Arrow Energy Pty Ltd

Surat Gas Project

Stage 1 CSG Water Monitoring and Management Plan

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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

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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 19.7ºC in winter to 32.5ºC 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)

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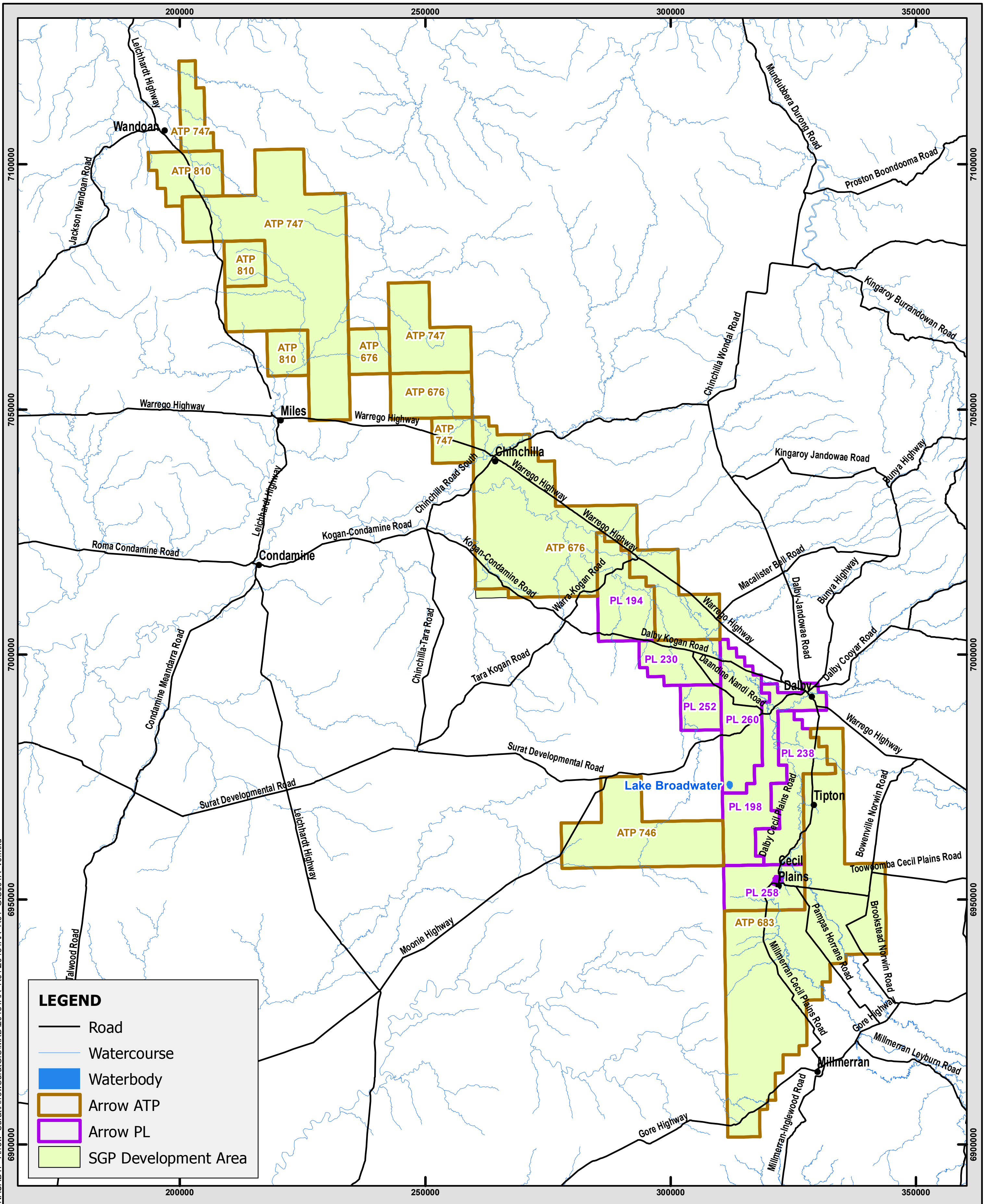

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Figure 2.1 Surat Gas Project area

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

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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.

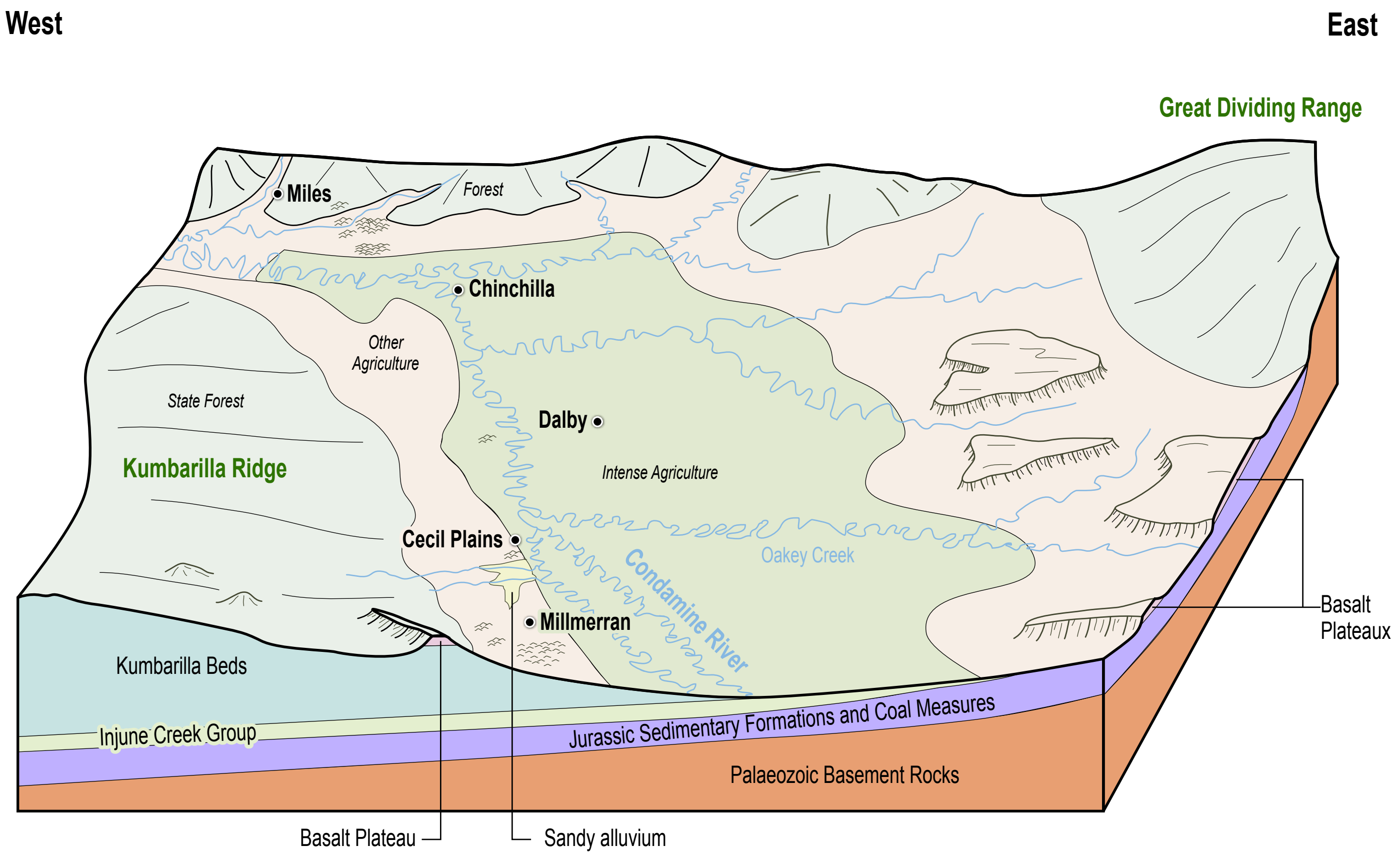

Figure 2.2 Landform characteristics of the Condamine River Valley

Source:
Arrow Energy Pty Ltd

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

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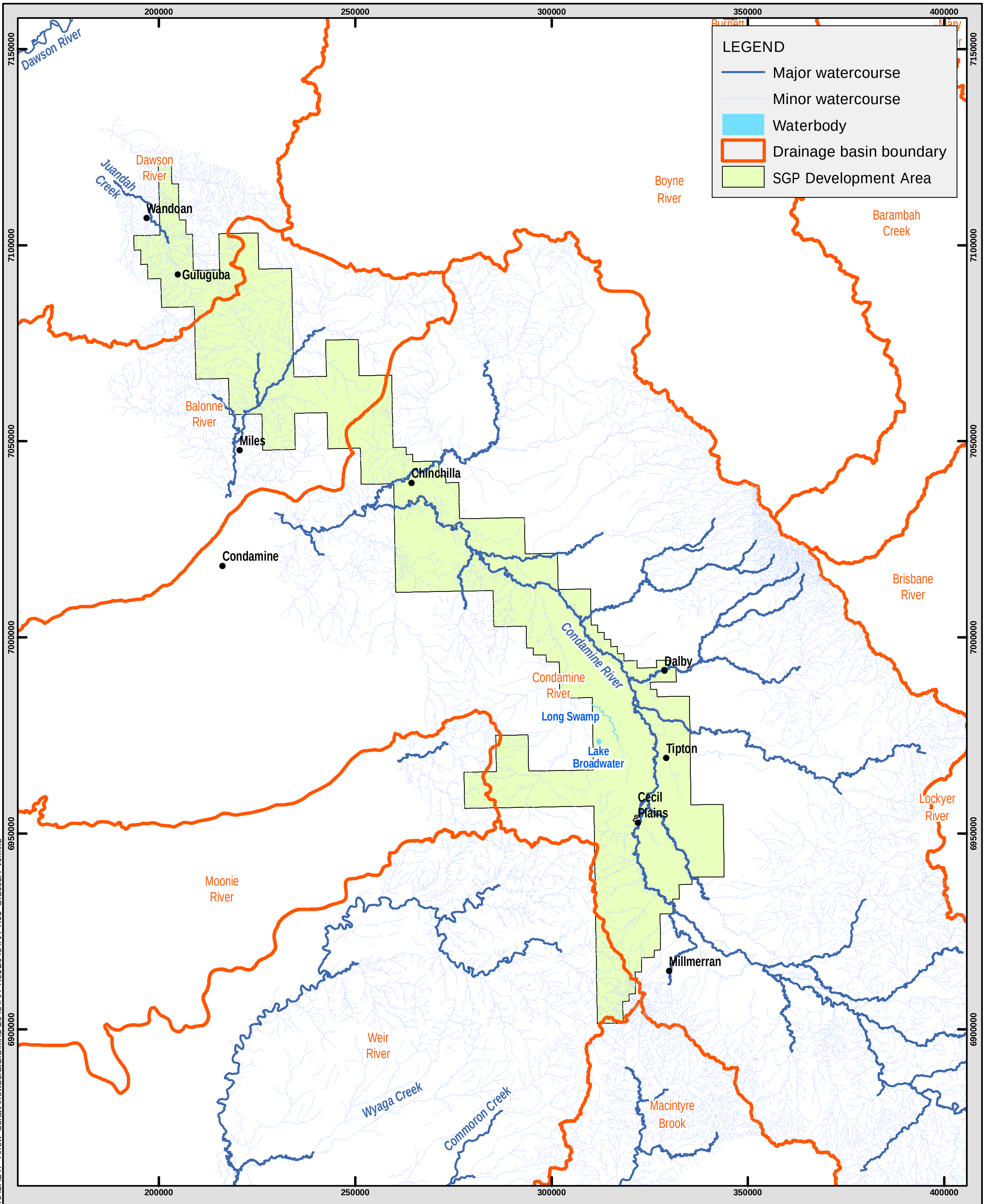

Figure 2.3 Major drainage systems in the Surat Gas Project area

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).

[8] Lacking flowing water, or marshy

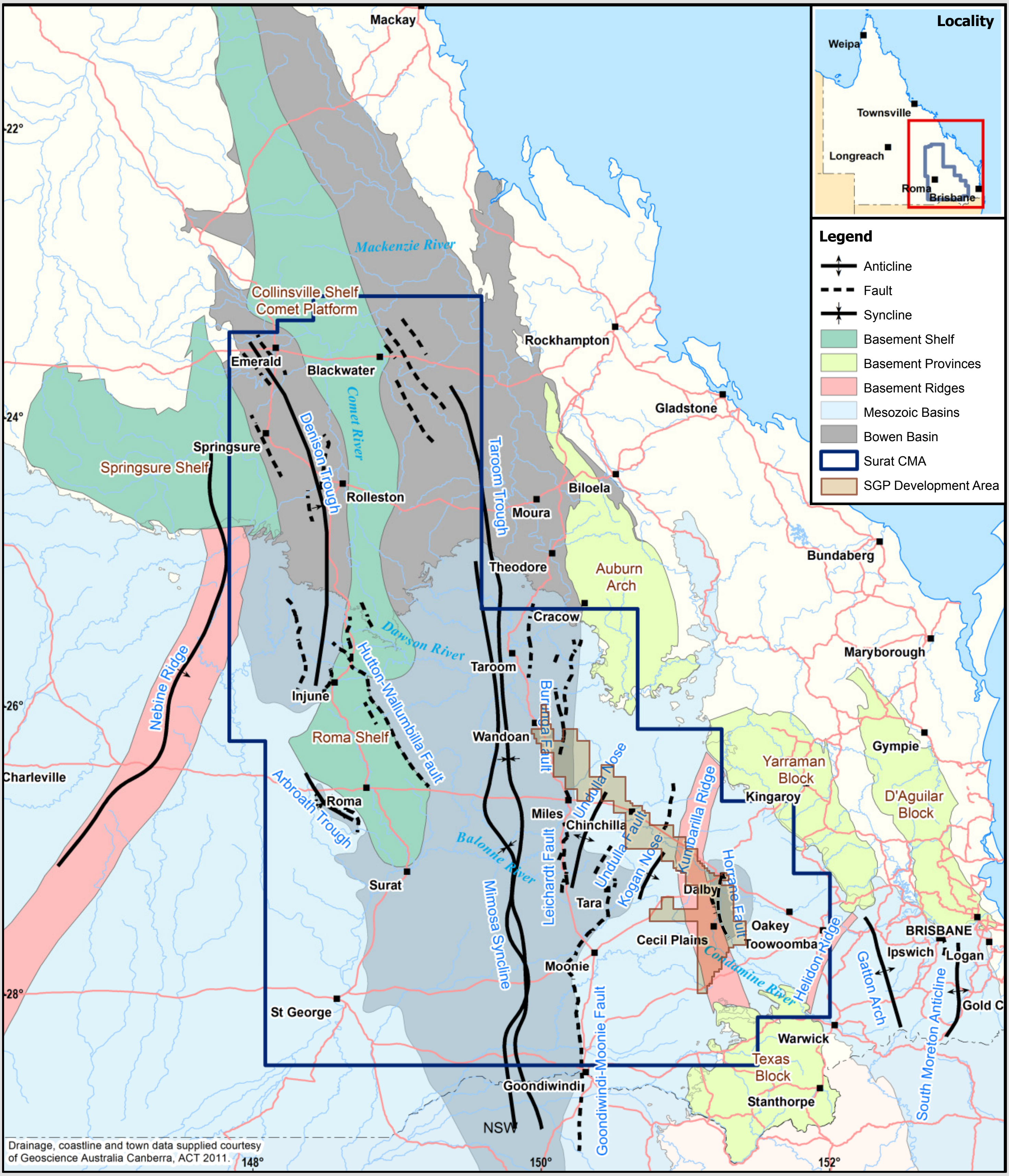

Figure 2.4 Major geological structures in the Surat CMA

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

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

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

Minor discontinuous aquifer	Major aquifer	Productive coal seam	Aquitard

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

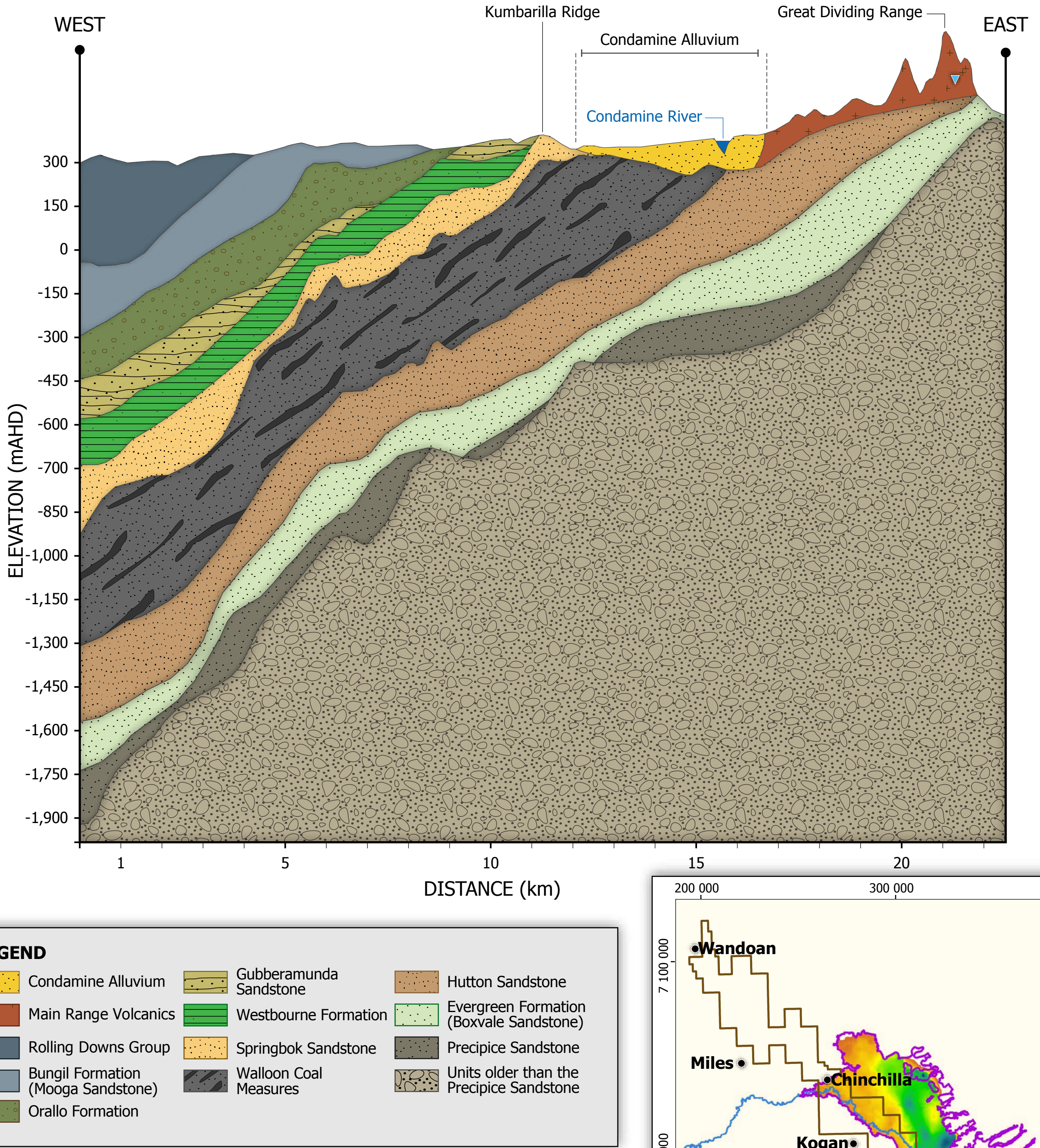
Condamine Alluvium

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.



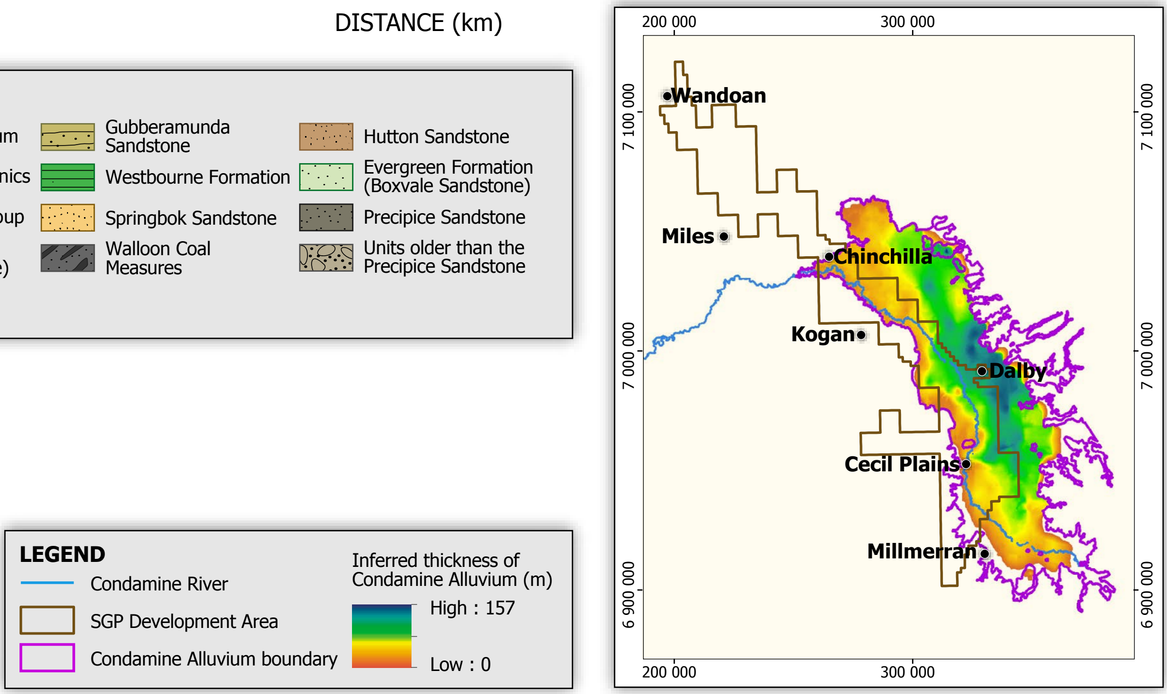


Figure 2.5 Schematic cross-section of Condamine Alluvium and underlying units

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

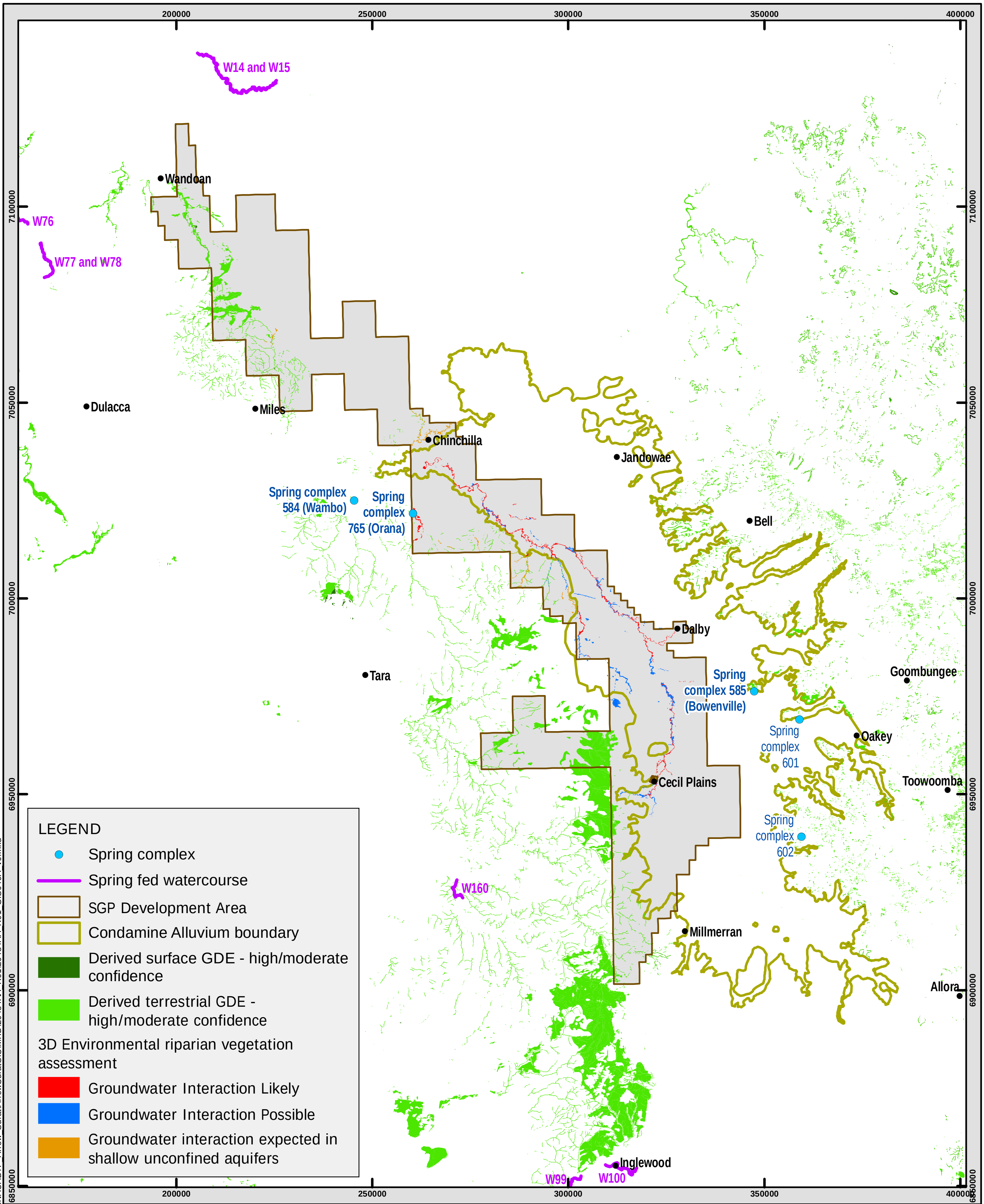

Figure 2.6 Known and potential GDEs

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

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

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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.

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

[14] Provided at the time of the SREIS

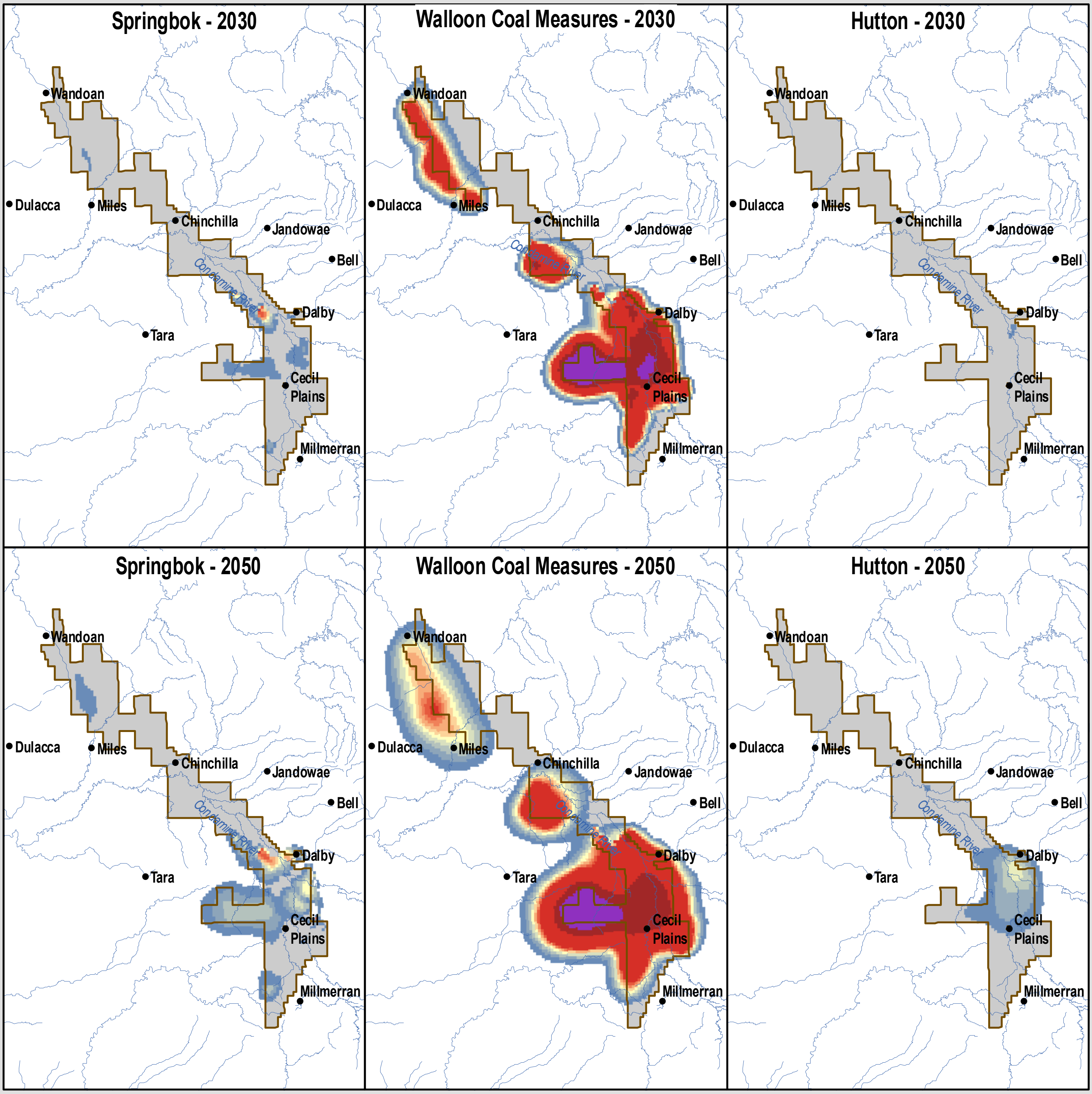
For the modelled period (up to 100 years from commencement) the flux change to the Condamine Alluvium due to cumulative water extraction was 79 GL for the calibrated model realisation, and 90 GL for the 95th percentile model realisation.

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).



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

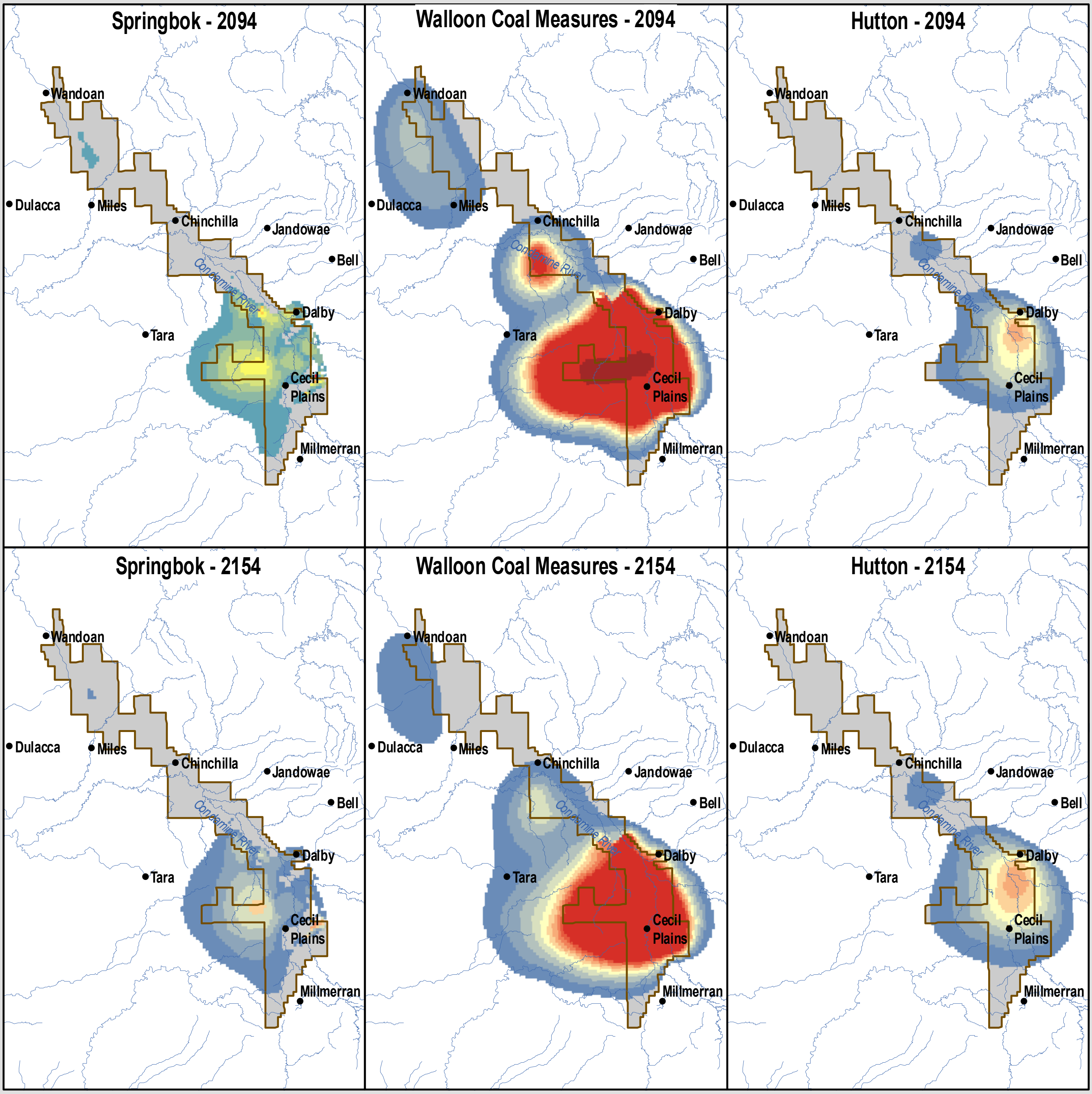
Source:
Arrow Energy Pty Ltd
GHD

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

N

Document: \\Abtfarcv01\data$\GIS\20484_ENAUABTF_Arrow_Surat\ArrowSuratGIS\MXD\20484AA_R01\20484AA_R01_GIS012A_v0.mxd



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 3.2 **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

N

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

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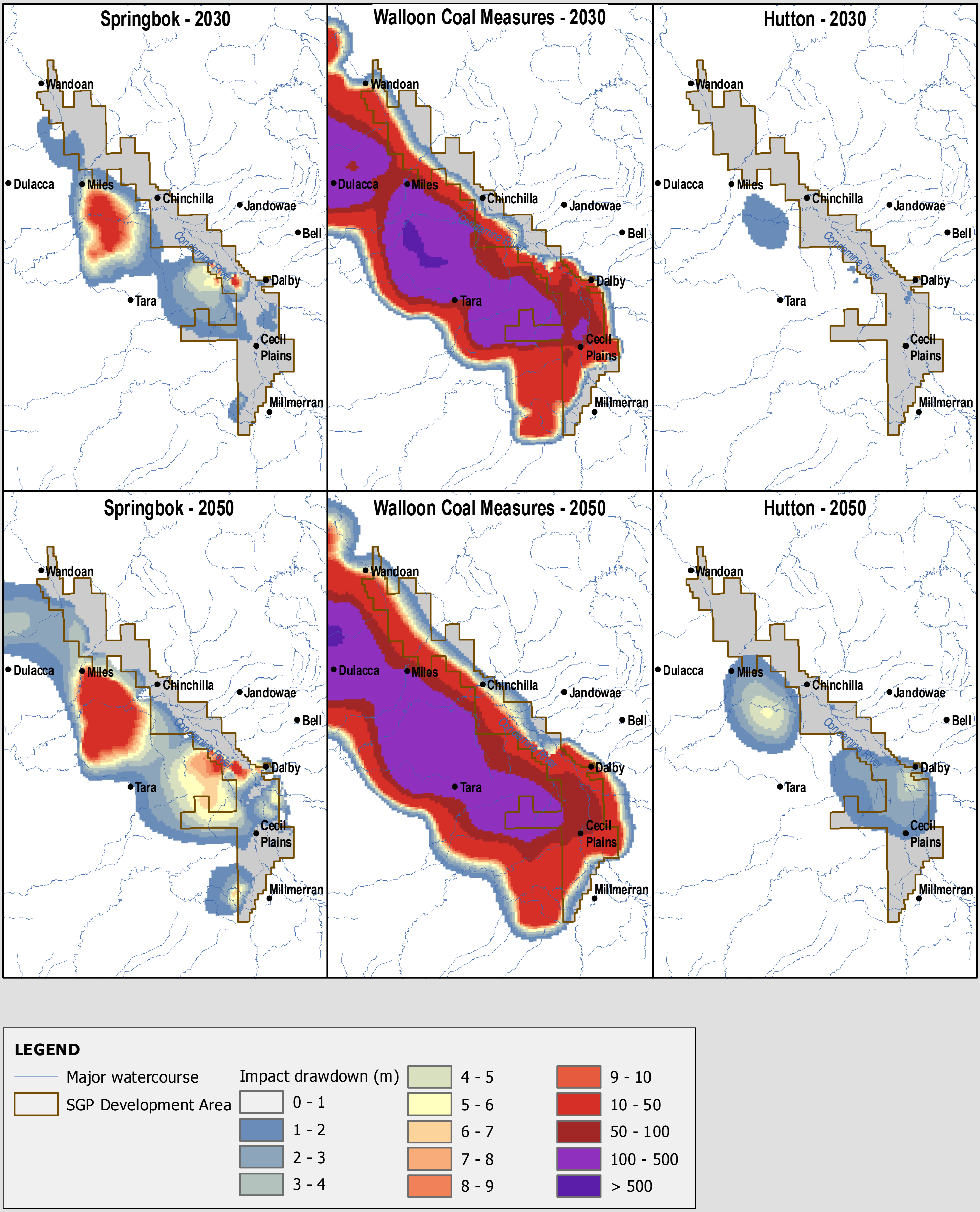

Figure 3.3 Calibrated case - cumulative drawdown at years 2030 and 2050

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

N

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

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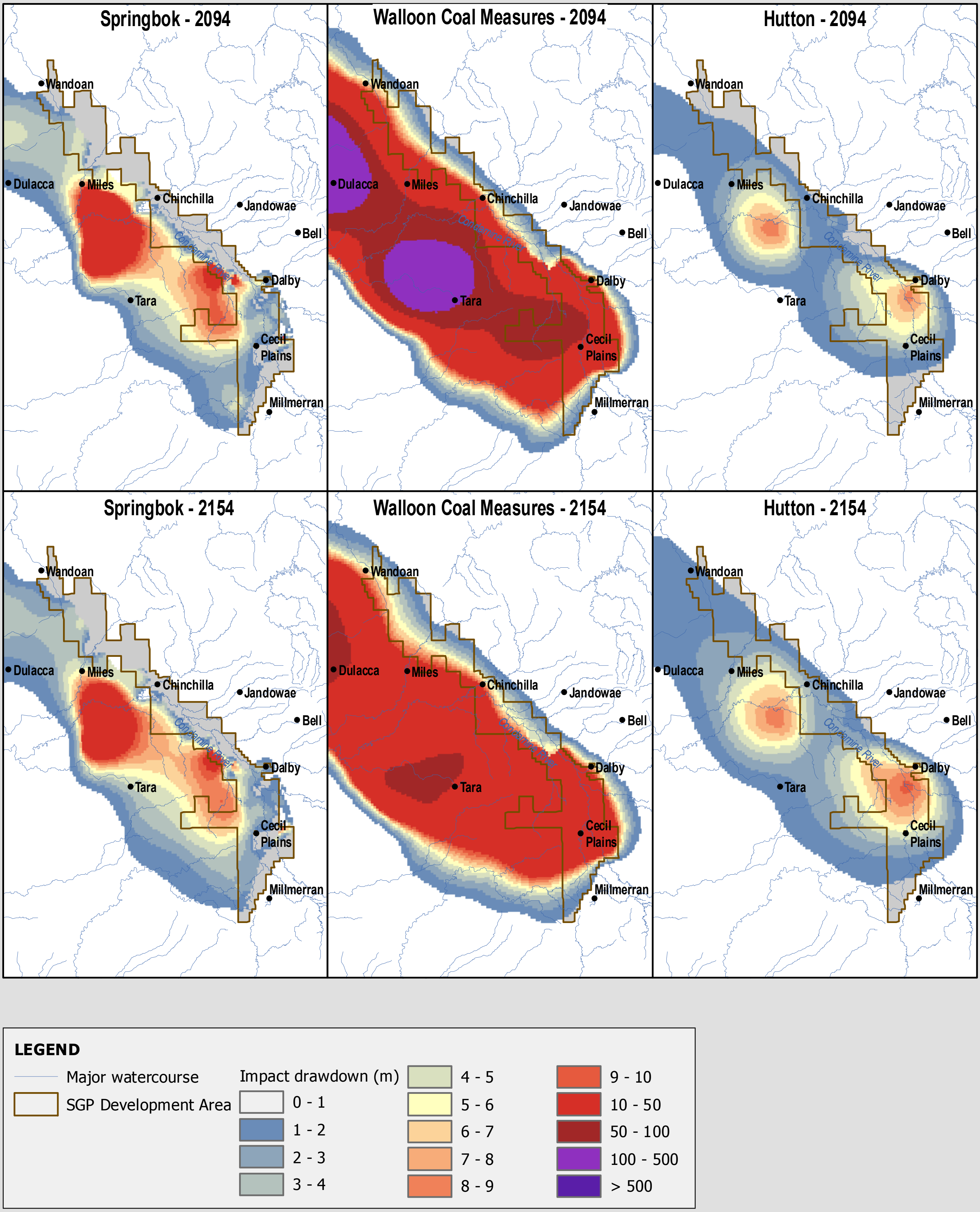

Figure 3.4 **Calibrated case - cumulative drawdown at years 2094 and 2154**

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

N

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

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NOT FOR CONSTRUCTION

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.

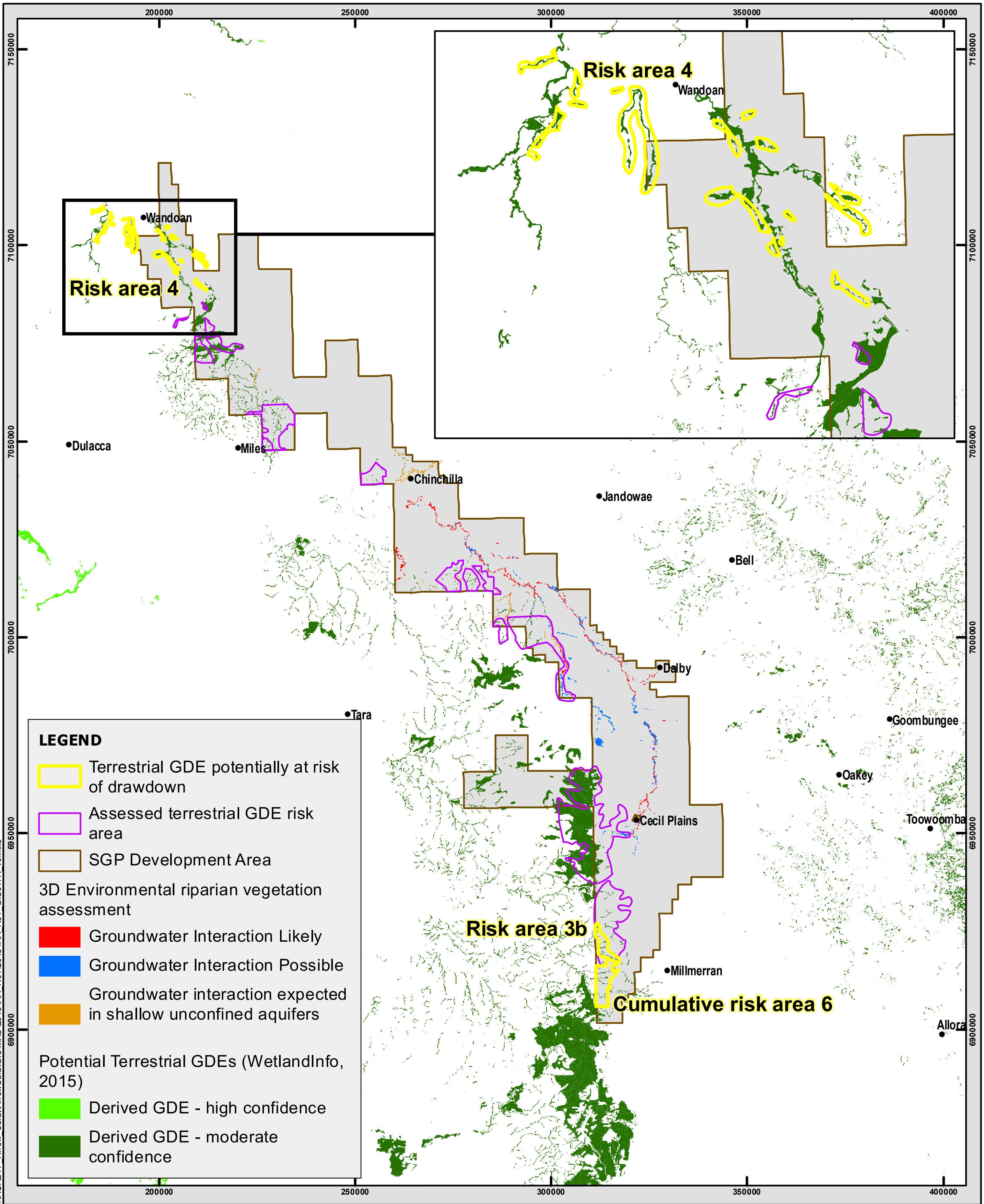

Figure 3.5 **Potentially impacted GDEs**

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

N

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

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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.

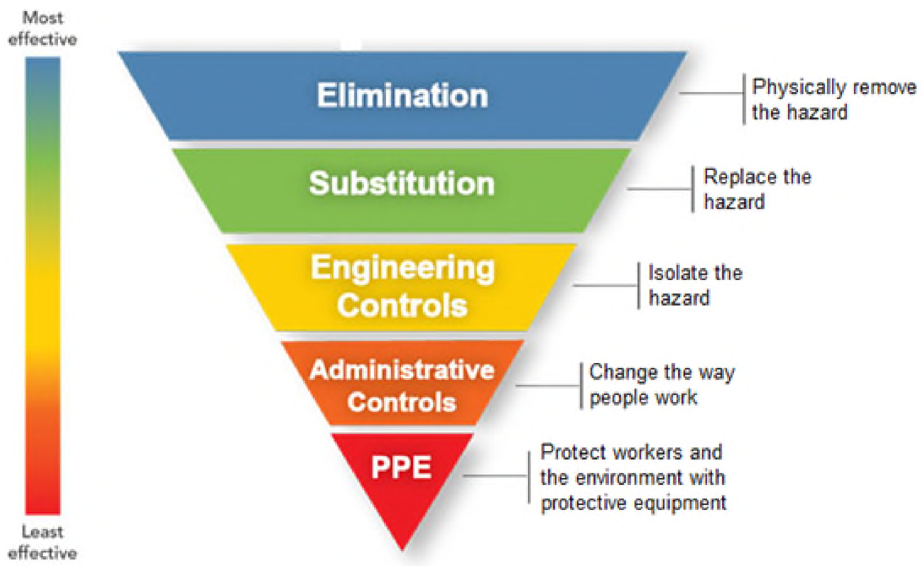

Fig. 4.1: Hierarchy of controls

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.

[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.

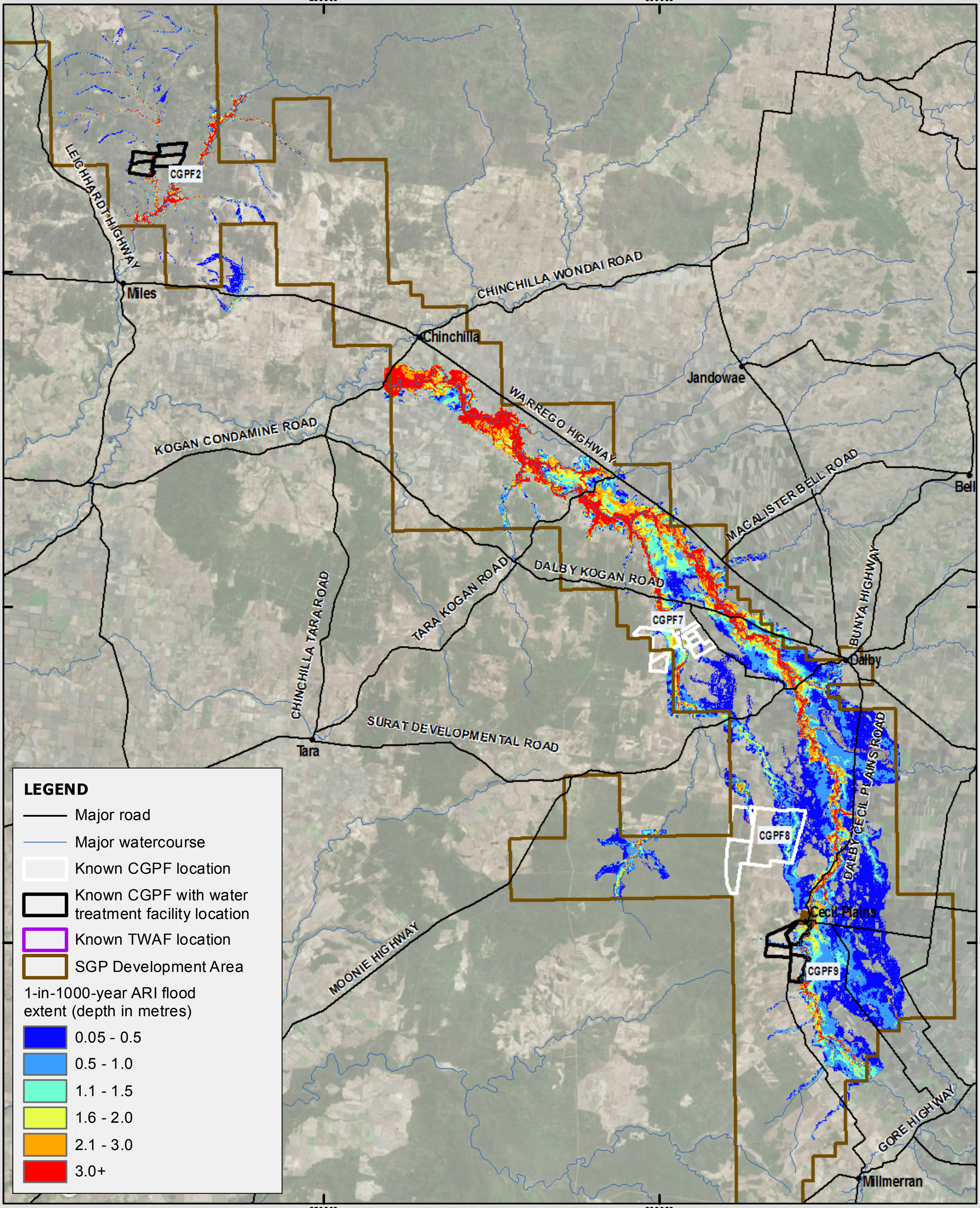

Figure 4.2 Proposed Surat Gas Project water storage facilities with 1:1000 ARI flood modelling

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

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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.

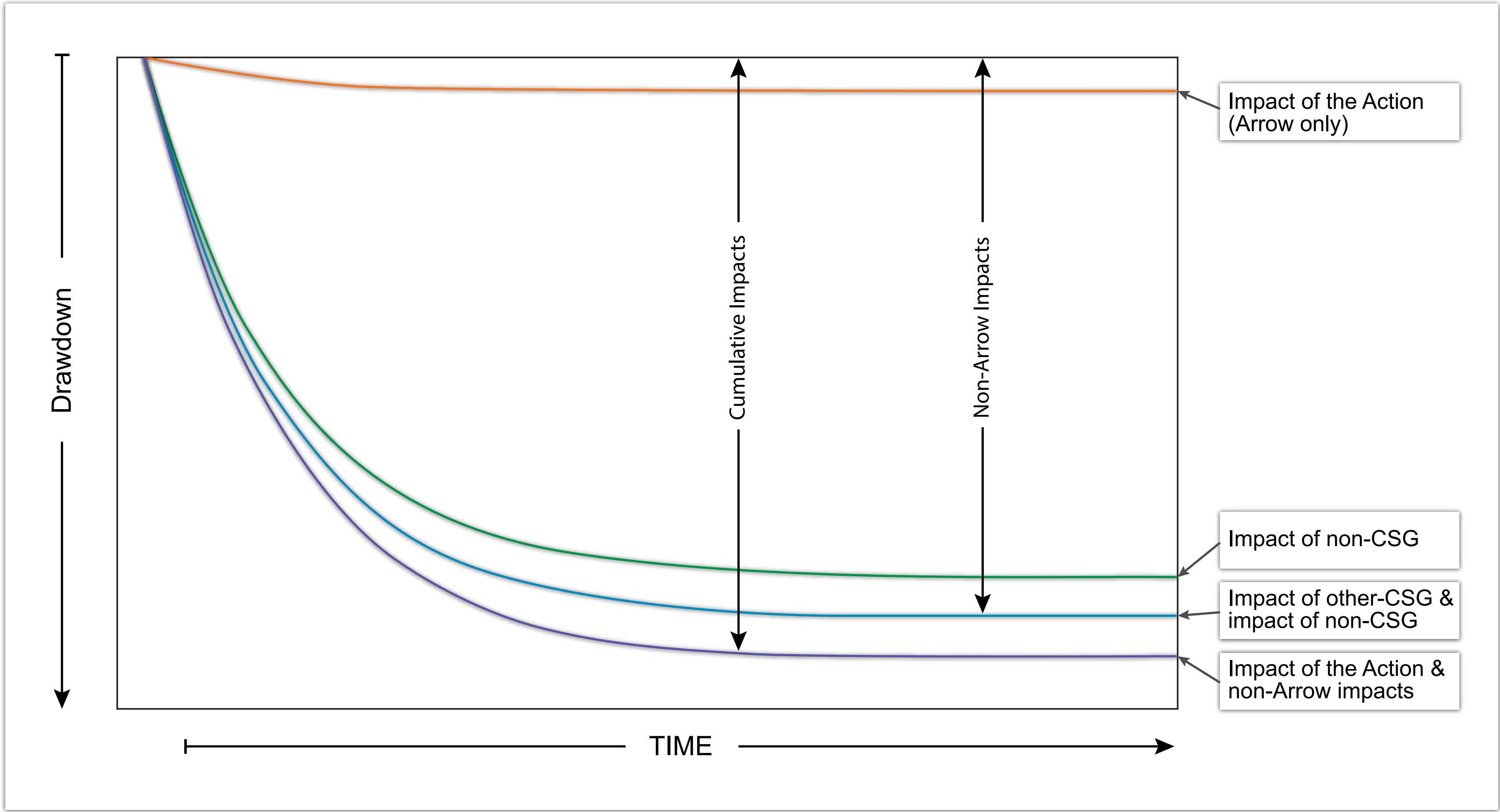

Figure 5.1 **Conceptual Representation of SGP Impacts**

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).

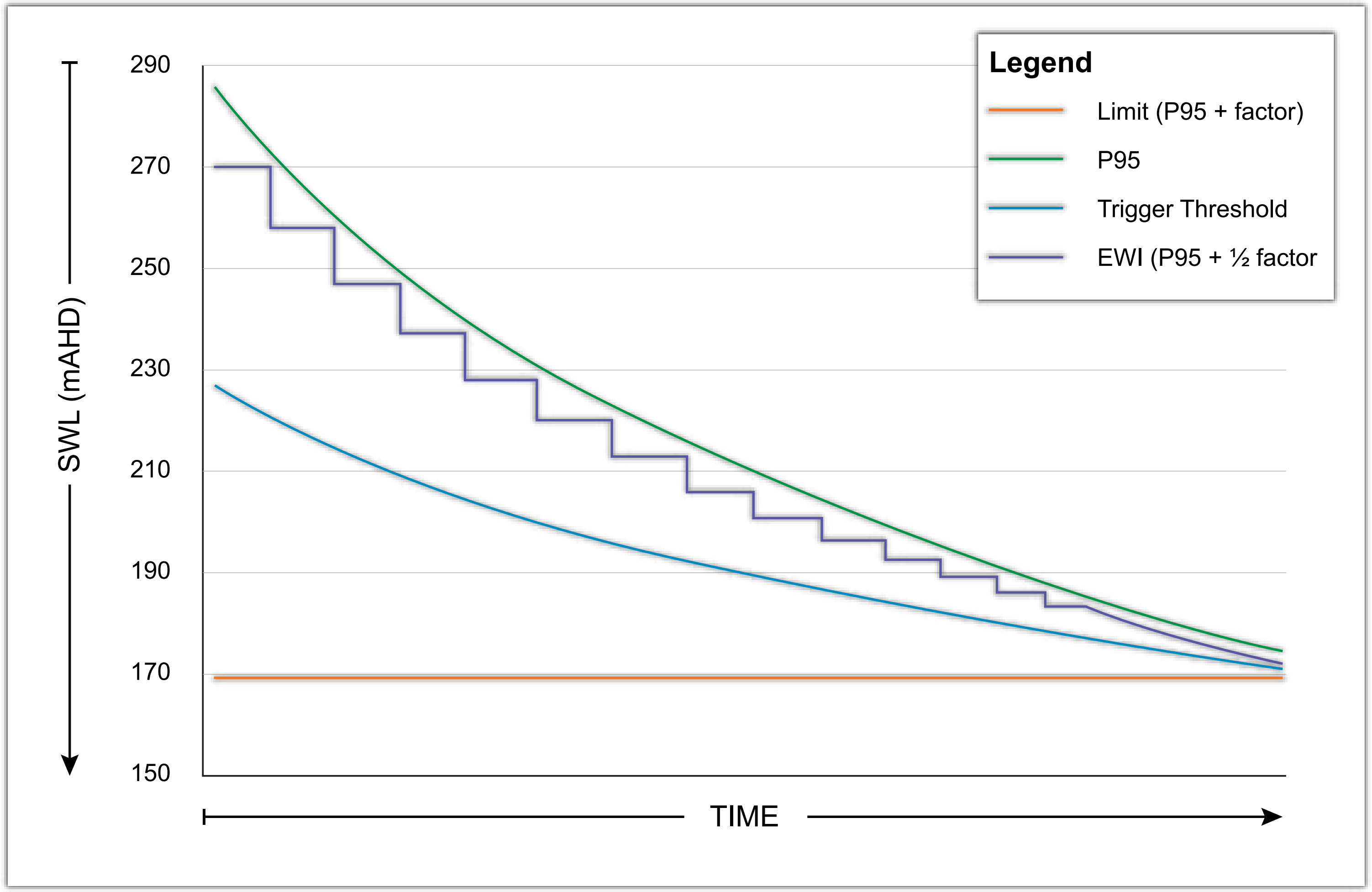

Figure 5.2 **EWMS Conceptualisation**

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.

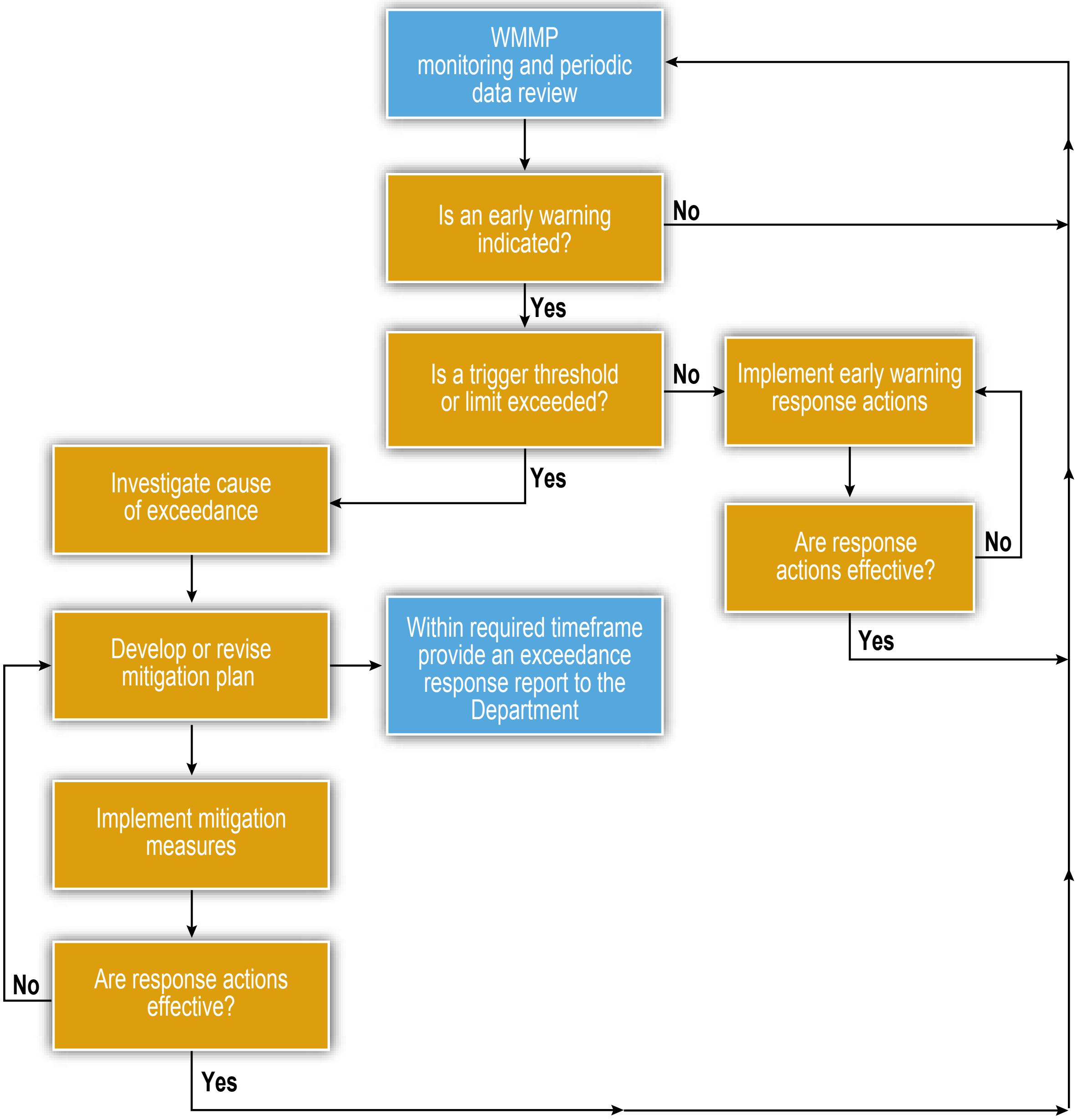

Figure 5.3 **EWMS process and actions**

Source:
Coffey

Date: 19/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich/Richard.Heath

arrow energy go further

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

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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).

[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.

ARROW ENERGY - SURAT GAS PROJECT

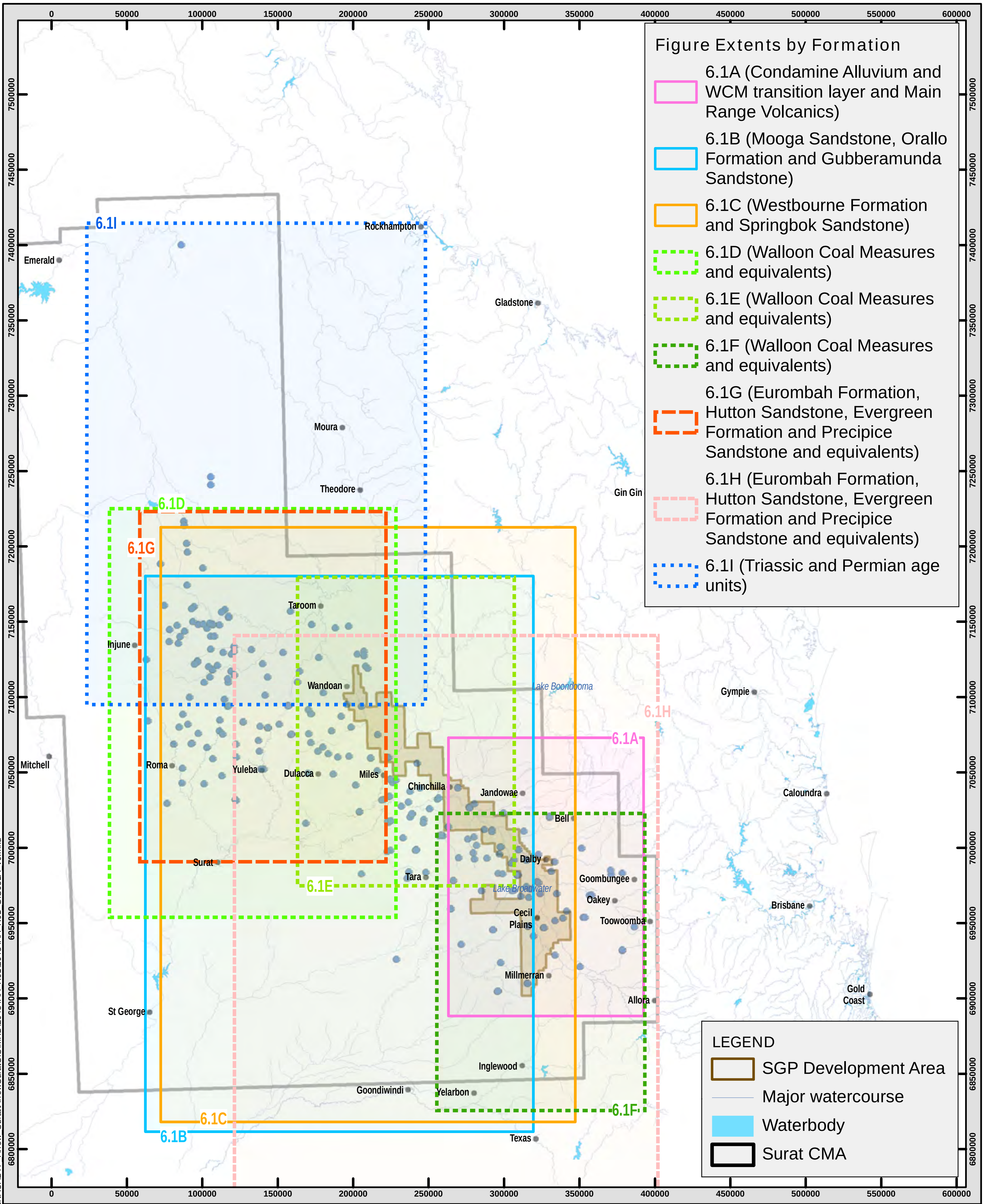

Figure 6.1 Surat CMA UWIR groundwater monitoring network overview

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
Scale: 1:3,250,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

N

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

Document: \\Abtfarcv01\data$\GIS\20484 ENAUABTF Arrow Surat\ArrowSurat\GIS\MXD\20484AA R01\20484AA R01 GIS051A v0.mxd

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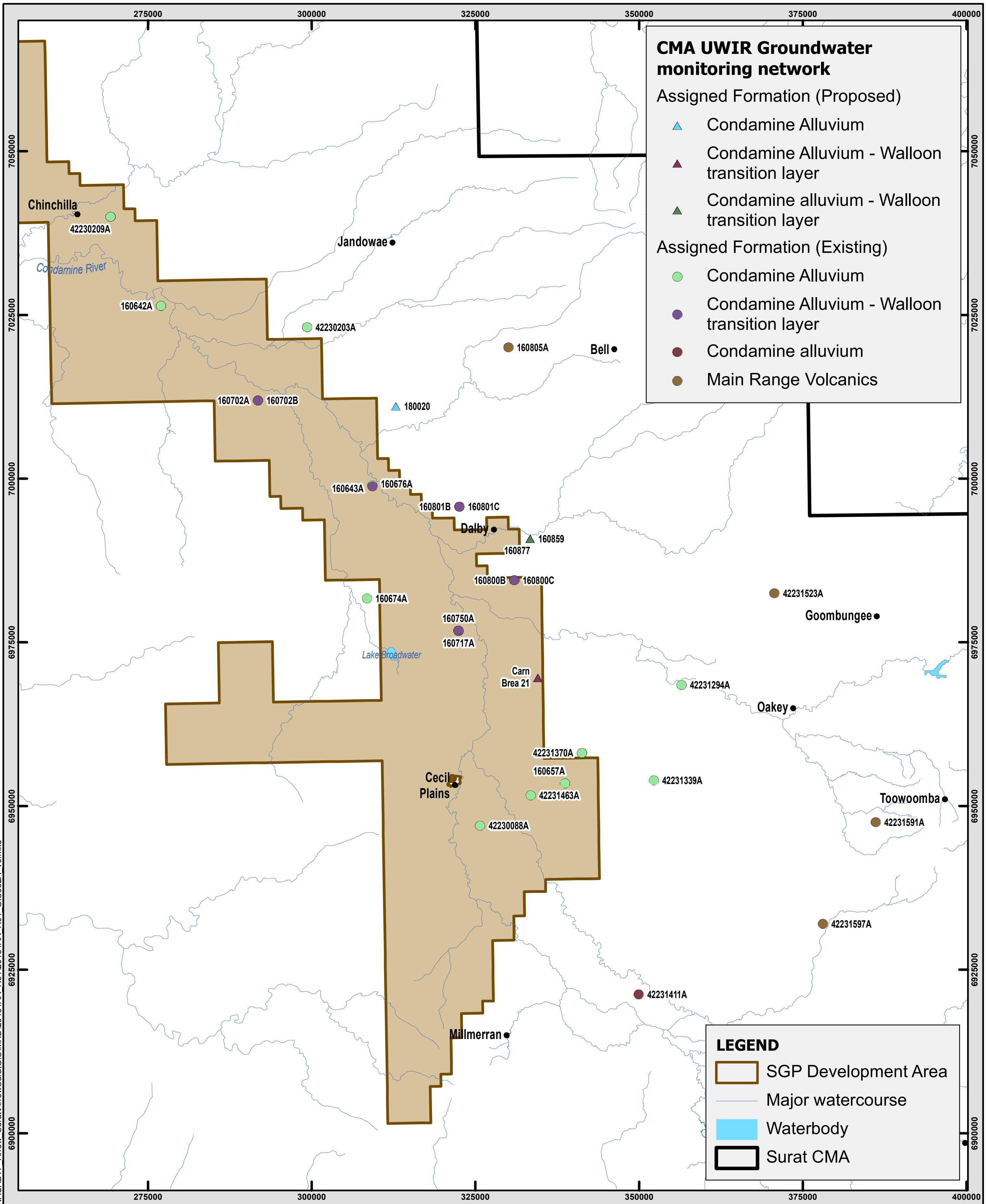

Figure 6.1A Surat CMA UWIR groundwater monitoring network - Condamine Alluvium and WCM transition layer and Main Range Volcanics

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

arrow energy go further

Document: \\Abtfarcv01\data$\GIS\20484_ENAUABTF_Arrow_Surat\ArrowSuratGIS\MXD\20484AA_R01\20484AA_R01_GIS052A_v0.mxd

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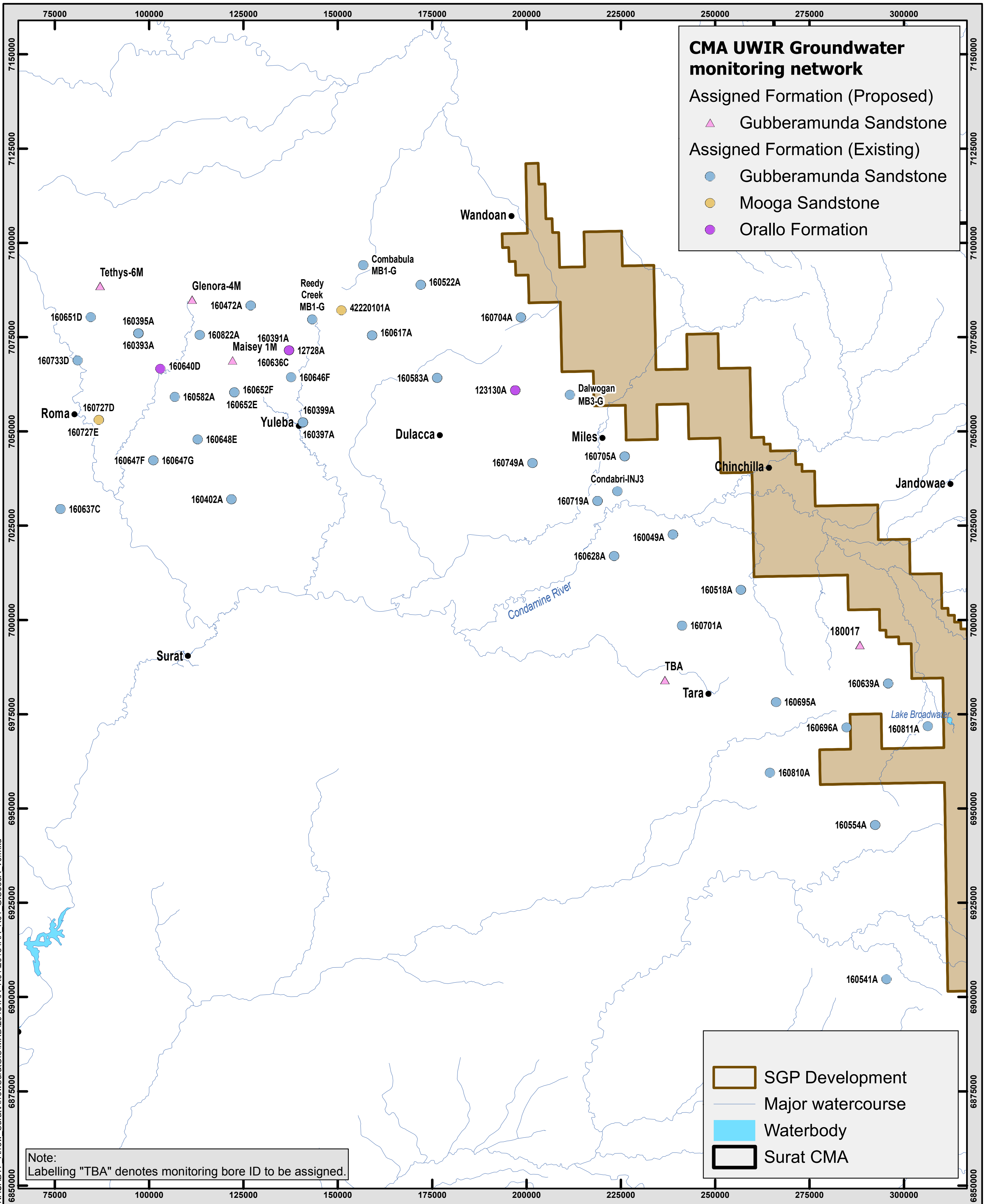

Figure 6.1B Surat CMA UWIR groundwater monitoring network - Mooga Sandstone, Orallo Formation and Gubberamunda Sandstone

Source:
Arrow Energy Pty Ltd
Coffey, UWIR
CDM Smith

Date: 26/09/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

Scale: 1:1,300,000 @ A4
Coordinate System: GDA 1994 MGA Zone 56

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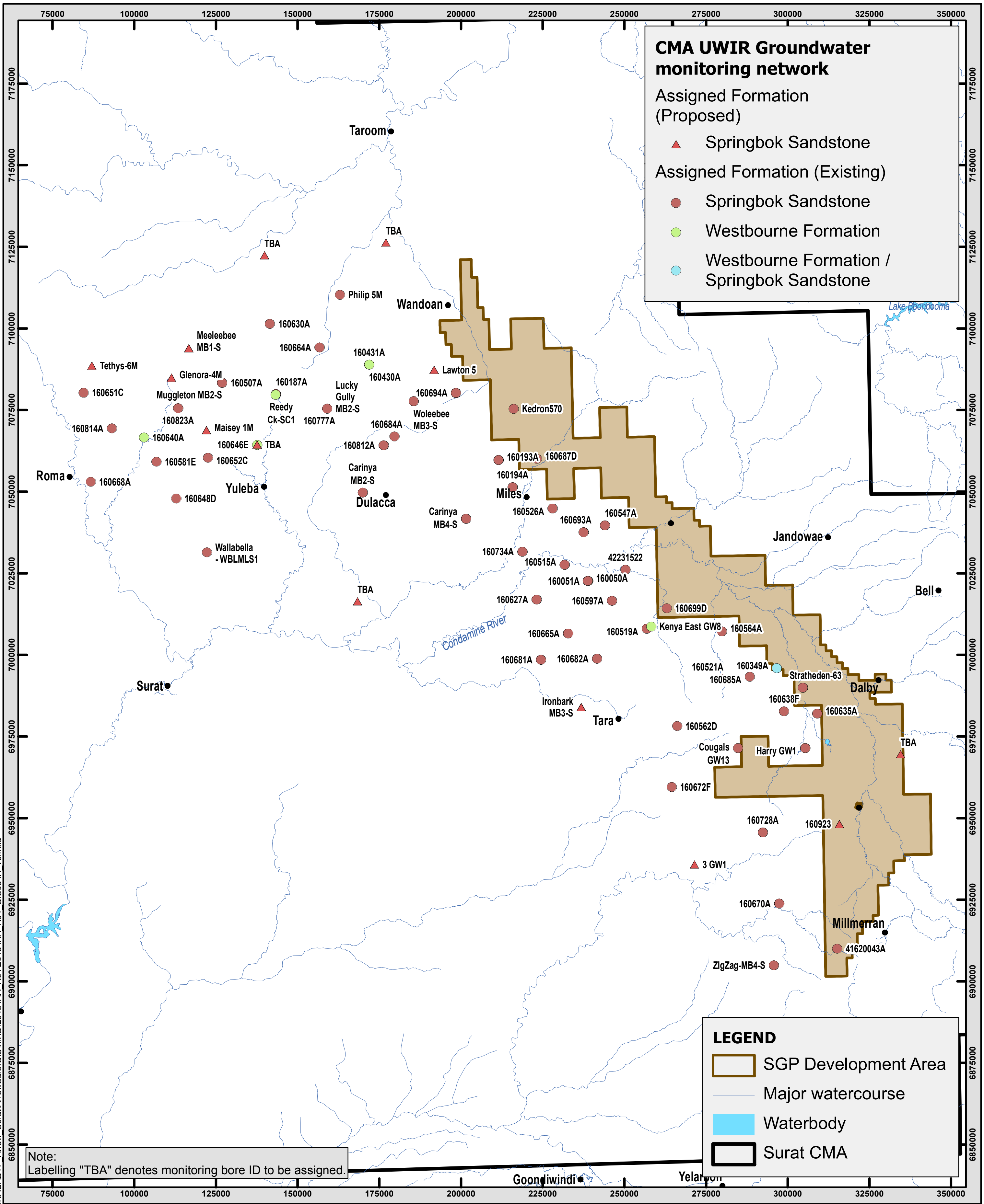

Document: \\Abtfarcv01\data$\GIS\20484_ENAUABTF_Arrow_Surat\ArrowSuratGIS\MXD\20484AA_R01\20484AA_R01_GIS054A_v0.mxd

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

NOT FOR CONSTRUCTION

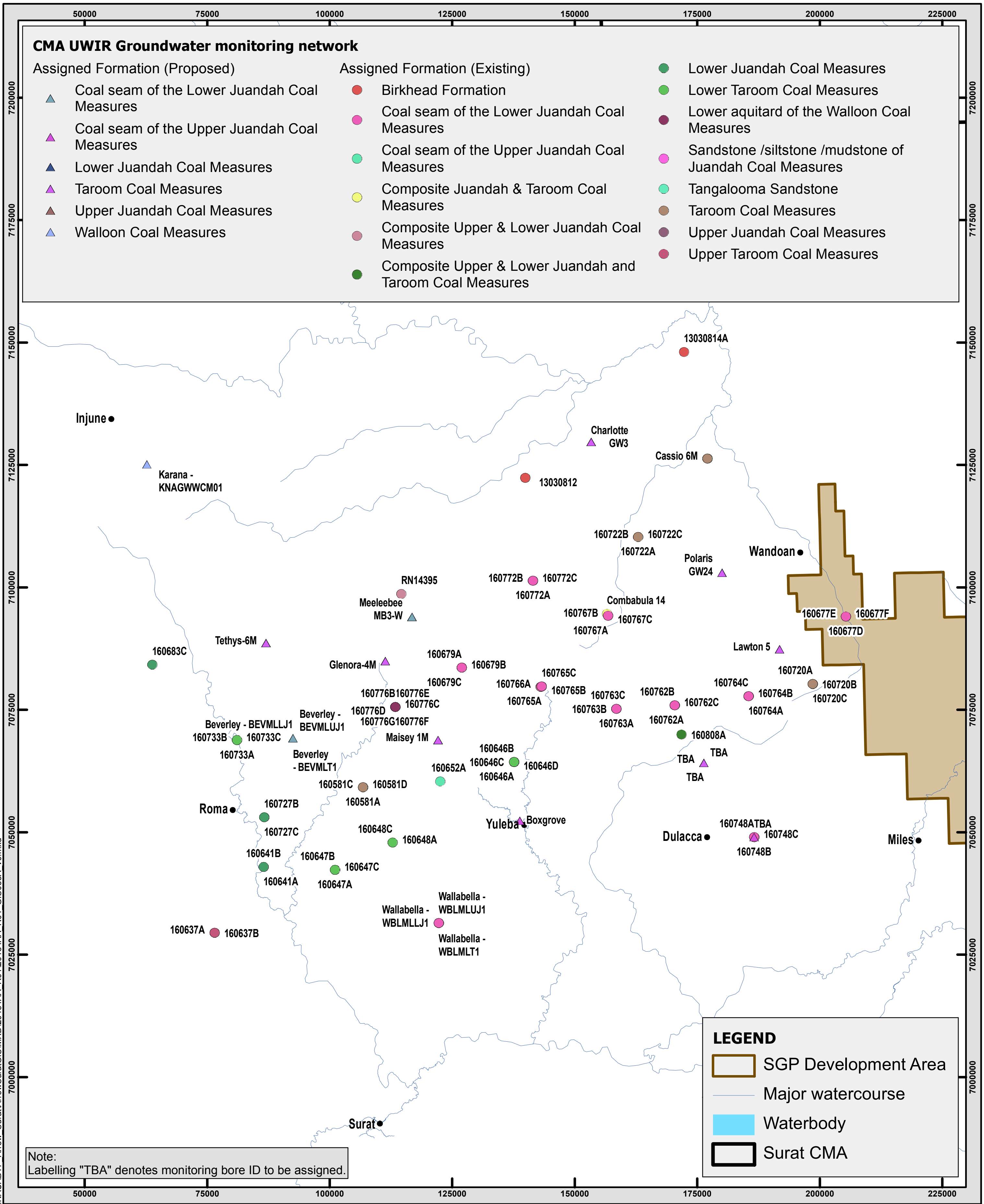

Figure 6.1D **Surat CMA UWIR groundwater monitoring network - Walloon Coal Measures and equivalents - Northern extent**

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

N

arrow energy
go further

Document: \\Abtfarcv01\data$\GIS\20484_ENAUABTF_Arrow_Surat\ArrowSuratGIS\MXD\20484AA_R01\20484AA_R01_GIS055A_v0.mxd

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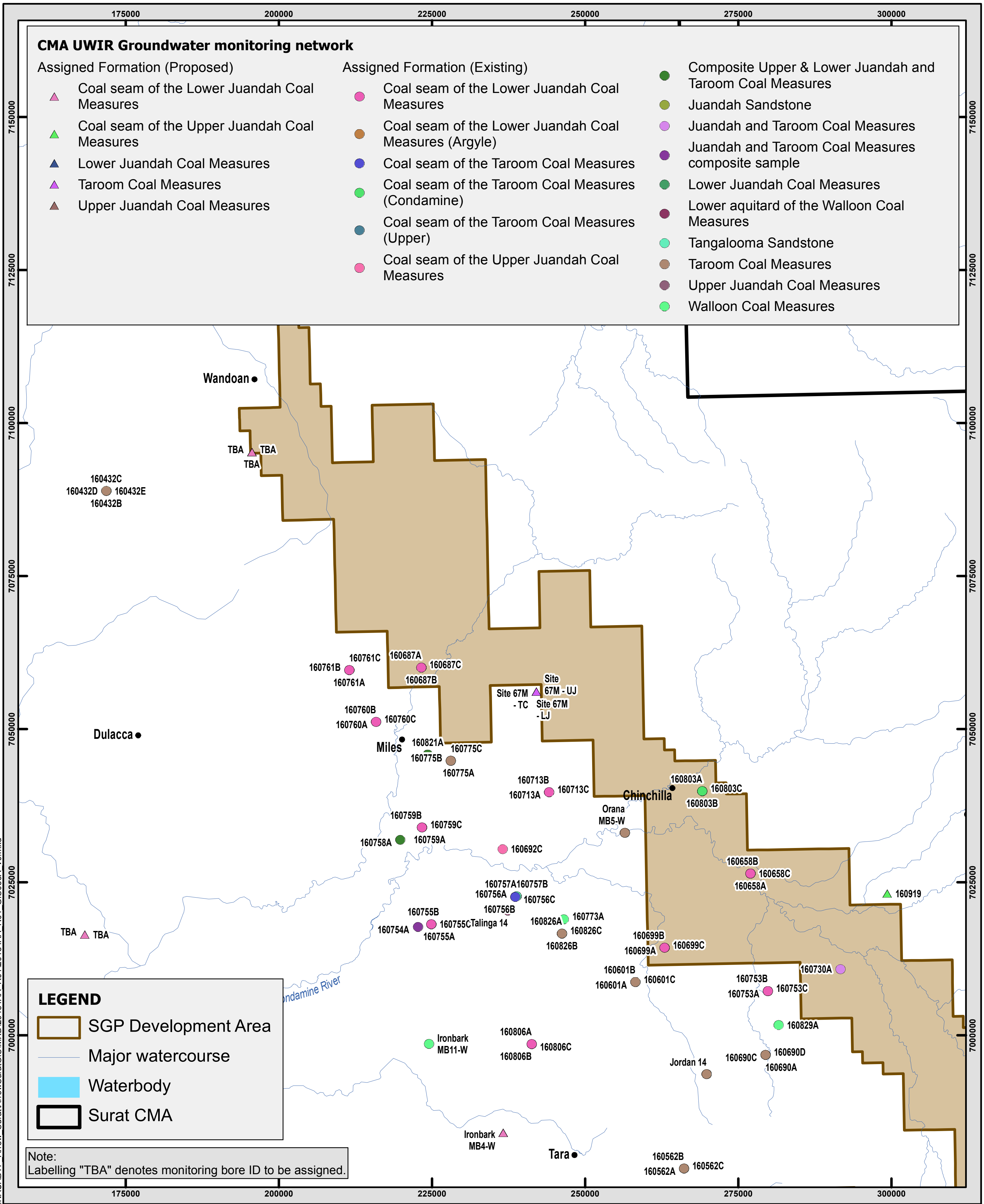

Figure 6.1E

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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Document: \\Abtfarcv01\data$\GIS\20484_ENAUABTF_Arrow_Surat\ArrowSurat\GIS\MXD\20484AA_R01\20484AA_R01_GIS056A_v0.mxd

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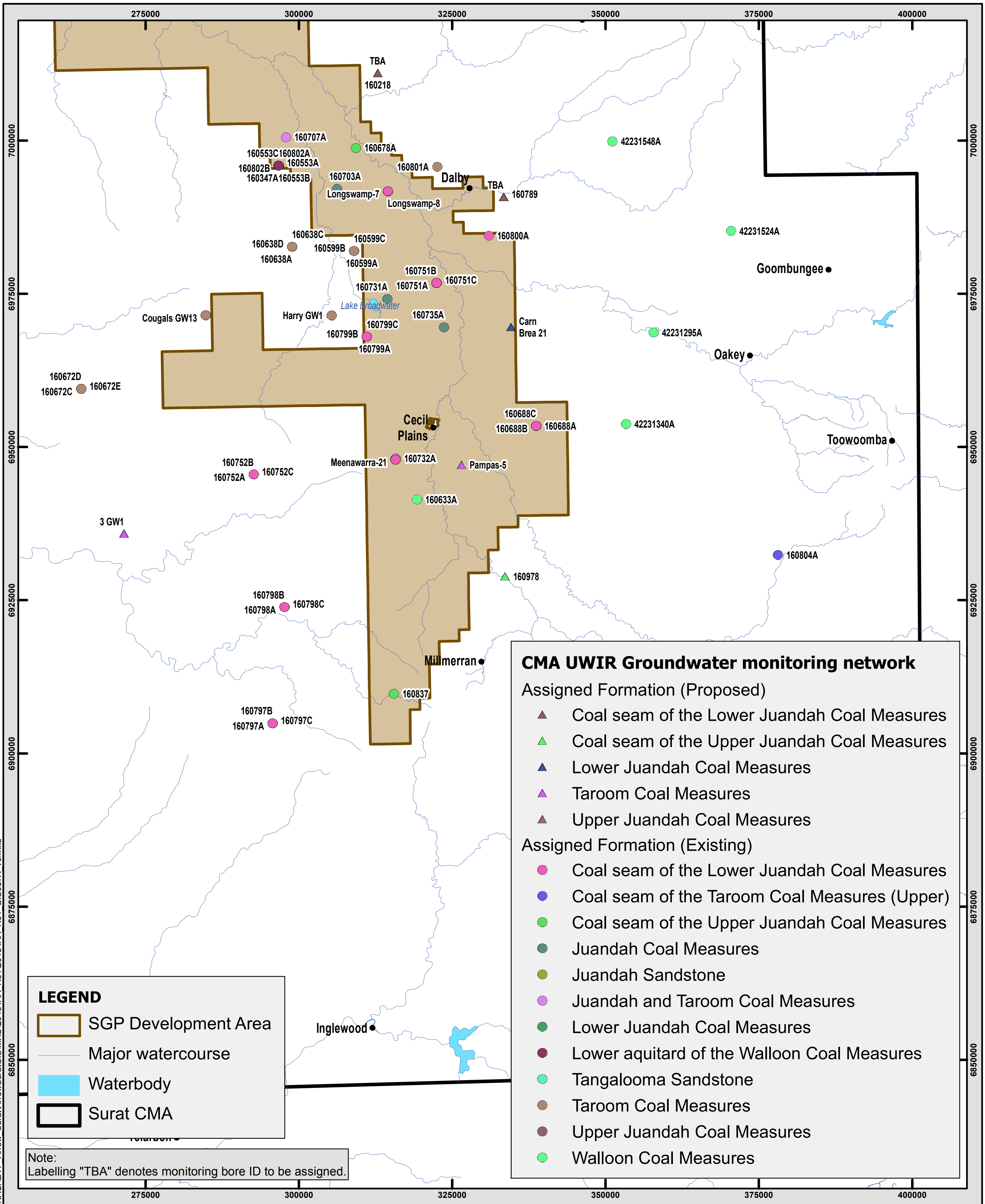

Figure 6.1F

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

N

arrow energy
go further

Document: \\Abtfarcv01\data$\GIS\20484 ENAUABTF Arrow Surat\ArrowSurat\GIS\MXD\20484AA R01\20484AA R01 GIS057A v0.mxd

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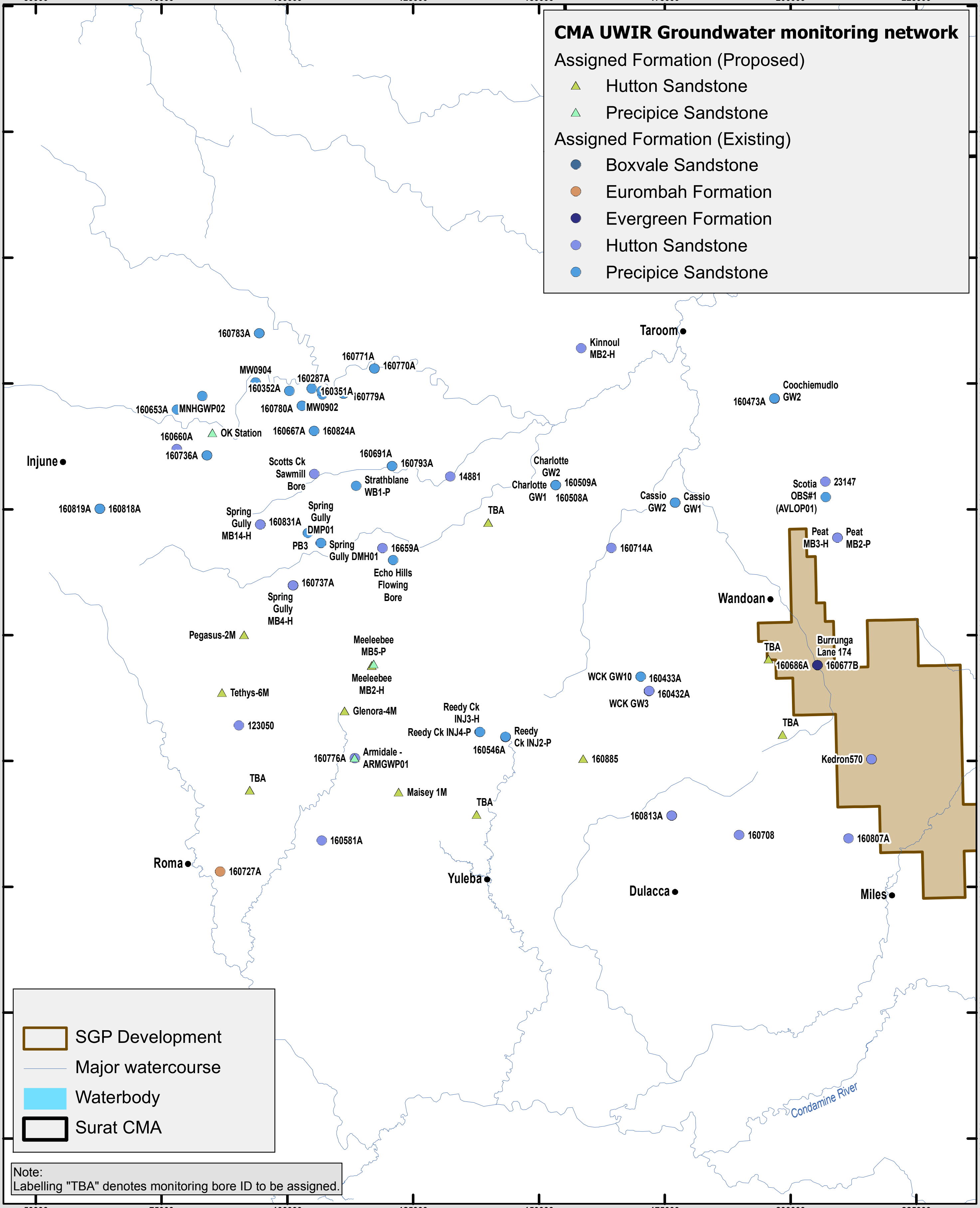

Figure 6.1G Surat CMA UWIR groundwater monitoring network - Eurombah Formation, Hutton Sandstone, Evergreen Formation and Precipice Sandstone and equivalents - Western extent

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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arrow energy go further

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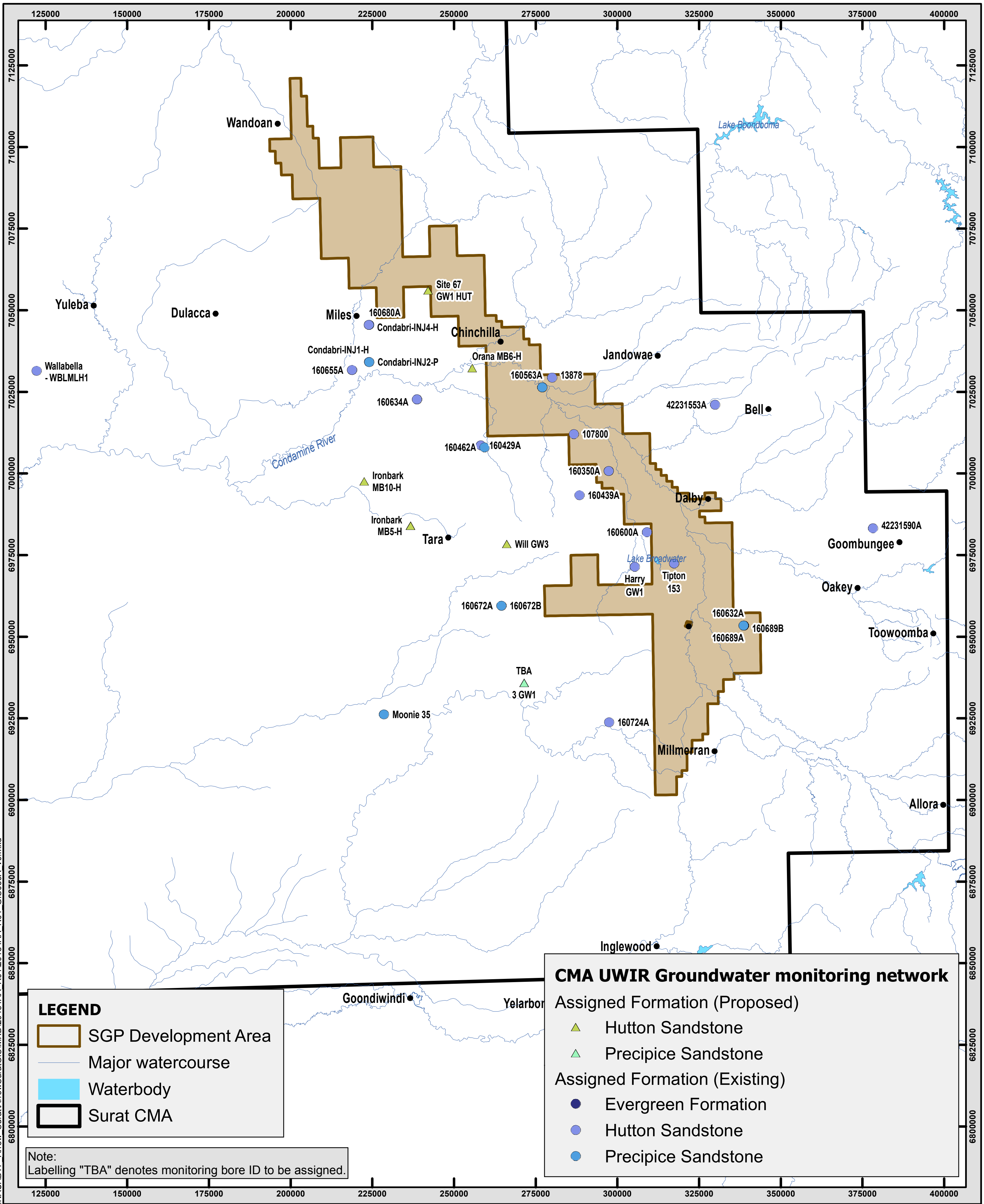

Figure 6.1H Surat CMA UWIR groundwater monitoring network - Eurombah Formation, Hutton Sandstone, Evergreen Formation and Precipice Sandstone and equivalents - Eastern extent

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

Document: \\Abtfarcv01\data$\GIS\20484_ENAUABTF_Arrow_Surat\ArrowSuratGIS\MXD\20484AA_R01\20484AA_R01_GIS059A_v0.mxd

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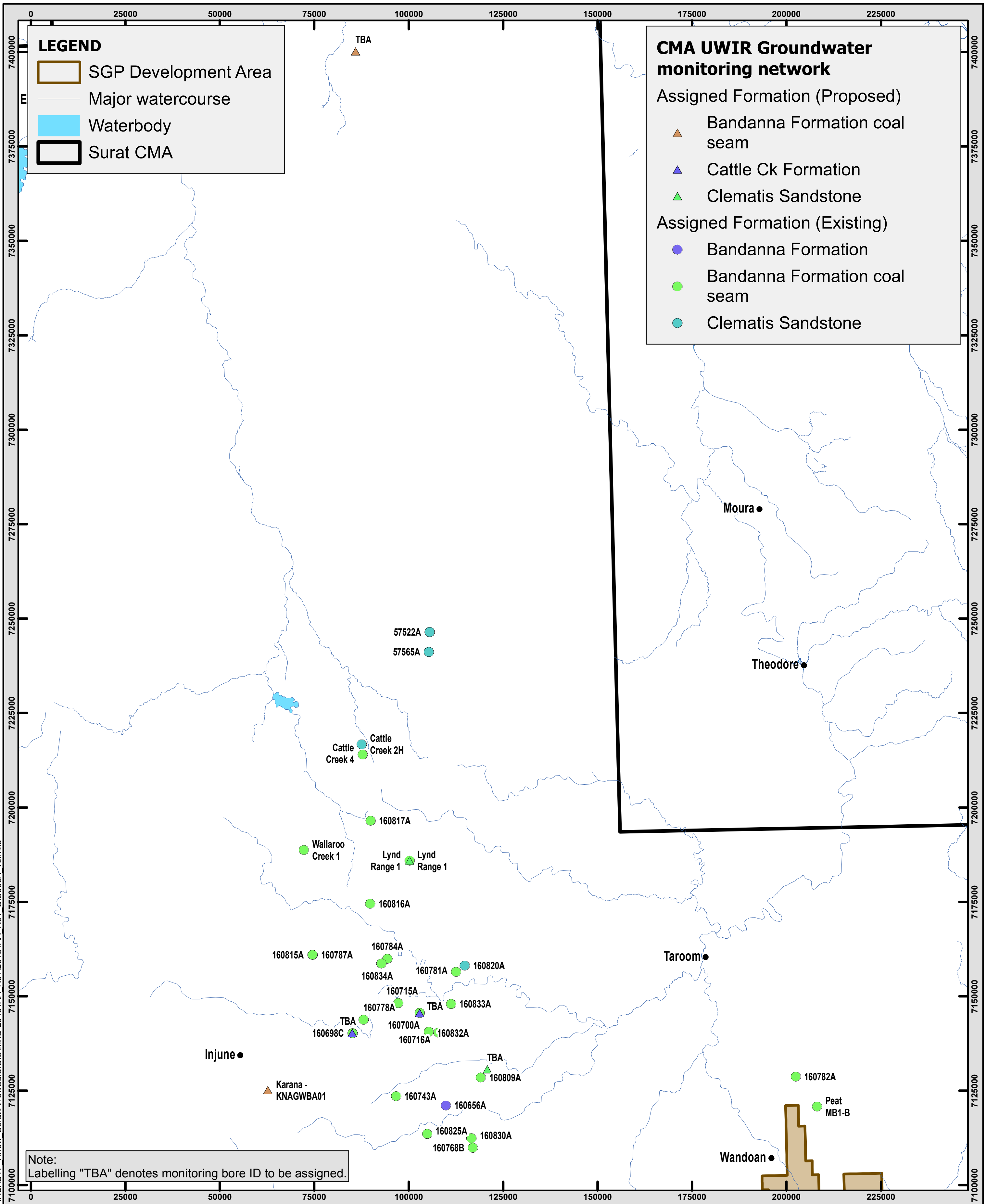

Figure 6.1I

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

N

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NOT FOR CONSTRUCTION

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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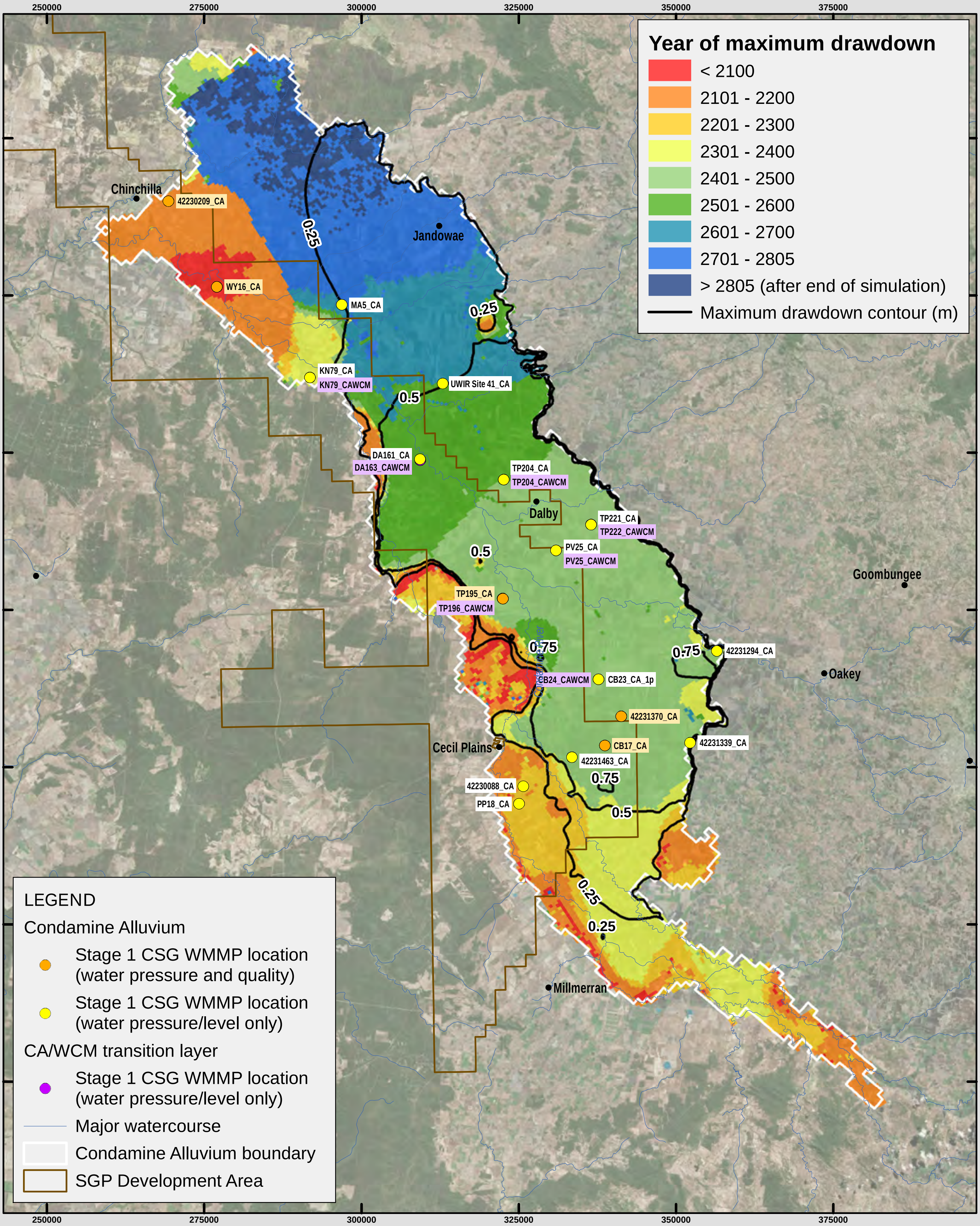

Figure 6.2

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

N

Document: \\Abtfarcv01\data$\GIS\20484_ENAUABTF_Arrow_Surat\ArrowSuratGIS\MXD\20484AA_R01\20484AA_R01_GIS061A_v0.mxd

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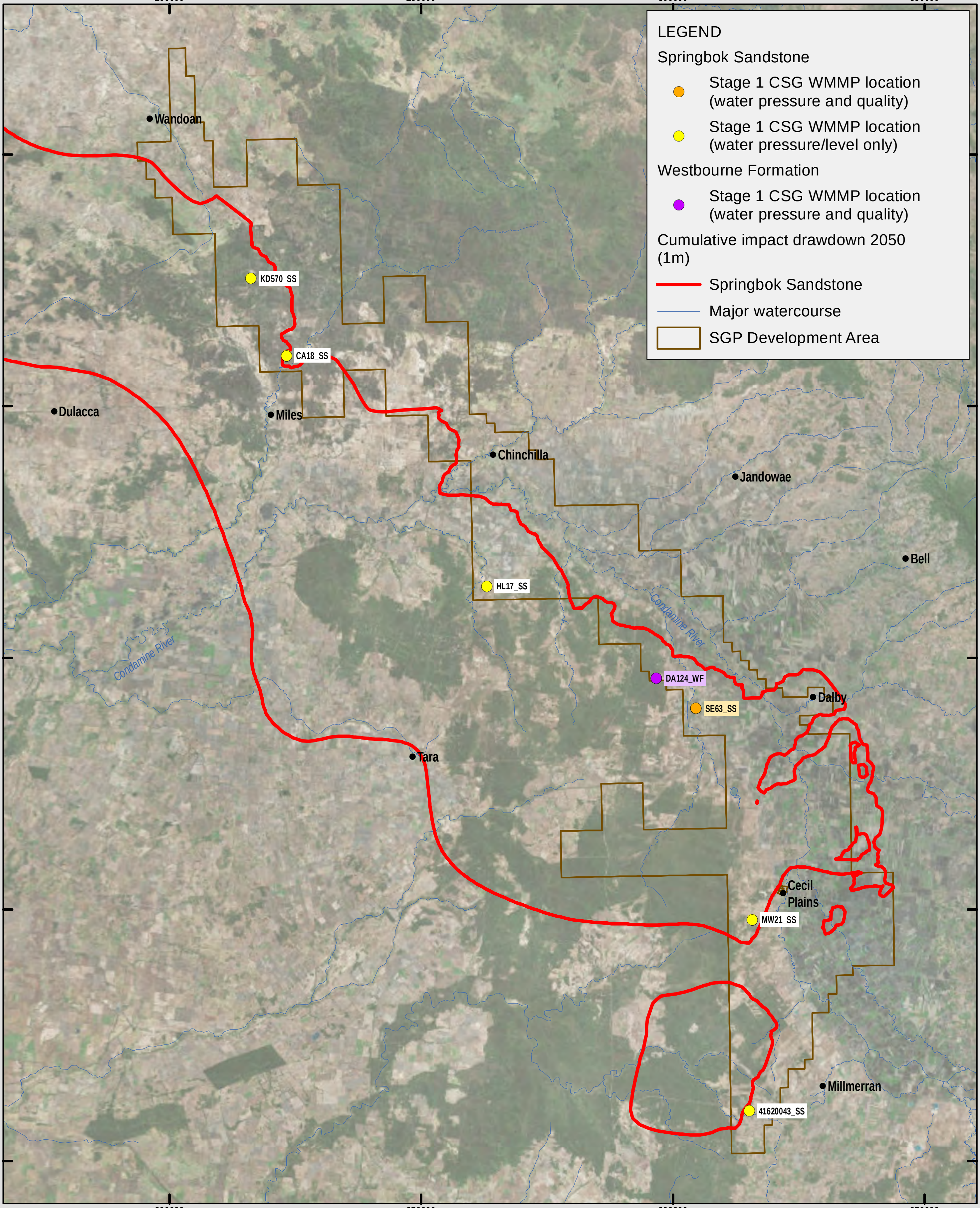

Figure 6.3 Stage 1 CSG WMMP monitoring points (Springbok Sandstone aquifer and Westbourne Formation)

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

Document: \\Abtfarcv01\data$\GIS\20484 ENAUABTF Arrow Surat\ArrowSuratGIS\MXD\20484AA R01\20484AA R01 GIS026A v0.mxd

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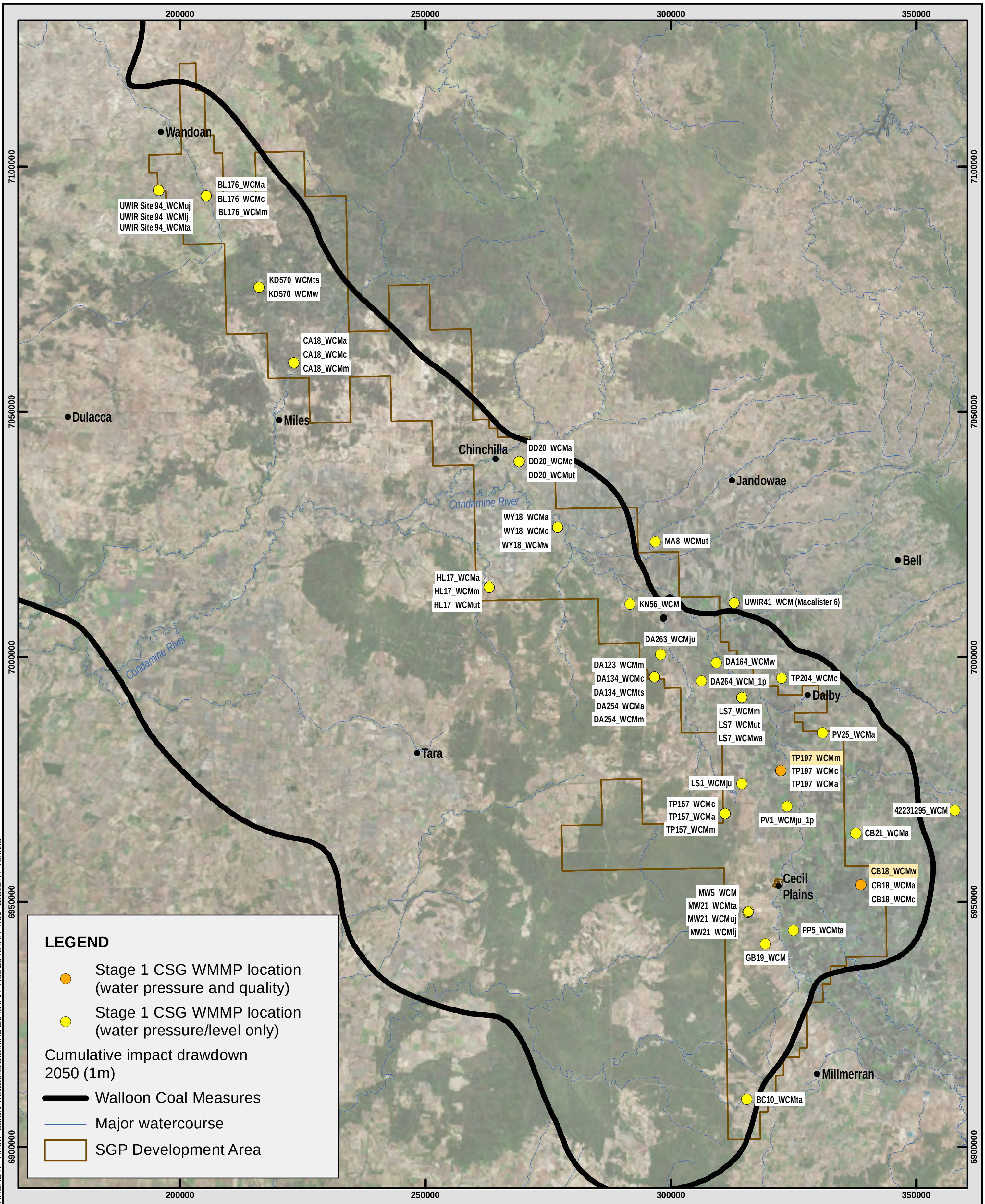

Figure 6.**4** Stage 1 CSG WMMP monitoring points (Walloon Coal Measures)

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

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

Document: \\Abtfarcv01\data$\GIS\20484 ENAUABTF Arrow Surat\ArrowSuratGIS\MXD\20484AA R01\20484AA R01 GIS027A v0.mxd

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ARROW ENERGY - SURAT GAS PROJECT

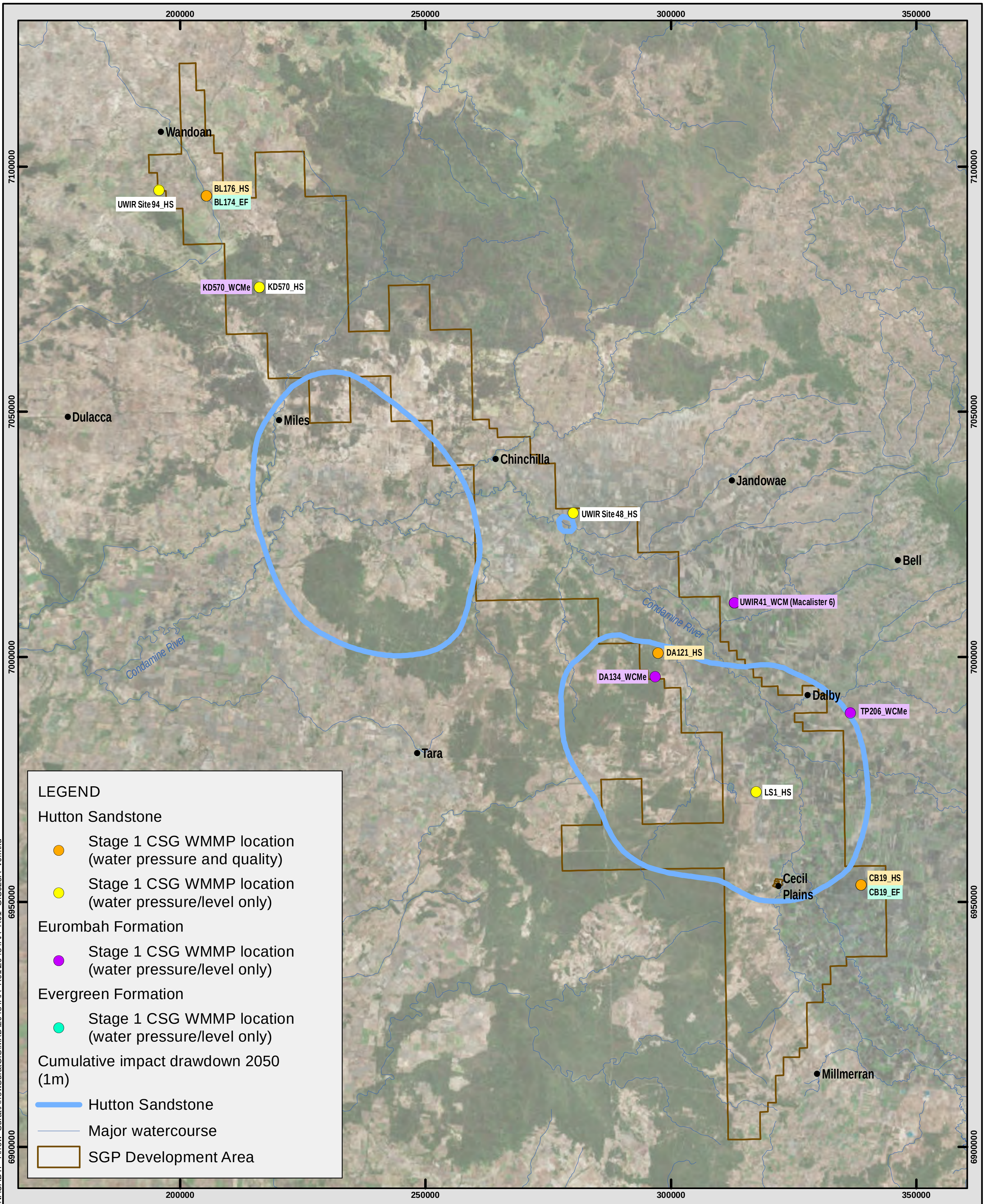

Figure 6.**5**

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

N

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

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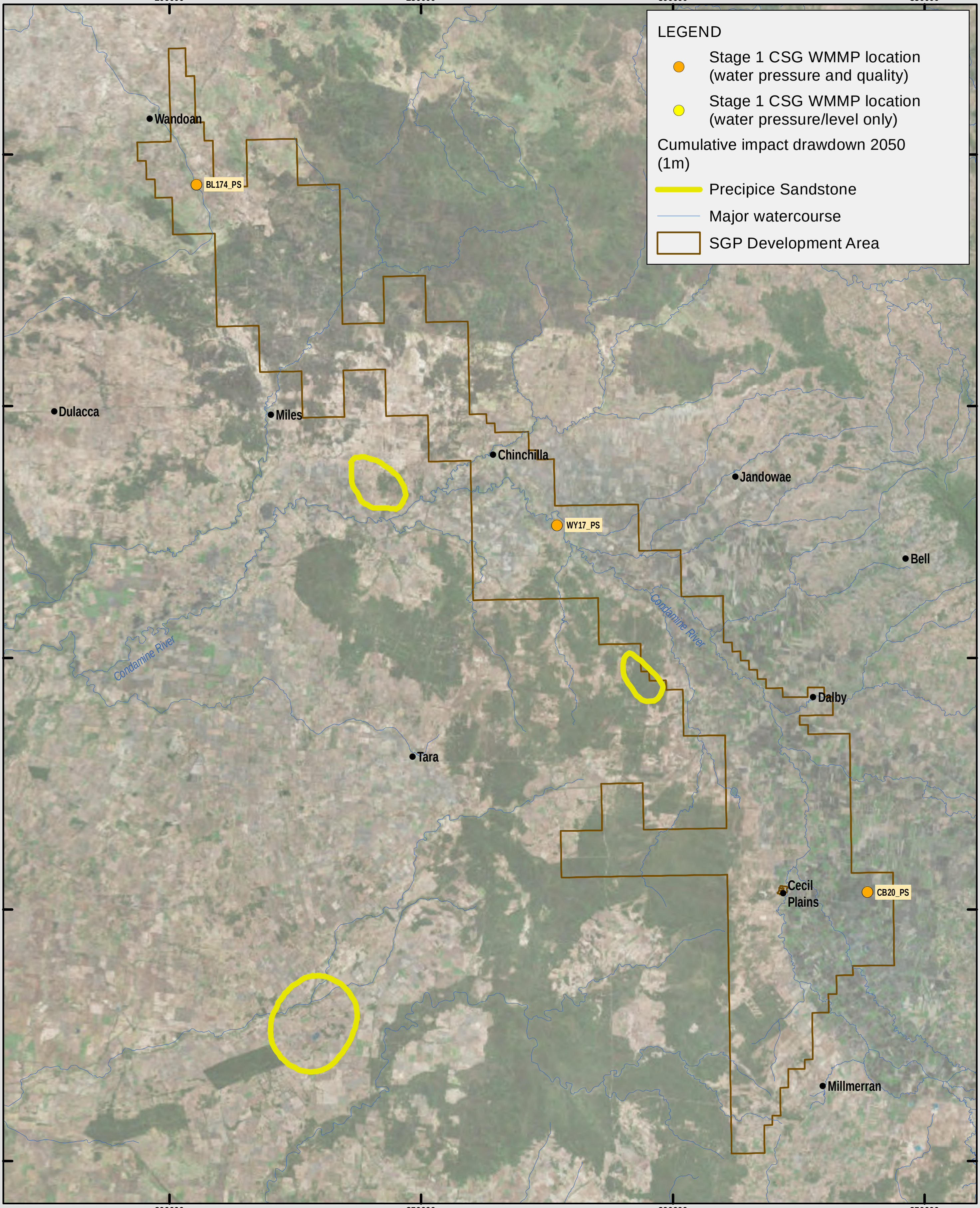

Figure 6.**6** Stage 1 CSG WMMP monitoring points (Precipice Sandstone aquifer)

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

N

Document: \\Abtfarcv01\data$\GIS\20484_ENAUABTF_Arrow_Surat\ArrowSuratGIS\MXD\20484AA_R01\20484AA_R01_GIS029A_v0.mxd

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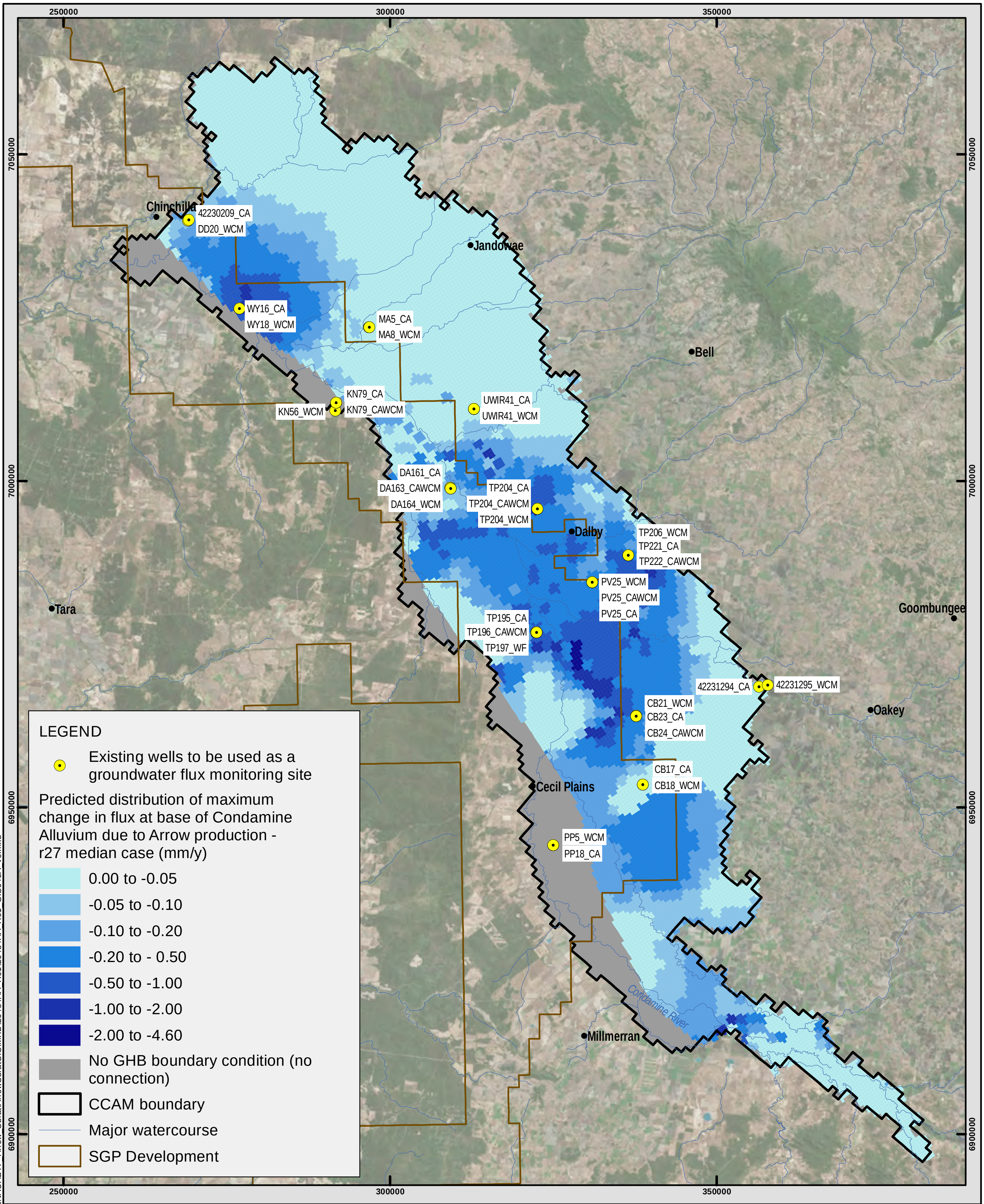

Figure 6.7 Condamine Alluvium flux monitoring locations

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

N

arrow energy go further

Document: \\Abtfarcv01\data$\GIS\20484_ENAUABTF_Arrow_Surat\ArrowSuratGIS\MXD\20484AA_R01\20484AA_R01_GIS045A_v0.mxd

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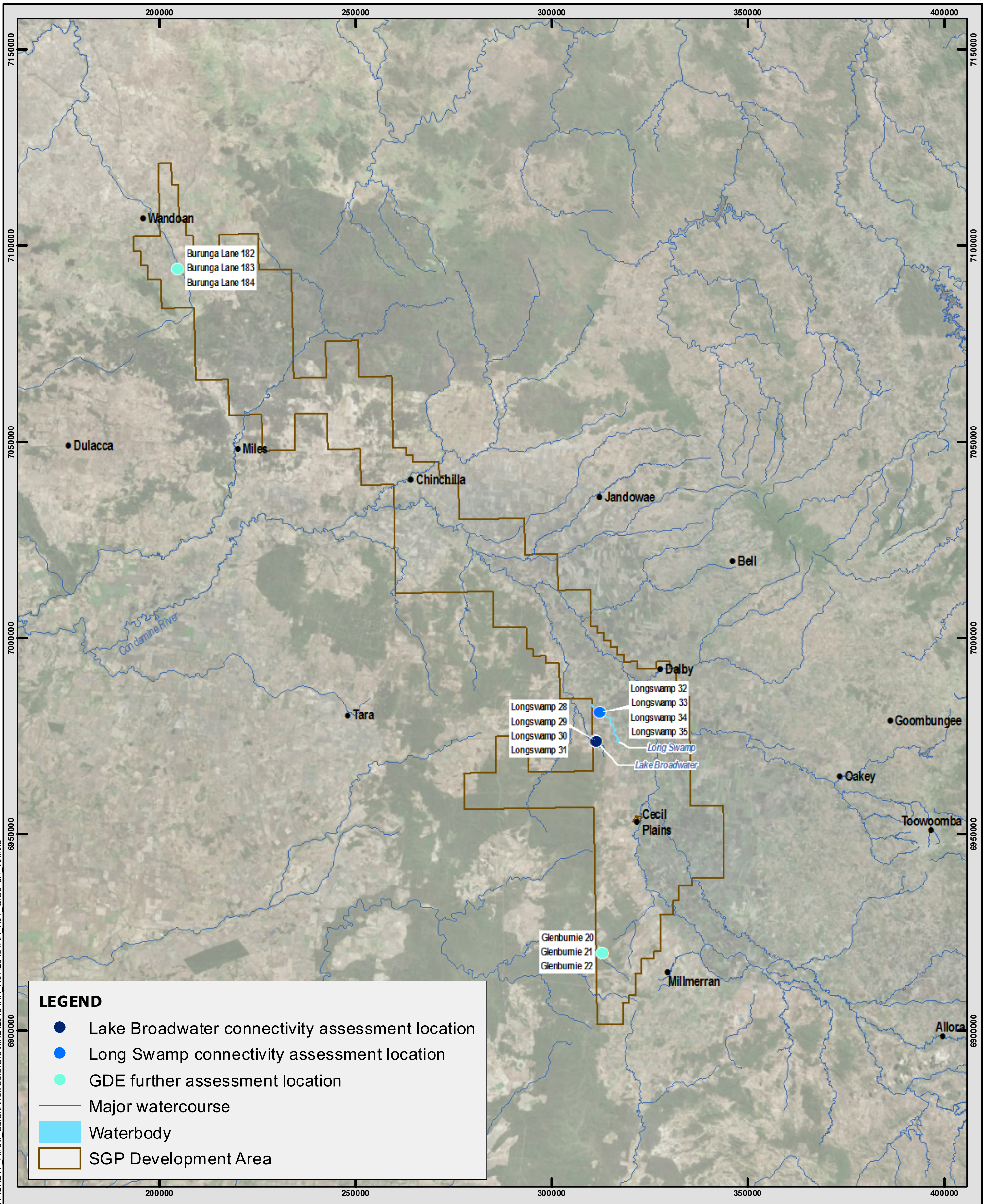

Figure 6.8 **GDE investigation locations**

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

N

Document: \\Abtfarcv01\data$\GIS\20484_ENAUABTF_Arrow_Surat\ArrowSuratGIS\MXD\20484AA_R01\20484AA_R01_GIS046A_v0.mxd

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).

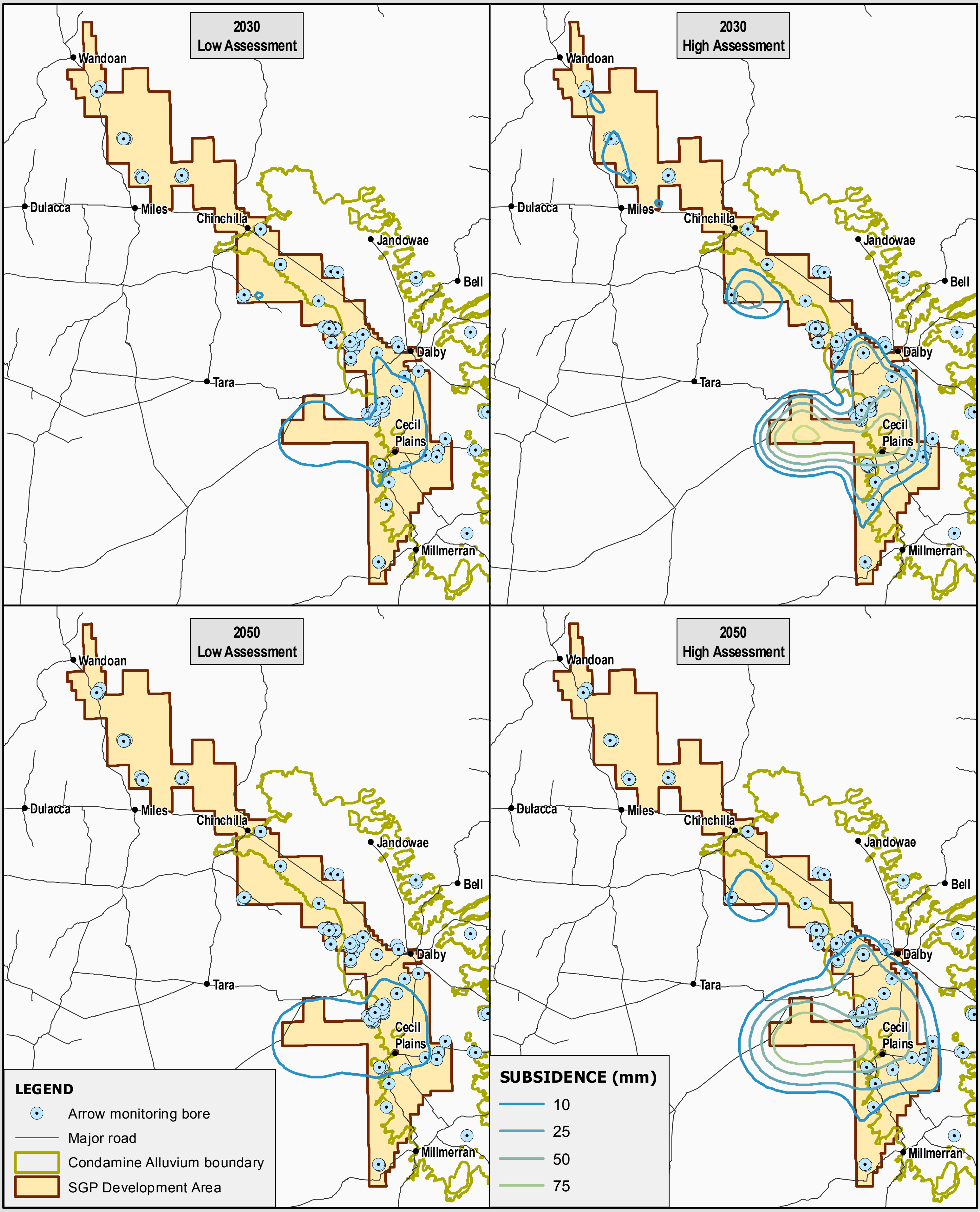

Figure 7.1 **Subsidence assessment - Arrow only case**

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

N

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

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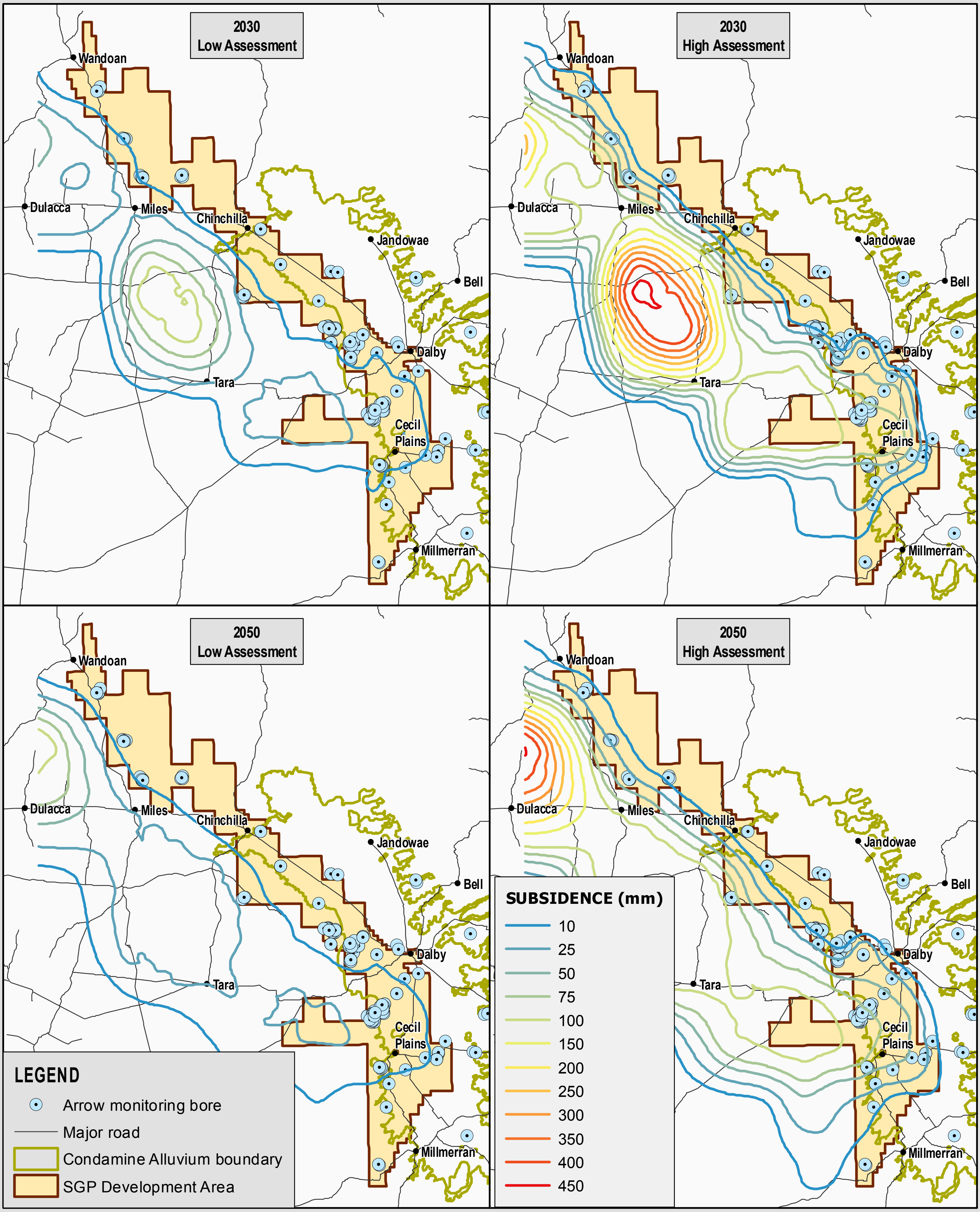

Figure 7.2 **Subsidence assessment - cumulative case**

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

N

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.

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no warranty is given that the information contained on this map is free from error or omission. Any reliance placed on such information shall be at the sole risk of the user. Please verify the accuracy of all information prior to using it.

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ARROW ENERGY - SURAT GAS PROJECT

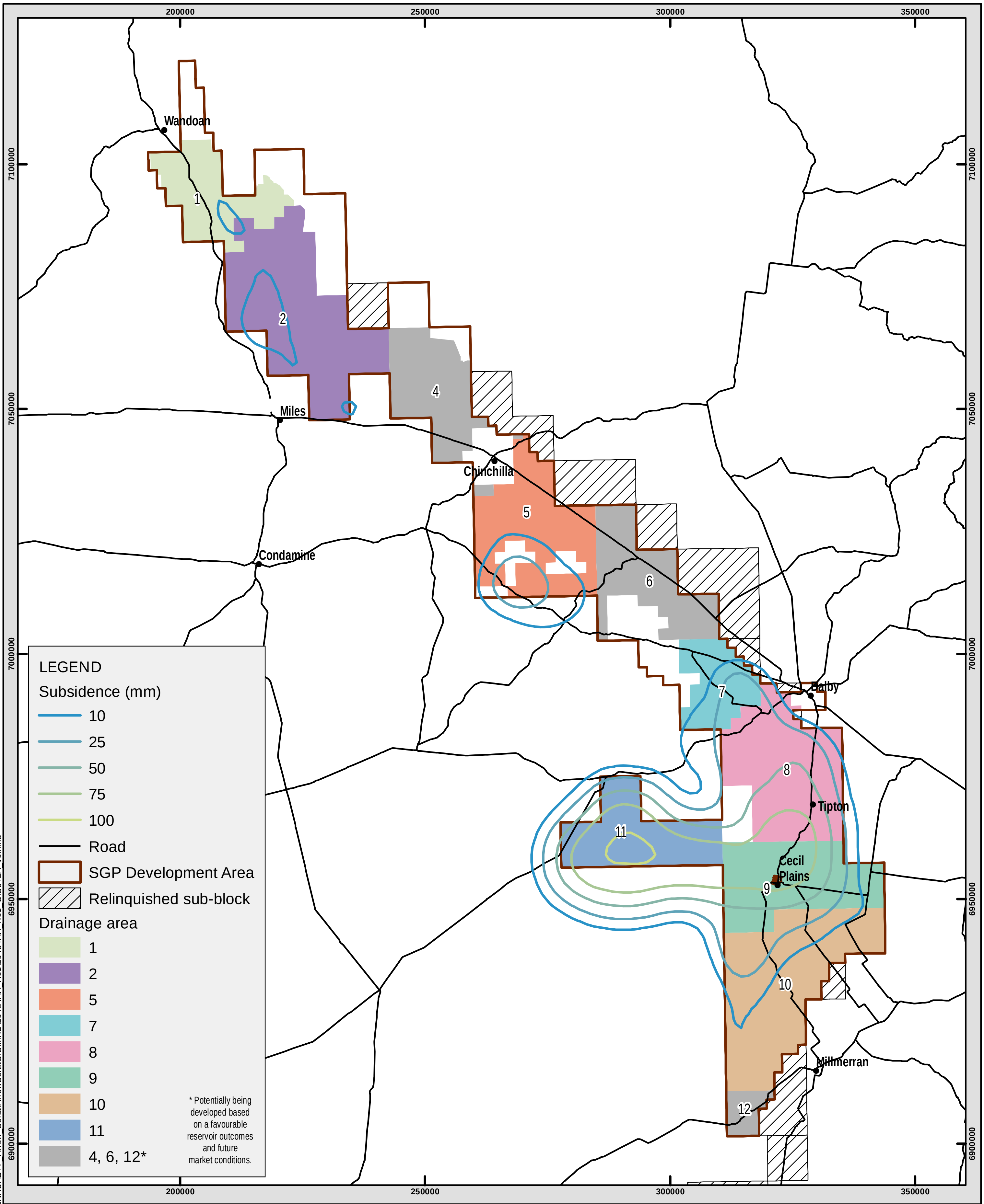

Figure 7.3 Predicted subsidence 2030 High assessment - Arrow only case

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

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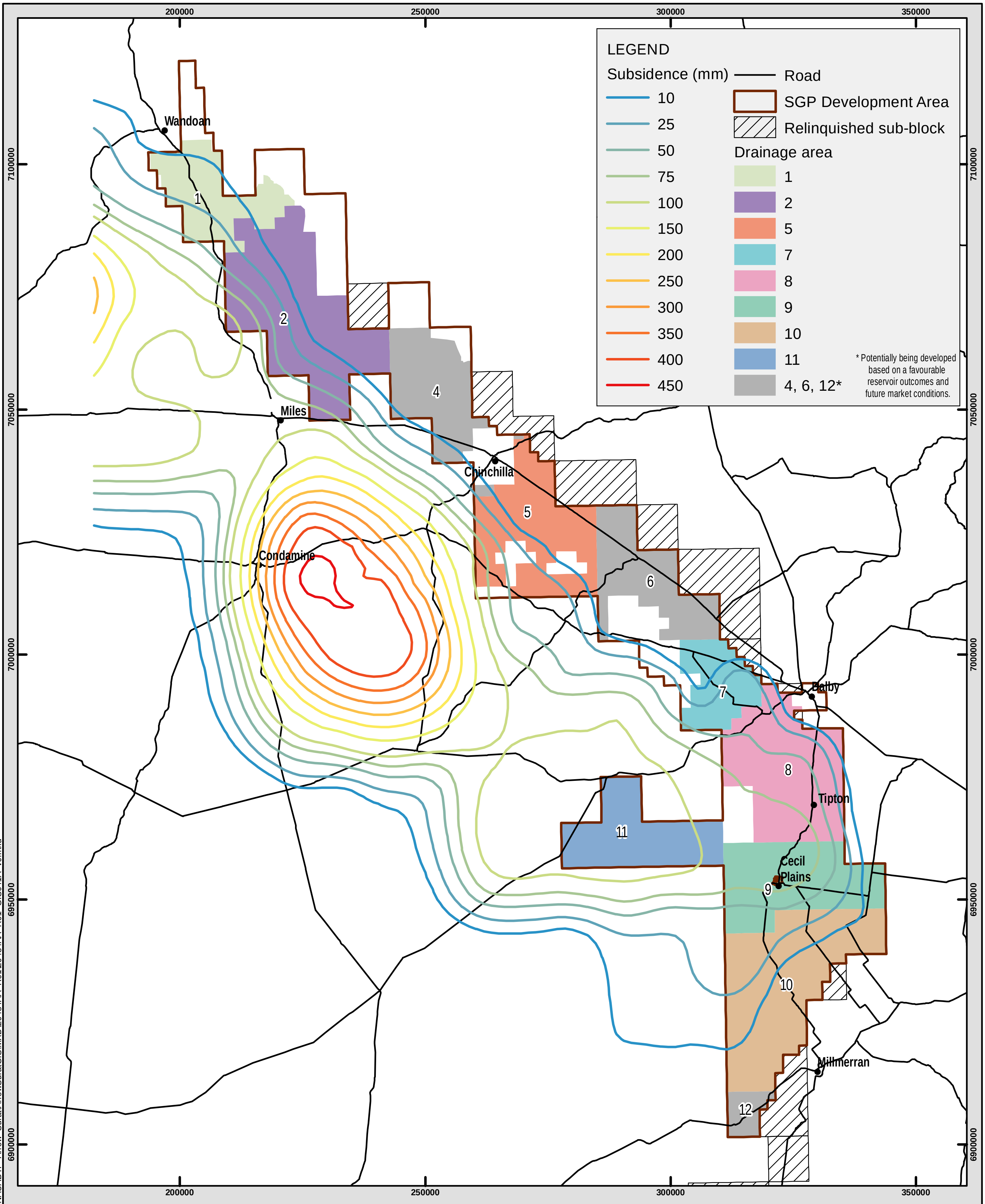

Figure 7.4 Predicted subsidence 2030 High assessment - Cumulative case

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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arrow energy go further

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

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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

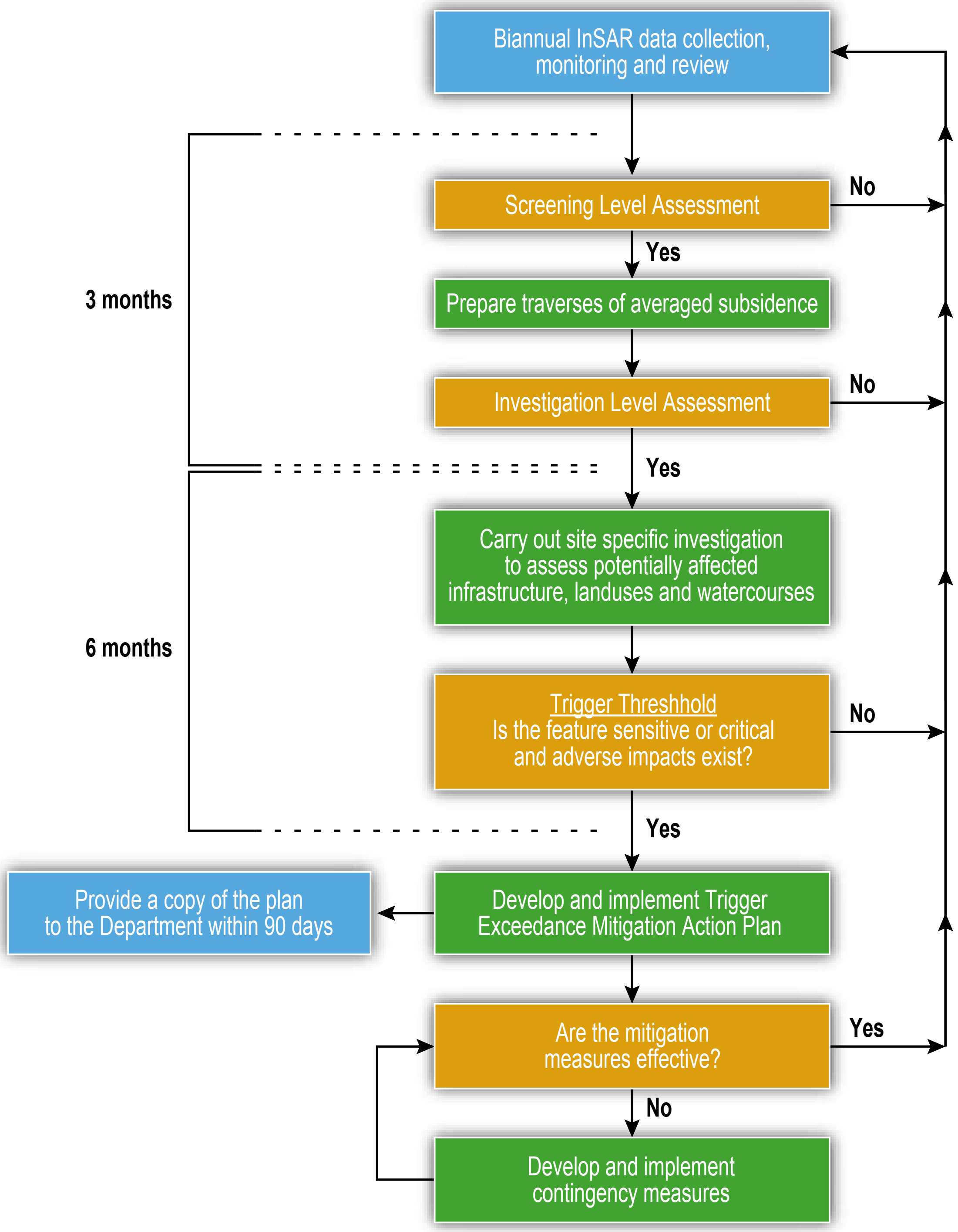

Figure 7.5 Subsidence monitoring assessment flow chart

Source:
Coffey

Date: 19/09/2018
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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.

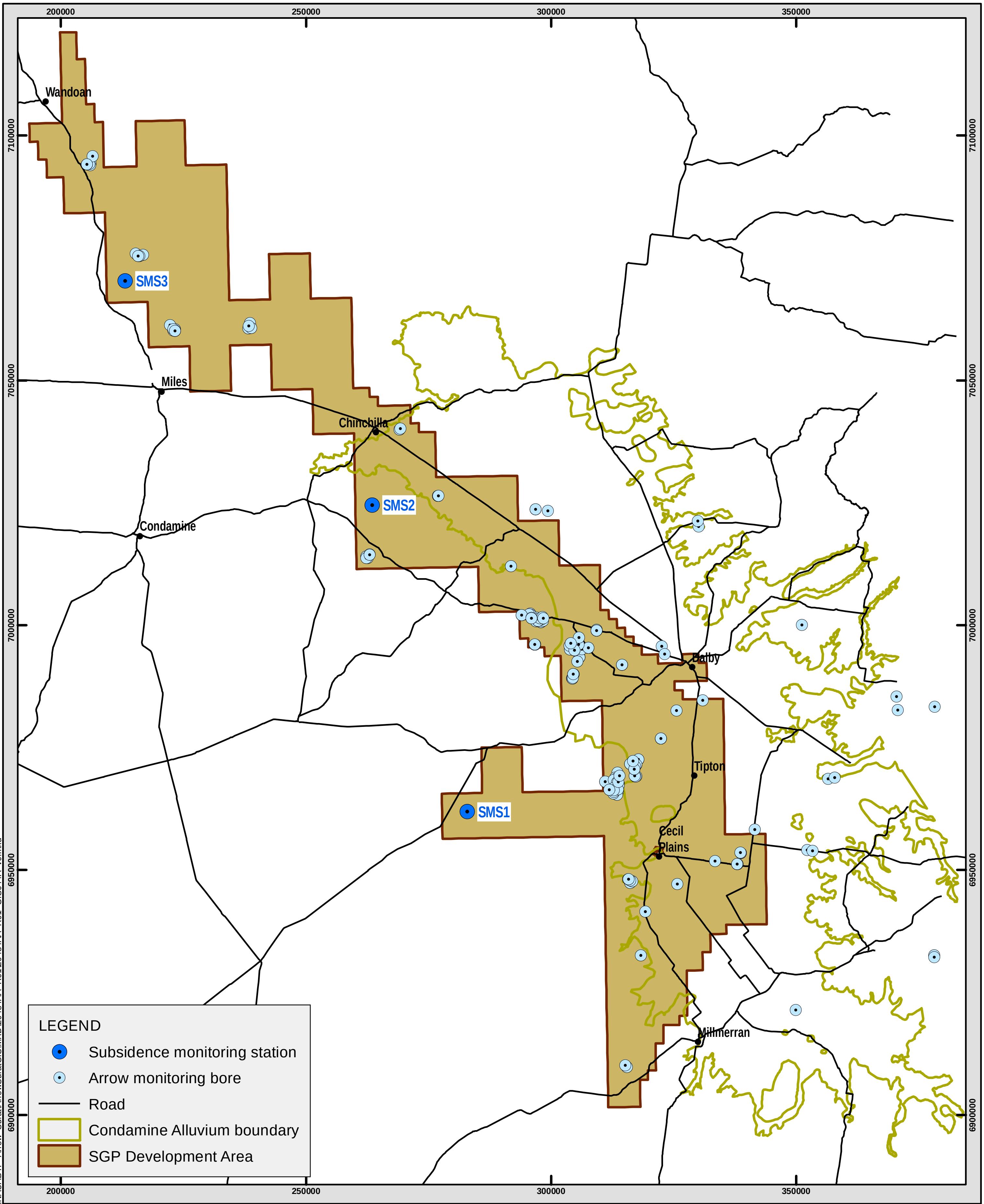

Figure 7.6

Subsidence monitoring stations

Source:
Arrow Energy Pty Ltd
Coffey

Date: 27/11/2017
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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™ 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

[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.

[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