of evidence which collectively provide confidence in the ecological and hydrogeological conceptual site model (CSM) which may or may not support the characterisation of each study site as a GDE. Through previous assessment undertaken by Arrow Energy and their consultants (such as Coffey, 2017, 3D Environmental/Earth Search, 2017a), preliminary CSMs have been developed for several potential GDEs within their Surat Basin Tenements, each requiring further assessment to better characterise GDE status. Phase 2 of the Arrow GDE Study Project involved the preparation of an Execution Plan (3D Environmental & Earth Search, 2017b) for this further assessment involving the establishment of a selection of detailed assessment and monitoring sites, and the initial (baseline) collection of new field data as lines of evidence to refine CSMs. Phase 3 of the GDE Assessment Project involves the field implementation of the programme of work detailed in the Execution Plan. Phase 3 does not include the ongoing monitoring at the GDE assessment sites. This decision process has been established to allow a preliminary refinement of potential GDE CSMs, and particularly GDE status, after the substantial collection and interpretation of new data collected during Phase 3 of the GDE study and is proposed to occur before embarking on an ongoing monitoring programme. The 'Decision Process' provided within encourages a "hold point" in the project where the CSM is refined and GDE status reviewed prior to embarking on monitoring which may prove unnecessary if there is a low confidence that the site/s present as a GDE. At the very least, the review process should allow a refinement of proposed monitoring objectives and scope prior to implementation of the monitoring programme. The process concerns particularly those localities proposed for detailed assessment and potential monitoring in the forthcoming GDE assessment program. In particular, these sites include groundwater monitoring bores Longswamp 31, Longswamp 35, Burunga Lane 82, Glenburnie 20. It should be noted that these sites, through the process of desktop assessment and field inspection, have already been assessed as having an existing vegetation type that is considered more likely to be accessing deeper groundwater sources (such as River Red Gum *Eucalyptus camaldulensis*)), and evidence of a groundwater table <20m depth. Types of data to be collected are:

1. Depth to the phreatic zone (SWL).
2. Rooting depth of trees collected from drill core.
3. Leaf water potential and soil moisture potential.
4. Stable isotope analysis of tree xylem and extracted soil moisture.

Table 1 details the data collection requirements, any relevant technical considerations, information dependencies, application of rules for each parameter measured and the likely timing for an assessment decision.

Table 2a applies a confidence score for data collected against each parameter regarding GDE identification. It should be noted that some parameters reflect a limited range of confidence values due to the nature of the data collected. As an example, identification of tree roots in cored material within the capillary fringe is considered diagnostic of a GDE, although absence of roots does not discount occurrence of a GDE as roots may have been missed during the coring process. **Table 2b** provides a definition of each confidence score.

Table 3 provides an aggregate score which combines scores for each parameter to provide confidence to the identification and assessment of each GDE site. It is intended as an arbitrary decision-making tool which considers multiple lines of evidence to assist the decision-making process.

Table 1. Information collection methods and technical considerations

GDE Characterisation requirement	Data Collection Process	Technical and other Considerations	Major information dependency	Rules Applied	Interpretation Timing
Identification of the Phreatic Surface (Standing Water Level) and the associated Capillary Fringe* within the likely rooting depth of tree species present (likely maximum 18m depth).	Shallow drilling (Sonic), construction of groundwater monitoring bores, and measurement of standing water levels.	The phreatic surface and associated capillary fringe may be seasonally variable in unconfined aquifers. Variations in SWL may be marked by geochemical horizons (Fe Oxides typically) which will be apparent in the drill core. Identification of these geochemical horizons may help define seasonal water usage by plants.	Rooting depth of trees identified through drill coring. Identification of tree roots within the capillary fringe will confirm a GDE although not being able to identify tree roots within the phreatic zone does not necessarily exclude the presence of a GDE (i.e. a line of evidence only)	- >18m to phreatic surface of uppermost aquifer (confined or unconfined – **Not a GDE.** - > 12m to <18m to upper phreatic surface – **Possibly a GDE.** - **<12m** to upper phreatic surface - **Likely to be a GDE**	Immediately upon drilling for phreatic surface depths > 18m. 2 – 4 weeks for Phreatic Surface depths < 18m following examination of drill core for tree roots.
Identification of tree roots in drilling core	Shallow drilling (Sonic) and detailed core inspection with hand lens (field), and stereo microscope (lab)	Tree roots will concentrate in the capillary fringe and generally won't penetrate into the zone of permanent saturation. Tree roots are generally spread widely throughout the vadose zone down to the phreatic zone and hence it is possible that tree roots will be missed by the drill core. The very fine nature of tree roots that are likely to occur within the capillary fringe means that detailed inspection (with stereo microscope) will be required.	Availability of suitable drill core for analysis and strong dependence on drill core intercepting rooting material.	- Rooting material within the capillary fringe or saturated zone of an aquifer is considered conclusive evidence that the site represents a GDE. Absence of intersected tree roots provides a line of evidence, although does not conclusively rule out the presence of a GDE.	2 to 4 weeks following completion of assessment to allow time for drill core inspection.
Leaf Water Potential / Soil Moisture Potential	Measurement of pre-dawn leaf water potential of trees at a potential GDE site / Measurement of soil moisture potential from soil samples in drill core.	The soil horizon / aquifer that a tree draws its predominant source of water from will likely vary throughout a climatic cycle. The leaf water potential will equilibrate with the water potential of the soil horizon that forms the predominant source of water for the plant at the time of measurement. High water potential recorded in leaf assessments will	Availability of drill core samples to analyse for soil moisture potential. Identification of root material in drill core coinciding with the inferred depth of tree groundwater extraction would add confidence to the assessment.	A measured leaf water potential that coincided with the water potential of soil in the phreatic zone, either shallow or perched, or a deeper aquifer gives high confidence of a GDE. Leaf water potential coinciding with that of the vadose	2 – 4 weeks following completion of drilling program to allow for analysis of leaf water potential and soil moisture potential data.

GDE Characterisation requirement	Data Collection Process	Technical and other Considerations	Major information dependency	Rules Applied	Interpretation Timing
		generally indicate extraction of groundwater from the phreatic zone, particularly when soil water potential of the overlying vadose zone is recorded as being considerably lower.		(unsaturated) zone would give a low level of confidence of the locality being a GDE.	
Stable Isotope Analysis	Analysis of stable isotope ratios (δ18O and δ2H) from water extracted from tree xylem water (stems), soil water and groundwater for comparative purposes.	Water may be drawn from a number of sources including from soil moisture and groundwater. Hence isotopic ratios may be mixed.	Availability of: - drillcore samples for extraction of soil moisture. - stems for collection of xylem water. - groundwater samples from an underlying aquifer <18m depth. Analysis to be undertaken by ANU.	Stable isotope ratios in water samples extracted from tree xylem that are comparative to isotope ratios in groundwater would infer a groundwater source (high confidence). Mixed ratios would be less certain and ratios that match those within samples extracted from soil moisture would indicate a low degree of confidence of the locality being a GDE.	4 – 8 weeks following dispatch of leaf, soil and groundwater samples to ANU. Allow time for data interpretation to be completed by ANU.

Table 2a. Confidence scoring for each source of information

Tree Rooting Depth	Confidence of GDE - Score	Lake Broadwater LS31a	Long Swamp LS35a.	Burunga Lane 182b.	Glenburnie 20
Tree roots identified in phreatic zone or capillary fringe <18m depth	1 (Conclusive)	Max tree root depth of 4m in fissured clay. Roots in and below perched water in shallow sandy aquifer. (1)		Could become (1) if shallow alluvium seasonally saturated.	
Tree roots not identified at phreatic zone	3 (Line of evidence against although inconclusive)		Maximum depth tree roots identified at 7.1m in LS35c (angle hole) with SWL at 15.8m (3)	Maximum depth tree roots identified at 6m depth in LS35b. No SW present in monitoring bore at time of assessment (3).	Maximum depth tree roots identified at 7.6m depth in GB20c (angle hole). (3).
Depth to Phreatic Zone	**Confidence of GDE**				
Depth to SWL <12m	2 (High degree of confidence though not conclusive)			Shallow alluvium aquifer unsaturated at time of assessment, but could become 2 if seasonally saturated.	
Depth to SWL >12m to <18m	3 (Line of evidence for the site representing a GDE although inconclusive in absence of tree roots)		SWL at 15.8m perched within a mostly depleted alluvium horizon, and perched above underlying clays and the regional alluvial aquifer (3).	Shallow aquifer intersected in coal seam at 13.5m. (note SWL rose to 7.5m under sub-artesian pressure) (3).	SWL 13.54m in shallow perched seepage zone in sandstone (3).
Depth to SWL >18m	4 (Considered unlikely to represent a GDE although is not conclusive).				
Leaf Water / Soil Moisture Potential	**Confidence of GDE**				
Pre -dawn leaf moisture potential is comparable to soil moisture potential in the phreatic zone	2 (High degree of confidence though not conclusive)	Yes – matches sand in the phreatic zone (2).			
Pre – dawn leaf water potential is lower than soil moisture potential in the phreatic zone although is higher than all soil moisture potential readings in the vadose zone.	3 (Moderate confidence that the site represents a GDE although not conclusive)				

Tree Rooting Depth	Confidence of GDE - Score	Lake Broadwater LS31a	Long Swamp LS35a.	Burunga Lane 182b.	Glenburnie 20
Pre-dawn leaf moisture potential matches soil moisture potential in the vadose zone (within one or several soil horizons) and is lower than soil moisture potential in the phreatic zone.	4 (Considered unlikely to represent a GDE although is not conclusive)**		Pre-dawn leaf water potential for Tree 1 matches soil moisture potential at 7 - 8m depth and for Tree 2 at 10.5m depth (4).	Pre-dawn leaf water potential for Tree 1 matches soil moisture potential at 6.5 m depth for tree 1 and tree 2 (4).	Pre-dawn leaf water potential for Tree 1 matches soil moisture potential at 5.4 m depth for tree 1 and tree 2 (4).
Stable Isotope Signatures	**Confidence of GDE**				
Stable isotopic signature from water contained in xylem is comparable to stable isotope signature measured from groundwater at the site.	2 (High degree of confidence though not conclusive)	Stable isotope signature matches zone of inferred groundwater uptake at 2.6mGL.			
Stable isotopic signature from water contained in xylem is intermediate between stable isotope signature of groundwater and soil moisture extracted from soils in the vadose zone. Represents extraction of moisture from a variety of sources which may include groundwater and soil moisture.	3 (Moderate confidence that the site represents a GDE although not conclusive)				
Stable isotopic signature in xylem matches stable isotopic signature of water extracted from soil in the vadose zone.	4 (Considered unlikely to represent a GDE although is not conclusive)**		Stable isotopic signature in xylem matches stable isotopic signature of water extracted from above regional aquifer (4)	Stable isotopic signature in xylem matches stable isotopic signature of water extracted from above regional aquifer at shallow depths in the soil profile (4).	Stable isotopic signature in xylem matches stable isotopic signature of water extracted from above regional aquifer at shallow depths in the soil profile (4).

** Note seasonal variations must be considered

Table 2b. Scoring for each assessment

Confidence of Site Being a GDE	Score
Conclusive – Site represents a GDE.	1
High confidence – High confidence that the site represents a GDE (although information is not conclusive).Further assessment and monitoring required	2
Low to Moderate confidence – Site may represent a GDE although evidence does not provide direct support. Further assessment and monitoring required	3
Low confidence – Site is considered unlikely to be a GDE although is not conclusive. Further assessment and monitoring required	4
Conclusive – Site does not represent a GDE	5

Table 3. Calculation of aggregate scores for each GDE parameter measured.

Rooting Depth	Depth to Phreatic Zone	Leaf Water / Soil Moisture Potential	Stable Isotope Signature
1**			
	2	2	2
3	3	3	3
	4	4	4

**Root material in the phreatic zone overrides all other assessment methods.

1 to 7 = Locality is accepted to be a GDE;

8 to 11 = Locality is considered likely to be a GDE although dependence is low or seasonal. Further assessment and monitoring required;

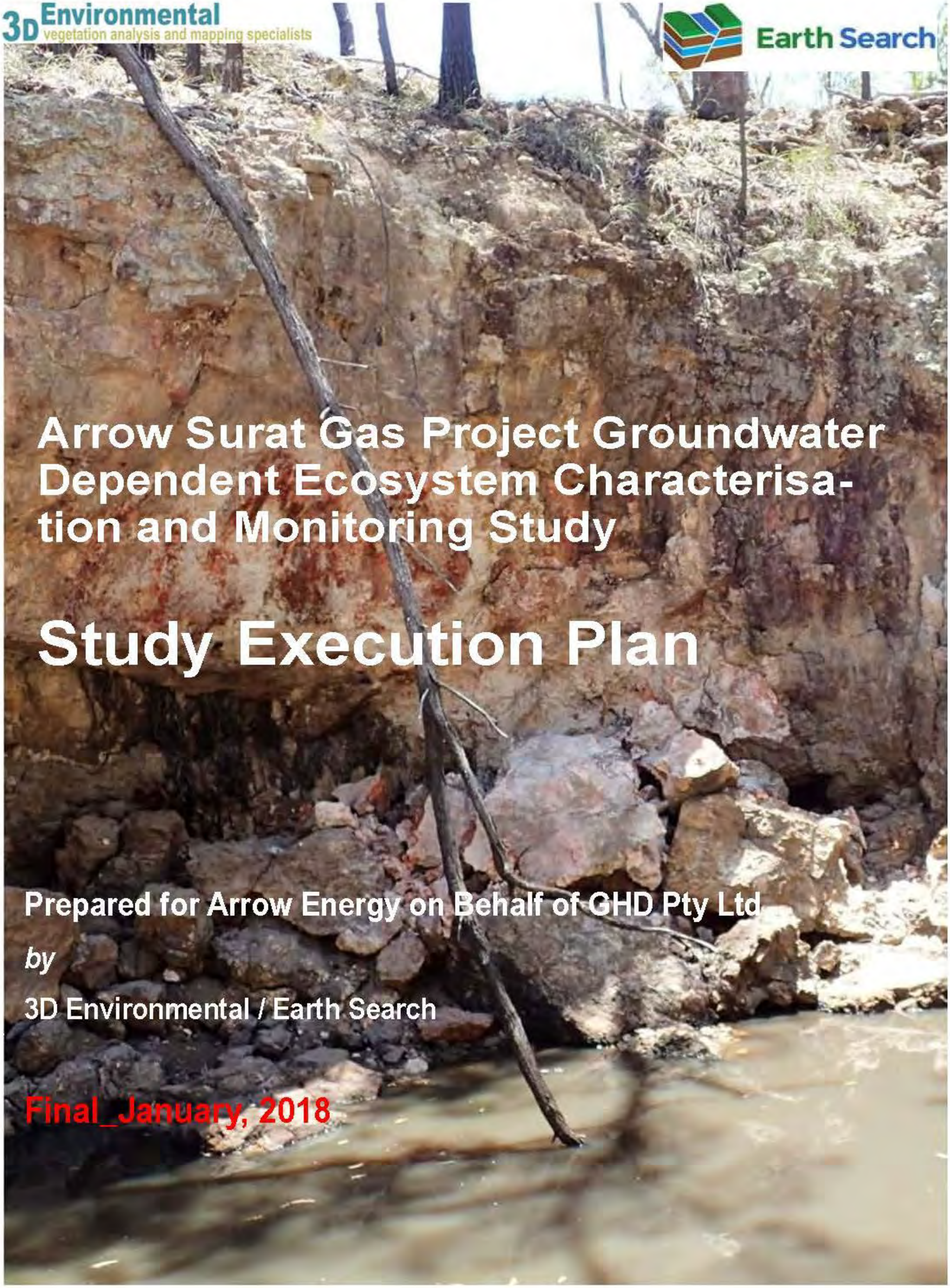
12 to 15 = Locality is considered unlikely to represent a GDE.

GDE Assessment Site	Tree Rooting Depth	Depth to Aquifer / Phreatic Zone	Leaf Water / Soil Moisture Potential	Stable Isotope Signature	Aggregate Score
Lake Broadwater	1				1
Long Swamp	3	3	4	4	14
Burunga Lane	3	3	4	4	14
Glenburnie	3	3	4	4	14

Appendix K. Study Execution Plan

3D Environmental
vegetation analysis and mapping specialists

Earth Search



Arrow Surat Gas Project Groundwater Dependent Ecosystem Characterisation and Monitoring Study

Study Execution Plan

Prepared for Arrow Energy on Behalf of GHD Pty Ltd

by

3D Environmental / Earth Search

Final_January, 2018

Project No. 2017_203

Project Manager: David Stanton

Client: Arrow Energy

Purpose: Surat Gas Project GDE Characterisation and Monitoring Assessment – Study Execution Plan

Draft	Date Issued	Issued By.	Purpose
Draft 1	28 August 2017	David Stanton/ Ned Hamer	First draft execution plan
Draft 2	20 November 2017	David Stanton/ Ned Hamer	Second draft incorporating comments and additional procedure
Final	30 January 2018	David Stanton/ Ned Hamer	Finalised document incorporating decision matrix

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CONTENTS

List of Figures

1 INTRODUCTION

Arrow Energy (Arrow) issued a request for proposal (RFP) on 12th June 2017 to undertake two phases of work related to ongoing assessment of groundwater dependent ecosystems (GDEs), and the potential impact on these ecosystems from the Surat Gas Expansion project (SGP).

Phase 1 of the RFP comprised a review of potential GDE assessment and monitoring methodology proposed in a File Note from Chris Jones (Arrow) Dated 07/06/17; *SUBJECT: Surat Groundwater Dependent Ecosystems Proposed Study Scope*. The outcome of this phase of work was provided in a letter report from 3d Environmental and Earth Search, dated 21 July, 2017 after review and refinements provided by Arrow.

Phase 2 of the RFP required the development of a GDE study execution plan (this document) based on the outcome of the Phase 1 review, including the selection of preferred GDE assessment and monitoring methods. This execution plan involves a detailed description of methods involved in the proposed implementation of an initial (baseline) field GDE assessment and installation of monitoring infrastructure. The Phase 2 scope does not include methods for ongoing monitoring, although it is considered likely that some of the methods adopted in this phase of work will be replicated on an ongoing basis for assessment of any changes from baseline conditions, and review of trends. The Phase 2 scope does not include implementation (fieldwork and reporting of results) of the study execution plan.

1.1 PROJECT BACKGROUND

Arrow Energy's (Arrow) Surat Gas Expansion Project's (SGP) Federal Environmental Approval Conditions require the development of a Coal Seam Gas (CSG) Water Monitoring and Management Plan (WMMP) to demonstrate how each obligation will be addressed. As part of this WMMP, three conditions relating to groundwater dependent ecosystems (GDEs) are required to be met, namely:

- Condition 13c: An assessment of potential impacts on non-spring based GDEs through potential changes to surface-groundwater connectivity and interactions with the sub-surface expression of groundwater.
- Condition 13f: A baseline monitoring network that will enable the identification of spatial and temporal changes to surface water and groundwater. This must include a proposal for aquifer connectivity studies and monitoring of relevant aquifers to determine hydraulic connectivity (including potential groundwater dependence of Long Swamp and Lake Broadwater) and must also enable monitoring of all aquatic ecosystems that may be impacted.
- Condition 13p: A cumulative impact assessment based on the outputs of the OGIA model which integrates groundwater model outputs with known and potential GDEs. Contribute to investigations coordinated through the OGIA to assess hydrological and ecological characteristics of impacted GDEs.

The Phase 1 work required a critical review of the monitoring methodology proposed to meet the above conditions as outlined in the Arrow File Note, and to provide either endorsement of the methodology or recommendations for alternate methods to ensure the study objectives are sufficiently addressed.

The proposed study scope presented by Arrow is based on a literature review of applicable methods for GDE investigation and monitoring of four identified areas within Arrow's project tenure. The scope of this assessment (both Phase 1 and Phase 2) do not involve a determination or review of the proposed monitoring locations or sites. Specific objectives of Phase 1 and Phase 2 (this phase) are provided in the Objectives - **Section 1.2**. The assessment to identify the monitoring sites was carried out by Coffey Environments as SGP Stage 1 - CSG WMMP (Coffey Environments 2017). This document was included as an attachment to the Arrow File Note within the original RFP.

Arrow has previously commissioned and completed multiple phases of investigation and assessment aimed at gaining an understanding of the project's potential impact on GDEs. The findings from this body of work has identified discrete geographic areas of risk that require further assessment, and has informed Arrow's development of a method by which to continue with further studies of risk to GDEs from potential depressurisation of aquifers.

A useful summary of the chronology of GDE studies undertaken by Arrow from 2008 to 2017 is presented in Schematic 1 on page 7 of the Coffey Environments (2017) attached to the Arrow File Note. The sequence of studies has allowed an iterative process of refinement of GDE risk areas.

Previous studies which have dealt specifically with GDEs within Arrow tenements and surrounding areas include an assessment of potential spring GDEs undertaken by AGE (2015). Subsequent reports include:

1. A characterisation of GDE types and distribution throughout Arrow Energy Tenements undertaken by 3d Environmental and Earth Search (2017) - Identification and Assessment of Groundwater Dependent Ecosystems – Surat Gas Project). Preliminary recommendations for monitoring of GDEs were made within this document.
2. Additional risk assessment of GDEs was provided within the SGP Stage 1 CSG WWMP (Coffey Environments 2017). A primary aim of the assessment was to screen potential GDEs to identify those at higher risk of impact through CSG related groundwater drawdown.

Coffey Environments (2017) relied on groundwater modelling undertaken by CDM Smith (2016) for Condamine River Alluvium (CRA) Aquifers and GHD (2013) for non-alluvial aquifers for its assessment to identify 'High Risk GDE Areas', which were defined as aquifers where >1m drawdown is predicted to occur over the life of the project. These areas were targeted for further assessment and numerous risk factors were evaluated which considered such factors as:

- Species identified at the site do not typically utilise groundwater.
- Groundwater is too deep to be accessed by plants.
- Shallow lithology does not allow root penetration to groundwater level.
- Modelled drawdown impacts are unlikely to propagate to the groundwater table due to intervening aquitard lithologies.
- Rate of modelled drawdown change is sufficiently slow to allow plant adaptation.
- Background fluctuations in groundwater level would render modelled changes as insignificant or immeasurable.

From the risk assessment completed by Coffey Environments (2017), five areas were identified for future monitoring purposes with a preference to refine further to four monitoring sites. These, as shown in **Figure 1** are:

1. Risk Area 4 GDE Investigation Site (northern portion of Arrows Tenements between Miles and Wandoan)
2. Risk Area 3b GDE Investigation Site (northwest of Millmerran); or Cumulative Risk Area 6 GDE Investigation Site (southwest of Millmerran).
3. Long Swamp GDE investigation site.
4. Lake Broadwater GDE investigation site.

The initial three sites are chosen to satisfy Condition 13c whilst monitoring of Lake Broadwater and Long Swamp areas is a requirement of Condition 13f. Risk Area 3b has been chosen as the location for ongoing assessment during the proposed survey with no work planned for Cumulative Risk Area 6 at this stage and it is not considered further in the assessment.

The refinement process completed by Coffey Environments (2017) removed several previously identified risk areas based on one or more mitigating factors. The rationale provided for carrying through the three Risk Areas to be included in the proposed Study scope is summarised below:

Risk Area 3b is located south-west of Cecil Plains on the western slopes of the Kumbarilla Ridge. Limited depth to groundwater data is available for the area and where Red River Gums (*Eucalyptus camaldulensis)* are present they may access groundwater in the Springbok Sandstone. In the southern part of Risk Area 3b the maximum predicted drawdown is 3.9 m with a rate of change of groundwater drawdown estimated to range between 0.07 to 0.3 m/yr based on hydrograph analysis. The predicted rate of change is within the historical range of variability. However, the overall drawdown of almost 4 m in this southern part of Risk Area 3b may result in vegetation stress if critical groundwater access thresholds are exceeded. Therefore, terrestrial GDEs in the southern part of Risk Area 3b are considered potentially at risk from groundwater drawdown.

Risk Area 4 is located to the south and west of Wandoan and is associated with potential areas of shallow Walloon Coal Measures subcrop. The Westbourne Formation and Springbok Sandstone (upper members of the Injune Creek Group) generally outcrop in this area, as well as shallow alluvial deposits along some drainage lines. Maximum predicted drawdown in the Walloon Coal Measures in Risk Area 4 ranges from 1.5 to 10 m. The rate of groundwater drawdown in the Walloon Coal Measures in this area may be up to 4

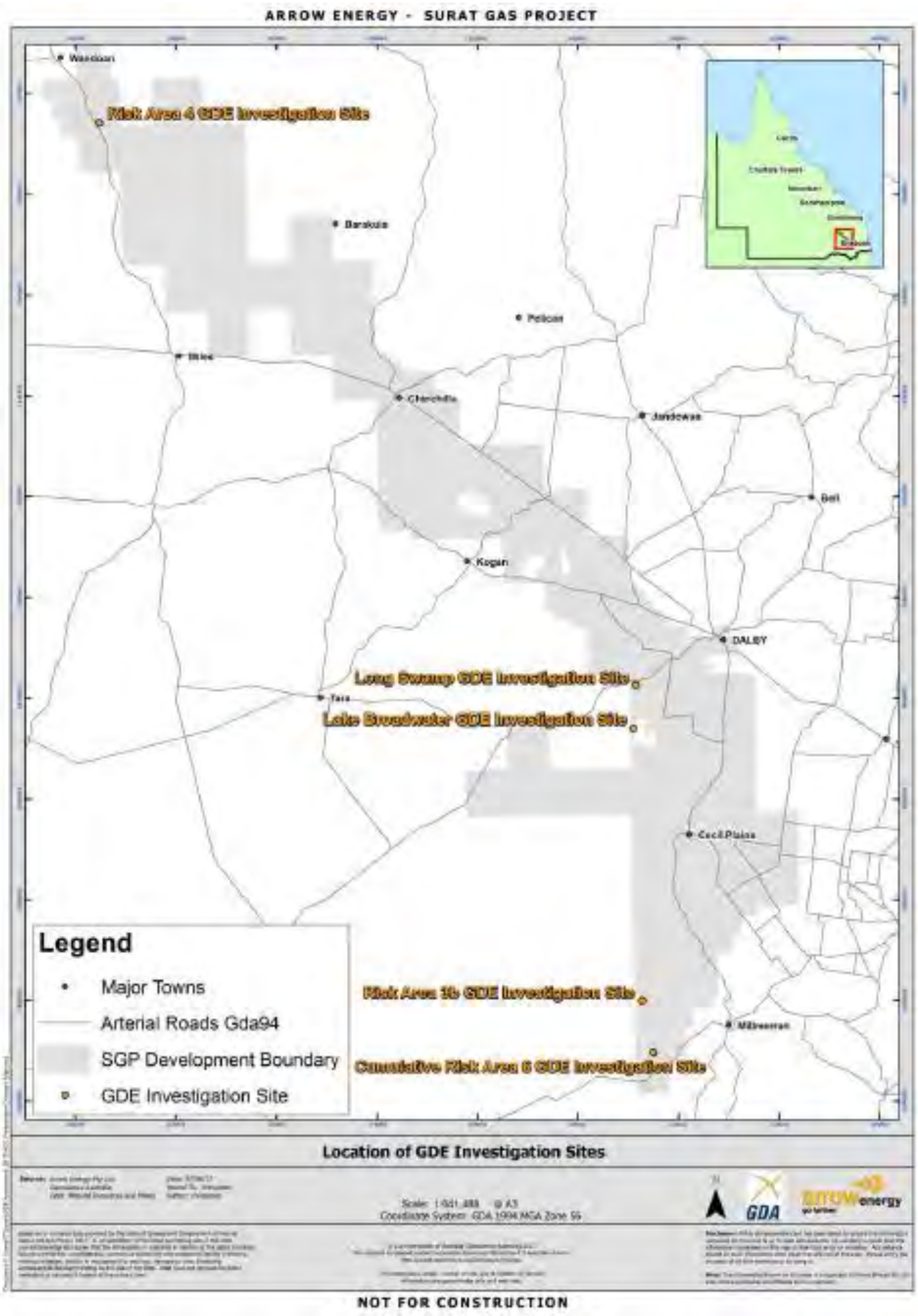


Figure 1 . Location of GDE assessment sites

m/yr early in the project life. Given this potential rate of change, and the potential for the presence of River Red Gums, GDEs in the northern parts of Risk Area 4 may be at risk of impact from groundwater drawdown in the Walloon Coal Measures.

Further review of ecological and geological factors at each proposed monitoring localities was undertaken by 3d Environmental/Earth Search during Phase 1 of this assessment to identify potential site conditions and constraints that may inform or direct GDE assessment methods. This information is provided in **Section 2**.

1.2 PROJECT OBJECTIVES

Objectives of Phase 2 of the GDE Study, as provided by Arrow Energy are:

- Identify if vegetation accesses groundwater (permanently or intermittently) to verify assumptions used in previous desktop GDE assessments.
- Identify the degree of connection between aquifer units (including coal formations) to verify if propagation of drawdown in deeper coal measures will impact shallow formations.
- Identify stratigraphy to confirm geological mapping at monitoring sites.

1.3 GDE MONITORING STUDY SCOPE

The scope of work required to complete Phase 2 objectives is as follows:

- Field ecological and hydrogeological characterisation of potential GDE sites,
- Installation of monitoring infrastructure.
- Data collation and reporting.

The techniques and methodologies identified to be used in this phase of the project are presented in **Section 7**. The assessment will also require clarification as to whether each assessment site does or does not meet the definition of a GDE. To facilitate this process, a GDE Decision Matrix was developed specifically to provide a measure of confidence in the GDE assessment. This decision matrix is included in **Appendix 2**.

2 BACKGROUND INFORMATION

The following information provides a preliminary ecological and geological characterisation of the features at each of the proposed monitoring sites to provide background to the assessment.

2.1 BURUNGA LANE

The Burunga Lane monitoring site (in Risk area 4) lies within ATP 810 between the townships of Wandoan and Miles to the west of the main channel of Juandah Creek. Three groundwater monitoring bores are proposed for this locality, including two deeper monitoring bores drilled into the Walloon Coal Measures (BL183 and BL184) and an additional shallow monitoring bore drilled into the overlying alluvium (BL182) to a maximum depth of approximately 30m. This execution plan details the work proposed for the shallow alluvium bore. The drilling program for the two deeper bores will be managed by Arrow Energy utilizing a different drilling subcontractor. While the execution details of the deeper bore drilling program are not provided here, these bores are complementary and together form part of the larger GDE groundwater assessment/monitoring network. The locations and depths of the proposed monitoring bores are listed below, along with the bore location plan shown in **Figure 2**. Well Specification Cards provided by Arrow are included in Appendix 3.

1. Burunga Lane 183 (-26.241641, 150.04367) – Target Seam is Walloon Coal Measures
2. Burunga Lane 184 (-26.241643, 150.04377) – Target seam is Walloon Coal Measures
3. Burunga Lane 182 (-26.242235, 150.044666) – Target lithology is shallow alluvium (estimated maximum 30m depth).

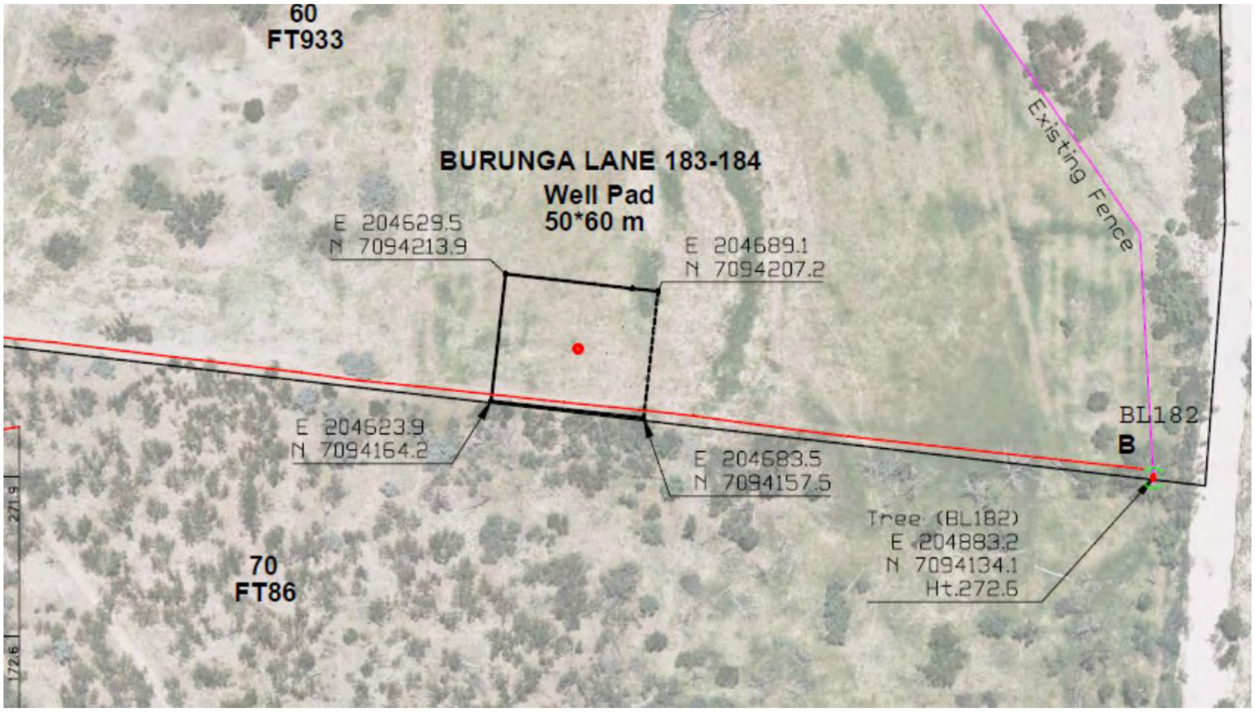


Figure 2. Location of proposed monitoring bores at the Burunga Lane site.

Ecology: The deeper monitoring bores (BL183 and BL184) are located on the margins of disturbed remnant vegetation (RE11.3.2). The mature trees in the immediate vicinity are likely to be Poplar Box which will potentially be accessing groundwater in a shallow alluvial aquifer if groundwater levels as high as 7.6mbtc are assumed as indicated in the shallow monitoring bore approximately 500m east of the proposed monitoring localities (-26.242904, 150.049992).

Shallow monitoring bore BL182 is located within 20m of the western bank of Juandah Creek with the proposed monitoring borehole placed directly adjacent to a mature River Red Gum that was selected during reconnaissance survey. It is proposed that the shallow monitoring borehole will be drilled to a depth of 20m, the inferred maximum rooting depth of fringing riparian trees.

Geology and Hydrogeology: Juandah Creek in this locality would be representative of a 'shallow alluvial system' as described by 3D Environmental/Earth Search (2017) with a shallow alluvial mantle, a component of the 'Juandah Creek flood plain system with shallow alluvium overlying weathered horizons of the Walloon Coal Measures. Drilling logs from the nearby Burunga Lane CSG pilot wells located approximately 350m from the proposed monitoring site suggest that the Macalister Seam within the upper Walloon Coal measures was intersected immediately below (approx. 5m depth) the shallow unconsolidated cover.

Figure 3. River Red Gum on the margins of Juandah Creek at the locality of proposed shallow monitoring bore BL182.

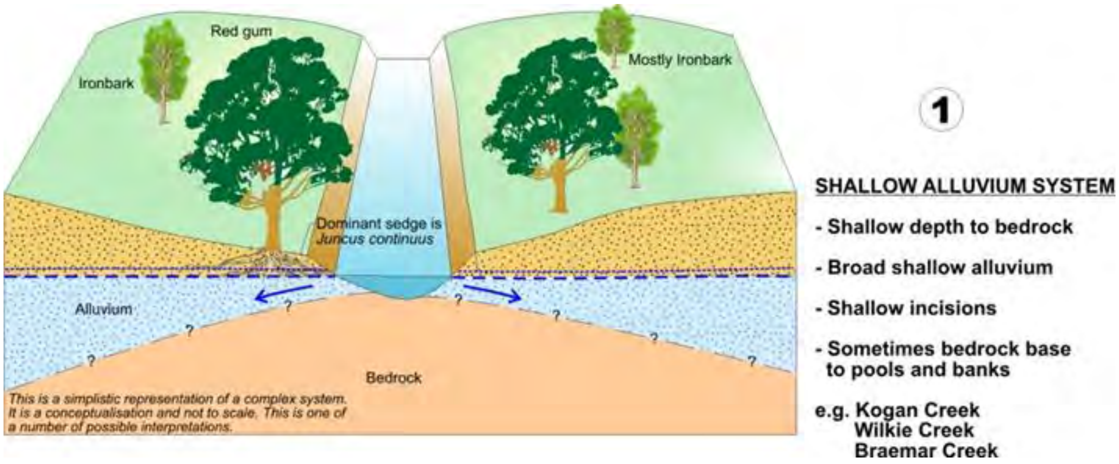


Figure 4. Diagrammatic illustration of a Shallow Alluvium GDE system.

2.2 GLENBURNIE

The Glenburnie monitoring site (in Risk area 3b) lies within ATP683, approximately 17km north-west of Millmerran. The site is located on a Western Creek, which is weakly incised into deeply weathered sediments of the Kumbarilla Beds. Three groundwater monitoring bores are proposed in this locality including two deeper bores drilled into the Walloon Coal Measures and a shallow bore targeting the Alluvium to a maximum depth of approximately 30m.

The locations and depths of the proposed monitoring bores are listed below. Well Specification Cards provided by Arrow are included in Appendix 3.

1. Glenburnie 20 (-27.833051, 151.097162) – Target lithology is shallow alluvium (estimated maximum 30m depth).
2. Glenburnie 21 (-27.832889, 151.097582) – Target Seam is Walloon Coal Measures
3. Glenburnie 22 (-27.83289, 151.097683) – Target Seam is Walloon Coal Measures.

This execution plan details the work proposed for the shallow alluvium bore. The drilling program for the two deeper bores will be managed by Arrow Energy utilizing a different drilling subcontractor. While the execution details of the deeper bore drilling program are not provided here, these bores are complementary and together form part of the larger GDE groundwater assessment/monitoring network.

Ecology: The water bores are co-located in a cleared paddock, on the margins of a well vegetated alluvial flat. Government vegetation mapping indicates RE11.3.2 is the dominant ecosystem formed by Poplar Box. River Red Gum is only likely on the immediate stream margins where it would be associated with RE11.3.25. Registered borehole RN32726A indicates groundwater levels in the Springbok Sandstone were 14.6m in 1969, and had dropped to 23.5m in 1983.

Geology and Hydrogeology: The watercourse in this locality would be representative of a 'shallow alluvial system' as described *Assessment of Groundwater Dependent Ecosystems; Arrow Surat Gas Project* (3d Environmental/Earth Search, 2017). with a shallow alluvial mantle overlying weathered horizons of the Springbok Sandstone and Walloon Coal Measures. The unknown factor is whether there is an ecological driver for River Red Gum to tap deeper aquifer sources, or if tree water requirements are being met by soil moisture stored in a shallow perched water table which is seasonally replenished. The maximum drilling depth in the shallow borehole is proposed as 20m, the inferred maximum rooting depth of riparian trees.

Figure 5. The proposed locality of monitoring bore site Glenburnie 20 adjacent to Western Creek.

2.3 LAKE BROADWATER

A total of 4 monitoring bores are proposed for Lake Broadwater. Three deeper monitoring bores are proposed to be located to the west of the lake with a shallow monitoring bore located on the lake margins. The deeper monitoring bores will be constructed in different geological formations to facilitate further connectivity investigation / monitoring as required. Details of monitoring bores including target lithology and proposed depth are provided below:

1. LS28 (-27.34125, 151.09221) – Target lithology is Westbourne Formation (30m depth).
2. LS29 (-27.34125, 151.09221) – Target lithology is Springbok Sandstone (140m depth).
3. LS30 (-27.34125, 151.09221) – Target lithology is Walloon Coal Measures (188m or first major coal seam).
4. LS31 (-27.343471, 151.095733) – Target lithology is weathered upper portions of the Westbourne Formation or alluvium (maximum 20m depth)

This execution plan details the work proposed for the shallow alluvium bore. The drilling program for the three deeper bores will be managed by Arrow Energy utilizing a different drilling subcontractor. While the execution details of the deeper bore drilling program are not provided here, these bores are complementary and together form part of the larger GDE groundwater assessment/monitoring network.

Proposed monitoring bore LS31 lies on the north-western side of Lake Broadwater within several metres of the water edge. A preliminary Conceptual Model for Lake Broadwater is presented in *Identification and Assessment of Groundwater Dependent Ecosystems; Arrow Surat Gas Project* (3d Environmental/Earth Search, 2017). The proposed groundwater monitoring site is located on a shallow sandy mantle of stranded shoreline deposits that fringes Lake Broadwater. The sandy feature is at its narrowest in this locality and broadens considerably toward the north-east where it forms a fringe around the lake that is approximately 250m wide. The site is located within fringing wetland woodland to open forest dominated by River Red Gum (RE11.3.27b). A question that should be answered through the proposed further assessment and monitoring program is whether the red gum is tapping shallow seasonal groundwater sources within the sandy mantle, a deeper wetting front that underlies Lake Broadwater, or possibly a deeper aquifer in the Springbok Sandstone.

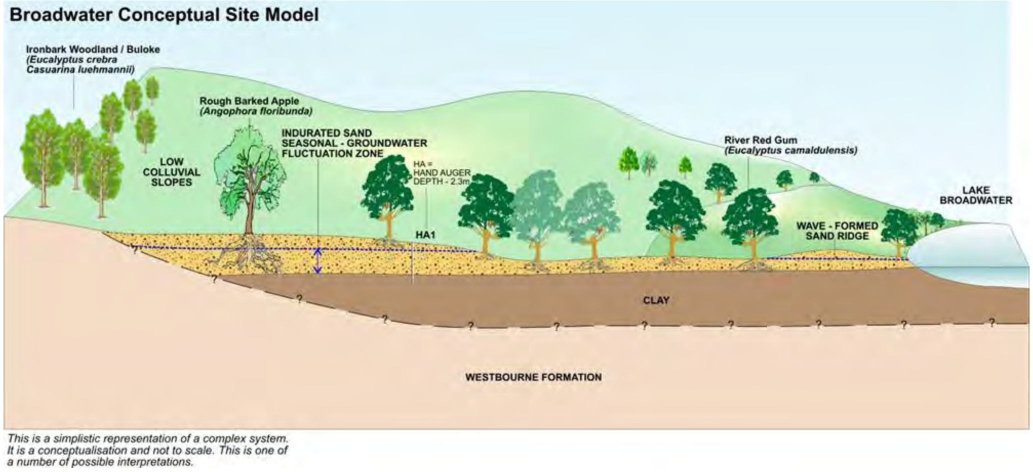


Figure 6. Diagrammatic illustration of Lake Broadwater – conceptual site model.

Figure 7. The proposed locality of GDE monitoring site Long Swamp 31 (Photograph supplied by Arrow Energy).

2.4 LONG SWAMP

Proposed groundwater monitoring bore Long Swamp 35 lies within the central linear depression of Long Swamp within PL 260 (-27.269982, 151.094634). A preliminary Conceptual Model for Long Swamp is presented in 3d Environmental/Earth Search (2017). This locality will have 3 deeper monitoring bores (LS 32, LS33 and LS34) which will be constructed in separate formations for the purpose of connectivity investigation/monitoring. A single shallow monitoring bore for the purpose of GDE characterisation (LS35) will also be constructed. Well locations, target formations and proposed depth are listed below:

1. LS32 (-27.268355,151.095389) – Target lithology is base of the Westbourne Formation (75m depth).
2. LS33 (-27.268257,151.095406) – Target lithology is base of the Springbok Sandstone (105m depth).
3. LS34 (-27.268159,151.095423) – Target lithology is Walloon Coal Measures (130m or first major coal seam).
4. LS35 (-27.343471, 151.095733) – Target lithology is the base of the Condamine River Alluvium (CRA) above the weathered upper portions of the Westbourne Formation (maximum 25m depth).

This execution plan details the work proposed for the shallow alluvium bore. The drilling program for the three deeper bores will be managed by Arrow Energy utilizing a different drilling subcontractor. While the execution details of the deeper bore drilling program are not provided here, these bores are complementary and together form part of the larger GDE groundwater assessment/monitoring network.

The proposed shallow GDE monitoring site (LS35) is located centrally within the broad sinuous swampy depression that forms Long Swamp. Vegetation is largely native with a groundcover of Water Chestnut

(*Eleocharis dulcis),* Nardoo (*Marsillea drummondii)* and patch covering of the exotic Condamine Couch (*Phylla canescens).* The canopy is formed by tall, broadly spaced River Red Gum at approximately 50% cover. The canopy is significantly stressed in some areas with signs of senescence and foliage loss. Determining the predominant source of water usage by the red gum is a central focus of this assessment, specifically to determine whether trees are utilising shallow soil moisture held in the upper vertic soil profile, or deeper aquifer sources contained within sandy horizons deeper within the CRA, or the Springbok Sandstone.

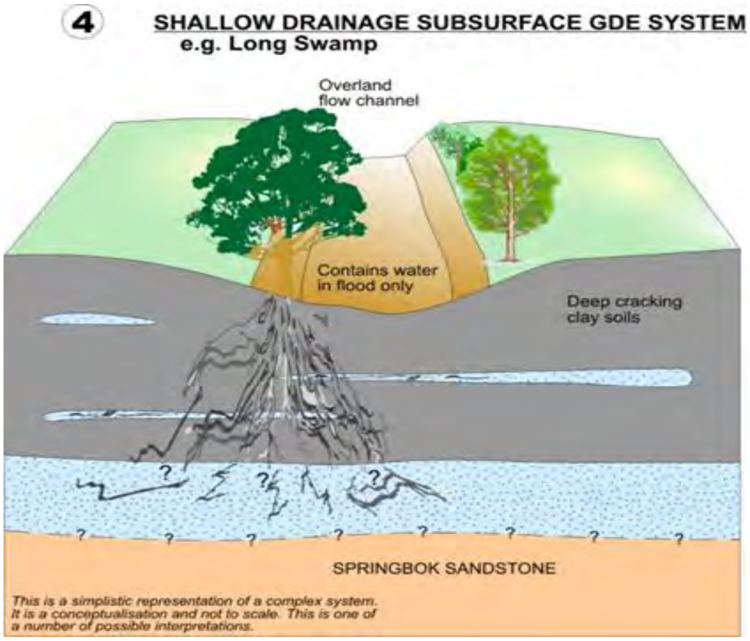


Figure 8. Conceptual model of the Long Swamp GDE system.

Figure 9. Photograph of the chosen monitoring locality at LS35 (photograph provided by Arrow Energy).

3 PROJECT TEAM

3.1 ORGANISATION STRUCTURE, ROLES AND RESPONSIBILITIES

The project team, comprising Arrow, GHD, 3D Environmental, Earth Search and their subcontractors is expected to be organised in the structure presented in **Figure 10**, which includes individual team members and responsibilities.

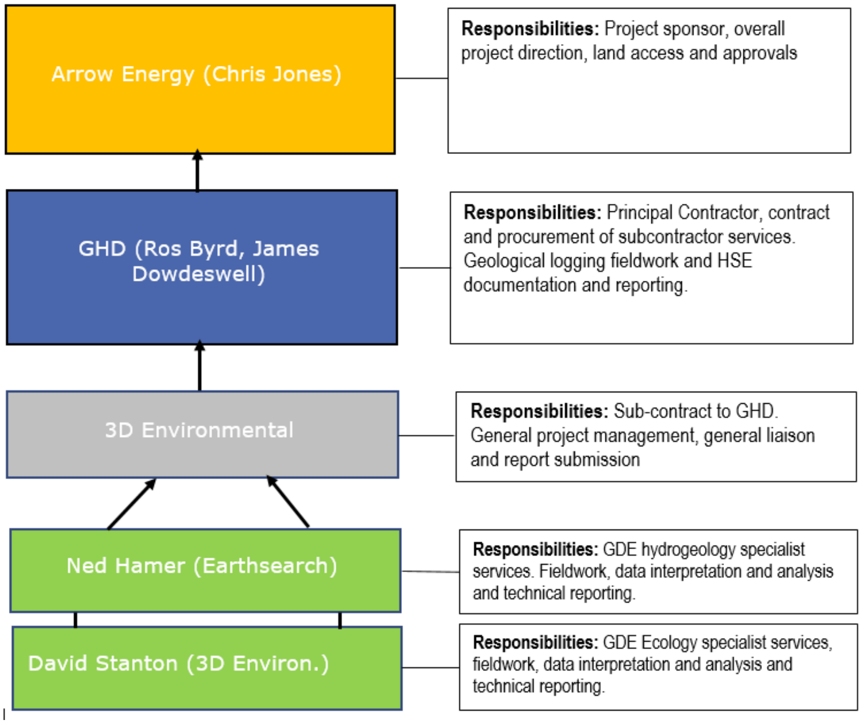


Figure 10. Proposed project management structure**.**

3.2 PROJECT INTERFACES

The GDE Phase 2 study will interface with other components of Arrow's CSG project. This will primarily be through the project sponsor and client representative assigned as interface with 3d. However, it is probable that there will be direct communication with other parts of the business such as land liaison officers, HSSE representatives and other stakeholders internal to Arrow.

External stakeholders are local, state and federal regulators, community and special interest groups, and suppliers/contractors.

4 PROJECT SCHEDULE AND MILESTONES

The first mobilisation for shallow drilling will commence on December 4, 2017 with the Burunga Lane locality (BL182) being the first to be completed. This will be followed by Lake Broadwater (LS31) and Long Swamp (LS35) completed between December 9 and December 19. Drilling at the Glenburnie site is anticipated to be delayed due to government approvals and is currently scheduled for completion in January 2018. The deeper drilling program is also planned for commencement in December 2017 and will run in parallel, although is expected to run through into 2018. The deeper drilling program will be managed by Arrow Energy.

Table 1. Proposed drilling schedule

Location	Shallow Drilling Borehole	Scheduled Commencement	Scheduled Completion
Burunga Lane	BL182	December 4, 2017	December 8, 2017
Long Swamp*	LS135	December 9, 2017	December 14, 2017
Lake Broadwater*	LS131	January 2018 (TBA)	TBA
Glenburnie	GB20	January 2018 (TBA)	TBA

*The order for drilling of LS135 and LS131 TBA.

Project Deliverables

The project deliverables will include:

- HSE Deliverables including JSEAs, SWMS and Travel Management planning as per requirements of Arrow Energy and GHD.
- A GDE assessment report that incorporates:
    - Raw data derived from laboratory analysis of stable isotopes and groundwater geochemical characterisation.
    - Raw data from field measurement of soil moisture potential, leaf water potential and groundwater monitoring.
    - Raw data derived from drill core including lithological characterisation and examination of core for rooting material.
    - Interpretation of physical and geochemical parameters measured including integration of data derived from a range of methods and sources (i.e leaf water potential, soil moisture potential and isotopes etc) to determine the ecological function at each assessed GDE site.
    - Synopsis that presents a concise characterisation of the GDEs and / or GDE potential at all proposed monitoring sites.
    - Integration of comments and data interpretation provided by ANU in regard to results of the isotopic analysis of soil moisture and xylem water.
    - Recommendations for ongoing assessment and monitoring.

5 HEALTH SAFETY SUSTAINABILITY AND ENVIRONMENT [HSSE]

The precise details are to be confirmed with Arrow Energy and GHD. Arrow's HSE Standard provides the minimum mandatory requirements for contractors and sub-contractors. 3D Environmental will comply with or exceed these requirements and align with any additional HSE requirements of GHD, the primary contractor. Task specific JSEAs will be prepared by 3D Environmental for review prior to undertaking field assessment task.

6 HYDROGEOLOGICAL AND ECOLOGICAL CHARACTERISATION AND MONITORING

6.1 INTRODUCTION

Arrow undertook a literature review of available methods for GDE assessment based on the identification of potential GDE localities from preceding programs of work. Methods were chosen based on applicability and cost-benefit and were reviewed as part of the Phase 1 work completed by 3D and Earth Search. A range of potential methods were considered and include measurement of both ecological and hydrogeological parameters.

6.2 IDENTIFIED METHODS

A synthesis of methods is considered to provide the best approach to developing a robust monitoring plan that will satisfy all stakeholders. The combined information obtained from the following methods will provide multiple lines of evidence suitable for assessing potential impacts on GDEs:

- Coring to root depth
- Groundwater monitoring and baseline hydrogeological characterisation
- Stable isotope analysis
- Leaf water potential
- Leaf area index (and ecological characterisation)

6.3 CORING TO ROOT DEPTH

6.3.1 Rationale

Dual aims of this coring activity are:

1. Assessment (through observations of presence in core) of tree root depth; and
2. Assessment of the hydraulic properties of the geological formations.

The key question to be assessed through this study is: are GDE species accessing groundwater present in the underlying formations that are forecast by modelling to be potentially affected by depressurisation? If they are, then further assessment and monitoring is required to determine if the magnitude of groundwater level fluctuation is likely to have any discernible or material impact on GDE health.

If GDE species are not likely tapping the identified potentially affected aquifer formation, but rather a shallower overlying aquifer, then a secondary key question to be answered is: what is the hydraulic connectivity between the 2 aquifer formations?

Coring observations and analysis of core samples for permeability (and subsequent hydraulic testing such as pump/slug testing) will allow the collection of data to assist answering these questions and quantifying any potential impacts through refinement of conceptual and numerical models.

Permeability data will directly address Federal Government Approval Condition 13f regarding "…aquifer connectivity studies and monitoring of relevant aquifers to determine hydraulic connectivity…"

6.3.2 Methodology

6.3.2.1 Coring Drilling Rig

Geological coring and installation of groundwater monitoring bores will be carried out with a Commachio MC900 sonic drilling rig. A sonic drilling rig employs a combination of rotation and high-frequency vibration for drill bit penetration. This method is suitable for use in either consolidated or unconsolidated materials. The advantages of this technology are rapid drilling rates, optional recovery of a continuous core, and relatively minimal amounts of waste generated.

Figure 11. Commachio MC900 sonic drilling rig in the field.

The selected drilling rig is equipped with sonic, rotary air, water and mud drilling method capabilities, and can also advance casing in the event of unstable formation conditions. A single rig with multiple capabilities was selected to allow flexibility within the drilling program due to uncertainty and likely variability in geological conditions, and minimize the risk of significant compromises to data gathering objectives. However, it cannot be ruled out that a second rig may be required if drilling objectives are significantly compromised due to unforeseen subsurface conditions.

Also given many of the monitoring sites are located within sensitive (GDE) landscapes, another reason for selection of the sonic drilling rig was choice of a rig with both a minimal disturbance footprint, as well as speed/efficiency features to minimize the time on site.

The diameter and method of drilling will depend on the geological conditions encountered. However currently it is anticipated that groundwater monitoring bores will be installed within a 9” (228.6mm) hole with temporary 9” casing advanced in the event of collapsing formation conditions. This gives the flexibility to install both 100mm and 50mm diameter uPVC nested monitoring bores within the same borehole. The default monitoring bore construction where only one aquifer is encountered is a 100mm diameter bore in an 8” or 9” bore hole. The diameter of the recovered core is 6”, which will allow sufficient volume of the considerable sample required.

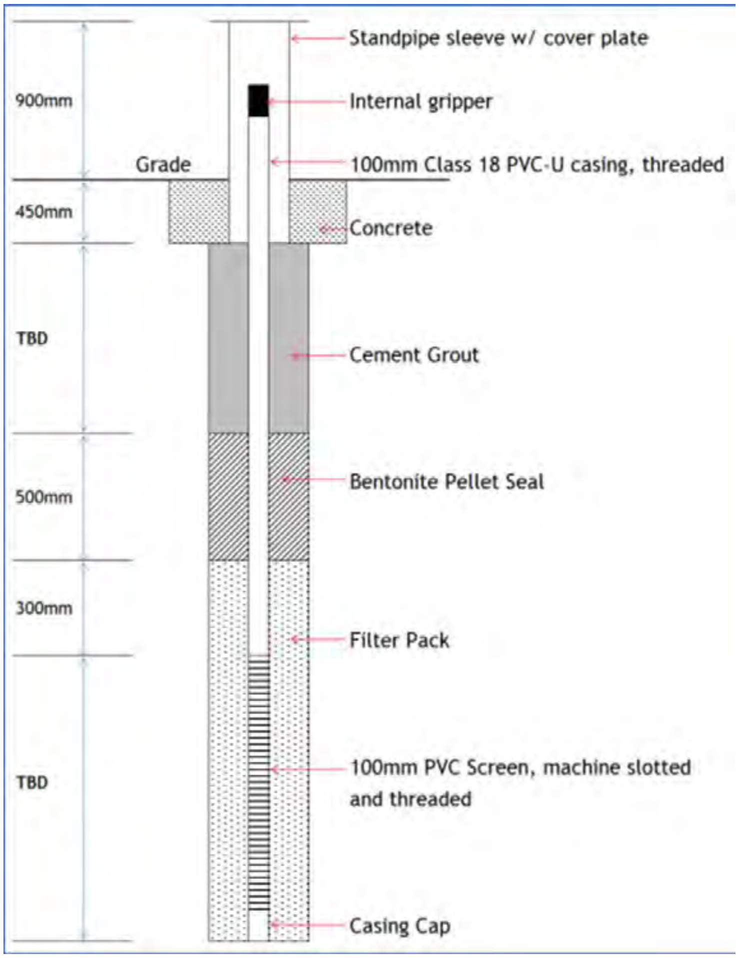


Figure 12. Monitoring borehole construction.

The chosen drilling methods will allow for collection of continuous core samples of both unconsolidated soils and consolidated rock for lithological logging, and to allow the collection of samples for:

- permeability measurement (lab),
- soil moisture analysis (lab),
- soil moisture stable isotope analysis (lab),
- soil moisture potential/pressure (field), and
- detailed inspection for tree root depth (field with lab verification).

6.3.2.2 HSE and Cultural Heritage

Safety precautions will be implemented for all drilling operations in accordance with the drilling company JSEA’s and SWMS’s, and all safety requirements, permits and instructions issued by Arrow Energy.

A site HSE Plan will be developed for each drilling area and the lead driller or designated safety person will be responsible for the safety of the drilling team, sub-contractors, consultants, and visitors during all drilling activities.

All personnel involved with drilling activities should be qualified in proper drilling safety procedures and have all the necessary permits, licences as well as evidence of completion of all relevant industry and Arrow Energy inductions.

A site reconnaissance should be undertaken in advance of drill site set up to evaluate physical conditions and equipment and logistical requirements. Particular interests include site access, proximal utilities, barriers and hindrances to movement of equipment, potential hazards, and geographical locations of support facilities (i.e., drilling supplies, drilling water, sample shipment facilities, and emergency facilities). Site modifications and adaptations to drilling plans should be made accordingly and as is practical.

All drilling sites are located in environmentally sensitive areas, typically within riparian vegetation close to creeks. Avoidance or minimisation of vegetation disturbance (approval required) is an essential requirement of the drilling program.

Riparian areas often contain artefacts or areas of cultural heritage significance. All appropriate Disturbance Approvals need to be obtained before mobilising. If any potential artefacts or sites of cultural heritage significance are observed during site preparation or drilling activities, these should be left undisturbed, work ceased, and Arrow Energy contacted immediately for instructions.

6.3.2.3 Utility Clearance

Excavation permits should be obtained from and approved by Arrow if required. If it suspected that underground services may be present, prior to drilling or excavation activities, Arrow Energy should be consulted for advice. If necessary, a professional cable locator or non-destructive testing may be required to locate and mark services before work commences. Overhead utilities and structures should also be considered with respect to clearance space required by the drilling equipment.

As appropriate, boreholes should be advanced to a minimum of 1m below ground surface (or more as required or needed) with a hand auger or hand tools. The diameter of the manually advanced borehole should be at least as wide as the largest auger or other equipment to be placed within the borehole.

6.3.2.4 Equipment

The driller should arrive at the site with all the necessary personnel, supplies, and equipment to complete the specified tasks. All equipment must have been properly inspected, serviced, maintained, and tested prior to relocation to the site to ensure that it is in proper working condition, and to minimize the potential for delays. Sufficient replacement or repair equipment and supplies shall be kept on hand or readily available in the event of mechanical failures or malfunctions.

6.3.2.5 Borehole Requirements

The borehole shall be drilled and constructed so as to 1) allow for the proper construction of the monitoring bore, 2) allow proper description and sample collection of the parameters of interest and 3) meet the objectives of the ground water monitoring program. The borehole must allow for the proper placement of the bore screen so as to allow for monitoring of parameters based upon chemical and physical characteristics.

The borehole shall be drilled as close to vertical as possible, except for the drilling of an intentionally slanted bore (discussed further below). The slanted bore will not be converted to a groundwater monitoring bore.

If the bore hole is drilled too deeply, it should be backfilled to the desired installation depth with pure bentonite pellets (for fine-grained aquifers). A minimum of 300mm of filter sand should be placed above the bentonite prior to screen installation. This will protect the bottom of the bore screen from bentonite intrusion.

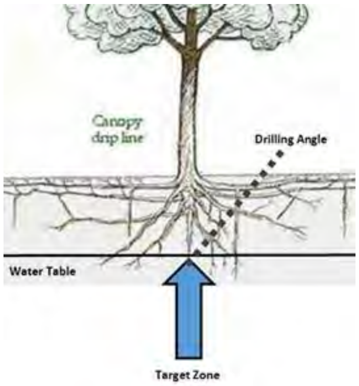
The temporary casing, or permanent surface casing should have an inside diameter (I.D.) sufficient to allow the installation of the prescribed diameter screen and bore riser plus annular space for a tremie pipe through which to place the filter pack and annular sealants.

At each monitoring site, up to three bore holes, including one slanted bore hole will be drilled at various locations around the potential GDE tree/s to increase the likelihood of intersecting and measuring depth of the tree root system. All bore holes will be advanced until an aquifer (first groundwater strike) is intersected, or until a depth of 20m (likely maximum tree rooting depth) is reached. One of the 3 bore holes will be extended to 30m to assess the underlying geology and hydrogeology for connectivity assessment purposes.

The following sequence of coring and related activities is suggested to maintain sample integrity and minimise drilling down-time while sampling is undertaken. This schedule may require adaptation to field conditions encountered:

1. 30m core to allow detailed geological logging which will inform subsequent sample collection, and design of groundwater monitoring bore/s to be constructed in Core 2. The following analysis and activities will occur on this core hole:
    a. Detailed geological logging.
    b. Complete core length photographs.
    c. Field inspection for tree root material.
    d. Preservation of core (see Section 6.3.2.8) for transport to 3D lab for lab inspection for tree root material; and collection, weighing (to determine any loss of moisture), and bagging of samples for potential future permeability analyses.
    e. Will be grouted upon completion.
2. 20m vertical core for comprehensive field and lab sampling program and construction of groundwater monitoring bore/s.
    a. Geological logging.
    b. Soil moisture sampling (dispatch to lab).
    c. Soil moisture potential testing (field).
    d. Soil moisture isotope analysis sampling (dispatch to lab).
    e. Field inspection for tree root material.

   f. Preservation of core (see Section 6.3.2.8) for transport to 3D lab for lab inspection for tree root material.
   g. Construction of groundwater monitoring bore/s.
3. 20m angled core to increase chance of encountering tree root material. The drill core will need to be angled to intersect the tree root zone directly below the tree at the projected depth of the water table / capillary fringe. This will be required to maximise chances of tree root intersection. In addition, the following activities will be implemented:
   a. Geological logging.
   b. Field inspection for tree root material.
   c. Preservation of core (see Section 6.3.2.8) for transport to 3D lab for lab inspection for tree root material.
   d. Will be grouted upon completion.



Upon completion of the two bore holes not converted into a groundwater monitoring bore, these should be properly abandoned in compliance with the Minimum Construction Guidelines for Water Bores in Australia – Version 3 (National Uniform Drillers Licensing Committee, 2012), by filling the bore hole from TD to surface with a bentonite/cement grout mix. This should be done by placing a tremie pipe to the bottom for the boring (i.e., to the maximum depth drilled) and pumping grout through the pipe until undiluted grout flows from the boring at ground surface. The grout sealant must consist of high-solids, 100 percent-pure sodium bentonite grout. The amount of approved water used should be kept to a minimum. Neither additives nor borehole cuttings should be mixed with the grout. No borehole shall be backfilled with cuttings.

6.3.2.6 Geological Supervision

A site geologist or hydrogeologist, suitably qualified to conduct hydrogeologic investigations should be present throughout the drilling operations at each site.

The geologist/hydrogeologist shall be responsible for logging, acquisition, and shipment of samples, drilling logs and bore construction diagrams. They should have onsite sufficient tools, forms, and professional equipment in operable condition to efficiently perform the duties as outlined in this plan.

6.3.2.7 Drilling Fluids

Due to the requirement for sampling and analysis of soil moisture and groundwater for characterisation with a comprehensive chemical analytical suite (including isotopes), to the extent practical, the use of water during drilling, and any other water used during monitoring bore installation and completion, should be held to a minimum. When use of water is deemed necessary, the source of any water used must be potable quality. The driller should have the responsibility to procure, transport, and store the approved water required for project needs in a manner that avoids the chemical contamination or degradation of the approved water once obtained.

It is advantageous that the drilling water be pretested (sampled and analysed) for the contaminants of interest. Knowledge of the water chemistry is the most important factor for water quality approval. Surface water bodies must not be used as a water source.

Only potable water (no detergents or additives) will be used during weed wash-downs.

Pure bentonite (no additives) is the only drilling fluid additive that is permissible. This includes any form of bentonite (powders, granules, or pellets) intended for drilling mud or sealants. Bentonite shall only be used if absolutely necessary to ensure that the borehole will not collapse or to support cuttings removal.

6.3.2.8 Core Handling

Rock/soil cores should be retrieved and stored in such a way as to reflect natural conditions and relative stratigraphic position. Gaps in the core and intervals of lost core should be noted in the core sequence. Cores should be stored in covered core boxes to preserve their relative position by depth. Boxes should be marked on the cover (both inside and outside) and on the ends to provide project name, boring number, cored interval, and box number in cases of multiple boxes. Each box shall clearly denote the top and bottom of the rock core present in that box. Core will need to be transported back to the 3D laboratory for detailed stereo microscope inspection for root material.

This core will be double-wrapped in cling wrap and alfoil to maintain soil moisture and integrity. Samples collected in the 3D lab for potential later permeability analyses will be wrapped in cling wrap, and then double bagged in zip lock bags to prevent moisture loss.

If photographs of the core are taken, the core surface must be cleaned or peeled, as appropriate, and wetted. Photographs will be taken in colour.

6.3.2.9 Documentation

Each drilling log should fully describe the subsurface environment and the procedures used to gain that description.

The unconsolidated geological profile (e.g. soil, alluvium) should be logged in accordance with the Unified Soil Classification System (USCS).

Rock cores should be fully described on the drilling log. Sample colours should be described using a Munsell rock colour chart. Samples should be described when wetted.

For rock core the log will include, denoting by depth, the location, orientation, and nature (natural or mechanical) of all core breaks. Also mark the breaks purposely made to fit the core into the core boxes. If fractures are too numerous to be individually shown, their location may be drawn as a zone and described on the log. Also note, by depth, the intervals of all lost core and hydrogeologically significant details. This sketch should be prepared at the time of core logging, concurrent with drilling.

All special problems and their resolution should be recorded in the field logbook, with appropriated entries on the log form. Examples of problems include, hole squeezing or collapse, recurring problems at a particular depth, sudden tool drops, excessive mud, grout or filter pack takes, drilling fluid losses, unrecovered tools in hole, and lost casings.

The dates and times for the start and completion of borings should be recorded on the log.

Each sequential boundary between the various soils and individual lithologies should be noted on the log by depth.

The depth of the first encountered free water should be indicated. Before proceeding, the first encountered water should be allowed to partially stabilise for a minimum of 5 to 10 minutes and recorded along with the time between measurements. It is important to note if the measured water level rises or falls over time.

The purpose and interval by depth for each sample collected, classified, and/or retained should be noted on the log.

When drilling fluid is used, a quantitative record in the field logbook should be maintained of fluid losses and/or gains and the interval over which they occur. Adjustment should be made for fluid losses due to spillage and intentional wasting (e.g., recirculation tank cleaning) to more closely estimate the amount of fluid lost to the subsurface environment. Losses should be noted by time and depth interval.

Record the total depth of drilling and sampling on the log.

Record significant colour and viscosity changes in the drilling fluid return, even when intact soil samples or rock core are being obtained. Include the colour/viscosity change, depth at which change occurred, and a lithological description of the cuttings before and after the change.

The drilling rig working area (breathing zone) and top of bore hole should be regularly monitored for methane. Readings should be recorded on the log. When possible, a general note on the log should indicate meter manufacturer, model, serial number, and calibration material.

A bore completion report should be produced for each bore, or within a report which covers the entire drilling program.

Monitoring bores will be drilled and constructed to intersect and monitor groundwater encountered at the first significant ‘water strike’ considered to be indicative of a permanent water bearing zone (aquifer).

After reaching total depth (TD) in the cored bore hole, installation of groundwater monitoring bores will be undertaken as described below.

6.3.2.10 Core inspection for root material

In addition to inspections for root material made in the field using a hand lens, all core will be transported back to a nominated laboratory for a detailed inspection of full cores using a stereo microscope. Descriptions and photographs of the root material, depth and extent of occurrence, root width, and all distinguishing features will be recorded in a log.

6.3.2.11 Core sampling and analysis for permeability

Samples of core material will be collected and preserved for the future possibility of permeability testing. The need for and scope of permeability testing is yet to be determined, and may consist of liquid/gas pulse permeameter, and/or centrifuge permeameter testing as described below. This equipment is available at the University of NSW (UNSW) Water Research Laboratory.

Approximately 10 samples of core per shallow (sonic cored) groundwater monitoring site will be collected for potential future permeability analyses. 150mm long samples will be collected from the inner, undisturbed core. The core samples will be weighed, wrapped in cling wrap, then double bagged in "zip-lock" air-tight bags for storage.

In addition, a full core (surface to Total Depth (TD)) from the deepest core hole (i.e. Longswamp 30, Longswamp 34, Burunga Lane 184 and Glenburnie 22) will be collected, preserved and stored for potential future permeability testing. This core collection work will be conducted by Arrow.

<u>Liquid/Gas pulse permeameter</u>

A liquid/gas pulse permeameter measures the decay of the gas/liquid pulsed into the core and provides a permeability measurement at in situ pressure in millidarcies (mD).

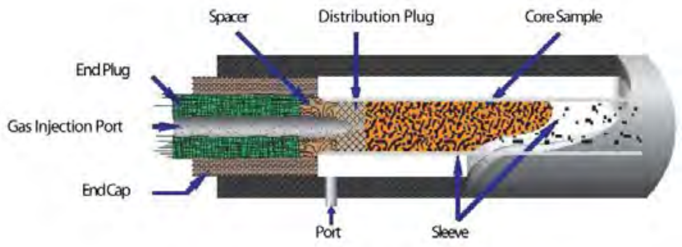


Figure 13. Liquid/gas pulse permeameter sample chamber.

The rock core sample is loaded in a holder and confining pressure is applied. The system is then charged with test gas/liquid to the desired pore pressure. Adequate time is given to allow this pressure to fully saturate the sample. After reaching equilibrium the upstream and downstream portions of the system are isolated from each other. A pulse is then created by raising the upstream pressure (or lowering the downstream pressure). Data is recorded throughout this process and is used in conjunction with known system volumes to calculate gas/liquid flow rates and permeability.

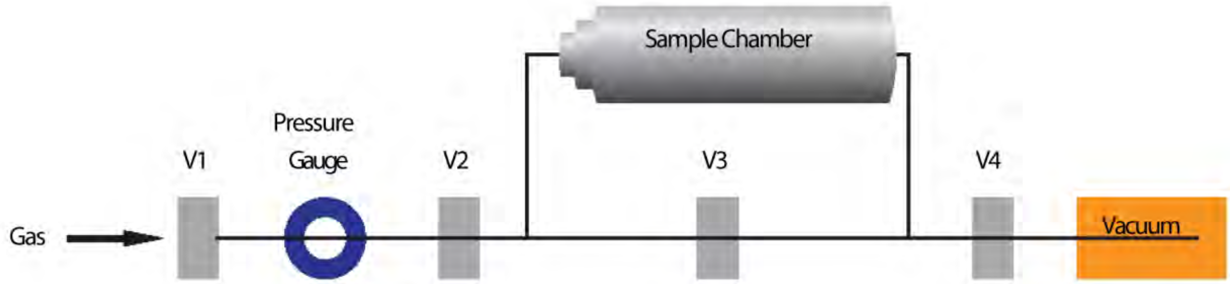


Figure 14. Liquid/Gas Pulse Permeameter

Centrifuge permeameter

The Water Research Laboratory centrifuge permeameter facility is one of only two of its type in the world for hydraulic characterisation of aquitards including clayey sediments and rock drill core. The Broadbent G-18 geotechnical centrifuge (2 m diameter) includes a permeameter module (~500 g-max) and strong box module for physical modelling. Pore pressures and core effluent are analysed while the centrifuge is in operation. Advanced data acquisition systems (DAS) designed by UWA COFS and sensors that operate 'in-flight' provide continuous measurements in real-time and at in-situ stress conditions to allow measurement of the hydraulic properties of aquitards.

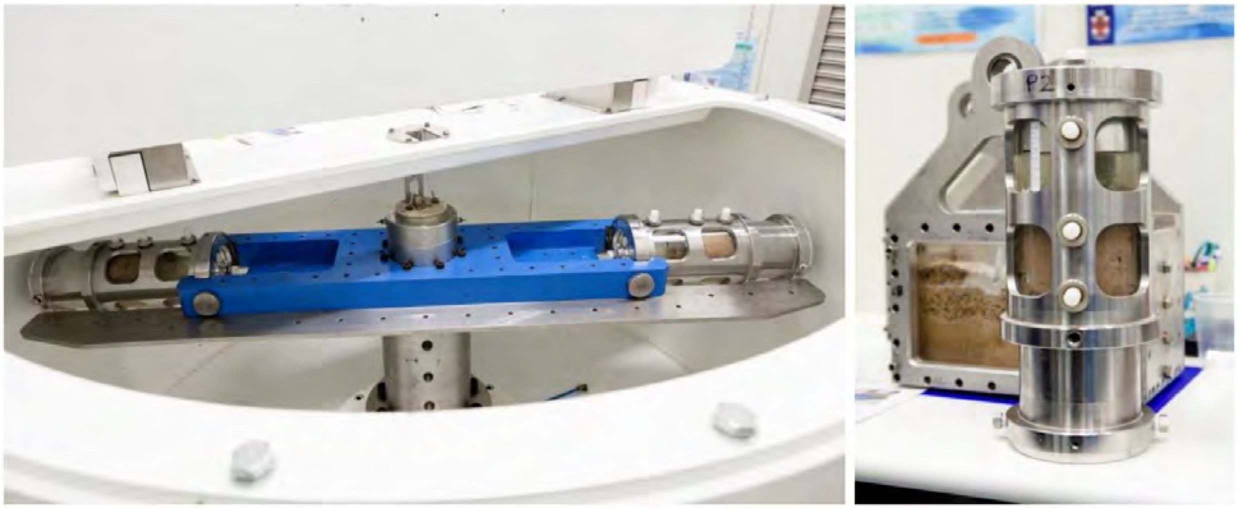


Figure 15. Centrifuge Permeameter

6.3.3 Outputs

Observations, measurements and data collected during the core logging and laboratory analyses program as described in Sections 6.3.2.9, 6.3.2.10 and 6.3.2.11 above will be provided in the form of detailed logs, laboratory analyses reports and data files for each bore.

6.4 GROUNDWATER MONITORING BORE CONSTRUCTION AND BASELINE HYDROGEOLOGICAL CHARACTERISATION

6.4.1 Rationale

The GDE monitoring trial sites subject to this study have been chosen as they occur in areas where:

- Groundwater modelling has indicated potential declines in groundwater levels due to CSG production;
- Aquifer formations are relatively shallow;
- Groundwater levels are relatively shallow;
- Phreatophyte species are known to occur. Phreatophytes are defined here as plants that have roots that can penetrate the capillary fringe and the saturated zone.

Therefore, the preliminary conceptual ecological/hydrogeological model shows that the potential GDEs may be vulnerable to groundwater level fluctuations.

Detailed baseline ecological and hydrogeological characterisation, through the proposed acquisition of surface and subsurface data, will be undertaken to allow refinement of conceptual models. The field drilling and sampling program will also allow the installation of groundwater monitoring infrastructure with which to continue to monitor groundwater level and chemistry trends for comparison with any responses in GDE health.

6.4.2 Methodology

6.4.2.1 Baseline Hydrogeological Characterisation

A detailed review of the site geological, geomorphological, ecological, hydrological and hydrogeological setting will be undertaken through a desk top and field reconnaissance of the immediate site and surrounding area. Observations will be documented to assist in early assessment of the likelihood, depth and extent of any shallow groundwater, and compilation of the conceptual site model. Desktop and field reconnaissance methods will follow earlier GDE Assessment work in the area (3D Environmental & Earth Search, 2017).

6.4.2.2 Groundwater Monitoring Bore Standards and Licencing

Groundwater monitoring bores will be designed constructed such that high-quality groundwater samples representative of in situ conditions can be collected. A properly designed, installed and developed ground water monitoring bore provides groundwater samples that exhibit the physical and chemical properties of that portion of the aquifer screened by the bore.

Ideally, monitoring bore installation should begin immediately after boring completion. Once installation has begun, no breaks in the installation process should be made until the bore has been grouted and temporary drill casing removed. This does not include the time required for proper hydration of the bentonite seal.

Groundwater bores will be designed and constructed in accordance with Minimum Construction Guidelines for Water Bores in Australia – Version 3 (National Uniform Drillers Licensing Committee, 2012), the Australian Drilling Industry Manual (5th Edition, revised 1995)", and where intersecting Great Artesian Basin (GAB) formations: Minimum standards for the construction and reconditioning of water bores that intersect the sediments of artesian basins in Queensland, (Queensland Government Department of Natural Resources and Mines (DNRM), 2014).

All groundwater monitoring bores will be drilled and constructed by a (minimum) Class 2 Licensed Water Bore Driller.

Bores will be registered with QLD Government DNRM as Groundwater Monitoring Bores.

6.4.2.3 Bore Construction

Monitoring bores will be constructed in accordance with the following protocols:

- Monitoring bores will be constructed from 100mm and 50mm (when nested) Class 18 uPVC casing and machine slotted (max 1mm) screen. All monitoring bore joints must be water tight. Couplings with the casing and between the casing and screen must be compatibly threaded. Thermal or solvent-welded couplings on PVC pipe shall not be used. All screen bottoms must be securely fitted with a PVC end cap. Solvents or glues are not permitted in the construction of monitoring bores.
- All bore screens and bore casings must be free of foreign matter (e.g., adhesive tape, labels, soil, grease, etc.). Clean materials must be stored in appropriate containers until just prior to installation.
- Bore screen lengths and placement depths should be selected in the field based on geological observations and the requirement to monitor a discrete zone. The bore should extend approximately 0.75m above the ground surface.
- A 2 mm washed silica sand filter pack should be installed to at least 1 m above the top of the screened interval.
- A minimum of 1 m bentonite (chips or pellets) must be added above the gravel pack and be hydrated with water after they are in place. The bentonite composition must be a 100 percent pure sodium bentonite (montmorillonite) supplied in bags or plastic buckets. The bentonite must be free of any additives or other material that may negatively affect water quality in the resulting monitoring bore. The diameter of the bentonite pellets used should be less than one fifth the width of the annular space into which they are placed. This will help reduce the possibility of the material bridging in the annular space.
- A cement/bentonite (10%) grout mix should be added above the bentonite chips to approximately 0.5 m below ground surface.
- All cement should be Portland.
- A lockable, above-ground steel monument cover should be installed to protect the monitoring bore riser pipe which will be fitted with a gas-tight cap equipped with a valve and surface pressure gauge to allow measurement of gas pressure and bleeding off and sampling of gases, and an internal “d-ring” for suspension of a pressure transducer/data logger.

The above requirements (and this document in general) apply to the shallow, Sonic-drilled, PVC groundwater monitoring bores. Arrow’s site-specific risk assessments may identify that some of the deeper groundwater monitoring bores’ construction design will need to allow for the potential presence of methane gas. This could include appropriate casing material and well heads designed to contain any potential gas presence and associated pressure. These bores will be designed and implemented by Arrow drilling engineers.

6.4.2.4 Bore Survey

An accredited surveyor will be engaged to determine the elevations of Top of Casing (TOC) and ground level (GL) adjacent to the bore to Australian Height Datum (in metres). Determination of the coordinates of each bore (Eastings and Northings) using the GDA94 system with an accuracy of +/-1 mm of each bore.

6.4.2.5 Bore Development

Airlifting is not considered an appropriate development method for this project as this method alters the chemistry of the aquifer, and may introduce contaminants to the aquifer via the air supply. Development by pumping using a submersible pump is required. During development, water should be removed throughout the entire water column in the bore by periodically lowering and raising the pump.

The development of monitoring bores should not be initiated sooner than 12 hours after or longer than 7 days beyond placement of grout. Bore development should be appropriately documented on a monitoring bore development record and included with the boring log in the bore completion report. Installation of a pressure transducer/logger should be considered during the development process to assist in the assessment of aquifer hydraulic properties.

Development should be overseen by the site geologist/hydrogeologist.

Bore development should continue until representative water; free of drilling fluids, cuttings, or other materials introduced during bore construction is obtained. In other words, the bore should be developed until the water is non-turbid. Bore discharge water should be metered in the field until it can be established that development has attenuated and monitored groundwater chemistry parameters have stabilised. All groundwater chemistry monitoring times, measurements and observations should be recorded on the bore completion form.

A minimum of five bore volumes should be removed during bore development.

6.4.2.6 Groundwater Bore Sampling

Groundwater samples are to be collected from each groundwater monitoring bore using the low flow method. Groundwater sampling will follow methods described in the Geosciences Australia *Groundwater Sampling and Analysis – A Field Guide* (Sundaram, et al., 2009).

Depth to the standing water level should be measured with a 9 volt electrical water level meter in each bore before lowering in the sampling pump.

Low flow pumps move groundwater across the bore screen (or slotted interval) at approximately the same rate it flows out of the formation, without disturbing the stagnant water column above. This is achieved by pumping at a rate which results in minimal drawdown of the water level within the bore. Typical flow rates for low flow sampling are in the order of 1 to 2L/min.

During sampling, the pump should be set within the middle or slightly above the middle of the slotted interval.

The pumping rate will be set to a level that will not induce or drawdown minimum which requires frequent measurements of water level before and during pumping.

Field water quality parameters need to be stabilised before sample collection.

The following field water quality parameters will be measured with a calibrated water quality meter:

- pH,
- Redox potential (Eh),
- Electrical Conductivity (EC),
- Total Dissolved Solids (TDS),
- Temperature, and
- Dissolved Oxygen (DO).

Sampling methods will be as specified in Sundaram et al. (2009).

Groundwater samples will be sent to a National Association of Testing Authorities (NATA) accredited laboratory for analyses of:

- pH, EC, Alkalinity,
- Ions: Ca, Mg, Na, K, F, Cl, SO4,
- Ionic balance
- SAR, TDS and Hardness
- Dissolved Silica
- Dissolved metals Al, As, B, Ba, Be, Cd, Co,Cr, Cu, Fe, Hg, Mo, Mn, Ni, Pb, Se, Sr, V, Zn + Bromide
- Dissolved C1-C4 gases (Methane, Ethylene, Ethane, Propylene, Propane, 1-Butene, Butane)
- Stable isotopes of oxygen and deuterium
- ^{87}Sr/^{86}Sr isotopes
- ^{13}C and ^{14}C isotopes

Most samples will be sent to ALS Laboratories, with exception of the specialist isotope analyses which will be analysed at:

- Rafter Radiocarbon Laboratories (NZ): ^{14}C
- Australian National University (ANU): Stable isotopes of oxygen and deuterium
- ANSTO: ^{87}Sr/^{86}Sr isotopes

<u>Groundwater Sampling QA/QC</u>

A duplicate groundwater sample will be collected at a rate of 1 in every 10 samples collected and a minimum of 1 per sampling event. Duplicate samples will be collected concurrently from a single location and submitted for separate analysis (same parameters) to one laboratory. Secondary samples for duplicates will be collected immediately following collection of the primary sample; and all duplicates will be blindly labelled. The secondary site ID used will also be dissimilar to the primary ID.

A chain of custody (COC) form provided from the laboratory shall accompany all sample batches sent to the laboratory. The COC shall include:

- Preservative methods applied to each sample;
- Any field filtering applied;
- Required analysis for each sample;
- Sample names, date, time;
- Samplers name and contact details;
- Monitoring program name;
- Sample type;
- Whether the samples have been chilled; and
- Any specific reporting requirements.

Additionally, laboratories appointed shall maintain a Quality Assurance System equivalent to ISO9001.

Each laboratory engaged under this program shall ensure the following quality control practices are employed as a minimum:

- A method or analysis blank: a laboratory sample prepared that contains no analyte. A method blank shall run for each analysis batch.
- A Laboratory Duplicate sample: a duplicate analysis of a field sample, including extraction. The laboratory prepares the sample by splitting the field sample at the time of sub-sampling and prior to extraction. One duplicate sample for each analyte shall be undertaken once every 20 samples or part thereafter. The relative percentage difference of the samples should be between 70 to 130%. If outside of this range, the laboratory must flag this result and comment on likely reasons for this.
- A Laboratory Control Sample: is a reference sample either prepared by the laboratory or purchased from an external source, which contains a known amount of an analyte. One laboratory control sample shall be run for each analyte every 20 field samples and part thereafter. The percentage recovery should be between 70-130%, with any result outside of this flagged and likely cause explained.
- A Matrix Spike (MS) and Matrix Spike Duplicate (MSD). A MS and MSD are laboratory prepared samples which contains a known amount of an analyte added to a field sample. One MS and MSD shall be undertaken for selected surrogates (laboratory to advise) every 20 field samples. The recovery values should be between 70- 130%, with any values outside of this flagged and likely causes explained.

6.4.3 Outputs

Bore completion reports documenting all aspects of the drilling, construction, development, purging and sampling of groundwater bores will be provided as separate reports and attached to the Phase 3 GDE Study Execution report.

6.5 STABLE ISOTOPE ANALYSIS

The overarching aim of stable isotope analysis is to determine the degree to which trees utilise groundwater on either a permanent or seasonal basis. It will be applied only at those sites which are specifically located to investigate the interactions between tree roots and groundwater (i.e sites LS31, LS35, GB20 and BL182).

6.5.1 Rationale

Trees may utilise water from a range of sources including the phreatic zone, the vadose zone and surface water and the stable isotopes of water, oxygen 18 (18O) and deuterium (2H) may be a useful tool to help define the predominant source of water used by terrestrial vegetation. The method relies on a comparison between the stable isotope ratios of water contained in plant xylem (from a twig or xylem core) with concentrations in the various sources of water including potential artesian water sources, and shallow soil moisture. The heavier isotopes of 18O and 2H fractionate differently to the lighter isotopes equivalents (16O and 1H). Rainfall has a typically large δ18O and δ2H as it is formed through the process of condensation which concentrates heavier isotopes. Surface water may have an extremely high δ18O if it is subject to a period of strong evaporation, whilst isotopic composition of groundwater will vary dependent on the input source, although tends to be relatively stable as it is not exposed to processes of fractionation.

The isotopic signature of water measured in a trees xylem may result from a combination of sources with varying signatures. As per **Figure 16** from Eamus et al (2006a) below, if an isotopic signature of 'A' is recorded, then water is being sourced from the phreatic zone, and for 'C' at the surface. If an isotopic signature of 'B' is recorded, this may represent water sourced from the middle of the vadose zone (at depth x), or may be a combination of water from a deeper phreatic source (A) or a shallow source (B). Hence there is potential for considerable uncertainty when mixed isotopic signatures occur and it may be necessary to apply a linear mixing model to aid the interpretation (as per Thorburn et al, 1993).

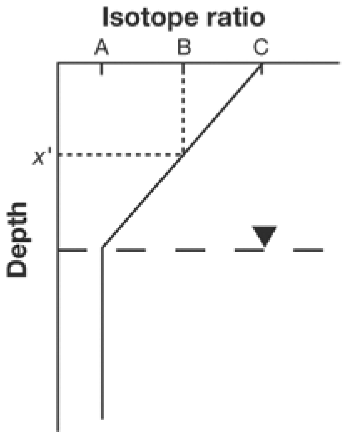


Figure 16. Schematic representation of isotope ratios within soil and groundwater and application in identifying plant water sources (from Eamus et al. 2006a).

For a robust application of stable isotopes signatures obtained from plant xylem and soil pore spaces, the following general protocols should be observed:

1. Sampling of plant and soil material will need to be completed during a single sampling event to ensure the results are directly comparable.
2. Sampling of plant xylem material would be completed most efficiently from twigs, collected whilst undertaking leaf water potential measurements. Leaves have tendency to concentrate isotopic concentrations during the process of transpiration and evaporation and hence should not be used.
3. The sampling program is best completed following a period of extended drought / dry conditions to maximise the potential that plants are utilising groundwater sources.
4. Sampling of soil pore water should be undertaken at consistent intervals throughout the vadose zone (the unsaturated zone above the groundwater table) down to the groundwater table. Soil samples are to be collected to the depth of the saturated zone or consolidated bedrock (whichever comes first). Sampling needs to extended beyond the saturated zone to consolidated bedrock in the case that a perched aquifer is identified.

6.5.2 Methodology

6.5.2.1 Sampling of Soil Pore Water for Stable Isotopes

Method: Soil sampling is to be undertaken at regular intervals along a retrieved soil core to capture signatures for possible isotopic end points (ground water and surface water) and a range of potential plant moisture sources within from the upper soil surface to the top of the phreatic zone. Mensforth et al (1994) completed soil sampling at 0.1m increments to 0.4m depth; 0.2m increments to 2m depth and 0.5m increments to the groundwater surface while others such as O'Grady et al (2006) applied sampling interval of 0.5m down the entire profile. The proposed sampling interval for this assessment is:

1. Initial soil sample taken within the top 10cm of the soil profile.
2. Subsequent soil sampled taken at 0.5m intervals down borehole to the top of the phreatic zone.
3. Additional soil samples take whenever there is a noted change is soil texture within the soil core (i.e change from clay to sandy clay / loam).

A summary of the proposed sampling interval and intensity is provided below in **Figure 17**.

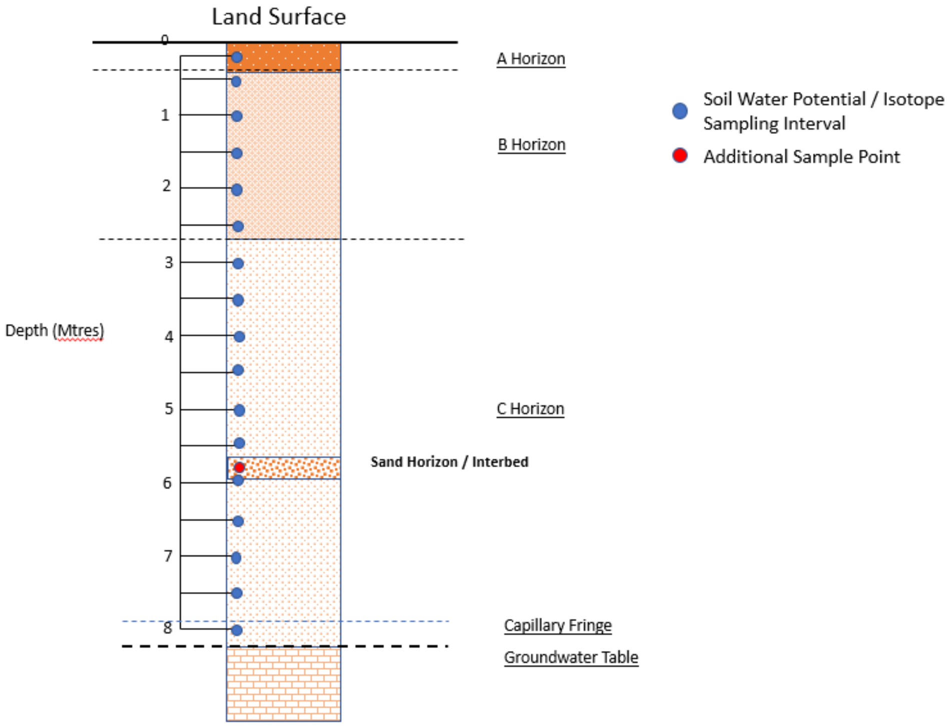


Figure 17. Proposed soil sampling intervals for stable isotopes.

Soil sampling is to be abandoned when consolidated bedrock is encountered; a depth of 20m is reached (the maximum rooting depth of River Red Gum) or the top of the groundwater table is intersected. There is some potential to intersect shallow perched water tables, particularly at the Long Swamp locality where discontinuous sandy lenses may be associated with the Condamine Alluvium. In the case that a perched water table is intersected, free water should be sampled at the perched horizon and soil sampling continued until either the groundwater table, fresh bedrock or a hole depth of 20m is reached.

Soil sampling protocols: The following protocols for soil sampling are to be applied based on advice from ANU Stable Isotope Laboratory:

1. A minimum 200ml equivalent of soil is to be collected for each sample to be analysed. This equates to roughly a 60mm length of 100mm drilled core that is halved.
2. Soil sample is to be extracted from the core using a stainless-steel blade (paint scraper of equivalent).
3. Samples are to be immediately sealed to prevent evaporation in an airtight clip seal freezer of sample bag (double bagging recommended).
4. Samples are to be labelled with the drill hole number and sampling depth / interval in a consistent format to aid data entry and recognition (e.g. BL-1-15 for Burunga Lane Borehole 1, 15m depth).
5. Samples are to be kept on ice and transported to a freezer for temporary storage prior to dispatch to the laboratory (at the completion of each hole).

6. Frozen samples are to be dispatched in an a sealed (as airtight as possible) esky via overnight courier.

Equipment: The following equipment will be required by the site geologist / ecologist.

1. Stainless steel spatula for sample collection (paint scraper of putty knife sufficient).
2. Tape measure (15m extendable steel builders measure).
3. Clip sealed plastic sample bags (up to 80 required per hole if double bagged).
4. Permanent marking pens.
5. Esky for sample storage and dispatch. Due to the potential weight of the samples, robust 10L esky's for sample storage are considered the most appropriate.
6. A chest freezer will need to be accessed off site for storage.

6.5.2.2 Sampling of XYLEM Water for Stable Isotopes

potential. This will require twigs to be collected from the outer branches of mature Red Gum (or Poplar Box) trees that are the subject of the assessment. It is anticipated that up to 4 twig samples will be collected from individual trees directly adjacent to the assessment locality. At each site, the following sampling protocols should be observed:Method: Sampling of leaf twigs will be undertaken in conjunction with sampling of leaves for water

1. Outer branches of up to four trees, including the central tree at the assessment locality plus three adjacent trees are to be harvested for twig material.
2. Trees subject to assessment are to be marked with a GPS and tagged (aluminium tree tag and aluminium nails) with a specific identifier code (e.g. BLT1 for Burunga Lane tree 1).
3. Outer branches from each tree will be harvested using an extendable aluminium pole and lopping head. The longest commercially available extension pole is 7.5m giving a maximum reach of approximately 10m.
4. Stem material that is the equivalent to one joint length of the small finger should be sourced (based on advice from ANU). Hence collected branches should contain some stem diameters of at least 10mm.
5. Selected stems are to be cut into maximum 5cm lengths and the bark stripped. One to two stems of 10mm diameter stems will be sufficient although more material will be required for smaller diameter stems.
6. Stems are to be sealed in wide mouth sample containers with leakproof polypropylene closure (approx. 125ml sample size).
7. Samples should be immediately labelled with the tree number and placed in an iced storage vessel before being transported to a freezer for temporary storage prior to dispatch to the laboratory (at the completion of each hole).
8. Frozen samples are to be dispatched in an a sealed (as airtight as possible) esky via overnight courier.

Equipment: The following equipment will be required by the site geologist / ecologist.

1. An extendable 7.5m aluminium pruning pole with an attached lopper head.

2. High quality secateurs for cutting stem material.
3. 125m wide mouth sample containers with a polypropylene seal cap (up to 16 required).
4. Permanent marking pens.
5. Esky for sample storage and dispatch. May be included with the frozen soil samples.
6. A chest freezer will need to be accessed off site for storage.

6.5.2.3 Groundwater sampling for stable isotopes

Method: Groundwater samples are to be collected from each groundwater monitoring bore using the low flow method. Groundwater sampling will follow methods described in the Geosciences Australia *Groundwater Sampling and Analysis – A Field Guide* (Sundaram, et al., 2009). Care should be taken not to oxygenate or agitate the sample during pumping or sample collection.

Samples for analysis of stable isotopes should be collected in laboratory prepared 28ml glass McCartney bottles or 15ml Vacutainers, and kept cool during storage and transport.

6.5.2.4 Sample Despatch and personnel

Personnel: Samples are to be collected, bagged and stored by the supervising geologist / ecologist who will also be responsible for the sample dispatch to the receiving laboratory

Dispatch: Samples are to be dispatched directly to the ANU Stable Isotope Laboratory (address provided below).

Hilary Stuart-Williams
Stable Isotope Laboratory
Research School of Biology
R.N. Robertson Building (46)
The Australian National University Canberra ACT 0200 Australia

6.5.3 Outputs

The outputs of the assessment will be up to 160 x 200cm3 soil samples (inferred maximum of 40 sites per borehole) dispatched to ANU Stable Isotope Laboratories for analysis of $\delta^{18}O$ and $\delta^{2}H$ in water extracted from soil pores, in addition to the groundwater samples collected from each site. ANU Stable Isotope Laboratory will:

1. Extract the soil pore water and twig xylem water using cryogenic distillation (i.e heat under vacuum with extracted water collected via a cryogenic medium such as liquid N^2).
2. Undertake analysis of groundwater, extracted soil pore water and xylem water for $\delta^{18}O$ and $\delta^{2}H$ using a Picarro Laser.
3. Provide raw data from the analysis.
4. Provide a summary interpretation of the data with comparison between groundwater, soil moisture and leaf and twig isotopic ratios.

6.6 LEAF / SOIL MOISTURE POTENTIAL

The measurement of leaf and soil moisture potential will be targeted to specifically assess the interactions between tree roots and soil moisture / groundwater. These measurements will only be undertaken at the monitoring bore localities LS31, LS35, BL182 and GB20 which are placed specifically to assess for these interactions.

6.6.1 Rationale

Leaf water potential is the total potential for water in a leaf consisting of the balance between osmotic potential, turgor pressure and matric potential. It is defined as the amount of work that must be done per unit quantity of water to transport that water from the moisture held in soil to leaf stomata. It is a function of soil water availability, evaporative demand and soil conductivity.

Measurement of leaf water potential is undertaken by collecting leaf samples at pre-dawn and using a Scholander pressure chamber (pressure bomb) to measure the pressure required to force water from the stem of the leaf. The results of the leaf water potential measurement are then compared to either the soil moisture potential at the same site collected at regular vertical intervals by drilling down to the water table and using a dewpoint potential meter.

It is assumed that trees will be using water from a source that requires the least energy (lowest water potential) to lift water from the soil, through plant xylem to the leaf for transpiration. This will be dependent to a large part on recent rainfall as well as the specific physical attributes of the soil that holds the rooting material. Heavy clays for example, may have a relatively high water content, although this water is hard to extract due to the cohesive forces of the fine particles which hold water very tightly. Clays will thus have a lower water potential than sand which has large pore spaces between the grains and much lower cohesive forces.

It is must also be recognised that trees at the chosen monitoring sites may not be accessing water from one specific source exclusively. Moisture from several horizons within the soil profile may be contributing to tree water requirements, and the predominant source of water may vary on a seasonal basis. To maximise the likelihood of identifying trees that are predominantly using groundwater, it is important that assessments be undertaken in the seasonally driest part of the year.

6.6.2 Methodology

Leaf water potential needs to be measured pre-dawn (prior to sunrise). The basis of this requirement is that pre-dawn measurement provides an estimate of the water potential of the wettest part of the soil profile that contains a significant amount of root matter (Eamus et al 2006a). It is assumed that pre-dawn leaf water potential will equilibrate overnight to the portion of the soil profile that has the highest water potential. Hence contemporaneous measurement of both pre-dawn leaf water potential from a canopy tree at a chosen monitoring locality and soil water potential from selected depth intervals down a co-located borehole will provide an indication of the predominant source of water (soil moisture or groundwater) being utilised by trees at the time of survey.

6.6.2.1 *Measurement of Leaf Water Potential*

Leaf water potential is measured pre-dawn (prior to 5.30 am in summer) using a Plant Water Potential Gauge (originally referred to as the Scholander pressure chamber or 'Pressure Bomb'). Measurement of leaf water potential requires:

1. Collection of leaves from an accessible part of the tree crown.
2. Preparing of leaf material for insertion into the pressure bomb.
3. Measurement of Leaf Water Potential using the pressure bomb.

Collection of Leaf Material: Leaf material is to be collected from the highest accessible portion of the tree crown using an extension pole and attached lopper head (see **Section 8.5.2.2**). Leaf material should be selected that is disease free (as far as practical) and vigorous, preferably with indications of new leaf growth at the growing tips.

Preparation of Leaf Material: A representative sample of healthy leaf is removed from the collected material with sufficient leaf stem (petiole) to allow it to protrude outside the water potential meter (typically 1 to 2 cm). The stem is cut square with a sharp blade and immediately inserted into the water potential metre with the grommet sealed.

Use of the Plant Water Potential Gauge: The preferred Plant Water Potential gauge is the Model 3115 Plant Water Status Console due to its compactness and portability. The device is manufactured in USA (Soil Moisture Equipment Corp.) and distributed in Australia by ICT International (Armidale). The device fits into a 16 x 13 x 7inch Pelican Case and weighs approximately 11kgs which includes the compressed gas cylinder.

Additional Safety and Operational Measures: The Model 3115 console is accompanied with a detailed unit operation manual which describes in detail the required operational procedures. The unit operates on a compressed gas cylinder which should be professionally refilled with compressed N_2. As pressure is applied to the chamber, there is potential for the leaf petiole to be forcefully ejected from the chamber. Hence safety glasses will be required during unit operation.

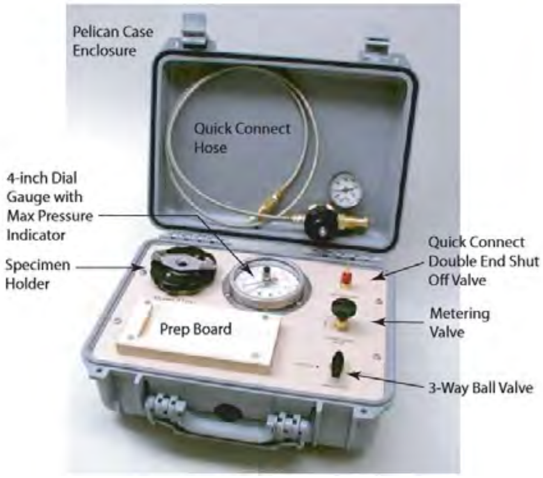


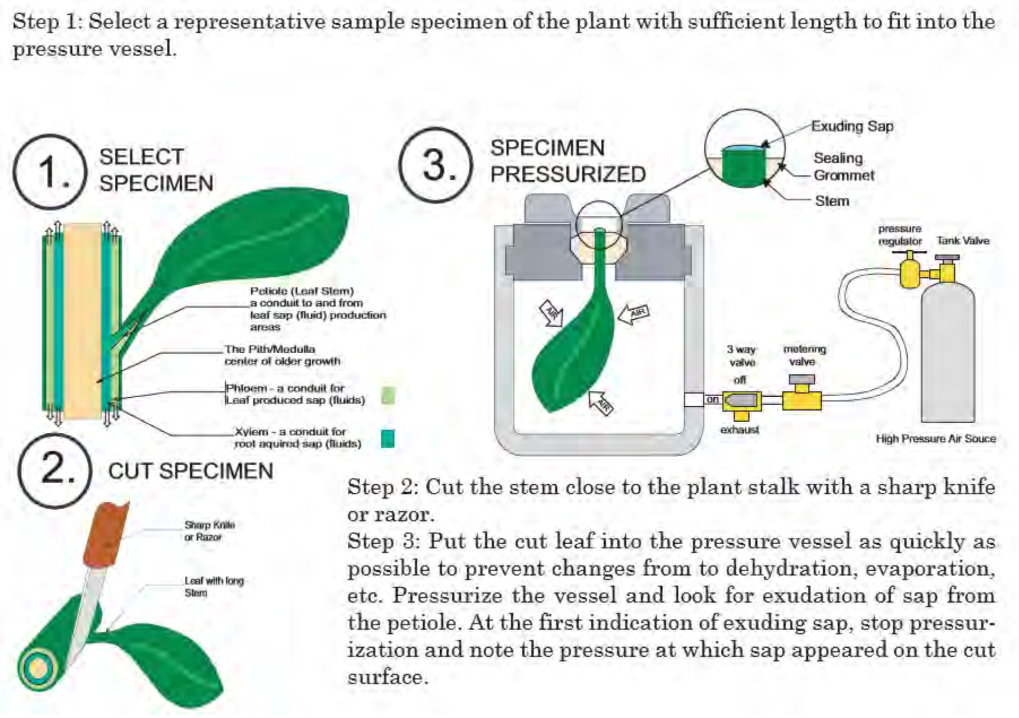
Figure 18. Model 3115 Plant Water Status Console with parts description.

The Water Potential gauge measures leaf or stem water status by the following method:

1. A leaf or stem is collected from the tree that is targeted for assessment.

2. The petiole (leaf stem) is cut and placed in the pressure chamber with the cut stem protruding from the chamber at atmospheric pressure.
3. The vessel is sealed around the petiole and pressure applied via an external gas cylinder.
4. The protruding stem is observed and pressure readings recorded at the first point that water is noted to be exuding from the leaf.
5. The positive pressure applied to the leaf that forced water from the leaf stem is measured. This is the leaf water potential.

The process as supplied by Soil Moisture Equipment Corp (2006) is provided in **Figure 19** below.


Step 1: Select a representative sample specimen of the plant with sufficient length to fit into the pressure vessel.

Step 2: Cut the stem close to the plant stalk with a sharp knife or razor.
Step 3: Put the cut leaf into the pressure vessel as quickly as possible to prevent changes from to dehydration, evaporation, etc. Pressurize the vessel and look for exudation of sap from the petiole. At the first indication of exuding sap, stop pressurization and note the pressure at which sap appeared on the cut surface.

Figure 19. Diagrammatic illustration of the use of the Pressure Bomb as per Soil Moisture Equipment Corp. (2006).

6.6.2.2 Measurement of Soil Water Potential

The same sampling protocols applied to soil sampling for stable isotopes should be applied to assessment of soil moisture potential. This includes:

1. An initial soil sample taken within the top 10cm of the soil profile.
2. Subsequent sampling at 0.5m intervals down borehole to the top of the phreatic zone.
3. Additional measurements taken whenever there is a noted change is soil texture within the soil core (i.e change from clay to sandy clay / loam).

This would facilitate the collection of soil moisture potential from the central portion of the collected core that has been exposed during soil sampling for stable isotopes.

The most convenient method of measuring soil moisture potential is with a portable Dew Point PotentiaMeter which enables measurement to be taken directly on site. Portable devices such as the WP4C uses the chilled mirror dew point technique to measure water potential with the sample being equilibrated with the headspace of a sealed chamber that contains a mirror and a means of detecting condensation on the mirror.

Figure 20. The WP4C Dew Point PotentiaMeter available for hire from ICT International Pty Ltd.

The following protocols are to be followed:

1. A 7ml soil sample is inserted into the sample draw of the potentiaMeter in a 15ml stainless steel sample cup.
2. A soil sample takes between 10 -15mins to analyse.
3. Faster settings (fast mode) should be used for samples with limited water holding capacity such as sand.

The WPC4 unit will require 12V power inverter that plugs into the 12V port of a vehicle if measurements are to be taken in the field. Alternatively, samples can be collected in a sealed sample bag (with air removed) and measurements taken in an office or other areas where there is a reliable power source. The inverter should have a continuous output of at least 140 Watts.

6.6.3 Outputs

The water potential assessments of both leaf (target tree at site) and soil (from soil core) will provided the following data outputs:

1. Pre-dawn leaf water potential measurements of canopy / sub-canopy leaf samples taken with the Pressure Bomb (3115 unit). The output unit will be provided in MPA.
2. Soil moisture potential taken with the portable WPC4 Potentiometer at standard intervals along the drillhole core. The unit output will be measured in MPA consistent with leaf moisture potential. The intervals for measurement will be:
    a. Top 10cm of the soil profile.
    b. At 0.5m intervals from the soil surface to the top of the phreatic zones.
    c. Where noticeable changes in soil texture or moisture content are noted during examination of the core.

The interval for measurement is purposefully coincident with the interval applied to soil sampling for stable isotopes. This will allow for more ready comparison of the results between differing sampling methods and applications.

6.7 BASELINE ECOLOGICAL CHARACTERISATION

Baseline ecological characterisation will be undertaken within intact (or the best-preserved representation) of riparian vegetation as close as practical to each of the four GDE monitoring boreholes (i.e LS31, LS35, BL182, GB20)

6.7.1 Rationale

To define the ecological function of a GDE, it will be necessary to characterise the constituent vegetation in terms of floristic composition, structure including canopy height and cover as well as measures of ecological health and vigour which includes foliage density. Leaf Area Index (LAI) is a useful ecological parameter for this assessment, being the ratio of the total leaf cover within a canopy compared to the ground area covered by the canopy. It is a measure of canopy vigour and the rationale applied is that plants with access to permanent sources of water (i.e. groundwater) will have greater vigour and hence LAI than vegetation that has only periodic access to groundwater resources (e.g. Zolfagher 2014). If a previous permanent groundwater resource is withdrawn (as might occur in a CSG operation), then leaf fall will occur and LAI will decrease.

Field based measurement of LAI is typically completed with a hemispherical lens and is particularly labour-intensive utilising specialised software to analyse foliage cover. There are also commercially available units that measure LAI directly in the field.

It is also possible to undertake a rapid visual assessment of LAI as undertaken by Kath et al (2014) and discussed by Eamus (2006b) which utilises a subjective assessment of total canopy cover and total foliage cover to arrive at a field based measurement of LAI and hence canopy health. The method utilised by Kath et al (2014) was considered rapid and provided a reliable field based measure of riparian vegetation health. The problem with this method is that it is non-repeatable and hence not suitable to ongoing monitoring of vegetation health. Hence a more robust approach is proposed which allows measurements to be undertaken rapidly that are repeatable on a temporal basis.

6.7.2 Methodology

As per standard floristic survey techniques identified in Neldner et al (2017), a transect will be formed with a 50m tape measure stretched tightly between end points, extended 5m either side of the centreline to provide a 50m x 10m survey transect (0.05ha). Specific details collected at each transect will be:

- Canopy intercept of woody species over the tape marking the centre line, from 0 to 50m separated into the T1 (canopy), T2 (sub-canopy) and S1 (shrub) structural layers.
- Tree and shrub species for all structural layers and identification of applicable regional ecosystem based on species composition.
- Counts of woody species within the survey plots within height classes (Trees T1 & T2; Shrubs S1).
- Groundcover of plants within 10 x 1m^2 quadrats placed at 10m intervals along the tape measure with the initial quadrat position (Q1) at the 4 – 5m interval on the left side of the tape measure and flipped to measure Q2 on the right. The final quadrats Q9 and Q10 are to be positioned at 44 – 45m on the left and right side of the transect respectively.

- Average canopy heights and canopy height range recorded for all canopy intercepts in the T1, T2 and S1 structural layers.

GPS localities of start and end points will be recorded in the field and photographs will be taken along the quadrat centreline.

Assessment of foliage cover is to follow a modified version of that applied by Reardon-Smith (2011) to provide a measure of LAI, being % living leaf cover relative to total canopy in the T1 and T2 structural layers. The assessment will be undertaken with the aid of a digital camera (Olympus Stylus Tough -TG4, 35mm lense or similar) retro-fitted with a bullseye level to assist horizontal camera alignment (see **Figure 21**). Canopy photographs will be taken from the transect start point at 5m intervals to the transect end point (11 photos in total), taken 1m off the ground directly above the tape measure marking with camera positioned horizontally. The following methods will be applied in the office to provide a measure of LAI:

1. The total projected canopy cover (PCC%) within each photo point will be estimated with the aid of a 1500 dot point matrix (0.5 cm centres) with the photos expanded to full screen (235 x 175mm) (see **Figure 22**).
2. Projected foliage cover (PFC%) will be estimated for the portions of each photograph possessing canopy cover.
3. Total foliage cover for each canopy photograph will be calculated (%canopy cover x %foliage cover).
4. LAI will be calculated using PFC / PCC x 100.

The proposed plot layout is provided in **Figure 23.**

Figure 21. Camera mounted with a bullseye level for canopy photograph.

Figure 22. A typical canopy photograph illustrating estimation of total canopy cover.

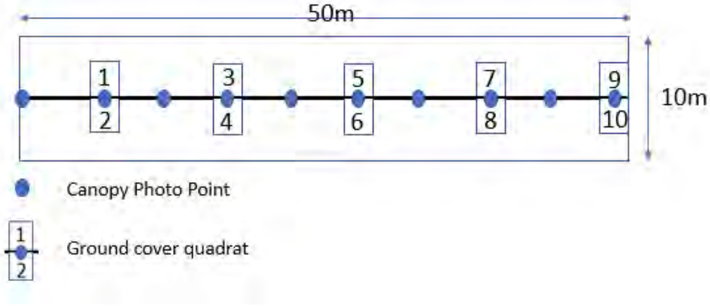


Figure 23. Monitoring transect layout.

6.7.3 Outputs

The information presented will include:

1. Structural measurements including
    a. Average height of all structural layers (T1, T2, S1, S2),
    b. Average canopy cover of all structural layers as measured via the crown intercept method.
    c. Average foliage cover as measured using canopy photographs.
2. Leaf Area Index as calculated from foliage cover and canopy cover data.
3. Composition and relative contribution of all ground cover species including shrub, forb, grass and exotic plants.
4. Transect and canopy cover photographs.
5. GPS localities of transect start and end points.
6. Floristic inventories of all structural layers.

7 PROJECT ASSUMPTIONS AND CONSTRAINTS

Assumptions related to resources, methods, expectations, cost, deliverables schedules or other factors that may affect the project success are summarised below:

- The larger drilling rigs required to install the deeper groundwater monitoring bores will not be able to access the preferred drilling sites immediately adjacent to the GDE (trees), and in some cases have been located as close as practicable to the shallow monitoring bore site.
- Weather and site conditions may present difficulties, particularly if significant rainfall events occur immediately prior to or during the drilling program.

- There is considerable subsurface uncertainty, and lack of detailed shallow geological data which may impact the utility of the proposed drilling and sampling techniques.
- Whilst it is considered that all proposed sites represent GDE vegetation, the source and depth of groundwater that the vegetation is accessing is uncertain. The assessment will utilise data drawn from a range of assessment methods any conclusions regarding interactions between tree roots and groundwater will be evidence based rather than definitive. It is possible that results may be inconclusive at some or all localities although it is expected that greater confidence will be reached with ongoing seasonal monitoring of groundwater levels.
- No known coring for vegetation rooting depth has been undertaken in the area and for assessment of the likely GDE species encountered in the Surat and hence the effectiveness of the technique remains untested. Similarly, leaf water potential, soil moisture potential and isotopic studies are not known to have been undertaken in the assessment area.
- Further discussion is recommended to agree the need, and method of construction, for multi-zone monitoring bores. The guideline (*Minimum Construction Guidelines for Water Bores in Australia – Version 3* (National Uniform Drillers Licensing Committee, 2012)) only supports "multiport monitoring bores" that involve the casing, cementing and then perforation of discrete aquifer monitoring zones, and does not cover the installation of 2 separate adjacent strings of casing within a single borehole isolated by bentonite/cement. The guideline advises that the preferred multi-aquifer monitoring method involves constructing separate groundwater monitoring bores for each aquifer or targeted monitoring zone.

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APPENDIX 1 - EQUIPMENT SUMMARY

Component No.	Sampling Component	Sampling Responsibility	Equipment
1	Soil Sampling for Stable Isotope	Site Ecologist / Geologist	1. Stainless steel spatula for sample collection (paint scraper of putty knife sufficient). 2. Tape measure (15m extendable steel builders measure). 3. Clip sealed plastic sample bags (up to 80 required per hole if double bagged). 4. Permanent marking pens. 5. Esky for sample storage and dispatch (10L 6. A chest freezer will need to be accessed off site for storage.
2.	Twig Xylem Sampling for Stable Isotope	Site Ecologist / Geologist	1. An extendable 7.5m aluminium pruning pole with an attached lopper head. 2. High quality secateurs for cutting stem material. 3. 125m wide mouth sample containers with a polypropylene seal cap (up to 16 required). 4. Permanent marking pens. 5. Esky for sample storage and dispatch. May be included with the frozen soil samples. 6. A chest freezer will need to be accessed off site for storage.
3.	Sampling for Soil Water Potential	Site Ecologist / Geologist	1. WPC4 PotentioMeter plus accessories for portable measurement of soil moisture potential (Hire). 2. Portable 12V adapter for connection of WPC4 to the vehicle. 3. Soil sampling tools, spatula, clip seal sample bags as per Component 1.
4.	Sampling for leaf water potential	Site Ecologist	1. An extendable 7.5m aluminium pruning pole with an attached lopper head. 2. Module 3115 pressure bomb (Hire) and accessories including full compressed gas cylinder. 3. Fine sharp blade for cutting petiole.
5.	Geological logging and core preservation	Site Geologist	1. Hand lens 2. Knife for splitting plastic core bag 3. Steel spatula for separating and inspection of core 4. Tape measure 5. Cling wrap and alfoil for core preservation.
6.	Groundwater sampling	Site Geologist	1. Purging and sampling pump, pump power source and compressor (depending on pump type), disposable tubing and all consumables. 2. Appropriately preserved and labelled sampling bottles 3. Water quality meter 4. Flow through cell 5. Pressure transducer/logger 6. Decontamination buckets and fluids 7. Demineralised water 8. Potable water 9. Permanent marking pens 10. Eskies and ice bricks or ice 11. Chain of custody forms and esky seals

APPENDIX 2 – GDE DECISION MATRIX

Decision Process to Identify Groundwater Dependant Ecosystems (GDEs)

This document aims to facilitate an informed decision as to whether an ecosystem is expected to be reliant on the presence of groundwater. The method considers several lines of evidence which collectively provide confidence in the ecological and hydrogeological conceptual site model (CSM) which may or may not support the characterisation of each study site as a GDE. Through previous assessment undertaken by Arrow Energy and their consultants (such as Coffey, 2017, 3D Environmental/Earth Search, 2017a), preliminary CSMs have been developed for several potential GDEs within their Surat Basin Tenements, each requiring further assessment to better characterise GDE status. Phase 2 of the Arrow GDE Study Project involved the preparation of an Execution Plan (3D Environmental & Earth Search, 2017b) for this further assessment involving the establishment of a selection of detailed assessment and monitoring sites, and the initial (baseline) collection of new field data as lines of evidence to refine CSMs. Phase 3 of the GDE Assessment Project involves the field implementation of the programme of work detailed in the Execution Plan. Phase 3 does not include the ongoing monitoring at the GDE assessment sites. This decision process has been established to allow a preliminary refinement of potential GDE CSMs, and particularly GDE status, after the substantial collection and interpretation of new data collected during Phase 3 of the GDE study and is proposed to occur before embarking on an ongoing monitoring programme. The 'Decision Process' provided within encourages a "hold point" in the project where the CSM is refined and GDE status reviewed prior to embarking on monitoring which may prove unnecessary if there is a low confidence that the site/s present as a GDE. At the very least, the review process should allow a refinement of proposed monitoring objectives and scope prior to implementation of the monitoring programme. The process concerns particularly those localities proposed for detailed assessment and potential monitoring in the forthcoming GDE assessment program. In particular, these sites include groundwater monitoring bores Long Swamp 31, Long Swamp 35, Burunga Lane 82, Glenburnie 20. It should be noted that these sites, through the process of desktop assessment and field inspection, have already been assessed as having an existing vegetation type that is considered more likely to be accessing deeper groundwater sources (such as River Red Gum *Eucalyptus camaldulensis*)), and evidence of a groundwater table <20m depth. Types of data to be collected are:

1. Depth to the phreatic zone (SWL).
2. Rooting depth of trees collected from drill core.
3. Leaf water potential and soil moisture potential.
4. Stable isotope analysis of tree xylem and extracted soil moisture.

Table 1 details the data collection requirements, any relevant technical considerations, information dependencies, application of rules for each parameter measured and the likely timing for an assessment decision.

Table 2a applies a confidence score for data collected against each parameter regarding GDE identification. It should be noted that some parameters reflect a limited range of confidence values due to the nature of the data collected. As an example, identification of tree roots in cored material within the capillary fringe is considered diagnostic of a GDE, although absence of roots does not discount occurrence of a GDE as roots may have been missed during the coring process. **Table 2b** provides a definition of each confidence score.

Table 3 provides an aggregate score which combines scores for each parameter to provide confidence to the identification and assessment of each GDE site. It is intended as an arbitrary decision-making tool which considers multiple lines of evidence to assist the decision making process.

Table 1. Information collection methods and technical considerations

GDE Characterisation requirement	Data Collection Process	Technical and other Considerations	Major information dependency	Rules Applied	Interpretation Timing
Identification of the Phreatic Surface (Standing Water Level) and the associated Capillary Fringe* within the likely rooting depth of tree species present (likely maximum 18m depth).	Shallow drilling (Sonic), construction of groundwater monitoring bores, and measurement of standing water levels.	The phreatic surface and associated capillary fringe may be seasonally variable in unconfined aquifers. Variations in SWL may be marked by geochemical horizons (Fe Oxides typically) which will be apparent in the drill core. Identification of these geochemical horizons may help define seasonal water usage by plants.	Rooting depth of trees identified through drill coring. Identification of tree roots within the capillary fringe will confirm a GDE although not being able to identify tree roots within the phreatic zone does not necessarily exclude the presence of a GDE (i.e. a line of evidence only)	– >18m to phreatic surface of uppermost aquifer (confined or unconfined – **Not a GDE.** – > 12m to <18m to upper phreatic surface – **Possibly a GDE.** – **<12m** to upper phreatic surface - **Likely to be a GDE**	Immediately upon drilling for phreatic surface depths > 18m. 2 – 4 weeks for Phreatic Surface depths < 18m following examination of drill core for tree roots.
Identification of tree roots in drilling core	Shallow drilling (Sonic) and detailed core inspection with hand lens (field), and stereo microscope (lab)	Tree roots will concentrate in the capillary fringe and generally won't penetrate into the zone of permanent saturation. Tree roots are generally spread widely throughout the vadose zone down to the phreatic zone and hence it is possible that tree roots will be missed by the drill core. The very fine nature of tree roots that are likely to occur within the capillary fringe means that detailed inspection (with stereo microscope) will be required.	Availability of suitable drill core for analysis and strong dependence on drill core intercepting rooting material.	– Rooting material within the capillary fringe or saturated zone of an aquifer is considered conclusive evidence that the site represents a GDE. Absence of intersected tree roots provides a line of evidence, although does not conclusively rule out the presence of a GDE.	2 to 4 weeks following completion of assessment to allow time for drill core inspection.
Leaf Water Potential / Soil Moisture Potential	Measurement of pre-dawn leaf water potential of trees at a potential GDE site / Measurement of soil moisture potential from soil	The soil horizon / aquifer that a tree draws its predominant source of water from will likely vary throughout a climatic cycle. The leaf water potential will equilibrate with the water potential of the soil horizon that forms the predominant source of water for the plant at the time of measurement. High	Availability of drill core samples to analyse for soil moisture potential. Identification of root material in drill core coinciding with the inferred depth of tree groundwater extraction would add confidence to the assessment.	A measured leaf water potential that coincided with the water potential of soil in the phreatic zone, either shallow or perched, or a deeper aquifer gives high confidence of a GDE. Leaf water potential coinciding with that of the vadose	2 – 4 weeks following completion of drilling program to allow for analysis of leaf water potential and soil moisture potential data.

GDE Characterisation requirement	Data Collection Process	Technical and other Considerations	Major information dependency	Rules Applied	Interpretation Timing
	samples in drill core.	water potential recorded in leaf assessments will generally indicate extraction of groundwater from the phreatic zone, particularly when soil water potential of the overlying vadose zone is recorded as being considerably lower.		(unsaturated) zone would give a low level of confidence of the locality being a GDE.	
Stable Isotope Analysis	Analysis of stable isotope ratios (δ18O and δ2H) from water extracted from tree xylem water (stems), soil water and groundwater for comparative purposes.	Water may be drawn from a number of sources including from soil moisture and groundwater. Hence isotopic ratios may be mixed.	Availability of: – drillcore samples for extraction of soil moisture. – stems for collection of xylem water. – groundwater samples from an underlying aquifer <18m depth. Analysis to be undertaken by ANU.	Stable isotope ratios in water samples extracted from tree xylem that are comparative to isotope ratios in groundwater would infer a groundwater source (high confidence). Mixed ratios would be less certain and ratios that match those within samples extracted from soil moisture would indicate a low degree of confidence of the locality being a GDE.	4 – 8 weeks following dispatch of leaf, soil and groundwater samples to ANU. Allow time for data interpretation to be completed by ANU.

*Capillary fringe represents the tension-saturated zone where water is held in pores by forces of tension against gravity. It represents the zone of the groundwater most frequently accessed by tree roots.

Table 2a. Confidence scoring for each source of information.

Tree Rooting Depth	**Confidence of GDE - Score**
Tree roots identified in phreatic zone or capillary fringe <18m depth	1 (Conclusive)
Tree roots not identified at rooting depth	3 (Line of evidence against although inconclusive)
Depth to Phreatic Zone	**Confidence of GDE**
Depth to SWL <12m	2 (High degree of confidence though not conclusive)

Tree Rooting Depth	**Confidence of GDE - Score**
Depth to SWL >12m to <18m	3 (Line of evidence for the site representing a GDE although inconclusive in absence of tree roots)
Depth to SWL >18m	4 (Considered unlikely to represent a GDE although is not conclusive).
Leaf Water / Soil Moisture Potential	**Confidence of GDE**
Pre -dawn leaf moisture potential is comparable to soil moisture potential in the phreatic zone	2 (High degree of confidence though not conclusive)
Pre – dawn leaf water potential is lower than soil moisture potential in the phreatic zone although is higher than all soil moisture potential readings in the vadose zone.	3 (Moderate confidence that the site represents a GDE although not conclusive)
Pre-dawn leaf moisture potential matches soil moisture potential in the vadose zone (within one or several soil horizons) and is lower than soil moisture potential in the phreatic zone.	4 (Considered unlikely to represent a GDE although is not conclusive)**
Stable Isotope Signatures	**Confidence of GDE**
Stable isotopic signature from water contained in xylem is comparable to stable isotope signature measured from groundwater at the site.	2 (High degree of confidence though not conclusive)
Stable isotopic signature from water contained in xylem is intermediate between stable isotope signature of groundwater and soil moisture extracted from soils in the vadose zone. Represents extraction of moisture from a variety of sources which may include groundwater and soil moisture.	3 (Moderate confidence that the site represents a GDE although not conclusive)
Stable isotopic signature in xylem matches stable isotopic signature of water extracted from soil in the vadose zone.	4 (Considered unlikely to represent a GDE although is not conclusive)**

** Note seasonal variations must be considered

Table 2b. Scoring for each assessment

Confidence of Site Being a GDE	**Score**
Conclusive – Site represents a GDE.	1
High confidence – High confidence that the site represents a GDE (although information is not conclusive).Further assessment and monitoring required	2
Low to Moderate confidence – Site may represent a GDE although evidence does not provide direct support. Further assessment and monitoring required	3
Low confidence – Site is considered unlikely to be a GDE although is not conclusive. Further assessment and monitoring required	4
Conclusive – Site does not represent a GDE	5

Table 3. Calculation of aggregate scores for each GDE parameter measured.

Rooting Depth	**Depth to Phreatic Zone**	**Leaf Water / Soil Moisture Potential**	**Stable Isotope Signature**
1**			
	2	2	2
3	3	3	3
	4	4	4

**Root material in the phreatic zone overrides all other assessment methods.

1 to 7 = Locality is accepted to be a GDE;

8 to 11 = Locality is considered likely to be a GDE although dependence is low or seasonal. Further assessment and monitoring required;

12 to 15 = Locality is considered unlikely to represent a GDE. **No further assessment and monitoring required**??

Appendix 2 GDE Connectivity Study (Arrow 2018)

Report

FBO-ARW-ENV-REP-00011

Surat Groundwater Dependent Ecosystems Connectivity Study

Version	2.0
Released	06/09/18
Document Owner	Team Lead Hydrogeology
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Security Classification	Restricted

Please see document administration section for more information

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Contents

List of Figures

List of Tables

1. Introduction

Arrow Energy (Arrow) has undertaken a groundwater dependent ecosystem (GDE) investigation at four locations within Arrow's Surat Basin tenure. The investigation program entailed two scopes of work comprising a site specific investigation at each of the four locations to determine if terrestrial ecosystems (identified through desktop assessments) are dependent on the presence of groundwater (work undertaken and reported by 3D Environmental / Earth Search [2018]), and assessments at the same four locations to improve the understanding of the hydraulic connection between the formations overlying the Walloon Coal Measures (WCM) (known as aquifer connectivity study hereafter). The information gathered from this GDE investigation program will be used to address Arrow's Federal Environmental Approval Conditions relating to GDEs.

This Report provides a summary of the four aquifer connectivity studies.

1.1 Background

Arrow's Surat Gas Expansion Project's (SGP) Federal Environmental Approval Conditions require the development of a Stage 1 Coal Seam Gas (CSG) Water Monitoring and Management Plan (WMMP) and a Stage 2 CSG WMMP to demonstrate how each obligation will be addressed. As part of the Stage 1 CSG WMMP and Stage 2 CSG WMMP, three conditions relating to groundwater dependent ecosystems (GDE) are required to be met, namely:

- Condition 13c: An assessment of potential impacts on non-spring based GDEs through potential changes to surface-groundwater connectivity and interactions with the sub-surface expression of groundwater.
- Condition 13f: A baseline monitoring network that will enable the identification of spatial and temporal changes to surface water and groundwater. This must include a proposal for aquifer connectivity studies and monitoring of relevant aquifers to determine hydraulic connectivity (including potential groundwater dependence of Long Swamp and Lake Broadwater) and must also enable monitoring of all aquatic ecosystems that may be impacted.
- Condition 17g: address any uncertainty in the groundwater dependency of ecosystems and springs with supporting evidence from field-based investigations for any groundwater-dependent ecosystems and springs confirmed in the OGIA model.

The above mentioned conditions form the basis of this Study.

1.2 Work Completed to Date

A summary of the work completed to date in relation to the abovementioned conditions is provided in the SGP Stage 1 CSG WMMP: GDE and Aquatic Ecosystem Impact Assessment Technical Memorandum (Coffey, 2017), with a short summary included here.

A desktop assessment of available data and information identified potential GDE landscapes within the SGP area. In 2016, Arrow then commissioned the development of a numerical surface water-groundwater model to identify any potential impact to GDEs from groundwater drawdown as a result of the SGP.

The model indicated that the potential impact is immeasurable (mm/annum) compared to background variations (cm/day to m/annum) (CDM Smith, 2016).

An impact assessment was then undertaken to confirm the status of potential GDEs, which included:

1. Adopting the 1m drawdown contour as the extent of where GDEs may be at risk of impact where this is predicted in the GDE source aquifer.
2. Predicted groundwater drawdown overlain with potential GDE landscapes and geology subcrop/outcrop to identify where GDEs may be at risk of impact.
3. For “at risk” GDEs a risk assessment was carried out to identify where additional investigations may be required. The assessment included a detailed assessment of:
    a. the likelihood the ecosystem is dependent on groundwater, taking into consideration:
        - Available groundwater level and pressure data,
        - Borehole logs and indicated stratigraphy (soil and lithology),
        - Vegetation mapping and site observations, and
        - Landscape position (hydrology and geomorphology).

    b. A review of available information regarding ecosystem sensitivity and ability to adapt to changes in groundwater availability.

    c. An assessment of potential impact to a non-spring GDE by considering the predicted rate of change in groundwater levels, historical trends in groundwater level fluctuations and the relative importance of the ecological community.

It should be noted that Lake Broadwater and Long Swamp were not identified to be at risk of impact.

1.3 Study Objectives and Approach

The results of this Study are intended to be used in conjunction with the results of the site specific GDE assessments undertaken by 3D Environmental / Earth Search (2018) to address the Federal conditions13c, 13f and 17g noted in Section 1.1.

The overall objective of the Study is to gather data that will improve the understanding of the hydraulic connection between the formations overlying the WCM within each of the four GDE study sites (Section 2).

The specific details of the investigations undertaken as part of the Study are set out in the following section.

2. Site Selection and Scope of Investigation

2.1 Site Selection

The results of the impact assessment summarised in Section 1.2 identified two locations that may be dependent on groundwater in the Springbok Sandstone (southern part of Risk Area 3b) and one location that may be dependent on shallow groundwater in the Walloon Coal Measures (WCM) (northern part of Risk Area 4) and both may be impacted by project-related groundwater drawdown:

- Southern part of Risk Area 3b (referred to as Glenburnie GDE Site hereafter):
    - depth to groundwater information indicates groundwater in the Springbok Sandstone may range from 14.6 to 23.5 m below ground level,
    - maximum predicted drawdown in the Springbok Sandstone is 3.9 m,
    - rate of change of groundwater drawdown estimated to range between 0.07 to 0.3 m/yr, and
    - RE type 11.3.25 which is dominated by Eucalyptus camaldulensis (River Red Gum) is present although not as the dominant RE. Where River Red Gums are present, they may access deeper groundwater. Other species present such as Poplar Box are unlikely to access groundwater in the Springbok Sandstone in this area due to their limited rooting depth (<12m).
- Northern part of Risk Area 4 (referred to as Burunga Lane GDE Site hereafter):
    - depth to groundwater information indicates groundwater in shallow WCM may range from 6.5 to 16 m below ground level,
    - maximum predicted drawdown in WCM ranges from 1.5 to 10 m,
    - rate of change of groundwater drawdown may be up to 4 m/yr, and
    - RE 11.3.25 which is dominated by Eucalyptus camaldulensis (River Red Gum) is mapped as being present along a number of the gullies within Risk Area 4 and is known to have the potential to access deeper groundwater.

These two locations, coupled with Condition 13f requirements (Lake Broadwater and Long Swamp sites nominated for further investigation into GDE potential), are the focus locations for this Study.

The GDE drilling sites were located to ensure they best represent the above site conditions and, taking into account Landholder discussions, the monitoring bores were drilled within 500 m of their associated shallow monitoring bores drilled as part of the study undertaken by 3D Environmental / Earth Search (2018).

The four GDE Sites are summarised in Table 2-1 and their location shown in Figure 2-1 to Figure 2-5.

Table 2-1: Summary of GDE Study Sites

GDE Site	Monitoring Bores	Distance to Shallow Monitoring Bore Drilled by 3D Environmental / Earth Search (2018)
Long Swamp	Longswamp 32	176m
	Longswamp 33	173m
	Longswamp 34	176m
	Longswamp 35 (shallow monitoring bore installed by 3D Environmental / Earth Search [2018])	-
Lake Broadwater	Longswamp 28	448m
	Longswamp 29	463m
	Longswamp 30R	481m
	Longswamp 31 (shallow monitoring bore installed by 3D Environmental / Earth Search [2018])	-
Burunga Lane	Burunga Lane 183	213m
	Burunga Lane 184	218m
	Burunga Lane 185	208m
	Burunga Lane 182 (shallow monitoring bore installed by 3D Environmental / Earth Search [2018])	-
Glenburnie	Glenburnie 21	104m
	Glenburnie 22	104m
	Glenburnie 20 (shallow monitoring bore installed by 3D Environmental / Earth Search [2018])	-

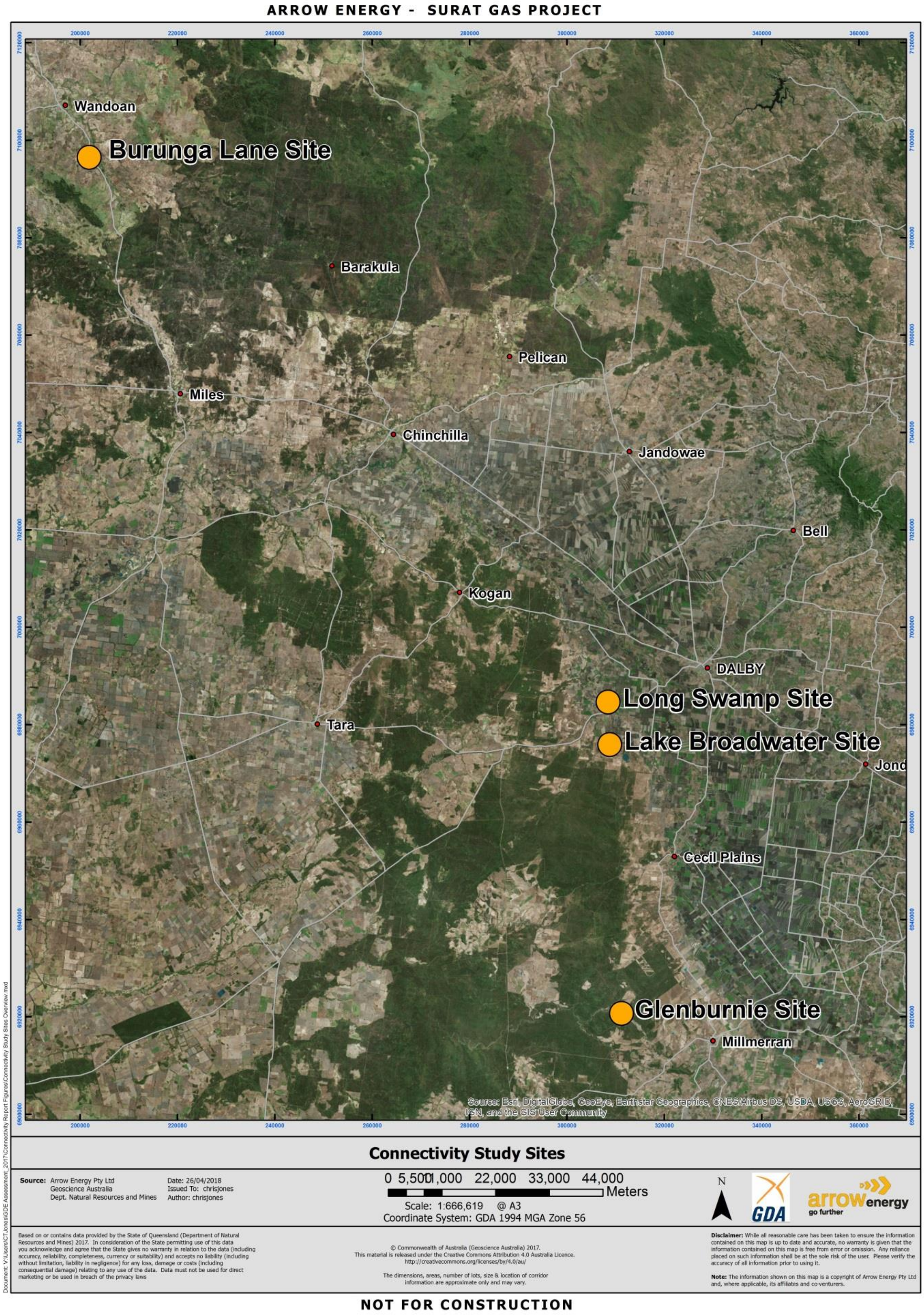

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Figure 2-1: Connectivity Study Sites Overview

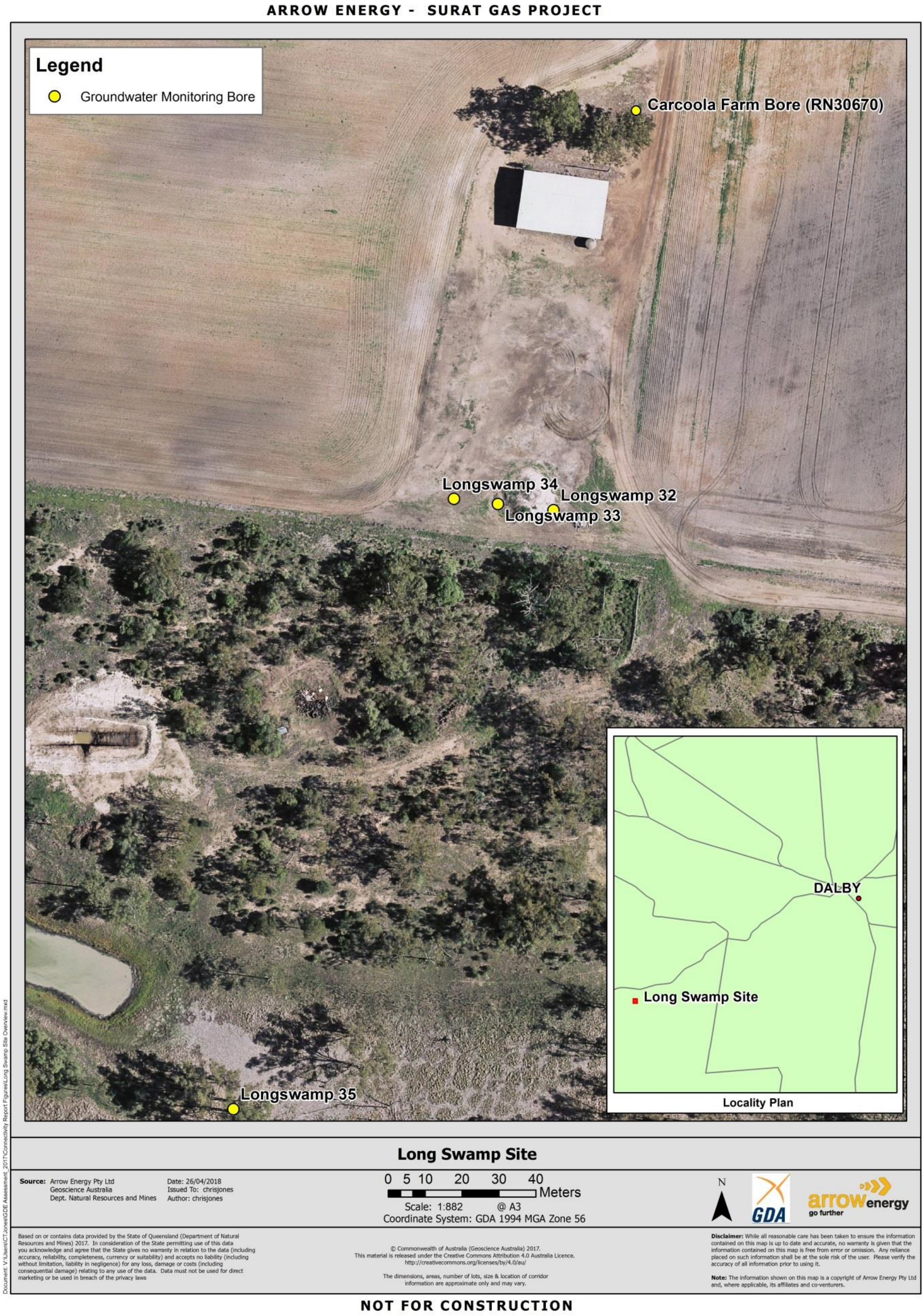

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Figure 2-2: Long Swamp Site Overview

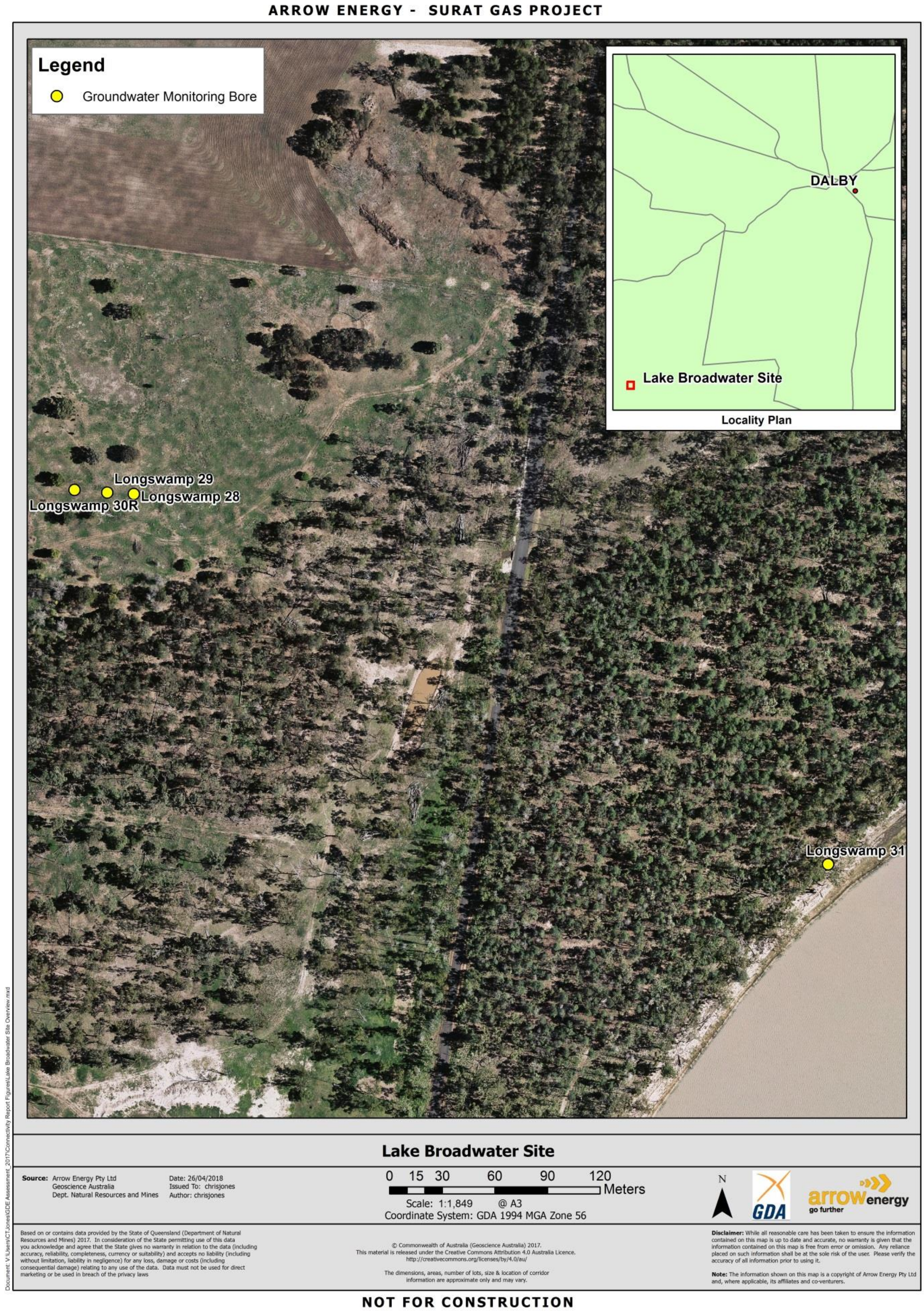

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Figure 2-3: Lake Broadwater Site Overview

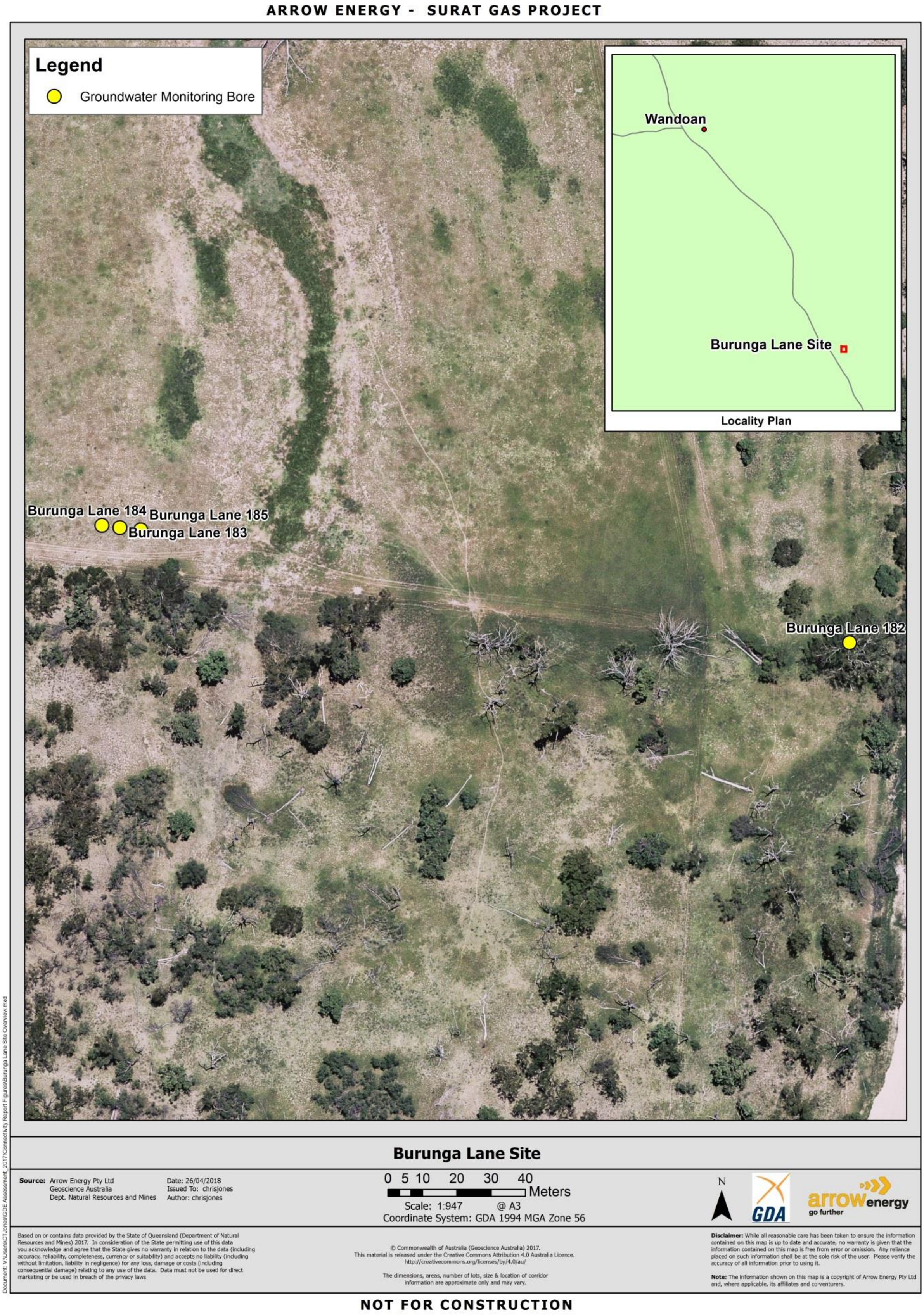


Figure 2-4: Burunga Lane Site Overview

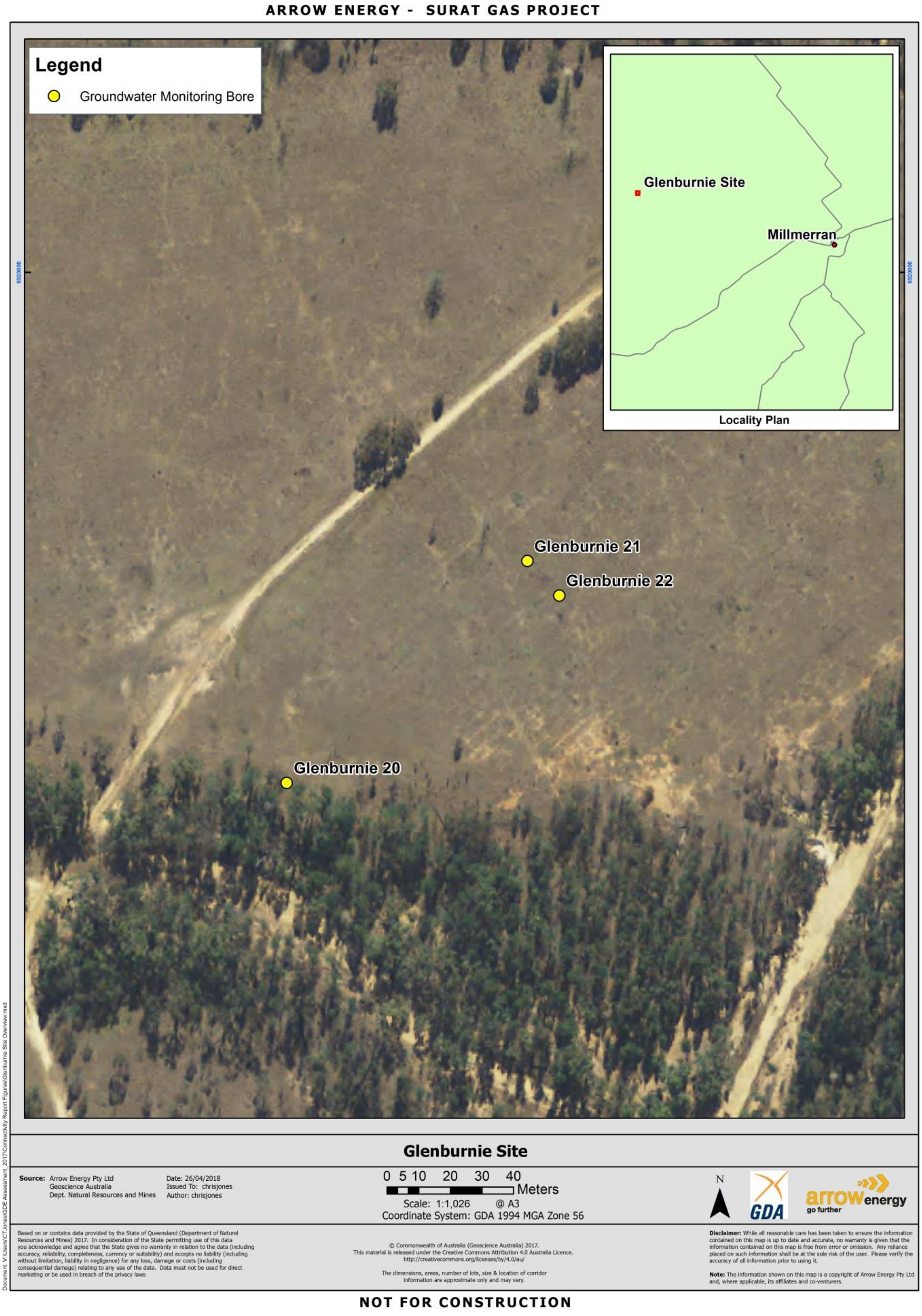


Figure 2-5: Glenburnie Site Overview

2.2 Site Objectives

The objectives for each of the Study sites are summarised in Table 2-2. The objectives outlined in Table 2-2 include the scope of work undertaken by 3D Environmental / Earth Search (2018) and are noted accordingly.

Table 2-2: Summary of Surat GDE Study Objectives

Site	Purpose	Bores and target aquifers for each site	Field testing scope
Long Swamp	Study objective is to identify aquifer connectivity to provide sufficient data to demonstrate that impacted aquifers, as predicted, are disconnected from the localised perched setting in which Long Swamp exists. In addition, to identify if mapped vegetation (i.e. River Red Gum or Poplar Box) are groundwater dependent in that area.	Longswamp 32: Westbourne Formation	- **Groundwater monitoring** to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy
		Longswamp 33: Springbok Sandstone	
		Longswamp 34: Walloon Coal Measures	
		Longswamp 35: Alluvium (tree rooting depth hole) – addressed in a separate report prepared by 3D Environmental / Earth Search (2018)	- **Coring to identify rooting depth** of target plant species known to access shallow groundwater (i.e. <20m) and confirm stratigraphy - **Groundwater monitoring** using data loggers to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy - **Stable isotopes** (deuterium and oxygen-18) collected from the groundwater, soil water and plant xylem water to potentially identify the single or most dominant source of water - **Leaf water potential** of target plant species to identify the level of water stress experienced by the plant during dry periods and therefore if it relies only on rainfall/surface water flows
Lake Broadwater	Study objective is to identify aquifer connectivity to provide sufficient data to demonstrate that impacted aquifers, as predicted, are disconnected from the localised perched setting in which Lake Broadwater exists. In addition, to identify if mapped vegetation (i.e. River Red Gums	Longswamp 28: Westbourne Formation	- **Groundwater monitoring** to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy
		Longswamp 29: Springbok Sandstone	
		Longswamp 30R: Walloon Coal Measures	
		Longswamp 31: Alluvium (tree rooting depth hole) – addressed in a separate report prepared by 3D Environmental / Earth Search (2018)	- **Coring to identify rooting depth** of target plant species known to access shallow groundwater (i.e. <20m) and confirm stratigraphy - **Groundwater monitoring** to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow

Site	Purpose	Bores and target aquifers for each site	Field testing scope
	or Poplar Box) are groundwater dependent in that area.		• Water quality variations • Confirmation of lithology/stratigraphy - **Stable isotopes** (deuterium and oxygen-18) collected from the surface water of Lake Broadwater, groundwater, soil water and plant xylem water to potentially identify the single or most dominant source of water - **Leaf water potential** of target plant species to identify the level of water stress experienced by the plant during dry periods and therefore if it relies only on rainfall/surface
Glenburnie (Southern part of Risk area 3b)	Study objective is to identify aquifer connectivity and if mapped vegetation (i.e. River Red Gums or Poplar Box) are groundwater dependent in that area.	Glenburnie 21: Walloon Coal Measures Glenburnie 22: Walloon Coal Measures	- **Groundwater monitoring** to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy
		Glenburnie 20: Springbok Sandstone (tree rooting depth hole) – addressed in a separate report prepared by 3D Environmental / Earth Search (2018)	- **Coring to identify rooting depth** of target plant species known to access shallow groundwater (i.e. <20m) and confirm stratigraphy - **Groundwater monitoring** to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy - **Stable isotopes** (deuterium and oxygen-18) collected from the groundwater, soil water and plant xylem water to potentially identify the single or most dominant source of water - **Leaf water potential** of target plant species to identify the level of water stress experienced by the plant during dry periods and therefore if it relies only on rainfall/surface
Burunga Lane (Site 4 Northern part of Risk Area 4)	Study objective is to identify aquifer connectivity and if mapped vegetation (i.e. River Red Gums or Poplar Box) are	Burunga Lane 183: Walloon Coal Measures Burunga Lane 184: Walloon Coal Measures	- **Groundwater monitoring** to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy

Site	Purpose	Bores and target aquifers for each site	Field testing scope
	groundwater dependent in that area.	Burunga Lane 182: Alluvium (tree rooting depth hole) – addressed in a separate report prepared by 3D Environmental / Earth Search (2018)	- **Coring to identify rooting depth** of target plant species known to access shallow groundwater (i.e. <20m) and confirm stratigraphy - **Groundwater monitoring** to collect information on: • Local connectivity of shallow aquifer units (including coal formations) • Daily (diurnal) and seasonal groundwater level trends • Depth to groundwater • Hydrogeological characteristics of each aquifer • Aquifer responses to rainfall and/or surface water flow • Water quality variations • Confirmation of lithology/stratigraphy - **Stable isotopes** (deuterium and oxygen-18) collected from the groundwater, soil water and plant xylem water to potentially identify the single or most dominant source of water - **Leaf water potential** of target plant species to identify the level of water stress experienced by the plant during dry periods and therefore if it relies only on rainfall/surface

2.3 Investigation Scope

Each site consisted of drilling and constructing multiple monitoring bores to monitor each formation from surface to the WCM. A summary of each sites' monitoring bores, their monitored formation and data collected is provided in Table 2-3.

This Study also uses information collected from the investigation program completed by 3D Environmental / Earth Search (2018) as noted in Table 2-4 and further information is provided in the associated report.

Table 2-3: Key Site Investigation Tasks

Bore and Screened Formation	Coring	Geophysical logging	Lab permeability tests (core samples)	Slug testing	Groundwater sampling	Data logger / pressure gauge installed
Longswamp 28 (Westbourne Formation)	▨	▨	▨	Yes	Yes	Yes
Longswamp 29 (Springbok Sandstone)	▨	▨	▨	Yes	Yes	Yes
Longswamp 30R (WCM)	Yes	Yes	Yes	No	Yes	Yes
Longswamp 32 (Westbourne Formation)	▨	▨	▨	Yes	Yes	Yes
Longswamp 33 (Springbok Sandstone)	▨	▨	▨	Yes	Yes	Yes
Longswamp 34 (WCM)	Yes	Yes	Yes	No	Yes	Yes
Burunga Lane 183 (WCM – Macalister)	▨	▨	▨	Yes	Yes	Yes
Burunga Lane 184 (WCM – Wambo)	Yes	Yes	Yes	No	Yes	Yes
Burunga Lane 185 (WCM – Macalister)	▨	▨	▨	Yes	Yes	Yes
Glenburnie 21 (WCM – Wambo)	▨	▨	▨	No	Yes	Yes
Glenburnie 22 (WCM – Argyle)	Yes	Yes	Yes	No	Yes	Yes

Table 2-4: Key Site Investigation Tasks Completed by 3D Environmental / Earth Search (2018)

Bore and Screened Formation	Coring	Groundwater Sampling	Data logger installed	Stable Isotopes	Soil Water and Leaf Water Potential
Longswamp 31 (Perched Alluvium)	Yes	Yes	Yes	Yes	Yes
Longswamp 35 (Condamine Alluvium)	Yes	Yes	Yes	Yes	Yes
Glenburnie 20 (Springbok Sandstone)	Yes	Yes	Yes	Yes	Yes
Burunga Lane 182 (Alluvium)	Yes	na (dry)	Yes	Yes	Yes

2.4 Investigation Timing and Schedule

Monitoring bore drilling commenced in December 2017 and was completed in April 2018. A summary of the investigation's key dates is provided in Table 2-5.

Table 2-5: Investigation Schedule

	Bore										
	Longswamp 28	**Longswamp 29**	**Longswamp 30R**	**Longswamp 32**	**Longswamp 33**	**Longswamp 34**	**Burunga Lane 183**	**Burunga Lane 184**	**Burunga Lane 185**	**Glenburnie 21**	**Glenburnie 22**
Bore installation completed	24/2/18	23/2/18	18/2/18	14/1/18	13/1/18	10/1/18	17/3/18	17/3/18	7/4/18	29/3/18	26/3/18
Bore development (and groundwater sampling)	25/2/18	25/2/18	20/2/18	15/1/18	14/1/18	11/1/18	17/3/18	16/3/18	7/4/18	29/3/18	26/3/18
Data logger / pressure gauge installed	6/3/18	6/3/18	23/2/18	19/1/18	15/1/18	23/1/18	17/3/18	18/3/18	12/4/18	30/3/18	27/3/18
Pressure data collection start	6/3/18	6/3/18	16/5/18	19/1/18	15/1/18	26/4/18	17/3/18	18/5/18	12/4/18	30/3/18	27/3/18
Lab permeability results received						21/06/18					
Slug testing completed	10/4/18	10/4/18	na	10/4/18	10/4/18	na	11/4/18	na	11/4/18	na	na

3. Site Geology, Bore Construction and Hydrostratigraphy

This section provides a description of the target monitoring depths for each bore together with bore construction details and presents the local geological description and hydrostratigraphy of the sites. Conceptual models for each site are presented in 3D Environmental / Earth Search’s report (2018).

Bore logs are presented in Appendix A and drilling and construction details are summarised in the following sections. Drilling and construction details for the four monitoring bores (Longswamp 31, Longswamp 35, Burunga Lane 182 and Glenburnie 20) installed by 3D Environmental / Earth Search are included in their report (2018).

3.1 Long Swamp

3.1.1 Drilling and Bore Construction

The Long Swamp site comprised of three groundwater monitoring bores (Longswamp 32, Longswamp 33 and Longswamp 34) monitoring the

Westbourne Formation, Springbok Sandstone and WCM. A summary of the bores’ construction details are provided in Table 3-1. The screen intervals in Longswamp 32 and Longswamp 33 were determined based on the core and geophysics data collected in Longswamp 34.

Table 3-1: Long Swamp Site Monitoring Bores’ Construction Details

	Bore ID		
	Longswamp 32	**Longswamp 33**	**Longswamp 34**
Monitored Formation	Westbourne Formation	Springbok Sandstone	WCM – Kogan Seam
Drilled Diameter	Conductor hole – $8^{1/2}$” Production hole – $6^{1/8}$”	Conductor hole – $8^{1/2}$” Production hole – $6^{1/8}$”	Core hole – $5^{1/2}$” Surface hole – $8^{1/2}$” Production hole – $6^{1/8}$”
Total Depth Drilled (mbgl)	38.0	79.0	128.3
Conductor Casing Diameter and Depth (mbgl)	7”, 6.9	7”, 7.2	$12^{5/8}$”, 6.7 (preinstalled prior to drilling program)
Surface Casing Diameter and Depth (mbgl)	na	na	$6^{3/8}$”, 51.9
Slotted Casing Diameter and Depth (mbgl)	2”, 32.0 to 38.0	2”, 73.0 to 79.0	2”, 106.9 to 116.9
Gravel Pack - annulus (mbgl)	31.0 to 38.0	71.0 to 79.0	106.9 to 116.9
Bentonite - annulus (mbgl)	30.0 to 31.0	70.0 to 71.0	na
Cement - annulus (mbgl)	0 to 30.0	0 to 70.0	0 to 101.3
Stickup (magl)	0.83	0.86	na
Easting (GDA94, Zone 56)	311473.61	311458.54	311446.63
Northing (GDA94, Zone 56)	6982384.86	6982386.53	6982387.90
Surface Elevation (mAHD)	336.12	336.08	336.07

Longswamp 32

Longswamp 32 is located approximately 176 m to the north of Longswamp 35. The bore was drilled by conventional mud rotary method to a depth of 38.0 mbgl within the Westbourne Formation. The monitoring bore was constructed with class 18 uPVC to TD. The bore was constructed to be open to the Westbourne Formation through 0.4 mm aperture slotted casing between 32.0 mbgl and 38.0 mbgl with blank casing from 32.0 mbgl to surface. A gravel pack was installed from 31.0 mbgl to 38.0 mbgl and a 1 m bentonite seal was placed above from 30.0 mbgl to 31.0 mbgl. The annulus was then cemented from 30.0 mbgl to surface. The bore was completed with a lockable steel monument and concrete plinth.

The bore was developed by airlifting with a total of 800 L purged and an observed approximate flow rate of 0.3 L/sec.

Longswamp 32 was completed with an Insitu LevelTroll pressure transducer and Insitu BaroTroll hung on stainless steel cables recording pressure at hourly intervals. The data collected in the BaroTroll were used to correct the LevelTroll pressure data for barometric pressure. Pressure data collection commenced on 15 January 2018.

Longswamp 33

Longswamp 33 is located approximately 173 m to the north of Longswamp 35. The bore was drilled by conventional mud rotary method to a depth of 79.0 mbgl within the Springbok Sandstone. The monitoring bore was constructed with class 18 uPVC to TD. The bore was constructed to be open to the Springbok Sandstone through 0.4 mm aperture slotted casing between 73.0 mbgl and 79.0 mbgl with blank casing from 73.0 mbgl to surface. A gravel pack was installed from 71.0 mbgl to 79.0 mbgl and a 1 m bentonite seal was placed above from 70.0 mbgl to 71.0 mbgl. The annulus was then cemented from 70.0 mbgl to surface. The bore was completed with a lockable steel monument and concrete plinth.

The bore was developed by airlifting with a total of 550 L purged and an approximate flow rate of 0.1 L/sec was observed.

Longswamp 33 was completed with an Insitu LevelTroll pressure transducer hung on stainless steel cable recording pressure at hourly intervals. The data collected in the BaroTroll installed in Longswamp 32 were used to correct the LevelTroll pressure data for barometric pressure. Pressure data collection commenced on 15 January 2018.

Longswamp 34

Longswamp 34 is located approximately 176 m to the north of Longswamp 35. The bore was cored at 4 inch size from 14.0 mbgl to 121.8 mbgl. Core recovery was reasonable with approximately 75% recovery. The majority of the core loss occurred in the section from 14.0 mbgl to 39.5 mbgl within the unconsolidated sandy clays of the Condamine Alluvium and Westbourne Formation. Where core loss occurred, observations of the chips coming over the shakers were recorded. Core box photographs are provided in Appendix B.

The recovered core samples and chip observations showed the Condamine Alluvium consisting of clayey sand and rounded pebbles from surface to 18 mbgl, overlying the plastic clays and weathered sandstones of the Westbourne Formation down to 52.9 mbgl, overlying the fine grained well cemented sandstones and minor coal and carbonaceous bands of the Springbok Sandstone down to 82.1 mbgl, overlying the Kogan Seam of the WCM consisting of tuff bands, siltstones, mudstones and coal down to 108.0 mbgl, overlying the Macalister Seam of the WCM consisting of similar lithology to the Kogan Seam to TD.

Following completion of coring, the hole was reamed out to $6^{1/8}$ inch to a total depth of 128.3 mbgl to allow for a sump for the downhole geophysics logging tool.

Following reaming, a suite of geophysical logs were run by Schlumberger. The logs are provided in Appendix C.

The monitoring bore was constructed with steel 2 inch casing to 116.9 mbgl. The bore was constructed to be open to the Kogan Seam through prepacked steel screens between 106.9 mbgl and 116.9 mbgl with blank casing from 106.9 mbgl to surface. A cement basket was placed at 101.3 mbgl and the annulus was then cemented to surface.

The bore was developed by airlifting with a total of 7,900 L purged and an observed approximate flow rate of 0.2 L/sec.

The bore was completed with a steel wellhead, and a GeoPSI digital pressure gauge (1000 psi) was installed at 108 mbgl on 23 January 2018. Pressure data collection commenced on 26 April 2018.

Carcoola Farm Bore (RN30670)

An existing decommissioned water supply bore is located approximately 110 m north of Longswamp 32, Longswamp 33 and Longswamp 34. The bore was drilled in 1969 with a cable tool rig. The DNRME borecard indicates the bore is screened within the base of the Condamine Alluvium and top of the Westbourne Formation from 16.8 to 18.9 mbgl with 5” steel casing, and open hole from 24.4 to 25.3 mbgl within the Westbourne Formation. The total depth of the bore was measured at 24.88 mbgl indicating the bore has partially collapsed within the open hole section. This location has not been considered further in this Report due to it being open to both the Condamine Alluvium and Westbourne Formation.

3.1.2 Site Geological Summary and Hydrostratigraphy

Coring and geophysical logging of Longswamp 34, chip samples from Longswamp 33 and coring of Longswamp 35 has provided a detailed picture of the site geology. These data were used to select monitoring targets and screen intervals / depths for bores Longswamp 32, Longswamp 33 and Longswamp 34.

A graphic of the geological sequence at the Long Swamp GDE site showing the depth and screened intervals of the bores, and potentiometric surface for each formation is provided in Figure 3-1.

The surface layout of bores at the site is shown in Figure 2-2, bore logs and the geophysical log for Longswamp 34 are presented in Appendix A and Appendix C respectively. Photographs of the core taken from Longswamp 34 are presented in Appendix B.

Condamine Alluvium

Drilling at Longswamp 34 commenced from 5 mbgl with coring commencing from 14 mbgl. During drilling of the interval between 5 and 14 mbgl, observations were made of the cuttings coming over the shakers. This process was continued when coring commenced from 14 mbgl due to the unconsolidated formation and subsequent core loss. However, during drilling of Longswamp 33, chip logging was undertaken from surface to 20 mbgl to allow for this core loss.

The lithology observed (cuttings over shakers during Longswamp 34 and chips collected during Longswamp 33) indicates the Condamine Alluvium consisted of 80% dark grey plastic clay with 20% fine to coarse sand (increasing with depth), subrounded, moderately sorted from surface to 9 mbgl overlying grey medium to coarse clayey sands with abundant iron stained quartz down to 14.5 mbgl, overlying brown / orange coarse sand, subrounded, poorly sorted with grey / brown clay of medium plasticity to base of the Alluvium.

The lithology observed in Longswamp 35 largely correlated with that observed in Longswamp 33 and Longswamp 34 with dark grey silty clay and clayey sand from surface to 10.8 mbgl overlying light brown fine to coarse grained sand and lenses of stiff grey silty clay to base of the Condamine Alluvium.

This observed lithology is regarded as being typical of Condamine Alluvium with thicker sequences of the coarse sands in other areas where Condamine Alluvium is present are considered significant unconfined aquifers and are targeted for groundwater abstraction.

The drilling data collected at the Long Swamp Site show the Condamine Alluvium is present from surface to 18 mbgl.

Westbourne Formation

The top of the Westbourne formation was picked at 18 mbgl and based on the formation density and gamma logs obtained through the downhole geophysical log in Longswamp 34 and compared with geophysical data in available offset wells. The observed lithology consisted of medium to dark brown clay of medium plasticity with pebble sized calcrete at 26 mbgl, and increasing sand (fine) content down to 34 mbgl. Between 34 and 41 mbgl, grey / yellow / maroon / orange / brown plastic clays with some claystone and siltstone observed.

The screen interval for monitoring bore Longswamp 32 targets the plastic clays overlying the sandstone at 41 mbgl.

Between 41 mbgl and the base of the formation (52.94 mbgl), the lithology consisted of grey weathered fine grained sandstone to 43 mbgl, overlying moderately cemented fine to medium grained maroon, yellow brown and white sandstone to the base of the Westbourne Formation.

The highly weathered intervals of the Westbourne Formation generally result in the formation being regarded as a regional aquitard and not a productive aquifer and the lithology of the Westbourne Formation observed at Long Swamp is consistent with this regional interpretation.

The drilling data collected at the Long Swamp Site show the Westbourne Formation is present from 18.00 mbgl to 52.94 mbgl.

Springbok Sandstone

The top of the Springbok Sandstone was picked at 52.94 mbgl and based on the formation density and gamma logs obtained through the downhole geophysical log in Longswamp 34 and compared with geophysical data in available offset wells.

The Springbok Sandstone lithology was observed as moderately cemented fine to medium grained grey / green sandstone grading to grey well cemented coarse grained sandstone towards the base of the formation. Carbonaceous wisps and a minor coal seam (6mm at 74 mbgl) were observed from 64.57 mbgl.

Longswamp 33 was screened within the base of the Springbok Sandstone against a section of coarse grained sandstone and inferred more permeable interval of the formation.

This observed sequence of the Springbok Sandstone in the vicinity of Long Swamp indicates it is a poor aquifer due to the moderate to high cementation and fine grain size of the sandstone, the poor yield during airlift development and the observed hydraulic conductivity value (Section 5.2). However, in areas further west of Long Swamp within the Surat Basin where the Springbok Sandstone is encountered much deeper, it is considered a productive aquifer.

The Springbok Sandstone aquifer within the vicinity of Long Swamp is likely confined with the overlying low permeable lithology of the Westbourne Formation acting as the confining layer.

The drilling data collected at the Long Swamp Site show the Springbok Sandstone is present from 52.94 mbgl to 107.97 mbgl.

Walloon Coal Measures

The top of the WCM was identified by a calcareous cemented light grey sandstone overlaying a 5.48 m moderately weathered dull coal band from 82.57 mbgl to 88.05 mbgl. This coal seam overlays moderately weathered light grey siltstone with frequent carbonaceous wisps. This interval was identified as the Kogan Seam of the WCM.

Underlying the Kogan Seam at 107.97 mbgl was the Macalister Seam of the WCM. The Macalister Seam consisted of 10 m of moderately weathered dull coal seams interbedded with moderately weathered carbonaceous mudstone and siltstone to 116.91 mbgl, underlain by carbonaceous siltstone grading to fine grained sandstone to total depth.

The screen interval for Longswamp 34 is adjacent to the coal seam identified within the Macalister Seam as the seam within the Kogan Seam was in close proximity to the base of the Springbok Sandstone and isolating this interval from the overlying formation would have been difficult.

Regionally within the WCM, the coal seams, which comprise approximately 10% of the total sequence, are typically the most permeable horizons although some of the coarser sandstone units may yield useful quantities of water. The thick sequences of thinly bedded mudstones, siltstones and fine silty clayey sandstones may be regarded as aquitards.

The WCMs have historically been utilised as a reliable source of small water production mainly for stock and domestic purposes. The observed lithology and airlift yield at Long Swamp indicates the WCM aquifer in this vicinity is consistent with this regional hydrogeological interpretation.

The WCM aquifer is generally considered to be confined due to its depth and the low permeable overburden and interburden between coal seams. The observed overlying lithology at Long Swamp and the observed head in Longswamp 34 indicates the WCM aquifer in the vicinity of Long Swamp is confined.

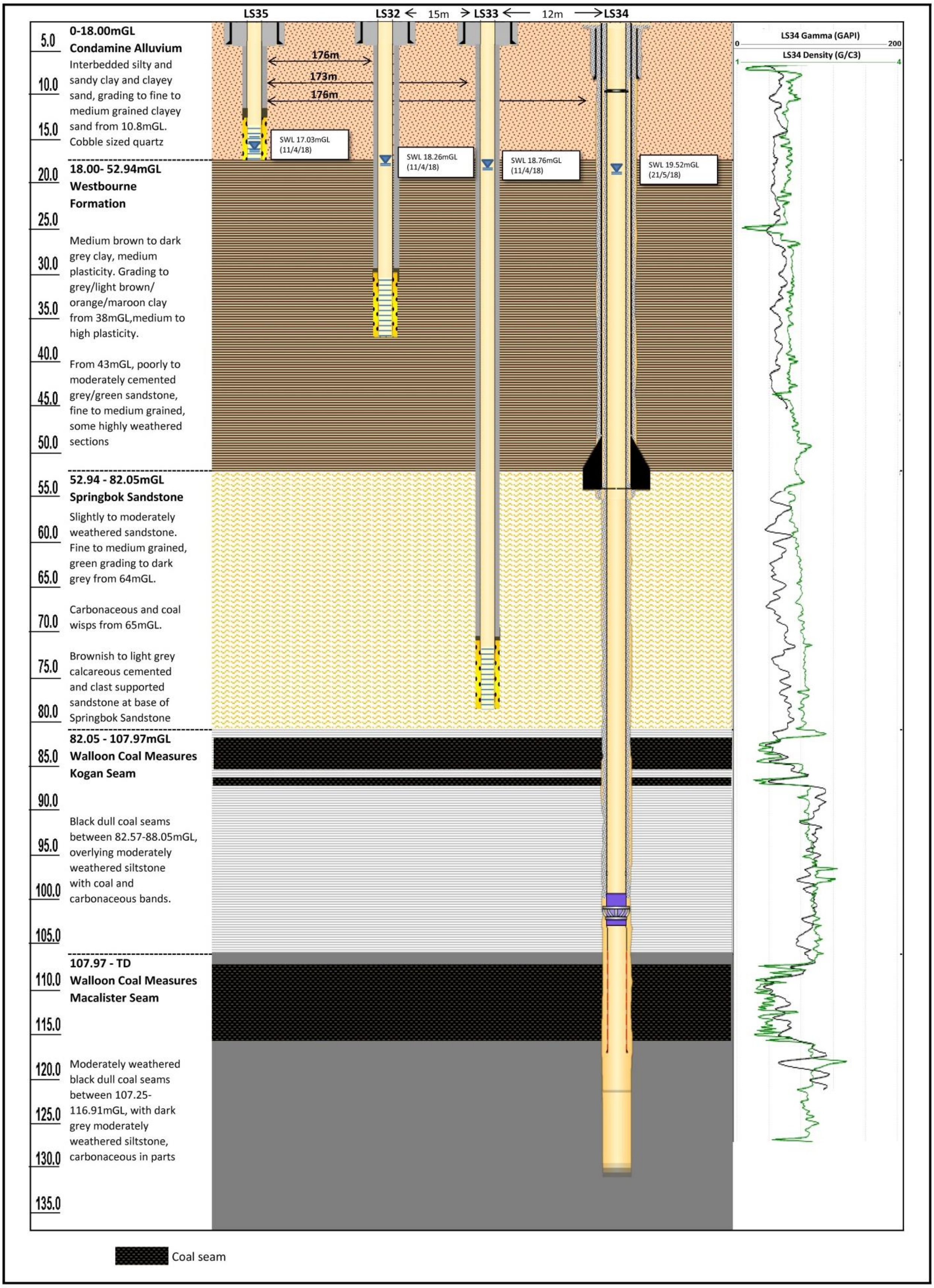


Figure 3-1: Long Swamp GDE Site Geological Summary

3.2 Lake Broadwater

3.2.1 Drilling and Bore Construction

The Lake Broadwater site comprised of three groundwater monitoring bores (Longswamp 28, Longswamp 29 and Longswamp 30R). A summary of the bores' construction details are provided in Table 3-2. The screen intervals in Longswamp 28 and Longswamp 29 were determined based on the core data collected in Longswamp 30R.

Table 3-2: Lake Broadwater Pad Monitoring Bores' Construction Details

	Bore ID		
	Longswamp 28	**Longswamp 29**	**Longswamp 30R**
Monitored Formation	Westbourne Formation	Springbok Sandstone	WCM – Kogan Seam
Drilled Diameter	Conductor hole – $8^{1/2}$” Production hole – $6^{1/8}$”	Conductor hole – $8^{1/2}$” Production hole – $6^{1/8}$”	Core hole – $5^{1/2}$” Surface hole – $8^{1/2}$” Production hole – $6^{1/8}$”
Total Depth Drilled (mbgl)	40.0	111.0	204.0
Conductor Casing Diameter and Depth (mbgl)	7”, 7.2	7”, 7.2	$12^{5/8}$”, 6.7 (preinstalled prior to drilling program)
Surface Casing Diameter and Depth (mbgl)	na	na	$6^{1/8}$”, 66.2
Slotted Casing Diameter and Depth (mbgl)	2”, 34.0 to 40.0	2”, 104.0 to 110.0	2”, 177.2 to 182.6, and 186.9 to 192.0
Gravel Pack - annulus (mbgl)	33.0 to 40.0	103.0 to 111.0	177.2 to 182.6, and 186.9 to 192.0
Bentonite - annulus (mbgl)	32.0 to 33.0	102.0 to 103.0	171.2 to 171.7
Cement - annulus (mbgl)	0 to 32.0	0 to 102.0	0 to 171.2
Stickup (magl)	0.92	0.93	na
Easting (GDA94, Zone 56)	311227.35	311212.21	311193.52
Northing (GDA94, Zone 56)	6974293.82	6974294.73	6974296.16
Surface Elevation (mAHD)	339.502	339.602	339.658

Longswamp 28

Longswamp 28 is located approximately 448 m to the northwest of Longswamp 31. The bore was drilled by conventional mud rotary method to a depth of 40.0 mbgl within the Westbourne Formation. The monitoring bore was constructed with class 18 uPVC to TD. The bore was constructed to be open to the Westbourne Formation through 0.4 mm aperture slotted casing between 34.0 mbgl and 40.0 mbgl with blank casing from 34.0 mbgl to surface. A gravel pack was installed from 33.0 mbgl to 40.0 mbgl and a 1 m bentonite seal was placed above from 32.0 mbgl to 33.0 mbgl. The annulus was then cemented from 32.0 mbgl to surface. The bore was completed with a lockable steel monument and concrete plinth.

The bore was developed by airlifting however it displayed a poor yield and obtaining a representative flow rate was not possible.

Longswamp 28 was completed with an Insitu LevelTroll pressure transducer hung on stainless steel cable recording pressure at hourly intervals. The data collected in the BaroTroll installed in Longswamp 32 were used to correct the LevelTroll pressure data for barometric pressure. Pressure data collection commenced on 6 March 2018.

Longswamp 29

Longswamp 29 is located approximately 463 m to the northwest of Longswamp 31. The bore was drilled by conventional mud rotary method to a depth of 111.0 mbgl within the Springbok Sandstone. The monitoring bore was constructed with class 18 uPVC to 110.0 mbgl. The bore was constructed to be open to the Springbok Sandstone through 0.4 mm aperture slotted casing between 104.0 mbgl and 110.0 mbgl with blank casing from 104.0 mbgl to surface. A gravel pack was installed from 103.0 mbgl to 111.0 mbgl and a 1 m bentonite seal was placed above from 102.0 mbgl and 103.0 mbgl. The annulus was then cemented from 102.0 mbgl to surface. The bore was completed with a lockable steel monument and concrete plinth.

The bore was developed by airlifting however it displayed a poor yield and obtaining a representative flow rate was not possible. Water was required to be injected into the bore to facilitate airlift development due to the low flow rate. Water quality sampling undertaken post bore completion identified elevated levels of hydroxide alkalinity as $CaCO_3$ and major ions, and displayed a pH of 13 indicating the water within the bore is not representative of the monitored formation and is likely influenced by the injected water. This monitoring bore will be further developed in the future.

Longswamp 29 was completed with an Insitu LevelTroll pressure transducer hung on stainless steel cable recording pressure at hourly intervals. The data collected in the BaroTroll installed in Longswamp 32 were used to correct the LevelTroll pressure data for barometric pressure. Pressure data collection commenced on 6 March 2018.

Longswamp 30R

Longswamp 30R is located approximately 481 m to the northwest of Longswamp 31. The bore was cored at 4 inch size from 6.85 mbgl to 194.16 mbgl however, during reaming of the surface section, the hole was over drilled by 7 m and core was unable to be collected between the interval 61.1 mbgl to 68.1 mbgl. Chip samples were collected between 60.0 mbgl and 70.0 mbgl during the drilling of Longswamp 29 to allow for the loss of core data. Core recovery was reasonable with approximately 94% recovery. Core box photographs are provided in Appendix B.

The recovered core and chip samples showed alluvium consisting of mudstone and weathered sandstone from surface to 30.8 mbgl, overlying fine to medium grained fresh sandstone with slightly weathered siltstones and mudstones of the Westbourne Formation down to 94.5 mbgl, overlying the Springbok Sandstone consisting of well cemented sandstones interbedded with hard blocky siltstones with thin coal and carbonaceous bands down to 178.2 mbgl, overlying the Kogan seam of the WCM consisting of fresh sandstones and moderately weathered dull coal bands to TD.

Following completion of coring, the hole was reamed out to $6^{1/8}$ inch to a total depth of 204.0 mbgl to allow for a 10 m sump for the downhole geophysics logging tool.

Following reaming, a suite of geophysical logs were run by Schlumberger. The logs are provided in Appendix C.

The monitoring bore was constructed with steel 2 inch casing to 192.0 mbgl. The bore was constructed to be open to the Kogan Seam through prepacked steel screens between 177.2 mbgl to 182.6 mbgl and 186.9 mbgl to 192.0 mbgl with blank casing from 182.6 mbgl to 186.9 mbgl and from 177.2 mbgl to surface. A cement basket was placed at 171.2 mbgl and the annulus was then cemented to surface.

The bore was developed by airlifting however it displayed a poor yield and obtaining a representative flow rate was not possible. In addition, water was required to be injected into the bore during airlifting to facilitate bore development. All injected water was removed from the bore during development.

The bore was completed with a steel wellhead, and a GeoPSI digital pressure gauge (1000 psi) was installed at 175 mbgl on 23 February 2018. Pressure data collection commenced on 16 May 2018.

3.2.2 Site Geological Summary and Hydrostratigraphy

Coring and geophysical logging of Longswamp 30R has provided a detailed picture of the site geology. These data were used to select monitoring targets and screen intervals / depths for bores Longswamp 28, Longswamp 29 and Longswamp 30R.

A graphic of the geological sequence at the Lake Broadwater GDE site showing the depth and screened intervals of the bores, and potentiometric surface for each formation is provided in Figure 3-2.

The surface layout of bores at the site is shown in Figure 2-3, bore logs and the geophysical log for Longswamp 30R are presented in Appendix A and Appendix C respectively. Photographs of the core taken from Longswamp 30R are presented in Appendix B.

Alluvium

Coring at Longswamp 30R commenced from 6.85 mbgl. The lithology observed during drilling of Longswamp 30R indicates the Alluvium consisted of highly to completely weathered grey and brown mudstone / highly plastic clays to 14.2 mbgl, grading to a weathered light grey / brown fine to medium grained sandstone / clayey sand with carbonaceous coating to 18.3 mbgl, overlying light grey and brown weathered mudstone / plastic clays with iron oxide colouration to 28.65 mbgl, overlying light grey siltstone to the base of the alluvium at 31 mbgl.

The lithology observed below 3 m (below the localised perched system associated with Lake Broadwater) in Longswamp 31 largely correlated with that observed in Longswamp 30R. The lithology in Longswamp 31 comprised grey highly plastic clays from 3 mbgl to 11.3 mbgl, overlying fine to medium grained sandy clay / clayey sand of medium to high plasticity with thin (2-5 mm) coal bands to 18.0 mbgl, overlying brown sandy clay of medium plasticity with orange mottling down to 21.0 mbgl.

The weathered nature of the lithology observed within the alluvium at the Lake Broadwater Site would largely restrict the unit to be utilised as a productive aquifer. The unit would be unconfined given there is not an overlying unit.

The drilling data collected at the Lake Broadwater Site show Alluvium is present from surface to 31 mbgl.

Westbourne Formation

The top of the Westbourne formation was picked at 30.78 mbgl based on the formation density and gamma logs obtained through the downhole geophysical log in Longswamp 30R and compared with geophysical data in available offset wells. The lithology comprised of brown / grey mudstone to 37.5 mbgl, overlying slightly weathered fine grained grey sandstone with carbonaceous wisps to 47 mbgl, overlying predominantly grey fine to medium grained poorly to moderately cemented sandstone with carbonaceous bands and wisps, with some hard blocky siltstone to the base of the formation.

The screen interval in Longswamp 28 targets the mudstone and weathered sandstones of the upper Westbourne Formation.

As discussed in Section 3.1.2, the highly weathered intervals of the Westbourne Formation generally result in the formation being regarded as a regional aquitard and not a productive aquifer. The observed lithology, and the poor yield recorded during airlift development of Longswamp 28, and the hydraulic conductivity value derived from hydraulic testing (Section 5.2) are indicative of the Westbourne Formation. As a result, the Westbourne Formation in the vicinity of Lake Broadwater is considered an aquitard.

The drilling data collected at the Lake Broadwater Site show the Westbourne Formation is present from 30.78 mbgl to 94.50 mbgl.

Springbok Sandstone

The top of the Springbok Sandstone was picked at 94.50 mbgl and based on the formation density and gamma logs obtained through the downhole geophysical log in Longswamp 30R and compared with geophysical data in available offset wells.

The Springbok Sandstone lithology comprised predominantly of fresh very well cemented fine to medium grained grey sandstone interbedded with hard blocky dark grey siltstone. From 132 mbgl, the lithology was predominantly sandstone to the base of the formation (178 mbgl). Carbonaceous bands and wisps were observed throughout the formation with coal seams ranging from 1 to 30 cm thick.

The screen interval in Longswamp 29 is adjacent to a medium to coarse grained sandstone and inferred more permeable interval of the formation.

As with the sequence of Springbok Sandstone observed at the Long Swamp site, the Springbok Sandstone present at the Lake Broadwater site is likely a poor aquifer with minimal yield due to the very well cemented sandstone and hard blocky siltstone. The very poor yield recorded during airlift development and the derived hydraulic conductivity value (Section 5.2) of Longswamp 29 confirms this assumption.

The Springbok Sandstone aquifer within the vicinity of Lake Broadwater is likely confined with the overlying low permeable lithology of the Westbourne Formation acting as the confining layer.

The drilling data collected at the Lake Broadwater Site show the Springbok Sandstone is present from 94.50 mbgl to 178.2 mbgl.

Walloon Coal Measures

The WCM were encountered from 178.2 mbgl within the Kogan Seam. The lithology consisted of weathered dull coal seams between 178.2-179.0 mbgl, and 186.6-190.7mbgl, interbedded with fresh very well cemented fine to medium grained sandstone, fresh siltstone and weathered carbonaceous mudstone to TD.

The screen intervals for Longswamp 30R are adjacent to the two coal seams identified within the Kogan Seam. The open interval of Longswamp 30R extends up to the depth at which the cement basket was placed (171.2 mbgl) which correlates to the base of the Springbok Sandstone (formation interval is 94.50-178.28 mbgl). Although the monitored zone for Longswamp 30R includes the base of the overlying formation, the monitored zone is still considered appropriate for the purposes of this Study (which is to assess the level of vertical hydraulic connectivity of the WCM to overlying formations) due to the following:

- There is 60 m vertical offset between the monitored zone of Longswamp 29 (Springbok Sandstone) and Longswamp 30R (WCM),
- The lithology of the interburden (well cemented sandstone and siltstone) within the WCM is similar to that of the overlying Springbok Sandstone with no distinct lithological change delineating the contact between the Springbok Sandstone and WCM except for the presence of coal at the top of the WCM, and
- The lithology, airlift development observations and hydraulic conductivity values (Sections 5, 5.2, and 5) of the Springbok Sandstone show the very low permeability of the formation and vertical movement of water within the formation would be low.

Regionally within the WCM, the coal seams, which comprise approximately 10% of the total sequence, are typically the most permeable horizons although some of the coarser sandstone units may yield useful quantities of water. The thick sequences of thinly bedded mudstones, siltstones and fine silty clayey sandstones may be regarded as aquitards.

The WCMs have historically been utilised as a reliable source of small water production mainly for stock and domestic purposes. The observed lithology and airlift yield at Long Swamp indicates the WCM aquifer in this vicinity is consistent with this regional hydrogeological interpretation.

The lithology encountered within the WCM and the poor yield observed during airlift development of Longswamp 30R indicate the Kogan Seam of the WCM is likely a poor aquifer in the vicinity of the Lake Broadwater site.

The WCM aquifer is generally considered to be confined due to its depth and the low permeable overburden and interburden between coal seams. The observed overlying lithology (within Westbourne Formation and Springbok Sandstone) at

Lake Broadwater and the observed head in Longswamp 30R indicates the WCM aquifer in the vicinity of Lake Broadwater is confined.

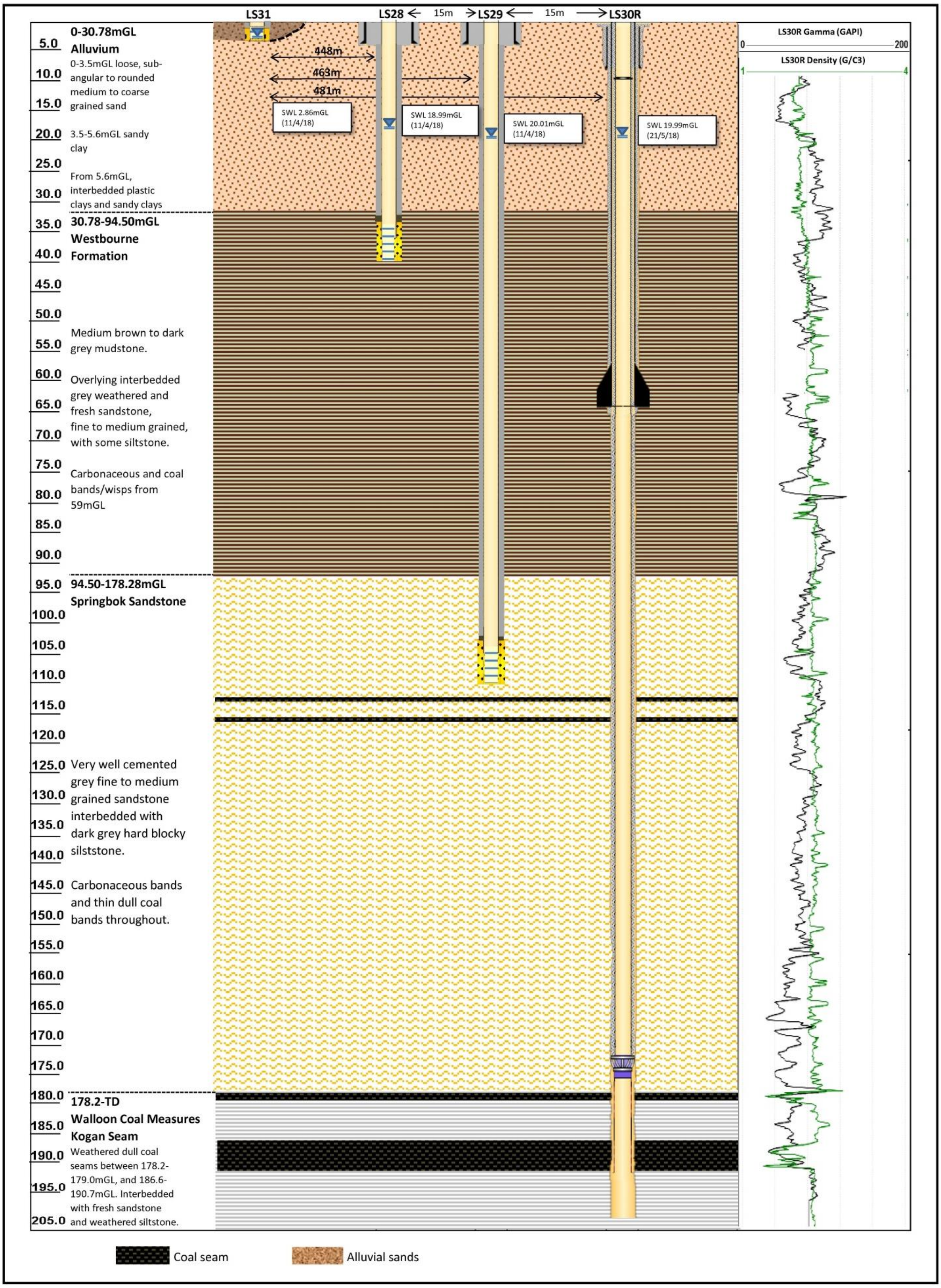


Figure 3-2: Lake Broadwater GDE Site Geological Summary

3.3 Burunga Lane

3.3.1 Drilling and Bore Construction

The Burunga Lane site comprised of three groundwater monitoring bores (Burunga Lane 183, Burunga Lane 184 and Burunga Lane 185). A summary of the bores' construction details are provided in Table 3-3. The screen interval in Burunga Lane 183 and Burunga Lane 185 was determined based on the core and downhole geophysics data collected in Burunga Lane 184.

Table 3-3: Burunga Lane Site Monitoring Bores' Construction Details

	Bore ID		
	Burunga Lane 183	**Burunga Lane 184**	**Burunga Lane 185**
Monitored Formation	WCM - Macalister	WCM - Wambo	WCM - Macalister
Drilled Diameter	Conductor hole – $8^{1/2}$” Production hole – $6^{1/8}$”	Conductor hole – $12^{1/4}$” Surface hole - $8^{1/2}$” Production hole – $6^{1/8}$” Core hole – $5^{1/2}$”	Conductor hole – $8^{1/2}$” Production hole – $6^{1/8}$”
Total Depth Drilled (mbgl)	40.0	85.0	27.0
Conductor Casing Diameter and Depth (mbgl)	7”, 7.2	$9^{5/8}$”, 7.2	7”, 7.2
Surface Casing Diameter and Depth (mbgl)	na	7”, 14.5	na
Slotted Casing Diameter and Depth (mbgl)	2”, 34.0 to 40.0	2”, 62.3 to 73.0	2”, 20.0 to 26.0
Gravel Pack - annulus (mbgl)	33.0 to 40.0	62.3 to 73.0	19.0 to 27.0
Bentonite - annulus (mbgl)	32.0 to 33.0	60.3 to 62.3	18.0 to 19.0
Cement - annulus (mbgl)	0 to 32.0	0 to 60.3	0 to 18.0
Stickup (magl)	0.81	na	0.84
Easting (GDA94, Zone 56)	204666.789	204661.563	204672.842
Northing (GDA94, Zone 56)	7094171.068	7094171.744	7094170.426
Surface Elevation (mAHD)	272.33	272.28	272.37

Burunga Lane 183

Burunga Lane 183 is located approximately 213 m to the west of Burunga Lane 182. The bore was drilled by conventional mud rotary method to a depth of 40.0 mbgl within the Macalister Seam of the WCM. The monitoring bore was constructed with class 18 uPVC to 40.0 mbgl. The bore was constructed to be open to the Macalister Seam through 0.4 mm aperture slotted casing between 34.0 mbgl and 40.0 mbgl with blank casing from 34.0 mbgl to surface. A gravel pack was installed from 40.0 mbgl to 33 mbgl and a 1 m bentonite seal was placed above from 33 mbgl to 32mbgl. The annulus was then cemented from 32 mbgl to surface. The bore was completed with a lockable steel monument and concrete plinth.

The bore was developed by airlifting with a total of 300 L purged and an observed approximate flow rate of 0.03 L/sec.

Burunga Lane 183 was completed with an Insitu LevelTroll pressure transducer hung on stainless steel cable recording pressure at hourly intervals. The data collected in the BaroTroll installed in Burunga Lane 182 were used to correct the LevelTroll pressure data for barometric pressure. Pressure data collection commenced on 17 March 2018.

Burunga Lane 184

Burunga Lane 184 is located approximately 218 m to the west of Burunga Lane 182. The bore was cored at 4 inch size from 14.5 mbgl to 78.02 mbgl. Core recovery was reasonable with approximately 97% recovery. Core box photographs are provided in Appendix B.

The recovered core showed conglomerate from 14.5 to 14.9 mbgl, overlying interbedded weathered to fresh sandstone, hard blocky siltstone, carbonaceous mudstone and dull coal seams of the Macalister and Wambo seams of the WCM to TD.

Following completion of coring, the hole was reamed out to $6^{1/8}$ inch to a total depth of 85.0 mbgl to allow for a 10 m sump for the downhole geophysics logging tool.

Following reaming, a suite of geophysical logs were run by Schlumberger. The logs are provided in Appendix C.

The monitoring bore was constructed with steel 2 inch casing to 73.0 mbgl. The bore was constructed to be open to the Wambo Seam through prepacked steel screens between 62.3 mbgl to 73.0 mbgl with blank casing from 62.3 mbgl to surface. A cement basket was placed at 60.3 mbgl and the annulus was then cemented to surface.

The bore was developed by airlifting with a total of 650L purged an observed approximate flow rate of 0.1 L/sec.

The bore was completed with a steel wellhead and a GeoPSI digital pressure gauge (300 psi) was installed at 62 mbgl on 18 March 2018. Pressure data collection commenced on 18 May 2018.

Burunga Lane 185

Burunga Lane 185 is located approximately 208 m to the west of Burunga Lane 182. The bore was drilled by conventional mud rotary method to a depth of 27.0 mbgl within the Macalister Seam of the WCM. The monitoring bore was constructed with class 18 uPVC to 26.0 mbgl. The bore was constructed to be open to the Macalister Seam through 0.4 mm aperture slotted casing between 20.0 mbgl and 26.0 mbgl with blank casing from 26.0 mbgl to surface. A gravel pack was installed from 19.0 mbgl to 27.0 mbgl and a 1 m bentonite seal was placed above from 18.0 mbgl to 19.0 mbgl. The annulus was then cemented from 18.0 mbgl to surface. The bore was completed with a lockable steel monument.

The bore was developed by airlifting with a total of 600 L purged and an observed approximate flow rate of 0.13 L/sec.

Burunga Lane 185 was completed with an Insitu LevelTroll pressure transducer hung on stainless steel cable recording pressure at hourly intervals. The data collected in the BaroTroll installed in Burunga Lane 182 were used to correct the

LevelTroll pressure data for barometric pressure. Pressure data collection commenced on 12 April 2018.

3.3.2 Site Geological Summary and Hydrostratigraphy

Coring and geophysical logging of Burunga Lane 184 and coring of Burunga Lane 182 has provided a detailed picture of the site geology. These data were used to select monitoring targets and screen intervals / depths for bores Burunga Lane 183, Burunga Lane 184 and Burunga Lane 185.

A graphic of the geological sequence at the Burunga Lane GDE site showing the depth and screened intervals of the bores, and potentiometric surface for each formation is provided in Figure 3-3.

The surface layout of bores at the site is shown in Figure 3-3, bore logs and the geophysical log for Burunga Lane 184 are presented in Appendix A and Appendix C respectively. Photographs of the core taken from Burunga Lane 184 are presented in Appendix B.

Alluvium

Coring at Burunga Lane 184 commenced from 14.5 mbgl and no lithology data were available for the alluvium in this hole. Nonetheless, coring of Burunga Lane 182 commenced from surface and provided lithology data for the alluvium section at the Burunga Lane Site.

The base of alluvium was identified at 7 mbgl at Burunga Lane 182. The lithology observed in Burunga Lane 182 indicates the alluvium consisted of very fine to coarse grained sand and clay. A conglomerate layer was observed as cobble sized subrounded to subangular fragments at 5.1 mbgl.

Based on regional geological mapping and Arrow's geological model, this layer of alluvium is likely a localised feature associated with Juandah Creek. Drilling data from Burunga Lane 182 shows this alluvium was dry during drilling and did not intersect water however the deeper pilot hole at Burunga Lane 182 noted the first noticeable true groundwater strike occurred at 13.5 mbgl (3d Environmental / Earth Search, 2018). Additionally, groundwater level monitoring in Burunga Lane 182 shows it has been dry during the monitoring period.

The drilling data collected at the Burunga Lane Site show the alluvium is present from surface to 7 mbgl.

Walloon Coal Measures

The Macalister Seam of the WCM was encountered below the abovementioned alluvium at 7 mbgl with the Wambo Seam being observed immediately below a minor conglomerate band at 63.42 mbgl.

The lithology of both the Macalister and Wambo Seams consisted of interbedded grey medium grained moderately to well cemented sandstone, dark grey and brown carbonaceous mudstone, dark grey blocky siltstone and weathered dull coal seams.

Coal seams were predominantly located between 18.0 mbgl and 25.1 mbgl, 39.0 mbgl and 46.4 mbgl, and 64.0 mbgl and 69.6 mbgl.

Given the encountered lithology, the screen intervals for the three monitoring bores were selected to monitor a shallow coal seam (Burunga Lane 185), a deep coal seam (Burunga Lane 184) and the interburden consisting of dark grey hard siltstone, carbonaceous mudstone and very well cemented fine to medium sandstone (Burunga Lane 183) between the shallow and deep coal seams.

As noted for the Lake Broadwater and Long Swamp Sites, regionally within the WCM, the coal seams, which comprise approximately 10% of the total sequence, are typically the most permeable horizons although some of the coarser sandstone units may yield useful quantities of water. The thick sequences of thinly bedded mudstones, siltstones and fine silty clayey sandstones may be regarded as aquitards. This is consistent with the Burunga Lane site with the yields observed during airlift development of the three monitoring bores showing greater yields within the coal seams (Burunga Lane 184 and Burunga Lane 185) than the interburden (Burunga Lane 183).   The recorded water levels in the three monitoring bores indicate that all three monitored zones are under pressure and are confined systems within the larger confined WCM formation.

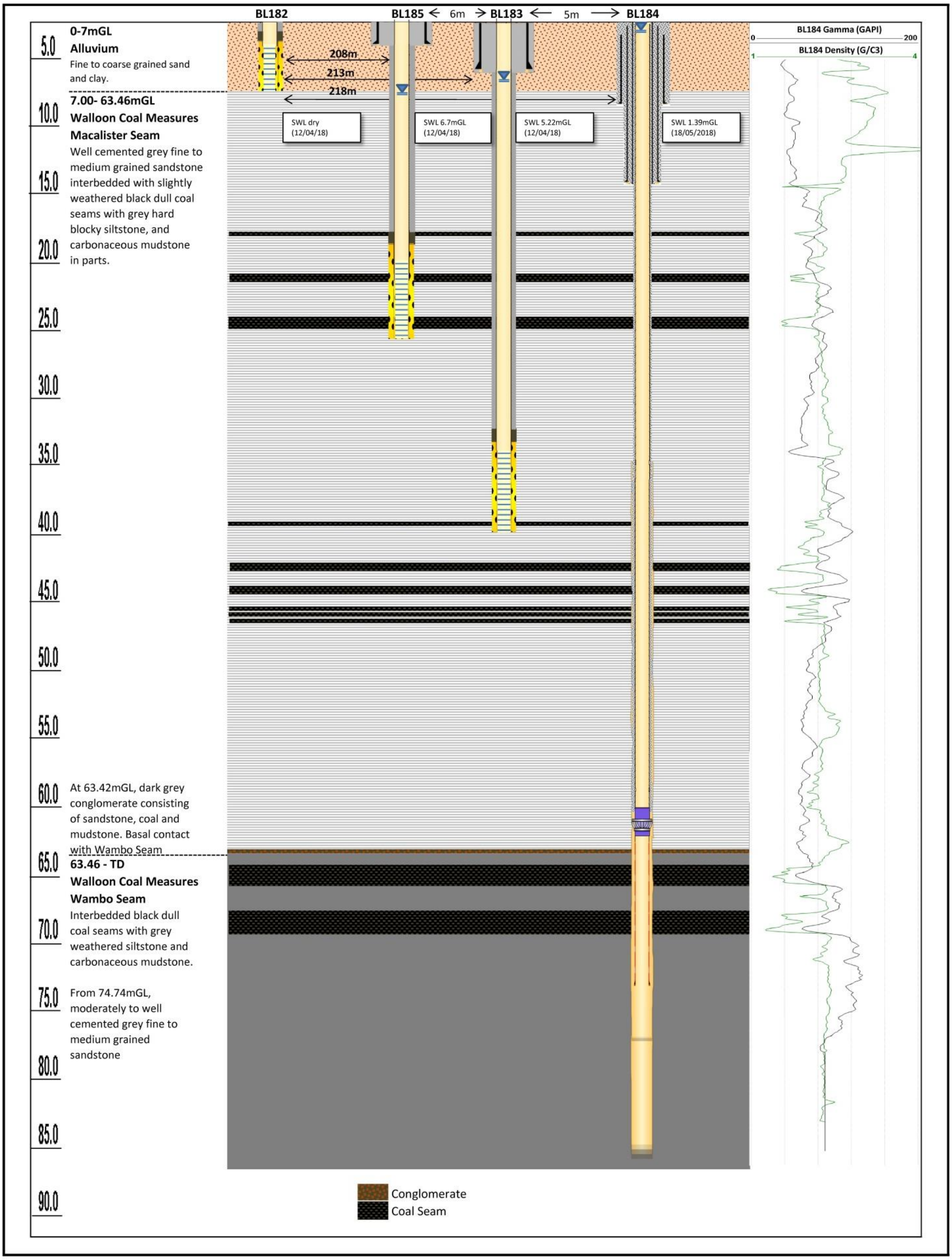


Figure 3-3: Burunga Lane GDE Site Geological Summary

3.4 Glenburnie

3.4.1 Drilling and Bore Construction

The Glenburnie site comprised of two groundwater monitoring bores (Glenburnie 21 and Glenburnie 22). A summary of the bores' construction details are provided in Table 3-4. The screen interval in Glenburnie 21 was determined based on the core and downhole geophysics data collected in Glenburnie 22.

Table 3-4: Glenburnie Site Monitoring Bores' Construction Details

	Bore ID	
	Glenburnie 21	**Glenburnie 22**
Monitored Formation	WCM - Wambo	WCM - Argyle
Drilled Diameter	Conductor hole – 8$^{1/2}$" Production hole – 6$^{1/8}$"	Conductor hole – 12$^{1/4}$" Surface hole - 8$^{1/2}$" Production hole – 6$^{1/8}$" Core hole – 5$^{1/2}$"
Total Depth Drilled (mbgl)	62.0	99.0
Conductor Casing Diameter and Depth (mbgl)	8$^{1/2}$", 14.0	9$^{5/8}$", 7.2
Surface Casing Diameter and Depth (mbgl)	na	7", 14.0
Slotted Casing Diameter and Depth (mbgl)	2", 55.7 to 61.0	2", 85.5 to 96.1
Gravel Pack - annulus (mbgl)	55.7 to 61.0	85.5 to 96.1
Bentonite - annulus (mbgl)	49.0-51.0	83.5 to 84.5
Cement - annulus (mbgl)	0 to 49.0	0 to 83.5
Stickup (magl)	na	na
Easting (GDA94, Zone 56)	312687.19	312697.29
Northing (GDA94, Zone 56)	6919908.67	6919897.77
Surface Elevation (mAHD)	384.27	384.30

Glenburnie 21

Glenburnie 21 is located approximately 104 m to the northeast of Glenburnie 20. The bore was drilled by conventional mud rotary method to a depth of 62.0 mbgl within the Wambo and Argyle Seams of the WCM.

The monitoring bore was constructed with 2 inch steel casing to 61.0 mbgl. The bore was constructed to be open to a coal seam situated at the top of the Argyle Seam with prepacked steel screens situated between 55.7 and 61.0 mbgl. A cement basket was installed at 51.0 mbgl and the annulus was cemented to surface.

The bore was developed by airlifting an observed approximate flow rate of 0.1 L/sec. A total purged volume was not recorded during operations.

The bore was completed with a steel wellhead and a GeoPSI digital pressure gauge (300 psi) was installed at 55 mbgl on 30 March 2018. Hourly pressure data collection has not yet commenced due to troubleshooting of onsite infrastructure however spot measurements have been collected.

Glenburnie 22

Glenburnie 22 is located approximately 104 m to the northeast of Glenburnie 20. The bore was cored at 4 inch size from 14.2 mbgl to 91.4 mbgl. Core recovery was good with approximately 97.5% recovery. Core box photographs are provided in Appendix B.

The recovered core showed weathered fine grained sandstone to 19 mbgl overlying fresh fine to medium grained sandstone interbedded with weathered coal seams and fresh siltstone to TD.

Following completion of coring, the hole was reamed out to $6^{1/8}$ inch to a total depth of 99.0 mbgl to allow for a sump for the downhole geophysics logging tool.

Following reaming, a suite of geophysical logs were run by Schlumberger. The logs are provided in Appendix C.

The monitoring bore was constructed with steel 2 inch casing to 96.1 mbgl. The bore was constructed to be open to the Argyle Seam through prepacked steel screens between 85.5 mbgl to 96.1 mbgl with blank casing from 96.1 mbgl to surface. A cement basket was placed at 83.5 mbgl and the annulus was then cemented to surface.

The bore was developed by airlifting an observed approximate flow rate of 0.13 L/sec. A total purged volume was not recorded during operations.

The bore was completed with a steel wellhead, and a GeoPSI digital pressure gauge (300 psi) was installed at 83.98 mbgl on 27 March 2018. Hourly pressure data collection has not yet commenced due to troubleshooting of onsite infrastructure however spot measurements have been collected.

3.4.2 Site Geological Summary and Hydrostratigraphy

Coring and geophysical logging of Glenburnie 22 and coring of Glenburnie 20 has provided a detailed picture of the site geology. These data were used to select monitoring targets and screen interval / depth for Glenburnie 21.

A graphic of the geological sequence at the Glenburnie site showing the depth and screened intervals of the bores, and potentiometric surface for each formation is provided in Figure 3-4.

The surface layout of bores at the site is shown in Figure 2-5, bore logs and the geophysical log for Glenburnie 22 are presented in Appendix A and Appendix C respectively. Photographs of the core taken from Glenburnie 22 are presented in Appendix B.

Alluvium

Coring at Glenburnie 22 commenced from 14.2 mbgl and no lithology data were available for the alluvium in this hole. Nonetheless, coring of Glenburnie 20 commenced from surface and provided lithology data for the alluvium section at the Glenburnie site.

The lithology observed during drilling of Glenburnie 20 indicates a thin layer of alluvium down to 2.5 mbgl consisting of brown fine to medium grained poorly sorted subangular to rounded sand.

The drilling data collected at the Glenburnie Site show the Alluvium is present from surface to 2.5 mbgl.

Springbok Sandstone

As noted above, coring at Glenburnie 22 did not commence until 14.2 mbgl and data collected in Glenburnie 20 has been utilised here to describe the lithology of the Springbok Sandstone.

Underlying the alluvium was the Springbok Sandstone down to 21.1 mbgl comprising predominantly fresh well cemented fine to medium grained light grey sandstone interbedded with slightly weathered black dull coal seams with dark grey siltstone in parts.

The 3d Environmental / Earth Search report (2018) states that there was a perched seepage zone observed between 11-18 mbgl in which Glenburnie 20 is screened against and the regional aquifer was intersected deeper within the WCM. As a result, the Springbok Sandstone in the vicinity of the Glenburnie Site is not considered a productive aquifer.

The drilling data collected at the Glenburnie Site show the Springbok Sandstone is present from 2.5 to 21.1 mbgl.

Glenburnie 20 was completed within the Springbok Sandstone.

Walloon Coal Measures

The top of the WCM was picked based on the formation density, gamma logs obtained through the downhole geophysical log in Glenburnie 22, and the core log from Glenburnie 20 and compared with geophysical data in available offset wells.

The WCM were encountered from 21.1 mbgl within the Wambo Seam. The Wambo Seam of the WCM comprised predominantly fresh well cemented fine to medium grained light grey sandstone interbedded with slightly weathered black dull coal seams with dark grey siltstone in parts. A 0.2 m fresh tuff band was observed at 41.6 mbgl overlying a 0.95 m thick slightly weathered dull coal seam.

The Argyle Seam of the WCM was then encountered from 57.03 mbgl and displayed similar lithology to the Wambo Seam except for the presence of slightly weathered mudstone and carbonaceous siltstone.

Coal seams were predominantly located between 41.8 mbgl and 42.95 mbgl, 57.04 mbgl and 59.96 mbgl, 67.0 mbgl and 69.2 mbgl, 72.4 mbgl and 73.0 mbgl, 81.5 mbgl and 82.0 mbgl, 84.28 mbgl and 84.55 mbgl, 86.7 mbgl and 87.3 mbgl, and 94.5 mbgl and 96.0 mbgl.

The screen intervals for Glenburnie 21 and Glenburnie 22 were selected to monitor a shallow and deep coal seam given the interburden of the WCM are generally considered aquitards, and the base of the Springbok Sandstone is only 21.1 mbgl.

As noted for the other GDE Sites, regionally within the WCM, the coal seams, which comprise approximately 10% of the total sequence, are typically the most permeable horizons although some of the coarser sandstone units may yield useful quantities of water. The thick sequences of thinly bedded mudstones, siltstones and fine silty clayey sandstones may be regarded as aquitards and were observed during drilling at the Glenburnie Site.

Given the lithology encountered within the WCM and the poor yield observed during airlift development of Glenburnie 21 and Glenburnie 22 the shallow seams of the WCM is likely a poor aquifer in the vicinity of the Glenburnie site.

The WCM aquifer is generally considered to be confined due to its depth and the low permeable overburden and interburden between coal seams. The observed lithology of the interburden (well cemented fine grained sandstones, mudstones and siltstones) at Glenburnie and the observed heads in Glenburnie 21 and Glenburnie 22 indicate the WCM aquifer in the vicinity of Glenburnie is confined.

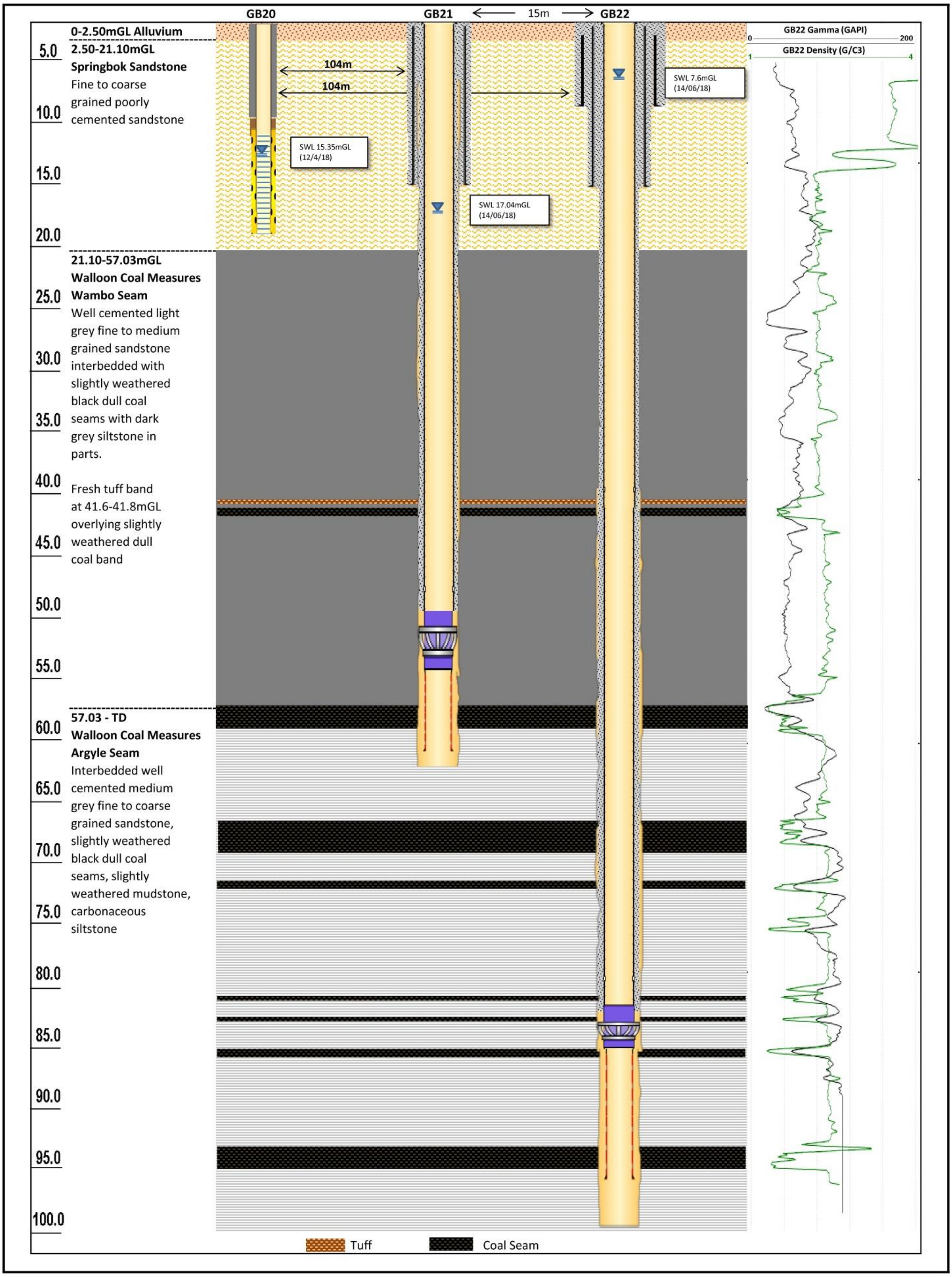


Figure 3-4: Glenburnie GDE Site Geological Summary

3.5 Confirmation of Lithology / Stratigraphy

The lithology data obtained through the drilling program supports the stratigraphic basis for the GDE risk assessment undertaken in the Stage 1 CSG WMMP (Coffey, 2017). The stratigraphy encountered at each of the four Sites are consistent with the regional stratigraphy that was used during the desktop study (Coffey, 2017), namely:

- At the Glenburnie site, the stratigraphy encompasses Springbok Sandstone overlying the WCM,
- At the Burunga Lane site, the WCM subcrop in this area with a thin alluvial cover at surface,
- At the Lake Broadwater site, the stratigraphy encompasses alluvium from surface overlying the Westbourne Formation, overlying the Springbok Sandstone, overlying the WCM, and
- At the Long Swamp site, the stratigraphy encompasses Condamine Alluvium from surface overlying the Westbourne Formation, overlying the Springbok Sandstone, overlying the WCM.

4. Groundwater Monitoring

4.1 Groundwater Levels

Groundwater level data were collected through both manual depth to water measurements (where access to bore was possible) and automatic measurements (i.e. pressure gauges). Details on the installed pressure gauges in each of the monitoring bores are provided in Section 3.

Data collected through pressure transducers were compensated for atmospheric pressure using barometric data collected in nearby barometric pressure loggers. Hydrographs for each Site are provided in Figure 4-1 to Figure 4-4.

Daily rainfall data are also provided in the hydrographs with the Bureau of Meteorology (BoM) station details and distance from the site noted. The groundwater monitoring periods at each site do not coincide with sufficient rainfall events occurring and, as a result, aquifer responses to incidental rainfall or seasonal rainfall periods is not yet possible to identify.

4.1.1 Long Swamp GDE Site

The Long Swamp Site hydrograph (Figure 4-1) shows:

- The water level in Longswamp 35 declined by four metres between the period of when the bore was installed in December 2017 to when it was developed and sampled in March 2018. This is likely due to the use of water during bore installation. Following bore development and sampling in March 2018, the water level dropped to below the pressure gauge in the bore and, as a result, no hourly pressure data are available between March and April 2018. It is expected that the water level in the bore would recover back to approximately the water level recorded in March 2018 as it appears to have been stabilising prior to development and sampling, and

- The distinct difference in hydraulic head between the formations, and the declining aquifer pressure with depth shows a downward vertical movement of groundwater and a lack of/poor hydraulic connection between the formations.

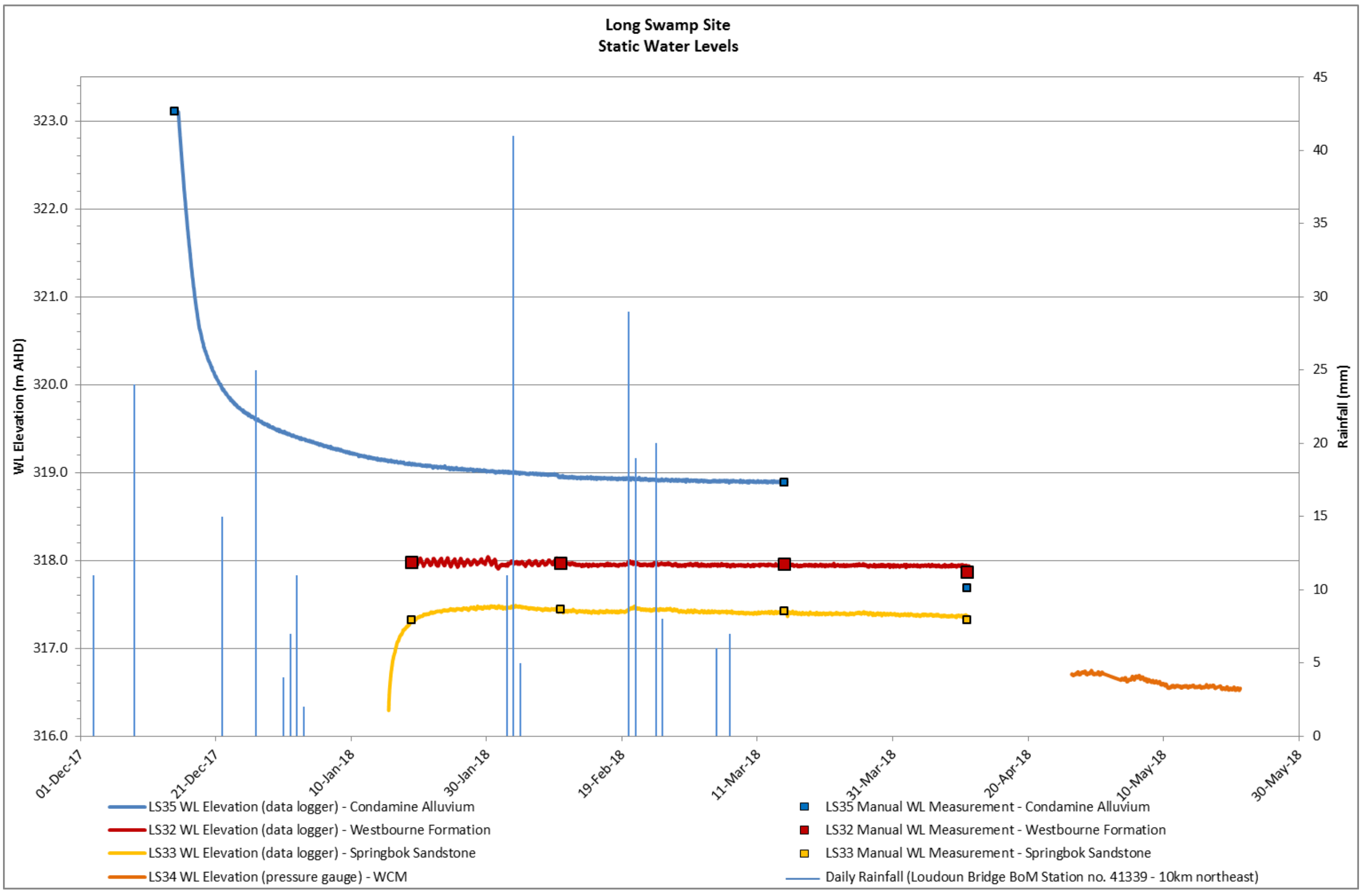


Figure 4-1: Long Swamp Site Hydrograph

4.1.2 Lake Broadwater GDE Site

The Lake Broadwater Site hydrograph (Figure 4-2) shows:

- There is a distinct difference in hydraulic head between the perched system at Longswamp 31 and the underlying Westbourne Formation, Springbok Sandstone and WCM, indicating its hydraulic separation from the underlying formations,

- The Westbourne Formation displays a greater groundwater pressure than the Springbok Sandstone and WCM formations indicating a downward movement of groundwater between the Westbourne Formation and the underlying formations, and

- The WCM and Springbok Sandstone display a similar groundwater pressure indicating potential hydraulic connection between the WCM and the Springbok Sandstone.

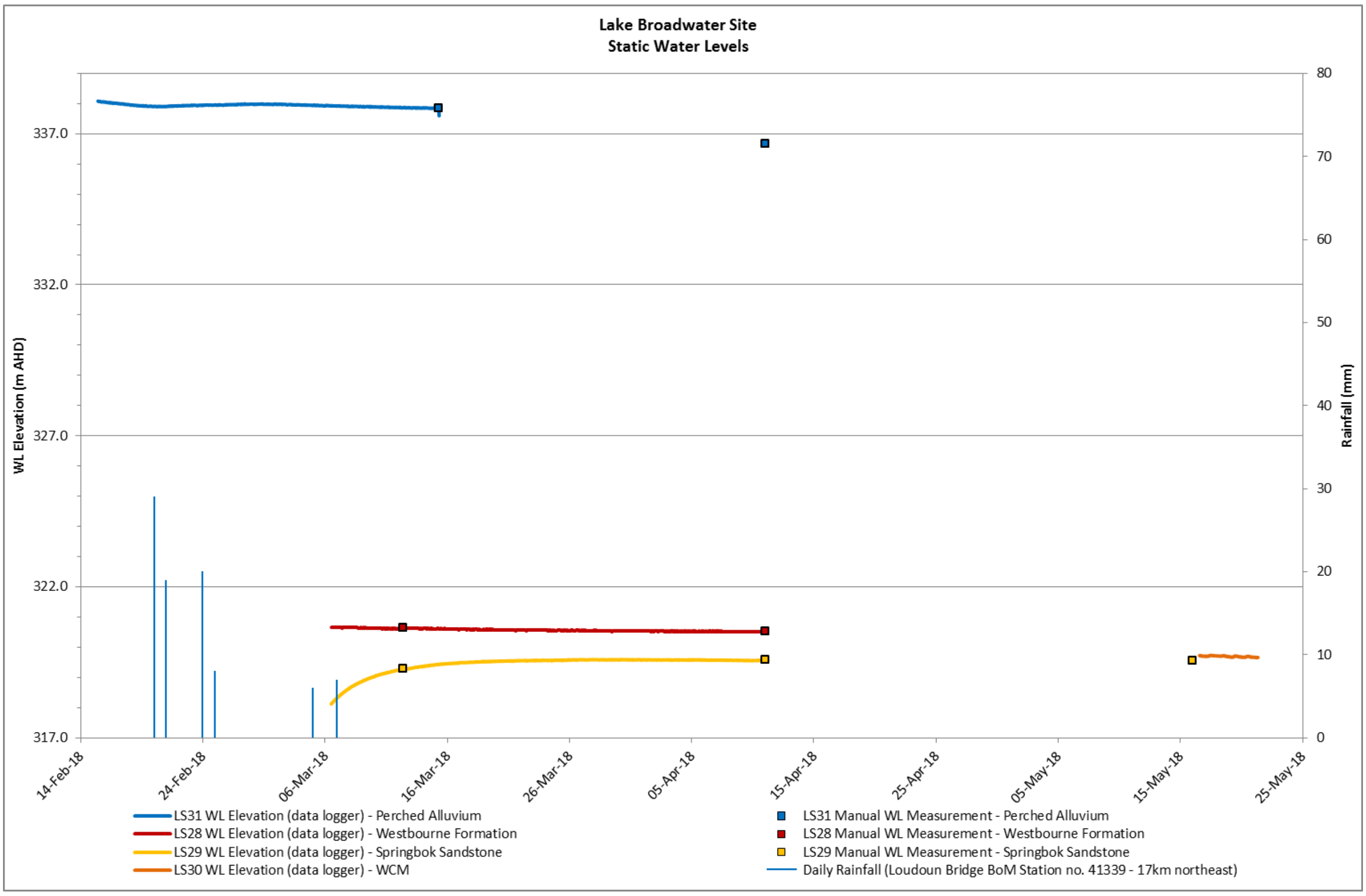


Figure 4-2: Lake Broadwater Site Hydrograph

4.1.3 Burunga Lane GDE Site

The Burunga Lane Site hydrograph (Figure 4-3) shows:

- Burunga Lane 182 has been dry when monitored. During drilling of the pilot hole at this site, the first noticeable true groundwater strike occurred at 13.5 mbgl (3d Environmental / Earth Search, 2018). The total depth of this monitoring bore coincides with the base of the alluvium indicating that this localised alluvial feature associated with Juandah Creek is not a permanent aquifer and possibly only contains water following recharge events. Arrow monitoring bore Burunga Lane 177 is located 630 m to the east of the Burunga Lane Site and is screened within the alluvium. The base of the alluvium is deeper in this location and the monitoring bore is screened from 4.4-10.0 mbgl. The latest water level measurement (15/04/16) in this bore is 7.08 mbtoc and is shown in Figure 4-3 for reference.

- There is a distinct difference in hydraulic head between each monitoring bore's monitored zone. This indicates all three monitored zones are under pressure and are confined systems within the larger confined WCM formation with the deepest monitored interval (Burunga Lane 184) almost under artesian pressure, and

- Groundwater pressure increases with depth indicating upward vertical movement of groundwater within the WCM however the hydraulic connectivity is considered to be low due to the low permeability of the interburden (Section 5).

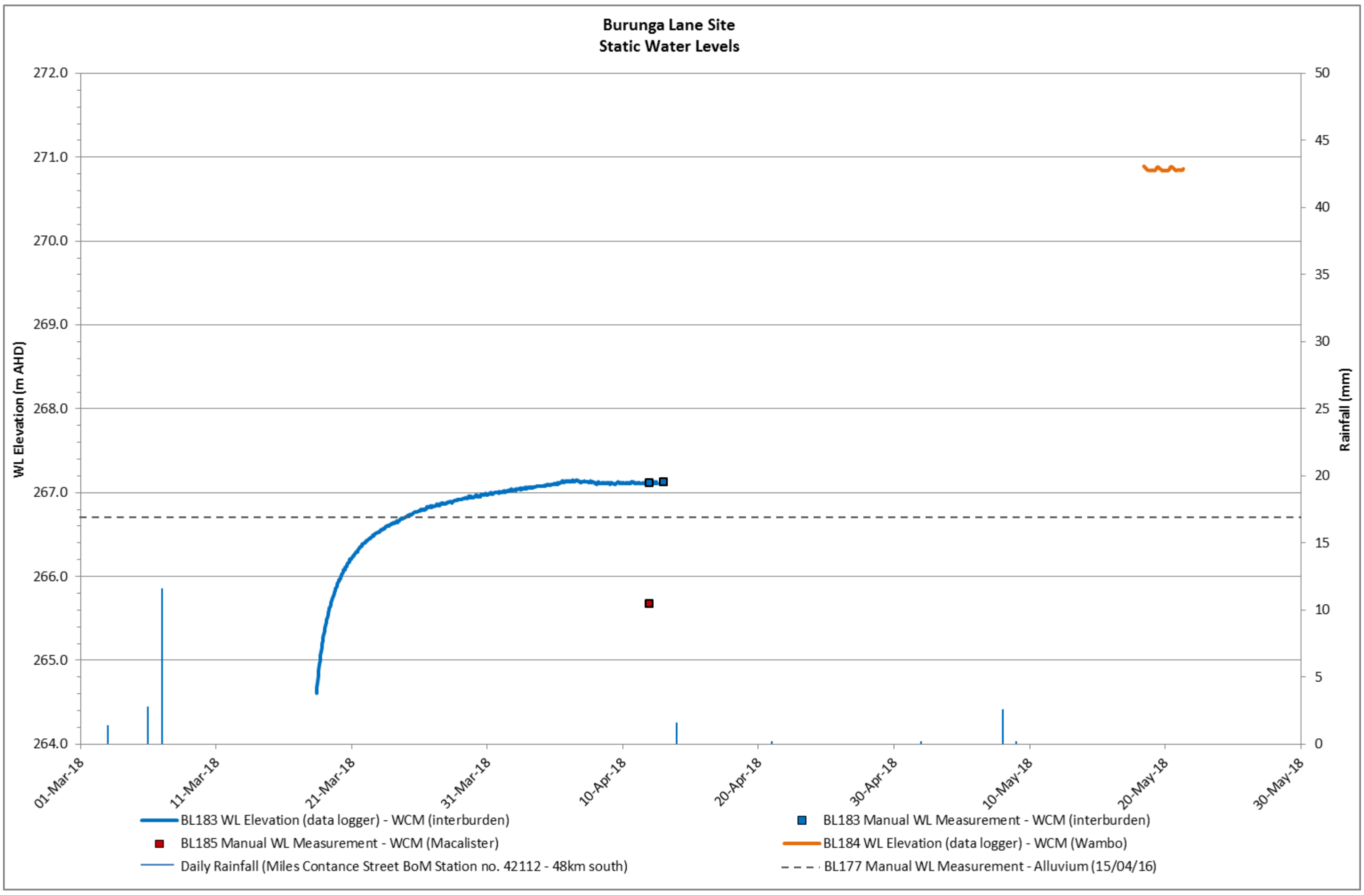


Figure 4-3: Burunga Lane Site Hydrograph

4.1.4 Glenburnie GDE Site

The Glenburnie Site hydrograph (Figure 4-4) shows:

- Substantial difference in hydraulic head between each monitored zone,
- Within the WCM, groundwater pressure increases with depth indicating upward vertical movement of groundwater within the WCM however the hydraulic connectivity is considered to be low due to the low permeability of the interburden (Section 5) and the large difference in hydraulic head (approximately 10 m) between Glenburnie 21 and Glenburnie 22, and
- As mentioned in Section 3.4.2, Glenburnie 20 is monitoring a perched seepage zone situated above the regional aquifer.

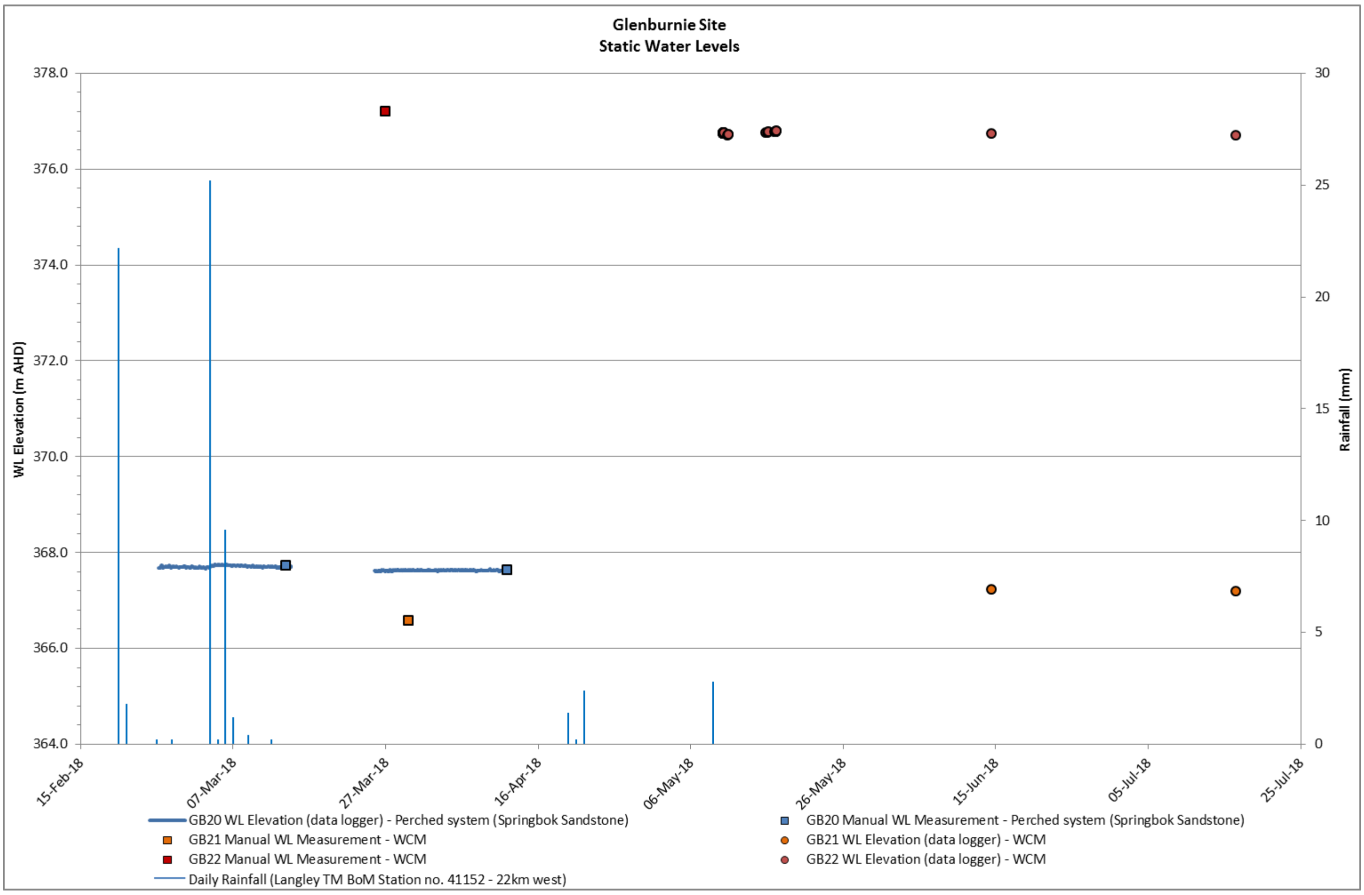


Figure 4-4: Glenburnie Site Hydrograph

4.2 Water Quality

4.2.1 Introduction

Water samples were collected from all monitoring bores and submitted to a NATA accredited laboratory (ALS) for analysis of the following analytes:

- Physical parameters (Electrical Conductivity (EC), Total Dissolved Solids (TDS),
- Alkalinity (Hydroxide Alkalinity as $CaCO_{3,}$ Carbonate Alkalinity as $CaCO_{3,}$ Bicarbonate Alkalinity as $CaCO_{3,}$ Total Alkalinity as $CaCO_3$),
- Major ions (Sulfate as SO_4, Chloride, Calcium, Magnesium, Sodium, Potassium), and
- Dissolved metals (Aluminium, Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Selenium, Zinc, Iron, Mercury).

Water samples were collected at the completion of airlift development for each monitoring bore except for Burunga Lane 185 and Longswamp 29 which were collected using a PVC bailer.

As noted in Section 3.2.1, Longswamp 30R required 320 L of water to be injected to the bore to facilitate airlift development. The daily drilling reports state all injected water was removed from the bore however there is a chance that the collected water sample may have been compromised through this process. Also mentioned in Section 3.2.1, water quality data collected for Longswamp 29 show the bore requires further development and, as a result, no water quality data are included here for this bore.

Water quality results from 3D Environmental / Earth Search's report (2018) are also provided for comparison.

4.2.2 Analytical Results

A summary of the water quality data is provided in Table 4-1, and copies of the laboratory analytical reports are provided in Appendix D.

Piper diagrams and Schoeller plots have been created (Figure 4-5 to Figure 4-12) to provide a graphical representation of the chemistry of the groundwater using the ratio of major ions with a discussion of the results provided in the following sections.

Long Swamp

The major ions data for the Long Swamp Site monitoring bores shows all four monitoring bores are sodium chloride type water with:

- Sodium as the dominant cation with minor calcium and magnesium components in all monitoring bores except for Longswamp 34, and
- Chloride as the dominant anion with a minor carbonate as $CaCO_3$ and bicarbonate as HCO_3 component in all monitoring bores.

The water quality data show variation in the ratio of major ions between the water samples collected from the four monitoring bores. This variation is mostly due to the decreasing calcium and magnesium contributions with depth across Longswamp 32, Longswamp 33 and Longswamp 34.

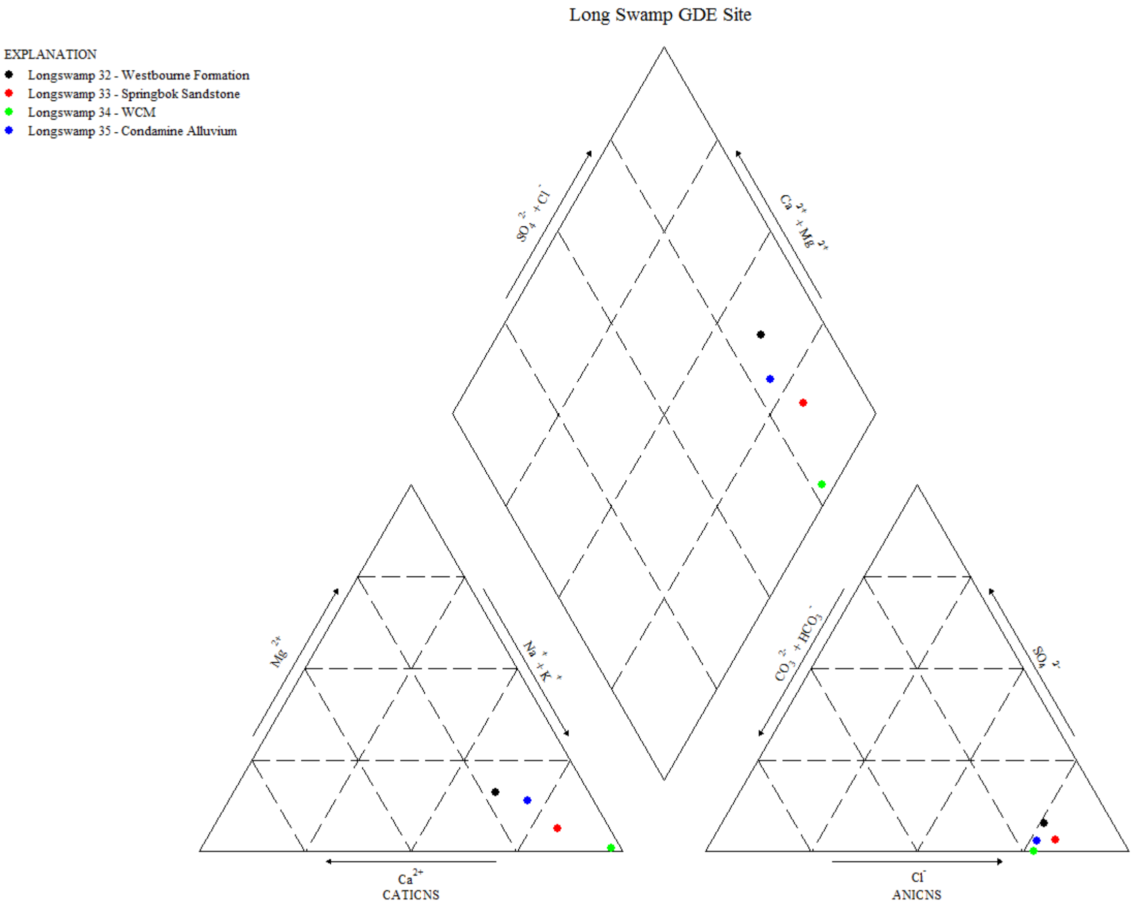


Figure 4-5: Long Swamp Site Piper Diagram

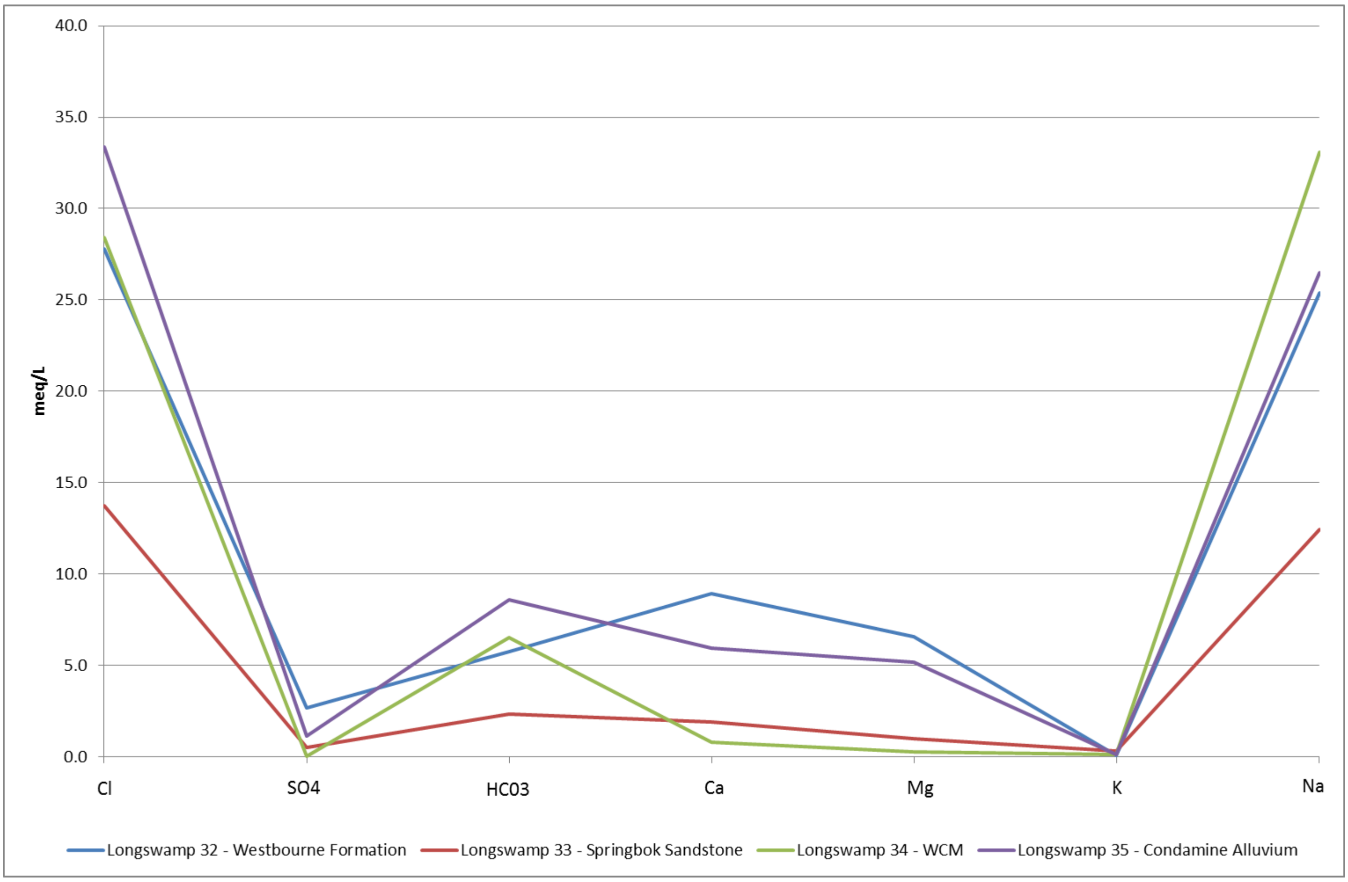


Figure 4-6: Long Swamp Site Schoeller Plot

Lake Broadwater

The major ions data for the Lake Broadwater Site monitoring bores shows the three sampled monitoring bores (Longswamp 28, Longswamp 30R and Longswamp 31) and Lake Broadwater surface water are sodium chloride type water with:

- Sodium as the dominant cation with no appreciable concentrations of other cations, and
- Chloride as the dominant anion with a minor carbonate as $CaCO_3$ and bicarbonate as HCO_3 component in all monitoring bores, with the Lake Broadwater surface water close to displaying no dominant anion.

While the samples are all sodium chloride type water their ratio of major ions

The water quality data show variation in the ratio of major ions between the water samples collected from the four sampling points (three monitoring bores and Lake Broadwater surface water) however there is not a clear pattern in the ratio of major ions with depth. In contrast to the Long Swamp site, differences in chemical composition at the Lake Broadwater site are governed mainly by the anion ratios specifically the carbonate as $CaCO_3$ and bicarbonate as HCO_3 to sodium ratio.

Of note is the difference in TDS between the Lake Broadwater surface water (fresh [290 mg/L]) and the TDS in all monitoring bores (brackish [3110 to 3930 mg/L]) however there is no trend in TDS with formation depth.

The chemical composition of Longswamp 30R is similar to that of Longswamp 34 (Long Swamp site) indicating that the data are representative of its screened interval (i.e. WCM) and has not been compromised by the injected water during airlift development.

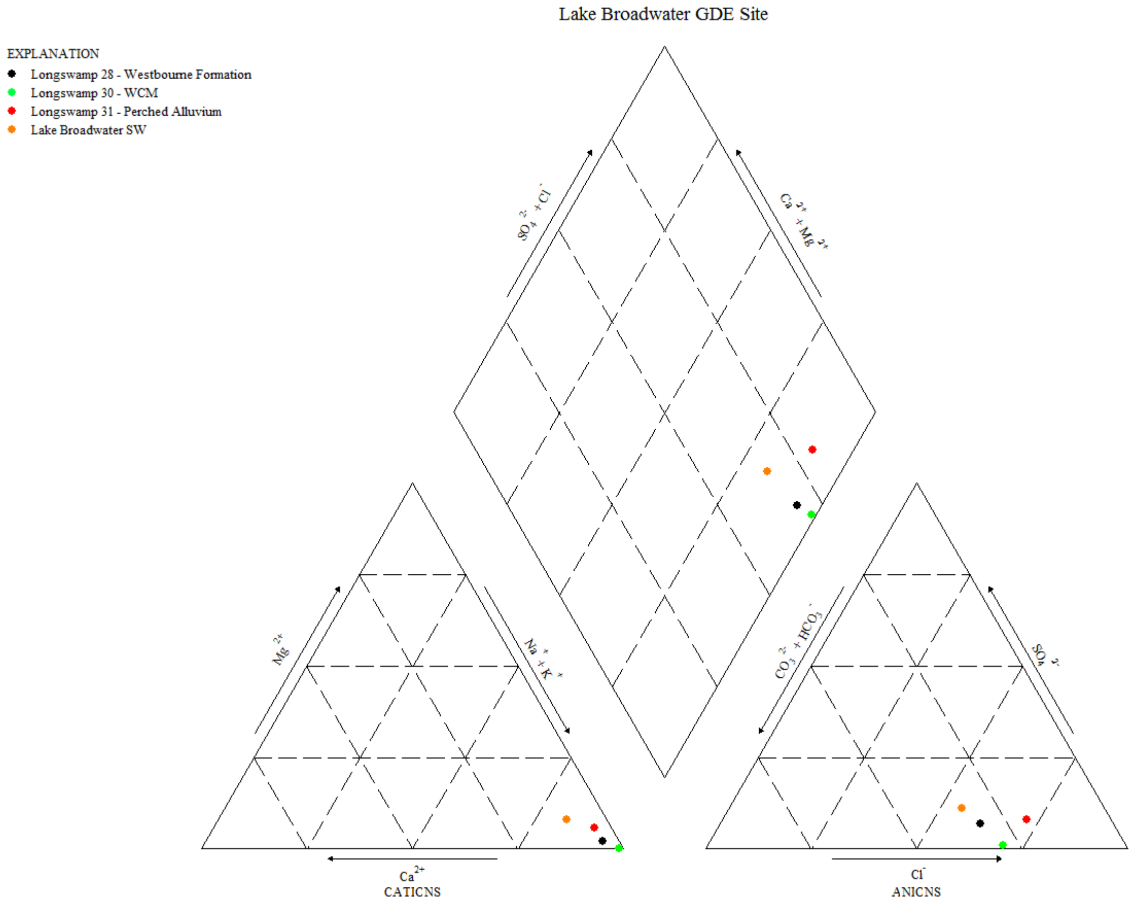


Figure 4-7: Lake Broadwater Site Piper Diagram

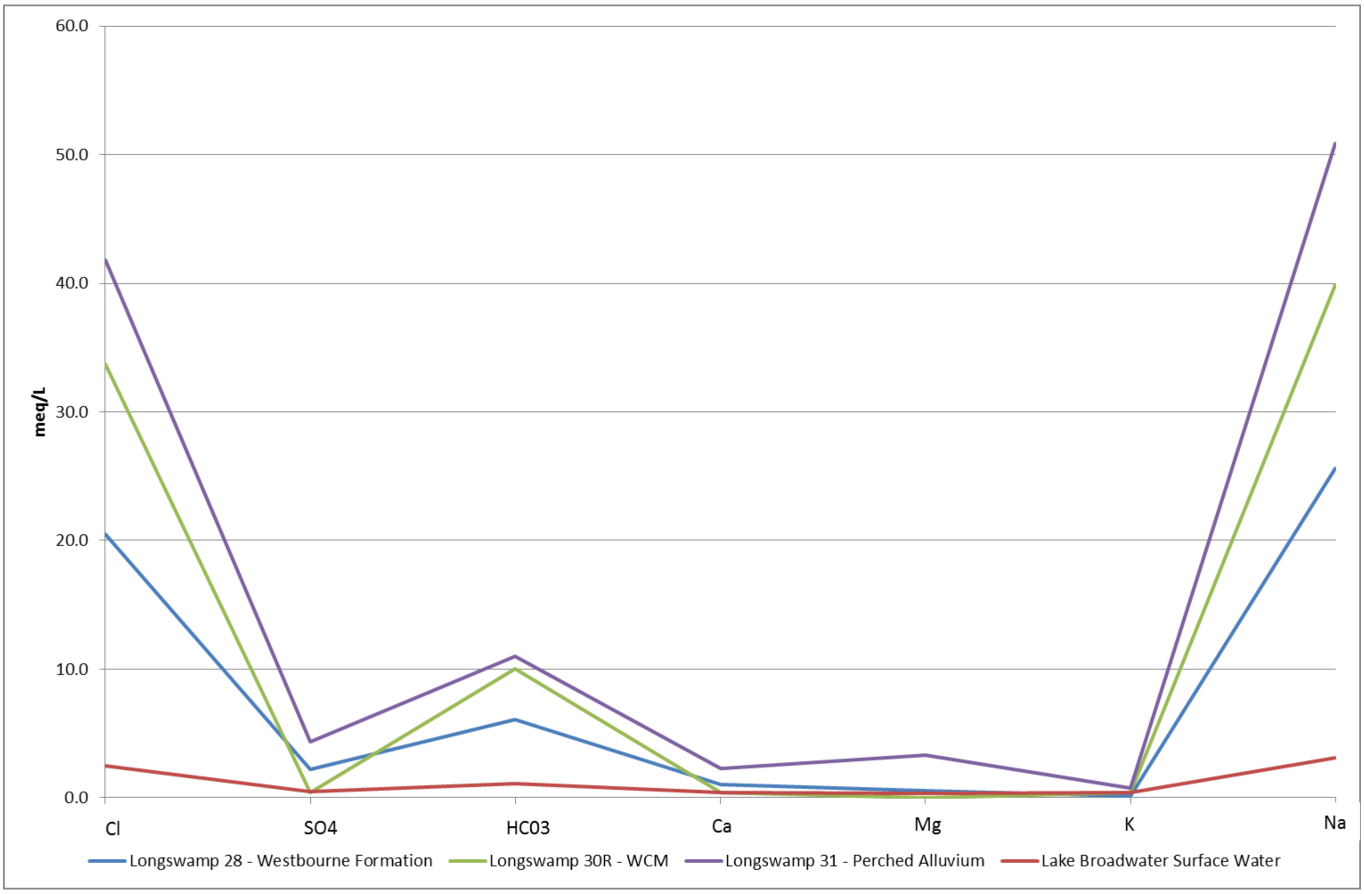


Figure 4-8: Lake Broadwater Site Schoeller Plot

Burunga Lane

The major ions data for the Burunga Lane Site monitoring bores shows they are all sodium chloride type water with:

- Sodium as the dominant cation with no appreciable concentrations of other cations, and
- Chloride as the dominant anion with no appreciable concentrations of other anions.

The water quality data show variation in the ratio of major ions between the water samples collected from Burunga Lane 183/Burunga Lane 185 (Macalister Seam) and Burunga Lane 184 (Wambo Seam) with greater levels of chloride and sodium observed in Burunga Lane 184 (Figure 4-10).

No data were available from Burunga Lane 182 due to the bore being dry (3D Environmental / Earth Search, 2018) however water quality data for Arrow monitoring bore Burunga Lane 177 (located 630 m east and further discussed in Section 4.1.3) has been used to provide a reference point in the piper diagram. The chemical composition of Burunga Lane 177 shows further variation between the chemical composition of the WCM monitoring bores.

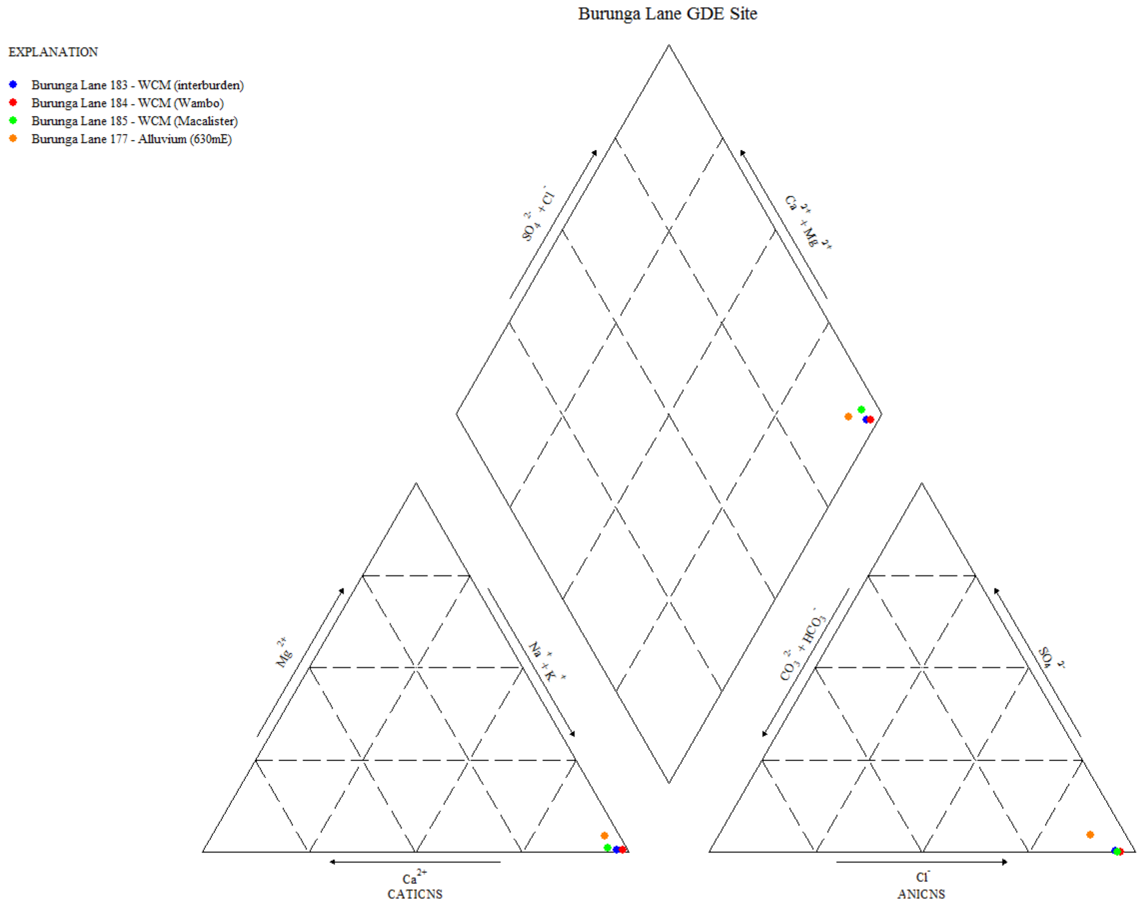


Figure 4-9: Burunga Lane Site Piper Diagram

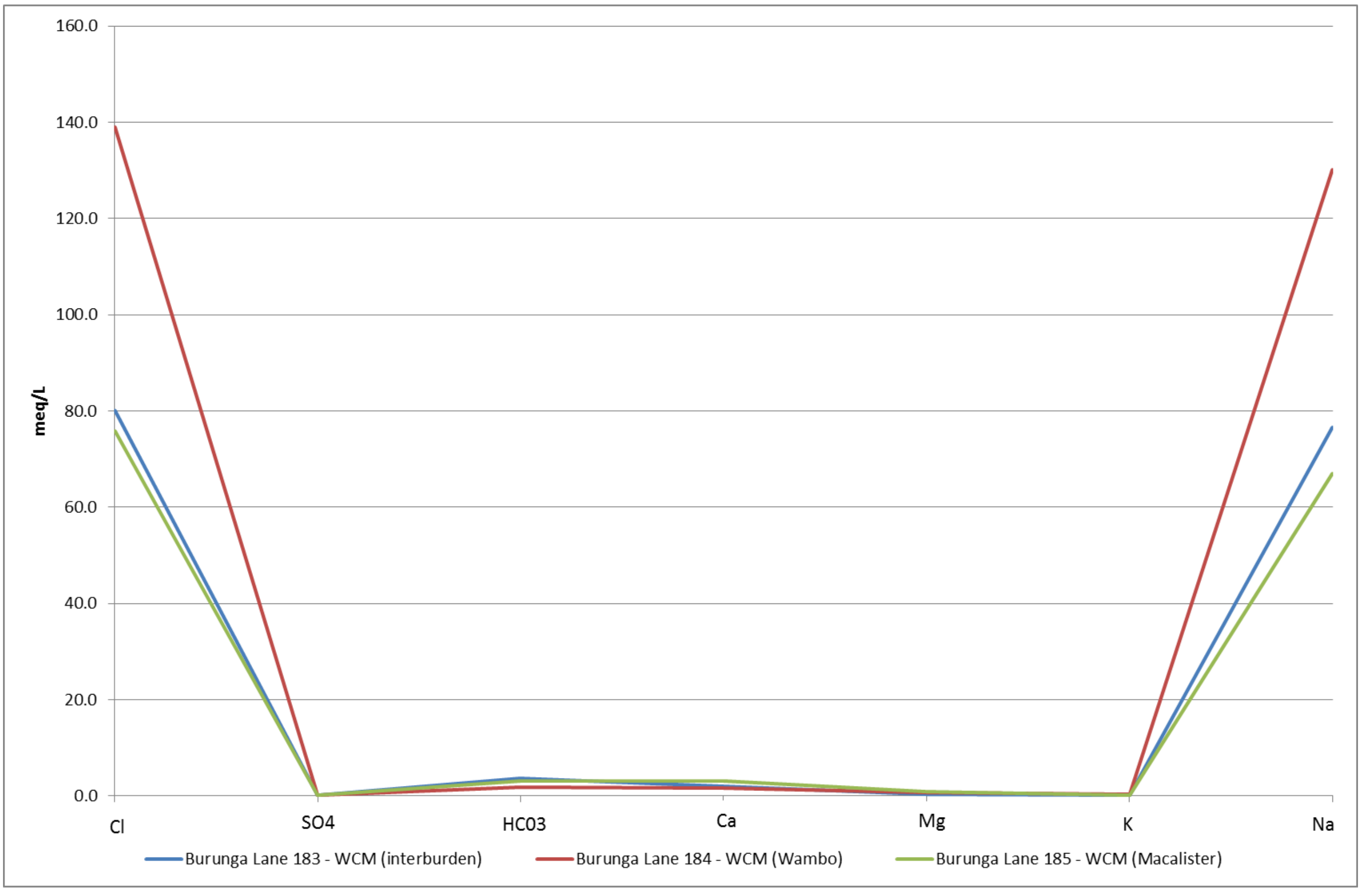


Figure 4-10: Burunga Lane Site Schoeller Plot

Glenburnie

The major ions data for the Glenburnie Site monitoring bores shows varying chemical compositions between the three monitoring bores with:

- Sodium as the dominant cation with no appreciable concentrations of other cations, and
- Differing anion components with:
  - Glenburnie 20 showing carbonate as $CaCO_3$ and bicarbonate as HCO_3 as the dominant anion with minor sulphate and chloride components,
  - Glenburnie 21 showing chloride as the dominant anion with a moderate carbonate as $CaCO_3$ and bicarbonate as HCO_3 component, and
  - Glenburnie 22 showing chloride as the dominant anion with a minor carbonate as $CaCO_3$ and bicarbonate as HCO_3 component.

The major ions data show separation between the three monitoring bores' chemical composition most notably between the deeper monitoring bores (Glenburnie 21 and Glenburnie 22) and the shallow monitoring bore (Glenburnie 20). The data show an increasing chloride component with depth.

In the absence of detailed water quality analyses (i.e. isotopes), the major ions data indicate appreciable exchange of groundwater between formations at the Glenburnie site is unlikely to be occurring based on the observed separation of chemical composition, however, as noted above, a trend in chemical composition with depth is evident.

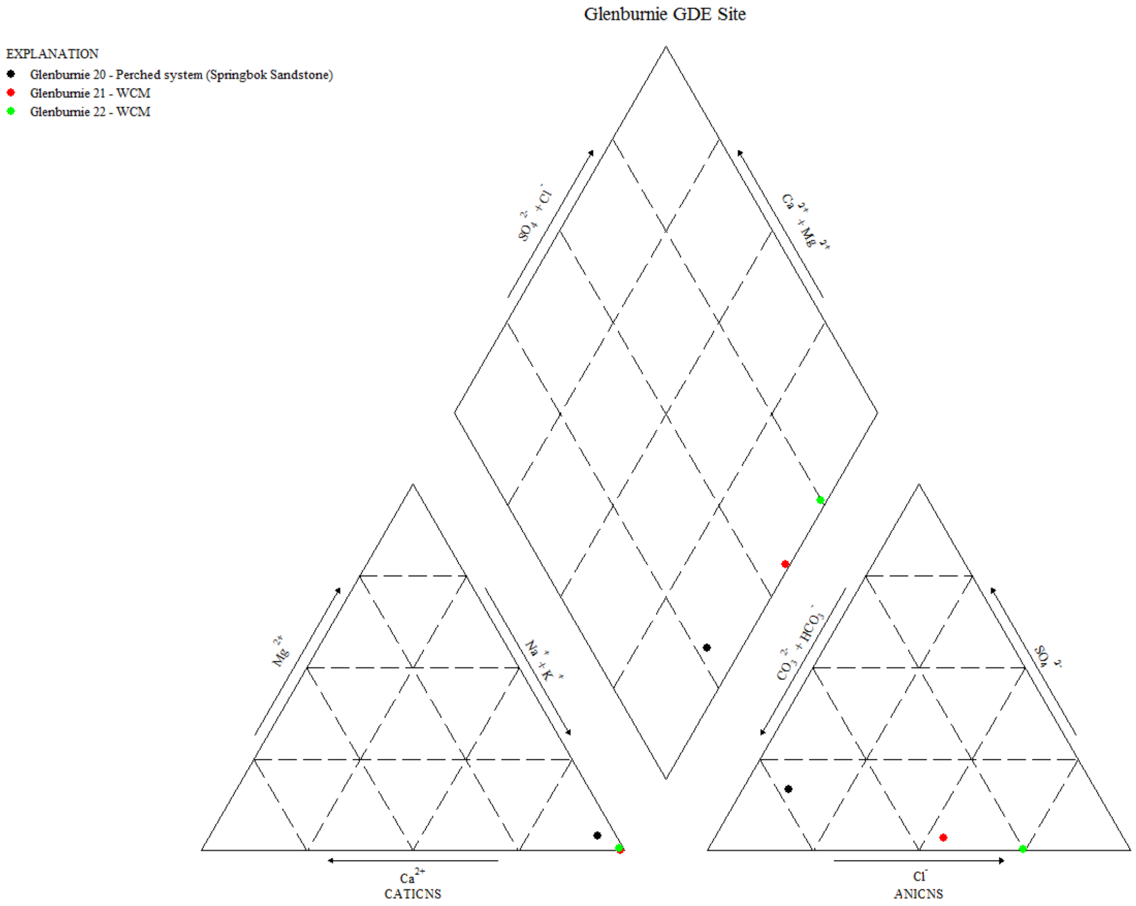


Figure 4-11: Glenburnie Site Piper Diagram

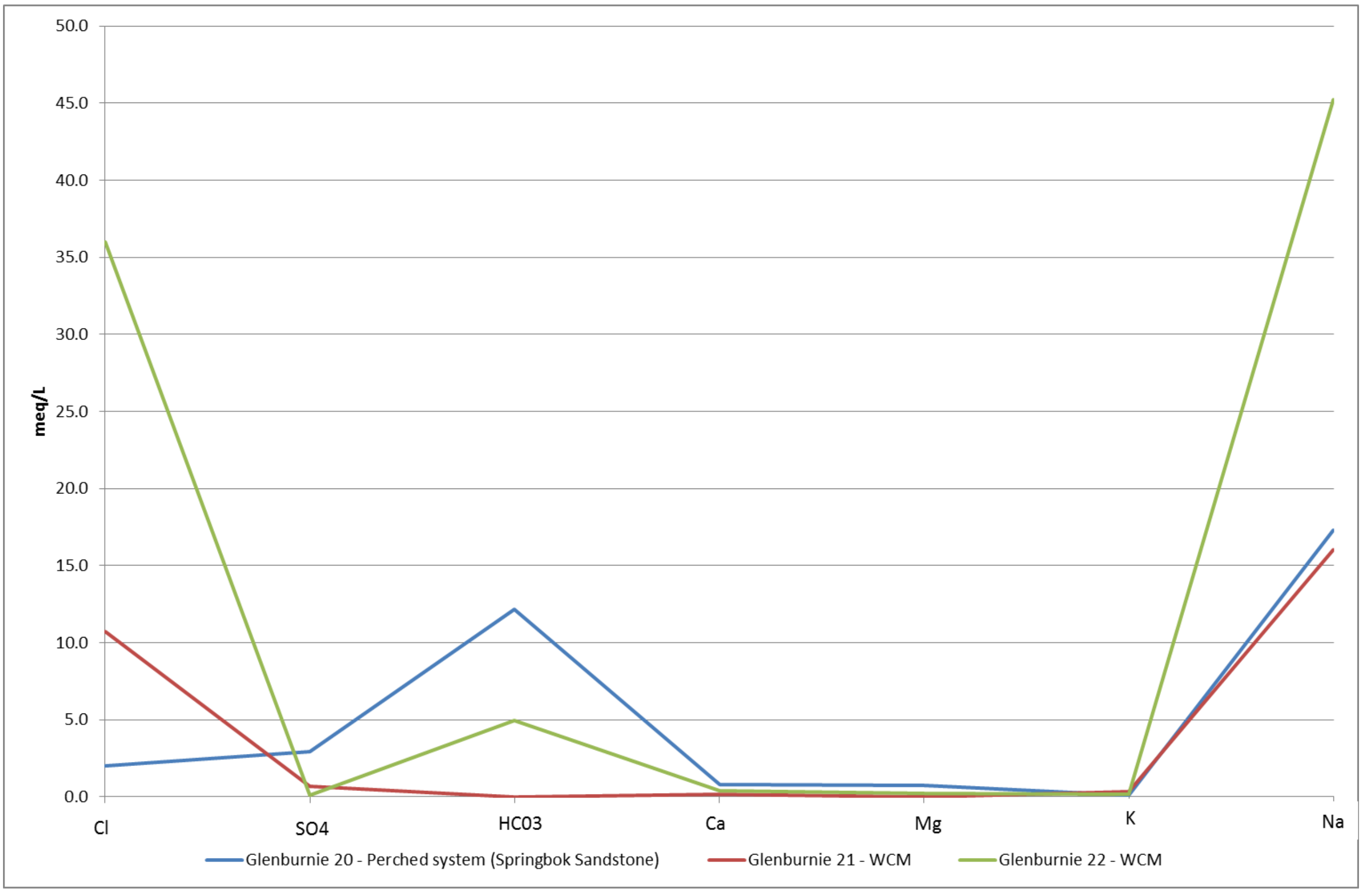


Figure 4-12: Glenburnie Site Schoeller Plot

Table 4-1: Summary of Water Quality Results

Analyte	Unit	Long Swamp GDE Site					Lake Broadwater GDE Site				Burunga Lane GDE Site			Glenburnie GDE Site		
		Longswamp 34	Longswamp 33	Longswamp 32	Longswamp 35	Longswamp 30R	Longswamp 28	Longswamp 29	Longswamp 31	Lake Broadwater SW	Burunga Lane 183	Burunga Lane 184	Burunga Lane 185	Glenburnie 20	Glenburnie 21	Glenburnie 22
		10/01/2018	14/01/2018	15/01/2018	17/03/2018	19/02/2018	25/02/2018	Insufficient data[1]	16/03/2018	16/03/2018	17/03/2018	17/03/2018	12/04/2018	16/03/2018	29/03/2018	26/03/2018
Electrical Conductivity @ 25°C	µS/cm	3740	1760	3760	4480	4340	2840		6050	446	8630	14000	8000	1860	1880	4850
Total Dissolved Solids @180°C	mg/L	2080	952	2130	2910	3850	3110		3930	290	5000	8030	5200	1210	1050	2710
Hydroxide Alkalinity as CaCO3	mg/L	<1	<1	<1	<1	<1	<1		<1	<1	<1	<1	<1	<1	69	<1
Carbonate Alkalinity as CaCO3	mg/L	44	7	<1	<1	108	122		9	12	<1	88	<1	22	244	207
Bicarbonate Alkalinity as CaCO3	mg/L	398	144	351	523	612	372		670	65	226	106	195	741	<1	302
Total Alkalinity as CaCO3	mg/L	442	151	351	523	721	494		680	77	226	194	195	763	314	510
Sulfate as SO4 - Turbidimetric	mg/L	2	24	129	55	18	107		210	23	9	6	3	142	32	5
Chloride	mg/L	979	473	957	1150	1160	706		1440	85	2760	4790	2610	69	370	1240
Calcium	mg/L	16	38	179	119	8	21		45	8	40	34	61	16	3	8
Magnesium	mg/L	3	12	80	63	<1	7		40	4	4	8	10	9	<1	3
Sodium	mg/L	761	286	584	609	916	588		1170	71	1760	2990	1540	398	368	1040
Potassium	mg/L	5	12	3	5	16	5		30	15	8	14	7	4	14	6
Dissolved Aluminium	mg/L	0.02	<0.01	0.32	<0.01	0.11	<0.01		<0.01	<0.01	0.02	0.17	0.01	<0.01	1.54	0.81
Dissolved Arsenic	mg/L	<0.001	0.01	<0.001	0.001	<0.001	0.015		0.001	0.002	0.011	0.001	0.002	<0.001	0.002	0.001
Dissolved Cadmium	mg/L	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Dissolved Chromium	mg/L	<0.001	0.002	0.011	0.001	<0.001	0.009		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.016	0.002
Dissolved Copper	mg/L	0.002	0.002	<0.001	<0.001	0.005	0.002		<0.001	0.002	0.001	<0.001	<0.001	0.001	0.003	0.001
Dissolved Lead	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Dissolved Nickel	mg/L	0.004	<0.001	0.001	0.009	0.003	0.002		0.003	0.002	<0.001	<0.001	<0.001	0.002	<0.001	0.001
Dissolved Selenium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dissolved Zinc	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Dissolved Iron	mg/L	<0.05	<0.05	0.34	10.4	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.45
Dissolved Mercury	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Total Anions	meq/L	36.5	16.8	36.7	44	47.5	32		58.6	4.42	82.6	139	77.6	20.1	17.4	45.3
Total Cations	meq/L	34.3	15.6	41	37.7	40.6	27.3		57.2	4.2	79.1	133	71	19	16.5	46
Ionic Balance	%	3.13	3.78	5.54	7.7	7.77	7.9		1.19	2.49	2.15	2.34	4.41	3.05	2.54	0.84

1. Water quality sampling indicates the bore requires further development and collected water quality data is not representative of the monitored formation (see Section 3.2.1).

5. Permeability Testing

5.1 Laboratory Permeability Tests

Core samples were collected during coring of Longswamp 30R, Longswamp 34, Burunga Lane 184 and Glenburnie 22 and preserved onsite before being sent to Weatherford Laboratories for permeability testing using a Hassler cell permeameter. Samples were collected from each formation within each core hole targeting the lower permeability lithologies. The purpose of the permeability testing is to provide an indication of the vertical and horizontal permeability of aquitards which may restrict vertical movement of groundwater between formations. A summary of the results is provided in Table 5-1.

The Hassler cell permeameter enables measurements of core sample hydraulic conductivity by forcing water through the samples at forces which can replicate the insitu stresses on the sample. The liquid permeability of the samples was evaluated using water prepared with the same major ion concentrations as the native groundwater. Each sample was individually placed into a hydrostatic cell with a 400 psi confining pressure applied. Synthetic formation brine was then pumped through the samples at constant upstream pressure of 70 psi and once 10 pore volumes of throughput had been achieved permeability was calculated using Darcy’s Law through knowledge of the differential flooding pressure, flow rate, viscosity of brine and the sample dimensions.

A number of the core samples were unable to be tested due to the presence of fractures and / or very high clay content for example, Longswamp 34 samples 110301 and 110302 had very high clay content and the samples collapsed during the sleeving process which involves setting the sleeve with 250 psi of pressure. This outcome in itself further supports the lower permeable lithology of the units across the Sites.

Two of the samples (Longswamp 30R [110318], and Burunga Lane 184 [110320]) where both vertical and horizontal measurements were successfully undertaken show the vertical permeability was approximately one and two (respectively) orders of magnitude lower than the horizontal permeability. This difference between horizontal and vertical permeability for the same material is what might typically be expected.

Laboratory estimates of permeability are generally acknowledged to provide lower values compared to field scale tests for a number of reasons including sampling bias, the small scale of measurement and sample alteration during both the drilling process and during testing (compaction of unconsolidated plastic materials etc.). Despite the acknowledged limitations of laboratory estimates of permeability such estimates can provide useful data for low permeability formations where larger scale field testing may be problematic or require long term aquifer pumping tests to fully evaluate the nature of over/underlying aquitards.

Further discussion of these results is provided in Section 5.2.3.

Table 5-1: Summary of Core Sample Hydraulic Conductivity Derived by Laboratory Permeability Testing

Sample ID	Sample Description	Core Plug Sample Depth (m)	Horizontal or Vertical Permeability	Liquid Permeability (m/day)
Longswamp 30R				
110308	Light grey / brown fine grained sandstone with clear lamine bedding	17.44	H	7.7 x 10-6
		17.48	V	9.4 x 10-6
110309	Dark grey fine grained sandstone with carbonaceous wisps and oxidised zones/bands	32.48	H	Failed
			V	Failed
110310	Grey sandstone, fine grained, slightly weathered, some carbonaceous bands	41.20	H	Failed
			V	Failed
110311	Grey sandstone, very well cemented, carbonaceous wisps throughout	60.71	H	Failed
		60.76	V	Failed
110312	Light to dark grey medium grained sandstone with sedimentary structures, and rare carbonaceous wisps	74.37	H	5.1 x 10-6
		74.65	V	Failed
110313	Light grey coarse to medium grained sandstone with carbonaceous wisps and a dark grey fine grained sandstone band at 81.11m	80.72	V	Failed
		80.85	H	Failed
110314	Grey sandstone, well cemented, fine to medium grained	102.01	H	Failed
			V	Failed
110315	Grey sandstone, very well cemented, fine to coarse grained. Note core left out overnight before sampling. Between 111.92 – 112.12mGL – thin coal seam (3cm) overlying conglomerate, well cemented, poorly sorted predominantly quartz (2-10mm in size), subrounded to subangular. Overlying coal band (1-2cm). Contact.	111.03	H	Failed
		111.34	V	Failed
110316	Siltstone, dark grey, hard, blocky. Carbonaceous bands	113.52	H	Failed
		113.74	V	Failed
110317	Grey sandstone, fine to medium grainsize, moderate to well cemented, with carbonaceous wisps throughout.	152.50	H	Failed
		152.55	V	Failed
110318	Light grey sandstone, coarse grained, well cemented	177.59	H	1.3 x 10-5
		178.04	V	1.7 x 10-7
110319	Grey sandstone, medium grained, with coaly / carbonaceous wisps	186.94	H	Failed
		187.53	V	Failed
Longswamp 34				
110301	medium brown clay, medium plasticity, sandy (fine) increasing with depth	28.25	H	Failed
			V	Failed
110302	Grey, light brown, orange clay, medium to high plasticity, some grey siltstone	40.10	H	Failed
			V	Failed
110304	Slightly Weathered sandstone: Greenish , Fine Sand Grainsize	64.40	H	1.0 x 10-4
		65.10	V	Failed

110305	Grey medium to fine grained sandstone with stained clay bands carbonaceous wisps	75.24	H	Failed
			V	Failed
110306	Brownish to light grey calcareous cemented and clast supported sandstone	83.86	V	Failed
		83.90	H	1.7 x 10-6
110307	Moderately weathered siltstone: light grey	92.53	H	Failed
		92.58	V	Failed
Burunga Lane 184				
110320	Slightly weathered sandstone, grey, fine to medium grained	15.25	V	1.7 x 10-7
		15.42	H	1.7 x 10-6
110321	Siltstone, dark grey, blocky, hard	26.29	V	Failed
		26.33	H	Failed
110322	Siltstone, dark grey, blocky, moderate hardness	35.23	V	Failed
		35.30	H	Failed
110323	Fresh sandstone, grey, medium grained, moderately to well cemented	50.27	H	2.2 x 10-5
		50.61	V	Failed
110324	Weathered 80% siltstone: Grey ; with 20% dull black coal	65.77	H	Failed
			V	Failed
Glenburnie 22				
110325	Fresh sandstone, light grey, fine to medium grained, very low hardness	21.54	H	Failed
			V	Failed
110326	Fresh sandstone, light grey, fine grained, hard	31.88	H	Failed
			V	Failed
110327	Fresh sandstone, medium grey, very fine grained, hard	38.55	V	2.6 x 10-6
		38.59	H	9.4 x 10-6
110328	Slightly weathered sandstone, light grey, fine grained, hard	46.39	H	Failed
		46.45	V	Failed
110329	Fresh sandstone, medium grey, very fine grained, hard	61.69	H	Failed
		61.76	V	Failed
110330	Fresh sandstone, medium grey, fine to medium grained, medium hardness	75.39	H	Failed
		75.44	V	Failed

5.2 Hydraulic Testing (Slug Testing)

Hydraulic testing was undertaken during the week of 9 April 2018 to determine the hydraulic conductivity of the aquifers underlying the Sites. Hydraulic testing was undertaken on all PVC constructed bores. Bores constructed with steel pressure wellheads were unable to be accessed and therefore not tested. The method of testing was by slug testing utilising a PVC slug filled with sand.

5.2.1 Testing

The general procedure for each slug test was as follows:

1. SWL measured in the bore.

2. Insitu Level Troll 400 (programmed to record every 1 second) installed in the bore.
3. Slug inserted to below groundwater level. Depth to groundwater manually measured in the bore after installing slug and periodically thereafter.
4. Bore left until SWL stabilised / returned to original SWL.
5. Slug removed from the bore. SWL measured in the bore.
6. Bore left until SWL stabilised / returned to original SWL. Level Troll 400 removed from bore. Depth to groundwater measured in the bore.

The dimensions of the PVC slugs were 1.02 m by 0.04 m.

5.2.2 Analysis

The slug test data analyses were performed using Aqtesolv software. The analysis method used was the Bouwer-Rice method for an unconfined aquifer. It should be noted that estimates of hydraulic conductivity derived from slug tests are an approximation with other methods such as a pumping test considered more accurate.

5.2.3 Results

The hydraulic conductivity values determined from the slug tests data are summarised in Table 5-2 with the output reports provided in Appendix E.

A rising head test was not undertaken in Longswamp 29 due to time constraints and the significant duration (11 hours) of the falling head test which correlates to the derived hydraulic conductivity value in this bore.

Table 5-2: Summary of Hydraulic Conductivity Values Derived from Slug Testing

GDE Study Site	Monitoring Bore ID	Monitored Formation	Test Type	Hydraulic Conductivity (m/day)	Bore Average Hydraulic Conductivity (m/day)
Long Swamp	Longswamp 32	Westbourne Formation	Falling Head	6.95	5.28
			Rising Head	3.61	
	Longswamp 33	Springbok Sandstone	Falling Head	7.99×10^{-3}	1.1×10^{-2}
			Rising Head	1.41×10^{-2}	
Lake Broadwater	Longswamp 28	Westbourne Formation	Falling Head	2.68×10^{-3}	2.53×10^{-3}
			Rising Head	2.38×10^{-3}	
	Longswamp 29	Springbok Sandstone	Falling Head	8.52×10^{-4}	8.52×10^{-4}
			Rising Head	Insufficient data	
Burunga Lane	Burunga Lane	WCM –	Falling	6.28×10^{-3}	5.54×10^{-3}

GDE Study Site	Monitoring Bore ID	Monitored Formation	Test Type	Hydraulic Conductivity (m/day)	Bore Average Hydraulic Conductivity (m/day)
	183	Macalister Seam	Head		
			Rising Head	4.80 x 10^{-3}	
	Burunga Lane 185	WCM – Macalister Seam	Falling Head	3.01 x 10^{-1}	3.04 x 10^{-1}
			Rising Head	3.06 x 10^{-1}	

5.3 Modelling

Numerical modelling has been used to assess the potential vertical hydraulic conductivity at the four GDE sites.

5.3.1 Scope

The scope of work involved the following process to achieve the goal of assessing the potential vertical hydraulic conductivity between the target formations:

- Review of site data for development of conceptual model;
- Review of observed data;
- Model design and preparation;
- Model Calibration and Uncertainty Assessment; and
- Recommendations.

The modelling was undertaken with the aim of assessing the vertical hydraulic conductivity. Monitoring data was either a point in time data or time series data without significant variation. No information from the monitoring data was present to inform potential external stresses to the model area. The head differences between units became the main driver for model behaviour. The model aim was to achieve the head pressures in the units and pressure differences between units and assess the vertical hydraulic conductivity at which these pressures and pressure differences could no longer be maintained in the model in order to assess the maximum probable vertical hydraulic conductivity.

5.3.2 Conceptual Models

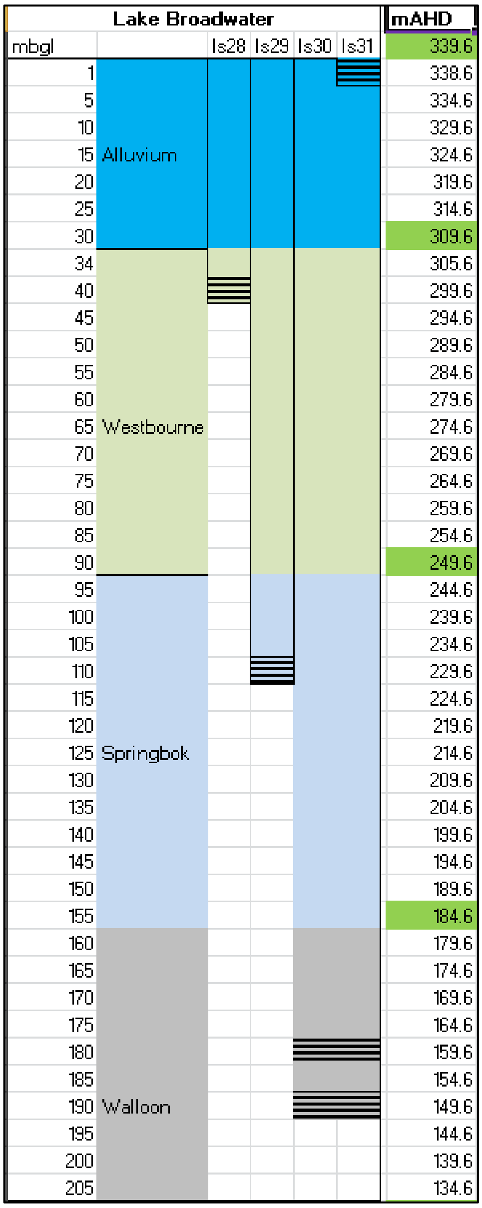
Lake Broadwater

The conceptual model for the site is shown in Figure 5-1 and comprises alluvium overlying Westbourne Formation, Springbok Sandstone and WCM.

The model uses the water level data provided in Section 4.1. These data indicate generally stable water pressures / levels with little natural variability during the monitoring period.

The absence of significant variation in water levels due to either pumping or climate signals indicated that a model solution would be driven by the head differences in the data.

Given the uniform data and absence of overlapping time series data a simple conceptual model for use in a steady state simulation was used to assess the potential vertical hydraulic conductivity.



Lake Broadwater						mAHD
mbgl		ls28	ls29	ls30	ls31	339.6
1						338.6
5						334.6
10						329.6
15	Alluvium					324.6
20						319.6
25						314.6
30						309.6
34						305.6
40						299.6
45						294.6
50						289.6
55						284.6
60						279.6
65	Westbourne					274.6
70						269.6
75						264.6
80						259.6
85						254.6
90						249.6
95						244.6
100						239.6
105						234.6
110						229.6
115						224.6
120						219.6
125	Springbok					214.6
130						209.6
135						204.6
140						199.6
145						194.6
150						189.6
155						184.6
160						179.6
165						174.6
170						169.6
175						164.6
180						159.6
185						154.6
190	Walloon					149.6
195						144.6
200						139.6
205						134.6

Figure 5-1: Lake Broadwater Conceptual Model

Long Swamp

The conceptual model for the site is shown in Figure 5-2 and comprises Westbourne Formation, Springbok Sandstone and WCM.

The stabilised water level in the alluvium indicated a saturated thickness of only a few metres of alluvium. The alluvial aquifer is therefore not a constraint on the model solution.

The model uses the water level data provided in Section 4.1. These data indicate generally stable water pressures / levels with little natural variability during the monitoring period.

The absence of significant variation in water levels due to either pumping or climate signals indicated that a model solution would be driven by the head differences in the data.

Given the uniform data and absence of overlapping time series data a simple conceptual model for use in a steady state simulation was used to assess the potential vertical hydraulic conductivity.

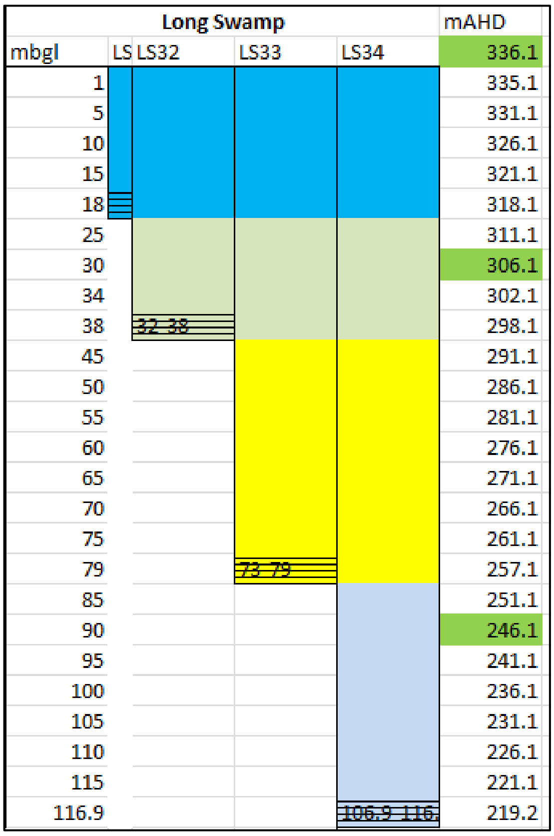


Figure 5-2: Long Swamp Conceptual Model

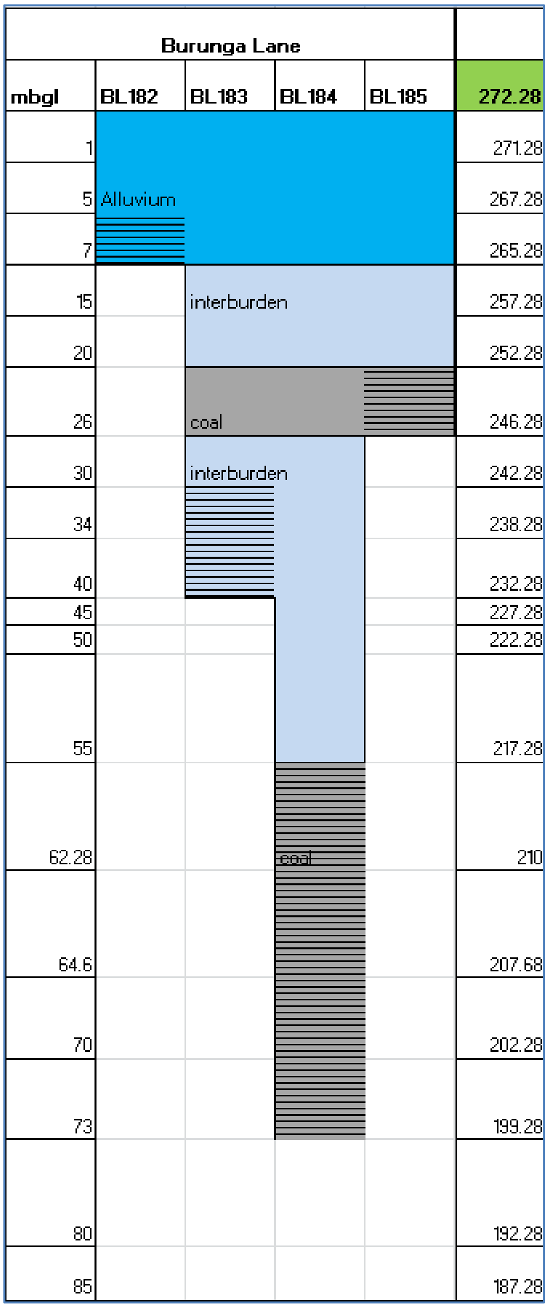
Burunga Lane

The conceptual model for the site is shown in Figure 5-3 and comprises Alluvium overlying the Macalister and Wambo seams of the WCM with interburden between the coal seams.

The model uses the water level data provided in Section 4.1. These data indicate generally stable water pressures / levels with little natural variability during the monitoring period.

The absence of significant variation in water levels due to either pumping or climate signals indicated that a model solution would be driven by the head differences in the data.

Given the uniform data and absence of overlapping time series data a simple conceptual model for use in a steady state simulation was used to assess the potential vertical hydraulic conductivity.



	Burunga Lane				
mbgl	BL182	BL183	BL184	BL185	272.28
1					271.28
5	Alluvium				267.28
7					265.28
15		interburden			257.28
20					252.28
26		coal			246.28
30		interburden			242.28
34					238.28
40					232.28
45					227.28
50					222.28
55					217.28
62.28			coal		210
64.6					207.68
70					202.28
73					199.28
80					192.28
85					187.28

Figure 5-3: Burunga Lane Conceptual Model

Glenburnie

The Glenburnie modelling component was undertaken by Australian Groundwater and Environmental Consultants (AGE) using the same methodology as the other three sites described above. The model layering is provided in Table 5-3.

The model uses the water level data provided in Section 4.1. These data indicate generally stable water pressures / levels with little natural variability during the monitoring period.

The absence of significant variation in water levels due to either pumping or climate signals indicated that a model solution would be driven by the head differences in the data.

Given the uniform data and absence of overlapping time series data a simple conceptual model for use in a steady state simulation was used to assess the potential vertical hydraulic conductivity.

Table 5-3: Summary of Glenburnie Model Layers

Layer	Hydrogeological unit	Thickness (m)
1	Alluvium	2.5
2	Springbok	18.6
3	Wambo Walloon Coal Measures	35.9
4	Argyle Upper Seam	1.9
5	Interburden	33.5
6	Argyle Lower Seam	2.66

5.3.3 Model Approach

The geological and hydraulic data provided indicated a relatively simple system with stable water pressures/levels at the GDE sites.

In order to assess the potential vertical hydraulic conductivity of these units a simple “sandpit” model was adopted. Due to the absence of significant transient variability in the water pressures/levels a steady state model was used.

The model domain extended for c. 1000 m around the model site. The model comprised layers representing the alluvium, Westbourne Formation, Springbok Sandstone and Walloon Coal Measures based upon the data provided from the well installation as discussed in the conceptual models above.

Constant head boundaries on the eastern and western boundaries of the model simulated a hydraulic gradient across the site providing starting heads similar to those observed at the monitoring points.

The model was run without recharge or evapotranspiration in fully confined mode with the aim of assessing vertical hydraulic conductivity in consolidated aquifers.

The modelling strategy was undertaken with the aim of assessing the vertical hydraulic conductivity. Monitoring data was either a point in time data or time series data without significant variation. No information from the monitoring data was present to inform potential external stresses to the model area. The head differences between units became the main driver for model behaviour. The model aim was to achieve the head pressures in the units and pressure differences between units and assess the vertical hydraulic conductivity at which these pressures and pressure differences could no longer be maintained in the model in order to assess the maximum probable vertical hydraulic conductivity.

Following this PEST utilities were used to assess the potential parameter ranges that could accommodate the water pressures/levels observed.

Calibration

Steady state calibration was undertaken with model conditions, the mass balance and calibration statistics for the models are summarised in Table 5-4.

Table 5-4: Calibration Statistics

Model	Mass Balance Error	RSS	Scaled RMS	RMS Error
Lake Broadwater	0.04	2.1	0.016	0.73
Longswamp	0.0003	0.0011	0.015	0.02
Burunga Lane	0.000002	0.0581	0.027	0.14
Glenburnie	0.000001	0.0086	0.005	0.05

PEST Parameterisation

PEST utilities were used to calibrate the models allowing for assessment of the effect of a range of parameter values simultaneously in order to assess the parameters that resulted in the minimum error.

The range of values derived from PEST calibration are summarised in Table 5-5.

The absence of transient, variable, contemporaneous water pressure data limits the ability of the model to constrain the potential parameter variability. When contemporaneous and variable pressure data are available modelling may be revisited to assess whether the data can further constrain parameter values.

Table 5-5: Model Vertical Hydraulic Conductivity (metres / day)

Model Layer	Lake Broadwater	Longswamp	Burunga Lane	Glenburnie
Alluvium	1.93 x 10^{-2}	nc	nc	5 x 10^{-3}
Westbourne Formation	1.67 x10^{-6} – 1.68x10^{-6}	1.12-0.50	nc	nc
Springbok Sandstone	3.01 x10^{-7} - 3.03x10^{-7}	1.00 x 10^{-4} to 7.90 x 10^{-3}	nc	5 x 10-3
WCM (coals)	1.11 x 10^{-3}	2.50 x 10^{-3}	0.021-0.009	1 x 10^{-3} – 1 x 10^{-7}
WCM (interburden)	nc	nc	0.094-1.5x10^{-8}	1 x 10^{-8}

Notes:
nc – not calculated

5.4 Discussion

A summary of all available hydraulic conductivity results is provided in Table 5-6. The OGIA 2016 UWIR model hydraulic conductivity values are also provided for comparison.

As noted in Section 5.1, laboratory estimates of permeability are generally lower than field scale tests and this is evident when comparing the hydraulic testing and laboratory testing results for an entire formation interval however the laboratory testing results generally align with the modelled results. The laboratory testing results provide a good indication of the low permeability of the interburden lithology.

The hydraulic testing results generally correlate with the 2016 UWIR model hydraulic conductivity values, except for Longswamp 32, providing an indication that the monitored zones in the constructed monitoring bores are representative of the regional formations. The laboratory testing and modelling results are generally lower than the 2016 UWIR model values.

Long Swamp Site

The derived values of hydraulic conductivity for the Westbourne Formation (Longswamp 32) are greater than what would be expected for the Westbourne Formation and this is possibly due to the higher than expected sand content of the Westbourne Formation at this location.

Both the horizontal and vertical hydraulic conductivity values for the Springbok Sandstone generally align well with their respective 2016 UWIR model values.

The available hydraulic conductivity data show the very low permeability of the Springbok Sandstone and WCM which further indicates a lack of hydraulic connection between the Westbourne Formation, Springbok Sandstone and WCM formations.

Lake Broadwater Site

The hydraulic testing values and the 2016 UWIR model values are generally aligned while the laboratory testing and modelled values are aligned. Of particular note is the alluvium’s hydraulic conductivity values derived from the laboratory testing and modelling are significantly lower than the 2016 UWIR model value.

As the hydraulic testing results represent the more permeable zones which the monitoring bores are screened against, the laboratory testing results represent the permeability of the interburden which is low to very low.

The available hydraulic conductivity data for the Lake Broadwater Site show the low to very low permeability of the WCM and overlying formations which indicate a lack of hydraulic connection.

Burunga Lane Site

The hydraulic conductivity values for the coal seams within the WCM align well across the different data sources.

These data support the Burunga Lane Site conceptual model that the coal seams are the more permeable zones while the interburden are very low permeable zones which restrict vertical movement of groundwater between the coal seams.

Glenburnie Site

Although the monitored zone within the Springbok Sandstone (Glenburnie 20) is adjacent to a perched seepage zone, this formation layer was still included in the Glenburnie model and the modelled value is slightly higher than the 2016 UWIR model value (vertical).

The laboratory testing results for horizontal hydraulic conductivity within the WCM is significantly lower than the 2016 UWIR model horizontal value which is likely due to the sample depth which correlates to interburden. The vertical hydraulic conductivity value derived from the laboratory testing, however is consistent with the 2016 UWIR model value.

The modelled vertical hydraulic conductivity values for the WCM generally show consistency with the 2016 UWIR vertical hydraulic conductivity values with the productive zones (coal seams) displaying a higher modelled value and the interburden showing a slighter lower modelled value than the 2016 UWIR values.

As the regional water table is situated within the WCM and the top of the formation is shallow at 21.1 mbgl making it the predominant shallow formation present at Glenburnie. The available data provide a robust indication of the low permeability of the interburden of the WCM and noting the tested core sample was retrieved from above the coal seams.

The available hydraulic conductivity data for the Glenburnie Site indicate vertical groundwater movement between coal seams is unlikely and they are unlikely to be hydraulically connected.

Table 5-6: Summary of Hydraulic Conductivity Data

Study Site	Formation	Sample Depth (mbgl)	Horizontal Hydraulic Conductivity Derived from Hydraulic Testing (slug test) (m/day)	Hydraulic Conductivity Derived from Laboratory Testing of Core Samples (m/day)	Modelled Vertical Hydraulic Conductivity (m/day)	2016 UWIR Model Formation Hydraulic Conductivity (m/day)[1]
Long Swamp	Condamine Alluvium (0.0 - 18.0m)	0.0 – 18.0				11.30 (H) 11.10 (V)
	Westbourne Formation (18.0-52.9m)	32.0-38.0	5.28		1.12 to 0.50	1.44 x 10^{-3} (H) 1.78 x 10^{-6} (V)
	Springbok Sandstone (52.9-82.1m)	64.4		1.00 x 10^{-4} (H)	1.00 x 10^{-4} to 7.90 x 10^{-3}	8.64 x 10^{-3} (H) 3.33 X 10^{-5} (V)
		73.0-79.0	1.10 x 10^{-2}			
	WCM (82.1-128.3m)	83.9		1.70 x 10^{-6} (H)	2.50 x 10^{-3}	Upper WCM – 2.16 x 10^{-2} (H) 7.82 x 10^{-7} (V)
Lake Broadwater	Alluvium (0.0 - 30.8m)	17.44		7.70 x 10^{-6} (H) 9.40 x 10^{-6} (V)	1.93 x 10^{-2}	22.90 (Other Alluvium) (H) 3.34 (Other Alluvium) (V)
	Westbourne Formation (30.8-94.5m)	34.0-40.0	2.53 x 10^{-3}		1.67 x 10^{-6}	1.44 x 10^{-3} (H) 1.78 x 10-^{6} (V)
		74.37		5.10 x 10^{-6} (H)		
	Springbok Sandstone	104.0-111.0	8.52 x 10^{-4}		3.01 x 10^{-7}	8.64 x 10^{-3} (H)

Study Site	Formation	Sample Depth (mbgl)	Horizontal Hydraulic Conductivity Derived from Hydraulic Testing (slug test) (m/day)	Hydraulic Conductivity Derived from Laboratory Testing of Core Samples (m/day)	Modelled Vertical Hydraulic Conductivity (m/day)	2016 UWIR Model Formation Hydraulic Conductivity (m/day)[1]
	(94.5-178.2m)	177.6		1.30 x 10^{-5} (H) 1.70 x 10^{-7} (V)		3.33 X 10^{-5} (V)
	WCM (178.2 - 204.0m)	178.2-204.0			1.11 x 10^{-3}	Upper WCM – 2.16 x 10^{-2} (H) 7.82 x 10^{-7} (V)
Burunga Lane	Alluvium (0.0-7.0m)	0.0-7.0				22.90 (Other Alluvium) (H) 3.34 (Other Alluvium) (V)
	WCM (7.0-85.0)	15.3		1.70 x 10^{-7} (V) 1.70 x 10^{-6} (H)	9.40 x 10^{-2} to 1.50 x 10^{-8}	Non-productive zone – 1.49 x 10^{-2} (H) 1.28 x 10^{-6} (V)
		20.0-26.0	3.04 x 10^{-1}		2.10 x 10^{-2} to 9.00 x 10^{-3}	Upper WCM – 2.16 x 10^{-2} (H) 7.82 x 10^{-7} (V)
		34.0-40.0	5.54 x 10^{-3}		9.40 x 10^{-2} to 1.50 x 10^{-8}	Non-productive zone – 1.49 x 10^{-2} (H) 1.28 x 10^{-6} (V)
		50.3		2.20 x 10^{-5} (H)	9.40 x 10^{-2} to 1.50 x 10^{-8}	Non-productive zone – 1.49 x 10^{-2} (H) 1.28 x 10^{-6} (V)
		62.3-73.0				Upper WCM – 2.16 x 10^{-2} (H) 7.82 x 10^{-7} (V)
Glenburnie	Alluvium (0.0-2.5m)	0.0-2.5				22.90 (Other Alluvium) (H) 3.34 (Other Alluvium) (V)
	Springbok Sandstone (2.5-21.1m)	2.5-21.1			5.00 x 10^{-3}	8.64 x 10^{-3} (H) 3.33 X 10^{-5} (V)
	WCM (21.1-99.0)	21.1-57.0			1.00 x 10^{-7}	Lower WCM - 2.44 x 10^{-2} (H) 3.24 x 10^{-7} (V)
		38.55		2.60 x 10^{-6} (V) 9.40 x 10^{-6} (H)		Non-productive zone – 1.49 x 10^{-2} (H) 1.28 x 10^{-6} (V)
		57.0-58.9			5.00 x 10^{-3}	Lower WCM - 2.44 x 10^{-2} (H) 3.24 x 10^{-7} (V)
		58.9-92.4			1.00 x 10^{-8}	Non-productive zone – 1.49 x 10^{-2} (H) 1.28 x 10^{-6} (V)

Study Site	**Formation**	**Sample Depth (mbgl)**	**Horizontal Hydraulic Conductivity Derived from Hydraulic Testing (slug test) (m/day)**	**Hydraulic Conductivity Derived from Laboratory Testing of Core Samples (m/day)**	**Modelled Vertical Hydraulic Conductivity (m/day)**	**2016 UWIR Model Formation Hydraulic Conductivity (m/day)[1]**
		92.4-99.0			1.00 x 10^{-3}	Lower WCM - 2.44 x 10^{-2} (H) 3.24 x 10^{-7} (V)

Notes:
1. Reference Table I17-1 Statistical summary for pre-calibrated and calibrated horizontal hydraulic conductivity (Kh) – 2016 UWIR and Table I19-1 Statistical summary for pre-calibrated and calibrated vertical hydraulic conductivity (Kv) – 2016 UWIR, Appendix I17 – Groundwater Modelling Report

6. Lake Broadwater Site Modelled Impact Assessment

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) (2018) assessed potential impacts to Lake Broadwater from coal seam gas extraction in the WCM, and to determine the pumping rate required to impact the ecosystem at the surface. This work was undertaken as the 3D Environmental / Earth Search report (2018) indicated that Lake Broadwater is considered to represent a GDE, however the results of this Report indicate Lake Broadwater is unlikely to be hydraulically connected to underlying aquifers (including the regional aquifer).

AGE built a sandpit groundwater model to simulate the pressure/pressure differences between the Lake Broadwater monitoring bores and assess when the well drawdown extends into the surface.

6.1 Modelling Construction

6.1.1 Model grid and layers

The model consisted of a simple square of measuring ~5 km by 5 km at a cell resolution of 250 m.

The model has four layers representing the key geological units including alluvium, Westbourne Formation, Springbok Sandstone, and WCM. Table 6-1 described the geological units represented by each numerical model layer.

Table 6-1: Model layering

Layer	**Hydrogeological unit**	**Thickness (m)**
1	Alluvium	30.73
2	Westbourne Formation	63.87
3	Springbok Sandstone	83.63
4	Walloon Coal Measures incl. Kogan Seam	61.37

6.1.2 Boundary conditions

Lake Broadwater monitoring data contains four bores with short-term transient datasets. The transient dataset shows no significant temporal changes; therefore a steady state simulation is appropriate. To produce the head/pressure difference between the bores, constant head boundaries were assigned to the four sides of model. To properly simulate the heads, the constant head level at each layer was selected based on the water level at the associated Lake Broadwater bores. Figure 6-1 shows the location of constant head boundaries. No recharge and evapotranspiration packages were applied to the model.

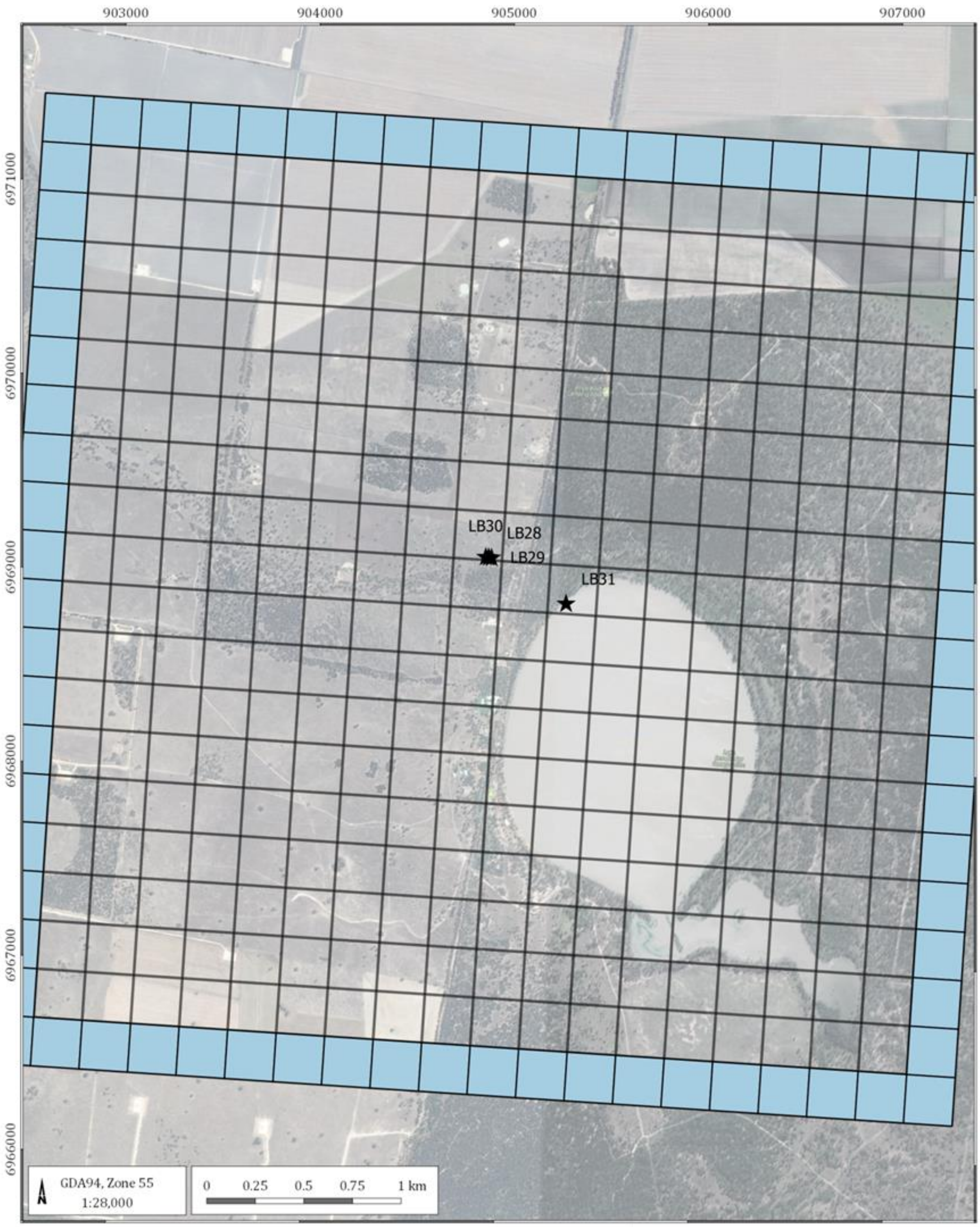


Figure 6-1: Model boundary and bore locations

6.1.3 Model Calibration

The calibration model involved a steady state simulation. The aim was to achieve the head and pressure differences at the monitoring bores. Automated parameter estimation software (PEST_HP: Watermark Computing, 2018) was used to speed up the calibration process. Table 6-2 and Table 6-3 show the calibrated heads and the summary of final hydraulic parameters. It should be noted that due to the simplicity of the model, the horizontal hydraulic conductivity (Kh) has little influence on the calibration performance of this model. The higher the Kh, the stronger the hydraulic influence of the boundary conditions, and therefore a better calibration. To address this, Kh was prescribed to values similar to the OGIA 2016 model at this location (OGIA, 2016[1]).

Table 6-2: Summary of modelled and observed heads

Bore	Observed (mAHD)	Simulated head (mAHD)
LS28	320.63	320.32
LS29	319.50	319.55
LS30	363.93	362.98
LS31	337.25	336.99

Table 6-3: Summary of hydraulic parameters

Layer	Hydrogeological unit	Hydraulic conductivity	
		Horizontal (Kh) (m/day)	Vertical (Kv) (m/day)
1	Alluvium	5	0.5
2	Westbourne Formation	0.01	2.48×10^{-7}
3	Springbok Sandstone	0.01	2.71×10^{-7}
4	Kogan seam	0.4	0.004

6.2 Alluvium drawdown due to pumping

The calibrated model was used to assess the rate at which pumping from the WCM (Kogan seam) induces groundwater drawdown in the alluvium. In doing so, extraction bore LS30 (i.e. Kogan seam) was added and the model was run in steady state condition. Pumping from LS30 is simulated using the MODFLOW well (WEL) package and the maximum permissible extraction rate was increased to a very high value (i.e. 100 ML/day), to allow for maximum depressurisation in the coal seam. The ‘autoflow reduce’ option was used to ensure groundwater levels did not fall excessively below the base of the model. To quantify the drawdown from the extraction bore, the pump was removed and the steady-state solution was re-derived.

The result indicates that the maximum pumpable rate from bore LS30 could be as high as 10 ML/day and that pumping produced no drawdown within the alluvium. Zero drawdown in the alluvium is expected given that the vertical K in layers above the Kogan seam is very low, which prevents the drawdown expanding to the alluvium.

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[1] Underground Water Impact Report for the Surat Cumulative Management Area, Department of Natural Resources and Mines, September 2016

6.3 Sensitivity on vertical hydraulic conductivity (Kv)

To assess the sensitivity of vertical hydraulic conductivity (Kv) on alluvium drawdowns, Kv was increased by one order of magnitude and the maximum drawdown in alluvium was derived. The change in Kv was repeated until the pressure difference between the bores could no longer be maintained. Table 6-4 shows the summary of vertical hydraulic conductivity (Kv) and Table 6-5 shows the associated heads at bores in each run when no pumping is applied. It should be noted that the Kv was capped at the associated Kh so that Kv does not go beyond Kh.

Table 6-4: Vertical hydraulic conductivity (Kv) within the sensitivity runs

Model layer	Hydrogeological unit	Run1	Run2	Run3	Run4
		Kv (m/day)	Kv (m/day)	Kv (m/day)	Kv (m/day)
1	Alluvium	5	5	5	5
2	Westbourne Formation	2.48×10^{-6}	2.48×10^{-5}	2.48×10^{-4}	2.48×10^{-3}
3	Springbok Sandstone	2.71×10^{-6}	2.71×10^{-5}	2.71×10^{-4}	2.71×10^{-3}
4	WCM - Kogan seam	0.04	0.4	0.4	0.4
	Maximum pumping rate (m3/day)	10.3 ML/day	10.4 ML/day	10.7 ML/day	11.8 ML/day
	Maximum drawdowns(m)	0	0	1.02	8.77

Table 6-5: Summary of changes in heads due to change in Kv

Bore	Head (m/day)				
	Observed	Run1	Run2	Run3	Run4
LB28	322.94	324.84	335.22	342.28	341.27
LB29	323.98	319.12	343.65	353.29	345.74
LB30	362.82	362.81	362.00	359.36	348.14
LB31	336.98	335.87	336.95	337.32	339.23

The results indicate that changing Kv by one or two orders of magnitude (i.e. Run1 and Run2) still creates no drawdown within the alluvium. In the very high vertical K cases (i.e. Run3 and Run4), the maximum drawdown is above 1 m, however; the vertical gradient between the monitoring bores is not maintained.

6.4 Impact of boundary condition on pumpable rate

The results indicate the maximum pumpable rate is 10 ML/day. However, this considerable amount of groundwater is likely to be an artefact and not the actual pumpable rate. This is mainly due to upscaled, effective transmissivity of the WCM model layer.

To assess further the impact of WCM transmissivity on the amount of pumpable rate, the Kh of the coal seam was decreased by one and two orders of magnitude and the pumpable rate was derived accordingly. Table 6-6 shows the impact of change in Kh in layer 4 on the amount of pumpable rate. As it shows, the amount of pumping is considerably sensitive to the Kh in the coal seam and the reduction of Kh by one order of magnitude changes the pumping rate similarly by one order of magnitude. The Kh of 0.4 m/day is considered to be extreme for the WCM given that the WCM generally consists of less permeable mudstone and sandstone units.

Table 6-6: Impact of Kh in coal seam (layer 4) on pumpable rate

Hydrogeological unit	1 (Basecase)	2 (Basecase/10)	3 (Basecase/100)
	Kh (m/day)	Kh (m/day)	Kh (m/day)
Kogan seam	0.4	0.04	0.004
Maximum pumpable rate (m3/day)	10 ML/day	1 ML/day	0.1 ML/day

As a comparison, general head boundary conditions were applied to the model in place of the constant head cells. The conductance rate was congruent with the calibrated horizontal hydraulic conductivity and model cell area. Inflow and drawdown results were consistent with the constant head boundary package simulation.

6.5 Conclusions

Groundwater modelling has shown that Lake Broadwater, associated with the alluvium, is likely to be unaffected by CSG pumping from the WCM. This is a result of the hydraulic disconnection between the aquitards required to maintain the observed vertical pressure gradient.

The calibrated vertical hydraulic conductivity values derived from this exercise represent the minimum value required to maintain equalisation at the centre of the model. It is possible that vertical conductivity values are lower than modelled, although the current model setup is insufficient to derive these values.

Due to the significant upscaling of the horizontal hydraulic conductivity of the WCM, the maximum sustainable pumping rate is likely to be extremely conservative. In reality, the WCM consists of interbedded mudstones and sandstones, with hydraulic conductivity values orders of magnitudes lower than the calibrated rate. Therefore, the maximum pumping rate from LS30 should be derived using a model that separates the coal seam layers from the less permeable units.

7. Conceptualisation

The work undertaken within this Report aims to establish multiple lines of evidence to determine the level of hydraulic connectedness, through the following:

- Confirmation of lithology/stratigraphy identified in the desktop study undertaken by Coffey (2017),

- Hydrogeological characteristics of each monitored aquifer/formation including characterising intervals of low permeable interburden (aquitards), and undertaking hydraulic testing (slug testing) and numerical modelling to estimate values of horizontal and vertical hydraulic conductivity,
- Depth to groundwater and differences in hydraulic head between monitored formations to identify level of hydraulic connection and vertical direction of groundwater flow. Additionally, assessing seasonal groundwater level trends and aquifer responses to rainfall and / or surface water flow however the monitoring period undertaken has not yet allowed this assessment to occur, and
- Water quality variations through groundwater sampling and analysis for physical parameters, major ions and dissolved metals.

Conceptualisations for each Site are provided in the following sections based on the available data.

Long Swamp Site

Drilling, monitoring and modelling data collected through this Study support that the Long Swamp Site comprises Condamine Alluvium (unconfined aquifer), Westbourne Formation (confined aquitard), Springbok Sandstone (confined aquifer), and WCM (confined aquifer). The findings from this Study suggest that all aquifers at this site are hydraulically disconnected from each other. These conclusions are based on the following:

- Substantial intervals of low permeable interburden throughout all three formations restricting vertical movement of groundwater,
- Low values of hydraulic conductivity (both vertical and horizontal) in Longswamp 33 (Springbok Sandstone), and
- Distinct difference in hydraulic head between the formations (including Longswamp 35), and the declining aquifer pressure with depth shows a downward vertical movement of groundwater and a lack of/poor hydraulic connection between the formations.

Lake Broadwater Site

Drilling, monitoring and modelling data collected through this Study support that the Lake Broadwater Site comprises a perched system associated with Lake Broadwater, Alluvium (unconfined aquifer), Westbourne Formation (confined aquitard), Springbok Sandstone (confined aquifer), and WCM (confined aquifer).

The findings from this Study suggest that the upper units at this Site (perched system situated at Lake Broadwater / Alluvium, Westbourne Formation and Springbok Sandstone) are hydraulically disconnected from each other. These conclusions are based on the following:

- There is a distinct difference in hydraulic head between the perched system at Lake Broadwater and the underlying Westbourne Formation, Springbok Sandstone and WCM, indicating its hydraulic separation from the underlying formations,

- The Westbourne Formation displays a greater groundwater pressure than the Springbok Sandstone and WCM formations indicating a downward vertical movement of groundwater between the Westbourne Formation and the underlying formations,

- Substantial intervals of low permeable interburden throughout all formations underlying the perched system at Lake Broadwater and a lack of perceived permeable zones restricting vertical movement of groundwater,

- Very poor yields observed during airlift development of Longswamp 28, Longswamp 29 and Longswamp 30R, and

- Very low values of hydraulic conductivity (both horizontal and vertical) in Longswamp 28 (Westbourne Formation) and Longswamp 29 (Springbok Sandstone).

The data also indicate a possible hydraulic connection between the Springbok Sandstone and the WCM based on the following:

- The WCM displays a greater groundwater pressure than the Springbok Sandstone indicating potential upward movement of groundwater between the WCM and the Springbok Sandstone.

Most notably, the results of the simulated pumping scenario (Section 6) indicate that perched system associated with Lake Broadwater, overlying the alluvium, is likely to be unaffected by CSG pumping from the WCM. This is a result of the hydraulic disconnection between the aquitards required to maintain the observed vertical pressure gradient.

Burunga Lane Site

Drilling, monitoring and modelling data collected through this Study support that the Burunga Lane Site comprises Alluvium (unsaturated) and WCM (confined aquifer). The findings from this Study suggest that formations at this site are hydraulically disconnected from each other. These conclusions are based on the following:

The data derived through this Report and 3D Environmental / Earth Search's Report (2018) indicate that the localised alluvial feature associated with Juandah Creek is not a permanent aquifer and possibly only temporarily contains water following recharge events.

These conclusions are based on the following:

- The lower permeable lithology types (well cemented fine grained sandstones, hard blocky siltstones and carbonaceous mudstones) separating the more permeable coal seams would greatly hinder vertical groundwater movement,

- Airlift yields observed during bore development of the three monitoring bores show greater yields within the coal seams (Burunga Lane 184 and Burunga Lane 185) than the interburden (Burunga Lane 183),

- Low values of hydraulic conductivity (both horizontal and vertical) in the interburden, compared with the coal seams' estimated value of hydraulic conductivity which is two orders of magnitude greater, and

- There is a distinct difference in hydraulic head between each monitoring bore's monitored zone and groundwater pressure increases with depth indicating upward vertical movement of groundwater within the WCM.

Glenburnie Site

Drilling, monitoring and modelling data collected through this Study support that the Glenburnie Site comprises Alluvium (unsaturated), Springbok Sandstone (perched seepage zone) and WCM (confined aquifer). The findings from this Study suggest that formations at this site are hydraulically disconnected from each other. These conclusions are based on the following:

- The major ions data show separation between the three monitoring bores' chemical composition most notably between the deeper monitoring bores (Glenburnie 21 and Glenburnie 22) and the shallow monitoring bore (Glenburnie 20) indicating appreciable exchange of groundwater between WCM and Springbok Sandstone at the Glenburnie site is unlikely to be occurring,
- During airlift development, Glenburnie 22 was observed to have a slightly higher yield than Glenburnie 21 however both intervals appear to be poor producers,
- Large difference in hydraulic head (approximately 10 m) between the two monitored coal seams,
- The regional aquifer is situated within the WCM and only a perched seepage zone was identified within the Springbok Sandstone,
- Very low values of hydraulic conductivity (both horizontal and vertical) of the interburden of the WCM, and
- Substantial intervals of low permeable interburden observed throughout the WCM restricting vertical movement of groundwater.

8. Conclusions

This Report has provided an overview of work undertaken to improve the understanding of the hydraulic connection between the formations overlying the WCM at four locations within Arrow Energy's Surat Basin tenure. The four sites were Lake Broadwater, Long Swamp, Glenburnie and Burunga Lane. The findings of this Report are proposed to be used in conjunction with the study undertaken by 3D Environmental / Earth Search (2018).

The findings from this Study suggest that all aquifers at the four Sites are hydraulically disconnected from each other except for the potential connection between the Springbok Sandstone and WCM in the vicinity of the Lake Broadwater Site.

9. Document Administration

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2	06/09/18	Update with LB modelling results	Chris Jones

Controlled document location

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NA	Arrow Energy – Lake Broadwater Sandbox Impact Assessment (AGE, 2018)

Acceptance and release

Author

Position	Incumbent	Release Date
Senior Hydrogeologist	Chris Jones	06/09/18

Stakeholders and reviewers

Position	Incumbent	Review Date
Team Lead Hydrogeology	Stephen Denner	14/06/18
Groundwater Management Lead	Kavita Singh	14/06/18

Approver(s)

Position	Incumbent	Approval Date
Team Lead Hydrogeology	Stephen Denner	21/08/18

Appendix A: Bore Logs

Appendix B: Core Box Photos

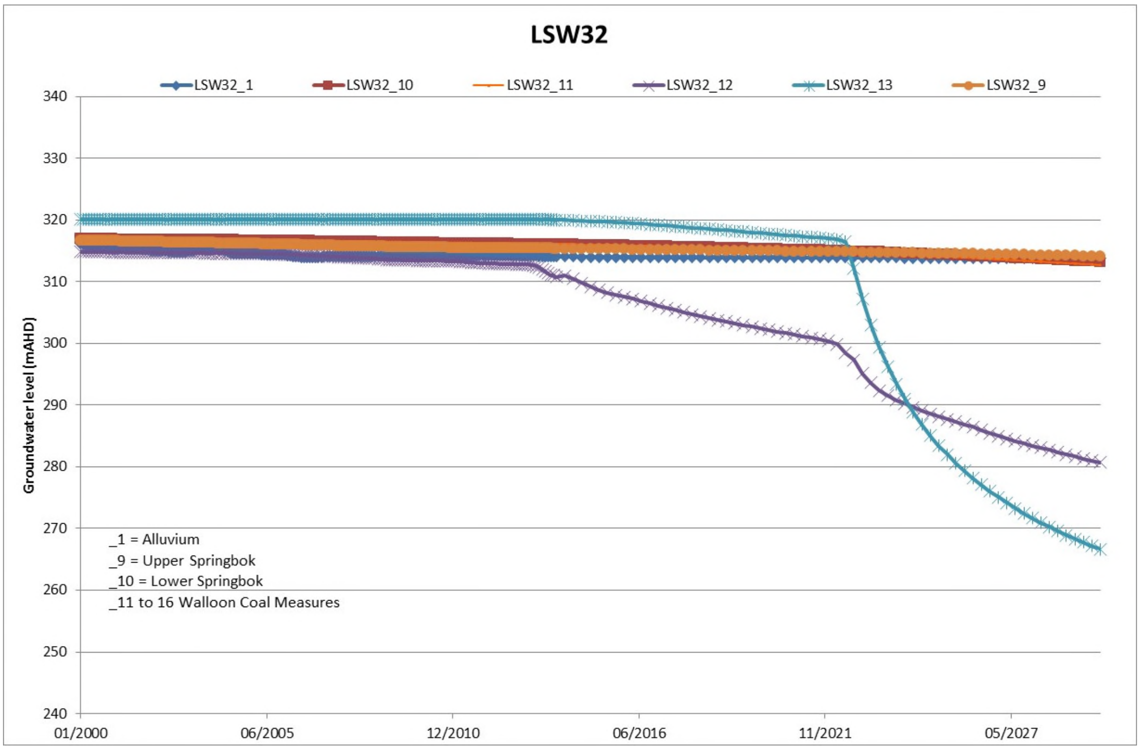
Appendix C: Downhole Geophysics Logs

Appendix D: Water Quality Analytical Reports

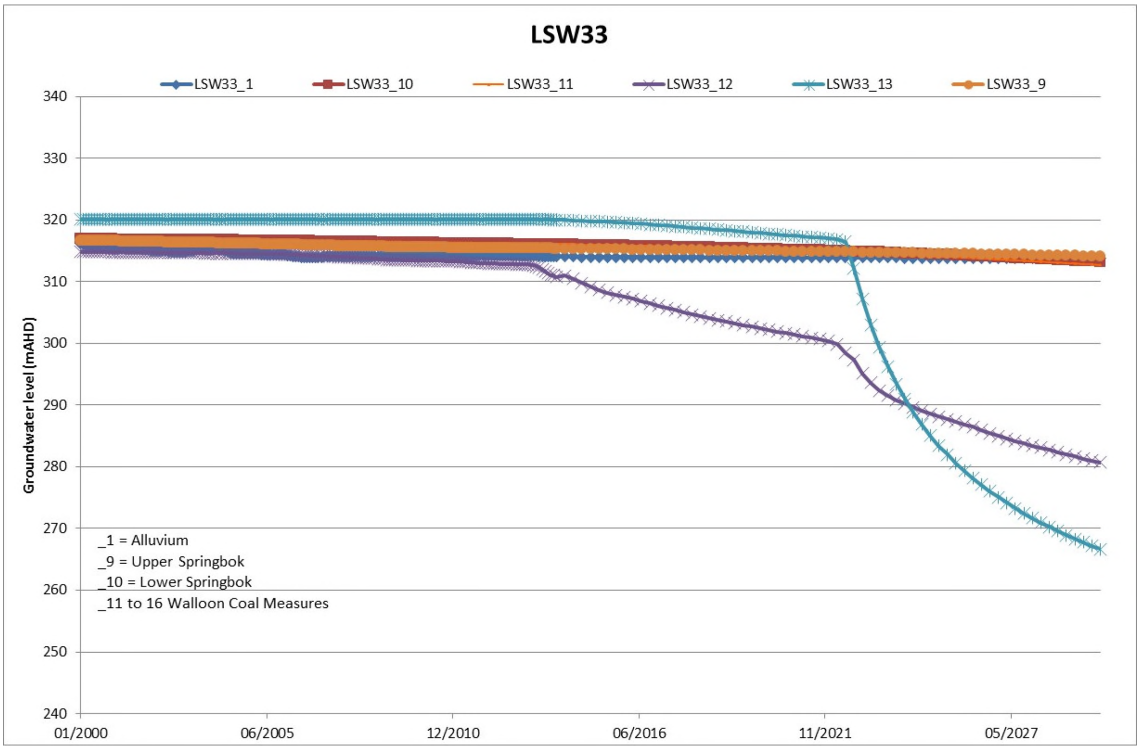
Appendix E: Slug Test Analyses Reports

APPENDIX E DRAWDOWN HYDROGRAPHS AT GDE INVESTIGATION SITES

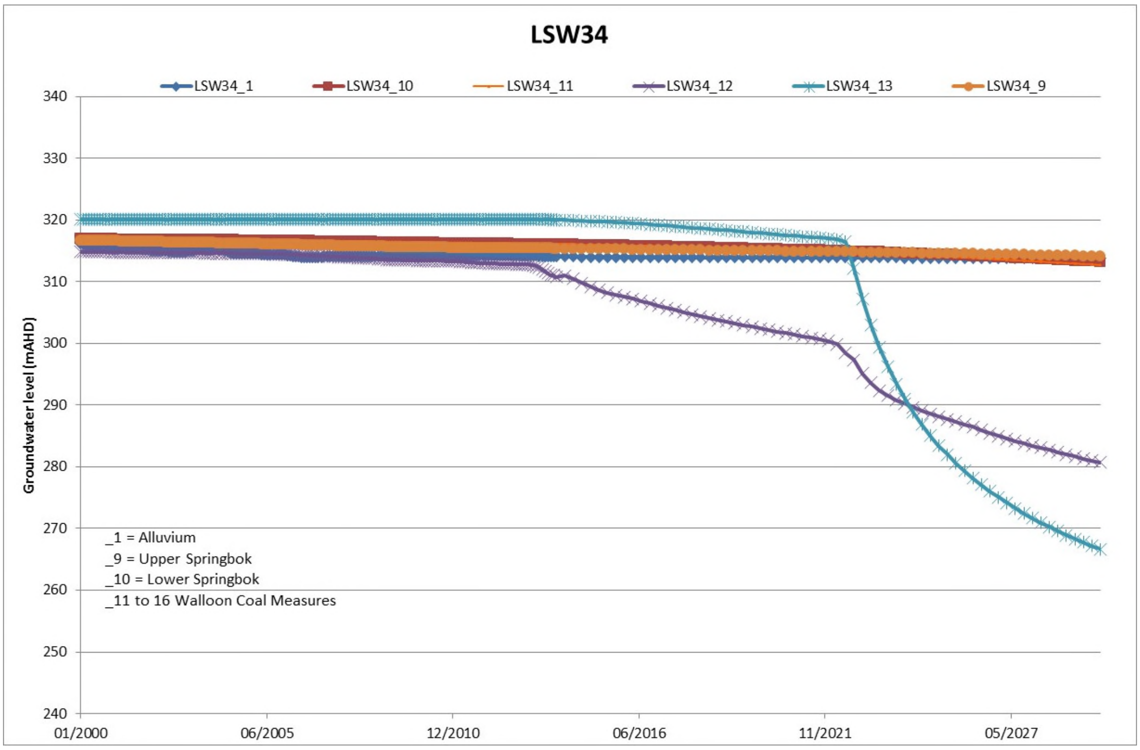
Long Swamp 32



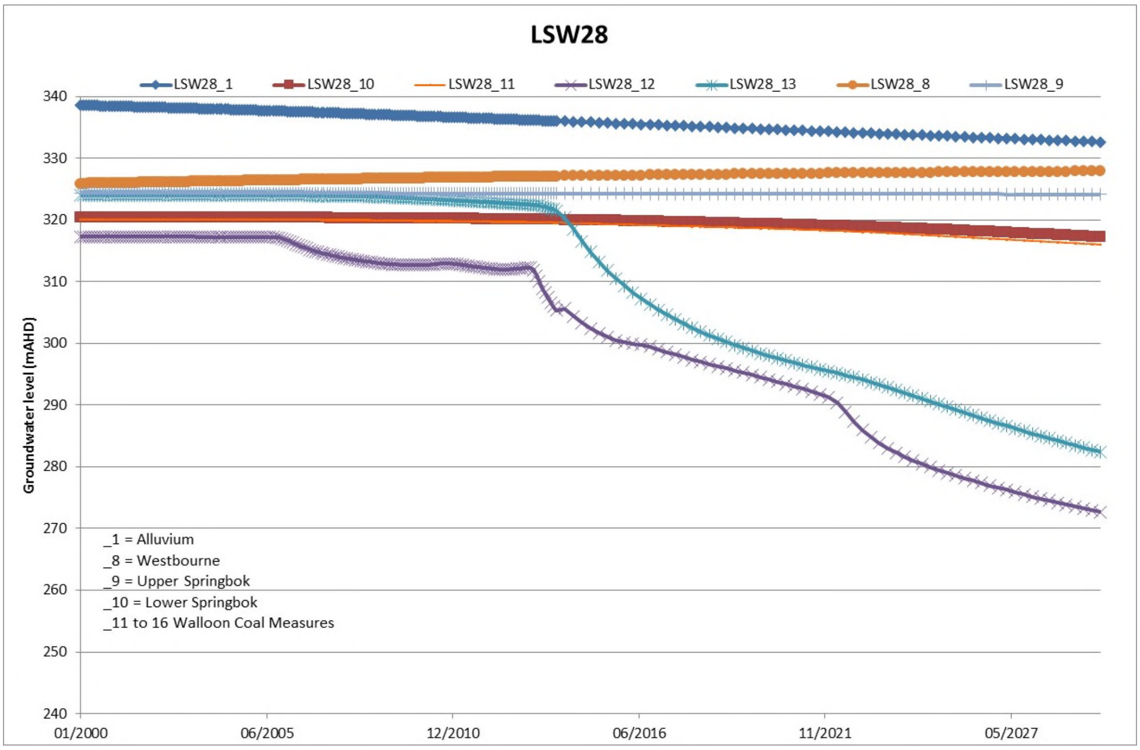
Long Swamp 33



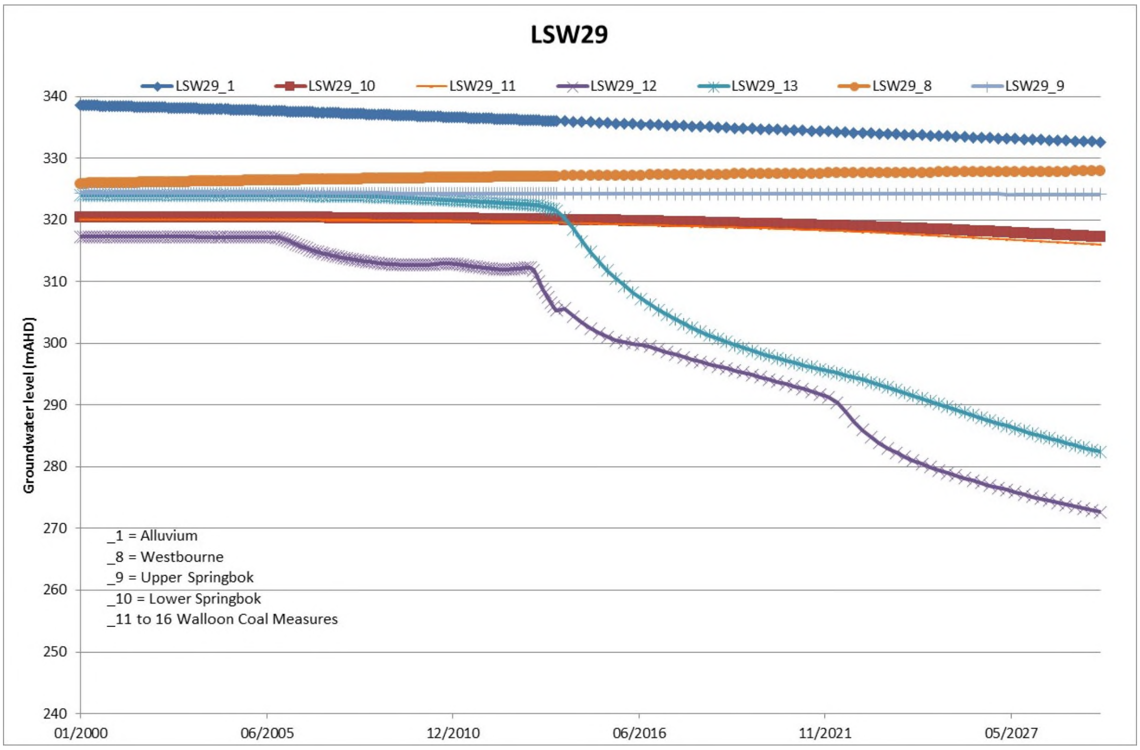
Long Swamp 34



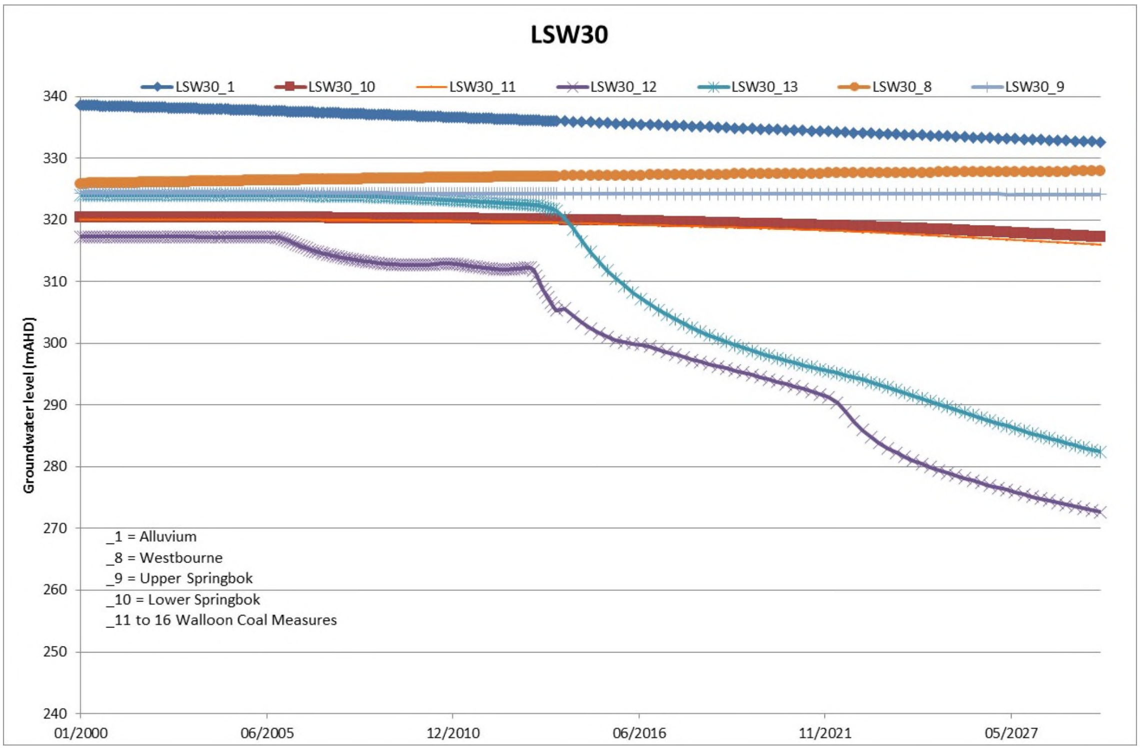
Long Swamp 28 – Lake Broadwater



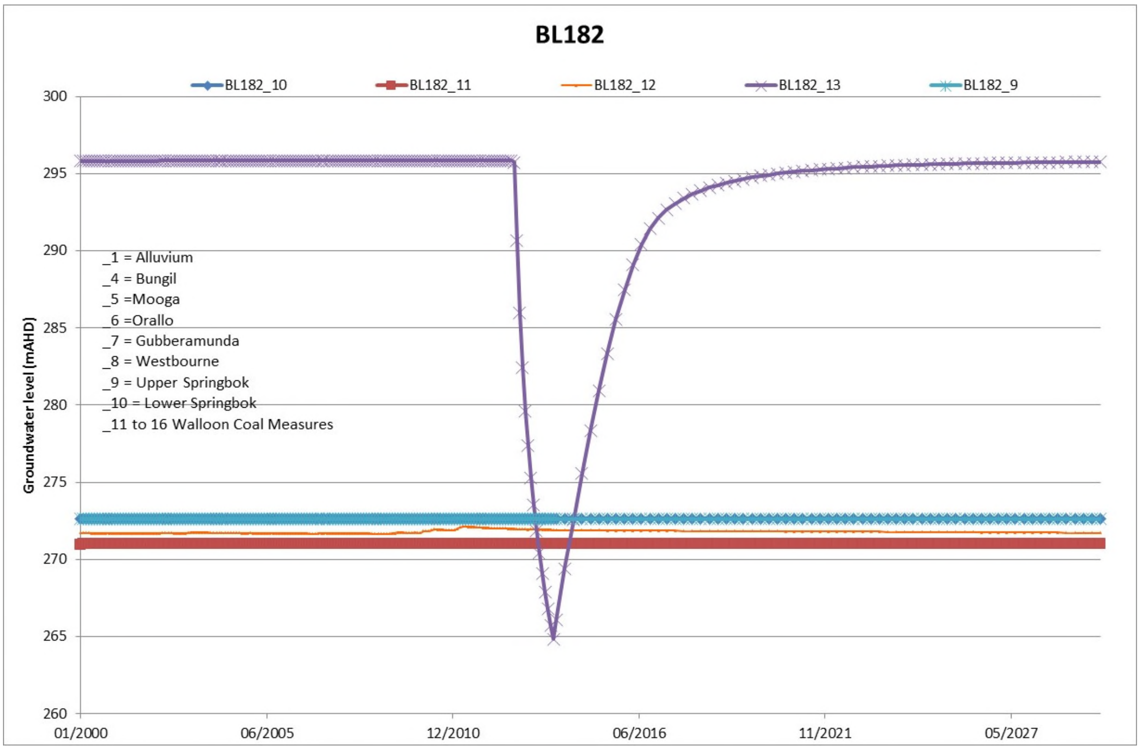
Long Swamp 29 – Lake Broadwater



Long Swamp 30 – Lake Broadwater



Burunga Lane 182



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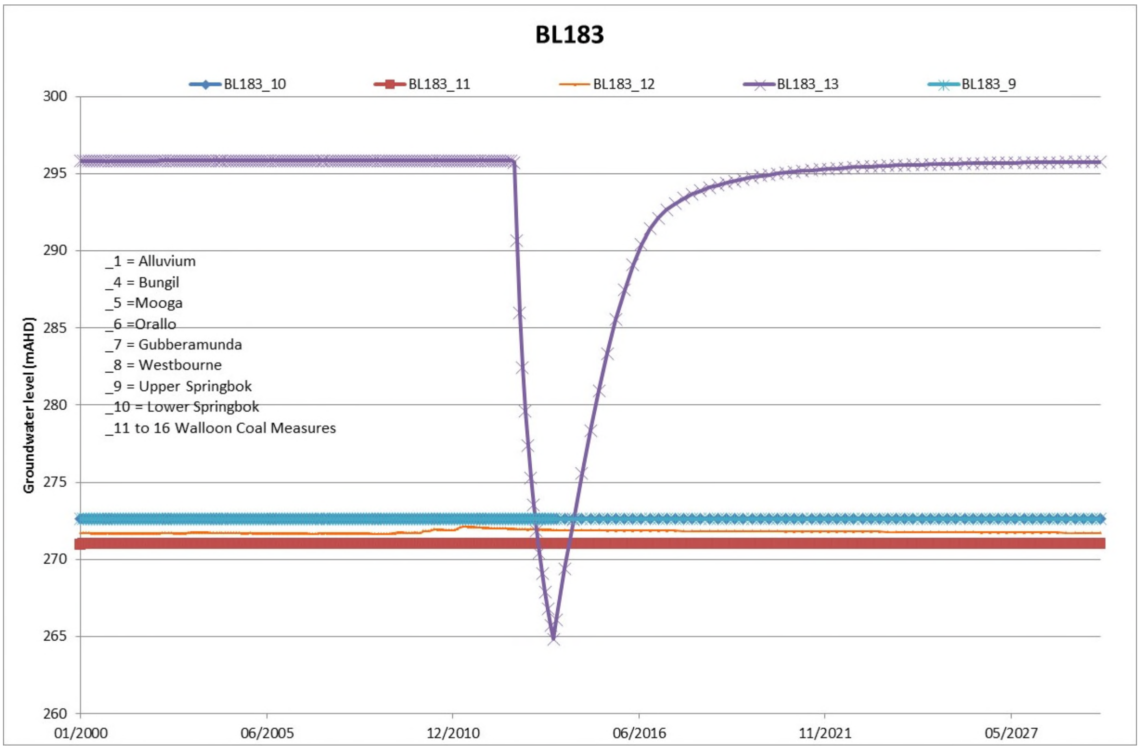
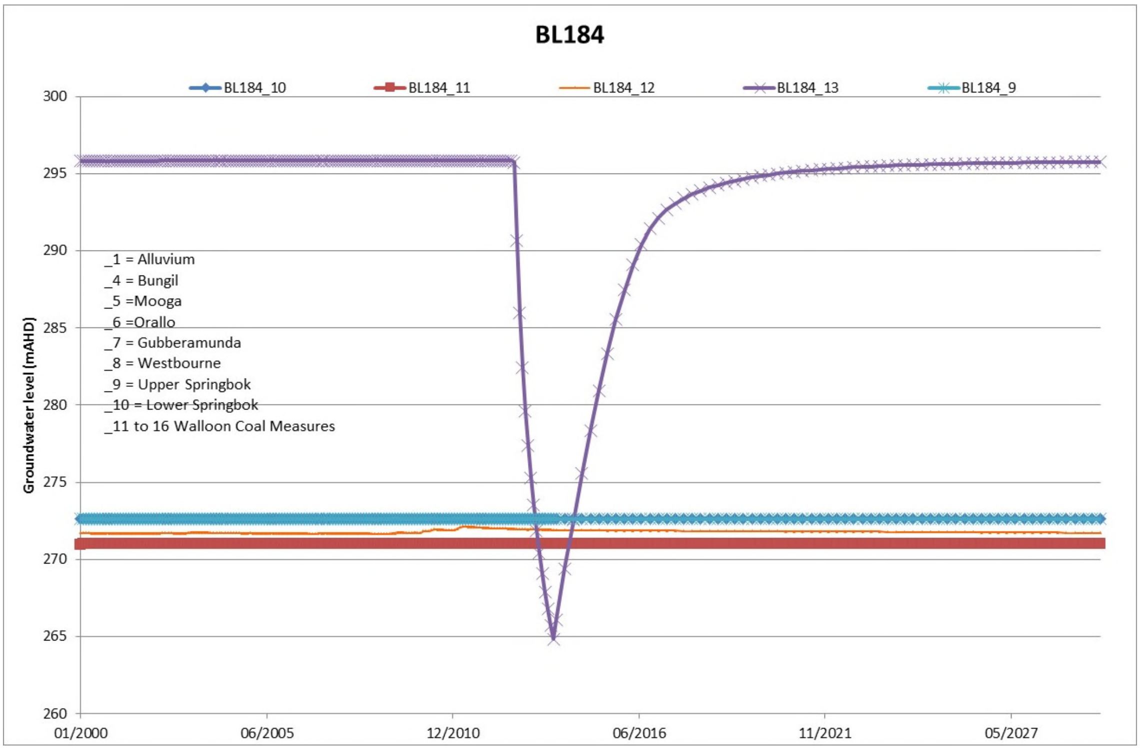
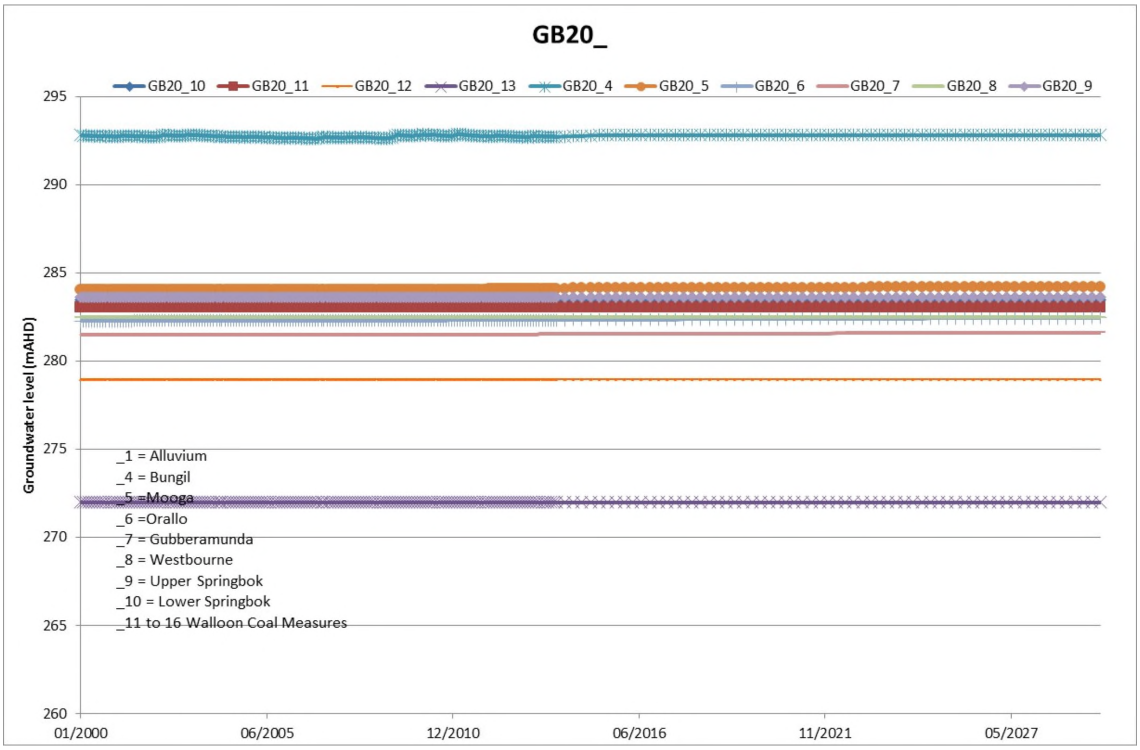


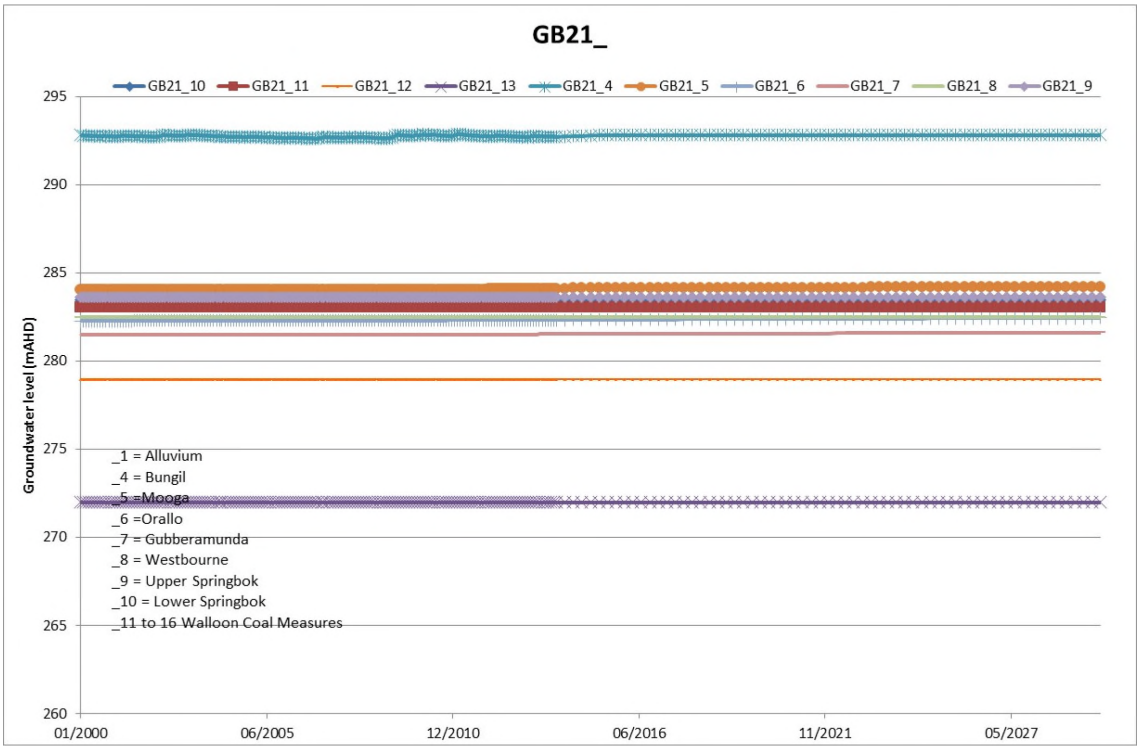
Burunga Lane 184



Glenburnie 20



Glenburnie 21



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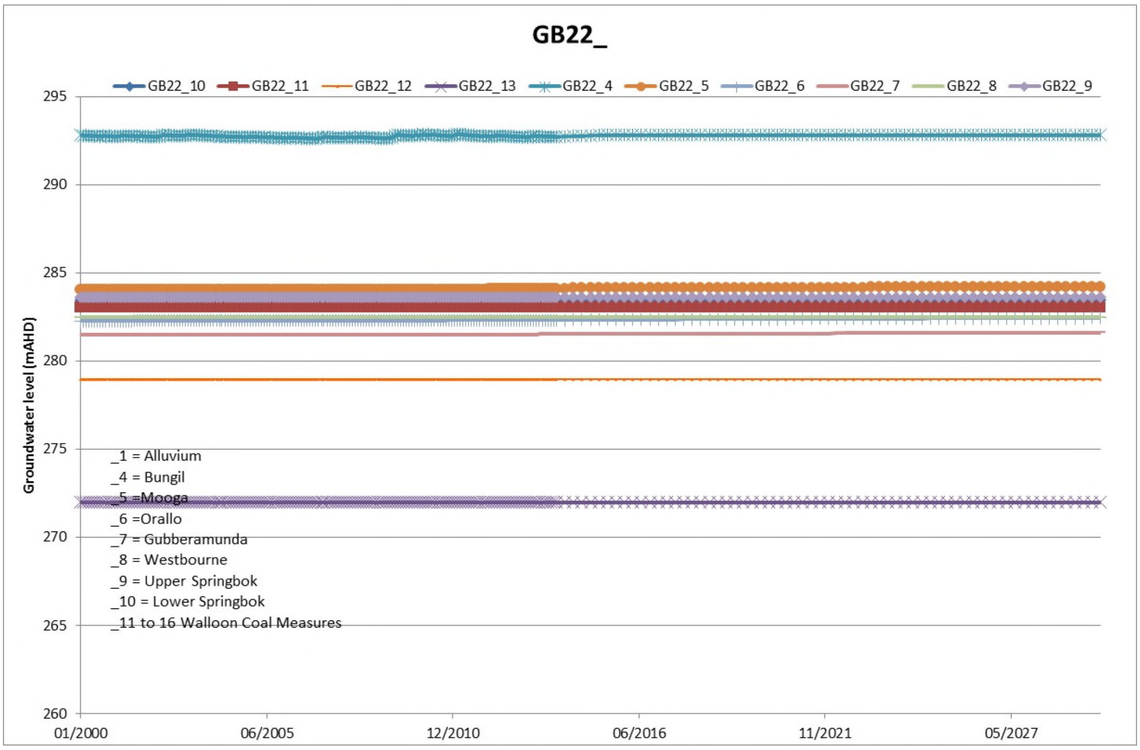

APPENDIX F SGP WATER MANAGEMENT STRATEGY

Strategy
ORG-ARW-ENV-STR-00001

Safe Work. Strong Business.

Surat Gas Project CSG Water Management Strategy

Version	3.0
Released	14 March 2019
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Contents

1. Introduction

This document is the coal seam gas (CSG) water management strategy (CSG WMS) for the Surat Gas Project (SGP). It is derived from Arrow Energy's corporate Coal Seam Gas Water and Salt Management Strategy[1] (Arrow Energy, 2013), which summaries the overarching management framework implemented by Arrow for water and salt. This document outlines the management of CSG water resulting from activities arising from the SGP Field Development Plan.

The CSG WMS provides a basis for compliance with government policy, and sets out the method for managing produced water for Arrow's Surat Basin tenements.

This CSG WMS applies to CSG water and brine resulting from CSG production activities. It does not apply to CSG exploration activities.

2. Regulatory system

2.1 Legislation

The regulatory system directly relevant to the management of CSG water comprises both legislation and policy, and has been previously described in Arrow Energy's Coal Seam Gas Water and Salt Management Strategy (2013). An updated summary of information on legislation and policy relating to specific aspects of CSG water management is provided in Appendix A.

2.1.1 Beneficial use of CSG water

The end of waste (EOW) framework under the *Waste Reduction and Recycling Act 2011* has replaced the previous beneficial use approval (BUA) framework for regulating resource recovery opportunities.

CSG water is defined as a waste under Section 13 of the *Environmental Protection Act* 1994 (EP Act). It can be approved as a resource through an EOW code or EOW approval issued by the Queensland Department of Environment and Science (DES). If the resource is not used in accordance with the EOW code or approval, it remains a waste and its use may be subject to enforcement action under the EP Act.

It should be noted that the beneficial use of CSG water is also regularly authorised through a State Government Environmental Authority as outlined in Appendix A.

2.2 Queensland Department of Environment and Science CSG Water Management Policy

The Department of Environment and Heritage Protection's (now Department of Environment and Science) 'Coal Seam Gas Water Management Policy' (DEHP, 2012) sets out the government's position on the management of CSG water and guides CSG operators to consider the feasibility of using such water to meet the obligations of the EP Act as part of developing their CSG water management strategies and plans.

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[1] Arrow Energy's corporate strategy for management of CSG water is defined in the 'Coal Seam Gas Water and Salt Management Strategy' (Arrow Energy, 2013, revision 2). It provided the supporting basis for water management and beneficial use under the Environmental Impact Statement (EIS) and Supplementary Report to the EIS (SREIS).

The policy objective is to encourage beneficial use of CSG water in a way that protects the environment and maximises its productive use as a valuable resource. This objective is achieved by managing CSG water and saline waste[2] consistently with the prioritisation hierarchies outlined below in Section 2.2.1, and the management criteria specified in the policy.

The policy focuses on the management and use of CSG water under the EP Act, and does not change obligations under the *Water Act 2000*, including ‘making good’ impacts to water bores as a result of CSG operators exercising their underground water rights. Make good measures under the Water Act may include a number of mechanisms such as the drilling of a bore to another aquifer, the provision of water from another source, or giving the bore owner monetary or non-monetary compensation.

2.2.1 DES prioritisation hierarchy

The DES prioritisation hierarchy provides a structure for prioritising the options for management of CSG water and saline waste. The strategy is based on the evaluation of potential management options for water and saline waste against preferred management approaches.

Priority 1 options are to be implemented wherever feasible. Where Priority 1 options are not feasible, Priority 2 options are implemented.

In determining the feasibility of implementing options, factors that may be considered include technical and economic considerations.

CSG water prioritisation

The objective of the policy is for the management and use of CSG water consistent with the following priority hierarchy:

- Priority 1 – CSG water is used for a purpose beneficial to one or more of the following:
    - the environment
    - existing or new water users
    - existing or new water-dependent industries.
- Priority 2 – After feasible beneficial use options have been considered, treating and disposing CSG water in a way that firstly avoids, and then minimises and mitigates, impacts on environmental values.

Saline waste prioritisation

Desalination of CSG water results in brine and/or solid salts. Operators must demonstrate that the management of these end products is in accordance with the following priority hierarchy:

- Priority 1 – Brine or salt residues are treated to create useable products wherever feasible.
- Priority 2 – After assessing the feasibility of treating the brine or solid salt residues to create useable and saleable products, disposing of the brine and salt residues in accordance with strict standards that protect the environment.

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[2] Saline waste includes brine and or solid or semi-solid salt, normally produced as a by-product of water treatment or desalination.

3. Water production and infrastructure

Based on the current field development plan, the SGP will produce an average ~14 GL/year CSG water over 40 years, with a total production of 575 GL. The peak production rate is estimated at 30 GL/year.

The predicted annual average coal seam gas water production rates over the life of the project are presented in Figure 3.1.

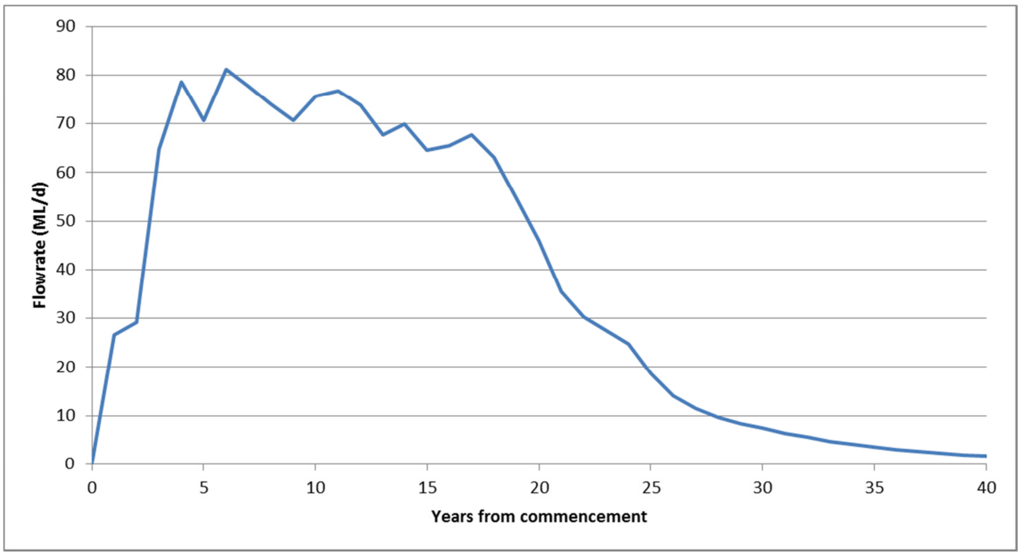

Figure 3.1 – Estimated Surat Gas Project water production

3.1 CSG water production

Planning for the management of CSG water from the SGP requires forecasting of production rates, storage volumes, and quality of CSG water for the life of the project.

It is also important to consider that field development changes will be made during the project which may affect the water production forecast. Accordingly, the CSG WMS is adaptable and ensures that potential changes to water production can be managed consistently with the objectives of the DES CSG Water Management Policy.

3.1.1 Water production forecasting

Arrow water production forecasts will be modelled via a process that includes:

- identifying expansion areas, gas sales targets and gas production rates
- simulating the subsequent water production rates using the reservoir model
- reviewing model performance against actual production data and history matching.

Once in operation, forecasting will also account for changes to the field development plan, and any identified production constraints. Water balance models will be used for short, medium and long-term planning of water management and supply infrastructure, including water supply and end use. This will enable an understanding of expected dam storage capacity based on forecast production rates, seasonality and water use. The operations water balance model accounts for:

- forecast water production
- dam storage capacity, surface area and current levels
- seasonal rainfall and evaporation scenarios
- natural pan evaporation and salinity factors
- beneficial use off-takes and disposal
- treatment capacity, including allowances for plant availability and recovery.

3.1.2 CSG raw water quality

CSG water from the Walloon Coal Measures varies from fresh to saline, but is typically brackish with the following characteristics:

- neutral to alkaline pH (approximately 7 to 11 pH units)
- salinity typically ranging from 3,000 to 8,000 mg/L, with total dissolved solids (TDS) including sodium salts, bicarbonate salts, chlorides and others
- suspended solids from the well that usually settle out
- other ions including calcium, magnesium, potassium, fluoride, bromine, silicon and sulphate
- trace metals and low levels of nutrients.

CSG water quality may vary over the life of a well. The beneficial use of this water is constrained by the salt content, often requiring treatment and/or amendment prior to use.

3.2 CSG water management infrastructure

Infrastructure required to manage CSG water includes gathering and distribution systems, storage facilities (dams), and water treatment systems.

3.2.1 Gathering and distribution systems

The types of pipelines required to manage the production, treatment and storage of CSG water include:

- Water gathering lines – a low pressure water gathering system is installed from each well head to aggregation dams.
- Transfer pipelines –pipelines, including associated pumps and controls, are required to transfer raw CSG water, treated water or brine between dams, facilities or to end users.

3.2.2 Storage facilities (dams)

Dams are integral to CSG water management, providing operational storage and water balance capacity to ensure the containment of CSG water under varying supply rates and beneficial use demand. Evaporation dams are not part of this system.

The types of dams required to manage the production, treatment and distribution of CSG water include:

- Aggregation dams – required to:
  - contain the CSG water collected via gathering pipelines prior to transport to water treatment facilities
  - to provide a buffer between the variations in production and water treatment flows at water treatment facility locations.
- Treated water dams – required to:
  - store treated water prior to beneficial use
  - to ensure a buffer between the treatment output and end use demand.
- Utility dams – required for the storage of chemical cleaning systems from the water treatment process.
- Waste water dams – required for storage of compression facility waste water, which may contain lubricants and chemicals from compression systems.
- Brine dams – required for the storage of water treatment plant concentrate.

Where new dams are required, their size will be optimised to ensure that suitable buffer storage capacity is provided, accounting for predicted water inflows, climatic conditions, treatment plant availability and end uses.

Dam consequence category compliance

All dams undergo consequence category assessments to determine the regulatory design and management requirements of each structure. In order to determine the consequence categorisation of its dams, Arrow will implement the assessment procedure outlined in the latest version of the *Manual for Assessing Consequence Categories and Hydraulic Performance of Structures* (DEHP, 2016) (Dam Manual). All Arrow dams are designed, built, operated and decommissioned in accordance with the Dam Manual, relevant guidelines and the applicable State Government Environmental Authority.

Regulated dam register and operating plans

Arrow maintains a Regulated Dam Register to record key information regarding dams in accordance with its State Government Environmental Authority conditions.

The procedures and criteria to be used for operating dams, including management, maintenance and monitoring are defined in Arrow's dam operating plans.

3.2.3 Water treatment systems

Arrow will treat the majority of produced CSG water to a quality suitable for a range of end uses. Treatment may comprise a combination of processes including microfiltration (MF), reverse osmosis (RO), blending (depending on the required end use) and chemical amendment.

Microfiltration enables the removal of turbidity, bacteria and other solids from the water to sizes of 0.1 to 3 µm. RO involves the separation of salts from solution through a semi–permeable, microporous membrane under elevated hydrostatic pressure, and reduces the concentration of dissolved salts resulting in high quality treated water and concentrated brine streams.

Where the need arises, Arrow will continue to investigate new and emerging technologies to treat CSG water and evaluate their applicability to the SGP.

Ancillary treatment processes such as ion exchange between the pre-treatment and the RO process may be used to optimise the performance of the water treatment facility – for example, to increase water recovery and reduce the size of brine dams.

Treated water is often amended to ensure the correct balance of ions for its intended use. This typically involves the addition of calcium.

4. Water and salt management

4.1 Overview

Arrow's water and salt management strategy for the SGP makes reference to the corporate strategy for CSG water and brine management (Arrow Energy, 2013), and aims to maximise the water's reuse as a resource (beneficial use) and reduce the potential for environmental impact. The water management approach is consistent with the regulatory framework, Arrow's EA conditions and the DES prioritisation hierarchy.

CSG water will be managed through a combination of options which address Arrow's statutory obligations and commitments. The field development plan (which will be refined over the life of the project) will determine the timing, combination and implementation of the management options.

4.1.1 CSG water management risks and uncertainties

The following risks and uncertainties are considered when determining Arrow's hierarchy of CSG water and salt management options:

- Production profiles – water volume forecasts vary across the Surat Basin:
  - The confidence in predictions is dependent on the extent of exploration and appraisal that has occurred.
  - CSG water management options will be determined by local conditions and, in some cases, further observations of reservoir behaviour will be necessary to better inform the reservoir model and increase confidence levels in forecast water production volumes.
  - Timing and quantity of water production is highly dependent upon the timing and extent of CSG development within the basin.
  - The water management options must therefore be tailored to the development plans and have the flexibility to meet a range of outcomes.
- Commercial agreements – a high level of certainty is required to enter into contractual arrangements, specifically:
  - available water volumes
  - the timing and duration of water availability

  - the ability to guarantee that water quality characteristics are fit for the intended application (for example, for third-party irrigation, where the water quality must be suitable for the soil type and the intended crop)
  - long-term approvals.
- Approvals – the water management options must meet regulatory requirements into the future, while retaining flexibility to meet a range of outcomes. Long-term approvals are a prerequisite to investment in infrastructure necessary to distribute water to end users, injection sites or discharge points.

4.1.2 Selection of options

Arrow systematically evaluates potential options to ensure the most sustainable portfolio of CSG water and saline waste management options. The performance of each option is assessed against multiple criteria including economic, schedule, operability, reliability, social impact, environmental impact and HSE/compliance.

To reflect differences in the relative importance of the considered criteria, each is assigned a weighting, and the weighted scores are ranked to categorise options as either ‘proposed’, ‘reserved’ or ‘not proposed’. Proposed options are developed as the base case whilst reserved options continue to be investigated. Options that are not proposed are not further investigated unless circumstances change.

4.2 Water management options

Under the Arrow corporate water management strategy (Arrow Energy, 2013), treated and untreated CSG water could be supplied to end users or a receiving environment through a range of methods and for a variety of end uses, including:

- agricultural uses
- industrial use, including power station cooling, coal washing, and use by Arrow for construction, drilling, well work-overs and operational uses
- urban uses such as potential water supply to towns
- injection into aquifers.

Opportunities for beneficial use in collaboration with other CSG developers may be implemented where they are feasible and align with the DES CSG Water Management Policy.

For the SGP, CSG water will be supplied to end users under the relevant State Government Environmental Authority or the EOW framework. Supply to end users will also be in accordance with negotiated water supply agreements.

A summary of the CSG water management options is presented in Table 4.1 which aligns Arrow’s proposed and not proposed options with the DES prioritisation hierarchy. Further detail on each option is included in the following sections.

Table 4.1 - CSG water management – alignment of Arrow and DES priorities

Arrow priority	Option	Comments	DES Priority
Proposed	Arrow operational supply	Dust suppression, construction, drilling, etc.	Priority 1
	Irrigation	Beneficial use to existing irrigators; substitution of groundwater allocations is preferred	Priority 1
	Stock watering	Stock drinking water in accordance with approval conditions	Priority 1
	Industrial supply	Non-Arrow use, where established	Priority 1
Reserved	Urban water supply	Likely difficult to implement within drinking water regulatory framework. Subject to negotiation and approvals. Supply as substitution of groundwater allocation is preferred	Priority 1
Not Proposed	Discharge to watercourse	Subject to State Government Environmental Authority (noting existing DXP project has permission to discharge)	Priority 2
	Injection (Managed Aquifer Recharge)	Managed aquifer recharge	Priority 1
	Ocean outfall	Non-preferred due to environmental and community concerns, and potential schedule impact	Priority 2
	Deep aquifer injection	Currently no identified target aquifer	Priority 2

Existing versus new uses

In some cases, potential beneficial use options may involve the establishment of new uses, industries or infrastructure or the expansion of existing operations. However, it is known that the duration of CSG water availability is limited (Arrow's plateau water production is expected to last for no more than 15 years, Figure 3.1). Furthermore, the experiences of other CSG producers has typically resulted in less water production than predicted. Therefore, Arrow proposes to supply water for existing uses as a supplement or replacement of existing supplies rather than as a new supply. (Were new uses to be created, based on Arrow's production forecasts, and actual production failed to meet those forecasts, the new users could potentially be left with stranded investments. Hence, new uses are not proposed for the SGP.)

Substitution of allocation

Where possible, Arrow prefers water to be supplied as a substitute for existing groundwater allocations (sometimes referred to as ‘virtual injection’). Substitution of groundwater allocations is preferred because it constitutes both a beneficial means of managing produced CSG water and a means of mitigating the potential impacts of Arrow’s CSG production upon certain aquifers. For example, Arrow has committed to mitigating its component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of CSG water extraction from the Walloon Coal Measures.

Arrow will supply treated CSG water to existing Condamine Alluvium groundwater allocation holders through water supply agreements. These agreements will describe how end users will receive and utilise treated water supplied by Arrow in lieu of using their groundwater allocations.

Substitution of allocations can be implemented through a beneficial use network that will distribute water to groundwater users within specified areas of the Condamine Alluvium. As the CSG water production profile varies over time, the beneficial use network capacity will be higher than the volume of water required to meet Arrow’s substitution commitment.

Not all CSG water will be able to be supplied as substitution of allocation because Arrow also aims, where possible, to provide water to users in other areas where CSG water is produced.

4.2.1 Irrigation

Irrigation, including using groundwater sourced from the Condamine Alluvium, is the predominant water use within the SGP development area. It is therefore likely that irrigation supply will form part of the mix of beneficial uses employed by Arrow.

As discussed above, substitution of groundwater allocations will be the preferred mechanism for delivering water for irrigation. However, some water may also be supplied to other existing irrigators (for example through the existing SunWater Chinchilla Weir scheme) or to Arrow’s own farms without substituting an existing groundwater allocation.

Key considerations for providing CSG water to end users for irrigation include:

- where water is supplied as substitution of allocation, that end users have water licences which authorise take from the Condamine Alluvium
- the ability of end users to take water regularly and reliably
- the location of end users to the proposed beneficial use network
- the approvals framework
- the extent to which the user may become reliant on water supplied by Arrow
- the appropriateness of the supply given the short-term nature of CSG water availability.

The water and implications of its use will be the responsibility of the end users. Arrow retains no control over how the water is used beyond the transfer point.

4.2.2 Arrow operational use

Arrow will use some CSG water for operational purposes such as construction, drilling and dust suppression. Demand for operational uses is typically only a small proportion of total CSG water production. Operational use is subject to the relevant approval conditions.

4.2.3 Stock watering

Water from the Walloon Coal Measures is widely used in the Surat Basin for stock drinking water. CSG water is subject to the relevant approval conditions before it can be used for this purpose. Both treated CSG water and, in some cases, untreated CSG water can meet these approval conditions. In some circumstances, Arrow may provide water to feedlots (including to substitute groundwater allocations where existing feedlot water supplies include groundwater extraction) or landholders for stock watering, although these supplies will typically only account for a portion of CSG water production.

4.2.4 Industrial supply

Some industrial supplies exist in the Surat Basin – for example, mining operations and power stations. It is not expected that there will be sufficient industrial demand for a substantial proportion of CSG water production. Therefore industrial supplies may be considered on a case by case basis. Any supply for industrial purposes will be subject to relevant approval conditions.

4.2.5 Discharge

Discharge of treated CSG water to watercourses can be permitted in some circumstances. However the nature of Arrow's SGP development is such that discharge is not currently required.

4.2.6 Urban uses

Urban supply is a potential CSG water end use but is not currently a proposed option. Urban supply would be subject to rigorous and complex regulatory approvals.

4.2.7 Aquifer injection

Aquifer injection (also referred to as managed aquifer recharge) involves pumping water into an aquifer through a purpose-built bore or field of bores. Aquifer injection, either for re-pressurisation or as a means for CSG water management, is not currently proposed for the SGP due to its technical complexity, potential risks and the availability of alternative beneficial use options.

4.2.8 Ocean outfall

Disposal of CSG water to the sea via an ocean outfall pipeline is recognised as a technically and environmentally feasible option but, due to potential community concerns and schedule impact, it is not proposed.

4.3 Brine and salt management options

Water treatment processes that include desalination, such as reverse osmosis, produce a brine stream by-product.

Assuming an average salt concentration of 4,500 mg/L for CSG water in the Surat Basin, treatment of CSG water by reverse osmosis (~500 mg/L TDS) will generate in the order of four tonnes of salt per megalitre of water treated. Raw water feed concentrations vary across tenements and may also change over time within any CSG field. Actual brine stream concentrations will therefore change accordingly.

Specific measures are required to manage the storage and disposal of brine. However a salt solution is not required for many years as brine is stored until sufficient volume is available to allow salt processing to commence.

A summary of the brine and salt management options is presented in Table 4.2 which compares Arrow's proposed, reserved and not proposed options with the DES prioritisation hierarchy. Further detail on each option is provided in the subsequent sections.

Table 4.2 - Saline waste management – alignment of Arrow and DES priorities

Arrow priority	Option	Comments	DES Priority
Proposed	Non-selective salt recovery and landfill encapsulation	Solid product landfill in purpose designed regulated waste facilities	Priority 2
Reserved	Selective salt recovery	Currently uneconomic and unable to demonstrate a commercial market	Priority 1
Not Proposed	Brine injection	Currently no identified target aquifer	Priority 2
	Ocean outfall	Non-preferred due to community concerns and potential schedule impact	Priority 2

4.3.1 Salt recovery

The concentrated brine by-product will be primarily sodium chloride, sodium carbonate and sodium bicarbonate salts. Salt can be recovered from the brine as a solid product and subsequently disposed of or beneficially used.

Non-selective salt recovery and landfill

Non-selective recovery can be undertaken in purpose designed, lined solar evaporation ponds, through other thermal processes, or using mechanical crystallisers. The mixed salt product has no commercial value, therefore landfill of the solid product is required, either in purpose-built or third-party landfills.

Selective salt recovery

Selective salt recovery (SSR) requires the selective crystallisation of salts from brine to provide separate, refined end product streams (typically sodium chloride, sodium carbonate and sodium bicarbonate) which can theoretically enable commercial opportunity for sale of the product. A waste salt by-product is also produced that is dependent on the chemical characteristics of the brine processed at the salt recovery facility and consists of the non-saleable components.

Arrow and others have undertaken considerable work which has demonstrated that the recovered salt product has only modest value and the market is fully supplied by existing low-cost producers. Furthermore, the process is energy intensive, requires transport over substantial distances to market and involves the transport of hazardous chemicals to site as inputs to the process. These issues result in safety considerations, high cost and a high emissions intensity for a final product which has limited marketability.

Because of these issues, Arrow does not currently propose this option. However Arrow reserves the option in recognition that investigations continue and an appropriate salt beneficial use could be identified in the future.

4.3.2 Brine injection

Brine injection requires identification of a target formation with permeability and parameters (including isolation from other formations) sufficient to enable injection and storage, and where the water quality is such that injection of the brine will not impact the environmental values of the groundwater system.

To date, suitable aquifers have not been identified within Arrow's Surat tenements, and brine injection is not a proposed management option.

4.3.3 Ocean outfall

Disposal of brine via an ocean outfall pipeline is recognised as a technically and environmentally feasible option but, due to potential community concerns, it is not proposed.

4.4 Proposed SGP water infrastructure

CSG water from the SGP will be treated at existing Arrow facilities and at QCLNG facilities operated by QGC. The majority of CSG water will be treated by QGC using its existing water management network of dams and transfer pipelines and will be treated at the existing Kenya water treatment facility (shown in Figure 4.1). Water treated by QGC will then be returned to Arrow as treated water and brine; legal ownership is not transferred to QGC. Remaining water will be dealt with at existing Arrow water treatment facilities at Daandine and Tipton.

Based on the preceding discussion in Section 4.2, treated water will be prioritised for supply as substitution for existing Condamine Alluvium allocations, most likely for irrigation. This water will be returned to these end users via a beneficial use network, with the exact route to be determined after consultation with end users. Remaining treated water will be supplied to existing users, including via the existing SunWater Chinchilla beneficial use scheme. In this case, treated water is transferred to QGC before it is supplied to SunWater under existing commercial and approval arrangements.

Brine produced as part of the water treatment process will be stored in existing brine dams at Daandine and Tipton and in new brine dams to be constructed for Arrow at Kenya. As outlined in Section 4.3, the base case for dealing with stored brine is currently to crystallise the brine to a solid waste salt product and then to landfill this waste at dedicated salt encapsulation facilities (SEF). It is currently assumed that a facility will be required for the Kenya location and that Arrow will require a separate salt solution for the Daandine and Tipton volumes.

Figure 4.1 provides an indicative illustration of the proposed SGP water management network.

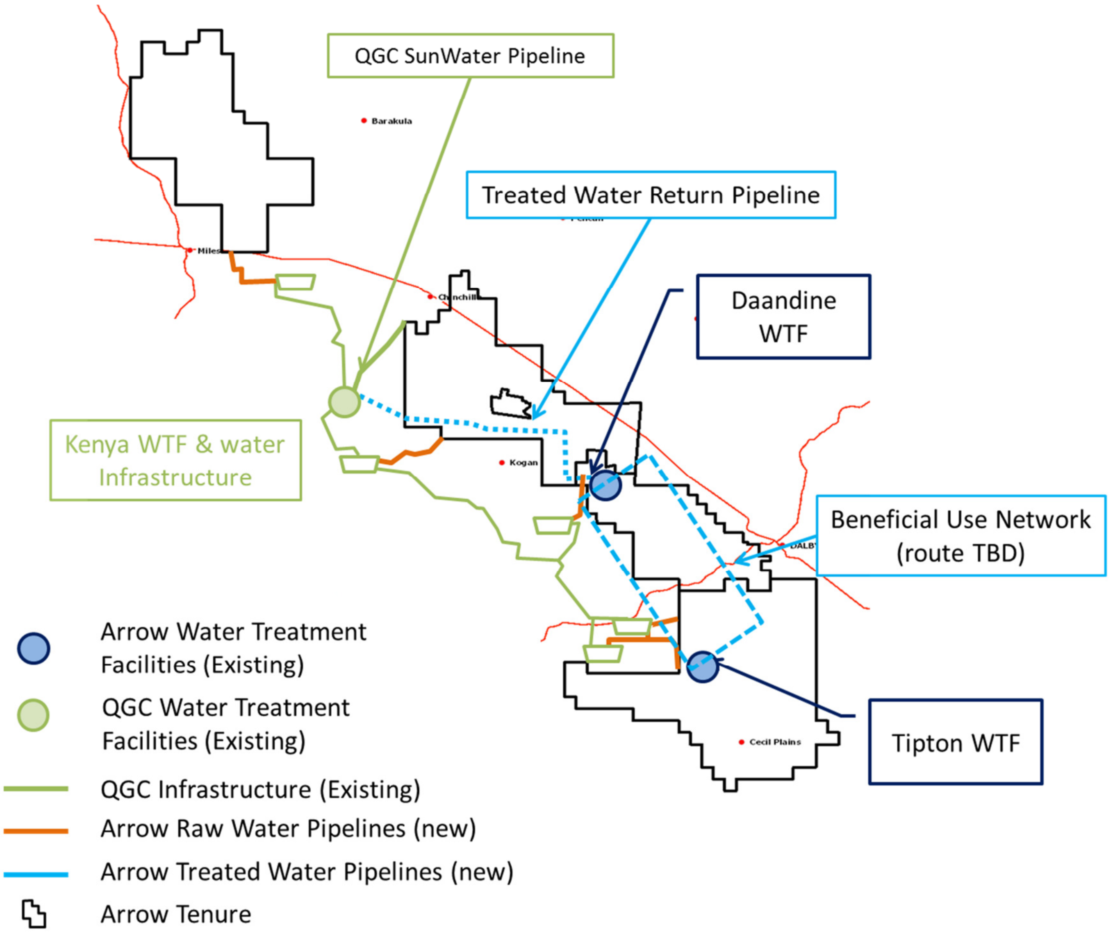

Figure 4.1 – Proposed SGP water management network

5. References

Arrow Energy, 2013. Coal Seam Gas Water and Salt Management Strategy.

Arrow Energy, 2012b. EIS Commitments Summary. Attachment 8 to the Arrow Energy Surat Gas Project EIS, February 2012.

Arrow Energy, 2013. Commitments Update. Attachment 4 to the Arrow Energy Surat Gas Project SREIS, June 2013

Department of Environment and Heritage Protection, 2012. Coal Seam Gas Water Management Policy, December 2012.

Department of Environment and Heritage Protection, 2016. Manual for assessing consequence categories and hydraulic performance of structures, ESR/2016/1933, March 2016.

6. Document Administration

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Revision history

Revision	Revision Date	Revision Summary	Author
1.0	2/06/2017	IFU	Groundwater Management Lead
2.0	29/01/2019	Updated for Stage 2 WWMP - IFU	Sr. Approvals Coordinator
3.0	14/03/2019	Revised coal seam gas water values	Sr. Approvals Coordinator

Controlled document location

Related documents

Document Number	Document title
DOC No: 003-000-AA5980-00003	Coal Seam Gas Water and Salt Management Strategy

Acceptance and release

Author

Position	Incumbent	Release Date
Sr. Approvals Coordinator	Jody Carew	08/01/2019

Stakeholders and reviewers

Position	Incumbent	Review Date
Groundwater Manager	Simon Gossmann	29/01/2019
Produced Water Manager	David Wigginton	29/01/2019
Manager Tenements	Suzanne Ferguson	29/01/2019
Project Environment Manager	Alison Way	29/01/2019
GM Surat Opportunities	Guy Young	29/01/2019
Surat FEDM	Nathan Blundell	29/01/2019
Community Engagement Manager	Brydie Hedges	29/01/2019
Manager Communications	Liz Edwards	29/01/2019
Water Operations Manager	Brad Wilson	29/01/2019

Approver(s)

Position	Incumbent	Approval Date
General Manager Commercial Projects & Water	Derek Hannigan	01/02/2019

Appendix A: Regulatory System

The regulatory system that applies to the extraction and management of CSG water is summarised in Table A1, and includes legislation in conjunction with government policies, guidelines and procedures that must be referred to, and corresponding plans and/or activities that must be prepared or implemented.

Some of the regulated obligations for water management and monitoring are separately addressed in Arrow's WMMP, and also as required through the annual UWIR reporting cycle (Underground Water Information Reports).

Table A1: Regulatory system requirements

Activities	Statutory Obligation/Guideline/Policy	Responsible Regulator
Extraction of Water	• Extraction of water is authorised under the *Petroleum and Gas (Production and Safety) Act 2004 or* Chapter 2 of the *Water Act 2000.* • Impacts from the exercise of underground water rights are managed through Chapter 3 of the *Water Act 2000* including: Baseline Assessments of landholder bores, Underground Water Impact Reports, Water monitoring obligations, Spring impact management strategies, Bore assessments and Make Good obligations. • Impacts to springs associated with species listed as Matters of National Environmental Significance under the *Environmental Protection and Biodiversity Conservation Act (1999)* are regulated through that Act. • Impacts to groundwater environmental values are regulated under the relevant State Government environmental authority granted under the *Environmental Protection Act 2004*. • Any bores constructed by Arrow are subject to the *Minimum Construction Requirements for Water Bores in Australia* and the *Minimum Standards for the Construction and Reconditioning of Water Bores that intersect the Sediments of Artesian Basins in Queensland*	DES[3] DotEE[4]
Treatment and Storage of CSG Water and Brine	• General obligations can be found in the *Environmental Protection Act 1994*, which is also responsible for the grant of environmental authorities which condition the activities for a petroleum tenure. • Dam design, construction, operation and monitoring requirements are outlined in the relevant State Government environmental authority and are based on an assessment under DES's *Manual for Assessing Consequence Categories and Hydraulic Performance of Structures and the Guideline for Structures which are dams or levees constructed as part of environmentally relevant activities.*	DES
Supply of CSG Water for Beneficial Use	• The Queensland Government Coal Seam Gas Water Management Policy (2012) outlines the Government's position with regards to the beneficial use and disposal of CSG water. • Supply of untreated or treated water to a third party is generally regulated through the relevant State Government environmental authority for a petroleum tenure. • In some cases, supply may be regulated through an End of Waste Approval or an End of Waste Code granted through the *Waste Reduction and Recycling Act 2011*. • Supply for urban use would require assessment as part of the service provider's Drinking Water Quality Management Plan under the Water Supply (Safety and Reliability) Act 2008.	DES DEWS[5]

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[3] Department of Environment and Science (Queensland)
[4] Department of Environment and Energy (Federal)
[5] Department of Energy and Water Supply (Queensland)

Discharge of CSG Water into Watercourse	• The discharge of CSG water into a watercourse is regulated through the conditions of the relevant State Government environmental authority.	DES
Injection into an aquifer used or potentially used as a source of supply for drinking	• The injection of CSG water into an aquifer is regulated through conditions in the relevant State Government environmental authority.	DES
Salt or brine disposal	• The storage, tracking, and disposal of waste is generally regulated through an State Government environmental authority granted under the *Environmental Protection Act 2004.* • There can be additional obligations (e.g. reporting obligations) under the *Waste Reduction and Recycling Act 2011.* • The Queensland Government's overall waste and recycling strategy shapes the obligations in the relevant State Government environmental authority and can be found in the Queensland Waste Avoidance and Resource Productivity Strategy (2014-2024).	DES
Beneficial use of salt or brine	• Beneficial use of salt or brine is regulated through the conditions of an End of Waste Approval or an End of Waste Code under the *Waste Reduction and Recycling Act 2011.* • The Queensland Government Coal Seam Gas Water Management Policy (2012) outlines the Government's position with regards to the beneficial use and disposal of salt and brine.	DES
Land access, including compensation for pipelines and Notice of Entry, ecology and cultural heritage clearances	• P&G Act • EP Act (EA) • Environment Protection and Biodiversity Conservation Act 1999 (Federal) • Nature Conservation Act 1992 • Vegetation clearing permit	DNRME[6] DES DotEE

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[6] Department of Natural Resources, Mines and Energy (Queensland)

APPENDIX G MONITORING, RISK AND ADAPTIVE MANAGEMENT MEMO

Memorandum

Recipient	Arrow Energy Pty Ltd
Memo date	16/09/2019
Author	Coffey Services Australia Pty Ltd
Project number	ENAUABTF20484AB
Memo Subject	Surat Gas Project Stage 2 CSG WMMP Monitoring, risk response and adaptive management memorandum

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1. Introduction

The Surat Gas Project (SGP) Approval Conditions (EPBC 2010/5344) require the development of a Coal Seam Gas (CSG) Water Monitoring and Management Plan (WMMP) to address potential impacts on surface water and groundwater resources. The requirements of the WMMP are set out in Conditions 13 to 25 and are to be delivered as two plans:

- Stage 1 CSG WMMP for activities in years 1 to 3 (following commencement); and
- Stage 2 CSG WMMP for activities in years 4 to 11.

The Stage 1 CSG WMMP involved the development of a proposed monitoring network and monitoring program to address Approval Conditions 13(e) and 13(f), together with an Early Warning Monitoring System (EWMS) in response to Approval Conditions 13(j)(i,ii,iii), 13(k) and 13(j)(iv). The Stage 1 CSG WMMP was approved by the Minister on 18 December 2018. The Stage 2 CSG WMMP must be approved by the Minister prior to extraction of CSG.

The current memorandum expands and builds on these monitoring, risk response and adaptive management themes in the Stage 2 CSG WMMP to include all matters in the Stage 1 CSG WMMP, and to fully address Approval Conditions 17(a), 17(e), 17(h), 17(i) and 22.

Specific requirements of these conditions are:

Approval Condition 17(a): *Include all matters in the Stage 1 CSG WMMP, and discuss how the Stage 1 CSG WMMP is informing adaptive management for the Stage 2 CSG WMMP.*

Approval Condition 17(e): *Review and update the monitoring network in Stage 1 WMMP to reflect changes in understanding of impacts to water resources, including from baseline monitoring and relevant research.*

Approval Condition 17(h): *Provide details of an ongoing monitoring plan that:*

> *(i) Sets out the frequency of monitoring and rationale for the frequency.*
>
> *(ii) Includes continued collection of baseline data for each monitoring site over the life of the project.*
>
> *(iii) Outlines the approach to be taken to analyse the results including the methods to determine trends to indicate potential Impacts.*
>
> *(iv) Builds on the groundwater early warning system required at condition 13j and sets out early warning indicators and trigger thresholds and limits for groundwater and surface water.*

Approval Condition 17(i): *Include a risk based exceedance response plan that details the actions the approval holder will take and the timeframes in which those actions will be undertaken if: early warning indicators and trigger threshold values contained in the Stage 2 CSG WMMP are exceeded, or there are any emergency discharges.*

Approval Condition 22: *To ensure an adaptive management approach, the proponent must submit periodic revisions of the Stage 2 CSG WMMP for approval by the Minister in writing, who may seek the advice of an expert panel. Revisions must be submitted at least 3 months prior to planned commencement of each new development stage for the project. The revised CSG WMMP must take into account outcomes of the ongoing monitoring program in the Stage 2 CSG WMMP, groundwater model updates and any bioregional assessments.*

In addition to the Stage 1 CSG WMMP, further supporting assessment for approval conditions is presented in separate memoranda, as summarised in Table 1-1. These documents provide the basis for development of the Stage 2 CSG WMMP.

Table 1-1 Summary of SGP Stage 2 supporting documents

Memoranda	Approval Conditions addressed	Document ID
Groundwater modelling and research technical memorandum	17(b), 17(c), 17(d), 23	ENAUABTF20484AB-M02
Stream Connectivity and GDE Impact Assessment	17(f), 17(g)	ENAUABTF20484AB-M03
Monitoring, risk response and adaptive management memorandum	17(a), 17(e), 17(h), 17(i), 22	ENAUABTF20484AB-M04 (this document)

2. Approach to addressing Approval Conditions

This memorandum addresses Approval Conditions 17(a), 17(e), 17(h), 17(i) and 22. The approach adopted to address these approval conditions for the Stage 2 CSG WMMP is described in Table 2-1.

As indicated in Approval Condition 17(a), all matters in the Stage 1 CSG WMMP are to be addressed in Stage 2. A copy of the Stage 1 CSG WMMP is supplied as an appendix to the Stage 2 CSG WMMP as a reference for Stage 2 and to demonstrate how all the requirements for Stage 1 have been addressed.

Table 2-1 Approach to addressing Approval Conditions relating to monitoring, risk response and adaptive management

Approval Condition	Approach to addressing Approval Conditions
Approval Condition 17(a): *Include all matters in the Stage 1 CSG WMMP, and discuss how the Stage 1 CSG WMMP is informing adaptive management for the Stage 2 CSG WMMP.*	The monitoring network and program and EWMS framework developed in the Stage 1 CSG WMMP is adapted and expanded upon (Section 4) on the basis of the baseline monitoring, research and modelling conducted as part of the Stage 2 CSG WMMP (Section 3).
Approval Condition 17(e): *Review and update the monitoring network in Stage 1 WMMP to reflect changes in understanding of impacts to water resources, including from baseline monitoring and relevant research.*	The Stage 2 CSG WMMP baseline monitoring, site investigations and modelling (Section 3) have informed the understanding of potential for impacts to water resources from the Action and cumulative CSG development. The Stage 1 CSG WMMP monitoring network has been reviewed to ensure any changes to the assessment of potential impacts or risks to water resources and connected receptors are captured by the early warning monitoring system (Section 4.1).
Approval Condition 17(h): *Provide details of an ongoing monitoring plan that:* *(i) Sets out the frequency of monitoring and rationale for the frequency.* *(ii) Includes continued collection of baseline data for each monitoring site over the life of the project.* *(iii) Outlines the approach to be taken to analyse the results including the methods to determine trends to indicate potential Impacts.* *(iv) Builds on the groundwater early warning system required at condition 13j and sets out early warning indicators and trigger thresholds and limits for groundwater and surface water.*	The ongoing monitoring program is presented in Section 4.2 and the monitoring data and trend analysis is expanded upon from the Stage 1 WMMP in Section 4.3. The EWMS has been adapted and expanded upon in the Stage 2 CSG WMMP (Section 4.4).
Approval Condition 17(i): *Include a risk based exceedance response plan that details the actions the approval holder will take and the timeframes in which those actions will be undertaken if: early warning indicators and trigger threshold values contained in the Stage 2 CSG WMMP are exceeded, or there are any emergency discharges.*	The risk based exceedance response plan developed in the Stage 1 CSG WMMP has been reviewed and expanded upon in the Stage 2 CSG WMMP (Section 4.5).

Approval Condition	Approach to addressing Approval Conditions
Approval Condition 22: *To ensure an adaptive management approach, the proponent must submit periodic revisions of the Stage 2 CSG WMMP for approval by the Minister in writing, who may seek the advice of an expert panel. Revisions must be submitted at least 3 months prior to planned commencement of each new development stage for the project. The revised CSG WMMP must take into account outcomes of the ongoing monitoring program in the Stage 2 CSG WMMP, groundwater model updates and any bioregional assessments.*	Arrow's commitment to periodic reporting and adaptive management is described in Section 4.6, which details the proposed approach to annual reporting of the WMMP and its periodic revision for approval by the Minister.

3. Stage 2 CSG WMMP - Baseline monitoring, research and modelling

3.1. Introduction

The following field based activities, investigations and corresponding assessments have contributed to the conceptualisation and evaluation of potential impacts. These underpin the adaptive management of impacts arising from the Action as described in the Stage 2 CSG WMMP. Each of these initiatives are explored further in the sections below:

- Arrow's ongoing groundwater and surface water baseline monitoring program (Section 3.2).
- Arrow's contribution to the Condamine Interconnectivity Research Project (CIRP) (OGIA 2016) (Section 3.3).
- Stage 2 CSG WMMP numerical modelling utilising the 2016 UWIR model and the 2012 OGIA model, with the revised Stage 2 CSG WMMP field development plan (FDP) (Section 3.4).
- Stage 2 CSG WMMP terrestrial GDE risk mapping and GDE and inter-aquifer connectivity field investigations (Section 3.5).

3.2. Groundwater and surface water baseline monitoring program

3.2.1. Baseline data

As described in the corresponding memorandum, the Stage 1 CSG WMMP monitoring network comprises a total of 105 discrete monitoring intervals (including 57 Walloon Coal Measures [WCM] intervals at 32 discrete monitoring locations). The monitoring network includes 26 co-located (nested) sites, which assist with the assessment of vertical pressure gradients.

Comprehensive water monitoring data have already been collected for the SGP, providing a baseline against which impacts can be assessed and trends established. Groundwater level baseline monitoring for the Stage 1 CSG WMMP monitoring network commenced in 2008 and as monitoring bores have been installed the baseline monitoring program, and the data collected, has expanded.

Table 3-1 lists the year baseline groundwater level monitoring commenced for monitoring intervals in each formation of the Stage 1 CSG WMMP monitoring network. The majority of the baseline groundwater level monitoring commenced in 2013 and 2014, providing 4 to 5 years of historic groundwater level data to date. By the end of quarter 1 2019, 101 of the 105 intervals were operating and collecting data.

Table 3-1 Stage 1 CSG WMMP monitoring network – history of groundwater level baseline activities

Formation	**Commencement year for baseline level monitoring and no. of intervals for water pressure and water quality monitoring**								
	2008	**2013**	**2014**	**2015**	**2016**	**2017**	**2019**	**Year to be advised (1)**	**Total monitoring intervals**
Condamine Alluvium		5 WP 4 WP&WQ	2 WP 1 WP&WQ	1 WP	3 WP	2 WP			**13 WP** **5 WP&WQ** **18 total**
CA / WCM transition layer		1 WP	3 WP	1 WP		2 WP			**7 WP** **7 total**
Westbourne Formation		1 WP&WQ							**1 WP&WQ** **1 total**
Springbok Sandstone		3 WP 1 WP&WQ	1 WP	1 WP					**5 WP** **1 WP&WQ** **6 total**
Walloon Coal Measures	4 WP	10 WP	25 WP 2 WP&WQ	9 WP	3 WP	1 WP		3 WP (2)	**55 WP** **2 WP&WQ** **57 total**
Eurombah Formation		1 WP	1 WP	1 WP		1 WP			**4 WP** **4 total**
Hutton Sandstone		1 WP	3 WP&WQ				2 WP	1 WP (3)	**4 WP** **3 WP&WQ** **7 total**
Evergreen Formation		1 WP	1 WP						**2 WP** **2 total**

Formation	Commencement year for baseline level monitoring and no. of intervals for water pressure and water quality monitoring								
	2008	2013	2014	2015	2016	2017	2019	Year to be advised (1)	Total monitoring intervals
Precipice Sandstone		1 WP&WQ	2 WP&WQ						**3 WP&WQ** **3 total**
Total monitoring intervals	**4 WP**	**22 WP** **7 WP&WQ**	**33 WP** **8 WP&WQ**	**13 WP**	**6 WP**	**6 WP**	**2 WP**	**4 WP**	**90 WP** **15 WP&WQ** **105 total (4)**

Notes:

WP: Water pressure monitoring interval

WP&WQ: Water pressure and water quality monitoring interval

(1) The nested bores at UWIR Site 94 are proposed for installation, consistent with the requirements, two years prior to development within 10 km of site.

(2) Walloon Coal Measures monitoring well - UWIR Site 94 is proposed for installation and will comprise three WP monitoring intervals.

(3) Hutton Sandstone monitoring well - UWIR Site 94 is proposed for installation and will comprise one WP monitoring interval.

(4) Upon completion of the proposed Walloon Coal Measures and Hutton Sandstone monitoring wells, the monitoring network will consist of 90 WP monitoring intervals and 15 WP&WQ intervals, totalling 105 monitoring intervals.

Fifteen groundwater monitoring bores have been used to provide baseline groundwater quality data as well as ongoing groundwater level monitoring data. Formations targeted for baseline groundwater quality monitoring include the Condamine Alluvium, Westbourne Formation, Springbok Sandstone, WCM, Hutton Sandstone and Precipice Sandstone. Groundwater sampling of these locations for baselining purposes commenced in 2013 and 2014 and at bi-annual frequencies in accordance with the program specified in the Stage 1 CSG WMMP Monitoring Network Memorandum (Coffey 2018b), providing 4 to 5 years of historic baseline groundwater quality data to date.

In addition to the baseline data that has already been collected from the Stage 1 CSG WMMP network, a substantial volume of data is available across the broader Surat CMA UWIR network as well as monitoring bores registered in the DNRME database.

As concluded in the Stage 1 CSG WMMP, impacts to surface water resources or aquatic ecosystems are not predicted due to the Action and subsequently a monitoring network to address these components of Approval Conditions 13(e) and 13(f) is not currently proposed.

A network of surface water and aquatic ecology baseline monitoring locations was established as part of the SGP EIS/SREIS process, inclusive of surface water quality, flow and aquatic ecology monitoring locations. Further to this, baseline data are available via the Queensland DNRME state monitoring network, with 17 currently open surface water gauging stations situated in or in close proximity to Arrow's tenure, 15 of which monitor water quality.

It is noted that the OGIA set out the requirements for responsible tenure holders for monitoring of potentially affected watercourse springs. As Arrow is not the responsible tenure holder for any identified watercourse springs, no monitoring sites nominated by the OGIA are located within relevant areas for the SGP, and therefore Arrow is not proposing to monitor any watercourse springs.

3.2.2. Rainfall trends

Rainfall records are a useful tool for understanding groundwater level response to recharge variation, for areas both near to and more distant from outcrop recharge areas.

Rainfall residual mass curves have been prepared for three weather stations across the SGP area; Miles Post Office (Station number 042023), Hereward (Station number 041240) and Dunmore State Forest (Station number 041025) (Figure 4-1). The rainfall residual mass curves, presented in Figure 3-1, show the cumulative sum of differences between the value at any time point and the average, and therefore how individual monthly rainfall compares to average monthly rainfall. A rising slope of the curve indicates a period of excess rainfall compared to the long-term monthly average (e.g. wetter than average period). Conversely, where the slope of the curve is falling, a period of deficit rainfall compared to the long-term average has been recorded (e.g. drier than average period).

Historical rainfall patterns and trends, and their influence on groundwater levels in the Surat CMA, have been assessed in the SGP EIS (Coffey 2012). The period of record of interest in the Stage 2 CSG WMMP baseline monitoring assessment is from 2013 to 2018. While rainfall has been variable, this period is characterised by a generally negative slope for which a rainfall deficit has been experienced across the SGP (Figure 3-1).

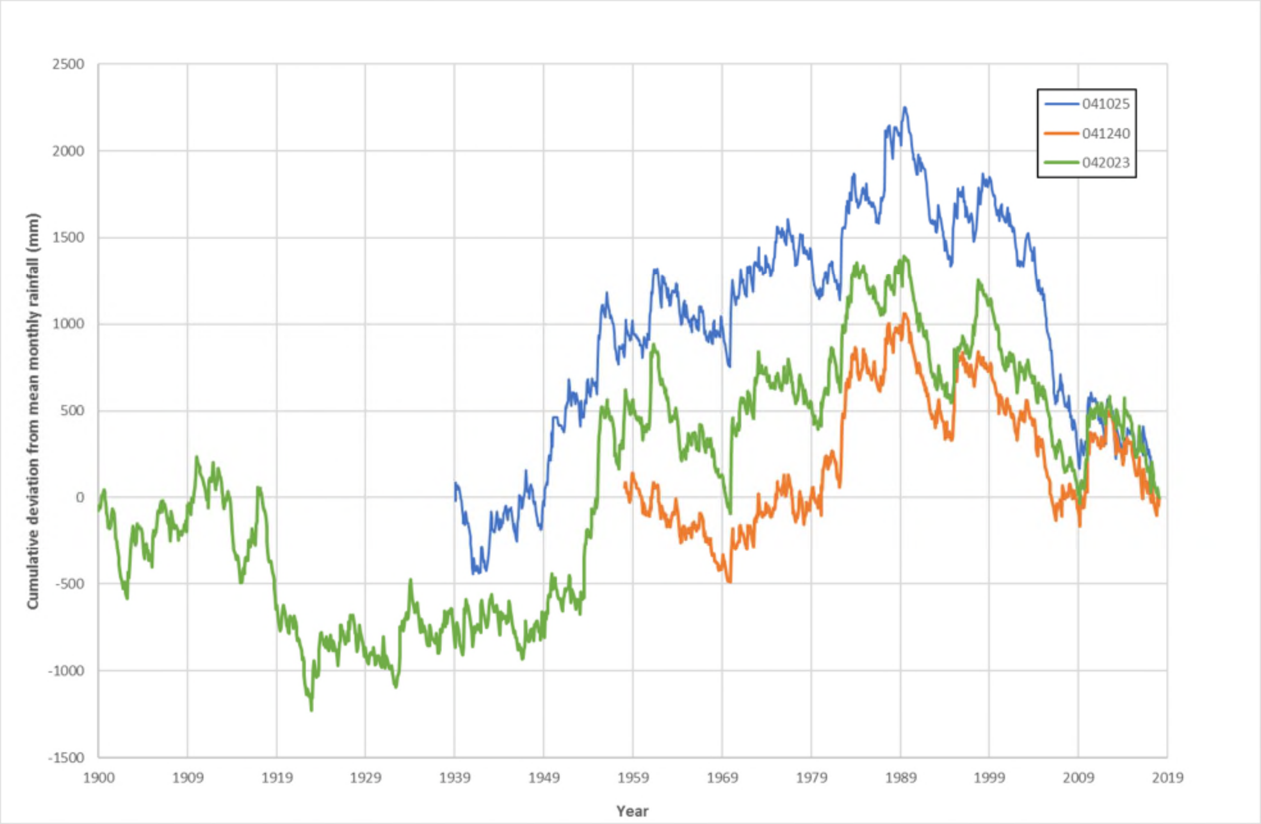

Figure 3-1 Rainfall residual mass curves, Miles Post Office (Station number 042023), Hereward (Station number 041240) and Dunmore State Forest (Station number 041025)

3.2.3. Groundwater level trend assessment

SGP EIS (Coffey 2012)

Groundwater level trends for key resource aquifers in the study area were assessed as part of the SGP EIS. The datasets were separated into two time periods; pre-1995 and post-1995, and analysed. The post-1995 dataset signifies the initiation of mining and coal seam gas projects in the area and observed groundwater level affects in the Walloon Subgroup and adjacent strata. Where available, the groundwater level trends described in the SGP EIS between 1995 and 2009 are compared below with the current (2013-2018) trends identified from the SGP Stage 1 WMMP baseline monitoring program.

UWIR for the Surat CMA (2016)

In areas of CSG development, the 2016 Surat CMA UWIR reported that groundwater pressures began to decline in the WCM at the commencement of development. Due to the nature of the coal formations (e.g. limited interconnection between laterally discontinuous coal seams), pressure impacts in the unit were observed to be limited to the immediate vicinity of the CSG production areas.

Approximately two thirds of the 133 GAB bores with long-term records exhibited declining trends prior to CSG development commencing. The number of long-term records with background trends in the GAB formations in the area of CSG development is limited, nevertheless sufficient information is available to support the following conclusions:

- In most of the long-term water pressure records, long-term declining trends which pre-date CSG development are apparent, and these reflect below-average rainfall over much of the recharge area between the period of 1990–2011 and increased water extraction for agriculture and other non-CSG purposes.

- The effect of lower rainfall on water pressure is clear in recharge areas, however, in areas more remote from recharge, subdued effects are also apparent. Water extraction from the major aquifers, for agriculture and other non-CSG purposes, has progressively increased over a long period, and in areas close to significant CSG development, this has contributed to the declining trend.

The 2016 Surat CMA UWIR reports that there is little evidence of a departure from background trends other than in the coal formations. The report notes that although there are declining background trends in the Hutton Sandstone, some records show recent relatively large declines of up to two metres per year (i.e. RN160634 and RN160439). It was considered likely that this is a response to progressive increases in water extraction from the Hutton Sandstone for non-CSG purposes. However, in the absence of a long-term record at this location, it was not possible (at the time of the 2016 UWIR) to determine if the rate of decline has increased since CSG development began.

Annual Report for the Surat CMA UWIR (2018)

The most recent (2018) annual report for the Surat CMA UWIR indicated a steady increase in the number of monitoring points in the WCM exhibiting significant pressure reductions, consistent with the gradual increase in the area of CSG development. As observed in the UWIR 2016, drawdown impacts in the unit were generally limited to the immediate vicinity of CSG production areas.

While pressures at most Springbok Sandstone monitoring locations were observed to have remained relatively stable or show no departure from background trends, it is possible CSG impacts were observed at a number of bores.

Groundwater levels at a number of monitoring points in the Hutton Sandstone, including at RN160634 and RN160439, had continued to decline since the UWIR 2016. It was concluded by OGIA that the observed pressure decline was largely due to non-CSG water extraction from the Hutton Sandstone, with no definitive evidence of contribution from CSG extraction from the overlying Walloon Coal Measures.

OGIA also reported that it was undertaking a review of the available groundwater level and water quality data for all monitored aquifers, with a particular emphasis on investigating potential causes for observed heightened pressure declines in the Hutton Sandstone. It is understood that the final outcomes will be available for inclusion in the next version of the UWIR in 2019.

SGP Stage 1 WMMP baseline monitoring program

Groundwater level data acquired from the SGP Stage 1 WMMP baseline monitoring program (Section 3.2.1) has been assessed to characterise recent (2013 to 2018) groundwater level trends across the SGP area. A comparison is also made, where available, with the groundwater level trends described in the SGP EIS (Coffey 2012) between 1995 and 2009.

The groundwater level trends are described for each bore (excluding WCM and aquitard intervals) comprising the SGP Stage 1 WMMP baseline monitoring program in Appendix A. The approximate rates of groundwater level incline/decline recorded for each monitoring bore over the monitoring period are spatially represented in Figure 2 (Condamine Alluvium), Figure 3 (Condamine Alluvium-WCM transition layer), Figure 4 (Springbok Sandstone), Figure 5 (Hutton Sandstone) and Figure 6 (Precipice Sandstone) of Appendix B.

To assist and provide context in the baseline groundwater level trend assessment, the indicative area of current (2018) active CSG development of all operators across the Surat CMA is presented in Figure 1 of Appendix B. The approximate magnitude of drawdown within the WCM across the Surat CMA (between 2011 and December 2017), estimated from Surat CMA UWIR monitoring data, is also illustrated in Figure 1.

Walloon Coal Measures

Groundwater level trends for seven bores in the WCM (around the Dalby and Millmerran CSG production areas) between the period of 1995 to 2009 were observed in the SGP EIS as generally exhibiting little variation in groundwater level. The effects of CSG production were observed in two

WCM monitoring bores (Daandine 1 and Daandine 2) with groundwater drawdown rates of up to 12.5 m/a observed in Daandine 2 between 2007 and 2009.

The baseline monitoring assessment indicated groundwater levels in the WCM were comparatively stable (+/-1m/yr) during the 2013 to 2018 period in the unit's subcrop/outcrop area, while closer to and within active CSG production areas, groundwater levels may be stable or declining by rates of up to 45 m/yr (Hopeland-17).

The observations made in the baseline assessment are consistent with those of the SGP EIS, 2016 UWIR and 2018 annual report to the UWIR which reported groundwater level declines in the WCM within the immediate vicinity of CSG production areas.

Condamine Alluvium

Groundwater level trends for the Condamine Alluvium between the period of 1995 to 2009 were reported in the SGP EIS to be generally declining within a range of a few centimetres to 10 m. The Condamine Alluvium and its tributaries have been extensively developed for irrigation, industrial, stock and domestic purposes and are characterised by over-development and over-allocation with respect to the productive yield of the system (DNRM 2012a). The effects of groundwater extraction (as shown on Figure 7.9 in the SREIS Appendix 4, which provides a comparison between the pre-development potentiometric surface (1969) and the groundwater surface in 2008) shows the development of a groundwater depression centred to the north-east where recorded drawdowns are in excess of 20 m, a value exceeding the 10 m observed above.

The decline was considered to be related to abstraction of groundwater for irrigation and other purposes, as well as long-term low residual recharge due to below average rainfalls. The more recent observations from the SGP Stage 1 WMMP baseline monitoring program are generally consistent with the declining groundwater level trends reported in the SGP EIS. The monitoring network also captured and identified numerous locations with relatively stable groundwater levels over the recent monitoring period indicating local scale processes are likely to be contributing to trends in this aquifer.

The observations from the SGP Stage 1 WMMP baseline monitoring program of the Condamine Alluvium are summarised below for each monitoring bore.

Groundwater levels in the Condamine Alluvium are generally characterised by either stable trends (Carn Brea-17, Macalister-5, Pampas-18, RN 42230088, RN 42230209, RN 42231339, Tipton-204 and Tipton-221) or slightly declining trends (Daandine-161, Plainview-25, RN 42231294, RN 42231370, RN 42231463, Tipton-195 and Wyalla-16) of between 0.1 to 0.5 m/yr over the monitoring period (2013/14 to 2018). The monitoring bores generally exhibited little direct response to rainfall events. A subdued and/or delayed correlation to rainfall was however observed in RN 42231370 and Planview-25.

The generally below average rainfall recorded during the monitoring period and/or non-CSG groundwater extraction, may be contributing to the declining groundwater level trend recorded for these bores. It is noted that all the Condamine Alluvium monitoring bores with declining groundwater level trends during the monitoring period are well outside (10 km to > 50 km) current active CSG development areas (Figure 1 and Figure 2, Appendix B) and therefore CSG related effects can be ruled out.

A number of the monitoring bores (RN 42231463, RN 42231370, Daandine-161 and Carn Brea-17) exhibited cyclical fluctuations represented by regular drawdown and recovery cycles of several metres over the monitoring period, consistent with groundwater extraction for agricultural or other non-CSG use.

The following hydrographs (Appendix C) are presented to demonstrate the range in background trends identified for the Condamine Alluvium:

- Stable groundwater level trend (Macalister-5) – Figure 7
- Declining groundwater level trend with moderate correlation with rainfall (RN 42231370) – Figure 8

- Declining groundwater level trend with cyclical fluctuations (Daandine-161) – Figure 9

For bores Carn Brea-23 and UWIR Site 41 (Macalister 7), groundwater level monitoring data is available from February 2017. Longer term monitoring data is required to establish background groundwater level trends for these bores.

In summary, the baseline monitoring assessment to date has not identified any evidence that current CSG development activities has affected groundwater levels of the SGP Stage 1 WMMP bores monitoring the Condamine Alluvium. The observed groundwater level declines are likely to be attributed to prolonged below average rainfall and/or non-CSG groundwater abstraction.

Condamine Alluvium – WCM transition layer

The SGP EIS did not directly assess groundwater level trends within the Condamine-WCM transition layer, and as such, no comparisons are made with earlier time periods.

Groundwater monitoring of the Condamine Alluvium-WCM transition layer during the 2013/14 to 2018 monitoring period indicated that groundwater level trends are influenced by local scale processes:

- Plainview-25 (Figure 10, Appendix C): the groundwater level rose steadily at an approximate rate of less than 0.5 m/yr during the monitoring period. Groundwater levels exhibited no correlation with rainfall patterns.
- Daandine-163 (Figure 11, Appendix C): the groundwater level exhibited regular drawdown and recovery cycles of 2-4 m over the monitoring period, consistent with groundwater extraction for agricultural or other non-CSG use. Groundwater levels exhibited only minor direct correlation with rainfall events, with a recorded minor decline of 0.5 m over the monitoring period. There is no active CSG development in this area.
- Tipton-204 (Figure 12, Appendix C): Between March and August 2015, the groundwater level rose by 6 m, remaining relatively stable until mid-2018 at which time a sharp 1 m decline was recorded. The initial groundwater level rise is considered to be due groundwater level equilibration following bore installation in low permeability lithology. The groundwater level exhibited regular drawdown and recovery cycles of less than 1 m over the monitoring period, consistent with groundwater extraction for agricultural or other non-CSG use. No correlation with rainfall is evident. The bore is not located in an active CSG development area. Longer term monitoring data is required to establish background groundwater level trends for this bore.

For monitoring bore Tipton-196A (Figure 13, Appendix C), between November 2014 and August 2015, the groundwater level declined sharply by 14 m/yr. Thereafter, until the close of the monitoring period (August 2018), the groundwater decline has reduced to 3 m/yr. Over the nearly 4 year monitoring period, the groundwater level has declined by close to 20 m. No cyclical variability is evident and groundwater levels exhibited no correlation with rainfall patterns. Nearby bore Tipton-195 screened within the overlying Condamine Alluvium, is not exhibiting any groundwater drawdown affects beyond background trends. Furthermore, WCM monitoring bore (Macalister seam) Tipton-197 at the same location is exhibiting only minor drawdown in the last year of a rate of less than 0.2 m/yr.

The monitored zone at Tipton196A is a transition zone which typically consists of plastic clays and resultant low permeability. While Tipton-196A is in close proximity to current CSG development by other operators, groundwater levels in the bore are not considered to be affected by these activities. Rather, the monitoring data is likely to indicate the pressure is still equalising with the formation pressure following well completion and the introduction of water during the installation of downhole monitoring equipment. Longer term groundwater monitoring is required to establish background groundwater level trends for this bore.

For bores Carn Brea-24 and Tipton-222, groundwater level monitoring data is available from February 2017. Longer term monitoring data is required to establish background groundwater level trends for these bores.

Springbok Sandstone

Groundwater level trends for the Springbok Sandstone aquifer, between the period of 1995 to 2009, were reported in the SGP EIS for two bores east of Millmerran. Both bores were observed to exhibit a generally declining groundwater level trend over most of the record, with a small recovery between 2006 to 2009.

Bore RN 41620043 is situated southwest of Millmerran and exhibited a declining groundwater level trend during the 2013/14 to 2018 monitoring period, consistent with that described in the SGP EIS. The other three bores in the SGP Stage 1 WMMP baseline monitoring network are situated at considerable distances north of Millmerran and are demonstrated to exhibit groundwater trends that respond to local, rather than regional scale, processes. The observations from the SGP Stage 1 WMMP baseline monitoring program of the Springbok Sandstone are summarised below for each monitoring bore.

As the Springbok Sandstone outcrops/subcrops over much of the tenement, bores monitoring this aquifer are affected by local scale factors. No regional scale groundwater level trend was identified for the Springbok Sandstone. Where monitoring data was available for the monitoring period, the following site-specific background trends were identified:

- Hopeland-17 (Figure 14, Appendix C): the groundwater level rose at an approximate rate of less than 1 m/yr during the monitoring period, with no correlation with rainfall patterns. Cyclical annual variations of 2 to 3 m were recorded which are considered to be related to local scale gas pressure increases in the unit. Such processes may occur as a consequence of local scale pressure changes following the shut-in of nearby (non-Arrow) CSG production wells, at regular intervals for routine maintenance.
- RN 41620043 (Figure 15, Appendix C): Groundwater levels exhibited a moderate correlation with rainfall during the monitoring period with an overall declining trend of less than 0.5 m/yr. The generally below average rainfall recorded during the monitoring period and/or non-CSG groundwater extraction, may be contributing to the declining groundwater level trend.
- Stratheden-63 (Figure 16, Appendix C): The groundwater level trend remained stable, with little variability in levels and no correlation with rainfall.

Groundwater levels in Meenawarra-21 (Figure 17, Appendix C) exhibited a sharp decline by close to 30 m between late 2015 and late 2016. Following a slight recovery, the groundwater steadily declined at a rate of 6 m/yr between late 2016 and mid-2018. There is no active CSG development in this area, nor does the WCM exhibit declining trends at the nested bore location of Meenawarra-21. The aquifer is characterised by very low permeability in this area and it is considered that the declining trends are not representative of background conditions but rather water level pressure equalising with the formation pressure following well completion and the introduction of water during the installation of downhole monitoring equipment. Longer term groundwater level monitoring is required to characterise baseline groundwater level trends at this bore.

Hutton Sandstone

Groundwater level trends for the Hutton Sandstone aquifer, between the period of 1995 to 2009, were reported in the SGP EIS for four bores, none of which exhibited any significant change in groundwater level over the time period. This contrasts to the more recent declining groundwater level trends for the aquifer identified in the SGP Stage 1 WMMP baseline monitoring. The declining trends are likely to be a more recent feature for the aquifer and are consistent with background regional trends reported by OGIA (2016, 2018). The extended period of below average rainfall and/or non-CSG groundwater extraction are expected to be the dominant factors contributing to these declining trends.

Monitoring bores Burunga Lane-176 (Figure 18, Appendix C), Carn Brea-19 and Kedron-570 exhibited steadily declining groundwater levels during the monitoring period (at an approximate rate of less than 0.5 m/yr). The declining groundwater level trend is consistent with background regional trends reported by OGIA (2016, 2018) and may be attributable to an extended period of below average rainfall and/or non-CSG groundwater extraction.

There is no currently active CSG development occurring in proximity to the Burunga Lane-176 and Carn Brea-19 monitoring bores, nor does the overlying WMC exhibit any significant drawdown at these locations. Active CSG development is occurring to the west/north-west and south of Kedron-570 and the WCM exhibited a sharp decline of 10 m/yr over the monitoring period at this nested site location. The rate of groundwater level decline in the Hutton Sandstone at Kedron-570 of 0.5 m/yr is consistent with background regional trends in this aquifer and there is no evidence that CSG production is contributing to the current declining groundwater level.

For Daandine-121 (Figure 19, Appendix C), the groundwater level exhibited a generally declining trend between September 2014 and mid-2017 of approximately 1.5 m/yr. Thereafter, to the close of the monitoring period (August 2018), the groundwater level has risen at an approximate rate of 1.5 m/yr. Groundwater levels exhibited no clear correlation with rainfall patterns. The bore is in close proximity to current CSG development however the groundwater level trend is not considered to be affected by this activity. Whilst elevated, the declining trend is considered to be within background regional trends and may be attributable to an extended period of below average rainfall and/or non-CSG groundwater extraction. It is noted that the recent groundwater level rise in August 2018 may potentially be associated with diminished abstraction by nearby non-CSG groundwater extraction. Longer term groundwater level monitoring data will assist in identifying whether this pattern is indicative of background groundwater level trends at this location.

Precipice Sandstone

Due to data limitations, the SGP EIS did not assess groundwater level data/trends within the Precipice Sandstone aquifer, and as such, no comparisons are made with earlier time periods.

Groundwater levels in the Precipice Sandstone are generally characterised by steadily declining trends of between 1 m/yr (Wyalla-17; Figure 20, Appendix C) and up to 2 m/yr (Carn Brea-20). At Burunga Lane-174, the groundwater level steadily declined by less than 0.3 m/yr between 2013 and 2015, and thereafter the groundwater level steadily rose by approximately 1.4 m/yr. Longer term groundwater level monitoring will assist in characterising background groundwater level trends in this bore, but it may be attributed to RO treated CSG water injection into the Precipice Sandstone by another operator.

There is no active CSG development at the bore locations. The extended period of below average rainfall and/or non-CSG groundwater extraction, is likely to be contributing to the generally declining groundwater level trends recorded in the Precipice Sandstone.

3.2.4. Groundwater quality data and trend assessment

SGP EIS (Coffey 2012) and SGP SRIES (Coffey 2013)

Groundwater quality for key resource aquifers in the study area were assessed as part of the SGP EIS by analysing available groundwater quality data in the DNRME database from the 1960s to 2009. For the SGP SREIS, a more comprehensive assessment of groundwater quality across the Surat CMA was undertaken by accessing and reviewing additional sources of groundwater quality data from recent studies including WorleyParsons (2012). Where available, the groundwater quality data described in the SGP SREIS is compared below with the current (2013-2018) data and trends identified in the SGP Stage 1 WMMP baseline monitoring assessment.

Surat CMA UWIR

Groundwater quality trends were not analysed or reported on in the 2016 Surat CMA UWIR or the most recent Annual Report for the Surat CMA UWIR (2018).

SGP Stage 1 WMMP baseline monitoring program

Groundwater quality data acquired from the SGP Stage 1 WMMP baseline monitoring program (Section 3.2.1) has been assessed to characterise more recent (2013 to 2018) groundwater quality trends across the SGP area for key hydrogeological units. A comparison is also made, where available, with the groundwater quality data described in the SGP SREIS.

The groundwater quality trends are described for the selected bore comprising the SGP Stage 1 WMMP baseline monitoring program in Appendix A.

Condamine Alluvium

With almost 1,300 groundwater quality data points, the Condamine Alluvium aquifer is well characterised in the SGP SREIS. The salinity is reported to range from 298 (P_{10}) to 5,670 (P_{90}) mg/L TDS (median of 714 mg/L TDS), while the pH ranges from 6.8 (P_{10}) to 8.3 (P_{90}) (median of 7.6). The groundwater is classified as a Na-HCO_3 water type with variable Cl influence. The variability of the groundwater quality is consistent with a shallow groundwater system influenced at a local scale by surface recharge processes and interactions with deeper groundwater systems. As indicated below, the groundwater quality monitoring data from the SGP Stage 1 WMMP baseline monitoring program generally fall within the range reported in the SGP SREIS.

The hydrochemical data recorded for the Condamine Alluvium monitoring bores (Carn Brea-17, RN 42231370, Tipton-195 and Wyalla-16) indicate a range in groundwater quality characteristics that are controlled by local scale processes. Groundwater salinity was recorded at the lower range of 511 mg/L TDS at Carn Brea-17 to an upper range of 1,280 mg/L TDS at Wyalla-16. The pH typically ranged from neutral to slightly alkaline.

The groundwater of those four bores was generally classified as Na-Ca-HCO_3, Ca-Na-HCO_3-Cl, Na-HCO_3-Cl and Na-Cl water types. The groundwater quality data exhibited some variability at each monitoring bore, however no temporal trends were identified. Longer-term monitoring will assist in defining the background range in groundwater quality parameters for these bores.

Springbok Sandstone

Groundwater quality across the Springbok Sandstone is characterised by 79 groundwater quality data points in the SGP SREIS. The salinity is reported to range from 505 (P_{10}) to 6,686 (P_{90}) mg/L TDS (median of 1,211 mg/L TDS), while the pH ranges from 6.9 (P_{10}) to 8.6 (P_{90}) (median of 7.7). The groundwater is classified as a Na-HCO_3-Cl to Na-Cl-HCO_3 water type. The variable quality is likely to reflect chemical evolution and mineral dissolution processes within the aquifer unit, matrix diffusion and inter-aquifer leakage of different quality groundwaters.

One bore (Stratheden-63) is being monitoring for groundwater quality in the Springbok Sandstone as part of the SGP Stage 1 WMMP baseline monitoring program. Between the monitoring period of October 2016 and November 2018, the groundwater salinity was generally recorded at between 1,950 and 2,210 mg/L TDS. One groundwater sample (2 November 2017) was recorded outside this range at 1,690 mg/L TDS which is considered to be laboratory error.[1] The pH is alkaline (8.6 to 9.5) and the groundwater is generally classified as a Na-Cl type water. Initial groundwater samples (October 2016) recorded a pH of up to 11 indicating at this time the water may have been impacted by bore construction processes (e.g. grouting). No temporal trends in groundwater quality was observed. Longer-term monitoring will assist in defining the background range in groundwater quality parameters for this bore.

The groundwater quality monitoring data from Stratheden-63 of the SGP Stage 1 WMMP baseline monitoring program generally falls within the range reported in the SGP EREIS, with the exception of a more elevated pH.

Hutton Sandstone

Groundwater quality across the Hutton Sandstone is characterised by 234 groundwater quality data points in the SGP SREIS. The salinity is reported to range from 218 (P_{10}) to 2,554 (P_{90}) mg/L TDS (median of 752 mg/L TDS), while the pH ranges from 7.4 (P_{10}) to 8.6 (P_{90}) (median of 8.1). The

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[1] Chloride concentrations for the period ranged from 1,030 mg/L to 1,170 mg/L (a difference of 14%) and Sodium concentrations ranged from 631 mg/L to 712 mg/L (a difference of 13%). The reported TDS of 1,690 mg/L (2 November 2017) is ~30% lower than the other reported salinity values and is accordingly considered to be a laboratory error.

groundwater is classified as a Na-HCO_3 to Na-Cl-HCO_3 water type. As for the Springbok Sandstone, the variable quality is likely to reflect chemical evolution and mineral dissolution processes within the aquifer unit, matrix diffusion and inter-aquifer leakage of different quality groundwaters. As indicated below, the groundwater quality monitoring data for Burunga Lane-176 and Daandine-121 of the SGP Stage 1 WMMP baseline monitoring program generally falls within the range reported in the SGP EREIS.

Two bores; Burunga Lane-176 and Daandine-121, are being monitored for groundwater quality in the Hutton Sandstone as part of the SGP Stage 1 WMMP baseline monitoring program. Groundwater salinities are similar between the bores ranging from 1,500 to 1,550 mg/L TDS in Burunga Lane-176 and 1,480 to 1,970 mg/L TDS in Daandine-121. Both bores consistently record alkaline pH.

While Burunga Lane-176 is classified as a Na-Cl to Na-Cl-HCO_3 water type, Daandine-121 is generally classified as a Na-HCO_3 water type. No temporal trends in groundwater quality were observed. Longer-term monitoring will assist in defining the background range in groundwater quality parameters for these two bores.

Precipice Sandstone

Groundwater quality across the Precipice Sandstone is characterised by 113 groundwater quality data points in the SGP SREIS. The salinity range is reported to range from 95 (P_{10}) to 848 (P_{90}) mg/L TDS (median of 151 mg/L TDS), while the pH ranges from 6.7 (P_{10}) to 8.3 (P_{90}) (median of 7.4). The groundwater is classified as a Na-HCO_3 water type.

Each of the three Precipice Sandstone monitoring bores (Burunga Lane-174, Carn Brea-20 and Wyalla-17) are monitored for groundwater quality as part of the SGP Stage 1 WMMP baseline monitoring program. The groundwater salinity is spatially variable being recorded at the lower range of 271 mg/L TDS at Burunga Lane-174 to an upper range of 6,730 mg/L TDS at Wyalla-17. The stabilised and representative (post-construction) groundwater salinity at Carn Brea-20 was recorded at between 1,910 and 2,020 mg/L TDS.[2] The pH typically ranged from slightly acidic to alkaline in Carn Brea-20 and Wyalla-17, while Burunga Lane-174 was consistently recorded with an alkaline pH ranging from 9.4 to 9.7.

The water type classification varied between Na-HCO_3-Cl to Na-Cl in Wyalla-17 and Na-HCO_3 in Burunga Lane-174 and Carn Brea-20. No temporal trends in groundwater quality were observed. Longer-term monitoring will assist in defining the background range in groundwater quality parameters for these bores.

The groundwater quality monitoring data for Burunga Lane-174 of the SGP Stage 1 WMMP baseline monitoring program generally falls within the range reported in the SGP EREIS. Carn Brea-20 and Wyalla-17 recorded more elevated salinities than the range reported in the SGP EREIS. As these bores are situated at substantial distances from the unit's outcrop area and source of recharge, chemical evolution and mineral dissolution processes occurring at increasing distances downgradient may be contributing to the more elevated salinities.

3.2.5. Summary

Groundwater level and quality data collected between 2013/14 and 2018 as part of the SGP Stage 1 WMMP baseline monitoring program has provided a comprehensive dataset from which background groundwater conditions in the key hydrogeological units including the Condamine Alluvium, Condamine Alluvium-WCM transition layer, Springbok Sandstone, Hutton Sandstone and Precipice Sandstone, have been characterised.

Background trends in bores constituting the monitoring network are generally influenced by long term rainfall patterns and/or non-CSG groundwater extraction. CSG development activities are not

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[2] The first three samples from 2015 are not considered representative. The salinity values were obtained by calculation rather than laboratory measurement. Furthermore, the first sample (6 March 2015) reported comparatively elevated Sulphate concentrations with respect to other anions, indicative of insufficient bore development following construction.

considered, at present, to have contributed to the groundwater level drawdown in any groundwater monitoring bores within the SGP Stage 1 WMMP monitoring network.

The Stage 1 WMMP baseline monitoring program is considered suitable for the purposes of defining background groundwater conditions in the key hydrogeological units across the SGP. The spatial distribution of monitoring bores will serve to capture the range of variability expected at the local scale and the early identification of groundwater level impacts (if any) as a consequence of cumulative scale CSG production. The groundwater level trends and groundwater quality data reported in the SGP EIS and SGP SREIS are broadly consistent with the monitoring data collected and analysed as part of the SGP Stage 1 WMMP baseline monitoring program. Some spatial variability in groundwater level trends and groundwater quality data was observed between the earlier studies and the current monitoring program for the Condamine Alluvium, Springbok Sandstone, Hutton Sandstone and Precipice Sandstone aquifers. This variability is believed to be due to local scale processes and temporal changes in rainfall patterns / groundwater extraction influencing the monitoring data.

Furthermore, data collected from the greater UWIR monitoring network, consisting of 675 groundwater pressure and/or quality monitoring points (of which 491 were established at the time of the release of the 2016 UWIR), and non-UWIR monitoring locations with the Surat CMA, will assist in the understanding of background trends and aquifer responses within production areas on a more regional scale.

The outcomes of this review respond to Approval Condition 17(e) (in part), and all the commitments made in Stage 1 regarding the evaluation of the Stage 1 baseline groundwater monitoring network.

3.3. Condamine Interconnectivity Research Project (CIRP)

The approach to the CIRP study (OGIA 2016d), and key findings as they relate to conceptualising the level of hydraulic connectivity between the Condamine Alluvium and the WCM is described in the Stage 2 CSG WMMP Groundwater Modelling and Research Technical Memorandum (Coffey 2019a).

The following are key findings:

- The geological data shows that a clay-rich or mudstone horizon at the base of the Condamine Alluvium and the top of the WCM acts as a physical barrier that impedes inter-formation flow.
- Persistent differences in groundwater levels between the formations, and the flow patterns within the formations, demonstrate that impediments to flow exist between the formations.
- Hydrochemical data indicate little past movement of water between the formations, even in areas where significant groundwater level differences have existed for a prolonged period.
- Detailed aquifer pumping tests at two sites found no significant flow of water between the formations in response to pumping tests around those sites. The tests showed that the vertical hydraulic conductivity for the material between the formations is consistent with that of a highly effective aquitard.

In addition, the findings (in the form of the OGIA Condamine Geological Model, OGIA&DNRM 2016b) have been adopted for the 2016 UWIR, and the OGIA 2016 groundwater model.

3.4. Numerical modelling

3.4.1. Model revisions and updates

To address Approval Condition 17(b), a review and summary of numerical groundwater modelling undertaken since the Stage 1 CSG WMMP is provided in the separate Groundwater Modelling and Research Technical Memorandum (Coffey 2019a). A key feature of the Stage 2 CSG WMMP modelling is the revised field development plan (FDP) for the Action (referred to as the Stage 2 FDP Case) and the use of the OGIA 2016 Groundwater Model for certain modelling tasks.

In preparation of the Stage 2 CSG WMMP, it has been assumed that the Action will be developed in accordance with the revised FDP. Additional groundwater modelling was undertaken to build on modelling previously undertaken in the Stage 1 CSG WMMP, and to understand impacts to groundwater resources from the Stage 2 FDP Case.

Further information summarising the additional groundwater modelling is provided in the separate Groundwater Modelling and Research Technical Memorandum (Coffey 2019a). Key points relevant to this memorandum are provided below.

3.4.2. Groundwater drawdown and flux predictions

Groundwater modelling under the Stage 2 FDP Case with the OGIA 2016 Groundwater Model was compared to, amongst other scenarios, previous modelling undertaken for the Stage 1 CSG WMMP using the OGIA 2012 Groundwater Model and the SREIS FDP (referred to herein as the SREIS FDP Case)[3].

Drawdown predictions

Minor differences in drawdown predictions for the Stage 2 FDP Case and the SREIS FDP Case are indicated. These are due to differences between the OGIA 2016 and OGIA 2012 groundwater models, differences between production and timing of the Action, and changes in CSG development by other tenure holders.

Flux predictions

The modelling results show that the modelled change in flux to the Condamine Alluvium for the Stage 2 FDP Case is lower than for the SREIS FDP Case.

Induced drawdown in the Condamine Alluvium

The differences in drawdown between the Stage 2 FDP Case and the SREIS FDP Case are minor, however the timing of maximum drawdown has changed for the Stage 2 FDP Case, compared with the SREIS FDP Case.

3.4.3. Predicted impacts to the Condamine River

As discussed in the Groundwater Modelling and Research Technical Memorandum (Coffey 2019a), flux changes to the river are small and the maximum predicted impacts are negligible under both modelled cases.

The IQQM model (CDM Smith 2018) was used to assess update predictions of potential impacts from the Stage 2 FDP Case on surface water users. The impacts are represented in IQQM by the reduction in flux between the Condamine Alluvium and the Condamine River.

For practical purposes the predicted impacts of groundwater flux changes to the connected reaches in the Condamine River from the Action are considered negligible. On that basis it was concluded that any potential impacts to water quality and existing aquatic ecosystems and surface expression GDEs dependent on the Condamine River are also likely to be negligible.

Further support to this finding is provided by the outcomes of the Stage 2 CSG WMMP GDE risk mapping and multiple lines of evidence from the GDE and connectivity field investigations (Coffey 2019b) which demonstrate limited potential for hydraulic connection between the WCM and overlying aquifers (Section 3.5).

3.5. GDE investigations and impact assessments

The SGP Stage 2 CSG WMMP Stream Connectivity and GDE Assessment Memorandum (Coffey 2019b) describes the terrestrial GDE risk mapping and GDE and inter-aquifer connectivity field programs conducted to address Approval Condition 17(g) and to fulfil the relevant commitments made in the Stage 1 CSG WMMP.

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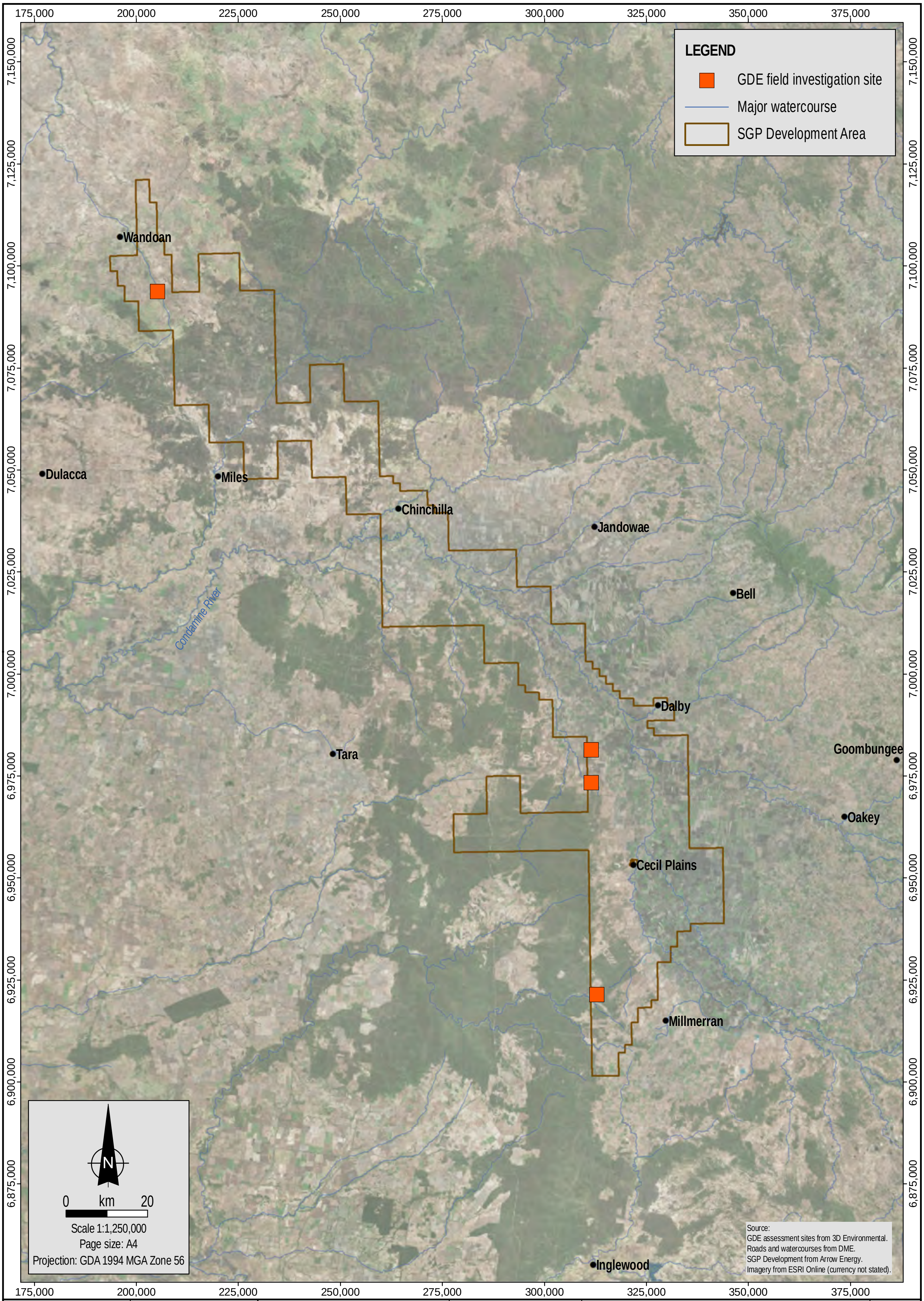
[3] A description of the FDPs is provided in the separate Groundwater Modelling and Research Technical Memorandum.

The terrestrial GDE risk mapping exercise conducted in the Stage 1 CSG WMMP was revised with the Stage 2 CSG WMMP modelling outputs, updates to the geological and GDE mapping of the Surat CMA and the outcomes of the GDE and inter-aquifer connectivity field programs. The Stage 2 CSG WMMP GDE risk mapping assessment aimed to address (in part) Approval Condition 17(g) which seeks to identify any uncertainty in the groundwater dependency of ecosystems that may be subject to potential impacts as a consequence of the Action. The Stage 2 assessment did not identify any areas of terrestrial GDEs at potential risk of impact from groundwater drawdown associated with CSG extraction from the Action, and in turn, no additional site-specific field investigations were required.

To satisfy the commitments made in the Stage 1 CSG WMMP and to address Approval Condition 17(g), comprehensive field investigations were conducted at four sites: Burunga Lane, Glenburnie, Long Swamp and Lake Broadwater (Figure 3-2). The field investigations, conducted in two parts, aimed to characterise GDEs and their reliance on groundwater (3D Environmental/Earth Search 2018) and quantify the degree of inter-aquifer connectivity between the WCM and overlying formations (Arrow Energy 2018), at each of the four sites.

Multiple lines of evidence from the two field investigations conducted in Stage 2 demonstrated that ecosystems at each of the selected sites are unlikely to be dependent on the regional groundwater systems and therefore unlikely to be at risk of impact from groundwater extraction associated with cumulative CSG development in the Surat CMA according to the following findings:

- The deeper-rooted trees at all four sites, with the exception of Lake Broadwater, are considered likely to be tapping downward-percolating water moving under gravity through a near-saturated vadose zone.
- The depth to the regional aquifer (potentially subject to CSG depressurisation) at each site is considerably deeper than: (i) the deepest observed rooting depth; (ii) the inferred likely zone of predominant soil moisture uptake by trees and (iii) with the possible exception of Burunga Lane, the likely maximum tree rooting depth for deeper rooted potential GDE species (such as river red gums) of 18 m.
- The relatively shallow maximum tree root depths observed (maximum of 7.6 m at Glenburnie) in comparison to the maximum anticipated depth threshold of 18 m based on literature studies (3D Environmental/Earth Search 2018).
- Limited potential for hydraulic connection between the WCM and overlying aquifers at each of the sites, the exception being potential connectivity between the Springbok Sandstone and WCM at Lake Broadwater. A shallow alluvium unit hosts a perched groundwater system associated with Lake Broadwater, however numerical modelling has demonstrated that groundwater extraction from the WCM in association with CSG development at Lake Broadwater, is unlikely to contribute to discernible drawdown in the shallow alluvium. Accordingly, ecosystems dependent on the shallow perched groundwater at Lake Broadwater are not considered at risk of impact from cumulative CSG production in the Surat CMA.



Source:
GDE assessment sites from 3D Environmental.
Roads and watercourses from DME.
SGP Development from Arrow Energy.
Imagery from ESRI Online (currency not stated).

MXD Reference: 20484AB_M04_GIS002_v0_1

Date: 04.02.2019	Arrow Energy	Distribution of GDE assessment areas	Figure No: 3.2
Project: ENAUABTF20484AA	Surat Gas Project WMMP		
File Name: 20484AA_M04_F03.2_GIS			

4. Stage 2 CSG WMMP – Monitoring, risk response and adaptive management

4.1. Monitoring network

The Surat CMA UWIR sets out regional monitoring requirements for groundwater pressure and quality monitoring across the Surat CMA. Through this, a substantial network of groundwater monitoring locations has been established across the Surat CMA and the regional monitoring network specified in the 2016 UWIR comprises 675 groundwater pressure and/or quality monitoring points, of which 491 were established at the time of the release of the 2016 UWIR. Arrow's UWIR monitoring locations, where in the vicinity of the SGP, are presented in Figure 4-1.

The Stage 2 CSG WMMP baseline monitoring, site investigations and modelling (Section 3) have informed the understanding of potential for impacts to water resources from the Action and cumulative CSG development. On the basis of the outcome of these activities, the Stage 1 CSG WMMP monitoring network has been reviewed to ensure its ongoing suitability as an early warning monitoring system.

No additional areas or heightened areas of potential impact or risk to water resources and connected receptors have been identified for the Stage 2 CSG WMMP. In response to Approval Condition 17(e), the monitoring network developed and implemented in the Stage 1 CSG WMMP remains valid in characterising background groundwater level and quality trends and suitable as an EWMS (Section 4.4).

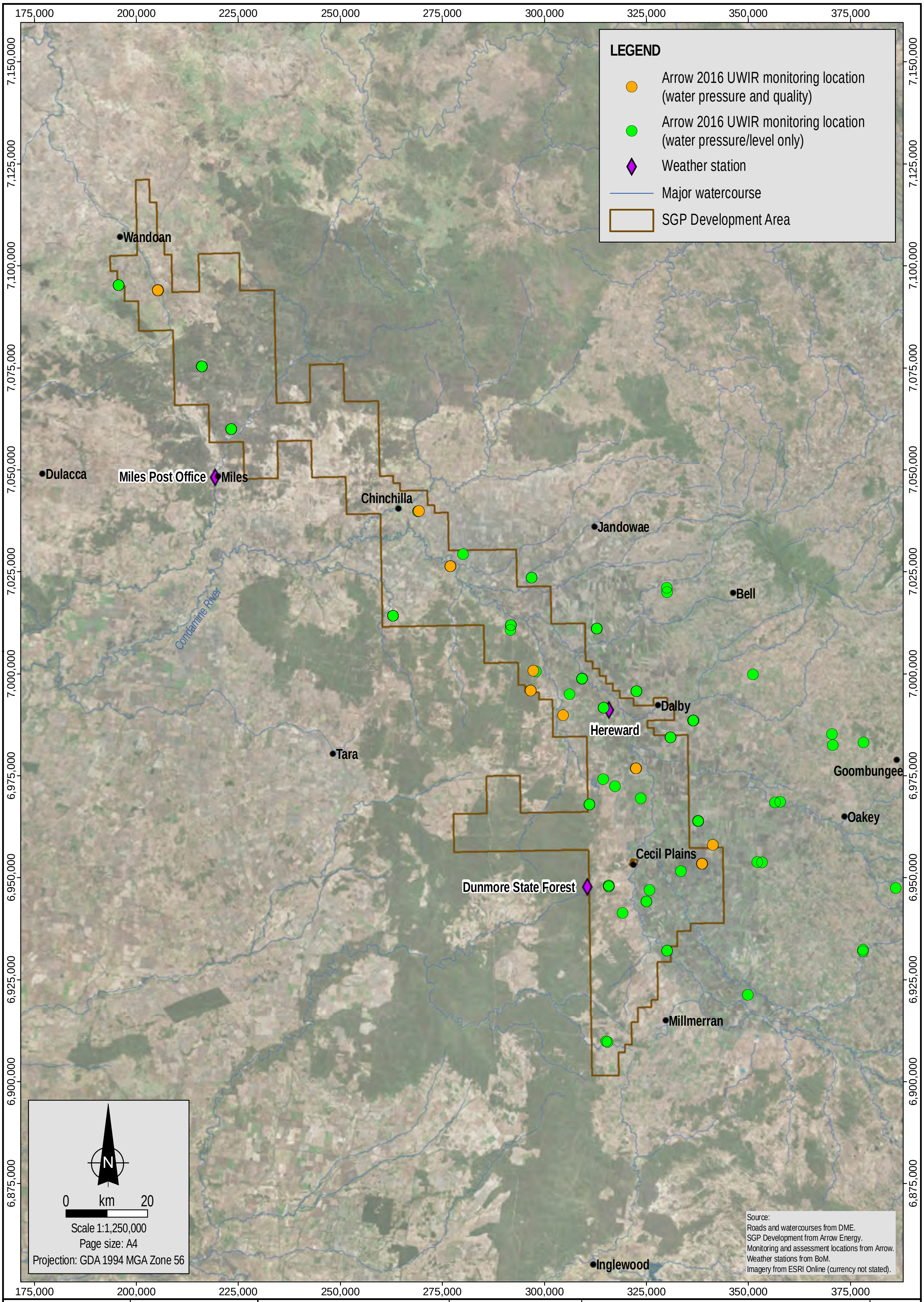
The Stage 2 CSG WMMP monitoring network comprises 105 monitoring bore/vibrating wire piezometer intervals. A total of 31 monitoring intervals across the unconsolidated and consolidated aquifers at 29 discrete monitoring locations will serve as early warning monitoring bores in the EWMS (Section 4.4). This represents all the unconsolidated and consolidated aquifers subject to monitoring in the Stage 2 CSG WMMP network with the exception of the Condamine Alluvium monitoring bores RN 42231370, Daandine-161 and Carn Brea-17. The baseline monitoring assessment (Section 3.2.3) conducted as part of the Stage 2 WMMP indicated regular drawdown and recovery cycles of several metres as a consequence of nearby groundwater extraction for agricultural or other non-CSG uses. The magnitude of these groundwater fluctuations is such that these bores have limited use for early warning monitoring, and therefore have been excluded as early warning monitoring bores in the CSG WMMP. Data from these bores, whilst excluded from the EWMS, will still be subject to groundwater trend analysis as part of the ongoing monitoring plan described in Section 4.3.

Appendix D presents the monitoring bores constituting the Stage 2 CSG WMMP and provides detail concerning monitoring bore location, target aquifer, status and purpose.

The GDE investigations and impact assessment for the Stage 2 CSG WMMP (Section 3.5) did not identify any terrestrial GDEs at risk of impact from groundwater extraction associated with cumulative CSG development in the Surat CMA. Accordingly, there are no monitoring requirements for terrestrial GDEs in the Stage 2 CSG WMMP.

The Joint Industry Plan (JIP) provides reference to OGIA's Spring Impact Management Strategy (SIMS) in the Surat CMA UWIR which provides an assessment of potential impacts to springs. There are currently no EPBC springs located within Arrow tenure and all off tenure EPBC springs are located closer to other CSG proponents who are the responsible tenure holders under the JIP (DotEE 2013). Arrow has no assigned responsibilities regarding potentially affected springs under the SIMS. The SIMS is considered to adequately address the potential impact to springs and no further assessment has been undertaken in this plan. In addition, no springs within Arrow tenure, other than those identified and considered in the Surat CMA UWIR, are known to be present.

The monitoring network presented in Table 3-1, and listed in Appendix D, demonstrates Arrow's commitment to groundwater level and quality monitoring across its tenure in each potentially affected aquifer unit which constitutes the groundwater resource.



Source:
Roads and watercourses from DME.
SGP Development from Arrow Energy.
Monitoring and assessment locations from Arrow.
Weather stations from BoM.
Imagery from ESRI Online (currency not stated).

MXD Reference: 20484AB_M04_GIS001_v0_2

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Project: ENAUABTF20484AA
File Name: 20484AA_M04_F04.1_GIS

Arrow Energy

Surat Gas Project WMMP

arrow energy
go further

Arrow 2016 UWIR monitoring locations

Figure No: 4.1

4.1.1. Condamine Alluvium flux monitoring locations

Discussion in the Stage 1 CSG WMMP identified the need for future WMMPs to review flux monitoring locations and to take into account future modelling predictions based on refined FDPs and data. As noted in the Stage 2 Groundwater Modelling and Research Technical Memorandum (Coffey 2019a), the results show that, using the same numerical model, the predicted change in flux to the Condamine Alluvium for the Stage 2 FDP Case is slightly lower than for the SREIS FDP Case (-58 GL compared to -63 GL).

Differences in predicted drawdown in the Condamine Alluvium between the development case assumed in the Stage 1 CSG WMMP and the current case (in both the cumulative and Arrow-only cases) are minor, noting however that the timing of maximum drawdown has changed for the current case. Differences in timing are influenced by the revised staging and location of Arrow’s updated production, as well as revisions to geological interpretation in the OGIA 2016 Groundwater Model that underpins the modelled flux change to the Condamine Alluvium. However, the established Condamine Alluvium flux locations are considered to remain relevant for the Stage 2 CSG WMMP.

4.2. Monitoring program

Approval Condition 17(h)(i) requires the Stage 2 CSG WMMP to present an ongoing monitoring plan that sets out the frequency of monitoring and rationale for the frequency. Approval Condition 17(h)(ii) requires continued collection of baseline data for each monitoring site over the life of the project. The Stage 1 CSG WMMP presents these aspects of the CSG WMMP, all matters of which are included in the Stage 2 CSG WMMP in accordance with Approval Condition 17(a).

Ongoing collection of baseline groundwater monitoring data is a key element of the monitoring system.

The monitoring frequencies, including any future revisions, will align with the monitoring frequencies specified in the Surat CMA UWIR. Arrow will seek approval from the Department prior to making any changes to the monitoring program.

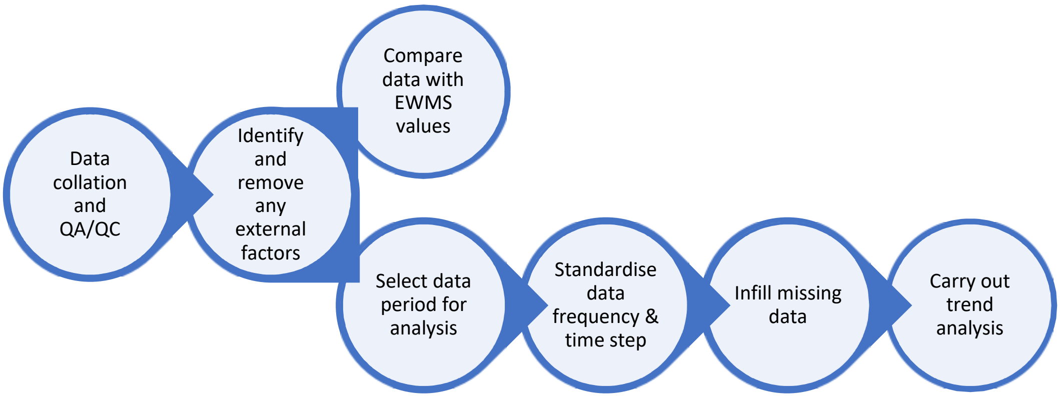
4.3. Monitoring data and trend analysis

Approval Condition 17(h)(iii) requires that the monitoring plan outlines the approach to be taken to analyse the results including the methods to evaluate trends which may indicate potential impacts. The trend analysis approach adopted is described in the following sections. The outcomes of the trend analysis will be reported in the annual review of the WMMP.

Measurement of groundwater levels, either as hydrostatic pressure or physical water levels in monitoring bores, is the primary means of assessing changes to a groundwater resource. The ongoing and structured monitoring of a network of groundwater monitoring points provides the base data that can be interrogated to enable an understanding of trends and identify whether impacts may occur.

A range of statistical techniques are established for analysing groundwater data, and the process described in this section is intended to provide a practical but robust analytical method for the SGP.

The general trend analysis process is illustrated below. This assessment will be completed within 90 days of the end of each 6 monthly monitoring period. It is underpinned by a hydrogeological conceptualisation and baseline assessment of each monitoring location to identify factors that will influence groundwater level and quality and therefore need to be considered in the trend analysis process. Also shown are the steps to identifying exceedances in the EWMS, further described below and in Section 4.4.



The key steps in the trend analysis process are described in turn below.

Data collation and QA/QC

Under the EWMS, groundwater monitoring data will be collated, checked and controlled by way of the following processes:

- Reviewing and checking data and field documents to identify transcription errors.
- Reviewing and checking the calibration of measurement equipment (e.g. pressure gauges, water quality meter).
- Correlation of logged data against manually gauged data.

Identify and remove any external factors

Groundwater systems are subject to a range of physical influences that can affect the potentiometric levels in aquifers. Some of these influences relate to actual changes in storage, such as pumping from the aquifer, whilst other influences may cause apparent groundwater level changes, with no actual resource volumetric changes, for example, barometric pressure changes. Table 4-1 provides a summary of influences, their relative timescales, and the effect of each in terms of resource storage for aquifers.

Table 4-1 Aquifer influences, timescales and storage effects

Influencing process	Relative time scale	Effect on resource storage
Natural processes		
Aquifer recharge variability due to seasonality	Short to medium term	Affects storage
Aquifer recharge variability due to climate change	Long term	Affects storage
Aquifer recharge variability due to land use changes	Medium to long term	Affects storage
Flood loading compression	Short term	Nil
Atmospheric pressure changes	Short term	Nil
Tides, including earth tides	Short term	Nil

Influencing process	Relative time scale	Effect on resource storage
Anthropogenic processes		
Groundwater pumping	Short to long term	Affects storage
CSG water abstraction	Short to medium term in pumped formation Medium to long term across adjacent formations	Affects storage
Urban development (reduced recharge) and land use change	Long term	Affects storage
Managed aquifer recharge schemes	Medium to long term	Affects storage

Careful analysis of data is required to understand the influence of the various processes in Table 4-1 and determine whether impacts to groundwater resources are occurring.

Data may require the removal of confounding influences, such as barometric effects and earth tides, to provide corrected data that does not lead to misinterpretation of trends. Software available for this purpose includes proprietary software provided by data logger manufacturers.

In addition, applications such as BETCO (Toll & Rasmussen 2005)[4] may be used for correcting data for barometric effects and earth tides. BETCO is a software application that adjusts water-level measurements using barometric and Earth-tide measurements collected at equal intervals by applying a multiple regression (deconvolution) technique. Because earth tide data is not usually collected, simulated data is normally substituted. Synthetic earth tide gravity data can be generated using codes such as TSOFT (Van Camp & Vauterin 2001)[5].

Compare data against EWMS values

The quality checked and controlled data will be subject to a review process that will:

1. Compare the observed data with the assigned early warning indicator, trigger threshold, and limit for each monitoring location (Section 4.4).

2. If the results indicate an exceedance, undertake the risk-based exceedance response in Section 4.5.

Select data period for analysis

The period of analysis can influence the trend analysis results such that different conclusions can be drawn concerning groundwater level behaviour based on examining the whole period of available data versus a shorter, more recent period.

Separation of the data into discrete time periods by visual inspection is a suitable approach where there are obvious changes in the trend of data over time. Where data contains high variability, break points may not be easy to visually identify and further analysis may be required to assist in detecting whether break-point exists. Tests such as the Distribution Free CUSUM test, Cumulative Deviation test and the Worsley Likelihood Ratio test (available in statistical analysis software packages such as the e-water CRC's TREND package) may be utilised, if necessary, for this purpose.

Standardise data frequency and time step

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[4] University of Georgia, Athens, Georgia, USA.

[5] Royal Observatory of Belgium

Data collected at high frequencies may exhibit serial-correlation, which can affect the interpretation of trends. Where this occurs, revised time-series will be generated using time-weighted averages over longer periods.

Infill missing data

Missing data can confound a trend analysis by introducing bias into the trend results. As a guide, it is proposed that where groundwater level data in the bore of interest is missing for less than 5% of the record over the period of analysis, that data will be infilled. The technique for infilling the missing data will be selected for individual bores, being guided by site specific variables. In the event that the missing data is greater than 5% of the record, consideration will be given to not undertaking a trend analysis.

Carry out trend analysis

A broad range of methods are available for groundwater level trend analysis. The applicability of any method depends on a range of factors, including the length of the data record, the frequency of data observations, the completeness of the record, and the statistical distribution of the data.

Guidelines for groundwater trend analysis provided by DES (2011) recommend that groundwater data should be analysed for time periods before and after the start of resource activities and linear regressions of the time series data should be completed for the analysis of trends. Where sufficient data are available, the groundwater trend analysis should also include non-parametric statistical tests.

Parametric tests are considered more suitable for normally distributed data, while non-parametric tests are considered more suitable for non-normally distributed data, or censored data (Yue et al. 2001). Because hydro-meteorological time-series data do not typically follow a normal distribution, non-parametric tests are considered appropriate for trend analysis.

The rank-based Mann-Kendall and Spearman’s rho tests are considered appropriate non-parametric tests for trend analysis for the SGP CSG WMMP. A study by Yue et al. (2001) using Monte Carlo methods demonstrated that these two methods have similar power in detecting a trend, to the point of being indistinguishable in practice. The study also demonstrated that the power of these tests increases as a function of sample size and decreases as a function of variation in the time-series.

An important interpretive aspect of trend analysis is that a statistically significant trend may not be practically significant, and vice-versa (Daniel 1978). Sufficiently large samples will reveal even the smallest change through statistical testing, even though the change is of no practical importance, and conversely, small sample sizes (i.e. short time-series) may fail to detect a change statistically, even though the degree of change is of practical significance (Yue et al. 2001).

It is concluded that any interpretation of trends in time-series groundwater monitoring data must necessarily consider both the statistical and the practical significance of any detected trends in conjunction.

In reference to the groundwater quality trend analysis, the use of transforms of compositional water quality data using log-ratio variants (as described by Aitchison, 1986, and implemented in CoDaPack), allow for assessment of correlations that are either not apparent in non-transformed data or are spurious because non-transformed data can produce spurious correlations. These methods also allow for correlations between trace components and major components that would be obscured in traditional multi-variate statistical methods. Given that changes in hydrochemistry maybe small and involve parameters present in trace or small relative concentrations, then compositional data analysis provides a robust method for the assessment of hydrochemical change and minimises potential for spurious correlations.

Where an exceedance[6] is indicated as a result of the risk-based exceedance response (refer Section 4.5) further detailed trend analysis may be undertaken and documented in any exceedance report required. This would include an estimate of:

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[6] An exceedance is defined as data exceeding a trigger value or limit for a continuous period of three months or greater.

- The component of drawdown due to Arrow operations, if available based on evaluation through statistical, analytical or modelling methods.
- Assessment of whether the exceedance is due to natural system variability or third-party groundwater abstraction, and where required compared to data from regional monitoring locations to identify whether an apparent exceedance is a result of regional hydrological or climatic changes.
- Groundwater level trend analysis.

Modelling, where adopted to assist in differentiating the SGP component of drawdown from cumulative drawdown, will utilise the latest OGIA model version (or its equivalent), recalibrated as necessary and incorporating (where available) updated production data for other CSG and non-CSG extractors, and other relevant data. In the case that this model is too coarse (in either space or time) more refined modelling approaches based on the OGIA model (or its equivalent) may be adopted, or if necessary, a sub-model encompassing the area of data being assessed will be developed. This will enable the calculation of the Arrow-only proportion of the impact for comparison with previous predictions. In addition, this process will also be undertaken within 90 days of the release of each new UWIR, to establish revised early warning indicators, trigger thresholds and limits.[7]

4.4. Early Warning Monitoring System

An Early Warning Monitoring System (EWMS) was presented and approved by the Department of Environment and Energy for the SGP Stage 1 CSG WMMP to address Approval Condition 13(j).

The EWMS framework as approved by the Department in the Stage 1 CSG WMMP has been refined and expanded upon in this Stage 2 CSG WMMP to address Approval Condition 17(a) and 17(h)iv.

In accordance with Approval Condition 13(j)(i)(iii), the EWMS is inclusive of the Condamine Alluvium and all consolidated aquifers potentially affected by the action, excluding the WCM. The potentially affected aquifers are the Springbok Sandstone, Hutton Sandstone and Precipice Sandstone. The monitoring bores constituting the EWMS are listed in Appendix D.

To address Approval Condition 13(j)(iii), the EWMS also includes non-spring GDE locations, determined to be at potential risk of impact from the Action.

Monitoring and management of springs located within the Surat CMA is undertaken through the implementation of the JIP (2013); a Joint Industry Plan for an early warning system for the monitoring and protection of EPBC Springs. There are currently no EPBC springs located within Arrow tenure and all off tenure EPBC springs are either currently allocated to other CSG proponents or, where not yet explicitly allocated, are located closer to other CSG proponents who would then be the responsible tenure holders under the JIP. In accordance with the JIP, Arrow does not currently have any monitoring obligations under the JIP. Should Arrow be assigned as the responsible proponent for any EPBC Springs under the JIP, Arrow will, if applicable, adopt the JIP for the monitoring and management of the EPBC spring/s.

4.4.1. Levels

The EWMS includes tiered levels, described below, with escalating responses:

1. Early warning indicators, for early identification of potential issues.
2. Trigger thresholds, for identifying the potential to exceed limits, and enable measures to be selected and implemented to reduce the likelihood of limit-exceedance.

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[7] It is understood that the Department are currently reviewing modelling and management methods for CSG projects, and that as a result of the review, different methods for modelling of drawdown and impacts may be specified by the Department.

3. Limits, that define levels of impact not to be exceeded.

Drawdown factors, where applied to the tiered levels, are described in the Stage 1 CSG WMMP, and are derived from the bore trigger thresholds under the Queensland Water Act 2000, being 5 m for consolidated aquifers and 2 m for unconsolidated aquifers. The drawdown factors provide a buffer against spurious level triggering.

Investigation and actions are incorporated in the EWMS, including processes for trigger and limit exceedances[8], and actions to manage, address and correct exceedances (refer Section 4.5). The sections below describe the basis of the EWMS that was included in the Stage 1 CSG WMMP.

Early warning indicators

An early warning indicator has been assigned by taking the maximum model-predicted P95 cumulative (CSG + non-CSG) drawdown on Arrow tenure (within a three year period) and adding half the drawdown factor (i.e. 2.5 m for consolidated aquifers, and 1 m for the Condamine Alluvium).

If any non-spring GDE locations were determined to be at potential risk of impact, early warning indicators would be assigned based on a drawdown level equivalent to the maximum model-predicted P95 cumulative (CSG + non-CSG) drawdown level for a three year period, at any point in the GDE host aquifer on Arrow tenure. No drawdown factor would be added to the prediction. However, as per Section 3.5, no non-spring GDEs have been identified as potential at risk from the Action.

Early warning indicators will be specified in three-yearly time steps and taken from the maximum predicted drawdown in each three year period. This is consistent with the review cycle of the WMMP.

This review will take into account the maximum model-predicted P95 cumulative (CSG + non-CSG) drawdown on Arrow tenure (for each three year period) and adding half the applicable drawdown factor (for consolidated aquifers, and the Condamine Alluvium). No drawdown factor will be added for non-spring GDEs.

Trigger thresholds

Trigger thresholds are assigned as a drawdown level half-way between the early warning indicator and the limit.

Groundwater and Drawdown Limits

Drawdown limits are minimum potentiometric groundwater levels specified for consolidated aquifers (i.e. the Springbok, Hutton and Precipice sandstone aquifers). Groundwater limits are minimum groundwater levels specified for the Condamine Alluvium and non-spring GDEs. The limit assigned for the consolidated aquifers and the Condamine Alluvium aquifer is:

- The maximum model-predicted P95 cumulative (CSG + non-CSG) drawdown level predicted to occur in 100 years (from commencement of CSG extraction), at any point in the relevant aquifer on Arrow tenure, plus a drawdown factor (5 m for consolidated aquifers and 2 m for the Condamine Alluvium); or

- For consolidated aquifers where dewatering of the aquifer itself is not predicted to occur, the top of the aquifer formation.

The limit assigned for non-spring GDEs, determined to be at potential risk of impact, is:

- The maximum model-predicted P95 cumulative (CSG + non-CSG) drawdown level predicted to occur in 100 years (from commencement of CSG extraction), at any point in the GDE host aquifer on Arrow tenure.

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[8] Exceedance is defined as groundwater levels measured in a monitoring bore that are greater than a threshold value for a continuous period of three months, to identify a real signal rather than a temporary spike due to natural or other anthropogenic factors.

4.4.2. Specification of levels

The assignment of EWMS levels has been generated on the basis of the Stage 2 CSG WMMP FDP, utilising OGIA's 2012 UWIR model. While groundwater drawdowns, fluxes and impacts have been characterised and assessed in the Stage 2 CSG WMMP employing the updated 2016 UWIR model (Section 3.4), the absence of a predictive uncertainty analysis means that the current version of the model cannot be used for the purposes of assigning EWMS levels, which relies on P95 model drawdown predictions.

The derivation of the groundwater drawdown limit component of the EWMS for the Condamine Alluvium and the consolidated aquifers are listed in Table 4-2, along with the trigger thresholds and early warning indicators for the 3-year periods of 2020 to 2023 and 2023 to 2026, to cover six years following the anticipated commencement of the Action.

The Stage 2 CSG WMMP early warning indicators, trigger thresholds and limits for the Condamine Alluvium and consolidated aquifers are presented graphically, as a function of time (over 100 years), in Appendix E.

With reference to non-spring GDEs, assessments and investigations conducted as part of the EIS, SREIS, the SGP Stage 1 WMMP and SGP Stage 2 WMMP have not identified any non-spring GDEs at potential risk of impact from the Action. Accordingly, there are no monitoring requirements under the SGP for these features, at present. Should any non-spring-GDEs be identified at potential risk of impact from the Action in the future, the EWMS will be reviewed and tailored according to the site-specific requirements of any identified features.

The limits, early warning indicators and trigger thresholds will be updated on an on-going basis every three years if a new or revised OGIA model simulation has been developed.

Where EWMS levels are revised, Arrow will provide an explanation of the revision based on the latest groundwater modelling that has led to the revised levels. This would be supported by a review of actual performance vs predicted, based on the evaluation of actual and predicted Arrow water production.

Table 4-2 EWMS for the Condamine Alluvium and consolidated aquifers

Aquifer	Maximum model-predicted P95 cumulative drawdown level (1) (over 100 years, at any point on Arrow tenure)	Drawdown factor	Limit (1)	Early warning indicator (EWI) (years 2020-2023) (1,2)	Trigger threshold (years 2020-2023) (1,2)
Condamine Alluvium	16 m	2 m	18 m	7 m	12.5 m
Springbok Sandstone	72 m	5 m	77 m	31 m	54 m
Hutton Sandstone	266 m	5 m	271 m	159 m	215 m
Precipice Sandstone	540 m	5 m	545 m	538 m	541.5 m

Note:

(1) The EWMS reported in the table applies until the close of year 2023, three years following the commencement of the Action. The model predictions and corresponding limits, early warning indicators and trigger thresholds will be updated every three years if a new or revised OGIA model simulation has been developed.

(2) The early warning indicator and trigger threshold will be updated at three-yearly intervals according to current model predictions. The next update will occur for the period 2024-2027.

4.5. Risk based exceedance response plan

Approval Condition 17(i) requires the Stage 2 CSG WMMP to include a risk based exceedance response plan that details the actions to be taken and timeframes if early warning indicators or trigger threshold values are exceeded. Response actions, in the form of escalating actions for responding to exceedances of early warning indicators or trigger thresholds, form a key component of the EWMS, and are described in the Limits, Indicators and Triggers Memorandum (Appendix I to the Stage 1 CSG WMMP).

EWMS response actions are risk-based in that escalating actions apply to exceedances due to the Action, depending on the level of the exceedance. The levels of exceedance are: 1) an early warning indicator, 2) a trigger threshold, or 3) a limit. It is recognised that incident specific management and mitigation measures will be implemented at the time of any exceedance, but that these cannot be determined prior to the exceedance, due to the variability in circumstances that may arise.

The response actions for each level are identified in Table 4-3.

Table 4-3 Risk-based exceedance response actions

Risk based exceedance level	**Response action**
Early warning indicator	Within 90 days, prepare and submit to the Department an Early Warning Exceedance Report which includes: a) The results of an evaluation of the reasons for the EWI exceedance (including trend analysis in Section 4.3) and the likelihood of a future exceedance of a trigger threshold or limit. b) The scope and schedule for implementing a groundwater investigation, to be undertaken if the evaluation indicated a likely future trigger threshold or limit exceedance. Within 90 days of the release of a new UWIR, comparison will be made between the Arrow only drawdown impact predictions
Trigger threshold	Within 120 days, prepare and submit to the Department a Trigger Threshold Exceedance Report which includes: a) The results of an evaluation of the reasons for the trigger threshold exceedance (including trend analysis in Section 4.3) and the likelihood of a future exceedance of a limit. b) If the evaluation indicates a likely future limit exceedance: prepare a scope and schedule for a management plan that includes procedures to reduce the likelihood of a future limit exceedance. The overarching principles that will apply to the management plan will include: • A mitigation hierarchy with the sequential steps of avoidance, minimisation, mitigation/management and offset; • Application of proven methods first; and • Consideration of the potential cumulative (CSG and non-CSG) impacts water resource and their receptors.
Limit	Within 120 days, prepare and submit to the Department a Limit Exceedance Report that includes:

Risk based exceedance level	Response action
	a) The results of an evaluation of the reasons for the limit exceedance (including trend analysis in Section 4.3) and an evaluation of any impacts that may arise due to the exceedance. b) An evaluation of the risk to groundwater environmental values that adopts local scale modelling and multiple lines of evidence. c) Corrective actions to mitigate against any impacts. The overarching principles that will apply to the corrective actions will include: • A mitigation hierarchy with the sequential steps of avoidance, minimisation, mitigation/management and offset; • Application of proven methods first; and • Consideration of the potential cumulative (CSG and non-CSG) impacts water resource and their receptors.

4.6. Periodic reporting and revisions

4.6.1. Submission of revised plans

To ensure an adaptive management approach, Arrow will submit periodic revisions (every three years) of the Stage 2 CSG WMMP for approval by the Minister in writing, as required under Approval Condition 22.

At least 3 months prior to the planned commencement of any new development stage for the SGP, Arrow will submit a revised CSG WMMP in support of the revised project. The revised CSG WMMP will take into account outcomes of the Stage 2 CSG WMMP monitoring program, groundwater model updates, and any bioregional assessments.

4.6.2. Annual reporting

An annual report on the Stage 2 CSG WMMP[9] will be prepared for the preceding 12 month period. It will be submitted to the Department and published on Arrow's website within three months of every 12-month anniversary of the commencement of the SGP. Each annual report will present a summary of progress towards Arrow's commitments and document Arrow's compliance against the approval conditions.

Annual reports will be factual, and will:

- Detail any updates to the FDP and implications for water monitoring and management.
- Report on any relevant ongoing studies and research projects and include any supporting technical studies as appendices to the annual report.
- Summarise relevant monitoring results, including:
  - Groundwater levels and trends
  - Groundwater chemistry results
  - Surface water monitoring results
  - Surface water chemistry results

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[9] Annual reporting of the Stage 1 CSG WMMP will cease following commencement of the Stage 2 CSG WMMP, which will include all matters relating to the Stage 1 CSG WMMP and supersede the Stage 1 reporting requirements.

  - Analysis and interpretation of data

- Document Arrow’s compliance against the approval conditions over the preceding 12 months, including monitoring obligations and implementation of the EWMS.
- Document corrective actions implemented to address any exceedances of trigger thresholds, limits, or non-compliance with approval conditions.
- Report against the performance measure criteria detailed in the Stage 1 CSG WMMP.

Relevant electronic data will be provided to the Department upon request and published as described in the Stage 1 CSG WMMP (Appendix A to the Stage 2 CSG WMMP).

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Appendices

Appendix A Description of groundwater level and quality trends

Location / bore ID	Target aquifer	Description of groundwater level and quality trends (2013/14-2018 unless otherwise stated)
Carn Brea-17	Condamine Alluvium	The groundwater level exhibited regular drawdown and recovery cycles of 2-3 m over the monitoring period, consistent with groundwater extraction for agricultural or other non-CSG use. Groundwater levels exhibited only minor direct correlation with rainfall events. Following recovery, the groundwater level generally remained consistent at 320 m AHD.
		During the monitoring period salinity was recorded at between 511 and 705 mg/L TDS. The pH varies between slightly acidic to slightly alkaline (6.8 to 8.0). The groundwater is generally classified as a Ca-Mg-HCO_3 water type with some variability. No temporal trends in groundwater quality was observed.
Carn Brea-23	Condamine Alluvium	Groundwater level data is available from February 2017 to April 2018 for Carn Brea-23. The groundwater level exhibited a subdued correlation with rainfall during this period. An overall rising trend of 0.5 m over the period is recorded. Longer term monitoring data is required to establish background trends for this bore.
Daandine-161	Condamine Alluvium	The groundwater level exhibited regular drawdown and recovery cycles of 3-5 m over the monitoring period, consistent with groundwater extraction for agricultural or other non-CSG use. Groundwater levels exhibited only minor direct correlation with rainfall events. Following recovery, the groundwater level has declined by close to 2 m over the 4 ½ year monitoring period; a likely reflection of generally below average rainfall and/or non-CSG groundwater extraction. There is no active CSG development in this area.
Kogan North-79	Condamine Alluvium	The monitoring bore was dry during the monitoring period.
Macalister-5	Condamine Alluvium	During the period of monitoring, the groundwater level trend has remained stable, with little variability in levels. No correlation with rainfall is evident.
Pampas-18	Condamine Alluvium	Between the period of monitoring (November 2016 to April 2018), the groundwater level trend remained stable, with little variability in levels. No correlation with rainfall is evident.
Plainview-25	Condamine Alluvium	The groundwater level exhibited a minor decline at an approximate rate of 0.15 m/yr during the monitoring period. Cyclical fluctuations in groundwater levels may be in due to groundwater extraction for agricultural or other non-CSG use and/or subdued a response to rainfall patterns . The generally below average rainfall recorded during the monitoring period and/or non-CSG groundwater extraction, may be contributing to the declining groundwater level trend. There is no active CSG development in this area.
RN 42230088	Condamine Alluvium	The groundwater level trend remained stable during the monitoring period with little variability in levels. No correlation with rainfall is evident.
RN 42230209	Condamine Alluvium	The groundwater level trend remained stable during the monitoring period with little variability in levels. No correlation with rainfall is evident.
		During the monitoring period salinity was recorded between the narrow range of 5,590 and 6,310 mg/L TDS. The pH varies between slightly acidic to neutral (6.7 to 7.0). The groundwater is consistently classified as a Na-

Location / bore ID	Target aquifer	Description of groundwater level and quality trends (2013/14-2018 unless otherwise stated)
		Cl water type. Minimal hydro-chemical temporal variability was recorded. No temporal trends in groundwater quality was observed.
RN 42231294	Condamine Alluvium	The groundwater level exhibited a minor decline at an approximate rate of less than 0.5 m/yr during the monitoring period. No cyclical variability is evident. The groundwater levels possibly exhibited some response to extended rainfall events. The generally below average rainfall recorded during the monitoring period and/or non-CSG groundwater extraction, may be contributing to the declining groundwater level trend. There is no active CSG development in this area.
RN 42231339	Condamine Alluvium	The groundwater level trend remained stable during the monitoring period with little variability in levels. No correlation with rainfall is evident.
RN 42231370	Condamine Alluvium	The groundwater level exhibited a subdued correlation with rainfall trends during the monitoring period, fluctuating by several metres between below and above average rainfall periods. Over the 4½ year monitoring period, the groundwater level has declined by almost 1 metre; a likely consequence of generally below average rainfall and/or non-CSG groundwater extraction. There is no active CSG development in this area.
		Between November 2015 and October 2018, the groundwater salinity was recorded between the narrow range of 1,050 and 1,160 mg/L TDS. Earlier sampling at the beginning of the sampling period were less saline (173 to 606 mg/L TDS) and these results are not considered representative of the water quality of the bore, These records may have been affected by bore construction / development, prior to equilibration with the native groundwater. The pH varies between neutral to slightly alkaline (7.3 to 8.5). The groundwater is generally classified as a Na-Cl type water with some variability. No temporal trends in groundwater quality was observed.
RN 42231463	Condamine Alluvium	The groundwater level exhibited regular drawdown and recovery cycles of up to 2 m over the monitoring period, consistent with groundwater extraction for agricultural or other non-CSG use. Groundwater levels exhibited only minor direct correlation with rainfall events. Following recovery, the groundwater level generally has declined by close to 2 m over the 4 ½ year monitoring period; a likely reflection of generally below average rainfall and/or non-CSG groundwater extraction. There is no active CSG development in this area.
Tipton-195	Condamine Alluvium	The groundwater level steadily declined at an approximate rate of 0.1 m/yr during the monitoring period. No cyclical variability is evident. While groundwater levels exhibited no direct correlation with rainfall periods, the generally below average rainfall recorded during the monitoring period and/or non-CSG groundwater extraction, may be contributing to the declining groundwater level trend. The rate of groundwater level decline recorded in the Condamine Alluvium at Tipton-195 is consistent with background trends in this aquifer. There is no evidence that nearby CSG production is contributing to the current declining groundwater levels in the Condamine Alluvium at this location. Future groundwater monitoring at Tipton-195 will assist in the early detection of groundwater level impacts (if any) within the alluvial aquifer.

Location / bore ID	Target aquifer	Description of groundwater level and quality trends (2013/14-2018 unless otherwise stated)
		During the monitoring period salinity was recorded between 848 and 1,070 mg/L TDS. The pH varies between neutral to slightly alkaline (7.1 to 8.4). The groundwater ranges between a Na-Cl and mixed water type. No temporal trends in groundwater quality was observed.
Tipton-204	Condamine Alluvium	Between the monitoring period of March 2015 and August 2018, the groundwater level exhibited a relatively stable trend with minor annual fluctuations of less than +/- 0.5 m. No correlation with rainfall is evident.
Tipton-221	Condamine Alluvium	Between the monitoring period of November 2016 and April 2018, the groundwater level remained stable, with little variability in levels. No correlation with rainfall is evident.
UWIR Site 41 (Macalister 7)	Condamine Alluvium	Between the monitoring period of mid-2017 to early-2018, the groundwater level exhibited a stable trend, after which a gradual decline over 2 months of 0.7 m was recorded. No cyclical variability is evident. While groundwater levels exhibited no direct correlation with rainfall periods, the generally below average rainfall recorded during the monitoring period and/or non-CSG groundwater extraction, may be contributing to the declining groundwater level trend. There is no active CSG development in this area, nor does the WCM exhibit declining trends at nested site bore UWIR Site 41. Longer term monitoring data at this nested site location will assist in characterising background groundwater level trends and identifying any potential deviations.
Wyalla-16	Condamine Alluvium	The groundwater level has steadily declined at an approximate rate of less than 0.5 m/yr during the monitoring period. No cyclical variability is evident. While groundwater levels exhibited no direct correlation with rainfall periods, the generally below average rainfall recorded during the monitoring period and/or non-CSG groundwater extraction, may be contributing to the declining groundwater level trend. There is no active CSG development in this area, nor does the WCM exhibit declining trends at nearby bore Wyalla-18.
		During the monitoring period salinity was recorded between 735 and 1,280 mg/L TDS. The pH varies between neutral to slightly alkaline (7.2 to 8.3). The groundwater is generally classified as a Na-Cl water type. No temporal trends in groundwater quality was observed.
Carn Brea-24	CA / WCM transition layer	Between the monitoring period of 2017 to mid-2018, the average groundwater level rose by almost 2.5 m, despite a generally below average monthly rainfall trend being recorded. No correlation of groundwater levels and rainfall is evident for this bore. Longer term monitoring data is required to establish background trends for this bore.
Daandine-163	CA / WCM transition layer	The groundwater level exhibited regular drawdown and recovery cycles of 2-4 m over the monitoring period, consistent with groundwater extraction for agricultural or other non-CSG use. Groundwater levels exhibited only minor direct correlation with rainfall events. Following recovery, the groundwater level recorded a minor decline of 0.5 m over the monitoring period. The generally below average rainfall recorded during the monitoring period and/or non-CSG groundwater extraction, may be contributing to the declining groundwater level trend

Location / bore ID	Target aquifer	Description of groundwater level and quality trends (2013/14-2018 unless otherwise stated)
		There is no active CSG development in this area.
Kogan North-79	CA / WCM transition layer	The monitoring bore was dry during the monitoring period.
Plainview-25	CA / WCM transition layer	The groundwater level rose at an approximate rate of less than 0.5 m/yr during the monitoring period. No cyclical variability is evident. Groundwater levels exhibited no correlation with rainfall patterns.
Tipton-196A	CA / WCM transition layer	Between November 2014 and August 2015, the groundwater level declined sharply by 14 m/yr. Thereafter, until the close of the monitoring period (August 2018), the groundwater decline has reduced to 3 m/yr. Over the nearly 4 year monitoring period, the groundwater level has fallen by close to 20 m. No cyclical variability is evident and groundwater levels exhibited no correlation with rainfall patterns. Tipton-196A is in close proximity to current CSG development by other operators. Nearby bore Tipton-195 screened within the overlying Condamine Alluvium, is not exhibiting any groundwater drawdown affects beyond background trends. Notably, WCM monitoring bore (Macalister seam) Tipton-197 at the same location is exhibiting only minor drawdown in the last year of a rate of less than 0.2 m/yr. The monitored zone at Tipton196A is a transition zone which typically consists of plastic clays and resultant low permeability. The monitoring data may indicate the pressure is still equalising with the formation pressure following well completion. In addition, this bore was topped up with water as a bore control barrier during installation of the downhole monitoring equipment. Pressure has gradually declined as this water has entered the aquifer. The rapid decline in pressure in early 2016 is considered to be either: - A result of the gas phase in the bore being above atmospheric pressure. When the bore was opened, the gas phase pressure was reduced to atmospheric pressure resulting in a total pressure which was lower than before the bore was opened; or - Water from the outer annulus of the bore (where the gauge is installed) flowing into the inner tubing of the bore when the well is opened, also resulting in an apparent reduction in pressure on the gauge. The subsequent sharp increases in pressure correspond to other manual interventions of the well (i.e. opening the well head; because the fluid level had been falling and creating a vacuum pressure in the head space of the well). Pressure increase occurs when the well is opened because the pressure of the gas phase in the well increases from 'vacuum' (i.e. something less than atmospheric) to atmospheric. Longer term groundwater monitoring is required to establish background groundwater level trends for this bore.
Tipton-204	CA / WCM transition layer	Between March and August 2015, the groundwater level rose by 6 m, remaining relatively stable until mid-2018 at which time a sharp 1 m decline was recorded. The initial groundwater level rise is considered to be due groundwater level equilibration following bore installation in low permeability lithology.

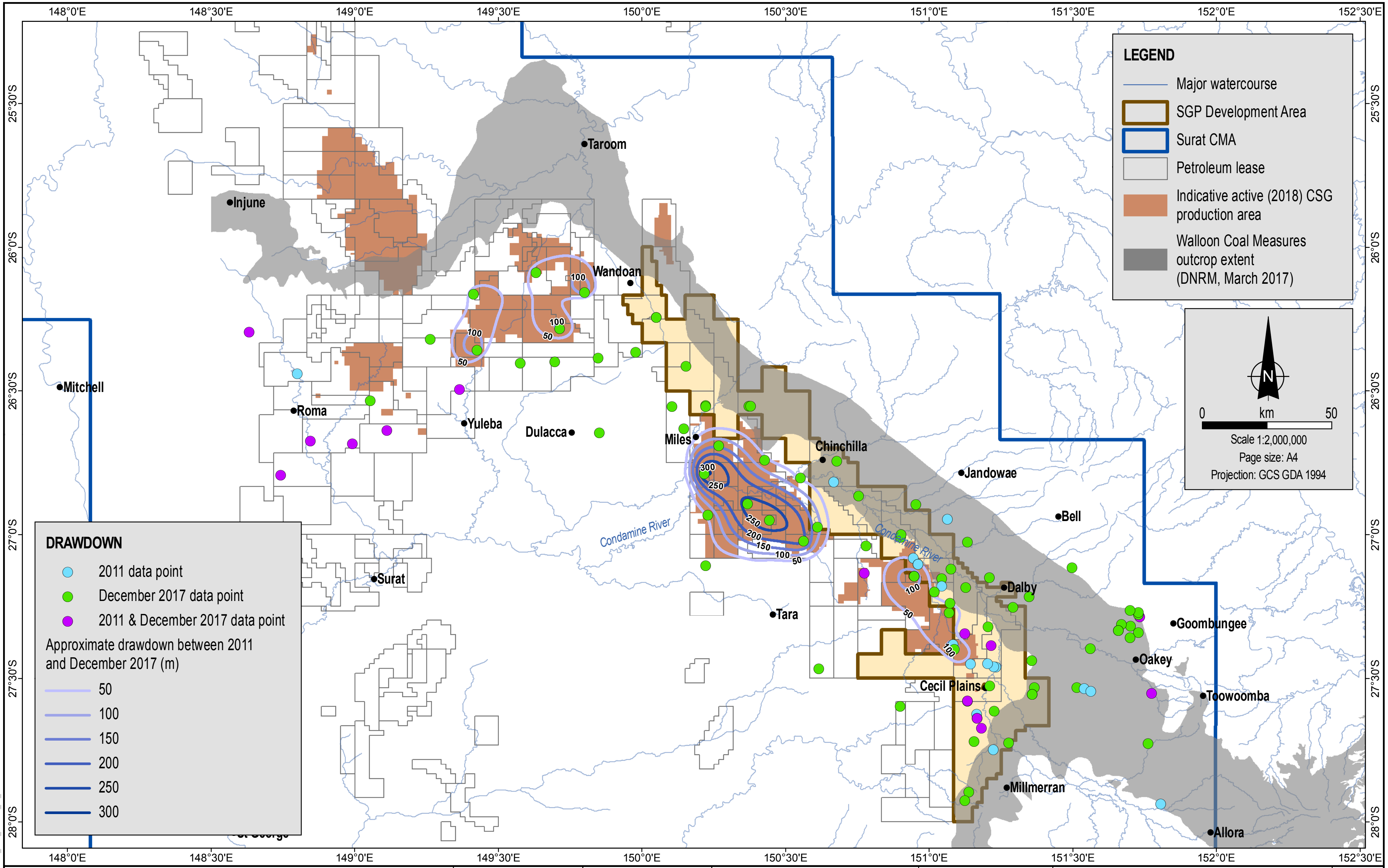
Location / bore ID	Target aquifer	Description of groundwater level and quality trends (2013/14-2018 unless otherwise stated)
		The groundwater level exhibited regular drawdown and recovery cycles of less than 1 m over the monitoring period, consistent with groundwater extraction for agricultural or other non-CSG use. No correlation with rainfall is evident. The bore is not located in an active CSG development area.
Tipton-222	CA / WCM transition layer	Groundwater level data is available from March 2017 to April 2018 for Tipton-222. An overall rising trend of less than 0.5 m/yr over the period is recorded. No correlation with rainfall is evident. Longer term monitoring data is required to establish background trends for this bore.
Castledean-18	Springbok	The monitoring bore was dry during the monitoring period.
Hopeland-17	Springbok	The groundwater level rose at an approximate rate of less than 1 m/yr during the monitoring period. The groundwater level exhibited a cyclical variation of 2 to 3 m on an annual basis which = is considered to be related to local scale gas pressure increases in the unit. Such processes may occur as a consequence of local scale gas migration following the shut-in of nearby (non-Arrow) CSG production wells, at regular intervals for routine maintenance Groundwater levels exhibited no correlation with rainfall patterns.
Kedron-570	Springbok	The monitoring bore was dry during the monitoring period.
Meenawarra-21	Springbok	The groundwater level declined sharply by close to 30 m between late 2015 and late 2016. Following a slight recovery, the groundwater steadily declined at a rate of 6 m/yr between late 2016 and mid-2018. There is no active CSG development in this area, nor does the WCM exhibit declining trends at the nested bore location of Meenawarra-21. The aquifer unit displays very low permeability in this area and the monitoring data may indicate the pressure is still equalising with the formation pressure following well completion. As for Tipton-196A, this bore was topped up with water as a bore control barrier during installation of the downhole monitoring equipment. Pressure has gradually declined as this water has entered the aquifer. Longer term groundwater monitoring is required to establish background groundwater level trends for this bore.
RN 41620043	Springbok	Groundwater levels exhibited a subdued correlation with rainfall during the monitoring period. An overall declining trend of less than 0.5 m/yr was recorded for this bore; a reflection of the below average rainfall experienced during the monitoring period.
Stratheden-63	Springbok	During the period of monitoring, the groundwater level trend has remained stable, with little variability in levels. No correlation with rainfall is evident.
		Between the monitoring period of October 2016 and November 2018, the groundwater salinity was generally recorded at between 1,950 and 2,210 mg/L TDS. One groundwater sample (2 November 2017) was recorded outside this range at 1,690 mg/L TDS which is considered to be laboratory error. Chloride concentrations for the period ranged from 1,030 mg/L to 1,170mg/L (a difference of 14%) and Sodium concentrations ranged from 631 mg/L to 712 mg/L (a difference of 13%). The reported TDS of 1,690

Location / bore ID	Target aquifer	Description of groundwater level and quality trends (2013/14-2018 unless otherwise stated)
		mg/L (2 November 2017) is ~30% different from the other reported salinity values and is accordingly considered to be a laboratory error. The pH is alkaline (8.6 to 9.5) and the groundwater is generally classified as a Na-Cl type water. Initial groundwater samples (October 2016) recorded a pH of up to 11 indicating at this time the water may have been impacted by bore construction processes (e.g. grouting). No temporal trends in groundwater quality was observed.
Burunga Lane-176	Hutton	The groundwater level steadily declined at an approximate rate of less than 0.5 m/yr during the monitoring period. No cyclical variability is evident. The declining groundwater level trend is consistent with background regional trends reported by OGIA (2016, 2018) and may be attributable to an extended period of below average rainfall and/or non-CSG groundwater extraction. There is no active CSG development in this area, nor does the WCM exhibit declining trends at the nested bore location of Burunga Lane-176.
		With the exception of the first monitoring sample (November 2013 at 2,780 mg/L TDS), the groundwater salinity has been recorded (up to April 2016) in the narrow range of 1,500 to 1,550 mg/L TDS. The pH is alkaline (9.3 to 9.4). The groundwater is consistently recorded as a Na-Cl water type. No temporal trends in groundwater quality was observed.
Carn Brea-19	Hutton	The groundwater level steadily declined at an approximate rate of less than 0.5 m/yr during the monitoring period. No cyclical variability is evident. The declining groundwater level trend is consistent with background regional trends reported by OGIA (2016, 2018) and may be attributable to an extended period of below average rainfall and/or non-CSG groundwater extraction. There is no active CSG development in this area, nor does the WCM exhibit declining trends at the nearby bore Carn-Brea-18.
		The groundwater salinity was recorded at between 579 to 932 mg/L TDS during the monitoring period. The pH is alkaline (8.7 to 8.9). The groundwater is generally classified as a $Na-HCO_3$ water type.
Daandine-121	Hutton	The groundwater level exhibited a generally declining trend between September 2014 and mid-2017 of approximately 1.5 m/yr. Thereafter, to the close of the monitoring period (August 2018), the groundwater level has risen at an approximate rate of 1.5 m/yr. Groundwater levels exhibited no clear correlation with rainfall patterns. The bore is in close proximity to current CSG developmentr, however the groundwater level trend is not considered to be affected by this activity. The declining groundwater level trend, whilst elevated, is considered to be within background regional trends and may be attributable to an extended period of below average rainfall and/or non-CSG groundwater extraction. It is noted that the recent groundwater level rise in August 2018 may potentially be associated with diminished abstraction by nearby non-CSG groundwater extraction. Longer term groundwater level monitoring data is required to establish the background trend of the Hutton Sandstone at this location.

Location / bore ID	Target aquifer	Description of groundwater level and quality trends (2013/14-2018 unless otherwise stated)
		The groundwater salinity was recorded at between 1,480 to 1,970 mg/L TDS during the monitoring period. The pH is alkaline (8.3 to 8.9). The groundwater is generally classified as a Na-HCO_3 water type. No temporal trends in groundwater quality was observed.
Kedron-570	Hutton	The groundwater level steadily declined at an approximate rate of less than 0.5 m/yr during the monitoring period. No cyclical variability is evident. The declining groundwater level trend is consistent with background regional trends reported by OGIA (2016, 2018) and may be attributable to an extended period of below average rainfall and/or non-CSG groundwater extraction. Groundwater levels within the overlying WCM exhibited a sharp decline of 10 m/yr over the monitoring period at this nested site location; a reflection of CSG development by another operator to the west/north-west and south of Kedron-570. The rate of groundwater level decline in the Hutton Sandstone at Kedron-570 of less than 0.5 m/yr is consistent with background regional trends in this aquifer. There is no evidence that CSG production is contributing to the current declining groundwater levels in the Hutton Sandstone at this location.
Burunga Lane-174	Precipice	Between 2013 to 2015, the groundwater level steadily declined by approximately 0.6 m and in the following three years to 2018, the groundwater level steadily rose by close to 5 m; a possible reflection of treated CSG water injection into the Precipice Sandstone aquifer by another operator. No cyclical variability is evident. Longer term groundwater monitoring is required to characterise the baseline groundwater level trend at the bore.
		The groundwater salinity was recorded at between 271 to 344 mg/L TDS during the monitoring period. The pH is alkaline (9.4 to 9.7). The groundwater is generally classified as a Na-HCO_3 water type. No temporal trends in groundwater quality was observed.
Carn Brea-20	Precipice	The groundwater level steadily declined at an approximate rate of 1 m/yr between 2014-2016, and thereafter the rate of decline has doubled to 2 m/yr to the end of the monitoring period. No cyclical variability is evident. The extended period of below average rainfall, which is more evident between 2016 and 2018, and/or non-CSG groundwater extraction, may be contributing to the declining groundwater level trend. There is no active CSG development in this area, nor does the WCM exhibit declining trends at the nearby bore Carn-Brea-18.
		The stabilised and representative (post-construction) groundwater salinity at Carn Brea-20 was recorded at between 1,910 and 2,020 mg/L TDS. The first three samples from 2015 are not considered representative. The salinity values were obtained by calculation rather than laboratory measurement. Furthermore, the first sample (6 March 2015) reported comparatively elevated Sulphate concentrations with respect to other anions, indicative of insufficient bore development following construction. The pH is neutral to alkaline (7.3 to 8.6). The groundwater is generally classified as a Na-HCO3 water type. No temporal trends in groundwater quality was observed.

Location / bore ID	Target aquifer	Description of groundwater level and quality trends (2013/14-2018 unless otherwise stated)
Wyalla-17	Precipice	The groundwater level has steadily declined at an approximate rate of just over 1 m/yr during the monitoring period. No cyclical variability is evident. The extended period of below average rainfall and/or non-CSG groundwater extraction, may be contributing to the declining groundwater level trend. There is no active CSG development in this area, nor does the WCM exhibit declining trends at nearby bore Wyalla-18.
		The groundwater salinity was recorded at between 5,670 to 6,730 mg/L TDS during the monitoring period. The pH is slightly acidic to alkaline (6.3 to 8.8). The groundwater is generally classified as a Na-Cl water type. No temporal trends in groundwater quality was observed.

Appendix B Spatial representation of baseline groundwater level trend assessment



MXD Reference: 20484AB_M04_GIS009_v0_3

Source:
Watercourses from DME.
SGP Development and drawdown contours from Arrow Energy.
Leases and subcrop extent from DNRM (2017).
Monitoring and assessment locations from Arrow.

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Date:
26.02.2019
Project:
ENAUABTF20484AA
File Name:
20484AA M04 F001 GIS

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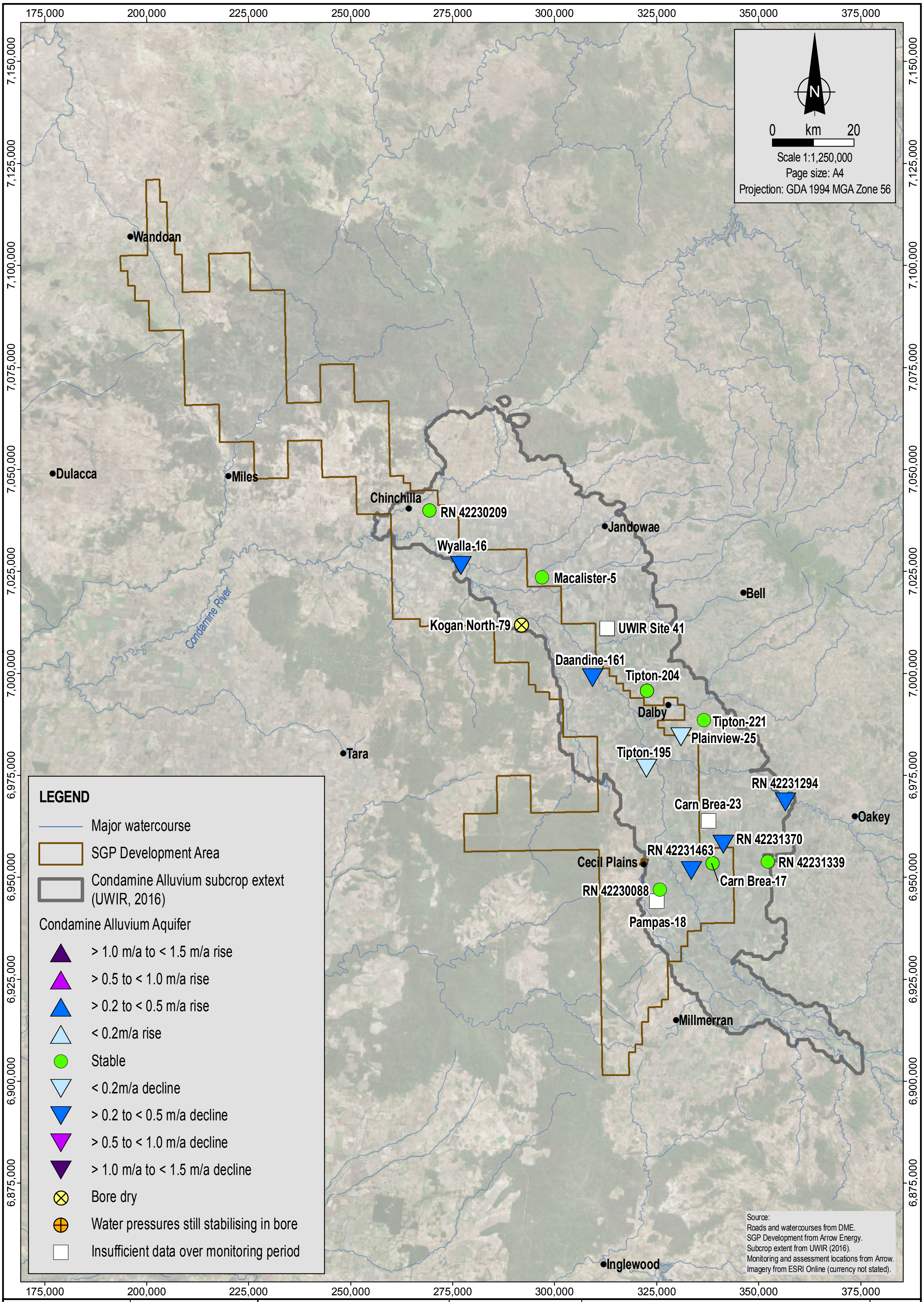
Active (2018) CSG production areas and approximate groundwater level drawdown in the WCM between 2011 and December 2017.

Figure No:
1



Source:
Roads and watercourses from DME.
SGP Development from Arrow Energy.
Subcrop extent from UWIR (2016).
Monitoring and assessment locations from Arrow.
Imagery from ESRI Online (currency not stated).

MXD Reference: 20484AB_M04_GIS003_v0_3

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Project:
ENAUABTF20484AA
File Name:
20484AA_M04_F002_GIS

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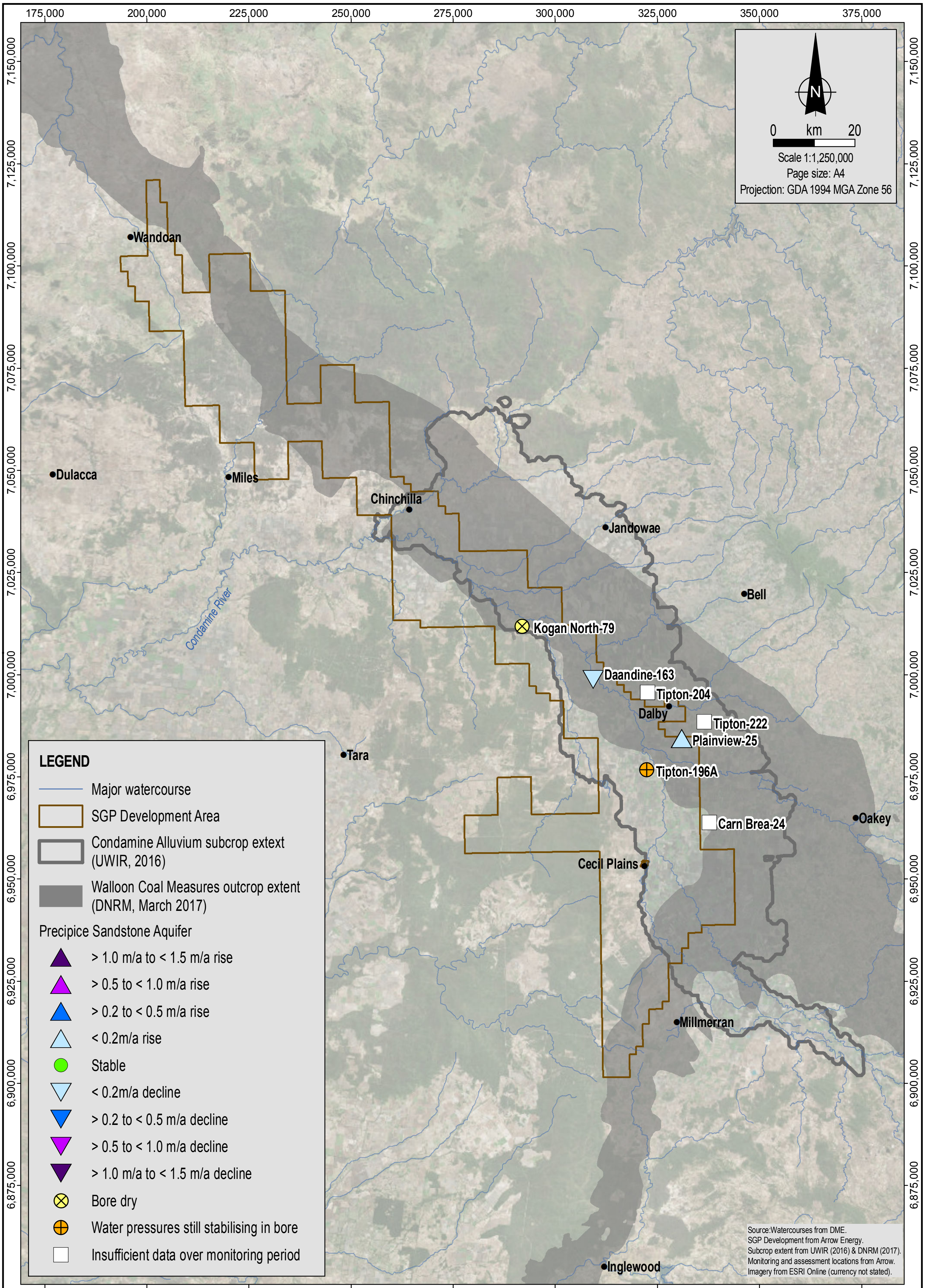
Baseline groundwater level trend assessment for 2013/14 to 2018 - Condamine Alluvium

Figure No:
2



Source:Watercourses from DME.
SGP Development from Arrow Energy.
Subcrop extent from UWIR (2016) & DNRM (2017).
Monitoring and assessment locations from Arrow.
Imagery from ESRI Online (currency not stated).

MXD Reference: 20484AB_M04_GIS004_v0_2

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Date: 18.02.2019
Project: ENAUABTF20484AA
File Name: 20484AA_M04_F003_GIS

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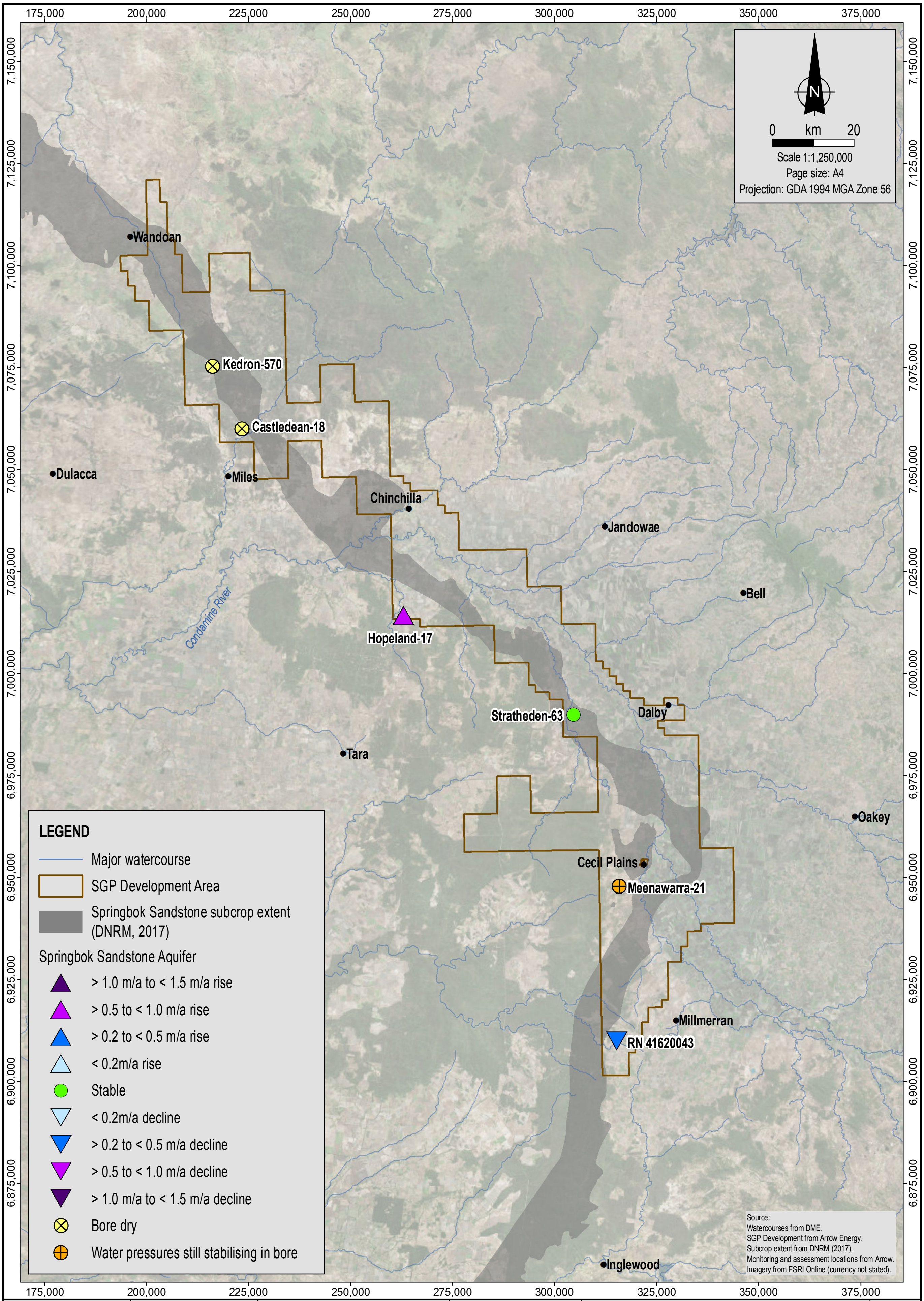
Baseline groundwater level trend assessment for 2013/14 to 2018 - Condamine Alluvium – WCM transition layer

Figure No: 3



Source:
Watercourses from DME.
SGP Development from Arrow Energy.
Subcrop extent from DNRM (2017).
Monitoring and assessment locations from Arrow.
Imagery from ESRI Online (currency not stated).

MXD Reference: 20484AB_M04_GIS005_v0_2

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Project: ENAUABTF20484AA
File Name: 20484AA_M04_F004_GIS

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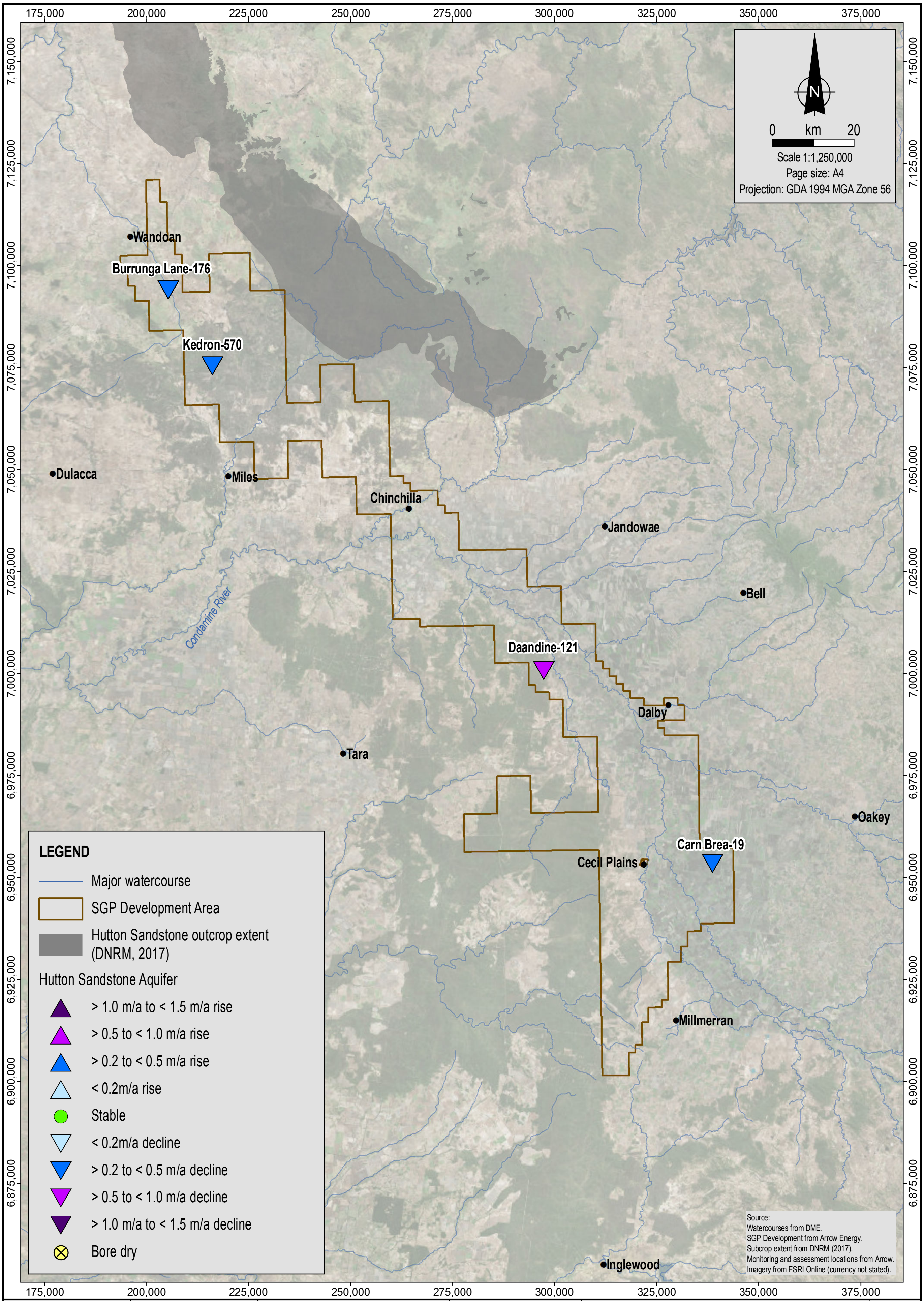
Baseline groundwater level trend assessment for 2013/14 to 2018 - Springbok Sandstone

Figure No: 4



MXD Reference: 20484AB_M04_GIS006_v0_2

Date:
18.02.2019
Project:
ENAUABTF20484AA
File Name:
20484AA_M04_F005_GIS

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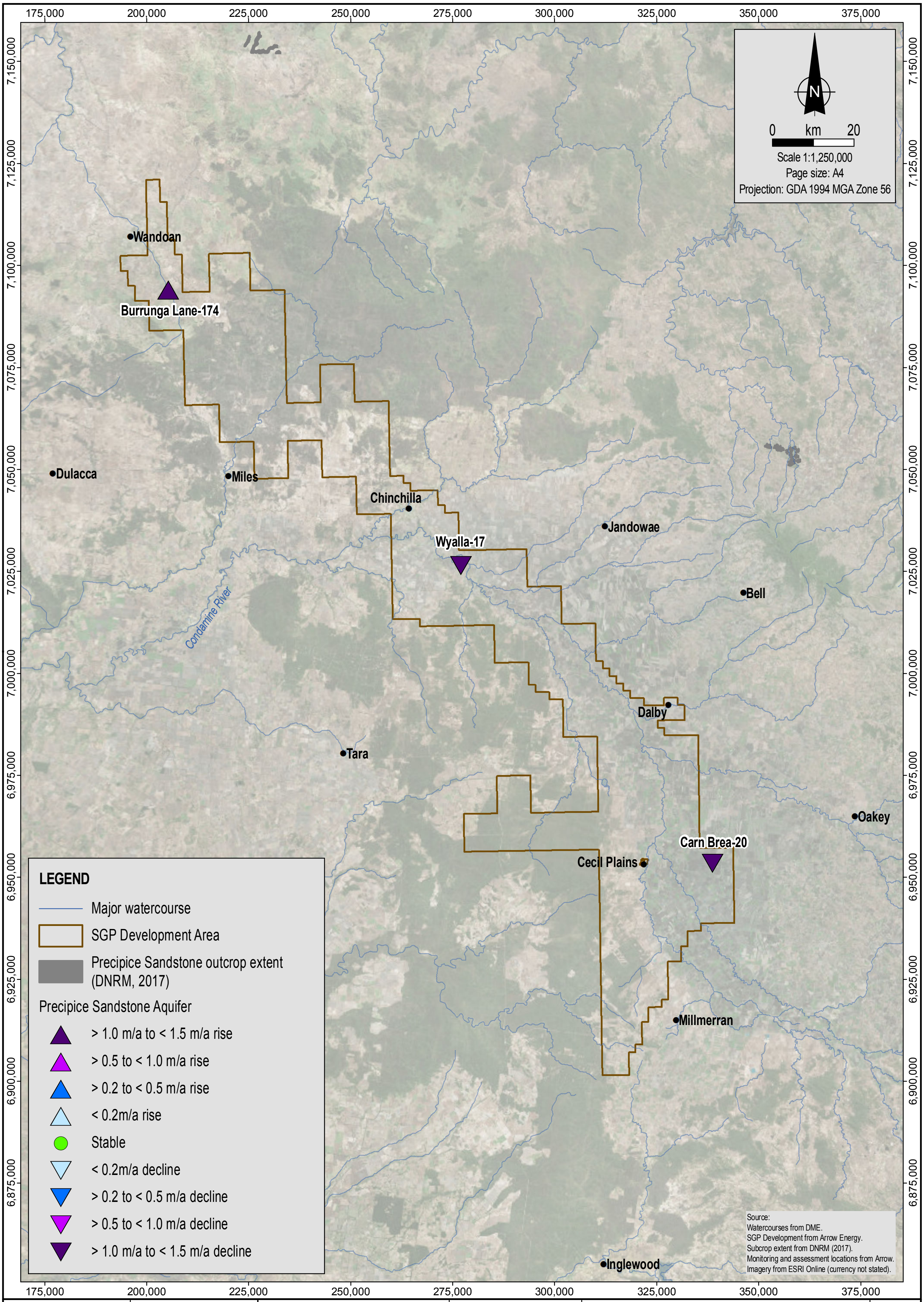
Baseline groundwater level trend assessment for 2013/14 to 2018 - Hutton Sandstone

Figure No:
5



Source:
Watercourses from DME.
SGP Development from Arrow Energy.
Subcrop extent from DNRM (2017).
Monitoring and assessment locations from Arrow.
Imagery from ESRI Online (currency not stated).

MXD Reference: 20484AB_M04_GIS007_v0_2

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Date: 18.02.2019
Project: ENAUABTF20484AA
File Name: 20484AA_M04_F006_GIS

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Surat Gas Project WMMP

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Baseline groundwater level trend assessment for 2013/14 to 2018 - Precipice Sandstone

Figure No:
6

Appendix C Hydrographs of selected monitoring bores

Figure 7 Macalister-5 hydrograph (Condamine Alluvium aquifer)

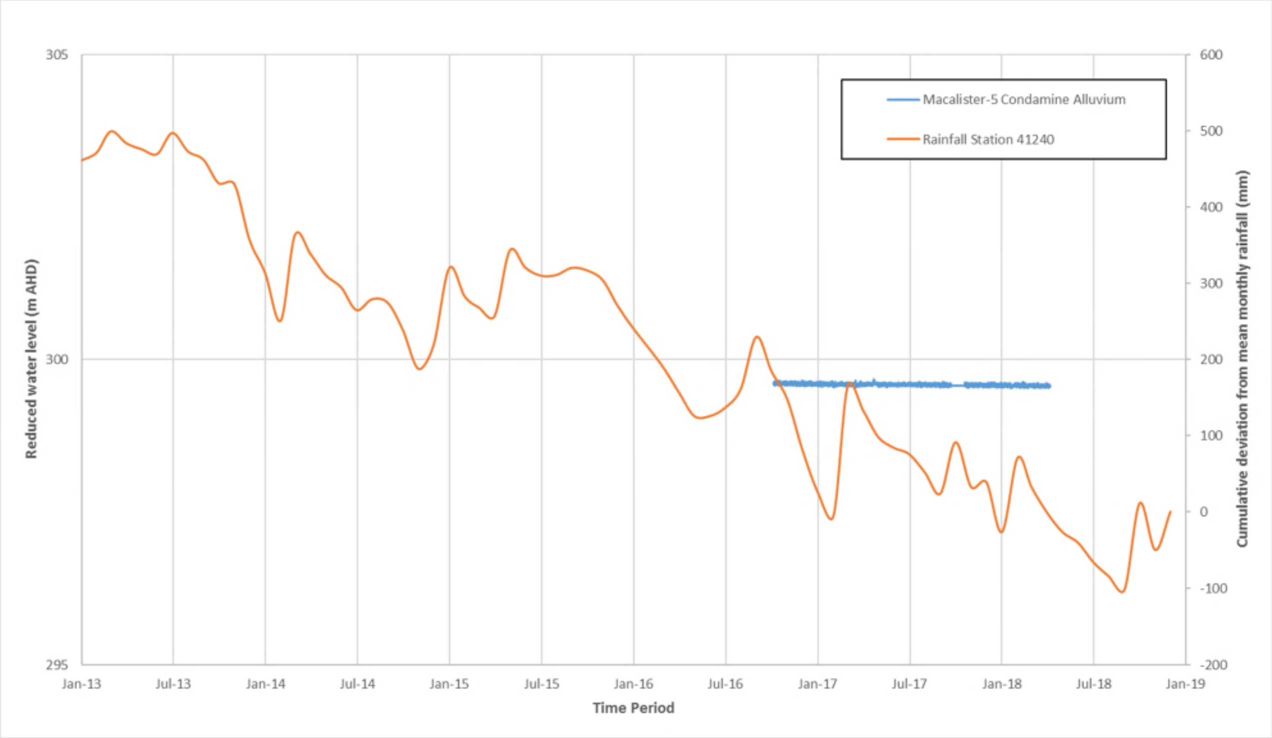


Figure 8 RN 42231370 hydrograph (Condamine Alluvium aquifer)

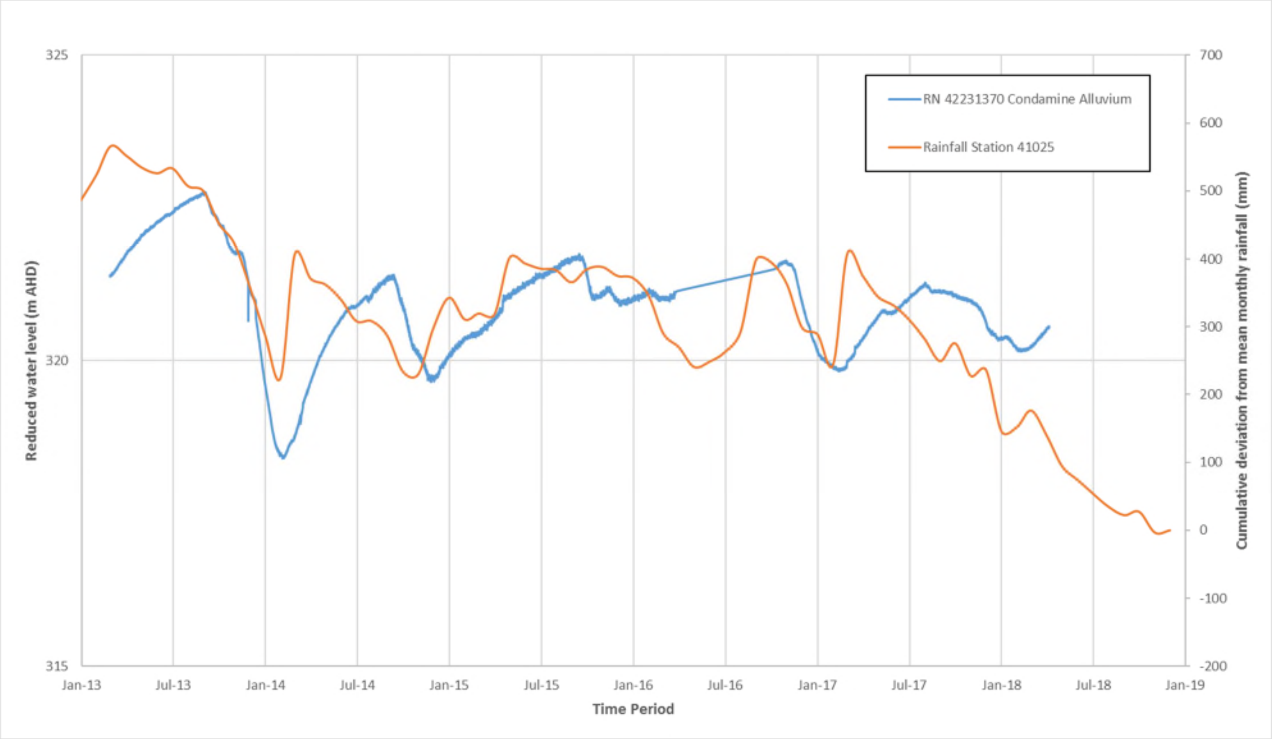


Figure 9 Daandine-161 hydrograph (Condamine Alluvium aquifer)

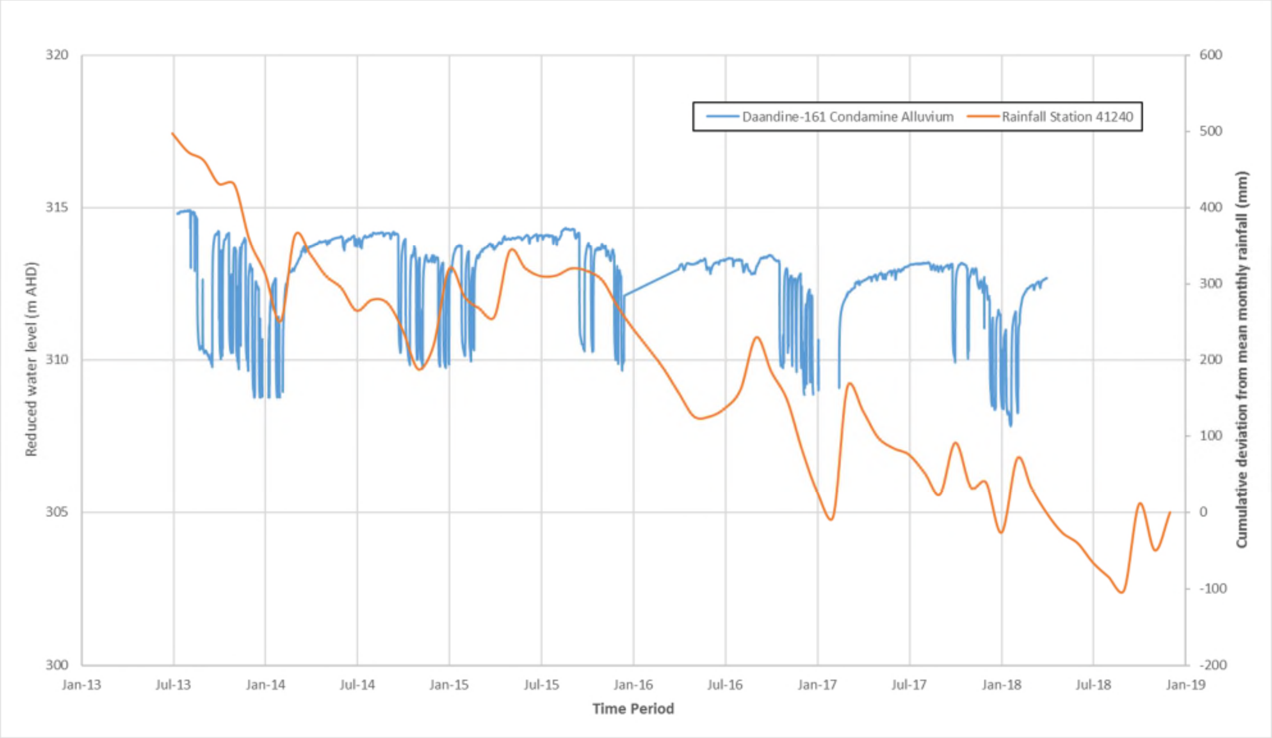


Figure 10 Plainview-25 hydrograph (Condamine Alluvium-WCM transition layer)

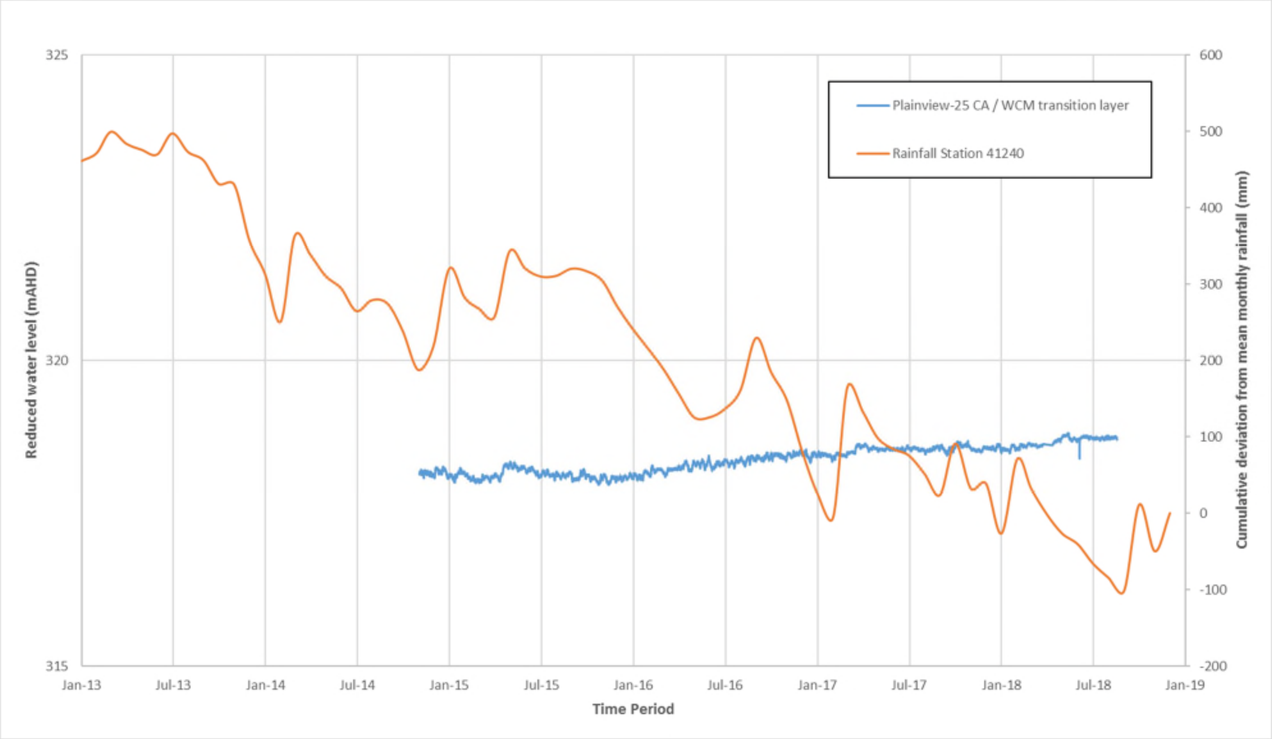


Figure 11 Daandine-163 hydrograph (Condamine Alluvium-WCM transition layer)

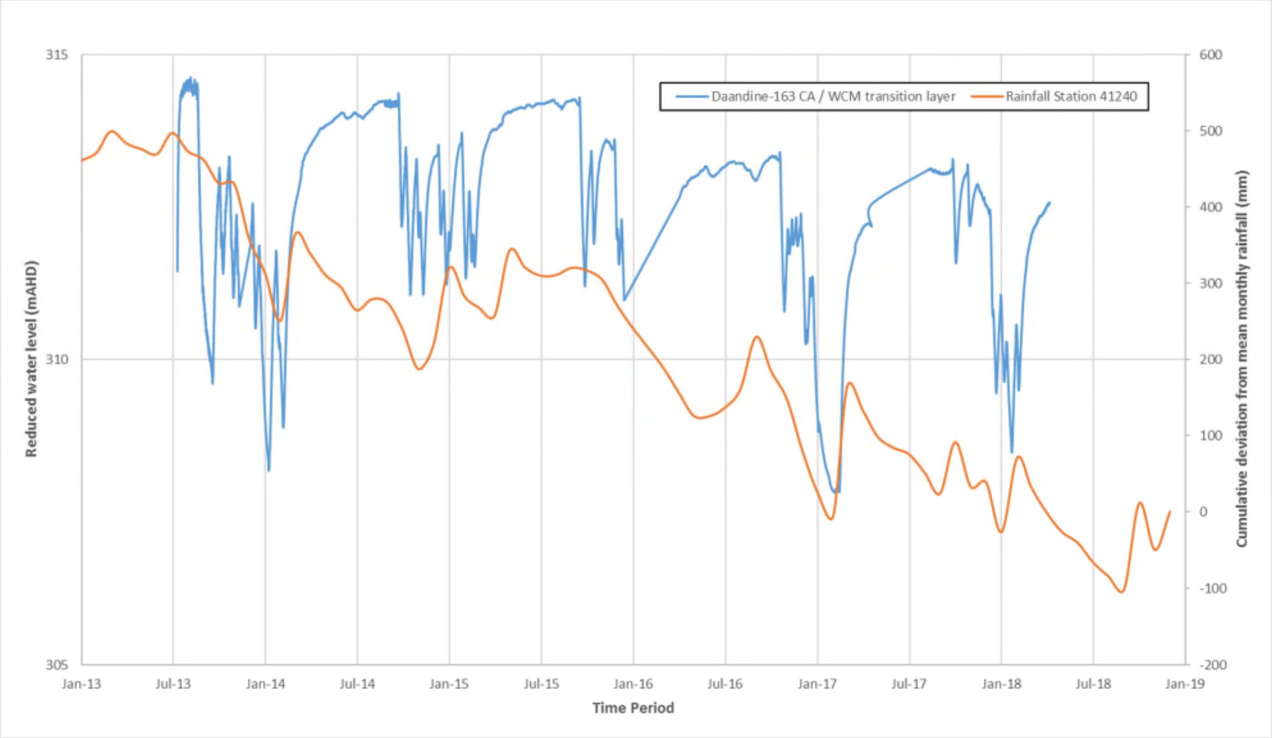


Figure 12 Tipton-204 hydrograph (Condamine Alluvium-WCM transition layer)

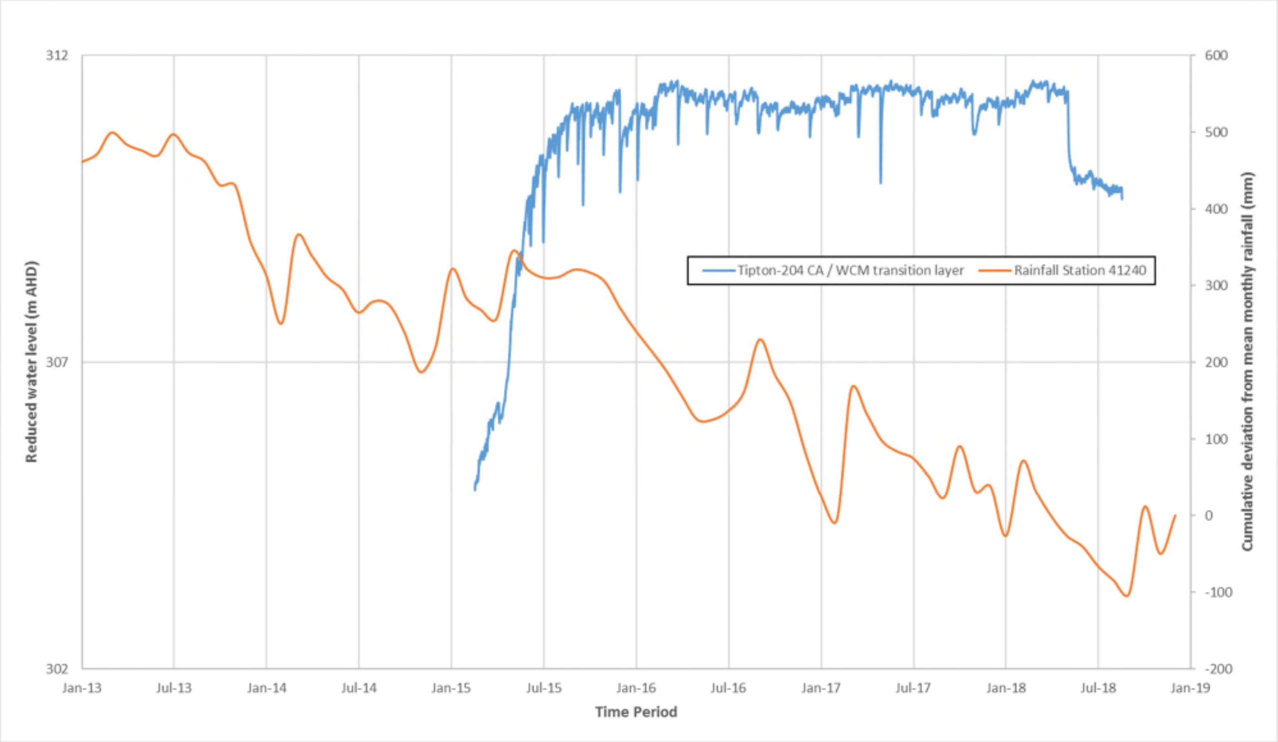


Figure 13 Tipton-196A hydrograph (Condamine Alluvium-WCM transition layer)

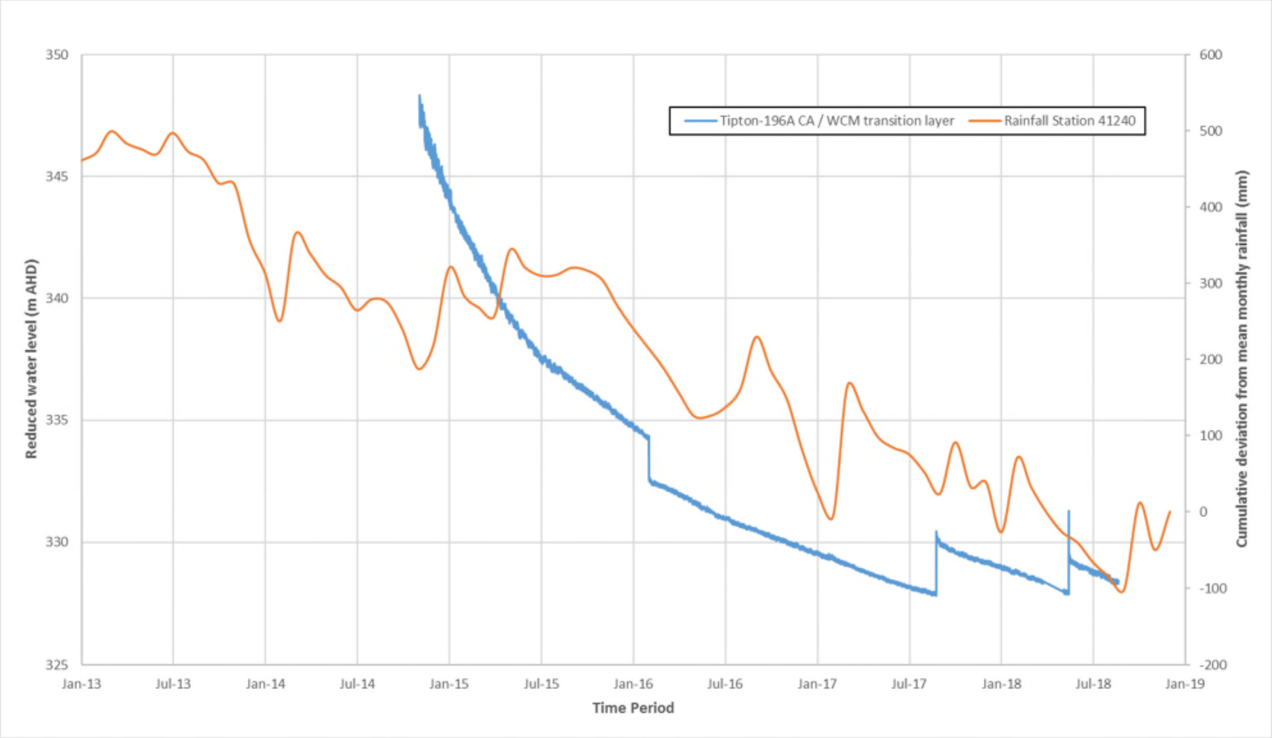


Figure 14 Hopeland-17 hydrograph (Springbok Sandstone aquifer)

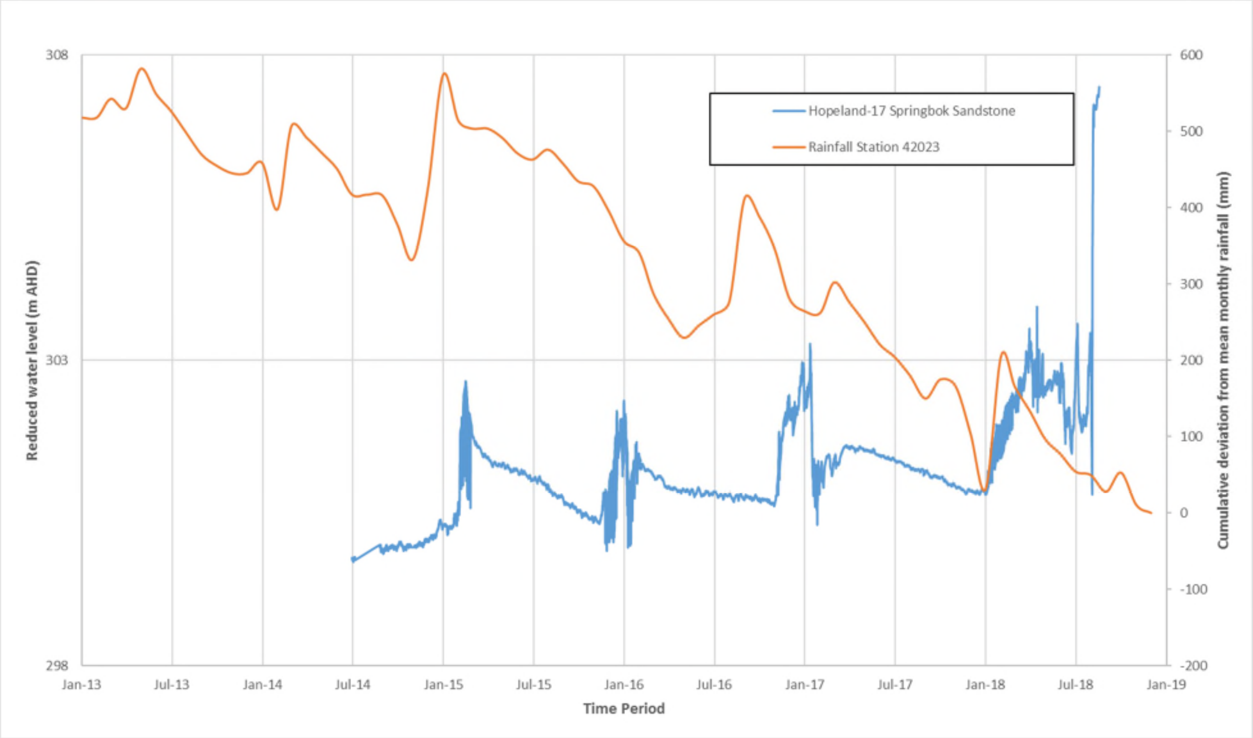


Figure 15 RN41620043 hydrograph (Springbok Sandstone aquifer)

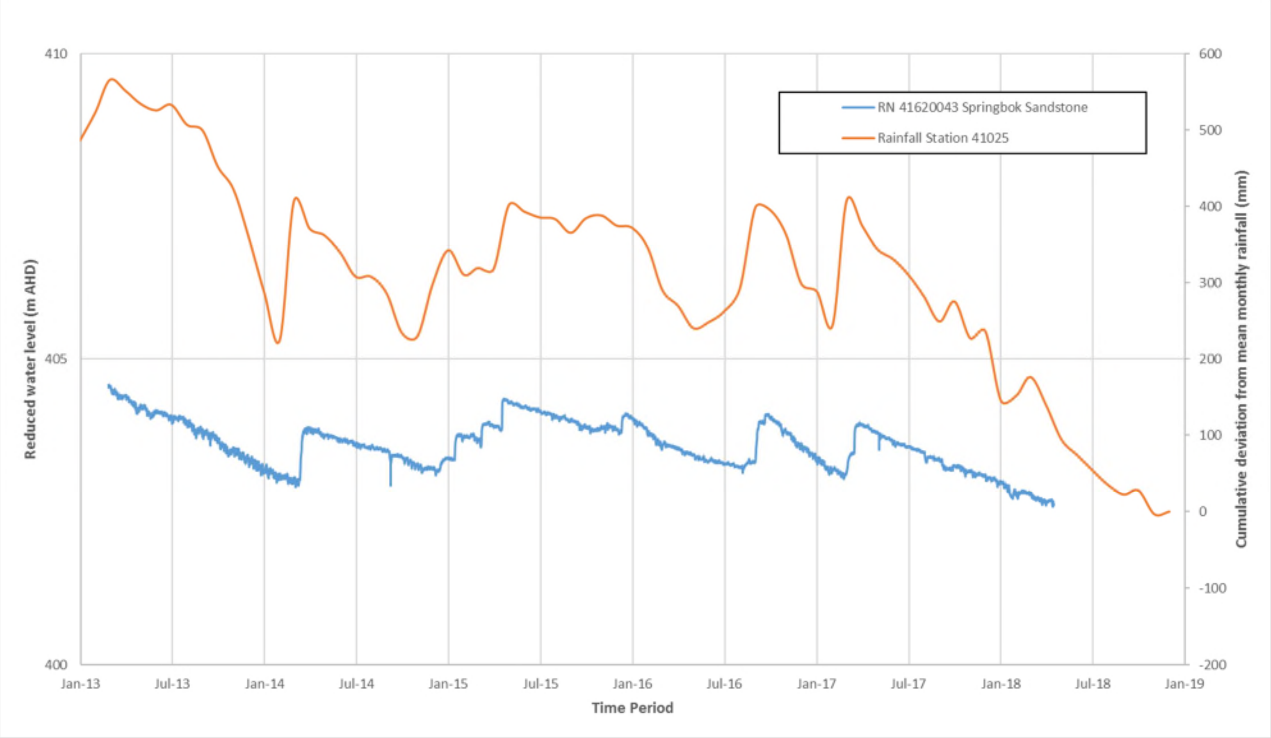


Figure 16 Stratheden-63 hydrograph (Springbok Sandstone aquifer)

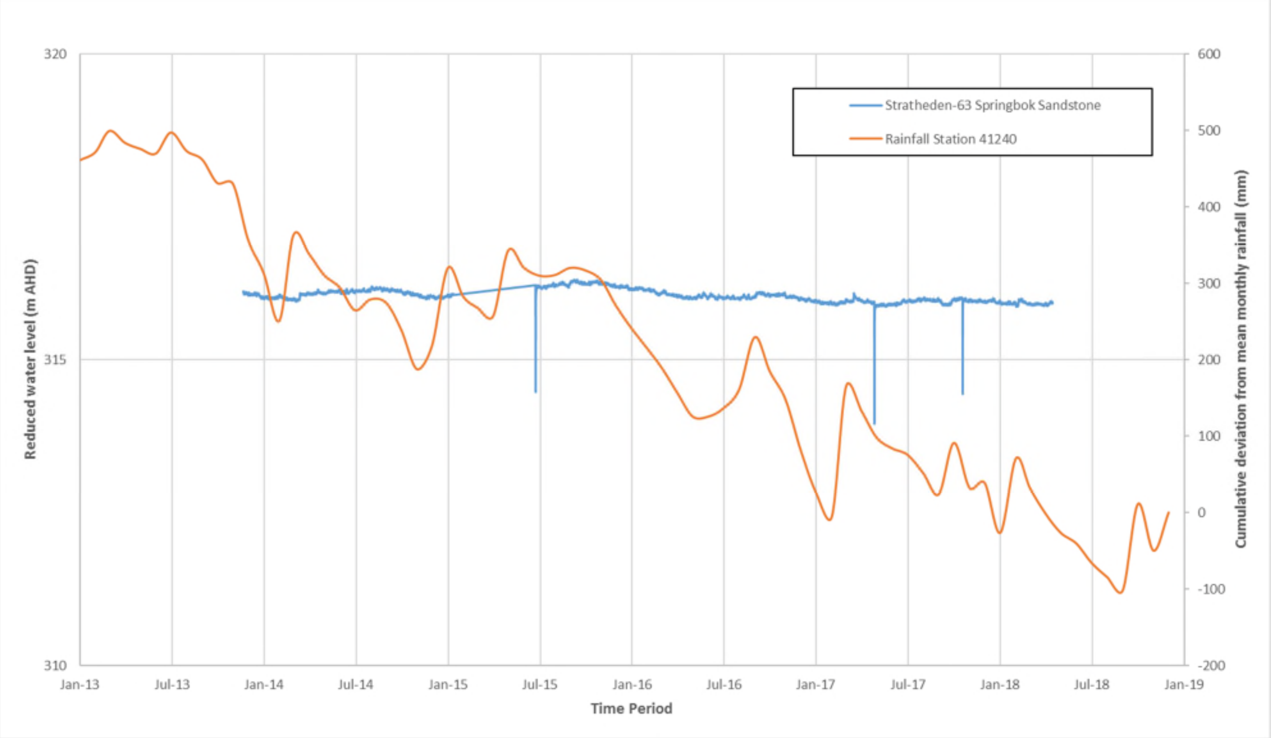


Figure 17 Meenawarra-21 hydrograph (Springbok Sandstone aquifer)

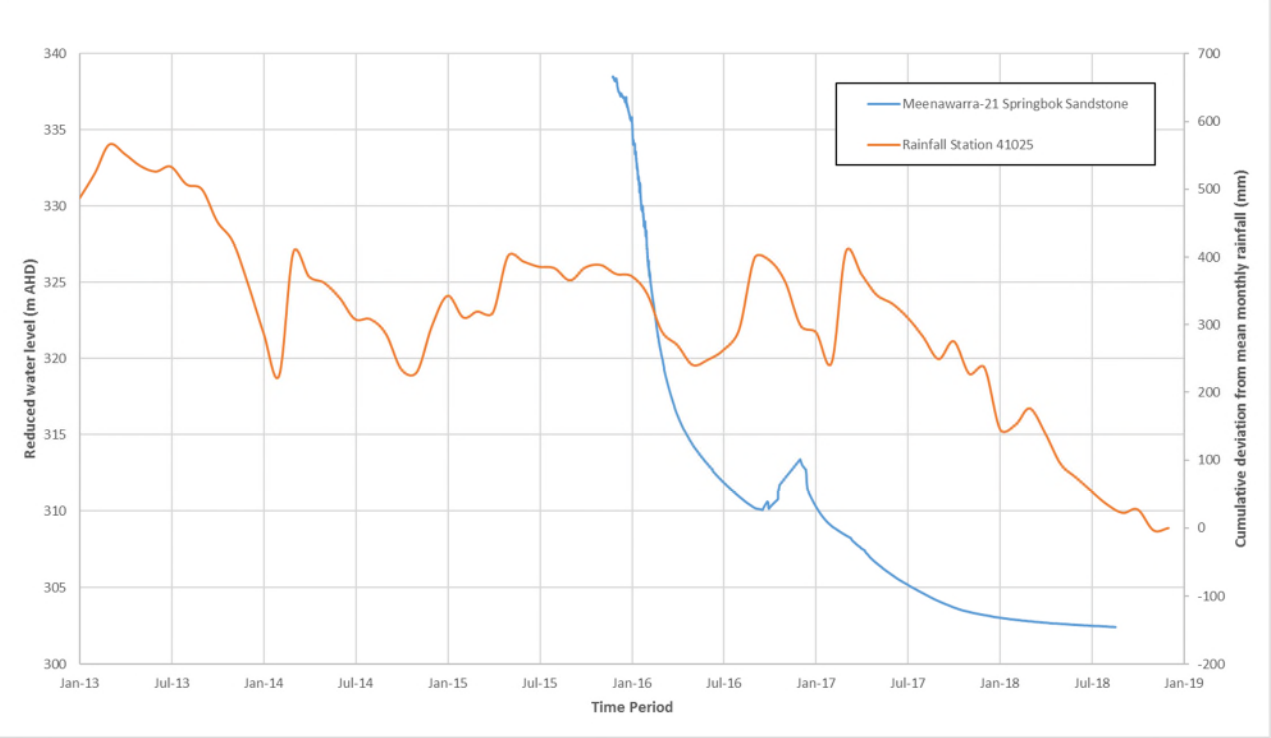


Figure 18 Burunga Lane-176 hydrograph (Hutton Sandstone aquifer)

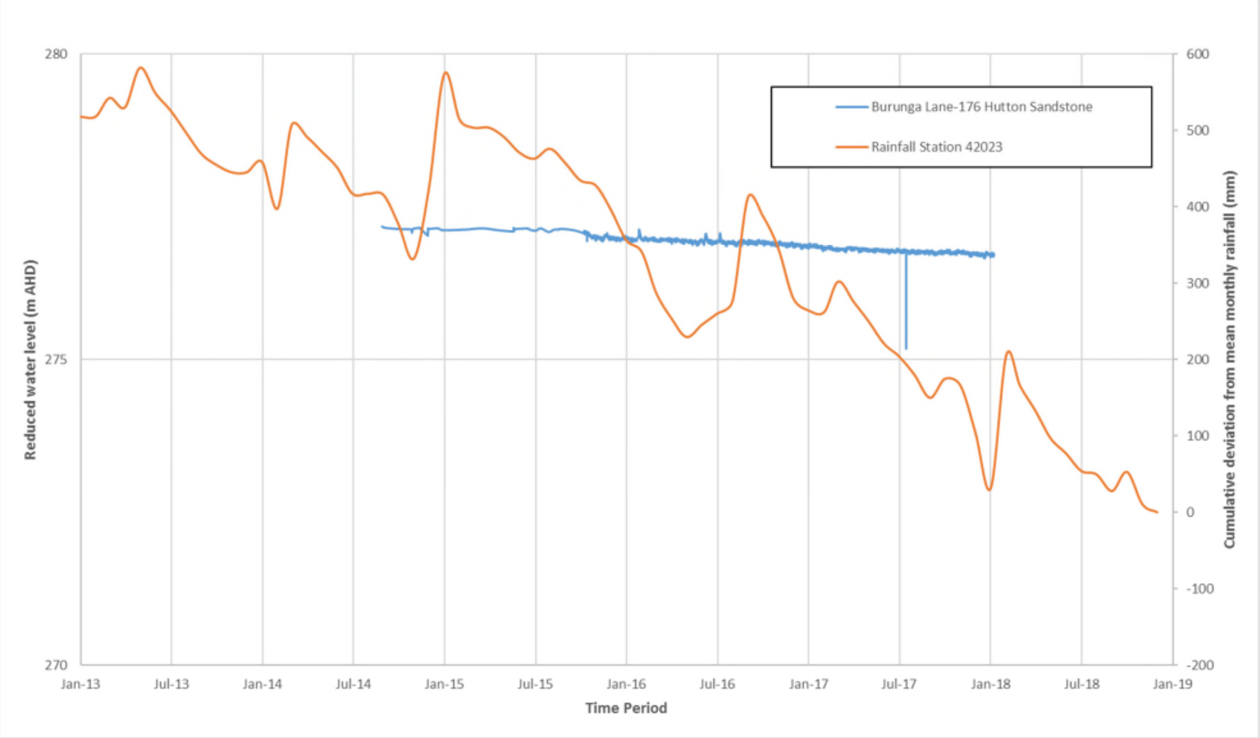


Figure 18 Daandine-121 hydrograph (Hutton Sandstone aquifer)

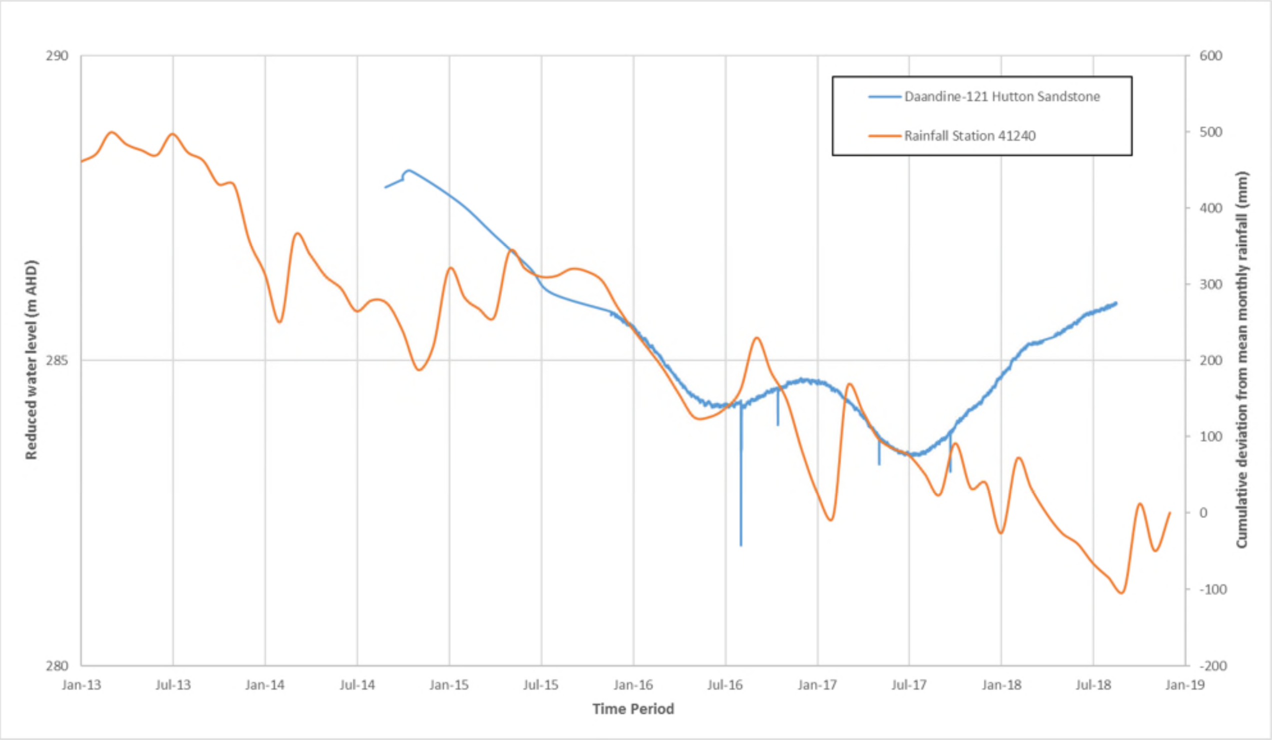
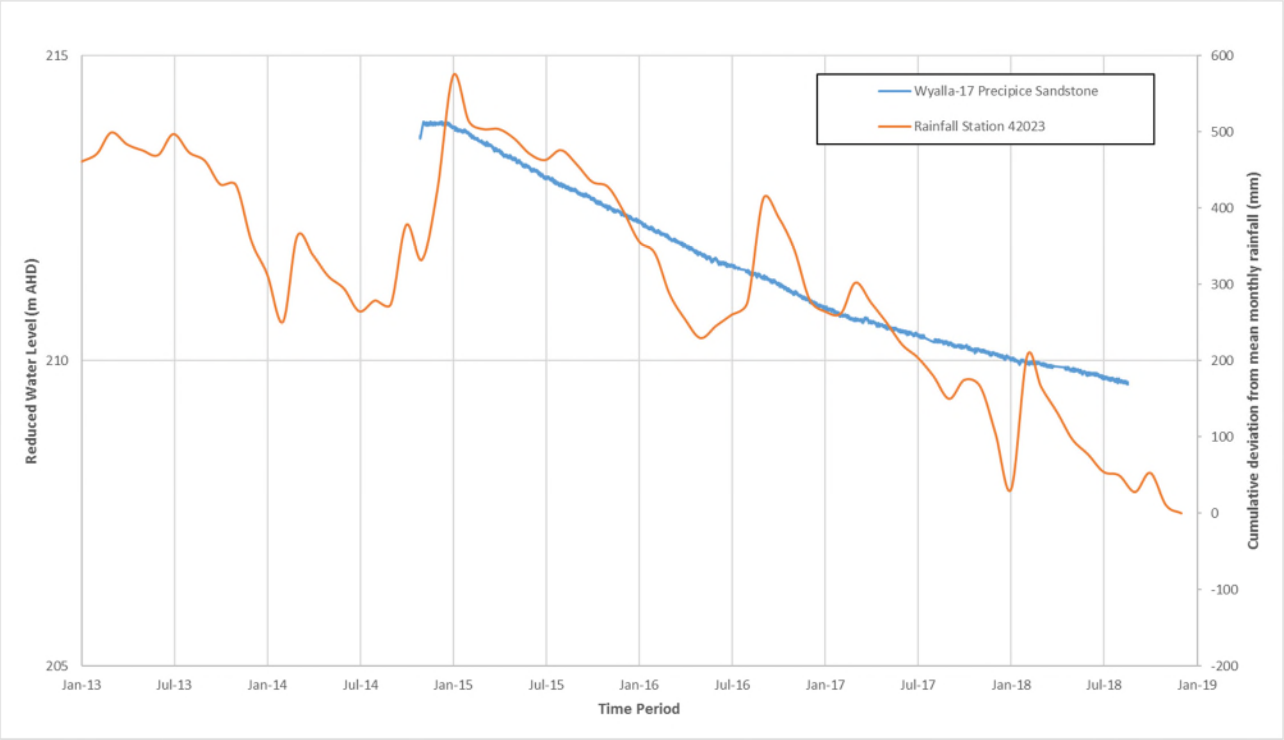


Figure 20 Wyalla-17 hydrograph (Precipice Sandstone aquifer)



Appendix D Stage 2 CSG WMMP Monitoring Network

Location ID	Figure ID	OGIA UWIR Site ID	OGIA monitoring Point ID	Latitude	Longitude	Target Aquifer	Status	Monitoring point purpose			
								Level / pressure	Quality	CA-WCM flux	Early warning
Bora Creek-10	BC10_WCM	124	579	-27.9245	151.1249	WCM	Installed	✓			
Burunga Lane-174	BL174_EF	91	625	-26.2427	150.0502	Evergreen	Installed	✓			
Burunga Lane-174	BL174_PS	91	478, 479	-26.2427	150.0502	Precipice	Installed	✓	✓		✓
Burunga Lane-176	BL176_HS	91	476, 477	-26.2429	150.05	Hutton	Installed	✓	✓		✓
Burunga Lane-176	BL176_WCM	91	473, 474, 475	-26.2429	150.05	WCM	Installed	✓			
Carn Brea-17	CB17_CA	8	38, 39	-27.533	151.3664	Condamine Alluvium	Installed	✓	✓	✓	(1)
Carn Brea-18	CB18_WCM	8	40, 41, 42, 43	-27.533	151.3663	WCM	Installed	✓	✓ (at 41 only)	✓	
Carn Brea-19	CB19_EF	8	46	-27.533	151.3662	Evergreen	Installed	✓			
Carn Brea-19	CB19_HS	8	44, 45	-27.533	151.3662	Hutton	Installed	✓	✓		✓
Carn Brea-20	CB20_PS	8	47, 48	-27.533	151.366	Precipice	Installed	✓	✓		✓
Carn Brea-21	CB21_WCM	19	94	-27.4376	151.3575	WCM	Installed	✓		✓	
Carn Brea-23	CB23_CA	19	92	-27.438	151.3576	Condamine Alluvium	Installed	✓		✓	✓
Carn Brea-24	CB24_CAWCM	19	93	-27.438	151.3574	CA / WCM transition layer	Installed	✓		✓	
Castledean-18	CA18_SS	73	375	-26.5529	150.222	Springbok	Installed	✓			✓
Castledean-18	CA18_WCM	73	376, 377, 378	-26.5529	150.222	WCM	Installed	✓			
Daandine-121	DA121_HS	37	182, 183	-27.1004	150.9557	Hutton	Installed	✓	✓		✓
Daandine-123	DA123_WCM	32	159	-27.1441	150.9481	WCM	Installed	✓			
Daandine-124	DA124_WF	32	157, 158	-27.1441	150.948	Westbourne	Installed	✓	✓		
Daandine-134	DA134_WCM	32	162, 163	-27.144	150.9486	WCM	Installed	✓			
Daandine-134	DA134_WCMe	32	164	-27.144	150.9486	Eurombah	Installed	✓			

Location ID	Figure ID	OGIA UWIR Site ID	OGIA monitoring Point ID	Latitude	Longitude	Target Aquifer	Status	Monitoring point purpose			
								Level / pressure	Quality	CA-WCM flux	Early warning
Daandine-161	DA161_CA	34	166	-27.1185	151.0756	Condamine Alluvium	Installed	✓		✓	(1)
Daandine-163	DA163_CAWCM	34	167	-27.12	151.0759	CA / WCM transition layer	Installed	✓		✓	
Daandine-164	DA164_WCM	34	168	-27.12	151.076	WCM	Installed	✓		✓	
Daandine-254	DA254_WCM	32	160, 161	-27.1442	150.9483	WCM	Installed	✓			
Daandine-263	DA263_WCM	37	181	-27.1024	150.9613	WCM	Installed	✓			
Daandine-264	DA264_WCM	29	148	-27.1533	151.0445	WCM	Installed	✓			
Dundee-20	DD20_WCM	55	283, 284, 285	-26.7435	150.6784	WCM	Installed	✓		✓	
Glenburnie-19	GB19_WCM	4	23	-27.6392	151.1677	WCM	Installed	✓			
Hopeland-17	HL17_SS	142	615	-26.9732	150.6118	Springbok	Installed	✓			✓
Hopeland-17	HL17_WCM	142	616, 617, 618	-26.9732	150.6118	WCM	Installed	✓			
Kedron-570	KD570_WCM	143	628	-26.4134	150.1537	Eurombah	Installed	✓			
Kedron-570	KD570_HS	143	629	-26.4134	150.1537	Hutton	Installed	✓			✓
Kedron-573	KD573_SS	143	630	-26.4143	150.1503	Springbok	Installed	✓			✓
Kedron-570	KD570_WCM	143	626, 627	-26.4134	150.1537	WCM	Installed	✓			
Kogan North-56	KN56_WCM	42	209	-27.0093	150.9003	WCM	Installed	✓		✓	
Kogan North-79	KN79_CAWCM	42	208	-26.9989	150.9018	CA / WCM transition layer	Installed	✓		✓	
Kogan North-79	KN79_CA	42	207	-26.9989	150.9018	Condamine Alluvium	Installed	✓		✓	✓
Tipton-153	TP153_HS	17	620	-27.3586	151.1531	Hutton	Installed	✓			✓
Long Swamp-1	LS1_WCM	17	83	-27.3431	151.1242	WCM	Installed	✓			
Longswamp-7	LS7_WCM	28	145, 146, 147	-27.1843	151.1274	WCM	Installed	✓			
Macalister-5	MA5_CA	47	245	-26.8951	150.9543	Condamine Alluvium	Installed	✓		✓	✓
Macalister-8	MA8_WCM	47	244	-26.8951	150.9544	WCM	Installed	✓		✓	
Meenawarra-21	MW21_SS	7	619	-27.5798	151.1335	Springbok	Installed	✓			✓

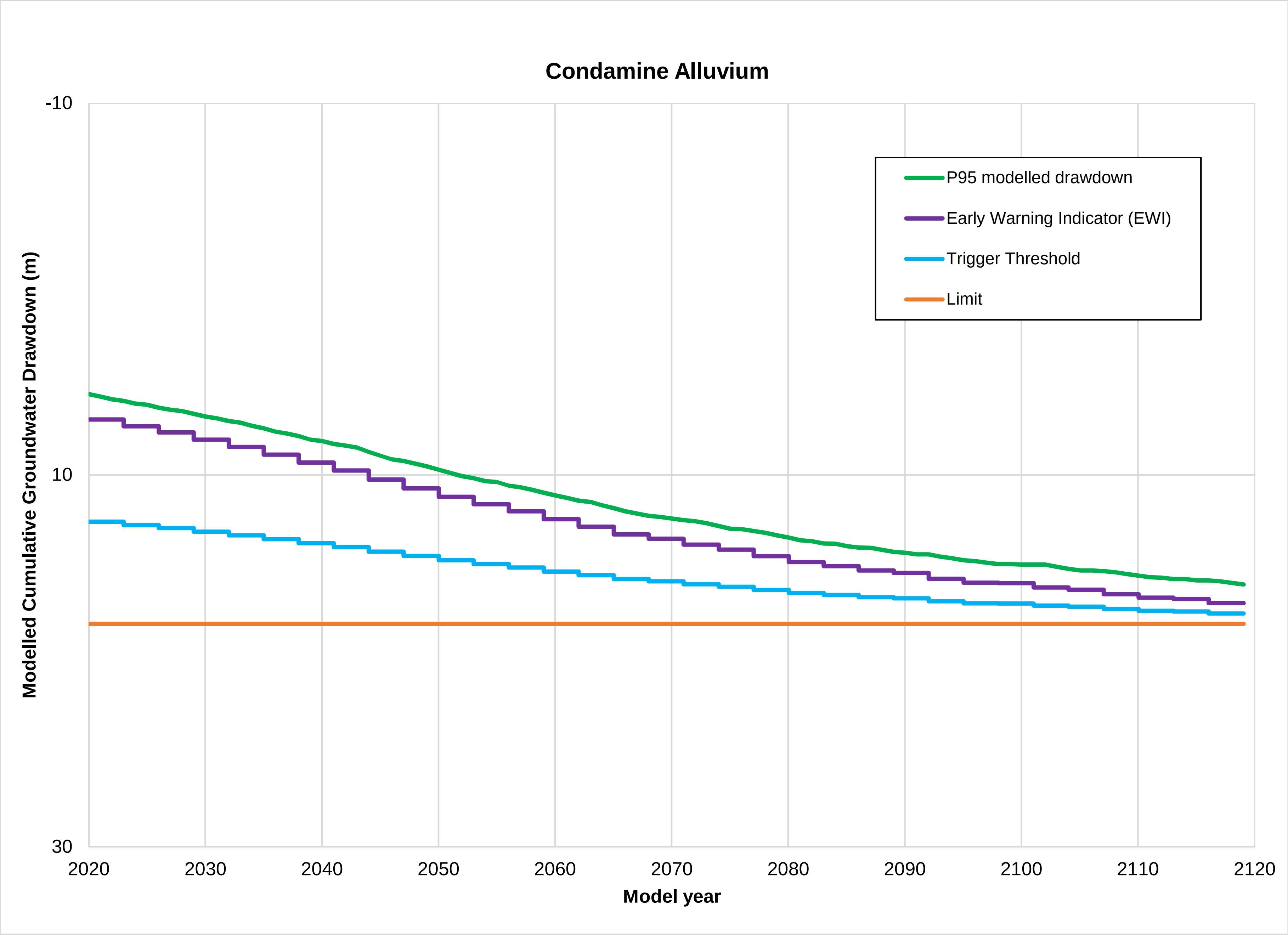
Location ID	Figure ID	OGIA UWIR Site ID	OGIA monitoring Point ID	Latitude	Longitude	Target Aquifer	Status	Monitoring point purpose			
								Level / pressure	Quality	CA-WCM flux	Early warning
Meenawarra-21	MW21_WCM	7	34, 35, 36	-27.5798	151.1335	WCM	Installed	✓			
Meenawarra-5	MW5_WCM	7	33	-27.5779	151.1338	WCM	Installed	✓			
Pampas-18	PP18_CA	5	24	-27.6147	151.2267	Condamine Alluvium	Installed	✓		✓	✓
Pampas-5	PP5_WCM	5	25	-27.6146	151.2267	WCM	Installed	✓		✓	
Plainview-35	PV35_WCM	15	77	-27.3842	151.2044	WCM	Installed	✓			
Plainview-25	PV25_CAWCM	23	120	-27.2521	151.2922	CA / WCM transition layer	Installed	✓		✓	
Plainview-25	PV25_CA	23	119	-27.2521	151.2922	Condamine Alluvium	Installed	✓		✓	✓
Plainview-25	PV25_WCM	23	121	-27.2521	151.2922	WCM	Installed	✓		✓	
RN 41620043	41620043_SS	124	578	-27.9222	151.1214	Springbok	Installed	✓			✓
RN 42230088	42230088_CA	5	24	-27.5898	151.2341	Condamine Alluvium	Installed	✓		✓	✓
RN 42230209	42230209_CA	55	281, 282	-26.7422	150.6799	Condamine Alluvium	Installed	✓	✓	✓	✓
RN 42231294	42231294_CA	14	75	-27.3993	151.5484	Condamine Alluvium	Installed	✓		✓	✓
RN 42231295	42231295_WCM	14	76	-27.3975	151.5619	WCM	Installed	✓		✓	
RN 42231339	42231339_CA	9	49	-27.5306	151.5037	Condamine Alluvium	Installed	✓			✓
RN 42231370	42231370_CA	10	51, 52	-27.4915	151.3932	Condamine Alluvium	Installed	✓	✓		(1)
RN 42231463	42231463_CA	8	37	-27.5488	151.313	Condamine Alluvium	Installed	✓		✓	✓
Stratheden-63	SE63_SS	29	622, 623	-27.1989	151.0268	Springbok	Installed	✓	✓		✓
Tipton-157	TP157_WCM	13	72, 73, 74	-27.3981	151.0889	WCM	Installed	✓			
Tipton-195	TP195_CA	18	84, 85	-27.3205	151.2054	Condamine Alluvium	Installed	✓	✓	✓	✓
Tipton-196A	TP196_CAWCM	18	86	-27.3202	151.205	CA / WCM transition layer	Installed	✓		✓	
Tipton-197	TP197_WCM	18	88, 89, 90, 91	-27.3202	151.2053	WCM	Installed	✓	✓ (at 89 only)	✓	

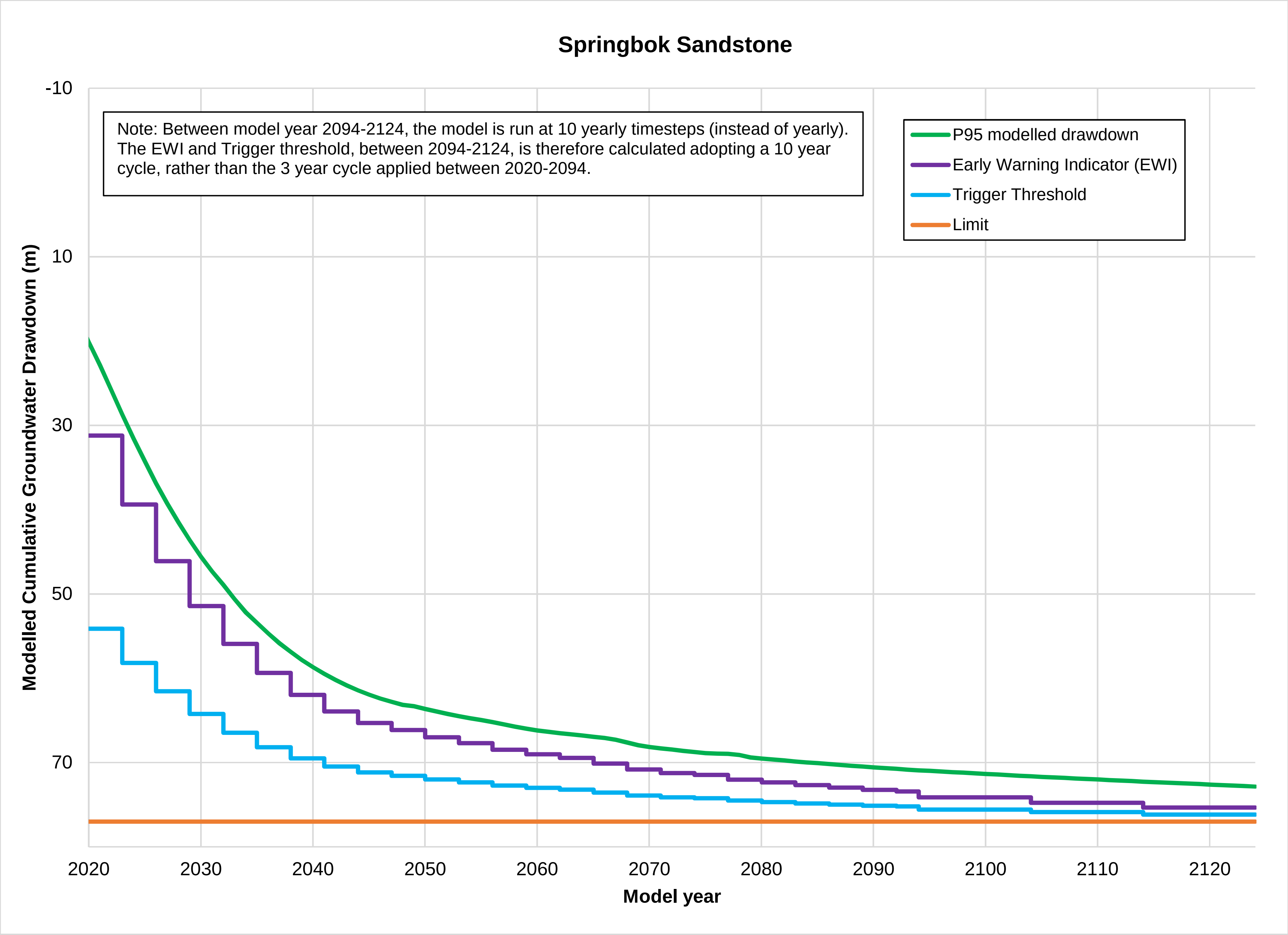
Location ID	Figure ID	OGIA UWIR Site ID	OGIA monitoring Point ID	Latitude	Longitude	Target Aquifer	Status	Monitoring point purpose			
								Level / pressure	Quality	CA-WCM flux	Early warning
Tipton-204	TP204_CAWCM	50	150	-27.1496	151.2094	CA / WCM transition layer	Installed	✓		✓	
Tipton-204	TP204_CA	30	149	-27.1496	151.2094	Condamine Alluvium	Installed	✓		✓	✓
Tipton-204	TP204_WCM	50	151	-27.1496	151.2094	WCM	Installed	✓		✓	
Tipton-206	TP206_WCMe	27	141	-27.2157	151.3489	Eurombah	Installed	✓			
Tipton-206	TP206_WCMc	27	142	-27.2157	151.3489	WCM	Installed	✓		✓	
Tipton-221	TP221_CA	27	138	-27.2156	151.3489	Condamine Alluvium	Installed	✓		✓	✓
Tipton-222	TP222_CAWCM	27	139	-27.2156	151.3488	CA / WCM transition layer	Installed	✓		✓	
Macalister 7	MA7_CA	41	203	-27.01	151.114	Condamine Alluvium	Installed	✓		✓	✓
Macalister 6	MA6_WCM	41	204	-27.01	151.114	WCM	Installed	✓		✓	
Macalister 6	MA6_WCMe	41	205	-27.01	151.114	Eurombah	Installed	✓			
Wyalla-17	WY17_HS	48	624	-26.8663	150.755	Hutton	Installed	✓			✓
UWIR Site 94	UWIR Site 94_HS	94	497	-26.2301	149.9534	Hutton	Proposed (UWIR)	✓			✓
UWIR Site 94	UWIR Site 94_WCM	94	494, 495, 496	-26.2301	149.9534	WCM	Proposed (UWIR)	✓			
Wyalla-16	WY16_CA	48	246, 248	-26.8662	150.755	Condamine Alluvium	Installed	✓	✓	✓	✓
Wyalla-17	WY17_PS	48	252, 253	-26.8663	150.755	Precipice	Installed	✓	✓		✓
Wyalla-18	WY18_WCM	48	249, 250, 251	-26.8661	150.7551	WCM	Installed	✓		✓	

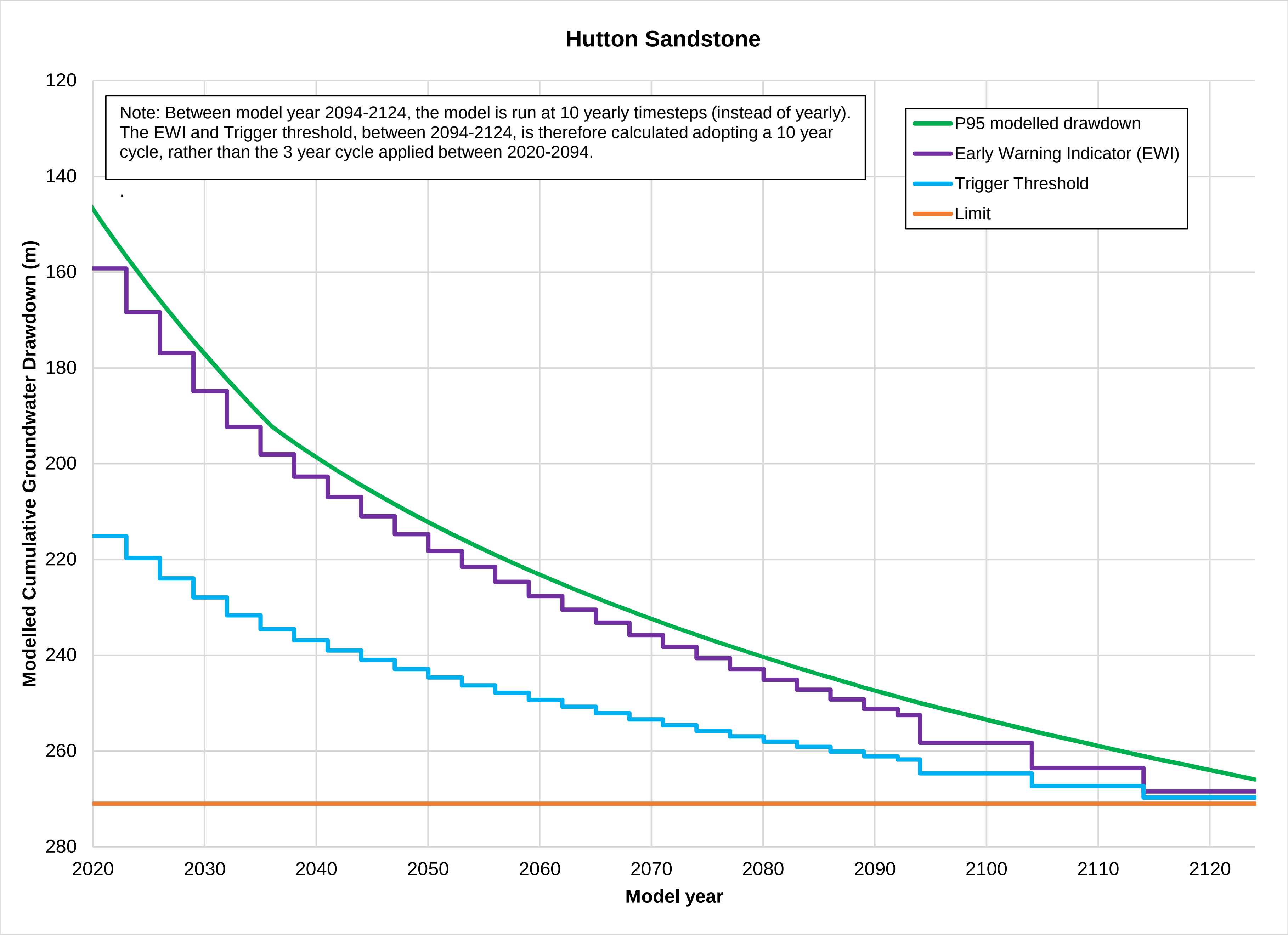
Note:

(1) The baseline monitoring assessment indicated Condamine Alluvium bores RN 42231370, Daandine-161 and Carn Brea-17, exhibited regular drawdown and recovery cycles of several metres as a consequence of nearby groundwater extraction for agricultural or other non-CSG uses. The magnitude of these groundwater fluctuations is such that these bores have limited use for early warning monitoring, and as such, have been excluded as early warning monitoring bores in the SGP Stage 2 WMMP.

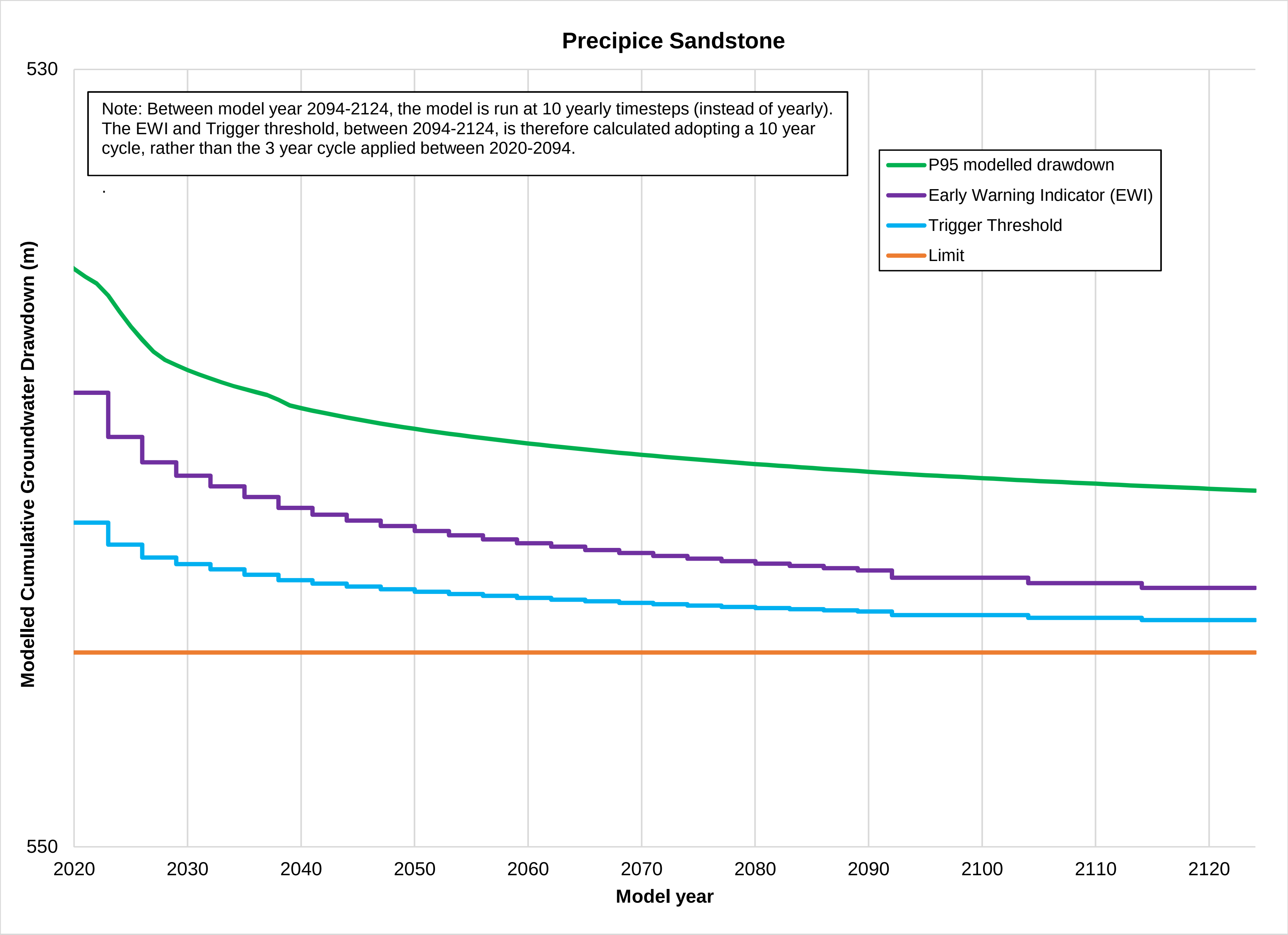
Appendix E EWMS for the Stage 2 CSG W


Condamine Alluvium
-10
10
30
Modelled Cumulative Groundwater Drawdown (m)
2020
2030
2040
2050
2060
2070
2080
2090
2100
2110
2120
Model year
P95 modelled drawdown
Early Warning Indicator (EWI)
Trigger Threshold
Limit


Springbok Sandstone
Note: Between model year 2094-2124, the model is run at 10 yearly timesteps (instead of yearly). The EWI and Trigger threshold, between 2094-2124, is therefore calculated adopting a 10 year cycle, rather than the 3 year cycle applied between 2020-2094.
P95 modelled drawdown
Early Warning Indicator (EWI)
Trigger Threshold
Limit
Modelled Cumulative Groundwater Drawdown (m)
-10
10
30
50
70
2020
2030
2040
2050
2060
2070
2080
2090
2100
2110
2120
Model year



Hutton Sandstone
Note: Between model year 2094-2124, the model is run at 10 yearly timesteps (instead of yearly). The EWI and Trigger threshold, between 2094-2124, is therefore calculated adopting a 10 year cycle, rather than the 3 year cycle applied between 2020-2094.
P95 modelled drawdown
Early Warning Indicator (EWI)
Trigger Threshold
Limit
Modelled Cumulative Groundwater Drawdown (m)
120
140
160
180
200
220
240
260
280
2020
2030
2040
2050
2060
2070
2080
2090
2100
2110
2120
Model year


Precipice Sandstone
530
550
Note: Between model year 2094-2124, the model is run at 10 yearly timesteps (instead of yearly). The EWI and Trigger threshold, between 2094-2124, is therefore calculated adopting a 10 year cycle, rather than the 3 year cycle applied between 2020-2094.
P95 modelled drawdown
Early Warning Indicator (EWI)
Trigger Threshold
Limit
Modelled Cumulative Groundwater Drawdown (m)
2020
2030
2040
2050
2060
2070
2080
2090
2100
2110
2120
Model year

APPENDIX H EWMS LEVELS

Model Period from	Model Period to	Condamine Alluvium EWMS (m)			Springbok Sandstone EWMS (m)			Hutton Sandstone EWMS (m)			Precipice Sandstone EWMS (m)		
		Limit	EWI	Trigger threshold	Limit	EWI	Trigger threshold	Limit	EWI	Trigger threshold	Limit	EWI	Trigger threshold
Jan-2021	Dec-2023	18.0	7.0	12.5	77.0	31.2	54.1	271.0	159.2	215.1	545.0	538.3	541.7
Jan-2024	Dec-2026	18.0	7.4	12.7	77.0	39.4	58.2	271.0	168.4	219.7	545.0	539.5	542.2
Jan-2027	Dec-2029	18.0	7.7	12.8	77.0	46.1	61.5	271.0	176.9	223.9	545.0	540.1	542.6
Jan-2030	Dec-2032	18.0	8.1	13.0	77.0	51.4	64.2	271.0	184.8	227.9	545.0	540.5	542.7
Jan-2033	Dec-2035	18.0	8.5	13.2	77.0	55.9	66.5	271.0	192.3	231.7	545.0	540.7	542.9
Jan-2036	Dec-2038	18.0	8.9	13.5	77.0	59.4	68.2	271.0	198.1	234.5	545.0	541.0	543.0
Jan-2039	Dec-2041	18.0	9.3	13.7	77.0	62.0	69.5	271.0	202.7	236.8	545.0	541.3	543.1
Jan-2042	Dec-2044	18.0	9.7	13.9	77.0	63.9	70.5	271.0	207.0	239.0	545.0	541.5	543.2
Jan-2045	Dec-2047	18.0	10.2	14.1	77.0	65.3	71.2	271.0	211.0	241.0	545.0	541.6	543.3
Jan-2048	Dec-2050	18.0	10.7	14.4	77.0	66.1	71.6	271.0	214.7	242.8	545.0	541.7	543.4
Jan-2051	Dec-2053	18.0	11.2	14.6	77.0	67.0	72.0	271.0	218.2	244.6	545.0	541.9	543.4
Jan-2054	Dec-2056	18.0	11.6	14.8	77.0	67.7	72.3	271.0	221.5	246.3	545.0	542.0	543.5
Jan-2057	Dec-2059	18.0	11.9	15.0	77.0	68.5	72.7	271.0	224.7	247.8	545.0	542.1	543.5
Jan-2060	Dec-2062	18.0	12.4	15.2	77.0	69.0	73.0	271.0	227.6	249.3	545.0	542.2	543.6
Jan-2063	Dec-2065	18.0	12.8	15.4	77.0	69.4	73.2	271.0	230.5	250.7	545.0	542.3	543.6

Model Period from	Model Period to	Condamine Alluvium EWMS (m)			Springbok Sandstone EWMS (m)			Hutton Sandstone EWMS (m)			Precipice Sandstone EWMS (m)		
		Limit	EWI	Trigger threshold	Limit	EWI	Trigger threshold	Limit	EWI	Trigger threshold	Limit	EWI	Trigger threshold
Jan-2066	Dec-2068	18.0	13.2	15.6	77.0	70.1	73.6	271.0	233.2	252.1	545.0	542.4	543.7
Jan-2069	Dec-2071	18.0	13.4	15.7	77.0	70.8	73.9	271.0	235.8	253.4	545.0	542.4	543.7
Jan-2072	Dec-2074	18.0	13.7	15.9	77.0	71.2	74.1	271.0	238.2	254.6	545.0	542.5	543.8
Jan-2075	Dec-2077	18.0	14.0	16.0	77.0	71.5	74.2	271.0	240.6	255.8	545.0	542.6	543.8
Jan-2078	Dec-2080	18.0	14.4	16.2	77.0	72.0	74.5	271.0	242.9	256.9	545.0	542.7	543.8
Jan-2081	Dec-2083	18.0	14.7	16.3	77.0	72.4	74.7	271.0	245.1	258.0	545.0	542.7	543.9
Jan-2084	Dec-2086	18.0	14.9	16.4	77.0	72.7	74.8	271.0	247.2	259.1	545.0	542.8	543.9
Jan-2087	Dec-2089	18.0	15.1	16.6	77.0	73.0	75.0	271.0	249.2	260.1	545.0	542.8	543.9
Jan-2090	Dec-2092	18.0	15.3	16.6	77.0	73.2	75.1	271.0	251.2	261.1	545.0	542.9	543.9
Jan-2093	Dec-2095	18.0	15.6	16.8	77.0	74.1	75.6	271.0	258.3	264.6	545.0	543.1	544.0
Jan-2096	Dec-2098	18.0	15.8	16.9	77.0	74.1	75.6	271.0	258.3	264.6	545.0	543.1	544.0
Jan-2099	Dec-2101	18.0	15.8	16.9	77.0	74.1	75.6	271.0	258.3	264.6	545.0	543.1	544.0
Jan-2102	Dec-2104	18.0	16.0	17.0	77.0	74.1	75.6	271.0	258.3	264.6	545.0	543.1	544.0
Jan-2105	Dec-2107	18.0	16.2	17.1	77.0	74.8	75.9	271.0	263.6	267.3	545.0	543.2	544.1
Jan-2108	Dec-2110	18.0	16.4	17.2	77.0	74.8	75.9	271.0	263.6	267.3	545.0	543.2	544.1

Model Period from	**Model Period to**	**Condamine Alluvium EWMS (m)**			**Springbok Sandstone EWMS (m)**			**Hutton Sandstone EWMS (m)**			**Precipice Sandstone EWMS (m)**		
		Limit	**EWI**	**Trigger threshold**	**Limit**	**EWI**	**Trigger threshold**	**Limit**	**EWI**	**Trigger threshold**	**Limit**	**EWI**	**Trigger threshold**
Jan-2111	Dec-2113	18.0	16.6	17.3	77.0	74.8	75.9	271.0	263.6	267.3	545.0	543.2	544.1
Jan-2114	Dec-2116	18.0	16.7	17.3	77.0	75.3	76.2	271.0	268.4	269.7	545.0	543.3	544.2
Jan-2117	Dec-2119	18.0	16.9	17.4	77.0	75.3	76.2	271.0	268.4	269.7	545.0	543.3	544.2

APPENDIX I PEER REVIEW AND MINISTERIAL ENDORSEMENT

IGS Innovative Groundwater Solutions

Mr. Greg Manning
Assistant Secretary
Assessments (WA, SA, NT) and Post Approvals
Department of the Environment and Energy
GPO Box 787
CANBERRA ACT 2600

19 March 2019

Dear Mr. Manning

RE: Letter of endorsement for the Surat Gas Project Stage 2 Coal Seam Gas Water Monitoring and Management Plan

Introduction

On 19th December 2013 the Australian Government Minister for the Environment approved the Surat Gas Expansion Project (EPBC 2010/5344) subject to conditions. Conditions 13(a) to 13(r) require that prior to commencement the proponent must submit a Stage 1 Coal Seam Gas Water Monitoring and Management Plan (Stage 1 CSG WMMP) for the approval of the Minister. The Stage 1 CSG WMMP was submitted to the Department of Environment and Energy by Arrow Energy in December 2017 and accepted in revised form in December 2018.

Conditions 17(a) to 17(i) require that prior to Stage 2 the approval holder must submit a Stage 2 CSG WMMP for the approval of the Minister, while Condition 18 specifies "*The Stage 2 CSG WMMP must be peer reviewed by a suitably qualified water resources expert/s approved by the Minister in writing. The peer review must be submitted to the Minister together with the Stage 2 CSG WMMP and a statement from the suitably qualified water resources expert/s stating that they carried out the peer review and endorse the findings of the Stage 2 CSG WMMP.*"

Compliance with Approval Condition 17

As the *suitably qualified water resources expert* approved by the Minister for the Environment on 7 July 2015, I have been actively involved in regular reviews of the methodologies, results, interpretation and reporting of the assessments of potential impacts caused by the Action. These assessments have been documented in three technical memoranda and three supporting technical reports, in order to specifically address the approval conditions (see Table 1 below).

I have progressively reviewed and endorsed these three memoranda (Table 1) and supporting technical reports. Briefly, I consider the most significant contributions of my peer review role over the 18 months year to be:

1. Providing feedback on both the project design and preliminary interpretation of results for the GDE connectivity study, including plant-water-soil isotope analysis and numerical 'sandbox' modelling of connectivity at Lake Broadwater.
2. Requesting greater transparency and improved reporting on reasons for the differences in model results obtained from the OGIA 2012 and OGIA 2016 models using the different field development plans (FDP).
3. Requesting justification for the use of drawdown factors in addition to cumulative P95 model-predicted drawdowns for the early warning monitoring system (EWMS).
4. Requesting further explanation of observed groundwater level trends in the current monitoring network.

Table 1. Summary of memoranda, the Approval Conditions they address, and reference to the Appendix in which they are provided in the Stage 2 CSG WMMP.

Memorandum Title	Approval Conditions Addressed	Appendix
Groundwater Modelling and Research Technical Memorandum	17(b), 17(c), 17(d), 23	D
Stream Connectivity and GDE Impact Assessment Memorandum	13(c), 13(p), 17(f), 17(g)	E
Monitoring, Risk Response and Adaptive Management Memorandum	17(a), 17(e), 17(h), 17(i), 22	F

Summary

Based on my iterative peer review of the scientific assessments undertaken and the technical memoranda prepared over the last 18 months, my overall assessment is that Approval Conditions 17(a) to 17(i) have been adequately addressed in the Stage 2 CSG WMMP (see Table 2 below).

Accordingly, I hereby provide my professional endorsement of the findings of the Stage 2 CSG WMMP.

Sincerely,

Dr. Glenn Harrington
Director & Principal Hydrogeologist

Table 2. Suitably qualified water resource expert peer reviewer's assessment of whether Approval Condition 17 and sub-conditions therein have been adequately addressed in the Stage 2 CSG WMMP.

Approval Condition	Condition Description	Condition Addressed
17	Prior to Stage 2 the approval holder must submit a Stage 2 Coal Seam Gas Water Monitoring and Management Plan (Stage 2 CSG WMMP) to the Minister for approval, who may seek the advice of an expert panel. The Stage 2 CSG WMMP must:	-
17(a)	Include all matters in the Stage 1 CSG WMMP, and discuss how the Stage 1 CSG WMMP is informing adaptive management for the Stage 2 CSG WMMP.	Yes
17(b)	Include any updated modelling for the project, including in respect of the OGIA model or any updates to the OGIA model by OGIA.	Yes
17(c)	Include an explanation of how the approval holder will contribute to the Condamine Interconnectivity Research Project. The Stage 2 CSG WMMP must present the findings of the Condamine Interconnectivity Research project and any modelling done by the OGIA to validate predicted drawdown and a review of trigger thresholds and corrective actions for the action.	Yes
17(d)	Report on the potential for flow reversal from the Condamine Alluvium to underlying aquifers, based on data obtained during the Stage 1 CSG WMMP.	Yes
17(e)	Review and update the monitoring network in Stage 1 WMMP to reflect changes in understanding of impacts to water resources, including from baseline monitoring and relevant research.	Yes
17(f)	Identify any predicted changes in stream connectivity due to groundwater drawdown from the action and assess potential impacts to groundwater dependent ecosystems due to any predicted changes in stream connectivity, including to water quality, quantity and ecology.	Yes
17(g)	Address any uncertainty in the groundwater dependency of ecosystems and springs with supporting evidence from field-based investigations for any groundwater-dependent ecosystems and springs confirmed in the OGIA model.	Yes
17(h)	Provide details of an ongoing monitoring plan that:	-
17(h) i	Sets out the frequency of monitoring and rationale for the frequency.	Yes
17(h) ii	Includes continued collection of baseline data for each monitoring site over the life of the project.	Yes
17(h) iii	Outlines the approach to be taken to analyse the results including the methods to determine trends to indicate potential impacts.	Yes
17(h) iv	Builds on the groundwater early warning system required at condition 13j and sets out early warning indicators and trigger thresholds and limits for groundwater and surface water.	Yes
17(i)	Include a risk based exceedance response plan that details the actions the approval holder will take and the timeframes in which those actions will be undertaken if: early warning indicators and trigger threshold values contained in the Stage 2 CSG WMMP are exceeded, or there are any emergency discharges.	Yes