Water Resource Monitoring and Management Plan

Surat Gas Project

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June 2025

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Revision history

Revision	Revision Date	Revision Summary
1	26 June 2025	Initial Issue

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Executive Summary

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

The SGP was approved by the Australian Government under the Environment and Protection and Biodiversity Conservation Act 1999 (EPBC Act) decision 2010/5344 on 19 December 2013. The conditions (as originally issued) attached to approval EPBC 2010/5344 required a Stage 1 CSG Water Monitoring and Management Plan (WMMP) (approved by the Australian Government on 18 December 2018) and an Updated CSG WMMP (approved by the Australian Government on 22 November 2019) be prepared.

The SGP then commenced[2] development of CSG resources in the Surat Basin on 22 October 2020.

On 17 March 2021, the Australian Government issued the Coal Seam Gas – Joint Industry Framework (JIF) to achieve defined environmental outcomes for groundwater in the Surat Basin. The JIF was collaboratively developed by the Federal Department of Agriculture, Water and the Environment and the CSG industry, with technical and regulatory advice from the Queensland Government.

The conditions of approval EPBC 2010/5344 were varied on 27 February 2025 to align the SGP with the JIF. Condition 17A (as varied) of approval EPBC 2010/5344 requires a Water Resource Monitoring and Management Plan (WRMMP) be prepared for the written approval of the Minister.

This document is the WRMMP for the SGP.

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 widespread decline in groundwater pressures, particularly in the Condamine Alluvium, which has historically been over-developed and over-allocated with respect to the productive yield of the system resulting in significant lowering of the watertable. Pressure declines in deeper GAB formations have also resulted.

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

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

[2] As defined in conditions attached to approval Surat Gas Expansion Project (EPBC 2010/5344)

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. Wilkie Creek is a tributary of the Condamine River that distributes flood flows during large flood events.

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

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

Predicted impacts of the SGP

Flux impacts on the Condamine Alluvium and surface water resources

Numerical modelling undertaken for the Updated WMMP (Arrow Energy, 2019) using the Underground Water Impact Report for the Surat Cumulative Management Area (UWIR) 2016 model demonstrated that the maximum flux changes to the Condamine River are small and the predicted impacts to the river and water resource are negligible under the FDP cases current at the time of writing the Updated WMMP.

Comparing the predicted magnitude of the groundwater flux changes provided in the Updated WMMP and that determined using the UWIR 2019 model, indicates a lower potential impact to the Condamine Alluvium and lower potential for subsequent impact to stream connectivity than previously estimated in the Updated WMMP. Output from the UWIR 2021 model predicts groundwater flux changes of 1,270 ML/year over the next 100 years, higher than predictions in the UWIR 2019 model but comparable to predictions in the UWIR 2012 and UWIR 2016 models and therefore the Updated WMMP.

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.

Surface water and aquatic ecology

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.

Subsidence impacts on surface water and groundwater resources

Potential impacts of subsidence to surface water systems include change in the drainage pattern of streams and channels; ponding of water in subsidence troughs (if they form); deepening or widening of pools in streams; alteration of riparian ecosystems and geomorphological stability; and increase the impact of, or exposure to, riverine flooding or delayed drainage. Potential subsidence impacts to groundwater systems include alteration to porosity and permeability of rocks. These potential impacts to surface water or groundwater systems may then have detrimental impacts on aquatic ecosystems, subterranean groundwater dependent ecosystems (GDEs), or terrestrial GDEs.

With the small magnitude of CSG induced subsidence and differential movement, as observed in monitoring of existing CSG fields and predicted in modelling, the inconsequential change in permeability or porosity, and the remote likelihood of fracturing of overburden materials, it is considered that the risk of affecting MNES groundwater resources, including the hydrology of the Great Artesian Basin aquifers or the surficial aquifers such as the Condamine Alluvium, is low.

Considering the low magnitude of slope changes predicted, reduced annual streamflow to the point it affects downstream environmental flows is expected to be unlikely and if noticeable at all, only of minor consequence. The low to very low risk of geomorphic impacts or alteration in flood behaviour or flows, results in a very low risk of impact to aquatic ecosystems.

Water management

CSG water and bring management

Arrow has an established CSG Water Management Plan (CSG WMP) for the SGP. The CSG WMP 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.

Monitoring network and program

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 (Arrow Energy, 2018b and Arrow Energy, 2019). Further, under the Arrow CSG WMP, discharge of produced water to surface water systems is not proposed. Therefore, consistent with the Stage 1 WMMP and the Updated WMMP, monitoring of surface water systems and aquatic ecology is not required.

Should future project requirements require changes to the FDP resulting in the potential for impact to surface water systems and aquatic ecology, Arrow will update this WRMMP to ensure the monitoring network and program remains appropriate, seek approval of the revised WRMMP from the Minister, and acquire adequate baseline data prior to any change.

Subsidence

Based on the data on CSG induced subsidence in the area of the SGP operations available since 2006 and predictions of subsidence with further CSG development, the effects of any subsidence are considered unlikely to have significant impact on MNES protected matters. Notwithstanding the low risk, ground deformation and water level monitoring will be carried out to verify the modelling, interpretation and the assessed risk.

Arrow's ground movement monitoring program will consist of acquisition of InSAR data on a 6-monthly basis from a 3rd party InSAR supplier; LiDAR surveys at least annually within 5 km of existing or planned CSG fields within the Condamine plain; 11 permanent GNSS monitoring stations; and annual terrestrial survey of 24 permanent survey marks with a six (6) hour observation time. As subsidence is related to depressurisation for CSG extraction, groundwater monitoring at multiple locations within, above and below the WCM for groundwater level/depressurisation will be undertaken at the locations and frequencies specified in the most recent UWIR published by OGIA.

Monitoring data will be assessed against a process of progressive trigger levels consisting of screening levels, investigation levels, and trigger thresholds. If trigger thresholds are exceeded and the potential for detrimental impacts is confirmed, a Trigger Threshold Exceedance Action Plan (TTEAP) will be developed and implemented within 90 days. A review of subsidence will be carried out and reported on an annual basis.

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To demonstrate compliance with the requirements of the approval conditions related to the WRMMP, Table A presents a summary of the approval conditions, cross-referenced to the relevant sections of the WRMMP where the conditions are addressed.

Table A. Approval condition compliance reference summary

Approval Condition	Condition Description	Relevant WRMMP section
17A	Within 4 months from the date this variation is signed, the approval holder must submit a Water Resource Monitoring and Management Plan (WRMMP) for the written approval of the Minister. The WRMMP must include:	
17A(a)	Parameters and a sampling regime to establish baseline data for surface water 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; and for determining connectivity between surface water and groundwater that may be impacted by the project.	3.1
17A(b)	A best practice monitoring network that will enable the identification of spatial and temporal changes to surface water parameters from baseline monitoring. This must enable monitoring of all aquatic ecosystems that may be impacted by the action.	4.3, 6.4
17A(c)	A program to monitor subsidence impacts from the action on protected matters. The subsidence monitoring program must: i. establish baseline data; ii. establish and justify subsidence monitoring and associated data collection methods; iii. establish and justify appropriate subsidence trigger thresholds. If subsidence trigger thresholds are exceeded, the approval holder must develop and implement an action plan to address impacts on protected matters within 90 calendar days of a trigger value being exceeded; iv. be reported annually and in accordance with the reporting requirements of condition 28. Annual reporting must compare subsidence monitoring results with baseline data and predicted impacts from the Supplementary Report to the Environmental Impact Statement (SREIS), and demonstrate the effectiveness of the implemented action plan, if required under 17A(c)iii.	7
17A(d)	Provision to make monitoring results publicly available on the approval holder's website to facilitate a greater understanding of cumulative impacts.	9.4
17A(e)	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.	5.1
17A(f)	Early warning indicators and trigger thresholds, including investigation, management and mitigation actions, which may include substitution and/or groundwater repressurisation, to address flux impacts on the Condamine Alluvium.	4.2, 6.1, 6.2
17A(g)	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.	5.1
17A(h)	Early warning indicators and trigger thresholds, including corrective actions for both early warning indicators and trigger thresholds, for aquatic ecology and aquatic ecosystems.	6.2

Approval Condition	Condition Description	Relevant WRMMP section
17A(i)	A discharge strategy, consistent with the recommendations and requirements of the Department of the Environment and Heritage Protection (now the Department of the Environment and Science) 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.	5.1
17A(j)	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 1:1000 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.	5.2
17A(k)	An explanation of how the WRMMP 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.	8
17A(l)	Details of performance measures; annual reporting to the department; and publication of reports on the website.	9
17A(m)	Include a risk based exceedance response plan that details the actions the approval holder will take and the timeframes in which those actions will be undertaken if early warning indicators and trigger threshold values contained in the WRMMP are exceeded, or there are any emergency discharges.	6.1.3, 5.1
18	The WRMMP must be peer reviewed by a suitably qualified water resources expert/s approved by the Minister in writing prior to the plan being submitted to the Minister for approval. The approval holder must, at the same time as the WRMMP is submitted for approval, provide to the Minister: a. a copy of the peer review; and b. statement from the suitably qualified water resources expert/s stating that they carried out the peer review and endorse the findings of the WRMMP.	9.5
20C	The Minister may direct, in writing, that the approval holder cease water or gas extraction from one or more coal seam gas production wells, or water discharge or use, if: a. an early warning indicator, trigger threshold, or limit in the WRMMP is exceeded, and b. the Minister is not satisfied that the corrective activities proposed or taken by the approval holder will reduce likely impacts on matters of national environmental significance (MNES) to acceptable levels.	NA
28	Within 60 business days of every 28 February anniversary of the commencement of the action, the approval holder must publish a compliance report on its website for the life of the approval.	9.2.4
34	Unless otherwise agreed to in writing by the Minister, the approval holder must publish each management plan referred to in these conditions of approval on the website. Each management plan must be published on the website within 20 business days of the date:	9.4

Approval Condition	Condition Description	Relevant WRMMP section
	a. the plan is approved by the Minister in writing, if the plan requires approval of the Minister; or b. of the approval of this variation, if the version of the plan to be implemented is specified in these conditions.	

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1 Introduction

The Surat Gas Expansion Project[3] (SGP) was approved by the Australian Government under the *Environment and Protection and Biodiversity Conservation Act 1999* (EPBC Act) decision 2010/5344 on 19 December 2013. The conditions (as originally issued) attached to approval EPBC 2010/5344 required a Stage 1 CSG Water Monitoring and Management Plan (WMMP) (approved by the Australian Government on 18 December 2018) and an Updated CSG WMMP (approved by the Australian Government on 22 November 2019) be prepared.

The SGP then commenced[4] development of coal seam gas (CSG) resources in the Surat Basin on 22 October 2020.

On 17 March 2021, the Australian Government issued the Coal Seam Gas – Joint Industry Framework (JIF) to achieve defined environmental outcomes for groundwater in the Surat Basin. The JIF was collaboratively developed by the Federal Department of Agriculture, Water and the Environment (now DCCEEW) and the CSG industry, with technical and regulatory advice from the Queensland Government.

The conditions of approval EPBC 2010/5344 were varied on 27 February 2025 to align the SGP with the JIF. Condition 17A (as varied) of approval EPBC 2010/5344 requires a Water Resource Monitoring and Management Plan (WRMMP) be prepared for the written approval of the Minister.

This document is the WRMMP for the SGP. This WRMMP addresses the Australian Government approval conditions relating to the assessment, management, and mitigation of water resource 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).

An evaluation of the SGP EIS/SREIS was also completed by the then 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 1994* which recognises that through the EIS and SREIS processes Arrow has committed to the management and monitoring of groundwater and surface water resources and CSG water, and is also obliged to carry out further investigations and monitoring under the approval processes. A table cross-referencing Arrow's commitments under the EIS/SREIS is presented in Appendix A.

1.1 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 5,385 km^2. Refinements to the basis of design, including revised typical or expected arrangements, configurations, construction methods and CSG infrastructure design, have allowed Arrow to incorporate new design elements to reduce the projects footprint. As described in the SREIS, the SGP comprised a Field Development Plan (FDP) based on 6,500 wells and total water production of 510 GL. The FDP has been subsequently revised (Appendix B), and this WRMMP is based

[3] Referred to as the Surat Gas Project (SGP) in this plan
[4] As defined in conditions attached to approval Surat Gas Expansion Project (EPBC 2010/5344)

on an updated FDP comprising 2,766 wells and total water production of 380 GL over a 42 year duration, as included in the Office of Groundwater Impact Assessment (OGIA) 2021 Underground Water Impact Report for the Surat Cumulative Management Area (UWIR) model (OGIA, 2021).

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

1.2 Definitions

Key terms relevant to the WRMMP are defined in Table 1-1, 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 1-1 Definitions[5]

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[6] for similar systems, being 5 m for consolidated aquifers and 2 m for unconsolidated aquifers.
Early warning indicator	A first-tier drawdown level that provides early indication of potential for an impact.
Groundwater drawdown due to the Action	Change in head relative to the background level arising from the Action.
FDP	Field development plan. Describes the CSG wellfield plan and timing for the Action.
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)
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.
Trigger threshold	A second-tier drawdown level that triggers response actions.

[5] Where relevant, the terms are defined in relation to the SGP induced change.
[6] Taken from the bore trigger thresholds under the Queensland *Water Act 2000*

2 Environmental Setting

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

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

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

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

2.1 Climate

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

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

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

Table 2-1 Mean climate characteristics

Precipitation (mm)	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Annual**
Mean	75	77	65	20	38	30	24	22	28	60	70	90	596
Dalby Airport (Station number 41522) (data downloaded Oct 2024)													
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)

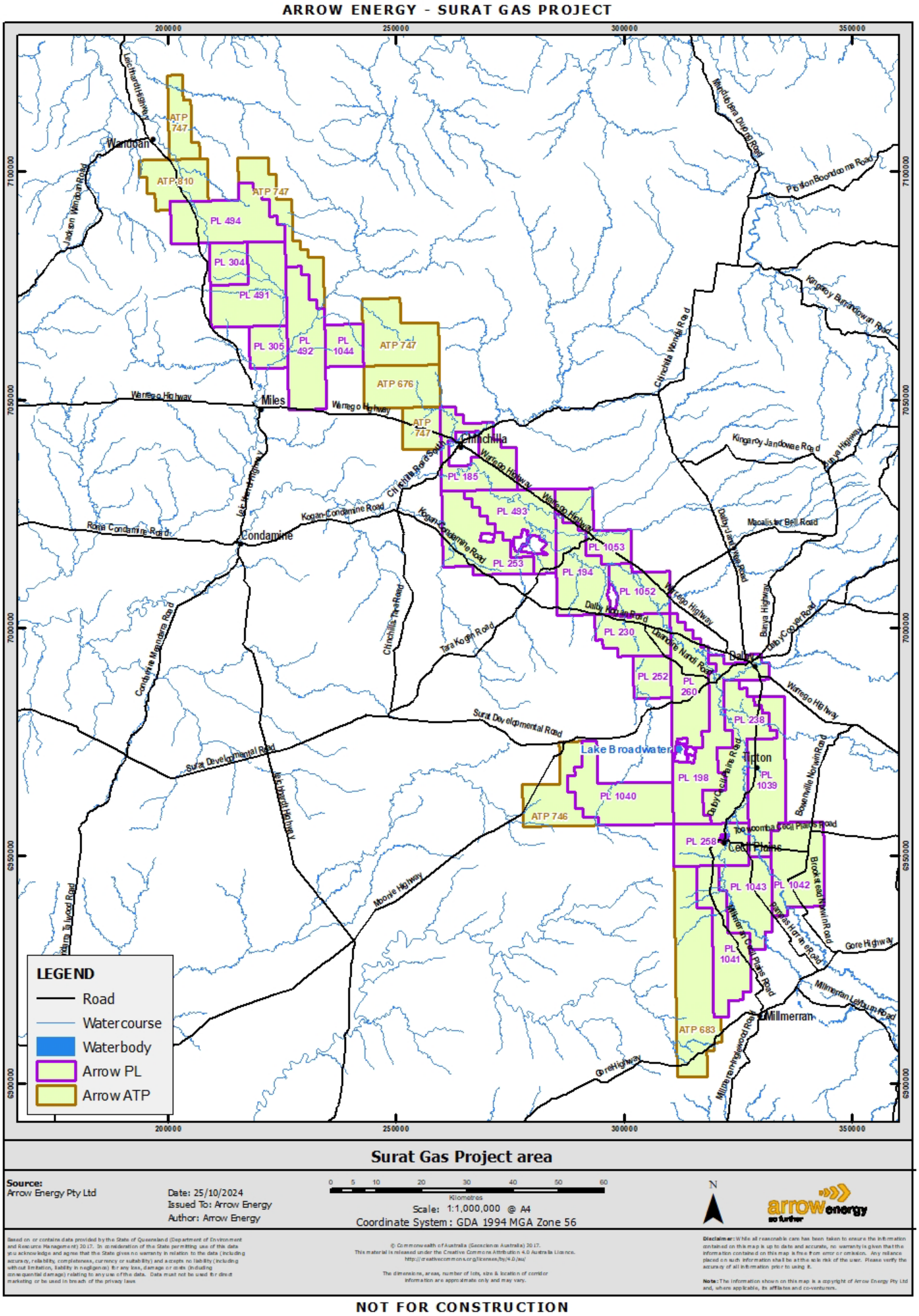

Figure 2-1 Surat Gas Project area

2.2 Topography and landform

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

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

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

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

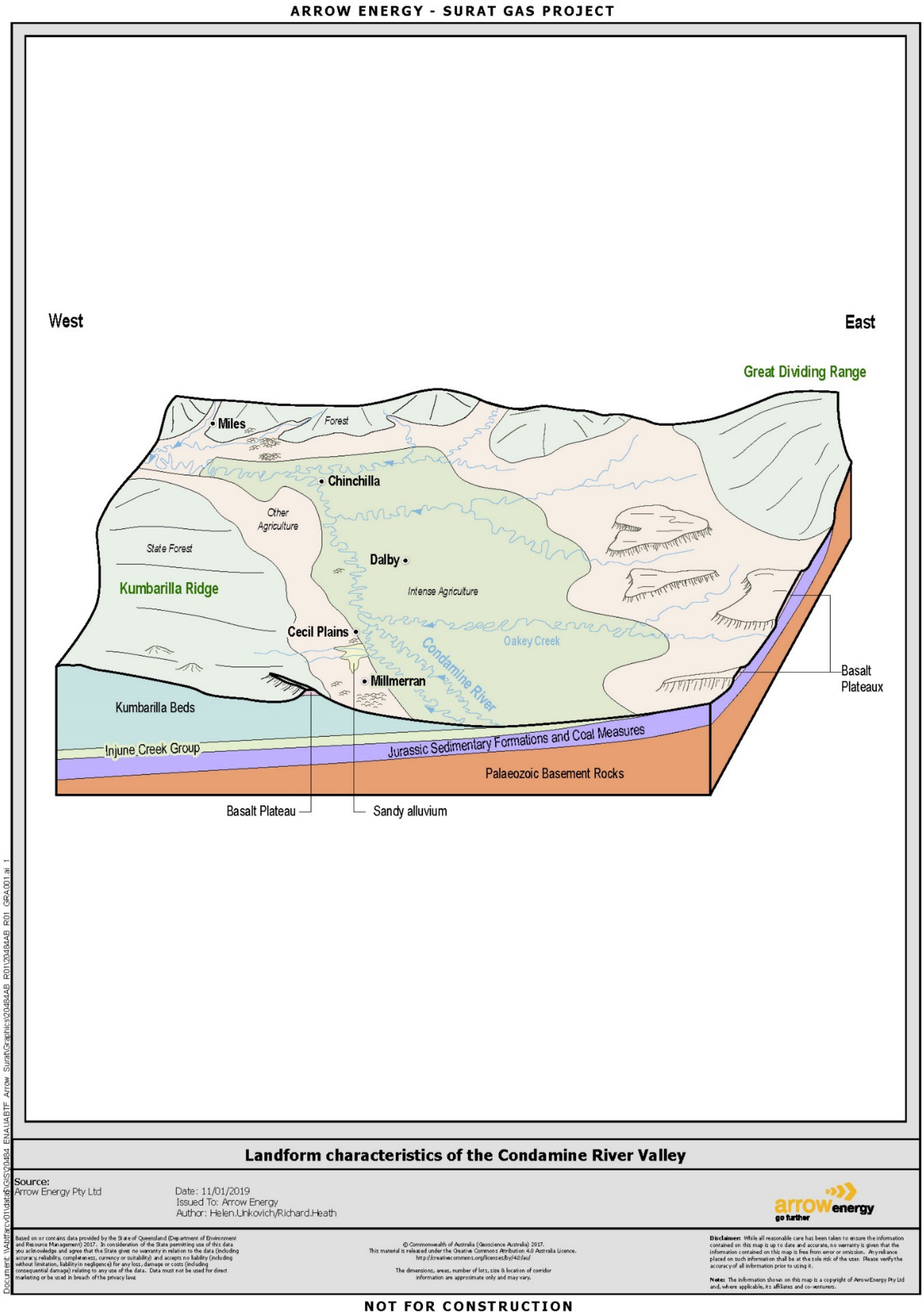

Figure 2-2 Landform characteristics of the Condamine River Valley

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.

Wilkie Creek

Wilkie Creek is a tributary of the Condamine River that distributes flood flows during large flood events. The Creek flows from southeast to northwest. It comprises a single thread moderately-sinuous channel that alternates between wide, slow-moving reaches and pools, and smaller, low-flow channels. Riparian vegetation is relatively intact along most of the length of the watercourse, although bank erosion and meander migration could potentially occur.

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.

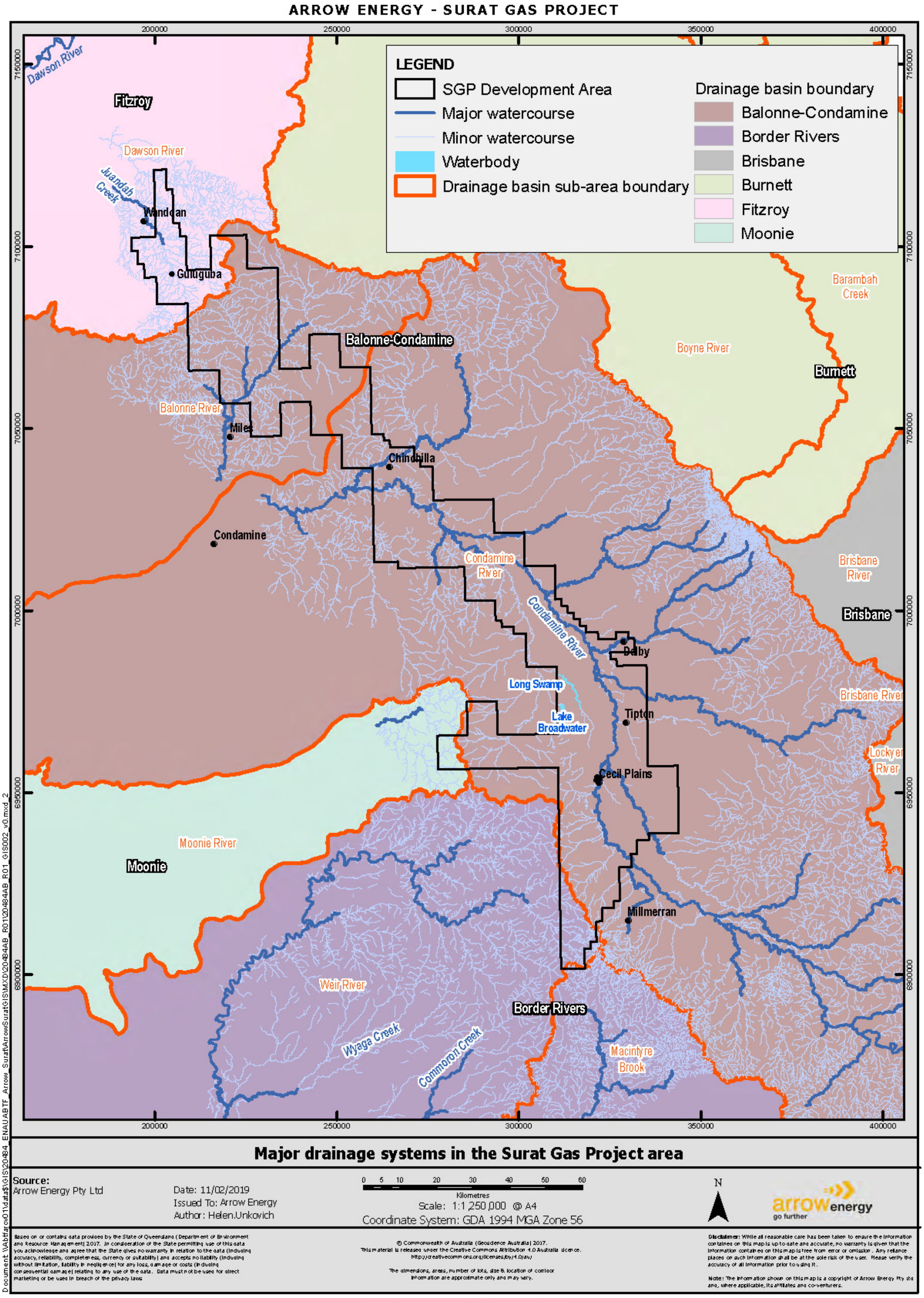

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Figure 2-3 Major Drainage systems in the Surat Gas Project area

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 (Figure 2-3).

Lake Broadwater is a naturally occurring, seasonal/intermittent, shallow, freshwater wetland which covers approximately 350 hectares. It 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[7] wetland to the north-east of Lake Broadwater, considered to be an older course of the Condamine River. It is a broad sinuous overland flow path that extends for approximately 30 km on the Condamine Alluvium. The feature comprises a broad drainage depression, with the central portion underlain by highly vertic surface soils with a strong shrinkswell structure of hummocks and deep cracks (3D Environmental/Earth Search 2018). 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, 2013).

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[7] Lacking flowing water, or marshy

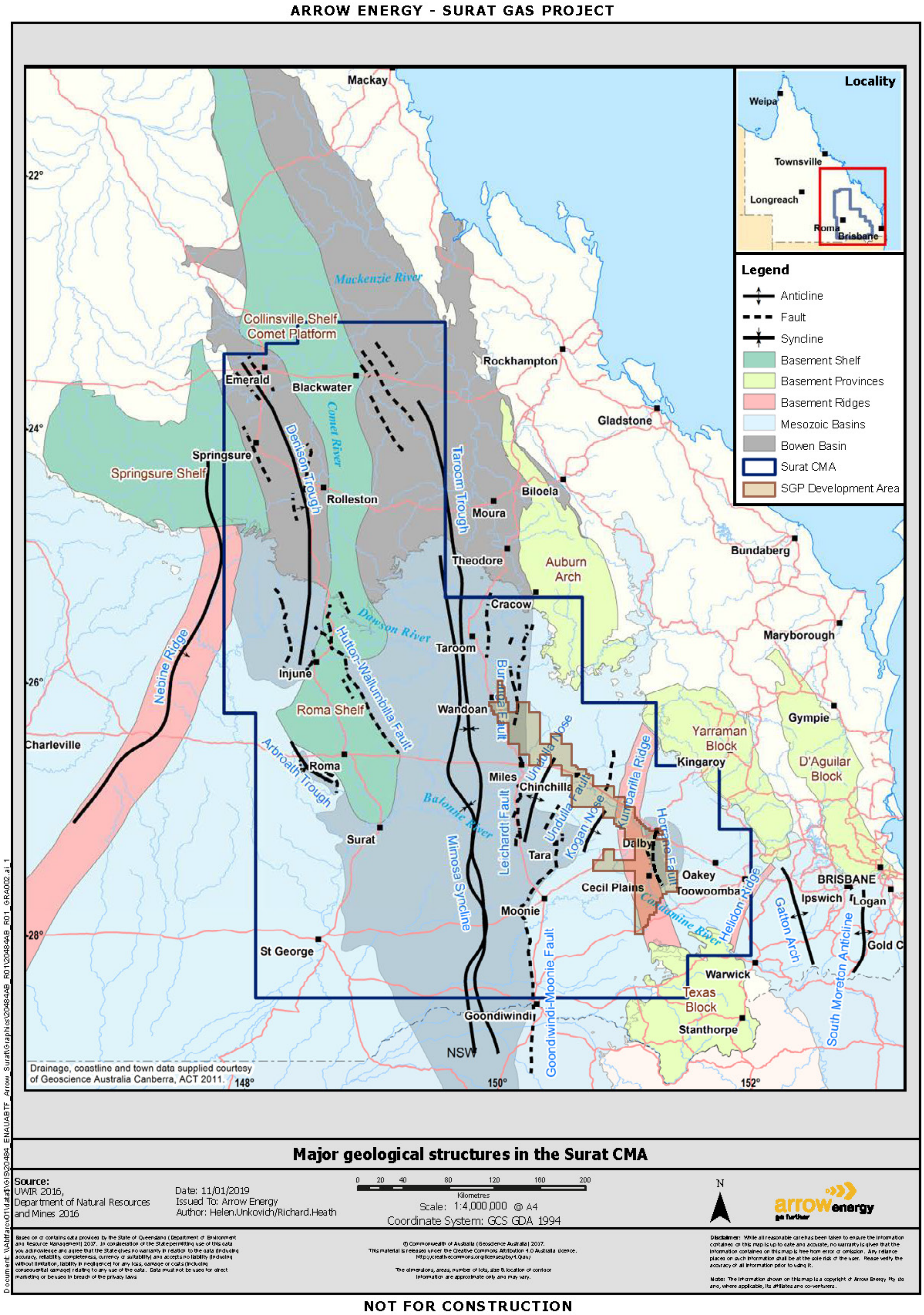

Figure 2-4 Major geological structures in the Surat CMA

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.

Figure 2-5 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 2021 Surat Cumulative Management Area (CMA) Underground Water Impact Report (UWIR) (OGIA, 2021).

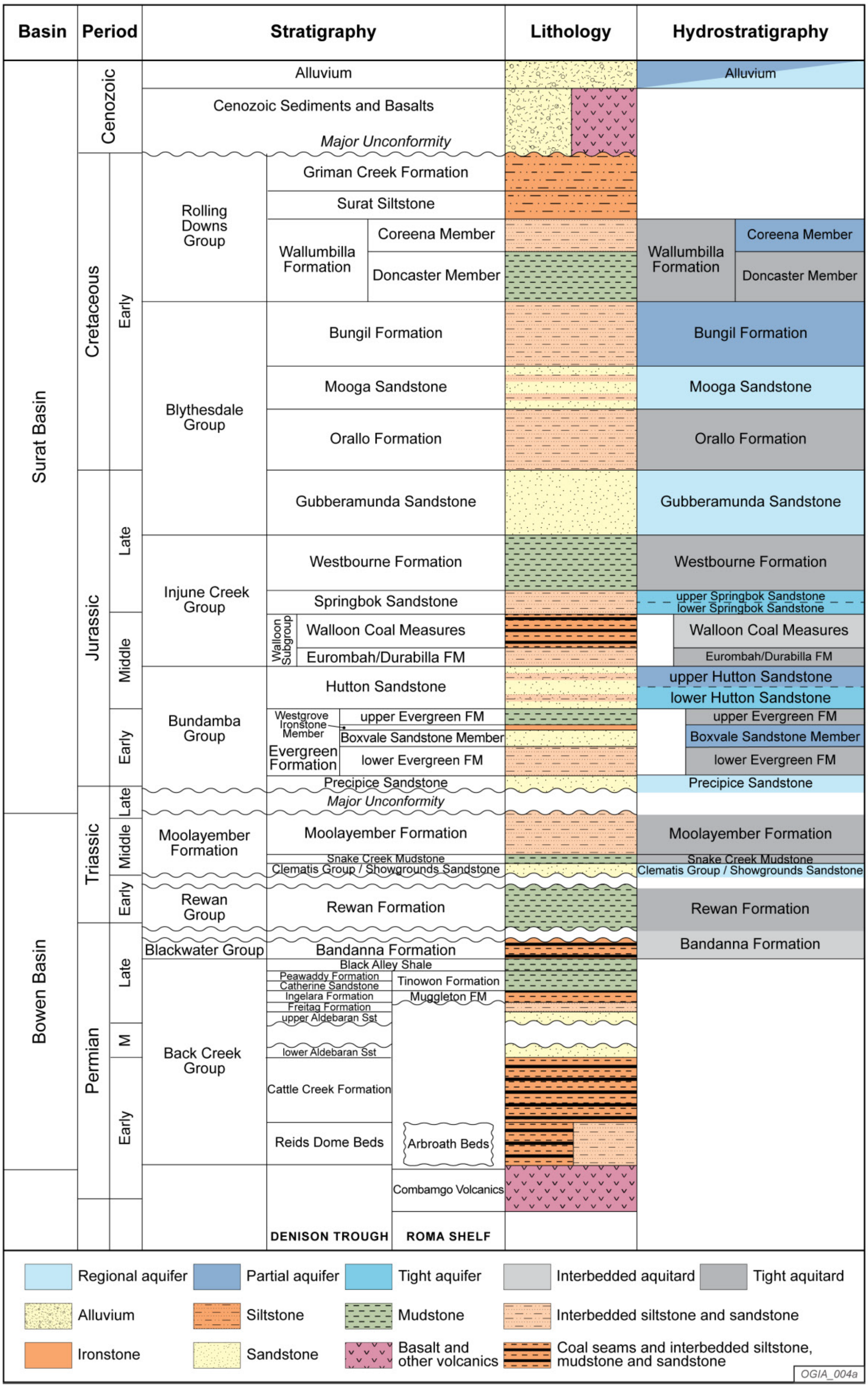

Figure 2-5 Generalised hydrostratigraphic classification in the Surat CMA (OGIA, 2021)

Condamine Alluvium

The Condamine Alluvium extends in a north-south direction from around Chinchilla in the north to Millmerran in the south (Figure 2-6). 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 and form a significant vertisol (black soil) cover over much of the Condamine River valley.

Figure 2-6 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.

Since 2012, OGIA and Arrow have led research into connectivity between the Condamine Alluvium and the underlying Walloon Coal Measures, using multiple lines of investigation: reinterpreting geology with a particular focus on the contact between the two systems; mapping regional groundwater level differences between the two systems; analysing the hydrochemistry of the two systems; drilling, coring and running pumping tests at representative sites; and numerically analysing the data (OGIA, 2021). Arrow complemented the study by coring, pump testing and drilling of monitoring bores.

DNRME (2016d) concluded that there was a low level of connectivity between the Condamine Alluvium and the Walloon Coal Measures. It was conceptualised that vertical flow and interaction between the Condamine Alluvium and the upper parts of the Walloon Coal Measures is impeded by a combination of the undifferentiated clay transition zone at the base of the alluvium and the firm mudstone/siltstone interburden of the Walloon Coal Measures, in which its coal seams are embedded (Figure 2-7). The vertical hydraulic conductivity for the transition zone and the upper Walloon Coal Measures is expected to range from 10^{-9} to 10^{-4} m/day across the Condamine Alluvium footprint (OGIA, 2016).

Data collected more recently from additional monitoring and pumping test sites has reaffirmed the findings that the degree of connectivity is low. Updated mapping of the contact between the Walloon Coal Measures and the Condamine Alluvium in the geological model, from additional wireline and bore data, also affirms that understanding of the geology is consistent with the previous investigations (OGIA, 2021).

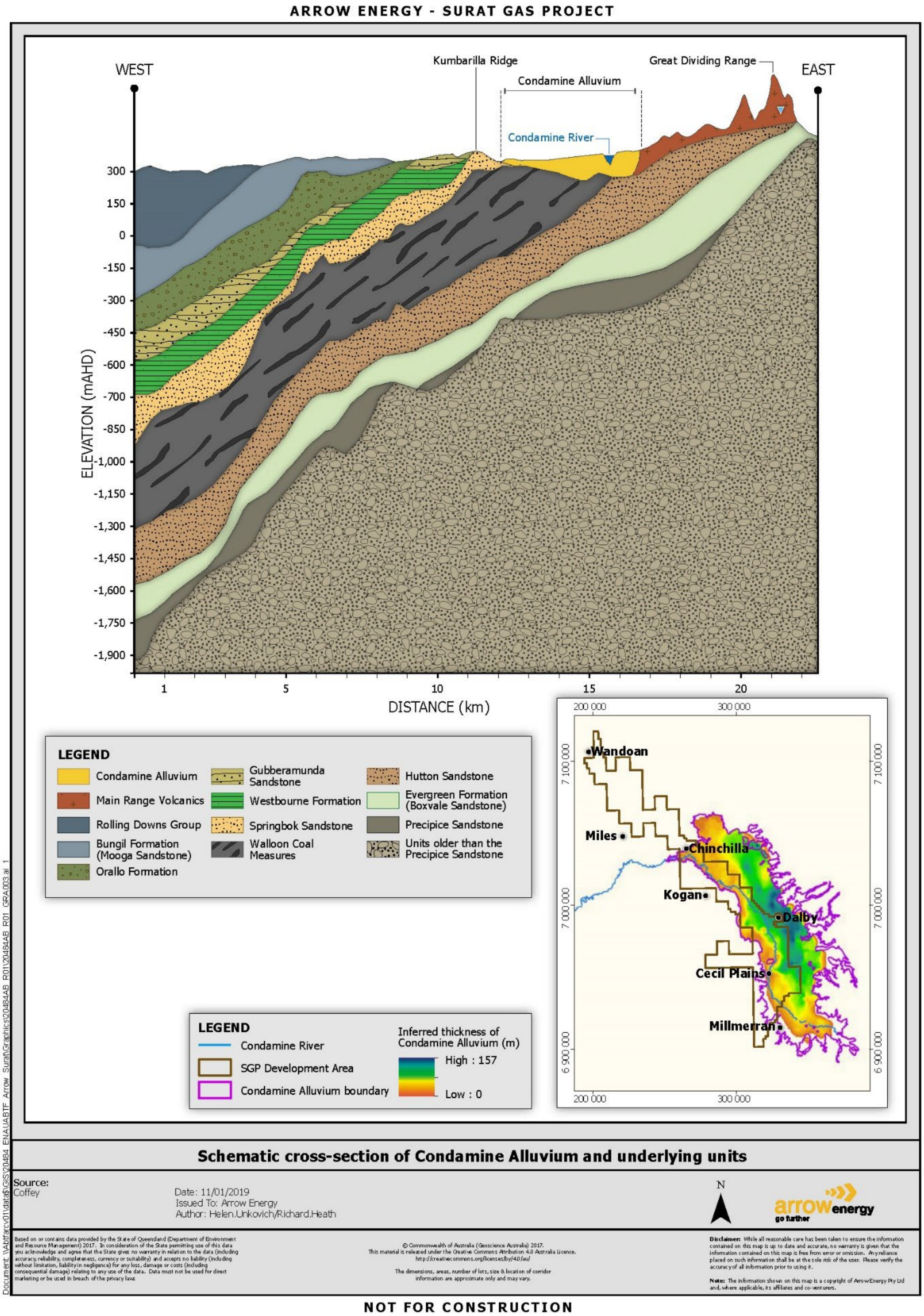

Figure 2-6 Schematic cross section of Condamine Alluvium and underlying units

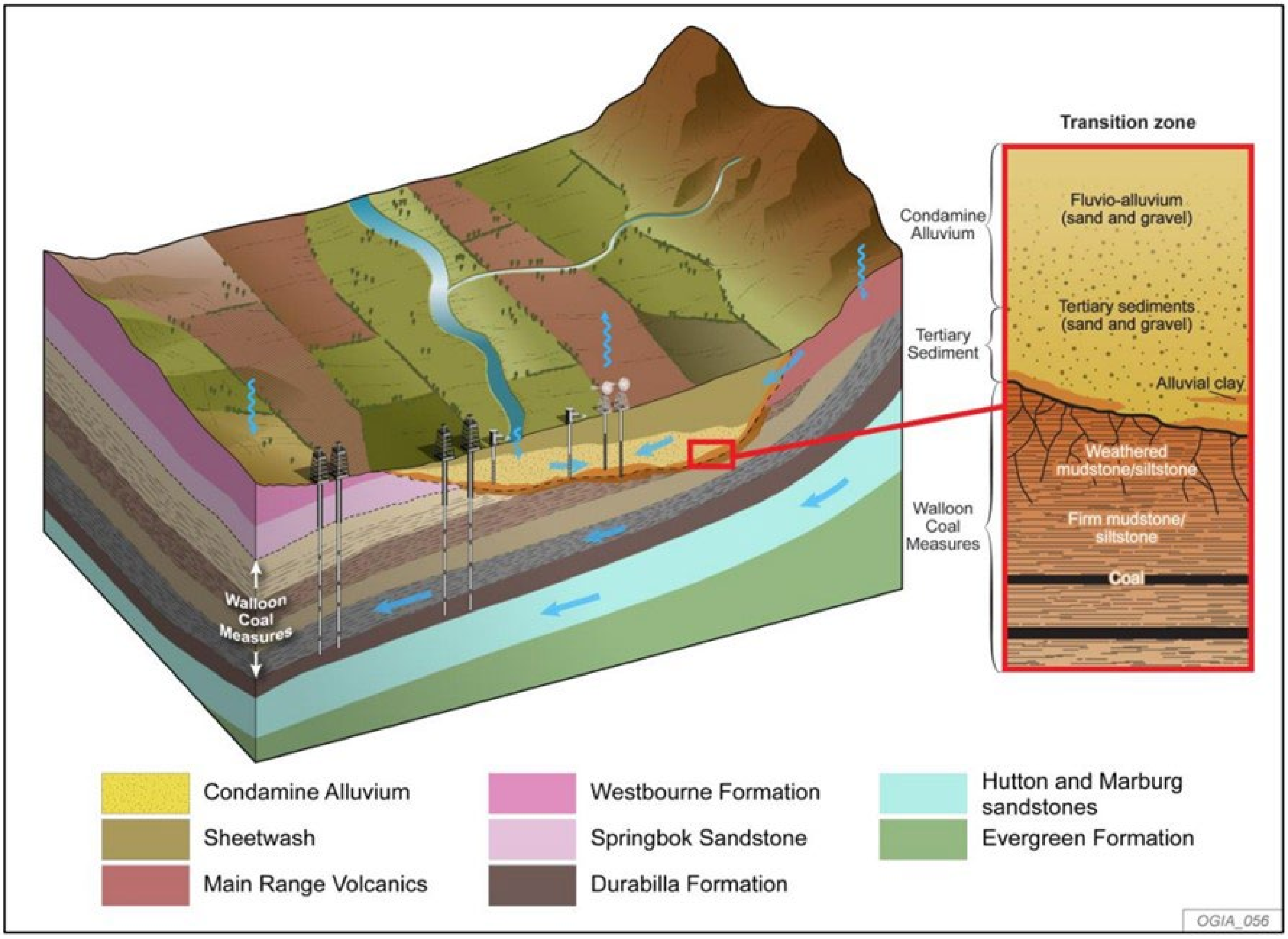

Figure 2-7 Schematic of the regional hydrogeological setting around the Condamine Alluvium (OGIA, 2021)

2.5 Hydrogeology

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

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

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

Further detailed information on the hydrogeological conceptualisation is provided in the SGP EIS/SREIS as well as more recent reports developed by OGIA including the Surat CMA UWIR (OGIA, 2021).

2.5.1 Hydrostratigraphy

The SGP area contains both unconfined and confined aquifers. Figure 2-5 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.
- Hutton[8] Sandstone: deeply buried confined consolidated sandstone GAB aquifer.
- Precipice Sandstone: deeply buried confined consolidated sandstone and siltstone GAB aquifer.

2.5.2 Aquifer recharge

Recharge mechanisms of the Condamine Alluvium

Recharge includes infiltration from the Condamine River, with contribution from rainfall infiltration and laterally from the surrounding bedrock and alluvium of the tributaries of the Condamine River (OGIA, 2021). Water balance modelling completed by KCB (KCB, 2011a) 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, 2011a).

Recharge mechanisms of GAB formations

Recharge to GAB formations is primarily by direct rainfall infiltration where the formations outcrop to the north, north-west and north-east of the Surat Basin along the Great Dividing Range. Recharge is primarily along

[8] Includes laterally equivalent Marburg Sandstone where present

preferential flow pathways including bedding planes and fractures (OGIA, 2021). 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 (OGIA, 2021).

Vertical leakage between GAB aquifers is restricted in many areas by the low permeability aquitards present throughout the GAB, including the Durabilla, Evergreen and Westbourne formations and their equivalents (OGIA, 2021).

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; OGIA, 2021). 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 WCM and the overlying Springbok Sandstone is indicated through seismic analysis. Faults affecting the contact between the Springbok Sandstone and the WCM are likely to juxtapose coals in the WCM and sandstones in the lower Springbok Sandstone at some locations (OGIA, 2020). However, for most of these faults, the contact area is likely to be small and may not facilitate significant cross-formational flow. There is only one location (which is outside of the SGP) where impact in the Springbok Sandstone can be directly attributed to a fault (OGIA, 2020). 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. Vertical connectivity through faults in the Surat Basin is limited by the presence of swelling clays, mineralisation and closing of fractures due to compressional forces associated with in-situ stress conditions (OGIA, 2021).

OGIA (2021) also report that as the coal seams within the major gas reservoirs generally represent less than 9% 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.

OGIA (OGIA, 2020) and Arrow (Viljoen et al., 2020) have undertaken investigations into the Horrane Fault which is a regionally significant structural feature in the eastern part of the Surat Basin. The fault originates from a basement fault system and has subsequently propagated into the Surat Basin. Reservoir pressure monitoring data suggests a large pressure difference across the fault, indicating a barrier to horizontal flow within the Walloon Coal Measures (OGIA, 2021). This is supported by Arrow's separate investigations based on interference tests and coring. These findings are consistent with the high degree of clay smearing that is likely to exist due to the high clay content of the Walloon Coal Measures and Durabilla Formation in most areas, inferred from nearby well lithological data. The Horrane Fault is simulated in the UWIR groundwater model.

2.5.4 Groundwater use

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

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

Groundwater use is detailed in the following sections.

Non-petroleum and gas related groundwater extraction

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

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

A summary of the non-petroleum groundwater extraction bores and extraction volumes within an area that captures the entire active resource development footprint and extends further to about 15 km (area of interest) as reported in the Surat CMA UWIR (OGIA, 2021) is provided in Table 2-2. Surface water licencing for the Condamine region is provided in Table 2-3 for comparison.

There are over 8,000 water bores within the UWIR area of interest with a combined water extraction in the order of 59,000 ML/yr. Of this, around 20,000 ML/yr is sourced from GAB formations, and 39,000 ML/yr from other aquifers. The total groundwater extraction presented in Table 2-2 represents groundwater used for stock and domestic purposes, non-stock and domestic purposes (agricultural, industrial, urban), and non-associated purposes (water taken by the petroleum and gas industry not associated with production of petroleum or gas).

Non-GAB aquifers having the greatest number of groundwater bores and extraction volumes in the UWIR area of interest are the Condamine Alluvium, with lower numbers of bores and extraction volumes for the Main Range and Tertiary Volcanics and other alluvium. Production from the GAB aquifers is mainly from the Hutton-Marburg Sandstone, the Gubberamunda Sandstone, the WCM, and the Precipice/Helidon Sandstone (OGIA, 2021).

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

Formation	Number of bores				Water use (ML/year)			
	S&D	Non-S&D	Non-assoc.	Total	S&D	Non-S&D	Non-assoc.	Total
Non-GAB upper formations								
Condamine Alluvium	1,903	503	0	2,406	1,784	29,696	0	31,480
Main Range Volcanics & Tertiary Volcanics	345	69	1	415	253	1,869	9	2,131
Other alluvium	510	46	0	556	2,995	1,780	0	4,775
Other units	108	4	0	112	138	250	0	388
Sub-total	**2,866**	**622**	**1**	**3,489**	**5,170**	**33,595**	**9**	**38,774**
GAB formations								
Hutton and Marburg Sandstones	1,101	123	0	1,224	1,611	6,275	0	7,886
Walloon Coal Measures	731	63	0	794	838	1,538	0	2,375
Precipice and Helidon Sandstones	164	15	7	186	299	1,742	184	2,225
Evergreen Formation	91	3	0	94	247	149	0	396
Gubberamunda Sandstone	602	40	12	654	787	2,098	325	3,210
Springbok Sandstone	157	6	3	166	190	151	28	369
Other units	1,290	26	0	1,316	2,002	1,293	0	3,296
Sub-total	**4,136**	**276**	**22**	**4,434**	**5,974**	**13,246**	**537**	**19,757**
Non-GAB (lower) formations								
Bowen Permian	12	0	0	12	15	0	0	15
Clematis Sandstone	26	0	0	26	28	0	0	28
Bandanna Formation	14	0	0	14	27	0	0	27
Other units	60	0	0	60	65	0	1	66

Surat Gas Project

Formation	Number of bores				Water use (ML/year)			
	S&D	Non-S&D	Non-assoc.	Total	S&D	Non-S&D	Non-assoc.	Total
Sub-total	112	0	0	112	135	0	1	136
Total	7,114	898	23	8,035	11,279	46,841	547	58,667

Source: OGIA (2021)

Table 2-3 Surface water licensing in the Condamine region

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

Source: CSIRO (2008); CDM Smith (2016)

Petroleum and Gas activity associated groundwater extraction

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

In the Surat CMA, conventional oil and gas production dates back to the 1960s and is now approaching end of life, with water extraction declining significantly since 2011 to the current level of around 1,000 ML/year. The main oil field is the Moonie field, which accounts for over 95% of the associated water extraction, operating in the Precipice Sandstone and Evergreen Formation. There is also some minor production from the Showgrounds Sandstone of the Bowen Basin (OGIA, 2021).

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 description of the nature and distribution of aquatic ecosystems is presented in the following sections, with further detail provided in the Surface Water and Aquatic Ecosystems Appendix (Appendix C).

Since the Updated WMMP was approved in November 2019, additional baseline data have been collected through an aquatic ecology assessment of the surface systems of Wilkie Creek. The location of the monitored sites and a summary of the monitoring results is provided in Appendix C.

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.

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.

3 Monitoring and Research

3.1 Surface water baseline monitoring program

A network of surface water and aquatic ecology baseline monitoring locations was established as part of the SGP EIS/SREIS process, inclusive of surface water quality, flow and aquatic ecology monitoring locations. 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. Further to this, baseline data are available via the Queensland DLGWV state monitoring network, with 19 currently open surface water gauging stations situated in or in close proximity to Arrow's tenure, 15 of which monitor water quality.

Further surface water and aquatic ecology baseline monitoring was also conducted in 2022 to assess environmental values on Wilkie Creek. The location of the monitoring sites and a summary of the baseline monitoring results is provided in Appendix C.

In addressing the component of Condition 17A(a) relating to establishing baseline data for determining connectivity between surface water and groundwater that may be impacted by the project, Arrow continues to carry out its groundwater monitoring obligations under the UWIR Water Monitoring Strategy (WMS). Provision of these data to the OGIA contributes to establishing baseline data, ongoing assessment of aquifer connectivity studies and to improving the collective hydrogeological knowledge of the Surat Basin. This ongoing monitoring Arrow conducts builds on the work jointly conducted between Arrow and OGIA since 2012 into assessing the connectivity between the Condamine Alluvium and the Walloon Coal Measures (further described in Section 8.1) including modelling changes in flux to the Condamine Alluvium in each UWIR. Section 5.6.2.3 of the 2021 UWIR illustrates how these data Arrow collect contribute to ongoing updates of the mapping of groundwater level differences between the Condamine Alluvium and the WCM, and a subsequent conclusion that the data presented in the 2021 UWIR is consistent with the previously reported findings in previous UWIRs.

4 Predicted Impacts

4.1 Impacts to Groundwater

Impacts to groundwater from CSG within the Surat Basin are predominantly managed through the Coal Seam Gas – Joint industry framework (JIF) (DAWE, 2021). The JIF was collaboratively developed by the federal Department of Agriculture, Water and the Environment (now DCCEEW) and the CSG industry, with technical and regulatory advice from the Queensland Government.

The JIF comprises defined environmental outcomes for groundwater in the Surat Basin. These include:

- maintaining or enhancing groundwater discharge and environmental values at springs which are part of the listed threatened 'community of native species dependent on the natural discharge of groundwater from the Great Artesian Basin';
- ensuring water supply bores continue to supply water;
- ensuring the continuing function and environmental value of groundwater dependent ecosystems; and
- maintaining habitat for subterranean fauna.

As noted in Section 1, the SGP EPBC approval conditions were varied to align the SGP with the JIF. As a result, conditions 17A(f) and 17A(g) (as varied) are the only groundwater-related conditions required to be addressed through the WRMMP. Condition 17A(f) is addressed in this section and 17A(g) is addressed in Section 5.1.

4.2 Flux impacts on the Condamine Alluvium and surface water resources

Numerical modelling was undertaken in the Updated WMMP (Arrow Energy, 2019) to quantify the impact that flux changes to the Condamine Alluvium may have on surface water flow in the Condamine River. This modelling applied the vertical flux at the base of the Condamine Alluvium from the regional UWIR model to the more detailed Central Condamine Alluvium Model (CCAM, developed by KCB, 2012) to simulate drawdown. This in turn provided inputs to the Integrated Quantity and Quality Model (IQQM), a hydrological modelling tool used for planning and evaluating water resources, enabling the evaluation of impacts on river flows and users from CSG induced drawdown.

Analysis of the CCAM modelled results found that approximately 80% of the river cells experienced no change in groundwater flux because they are 'disconnected' from groundwater. Most of the predicted impact on the Condamine River due to CSG production occurs in river cells located between Warra Town Weir and Chinchilla Weir with maximum flux changes of between 0.001 ML/d and 0.009 ML/d per cell, and a predicted maximum flux change to the entire Condamine River of 0.267 ML/d over the simulated period to 2805. Based on the IQQM modelling, the potential impacts to downstream users and environmental flow objectives was assessed as negligible, with almost no discernible impact from CSG production. The modelling demonstrated that the maximum flux changes to the Condamine River are small and the predicted impacts to the river and water resource are negligible under the FDP cases current at the time of writing the Updated WMMP. Accordingly, the mitigation proposed in the EIS/SREIS, and monitoring under the Updated WMMP, remains valid for management of potential impacts to the Condamine Alluvium and Condamine River.

Assessment of CSG induced flux between the Condamine Alluvium and the underlying GAB formations is undertaken by OGIA as part of numerical modelling for the UWIR. As documented in the 2021 UWIR (OGIA, 2021) predicted impacts on the Condamine Alluvium are minor despite the proximity of CSG fields, reflecting the relatively high storage, transmissivity, and incidental recharge to this aquifer. The magnitude of CSG induced drawdown is less than 0.3 m for most of the Condamine Alluvium, and the average net loss or flux of water from the Condamine Alluvium to the Walloon Coal Measures is predicted in the 2021 UWIR (OGIA, 2021) to be about 1,270 ML/year over the next 100 years. This flux is higher than predictions in the 2019 UWIR (735 ML/year) but comparable to predictions in the 2012 UWIR (1,100 ML/year) and 2016 UWIR (1,160 ML/year) and therefore the Updated WMMP.

Addressing approval condition 17A(f), in light of the predicted negligible impact to the Condamine Alluvium as a result of the change in flux, early warning indicators and trigger thresholds are not proposed for the Condamine Alluvium. If in the future a predicted change in flux requires early warning indicators and trigger thresholds to be set, this will be done consistent with the approach documented in Section 6.1.

Arrow will reassess potential changes to the Condamine Alluvium as a result of a change in flux within 90 days of an approved UWIR being issued and upon receiving technical files from OGIA for that UWIR. Reassessment will involve a comparison of the predicted magnitude of the groundwater flux changes in the latest UWIR to previous UWIRs. If the change in flux reported in the latest UWIR is not negligible (as demonstrated in previous UWIRs), Arrow will report this in the WRMMP annual report and, as stated above, early warning indicators and trigger thresholds will be assigned inline with the approach documented in Section 6.1.

4.3 Impacts to Surface Water

NRA Environmental Consultants (NRA) carried out a desktop assessment (Appendix C) as part of the Stage 1 WMMP to provide an overview of aquatic ecology and ecosystems present within areas that may be affected by groundwater depressurisation. In general, the desktop assessment identified that environmental conditions with regards to aquatic ecology and aquatic ecosystems were assessed as being highly disturbed, and there is not likely to be significant impacts to aquatic ecosystems as a result of the SGP. Further detailed site assessment is therefore not considered to be required to inform potential impacts to aquatic ecosystems as a result of CSG depressurisation.

As a result of the surface water groundwater connectivity predictive modelling undertaken (detailed in Appendix C) in the Stage 1 WMMP, Updated WMMP and subsequent UWIRs, surface water features and aquatic ecosystems are not predicted to be impacted by depressurisation of the WCM whereby adverse effects to ecosystems would arise. Subsequently a monitoring network to address these components of Approval Condition 17A(b) is not currently proposed to be undertaken. Nonetheless, Section 6.4 provides an overview of a surface water and aquatic ecology monitoring program if future assessment indicates the potential for groundwater drawdown related impact.

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

5 Water Management

5.1 CSG water and brine management

The Arrow CSG Water Management Plan (CSG WMP) for the SGP is provided in Appendix D. 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 17A(e) and 17A(g).

The CSG WMP 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 WMP includes all possible water and brine management options for the SGP, it is noted that discharge[9] of CSG water to surface water or re-injection of CSG water are not components of the SGP.

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

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

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

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

Further details on how conditions 17A(e), 17A(g) and 17A(i) are addressed is provided in Appendix E.

5.2 Flood risk management

SGP approval condition 17A(j) requires that the WRMMP 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.

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

The risk assessment process is provided in Section 5.2.1 and 5.2.2, with further detail provided in the Flood Risk Appendix (Appendix E).

5.2.1 Hierarchy of controls

Arrow has applied a hierarchy of controls for managing flood risks to major gas and produced water infrastructure (refer Figure 5-1). 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.

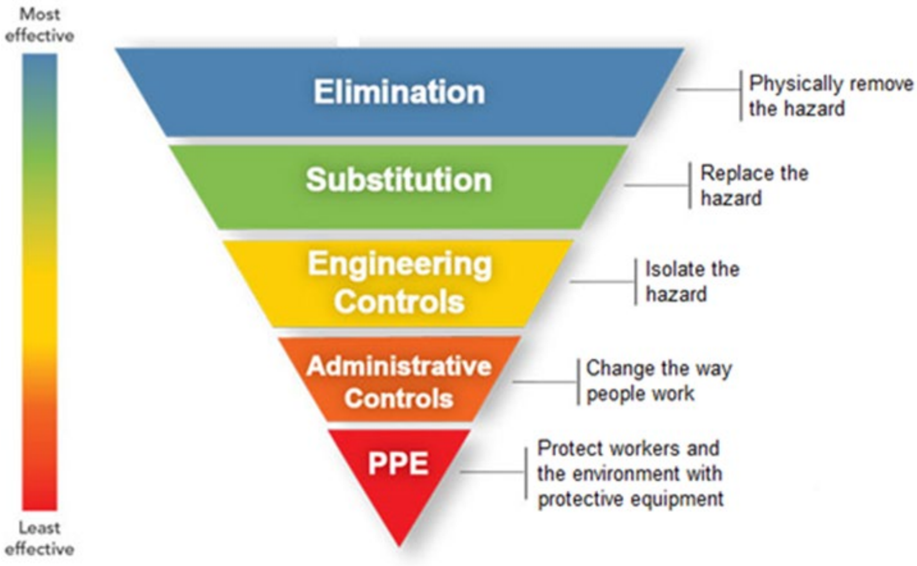

Figure 5-1 Hierarchy of controls

5.2.2 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 5-1).

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 5-2 shows proposed facility locations in relation to the modelled extents of the 1,000 ARI flood event.

Table 5-1 Estimated land outside flood extent compared to proposed infrastructure footprint[10]

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.
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.
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

[10] Based on locations / properties Arrow has acquired

Drainage area and property	Proposed infrastructure and footprint	Available land outside inundation zone	Assessment against flood mapping
			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 Environmental Authorities for environmentally relevant activities associated with the development of major infrastructure.

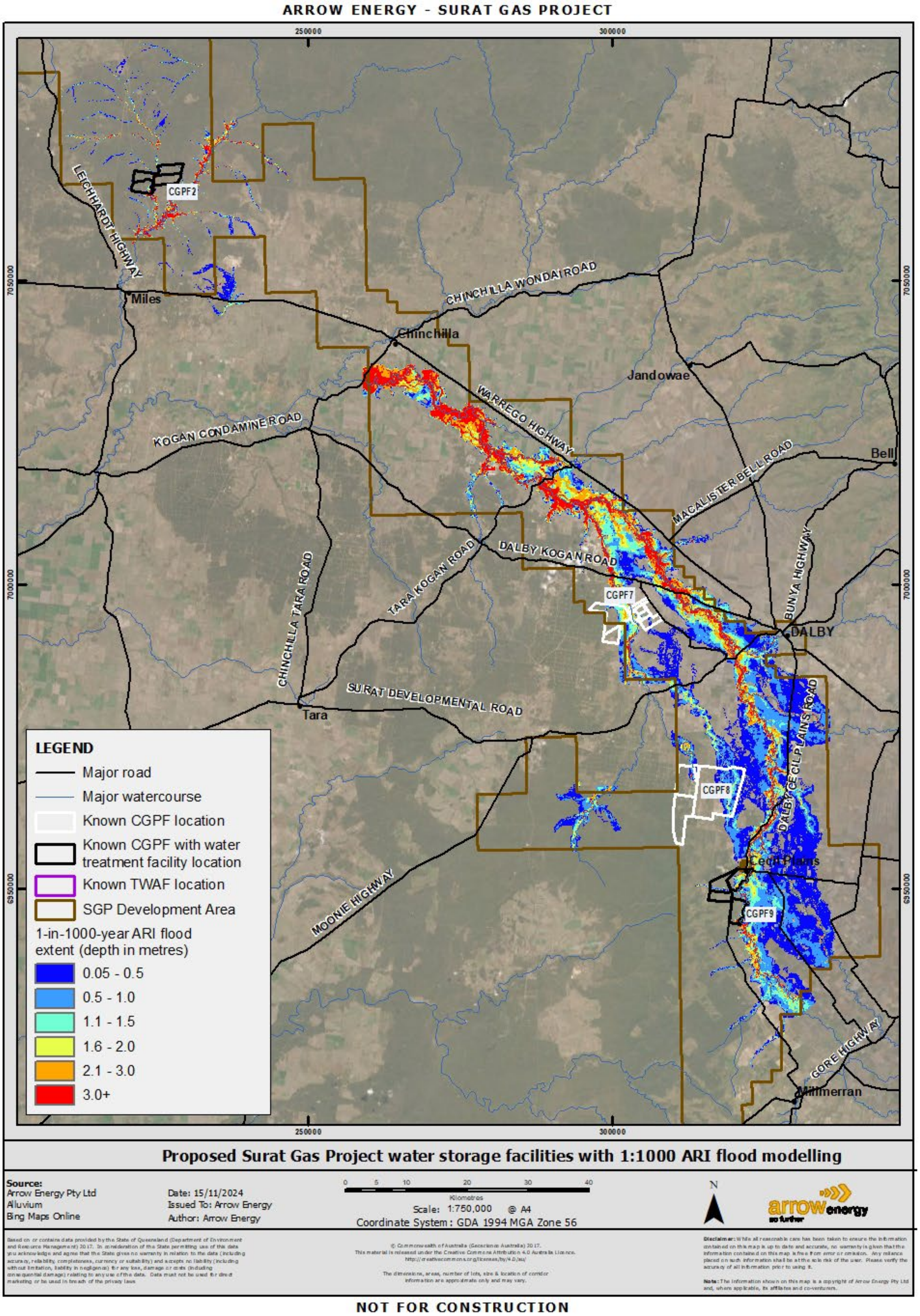

Figure 5-2 Proposed Surat Gas Project water storage facilities with 1:1000 ARI flood modelling

6 Monitoring, Risk Response and Adaptive Management

6.1 Early Warning Monitoring System

An EWMS was presented in the Stage 1 WMMP and subsequently refined and expanded upon in the Updated WMMP. The following sections provide an overview of the EWMS as presented in these documents with further information provided in Appendix F. Although as presented in Sections 4.2, 6.2 and 6.3, EWMS values are not currently required to be nominated, this EWMS framework will be used to set early warning indicators and trigger thresholds where any future predicted impacts necessitate them inline with the Action's conditions of approval.

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 6-1provides a conceptual representation of Arrow and non-Arrow drawdown impacts.

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

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

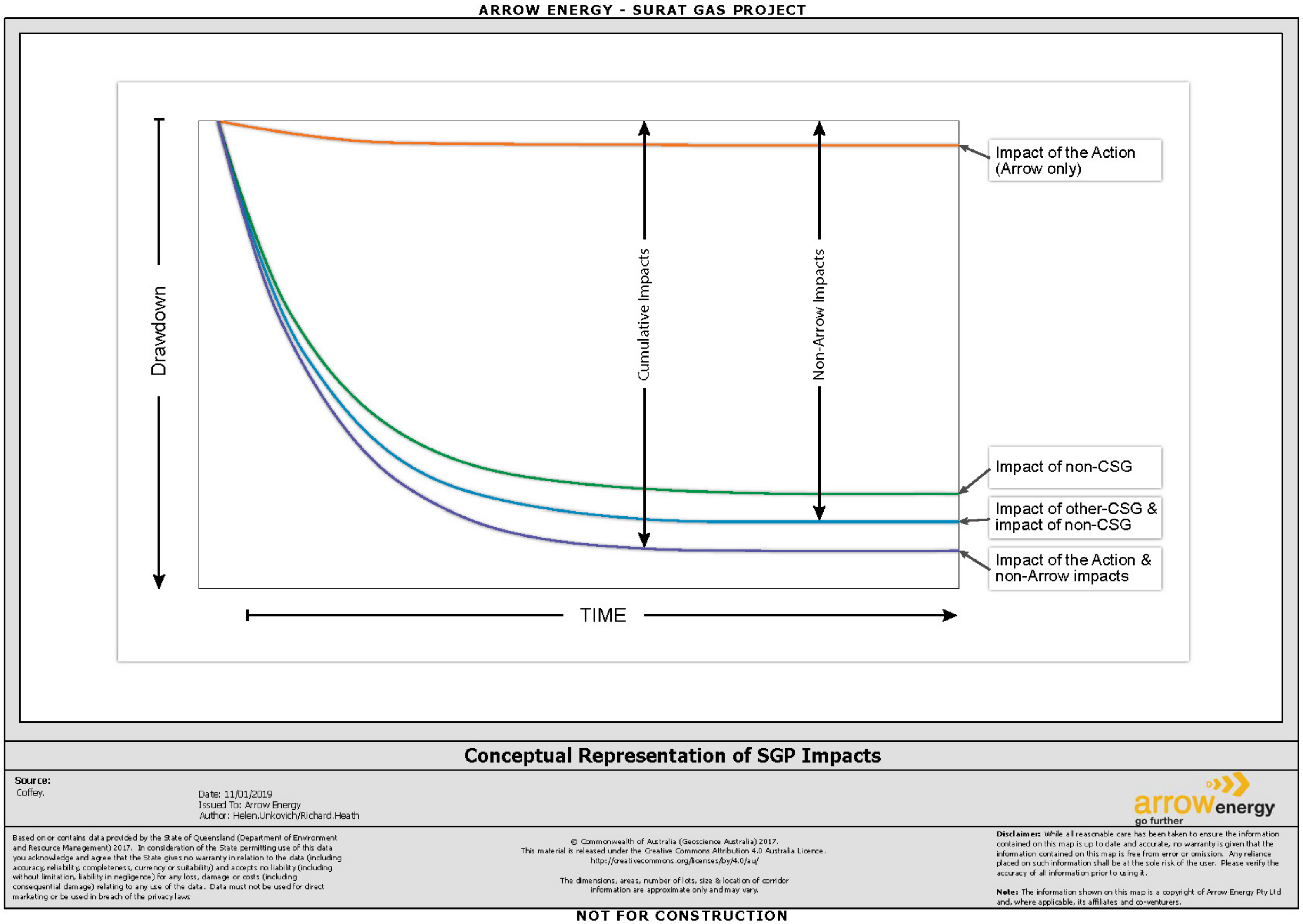

Figure 6-1 Conceptual representation of SGP impacts

6.1.1 EWMS Elements

The EWMS comprises the following elements which are described in the following sections and the EWMS conceptualisation is illustrated in Figure 6-2.

- 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.
- 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 (cumulative case) across Arrow tenure within an aquifer, 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 - taken from the Queensland Water Act 2000 for similar systems, being 5 m for consolidated aquifers and 2 m for unconsolidated aquifers. The drawdown factors provide a buffer against spurious level triggering.

EWMS levels are derived from numerical groundwater modelling of cumulative drawdown. The levels will be established 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 WRMMP or WRMMP annual report. The EWMS relies on periodic collection, review and assessment of data.

Investigation and actions are incorporated in the EWMS, including processes for trigger and limit exceedances[11], and actions to manage, address and correct exceedances.

Early warning indicators

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

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

Trigger thresholds

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

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

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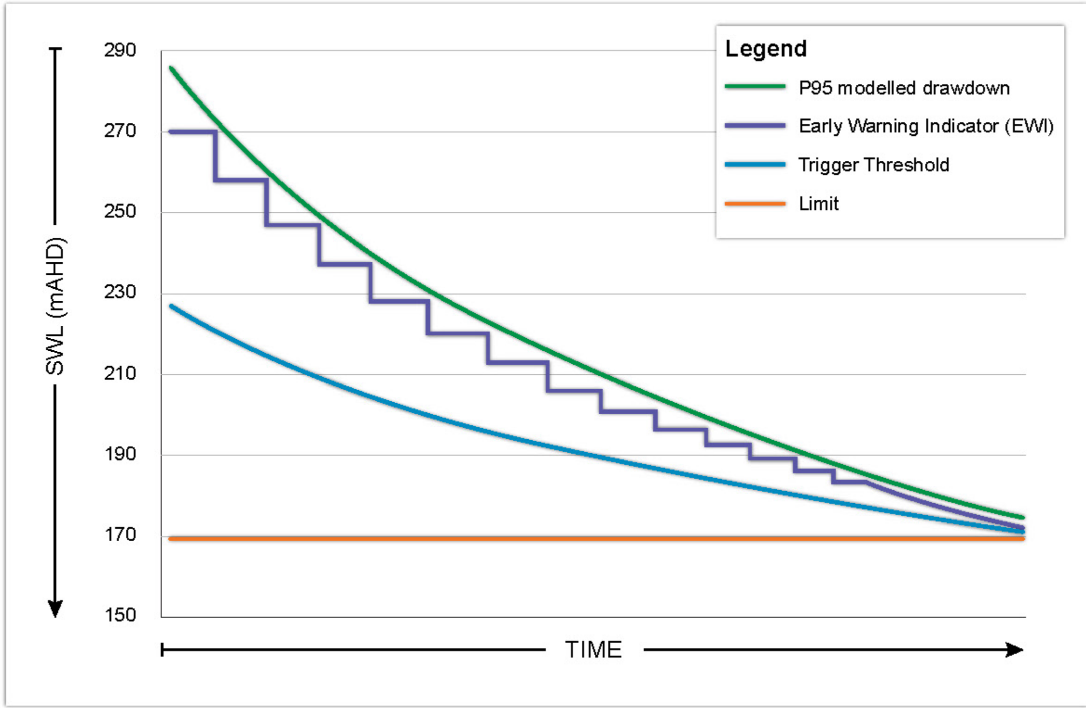

EWMS Conceptualisation

Source:
Coffey.

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

arrow energy
go further

NOT FOR CONSTRUCTION

Figure 6-2 EWMS conceptualisation

Limits

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

- The maximum model predicted P95 cumulative (CSG + non-CSG) drawdown level predicted to occur in 100 years (from commencement of CSG extraction), at any point in the relevant aquifer on Arrow tenure, plus a drawdown factor (5 m for consolidated aquifers and 2 m for the Condamine Alluvium); or
- For consolidated aquifers where dewatering of the aquifer itself is not predicted to occur, the top of the aquifer formation.

6.1.2 EWMS review

As noted in Sections 4.2, 6.2 and 6.3, EWMS values are not required to be nominated for the WRMMP due to the current determination that aquatic ecology and ecosystems (Condition 17A(h)) are not predicted to be impacted by the Action, and there is a predicted negligible impact to the Condamine Alluvium as a result of a change in flux (Condition 17A(f)).

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

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

6.1.3 Risk-based exceedance response

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

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

Figure 6-3 illustrates the EWMS process and actions. The response actions for each level are identified in Table 6-1.

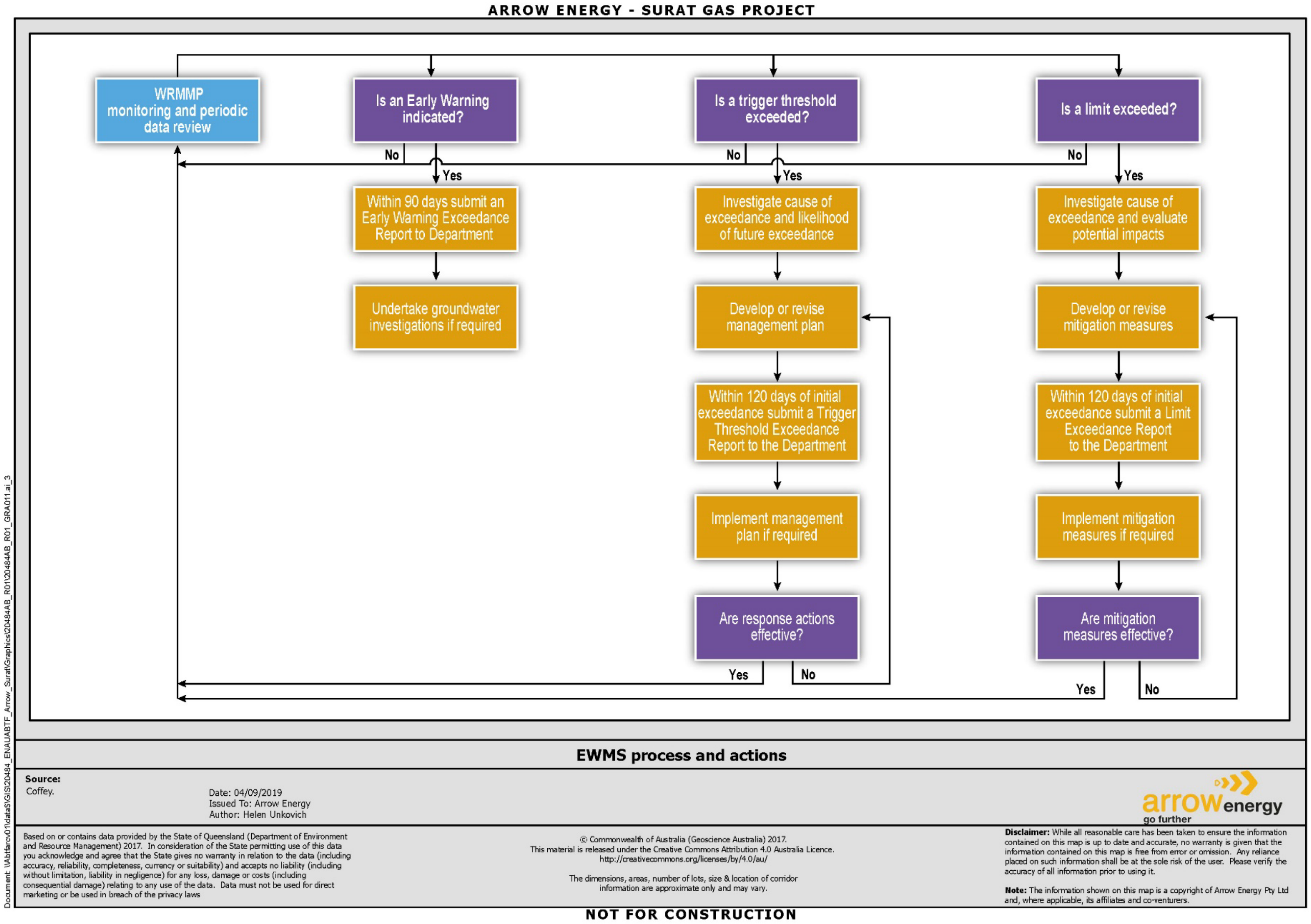

Figure 6-3 EWMS process and actions

Table 6-1 Risk-based exceedance response actions

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

6.1.4 Monitoring

If EWMS values are required to be established in the future (Sections 6.2 and 6.3), the monitoring plan including monitoring locations, their monitoring frequency and their associated EWMS values will be outlined in the Annual Report and included in the next revision of the WRMMP. Upon EWMS values being established, monitoring data collected will be compared to the EWMS values within 90 days of the end of each six monthly monitoring period.

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

6.2 EWMS: aquatic ecology and ecosystems

Approval Condition 17A(h) requires an EWMS for aquatic ecology and ecosystems. The EWMS is to include early warning indicators and trigger thresholds, including corrective actions.

Impact to aquatic ecology and ecosystems due to the Action may occur as a result of the discharge of produced water to surface water systems or due to groundwater drawdown. Discharge of produced water to surface water systems is not part of the SGP. Therefore discharge-related impacts are not considered further in this WRMMP. Should discharge be proposed in the future, the WRMMP will require update and approval for discharge will be sought from the Minister, and adequate baseline data will be collected prior to the discharge.

Based on this approach, and it is unlikely significant impacts to aquatic ecosystems will occur as a result of the SGP (Section 4.3), a stand-alone EWMS for aquatic ecology and ecosystems is not considered necessary. Should discharge to surface water systems be proposed in the future, this will necessitate the submission of a revised WRMMP within 90 days of identifying the requirement for discharge, for Ministerial approval. An aquatic ecology and ecosystems EWMS will be included in the revised plan if this eventuates.

6.3 EWMS: Condamine Alluvium

As described in Section 4.2, addressing approval condition 17A(f), in light of the predicted negligible impact to the Condamine Alluvium as a result of the change in flux, early warning indicators and trigger thresholds are not proposed for the Condamine Alluvium. If in the future a predicted change in flux requires early warning indicators and trigger thresholds to be set, this will be done consistent with the approach documented in Section 6.1.

6.4 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 (DES, 2018) for the establishment of baseline conditions, in particular for the establishment of reference[12] sites.

DES (2018) 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[13] 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.

Further information is provided in Appendix C.

[12] Sites considered to be suitable baseline or benchmark for the assessment and management of sites in similar water bodies
[13] Watercourses within the SGP development area are reported to range from slightly to highly disturbed

6.4.1 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 6-2. This will take in to account existing data and the need for additional baseline data, as relevant to the site.

Given the variable flow conditions and site setting of each monitoring location the specific monitoring requirements at each location should be tailored to suit the specific data 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.

Table 6-2 Monitoring frequencies for baseline condition and impact monitoring

Monitoring domain	Monitoring type	Frequency	Monitoring suite
Ephemeral stream	Water quality and flow	Continuous (logged)	EC, temperature and water level. Flow derived from level.
	Water quality	Bi-annual (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 and aquatic ecology	Bi-annual (nominally pre and post-wet season)	Physical parameters. Full surface water baseline. Aquatic ecology.
	Aquatic ecology	Bi-annual	Aquatic ecology.

6.4.2 Monitoring parameters

The suite of parameters (Table 6-3) is consistent with water quality assessments carried out for the EIS / SREIS. The suite would be reviewed and amended as required for site-specific conditions based on available data and the nature of potential impacts predicted.

Table 6-3 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, TKN • Reactive phosphorus, total phosphorus • Fluoride • Sodium adsorption ratio	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.

Suite	Parameters	Explanation
	• Total and dissolved metals (arsenic, boron, cadmium, cobalt, copper, lead, mercury, nickel, selenium, vanadium, zinc) • Phenol • Triethylene glycol (TEG)	
Aquatic ecology	• Physical parameters (as above) • AusRivAS assessment • Fish and habitat assessment	

7 Subsidence Assessment and Monitoring

At any point below the ground surface, the weight of overlying strata is supported partly by water pressure and partly by the fabric of the rock mass. Any reduction in water pressure therefore results in an increased proportion of the load being carried by the rock mass, leading to compression of the rock. Coal seam gas occurs within coal formations through adsorption of the gas to the coal under hydrostatic pressure. Depressurisation of the coal seams by groundwater extraction reduces hydrostatic pressure and liberates the gas from the formation. This depressurisation results in compression of the formation while the desorption of the gas also results in shrinkage of the coal. The combination of depressurisation and coal shrinkage results in formation compaction which, after some attenuation by the overburden, manifests as surface subsidence.

The potential impacts to MNES that could result from CSG induced subsidence include changes to surface water flows that support aquatic ecosystems, and impairment of aquifer integrity or changes to landform that impact groundwater or surface water resources. The following sections provide an overview of the subsidence assessment, monitoring and management, with further information provided in Appendix H.

7.1 Previous assessments of subsidence

A technical memorandum relating to subsidence, including analytical geomechanical modelling, was prepared to support development of the Stage 1 CSG WMMP (Arrow Energy, 2018b). Subsequently, OGIA undertook a preliminary risk-based assessment of potential impact to environmental values due to CSG induced subsidence for the 2019 UWIR following amendment of the Queensland Department of Environment and Science (DES) guidance material for the preparation of UWIRs. The approach in the 2019 UWIR incorporated an assessment of the likelihood of CSG induced subsidence and a description of the environmental values located within risk areas (OGIA, 2019). The likelihood of CSG induced subsidence was assessed using an estimate of total compaction within the Walloon Coal Measures using the predictions of groundwater level change; and the presence or absence of overlying consolidated sandstone formations that may attenuate any potential subsidence at the surface. Under this assessment, all areas containing environmental values within Arrow tenures were found to be at low to moderate risk of subsidence.

For the 2021 UWIR, OGIA developed a numerical model coupling geomechanics to groundwater depressurisation, predicting magnitude of subsidence and change in slope as a result of CSG operations in the area of the Condamine Alluvium, and an analytical model predicting magnitude of subsidence in the greater Surat Basin (OGIA, 2021). The OGIA modelling was history matched to observed ground movement data from Interferometric Synthetic Aperture Radar technology (InSAR) in areas of existing CSG production, allowing improved parameterisation and estimates of predictive uncertainty. With respect to aquatic ecosystems associated with surface watercourses in the Surat Basin, OGIA considered that depending upon the magnitude, CSG induced subsidence may change the slope of tributaries, resulting in changes in flow and direction that could affect aquatic systems. However, OGIA found that observed and predicted subsidence in the Surat Basin, including Arrow's SGP area, is very small and unlikely to materially change surface flows to watercourses (OGIA, 2021). The potential to alter the porosity and permeability of the surrounding aquifers was found likely to be inconsequential as they are less prone to compaction compared to the CSG target formation.

7.2 Ground movement monitoring methods

A description of ground movement monitoring techniques suitable for the CSG induced subsidence context is provided in a report prepared for the Independent Expert Scientific Committee by Leonardi (2024). Detail of the monitoring techniques adopted in this WRMMP are provided in Appendix H, with an overview of the techniques and data acquired by Arrow provided below.

As well as movement related to CSG induced subsidence, these ground movement monitoring techniques also detect changes in surface elevations and slopes caused by other anthropogenic and natural ground movement processes.

7.2.1 Interferometric Synthetic Aperture Radar

Satellite-mounted Synthetic Aperture Radar (SAR) sensors acquire single look complex (SLC) images of the Earth's surface by transmitting electromagnetic pulses from the microwave spectrum and analysing any backscatter energy from the Earth's surface. Interferometric SAR (InSAR) exploits the phase difference between two SLC images of the same area taken at different times with the same orbit orientation. If the Earth's surface has moved between the image acquisitions, a phase shift occurs, representing changes in the relative distance between the surface and SAR satellite over time as an interferogram. To determine if subsidence or uplift is occurring over time, a stack of interferograms is required to generate a time-series dataset. InSAR is a well established technique for time series analysis of deformation of the Earth's surface, including subsidence and structural stability. The time-series results reflect the total surface movement and cannot distinguish between natural and anthropogenic causes of the movement.

Arrow has obtained InSAR data collected by Sentinel-1 satellite constellation since August 2015, with historic data by Radarsat-2 and ALOS-1 for the periods July 2012 to November 2017 and December 2006 to March 2011, respectively. The time-series datasets represent surface movement captured in one dimension, that is, along the line of sight (LOS) and not vertical. The LOS is the angle at which the microwave energy pulses are transmitted and received by the SAR satellites. For the Sentinel-1 satellite constellation both ascending and descending data is available over the same area, and therefore the up-down and east-west movement can be resolved. Leonardi (2024) reports that precision estimates for InSAR range from +/- 1mm/year displacement rate and +/-5mm total displacement up to approximately 10mm.

The InSAR data provides a temporal 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.

7.2.2 Light Detection and Ranging

Light Detection And Ranging (LiDAR) is a remote-sensing technique using airborne scanning systems emitting focussed electromagnetic waves in the visible light to infrared ranges, with the reflected signal used to develop a distance map of objects in the scene including vegetation, buildings and the ground, resulting in a detailed three-dimensional point cloud. Processing is undertaken to remove the non-ground points from the point cloud. Ground points measured with LiDAR are used to generate a Digital Elevation Model (DEM), resulting in a detailed snapshot of elevation of the land and derived slopes at moment of capture.

LiDAR surveys, which provide for detailed assessment of slopes at property and regional scale, were acquired for all SGP for Arrow in 2012 with follow-up surveys of some SGP areas in 2014, 2020 and 2021. Following a further survey of all existing and future development plan areas in the SGP in 2022, surveys within the area of the Condamine Alluvium (which is more sensitive to slope changes affecting surface flows) have been conducted in May, August and October in both 2023 and 2024. Survey uncertainty for LiDAR techniques has improved over time with advancements in technology and processing. The 2012 and 2014 LiDAR survey undertaken by Arrow Energy had vertical uncertainty of +/- 120mm and +/- 700.07m respectively, for data points in the point cloud. Since 2020 the surveys have been better than +/- 0.05m (at 1 standard deviation) for data points.

The LiDAR data provides a temporal baseline from which future data can be assessed to determine changes in topography and slope.

7.2.3 Geodetic ground point monitoring

Precise location information for a ground point can be derived from global navigation satellite systems (GNSS). GNSS is the generic term used for satellite positioning systems which consist of satellite constellations that transmit positioning and timing data to ground receivers, and is currently one of the most popular geodetic monitoring techniques for surveyors and engineers worldwide (Ng et al, 2023).

Between November 2020 and May 2023, Arrow installed a network of 11 permanent GNSS ground movement monitoring stations within the area of the SGP operations. Daily processing of coordinates of these stations is provided by Leica Geosystems via the Leica Crosscheck system. Some of these permanent ground movement monitoring stations are co-located with groundwater monitoring bores which provide information on the groundwater depressurisation potentially influenced by Arrow SGP operations. These instrumented sites are preferentially located within the topographically flatter area of Arrow SGP operations. At one location (Longswamp 40, 43 and 44) separate ground movement monitoring of the upper and lower parts of the Condamine Alluvium and the Springbok Sandstone is undertaken to differentiate movement between the formations. Since 2020 Arrow has also undertaken, at a minimum, annual survey of selected permanent survey marks identified as GNSS compatible in the Queensland Survey Control Database (SCDB). Static surveys of these marks are undertaken with a six (6) hour observation time. Post-processing of these surveys to provide survey mark coordinates is then undertaken using Geoscience Australia's Auspos online GPS processing service.

The location of the permanent GNSS ground movement monitoring stations and survey marks were selected based on land resource area (combination of geology, topography, soil, vegetation and land use); spatial distribution across field development areas; and proximity to persistent scatters in InSAR. Survey Uncertainty of GNSS techniques for ellipsoidal height improves with observation time. Quick static surveys are generally considered +/- 30-40mm vertical accuracy. However, this is reduced to less than +/- 20mm when a 6hr observation is undertaken. Continuously operating GNSS ground movement monitoring stations are considered to be better than +/- 3mm vertical accuracy. The permanent GNSS monitoring stations and regular survey of survey marks provide ground truthing for the results of InSAR and LiDAR monitoring.

7.3 Topography and observations of ground movement

7.3.1 Topography

The south of the SGP operations area overlie part of the Condamine River and associated floodplain. The floodplain occupies the area between Ellangowan (E151.67°, S27.92°) east of Millmerran and Chinchilla

(E150.72°, S27.74°), southern inland Queensland. It stretches over an area of about 7,000 km^2, and is ~190 km long. Its upstream and downstream edges are narrow, but most of the floodplain is 15-40 km wide. The southern and eastern extents of the floodplain are outside the area of the SGP. The topography drops steadily from the south to the north, from +400 metres Australian Height Datum (mAHD) near Ellangowan outside the area of the SGP operation to +350 mAHD near Dalby and to +310 mAHD near Chinchilla, with an overall topographic gradient of 0.05% (500 mm in 1km). The flattest drainage features of the floodplain, such as Long Swamp, are approximately 0.01% (100 mm/km). The uplands forming the western boundary of the Condamine floodplain in the area of the SGP, are characterised by gentle slopes developed with maximum elevations of around 420 mAHD. The Condamine River and tributary watercourses are generally incised with well-defined channels. 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. In the north of the SGP operations area, Juandah Creek and Dogwood Creek are headwater reaches with steeper slopes compared to the Condamine floodplain. Most of the second-order and greater reaches of these catchments are partly confined with widespread bedrock.

Slopes within the Arrow tenements prior to the SGP commencement were derived from the 2012 LiDAR data at a 10 m resolution (downsampled from the original 1 m resolution to remove the effects of surface roughness). The results of the area and percentage of each slope class across the whole Arrow tenement are presented in Table 7-1, with the dominant slope class being greater than 0.5 % (5 m in 1 km). The slope increments/classes were selected to focus on the flatter slopes in the landscape that are more sensitive to slope changes affecting surface flows to watercourses. Slopes of less than 0.03 % (0.3 m in 1 km) occupy less than 1 % of the area of the SGP.

Table 7-1: Slope classes within Arrow SGP development area

Slope Class	Area (ha)	Area (%)
< 0.01%	465	0.07%
0.01 - 0.03%	3,650	0.52%
0.03 - 0.06%	11,766	1.68%
0.06 - 0.12%	39,420	5.62%
0.12 - 0.5%	190,452	27.15%
> 0.5%	455,790	64.97%

7.3.2 Regional ground movements

As presented in Appendix H, regional InSAR ground movement monitoring data for the period August 2015 to June 2024 captured by the Sentinel-1 satellite was reviewed. The fastest rate of downward movement (-63 mm/year) is observed in spoil dump areas of the Kogan and Wilkie Creek coal mines north west of Dalby, with total settlement of up to 0.5 m observed over the period. Within the CSG fields, the deformation rate is slower (up to -26 mm/year) with total subsidence up to about 0.1 m observed in the Daandine field and 0.05 m in the Tipton field. The fastest uplift rates (up to +22 mm/year) are observable at individual measuring points, distributed within the eastern area over agricultural lands and around Dalby in the Condamine floodplain. Reactive clays such as the vertisols of the Condamine River floodplain swell and shrink in response to moisture changes, an effect which is greatest close to the surface where the clay is less confined by overburden and where the moisture content can be more quickly changed by rainfall or irrigation and by evapo-transpiration. OGIA (2021) analysed available InSAR data and found that "*ground movement unrelated to CSG depressurisation and away from existing CSG development, both within and outside the Condamine Alluvium,* *suggests that the ground can frequently move up and down by around 25 mm/year and the ground movement can also vary significantly at a local scale (by up to 25 mm within 100 m). This is likely to be due to variations in soil type and associated changes in moisture content*". DataFarming (2021) also looked at the natural variations in the surface due to the swell shrink nature of the vertisol clays present on the Darlings Downs. Anecdotal evidence from soil experts suggest that vertical movement is up to 200 mm between wet and dry, and assessment of strip cropping by DataFarming found likely vertical movement due to differences in soil water content of up to 200 mm. These variations in non-CSG ground movement at a local scale will result in changes in slope. These rates and total movement observed in Appendix H from CSG induced subsidence, other anthropogenic and natural ground movement processes are comparable to those observed by OGIA (2021).

7.3.3 Ground movement away from CSG activities

Observed ground movement in areas with no CSG activity was assessed in Appendix H by considering InSAR observations in four reference areas. These areas are located away from areas with CSG activity, with two locations on cleared agricultural properties within the extent of the Condamine Alluvium, one on residential land in Dalby, and one on a non-farmed forested area outside the Condamine Alluvium. For the forested area, ground movement of individual InSAR derived points up to approximately 15 mm vertically and a range of approximately 20 mm across the points was observed since August 2015, with the average ground movement relatively stable through the monitoring period. This site has the lowest individual and range of ground movement of the reference sites, reflective of the less expansive nature of the soils and the light vegetation in a non-farmed area. More ground movement was identified in the reference sites over the Condamine Alluvium, with ground movement of individual InSAR derived points up to approximately 40 mm, with a range of over 50 mm across the points observed since August 2015. In these reference sites ground movement reflected the shrink-swell of expansive soils and the Condamine Alluvium aquifer responding to longer term rainfall, as well as agricultural activities such as cultivation. The change in ground slope from the InSAR derived points within this area is at least approximately 0.022% or 220 mm/km over the approximately nine years of monitoring.

7.3.4 Ground movement associated with CSG production

Appendix H also assessed CSG induced subsidence related ground movement within areas of CSG development. At the Tipton-198 GNSS ground movement monitoring station, ground movement of approximately -40 mm was observed over a 12 month period after commencement of CSG production in October 2023, with the related depressurisation of the coal seams at the collocated Tipton-197 monitoring bore being up to 214 m over the same period. At the Daandine nested monitoring bore site, InSAR data within 150 m of the monitoring bores detected ground movement of approximately -50 mm with depressurisation of the coal seam up to 142 m over an approximately nine year period.

7.4 Predicted subsidence

Predictions of subsidence due to CSG operations has been undertaken through the SGP Stage 1 WMMP (Arrow Energy, 2018) and through the 2021 UWIR (OGIA, 2021), as presented in Appendix H. These predictions are sensitive to the modulus of the coal measure rocks; volume loss of coal associated with removal of coal seam gas; and predicted groundwater drawdown. Whilst there is some uncertainty in these parameters, Arrow Energy (2018) and OGIA (2021) both assessed uncertainty as part of predictions, and it is noted that CSG extraction by Arrow and other proponents has been occurring for several years, and observed subsidence is generally of the order predicted by the models. It is noted that the thickness of the compressible formations (principally the Walloon Coal Measures) changes over large distances and the depressurisation of those formations is diffusive. These two key drivers of CSG-induced subsidence vary in space over distances in the order of hundreds of metres, and therefore the compaction and associated subsidence at surface is expected to change over large areas and not result in small scale differential movement.

The subsidence modelling undertaken by OGIA (2021), which incorporates the most recent depressurisation data and predictions of the 2021 UWIR and is history matched to the ground movement monitoring data, is the most up to date and advanced prediction of CSG induced subsidence within the Surat Basin.

OGIA developed a 3D numerical geomechanical model for the Condamine Alluvium and adjacent CSG production, encompassing an area of 50 km × 130 km, incorporating all available data on local geomechanical properties and lithological distribution. The 3D numerical geomechanical model is underpinned by a regional geological model developed by OGIA, a calibrated 1D mechanical earth model (MEM) developed by Schlumberger, and pressure predictions from OGIA's regional groundwater flow model. The model extends from the ground surface to the base of the Eurombah/Durabilla Formation, with the Walloon Coal Measures subdivided into 12 layers to differentiate between the coal and interburden units, with coal layer thickness constrained by mapping from wireline logs. To support numerical stability, the model was further subdivided into 88 vertical layers, with a model grid ranging from 250 × 250 m to 750 × 750 m to account for variations in lithology. Rock properties were derived from 41 wells with available data such as from wireline geophysics for the 1D MEM. When assessing subsidence impacts, OGIA considered both the absolute subsidence magnitude, as well as progressive development of subsidence as the CSG fields are developed resulting in change in slope with time.

For the greater Surat Basin, OGIA developed an analytical model integrating geomechanical rock properties and predicted depressurisation. The domain of this model covers an area of around 460 km × 650 km, encompassing the entire Arrow SGP area and includes CSG activities by other resource companies. For the same geomechanical properties and pressure distribution, OGIA found the analytical model was able to approximate predictions of subsidence comparable to the 3D numerical geomechanical model of the Condamine Alluvium area. For the analytical model, OGIA generated a set of 1,000 models from stochastic realisations of geomechanical properties to explore the range of uncertainty in predictions. History matching these models to the available InSAR data in the vicinity of the Condamine Alluvium allowed the 50 best fitting models to be selected to generate predictions of subsidence. Predicted subsidence and change in slope are therefore reported statistically in the 2021 UWIR as a median (P50) prediction derived from those 50 model runs. Predicted subsidence from the 2021 UWIR, including predicted temporal development of subsidence at specific locations, is presented in Figure 7-1, with predicted maximum changes in slope within the areas of the Condamine River floodplain presented in Figure 7-2.

OGIA processed outputs from the uncertainty analysis to derive probability of magnitudes of subsidence and slope occurring at each model cell. This is presented as maps of the probability of 0.001% (0.01 m in 1 km) and 0.005% (0.05 m in 1 km) slope change at any time, together with probability of 100 mm and 150 mm magnitude subsidence occurring within the area of the Condamine River floodplain, the area most susceptible to changes in slope affecting overland flow to MNES, in Figure 7-3. OGIA found that, within the area of the Condamine Alluvium, the greatest change in slope is predicted across the Horrane Fault, as a result of differential drawdown patterns either side of the fault. The Horrane Fault is a large north-south trending fault zone east of Cecil Plains, with displacement of up to approximately 100 m. Displacement of formations across the fault and the low permeability of the fault core, as described by Viljoen et al (2020), can result in differential depressurisation patterns either side of the fault. In this Horrane Fault area there is about 80% probability of change in slope of 0.005%, while most of the area between Dalby and Cecil Plains is likely to experience 0.001% or less change in slope. In terms of the magnitude, this area near the Horrane Fault is also predicted to have a 50% chance of 150mm of CSG induced subsidence occurring, while other areas of the SGP are expected to have less than 100mm of CSG induced subsidence. Co-ordinated development of coal depressurisation on either side of the fault may be used to mitigate development of these changes in slope.

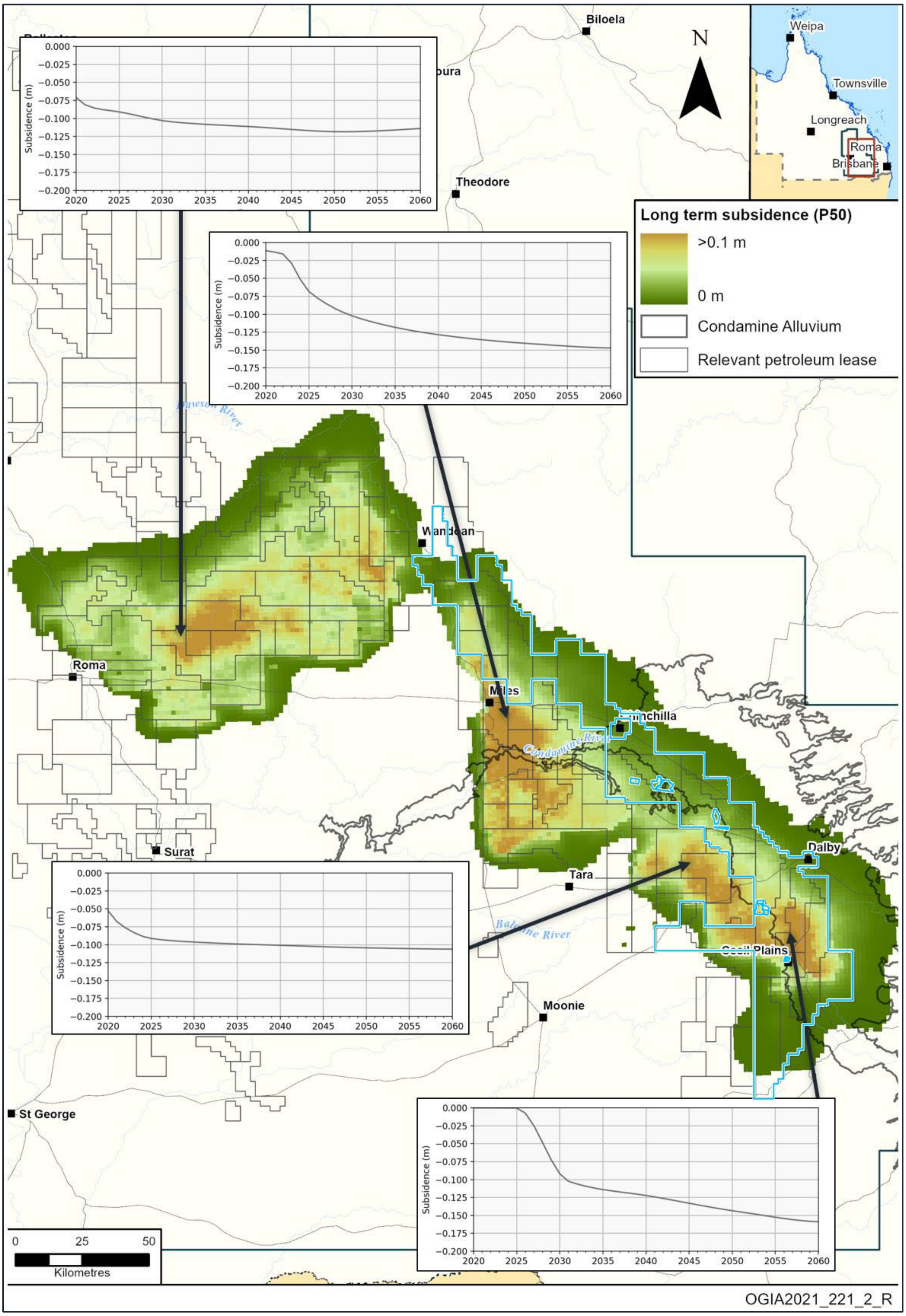

Figure 7-1: Predicted long-term subsidence from the 2021 UWIR for the Surat CMA (from OGIA, 2021, modified with outline of Arrow tenements in blue)

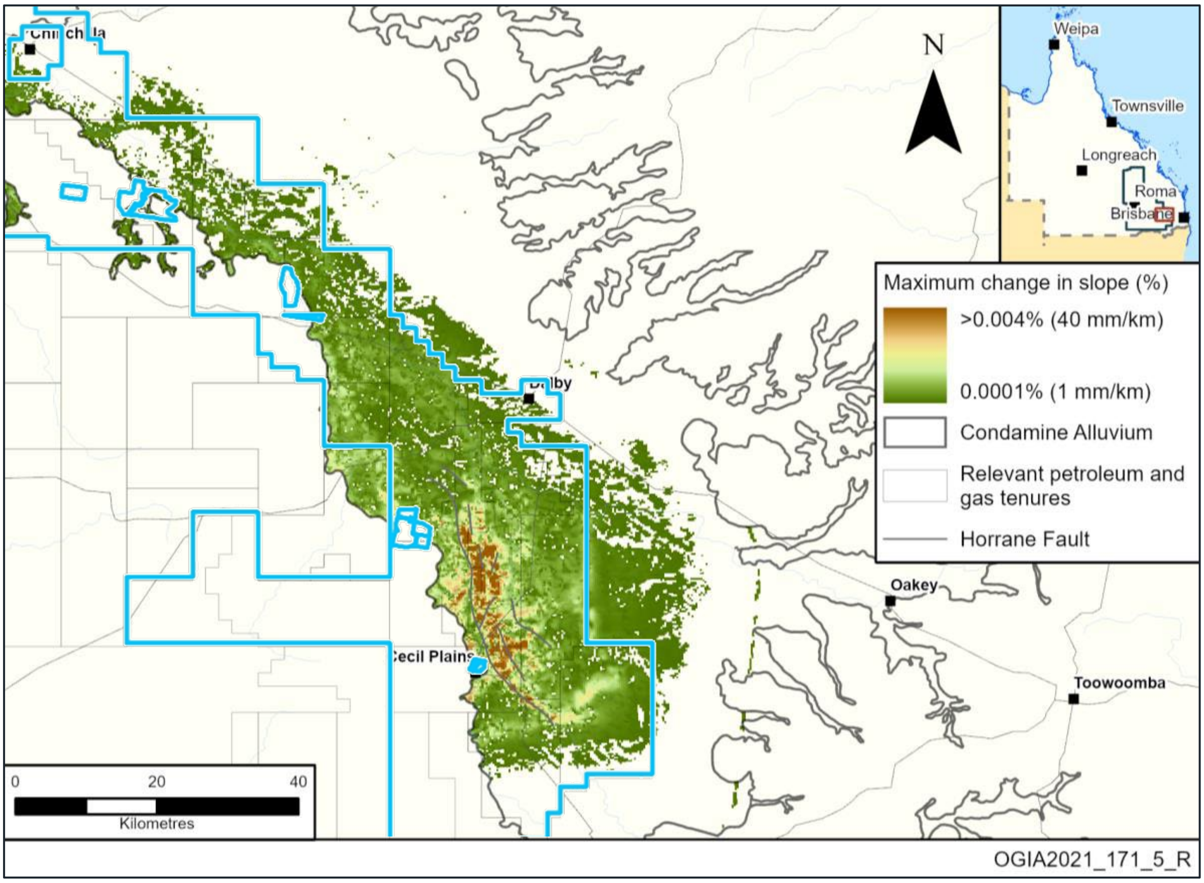

Figure 7-2: Predicted maximum change in ground slope in the Condamine Alluvium area from the 2021 UWIR (from OGIA, 2021, modified with outline of Arrow tenements in blue)

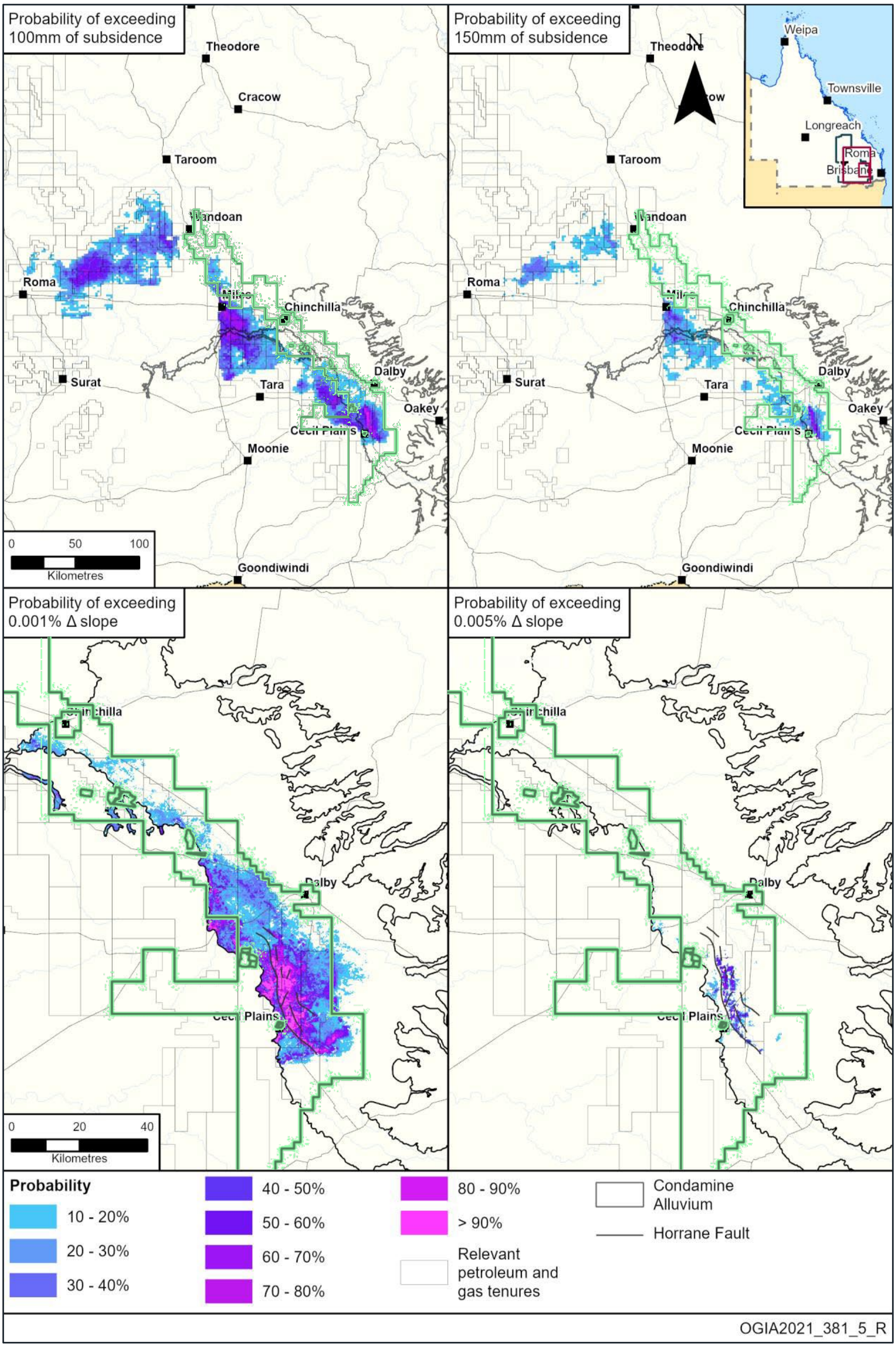

Figure 7-3: Uncertainty output of probabilities of predicted subsidence and change in ground slope in the Condamine Alluvium area from the 2021 UWIR (from OGIA, 2021, modified with outline of Arrow tenements in green)

7.5 Potential impacts to MNES protected matters

An assessment of risk to protected matters from subsurface settlement and ground subsidence associated with the development of the Arrow SGP was carried out in Appendix H. Subsidence, in the context of MNES protected matters, can have an impact on the surface water or groundwater systems and their associated environmental values within the Arrow SGP and in the vicinity.

Leonardi (2024) listed groundwater withdrawal (including from CSG) induced subsidence potential impacts to surface water systems including change in the drainage pattern of streams and channels; ponding of water in subsidence troughs (if they form); deepening or widening of pools in streams; alteration of riparian ecosystems and geomorphological stability; and increase in the impact of, or exposure to, riverine flooding or delayed drainage. OGIA (2021) identified CSG induced subsidence potential impacts to groundwater systems as alteration to porosity and permeability of rocks. These potential impacts to surface water or groundwater systems may then have detrimental impacts on aquatic ecosystems, subterranean groundwater dependent ecosystems (GDEs), or terrestrial GDEs.

7.5.1 Groundwater systems

The increase in effective stress in the coal measures from depressurisation together with coal shrinkage from desorption of gas result in compaction of the coal. The increase in effective stress tends to cause a reduction in coal permeability, while the desorption of methane and resultant coal shrinkage during gas during production tends to cause an increase in coal permeability. Results from Harpalani & Chen (1997) suggest that the decrease in permeability due to increased effective stress is balanced by the overall increase in permeability from matrix shrinkage. The CSG production induced pressure declines are much lower in the surrounding formations including the Springbok Sandstone than in the Walloon Coal Measures, and the mechanical properties of these surrounding formations, particularly the sandstone aquifers, are less prone to compaction. For these surrounding formations, reduction in porosity and permeability is therefore likely to be inconsequential (OGIA, 2021).

To result in adverse differential movement of rock formations, the subsidence would need to be significant and occur on a localised scale, at differing rates. Both the magnitude and lateral extent of depressurisation of the coal seams from individual production wells overlap each other with time within the CSG fields and tapers away from the CSG field. This infers that compaction will also occur over a broader area than the footprint of the CSG well field, and is reflected in assessment conducted by OGIA (2021) using ground movement observed from InSAR, with the magnitude of downward ground movement gradually reducing away from the margin of gas fields. Due to this broad lateral extent of depressurisation, there is also likely to be little or no potential for a reduction in surface settlements through arching or similar mechanisms in depressurised CSG fields, particularly later in field life, and is consistent with the findings of the OGIA 3D geomechanical modelling (Aghighi et al, 2024a). Although fissuring can be produced through differential settlement of subsiding lands (Zekster, Loaiciga, & Wolf, 2005), coal seam gas formations in the SGP are non-structurally controlled reservoirs in horizontal or sub-horizontal strata and the magnitude of compression that occurs at depth in the coal measures is likely to be closely reflected at the surface. Therefore the stresses and strains of bending induced in the overburden will be significantly lower than in the case of underground mining or structurally complex formations. Consequently it is unlikely that CSG induced subsidence could lead to shear displacements of overburden materials and therefore cause an increased interconnection between the coal measures and overlying aquifers.

With the small magnitude of CSG induced subsidence and slope change, as observed in monitoring of existing CSG fields and predicted in OGIA (2021) modelling, the inconsequential change in permeability or porosity, and the remote likelihood of fracturing of overburden materials, it is considered that the risk of affecting MNES groundwater resources, including the hydrology of the Great Artesian Basin aquifers or the surficial aquifers such as the Condamine Alluvium, is low. The low risk is consistent with that determined in Arrow's SREIS (Arrow Energy, 2013).

7.5.2 Surface water systems

The occurrence of subsidence can cause changes to flood plain morphology (Zekster, Loaiciga, & Wolf, 2005). From a water resources perspective, changes to the landform may also result in retention of water on the floodplain which could have potential to reduce catchment yields and ultimately annual stream flow.

Using the existing topographic gradient (Section 7.3.1) and predictions (Section 7.4) as a guide results in subsidence leading to changes in gradient of up to 2% of the existing gradient across most of the Condamine floodplain area, and up to 10% in small areas. Predicted subsidence and slope change in the steeper Juandah Creek and Dogwood Creek catchments result in substantially lower change in gradients. Alluvium (2013) as part of the SREIS (Arrow Energy, 2013) reviewed an InSAR study of the period December 2006 to February 2011, which covered the Surat Basin including Arrow's existing DXP development and then proposed SGP development. This review found that the observed ground movement (which was up to 16 mm/year and cumulative up to 80 mm at that time) was substantially smaller than the tolerances allowed for when configuring hydrodynamic models. The review further concluded that small regional scale subsidence of the Condamine River floodplain would not adversely affect the geomorphology of watercourses, with the risk of geomorphic change assessed as low, and that differential settlement at a local scale might induce geomorphic changes in low-resilience watercourses or alteration of overland flow and flood behaviour, although this is not expected. If differential settlement were to occur, mitigation measures to protect vulnerable reaches of affected watercourses from erosion and channel migration would be effective in managing the impacts. Alluvium (2013) also found that the broad flood plain across the Condamine River catchment suggests that changes to the topography would have minimal if any impact on flood levels, although this was not modelled. Alluvium also concluded that on steeper and more resilient waterways, such as observed in the Juandah Creek and Dogwood Creek catchments, induced geomorphic impacts or alteration in flood behaviour or flows as a result of CSG induced subsidence is not expected to be discernible. For subsidence to affect catchment yields and environmental flows, the hydrology of the floodplain would need to be materially altered, such as increased surface storage across the flood plain, slower drainage of the flood plain or water retention within previously draining creek beds. Considering the low slope changes predicted and that the Condamine River floodplain makes up only a small part of the broader Condamine-Balonne catchment, reduced annual streamflow to the point it affects downstream environmental flows is expected to be unlikely and if noticeable at all, only of minor consequence.

Subsidence related impacts to aquatic ecosystems and GDEs may potentially occur if there are changes in the integrity of hydrological or hydrogeological connectivity, resulting in changes to surface water flow or groundwater levels that the aquatic ecosystems and GDEs rely on. CDM Smith (2016, 2018) assessed surface water-groundwater connectivity in the area of the SGP and found the majority of the length of the Condamine River and its tributaries function as disconnected losing streams. This disconnectedness, and the low risk of subsidence affecting MNES groundwater resources (Section 7.5.1), results in a very low risk of impacting surface water-groundwater connectivity and the reliant GDEs. The low to very low risk of geomorphic impacts or alteration in flood behaviour or flows, as described previously, results in a very low risk of impact to aquatic ecosystems.

7.6 Subsidence trigger thresholds

A process of progressive trigger levels has been developed for CSG induced subsidence assessment as required by approval condition17A(c)(iii). They are derived from calculated risk assessments of potential subsidence described in Appendix H. These progressive thresholds are presented in Table 7-2, and further discussed below. The flow chart of the assessment process that will be implemented is presented in Figure 7-4.

Review of potential impacts on various assets indicates that differential settlement or change in slope is more relevant than total subsidence. A three-level assessment process is set out. Initial assessment would involve a screening level to identify areas where significant subsidence is occurring, based upon the annual velocity reported from InSAR monitoring results or slope change from LiDAR results. In areas where this significant movement is recorded, further assessment against investigation levels will be carried out to identify CSG-induced movement with potential to impact on particular protected matters. Where investigation levels for potential impacts on protected matters are exceeded, site-specific investigations will be conducted to determine if actual impacts to MNES protected matters are more than minor and therefore exceed the trigger threshold.

7.6.1 Screening level

The screening level assessment includes two steps. Step 1 is screening of InSAR data for areas of vertical ground movement near to gas production. This allows focus areas to be identified where ground movement is occurring that may be related to CSG production. Step 2 is further screening of areas for changes in slope from determined LiDAR data that may be indicative of changes in floodplain morphology.

Step 1

Screening for Step 1 is undertaken by spatially analysing an InSAR dataset every 6 months using a pre-defined 1 km grid. This is done by checking for changes of greater than 20 mm/year for greater than 50% of InSAR points within the 1 km grid cell. The screening level has been determined as 20 mm/yr and is considered conservative regarding the type of changes across the flood plain necessary to result in the water resources or environmental impacts considered in the risk assessment. Where the 1 km grid cells have less than 5 InSAR points, they are progressed to Step 2 for assessment using LiDAR. Changes of greater than 20 mm/year in grid cells away from gas production are assumed as being from other causes (nominally 4.5 km or further from the well head). The basis of the 4.5 km area of influence is the 2.5 km as recommended by OGIA (2021) for further monitoring, plus an additional 2 km for allowance for deviated well paths, given that depressurisation occurs along the entire length of the well's slotted casing interval.

Any of the 1 km grid cells near to gas production that exceed 20 mm/year movement over the 12 months prior, or have less than 5 valid InSAR points, are then progressed to Step 2.

Step 2

Step 2 of the screening process involves further analysis of the grid cells for areal slope change. The intent of applying this step across the Condamine the floodplain is to identify areas where CSG-induced subsidence may be may affecting water being able to drain to the receiving environment. The screening level adopted for slope change has been taken as a slope change of 1 in 10,000 (0.01% or 100 mm/km). This is approximately equal to the existing grade of the flattest drainage features on the flood plain, such as certain sections of Long

Swamp. For reference, OGIA found ground movement can vary significantly at a local scale, by up to 25 mm within 100 m (0.025%) due to natural mechanisms (OGIA 2021a).

To estimate areal slope change, the most recent LiDAR is used to generate a slope DEM and compared to LiDAR obtained closest to 12 months prior. The slope DEM is generated from the LiDAR derived ground points on a 10 m resolution by averaging the LiDAR ground points within that 10 m resolution cell. Areal slope statistics are calculated from the 10 m resolution DEM for the 1 km grid cells from Step 1 and compared to data collected approximately 12 months prior (depending on when the LiDAR capture occurred). Where the average areal slope change exceeds 1 in 10,000 (0.01% or 100 mm/km), those 1 km grid cells are progressed to an investigation level assessment.

7.6.2 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 or LiDAR measurements with consideration for the cumulative industry impact and reported subsidence since the commencement of the Arrow SGP operations.

Investigation levels are to be assessed based on change in slope derived from LiDAR. Investigation levels have been developed based on existing gradients of catchments and water courses, background changes in slope, and risk of impacts. Assessment against investigation levels will consider the maximum differential settlement and change in slope along transects for comparison with the investigation values. Those areas where ground movement is obviously related to non-CSG natural or anthropogenic causes such as earthworks, land clearing, erosion/deposition, land levelling or tillage will be excluded from assessment. Identification of natural or anthropogenic causes will be based on imagery co-collected with LiDAR, and other available remote sensing data. Transects will be prepared parallel to, and perpendicular to, drainage features, with the gradient of each transect estimated by averaging the slope from one end to the other unless the lowest point on the transect clearly occurs away from either end. Multiple slopes may be fitted to the profile to best approximate the general slope of the transect. It is noted that variations in soil moisture content across areas and/or storm events that results in uneven soil wetting can also cause material changes to surface elevations, however these will not be excluded from further assessment because of these effects. Standing water identified from the point cloud classification process will be considered during the assessment to interpret where water is sitting and affecting slope results along the transects. The gradients of any slopes identified along the transect will be compared between the most recent measurement/survey event, and the pre-CSG[14] influenced measurement / survey event(s) considering the relative uncertainty of the surveys.

7.6.3 Trigger threshold

Where the CSG-related subsidence exceeds the investigation levels, further assessment will be carried out to assess the site-specific assets that may be impacted and identify whether a detrimental impact to MNES protected matters has occurred as a result of the Arrow SGP operations.

Assessment for trigger threshold exceedance will include site-specific investigations to identify and assess potentially affected MNES protected matters. Site-specific investigations are likely to include additional data such as imagery or multispectral remote sensing, ground investigation and verification. Site-specific

[14] Defined as any measurement/survey events conducted prior to production from any SGP CSG well which could reasonably have induced ground movement at any point along the transect. As a minimum this analysis must include the most recent pre-CSG measurement/survey event.

investigation may include soil sampling, ecological assessment, or hydrological and hydraulic modelling. Consideration will be given to development of new local low points, gradients to existing low points, catchment area of low points, inundation of an area not previously known to be or could reasonably be assumed to have been inundated, total variation in slope, and total drainage in catchments or sub-catchments. This evaluation will include analysis of depressions, comparison of contours at 100 mm intervals, and drainage mapping to compare to pre-CSG drainage and slope.

Where adverse consequential impacts to a MNES protected matter are identified to have occurred due to CSG induced subsidence 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 7.6.4. The trigger threshold will not be considered exceeded if it is reasonably apparent that the impact was caused by a pre-existing characteristic of drainage or slope of the area or the alteration to drainage or slope was caused by a non-CSG factor, activity or event.

Table 7-2: Subsidence monitoring screening level, investigation levels and trigger threshold

Item	Description	Relevant assets	Criteria	Action / comment
Screening level – Step 1	Settlement rate from InSAR	All natural features	20 mm/year (for >50% of sampling points in 1 km by 1 km), or where there are <5 InSAR sampling points, within 4.5 km of CSG production wells	Areas where this criteria is exceeded will be subject to further screening for areal slope change and ponding areas (Step 2).
Screening level – Step 2	Change in slope	All natural features	0.01% change in average areal slope over 12 months (for 1 km by 1 km cell)	Areas where Step 1 criteria and this criteria are exceeded will be subject to investigation level assessment.
Investigation levels	Change in slope along transect from LiDAR	Drainage features across the Condamine River Floodplain.	Changes in slope of 0.01% or greater (for areas 0.03-0.09% existing slope), or absolute changes in slope greater than 20% of existing (for areas >0.09% existing slope) over ~12 month previous (nearest suitable LiDAR surveys), due to subsidence.	Areas where this criteria is exceeded will be subject to trigger level assessment. Existing gradients less than 0.03% are already poorly draining and not progressed.
Trigger threshold	Outcome of site specific investigation confirms detrimental impact on MNES protected matter due to CSG induced subsidence	Any natural feature	Site specific investigation determines consequence category of medium or greater and risk to asset is medium or greater	Individual threshold based on the local conditions for identified MNES protected matter. Eg: confirmation of material reduction in yield to the receiving environment by hydrological assessment.

7.6.4 Trigger threshold exceedance response actions

Approval condition 17A(c)(iii) requires the development and implementation of an action plan to address identified subsidence impacts on protected matters 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 Trigger Threshold Exceedance Action Plan (TTEAP) will be developed and implemented within 90 days.

Actions in the TTEAP will be dependent on the:

- Evaluation of the cause of the exceedance;
- Magnitude, location and expected duration of the impacts;
- Site specific conditions e.g. hydrogeology, hydrology, ecology, soils, etc.;
- Remediation options; and
- Any other relevant factors.

The TTEAP will:

- Identify potential mitigation or remediation 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 or remediation implementation, with consideration for the anticipated timing of the indicated impact; and
- Contain procedures to evaluate the effectiveness of the response actions.

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.

It is worth noting that a TTEAP is unlikely to be required because the predicted cumulative CSG-induced subsidence and change in slope is low and is well below the thresholds likely to cause an impact to MNES protected matters.

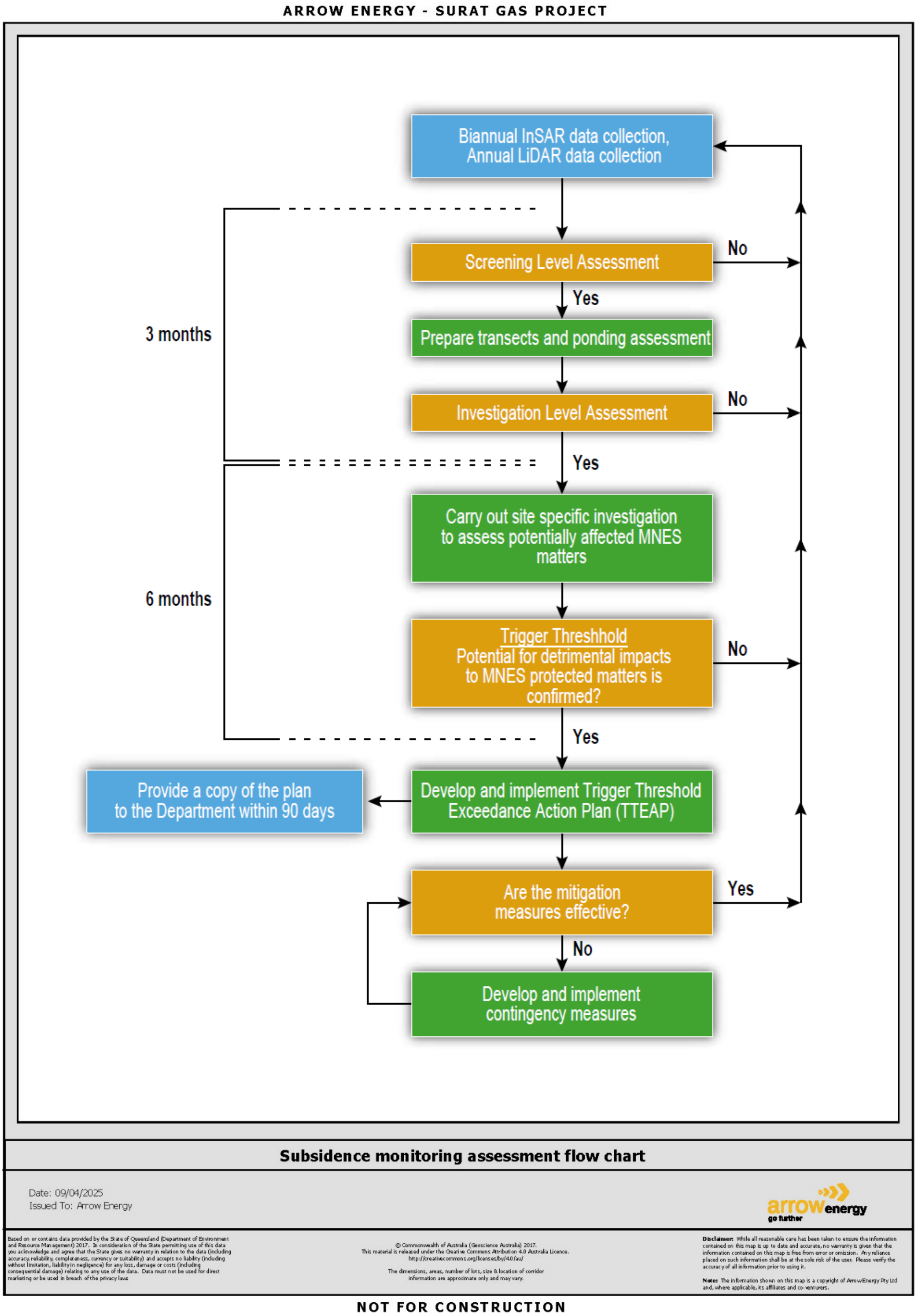

Figure 7-4: Subsidence assessment flowchart for Condition 17A(c)(iii)

7.7 Monitoring program

Based on the data on CSG induced subsidence in the area of the SGP operations available since 2006 and predictions of subsidence with further CSG development, it is considered that the magnitude of subsidence and slope change is not high, and it is recognised that the major pressure reductions will occur in geological formations comprising consolidated rock. Because of the significant depth to the coal bearing formations, and the large areal extent of the depressurisation, the likely effects of any subsidence are considered unlikely to have significant impact on MNES protected matters. Notwithstanding the low risk, ground deformation and water level monitoring will be carried out to verify the above modelling, interpretation and the assessed risk.

The current monitoring program provides groundwater level monitoring and monitoring of ground movement using InSAR, LiDAR, and geodetic ground monitoring points as presented in Section 7.2. The interpretation of subsidence responses, and the prediction of future subsidence, requires good quality groundwater level monitoring over the depth of the affected ground, and collocated ground movement measurements.

Arrow's ground movement monitoring program will consist of:

- InSAR data updates within the whole of the SGP boundary received on a 6-monthly basis from a 3rd party InSAR supplier, providing high resolution and wide coverage of ground movement. Processing and review of the InSAR against the screening level will be undertaken within 3 months of the data being received.
- LiDAR survey at least annually, on or around May when vegetative cover is minimised between cropping cycles, within 5 km of existing or planned CSG fields within the Condamine plain. Regular LIDAR surveys in this area where coherence of InSAR response is poor are useful to assess ground movement, in particular for changes in slope and hydrology.
- 11 permanent GNSS monitoring stations, with final orbit processed daily average co-ordinates. The permanent GNSS monitoring stations provide ground truthing for the results of InSAR and LiDAR monitoring.
- 24 permanent survey marks, with annual surveys of these marks undertaken with a six (6) hour observation time, post-processed to determine co-ordinates. The regular survey of permanent survey marks provide ground truthing for the results of InSAR and LiDAR monitoring.

These monitoring methods and locations are considered to provide appropriate coverage of the areas potentially affected by Arrow operations. An overview of the monitoring methods is provided in Table 7-3.

Groundwater monitoring at multiple locations within, above and below the WCM for groundwater level/depressurisation will be undertaken at the locations and frequencies specified in the most recent UWIR published by OGIA.

Table 7-3: Overview of selected ground movement monitoring methods

Monitoring method	Data Type	Data Products
InSAR	C band SAR satellite (provides moderate capability to penetrate canopy of SGP vegetation to get a ground surface measurement) Processed with PS, SBAS or TCS methodology to maximise data coverage over low coherence areas of the Condamine Alluvium	• Time-series data for each data track (ascending and descending) • Conversion of ascending and descending time-series into vertical and east-west displacement Both data products to include: • cumulative displacement for each acquisition date (mm) • displacement rate (mm/year)
LiDAR	Plane flown LiDAR and imagery. Specification of greater than 4ppsqm and better than +/-0.05m (1SD) for data points.	Point cloud data and digital elevation model • Classified point cloud, LAS format (.las) - orthometric heights. • ICSM Level 3 ground correction for ground points. • 1m resolution DEM, GeoTIFF format (.tif) - orthometric heights.
Permanent GNSS stations	GNSS survey data, post processed at daily intervals	• Time series of elevation data
Terrestrial Survey of permanent survey marks	GNSS survey data, acquired with minimum 6hr observation and post-processed on Auspos	• Time series of elevation data

7.8 Reporting

Monitoring of subsidence and groundwater level variation based on existing data indicates that settlement is gradual and accompanies depressurisation of the Walloon Coal Measures. The changes develop gradually over months and years, and as a result a review of subsidence will be carried out on an annual basis. An annual report of this review will provide diagnostic plots of ground movement from each of the monitoring methods, and associated depressurisation. The annual review and reporting will cover:

- Changes from the baseline condition.
- Incremental changes in groundwater level and ground movement over the previous twelve months.
- Review of ground movement monitoring against adopted screening level, investigation levels, and trigger threshold.
- Review of the predictions of subsidence and appropriateness of developed trigger levels.
- Consideration of complaints in relation to ground movement and impact on MNES.
- Recommendations in relation to monitoring methods, the future frequency of monitoring, repair or investigation of instruments producing inconsistent results.

8 Contribution to Industry Plans, Knowledge and Research

8.1 Condamine Interconnectivity Research Project

The Condamine Interconnectivity Research Project (CIRP) (DNRM, 2016d) is an OGIA-directed project to further quantify connectivity between the Condamine Alluvium and the WCM. Since 2012, OGIA and Arrow have led research into connectivity between these formations. It has involved multiple lines of investigation:

- 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 through a collaborative arrangement with Queensland University of Technology.
- 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 these on-site investigations, including drilling, installation of groundwater monitoring wells and completion of aquifer pumping tests.

The results are reported in the OGIA hydrogeological investigation report "Groundwater connectivity between the Condamine Alluvium and the WCM" (DNRM 2016d) and are of direct relevance to the prediction of impacts from the SGP to the Condamine Alluvium and Condamine River. The CIRP concluded that the level of hydraulic connectivity between the Condamine Alluvium and the WCM is low, with a range of findings through the multiple lines of investigation supporting this conclusion. Conceptualisation, as well as the confidence in conclusions about the connectivity, has improved significantly due to the CIRP investigations. The following are key findings:

- The 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.

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

Arrow continues to contribute to the CIRP study through fulfilling its monitoring obligations under the UWIR. This ongoing monitoring which Arrow conducts builds on the previous work jointly conducted between Arrow and OGIA. Section 5.6.2.3 of the 2021 UWIR illustrates how these data Arrow collect contribute to ongoing updates of the mapping of groundwater level differences between the Condamine Alluvium and the WCM, and a subsequent conclusion that the data presented in the 2021 UWIR, which is consistent with the previously reported findings in previous UWIRs, suggests overall low connectivity between the two formations.

8.2 Horrane Fault

As noted in Section 2.5.3, the Horrane Fault is a regionally significant structural feature in the eastern part of the Surat Basin. The fault originates from a basement fault system and has subsequently propagated into the Surat Basin (OGIA, 2020). The Horrane Fault is significant due to its relatively large displacements (~100 m) and proximity to active CSG production as well as the Condamine Alluvium. The Horrane Fault is one of two instances where a fault in the Surat Basin is thought to have sufficient displacement to juxtapose the Hutton Sandstone with the WCM.

OGIA and Arrow have conducted investigations into the Horrane Fault with OGIA to evaluate the potential for hydraulic connection between formations across the fault.

OGIA's investigation involved interpreting existing seismic data to map the full extent and displacement of the fault, assessing cross-fault leakage and conducting a 2D fault seal analysis, and comparing groundwater pressure monitoring data either side of the fault. OGIA found that reservoir pressure monitoring data suggests a large pressure difference across the fault, indicating the fault may act as a barrier to horizontal flow within the WCM. Furthermore, the high degree of clay smearing that is likely to exist due to the high clay content of the WCM and Hutton Sandstone is expected to produce low-permeability fault core material.

Arrow contributed to the investigation through evaluating reservoir characteristics of the WCM and establishing hydraulic characteristics of the fault (Viljoen et al., 2020). This work included a 2D seismic survey, coring through the fault zone and hydraulic testing across the fault zone. Results indicate that above the fault zone (eastern side), the pressure in the WCM is close to hydrostatic conditions with high gas content, while below the fault zone (western side), the pressure is 50% below hydrostatic pressure with lower gas content. This suggests limited connectivity across the fault zone within the WCM.

Furthermore, Arrow continues to contribute to the Horrane Fault investigation by collecting and submitting groundwater pressure data as per the UWIR WMS, and also by installing monitoring bores associated with the Horrane Fault as indicated in the 2021 UWIR or future UWIRs.

8.3 Data sharing

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. This data is provided to OGIA on a biannual basis as a requirement of the water monitoring strategy of the UWIR, with OGIA then making the data available on the Queensland Globe (https://qldglobe.information.qld.gov.au/).

8.4 Subsidence monitoring

Arrow, along with other CSG proponents, maintain a subsidence monitoring program involving the use of satellite imaging using 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.

Arrow provides LiDAR data to OGIA at least on an annual basis as a requirement of the UWIR. OGIA then provide the ability to interrogate the DEM by generating elevation profiles in an interactive web-based LiDAR tool
(https://qportal.information.qld.gov.au/arcgis/apps/experiencebuilder/experience/?id=03674f2b68fc4b7e958

3b13b3686cb1e), and the imagery is made available through the Queensland Globe (https://qldglobe.information.qld.gov.au/). The DEMs derived from the LiDAR surveys are made available by the Queensland Government through the ELVIS Elevation and Depth data repository (https://elevation.fsdf.org.au/).

8.5 Other areas of research

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 WRMMP, monitoring, research and detailed studies 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.

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.
- 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 17A(l) and 26A through to 29A require record keeping, reporting and non-compliance notification. Arrow will meet the requirements of these conditions as set out in this Section.

9.1 Record keeping and data management

Arrow will maintain records of relevant activities carried out in accordance with the WRMMP. These records will be made available to the Department[15] upon request.

Implementation of the WRMMP will generate significant data including field records and observations, laboratory water-quality analytical data and InSAR and LiDAR data captures.

[15] Department is defined to mean the Australian Government Department administering the *Environmental Protection and Biodiversity Conservation Act 1999* (Cth.), currently the DCCEEW.

Data will be subject to a quality control review program or system to identify data or transcription errors.

9.2 Reporting

Reporting for the WRMMP is detailed below, and includes:

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

9.2.1 Potential non-compliance reporting

In accordance with Approval Condition 29, the Department will be notified in writing as soon as practical and no later than ten business days after becoming aware of any potential non-compliance with any Approval Condition.

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 (noting that the JIF (DAWE, 2021) states that its framework relates to groundwater and all aspects of the groundwater resource [including groundwater, organisms and other components and ecosystems that contribute to the physical state and environmental value of the groundwater resource]);
- the measures to be taken to address the impacts of the potential non-compliance on MNES and to rectify the potential non-compliance; and
- The time by when the approval holder will rectify the potential non-compliance.

9.2.2 Early warning monitoring system exceedance reports

As described in Sections 6.2 and 6.3 to address approval conditions 17A(f) and 17A(h), early warning indicators and trigger thresholds are not proposed for the Condamine Alluvium or for aquatic ecology and aquatic ecosystems. If in the future a predicted change in flux or impact to aquatic ecology and aquatic ecosystems requires early warning indicators and trigger thresholds to be set then any exceedance will be reported in accordance with the Action's Approval Conditions.

9.2.3 Subsidence action plan reporting

As described in Section 7.6, ground movement monitoring data will be assessed against a process of progressive trigger levels consisting of screening levels, investigation levels, and trigger thresholds. If trigger thresholds are exceeded and the potential for detrimental impacts to MNES protected matters is confirmed, a Trigger Threshold Exceedance Action Plan (TTEAP) will be developed and implemented within 90 days.

Where required to be developed, a TTEAP will:

- Identify potential mitigation or remediation 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 or remediation implementation, with consideration for the anticipated timing of the indicated impact; and
- Contain procedures to evaluate the effectiveness of the response actions.

9.2.4 Annual report

An annual report on the WRMMP will be prepared for each annual compliance report period which, as defined in the Approval Conditions, is each subsequent 12-month period following the date of the approval decision (27 February 2025). It will be submitted to the Department and published on Arrow's website within 60 business days of every 28 February anniversary of the commencement of the SGP (22 October 2020).

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:

- 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 (if required to be collected), including:
  - Groundwater levels
  - Groundwater chemistry results
  - Surface water monitoring results
  - Surface water chemistry results
  - Subsidence monitoring data
  - Analysis and interpretation of data
- Document Arrow's compliance against the approval conditions over the preceding 12 months, including monitoring obligations and implementation of the EWMS.
- Document corrective actions implemented to address any exceedances of EWMS values, 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.
- Approach in WRMMP is aligned with an adaptive management approach (i.e. assess and monitor potential impacts to MNES where predicted or identified material impact changes significantly).
- Where an exceedance under the EWMS has occurred, the corrective actions for ameliorating impacts from exceedance of the limits are implemented, and effective.

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 WRMMP on Arrow's website.
- Publication of the annual reports on Arrow's website. The reports will be published within 60 business days of every 28 February anniversary of the commencement of the SGP.
- Providing raw data to the Queensland DLGWV for potential inclusion (at DLGWV's discretion) on the 'Queensland Globe'[16].

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 UWIR Water Monitoring Strategy.

9.5 Peer review

Approval Condition 18 requires formal peer review by a suitably qualified water resources expert of the WRMMP. The WRMMP peer review and statement of endorsement are provided in Appendix H.

9.6 Revision of the WRMMP

Triggers, and their associated timing, for revising the WRMMP are listed below.

- Identification of a requirement for discharge (other than emergency discharge) (Section 5.1 and 6.2). Should discharge to surface water systems be proposed in the future, this will necessitate the submission of a revised WRMMP within 90 days of identifying the requirement for discharge, for Ministerial approval. An aquatic ecology and ecosystems EWMS will be included in the revised WRMMP if this eventuates.
- If an early warning indicator and/or trigger level and/or limit for the next 3 year period (calculated upon review of each release of a new UWIR) is greater than +/-10% of the values reported in the latest version of the WRMMP for any of the aquifers. As outlined in Section 6.1.2, the early warning indicators, trigger thresholds and limits will be reviewed according to new OGIA model outputs within 90 days of an approved UWIR being issued and upon receiving technical files from OGIA for that UWIR. If triggered, Arrow will submit a revised WRMMP within 90 days for Ministerial approval (following the initial 90 day review period of the early warning indicators, trigger thresholds and limits). The revised WRMMP will reflect the revised early warning indicators and/or trigger levels and/or limits based on drawdown predictions from the new UWIR.

[16] 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 DLGWV current and historical records.

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

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11 Abbreviations

Table 11-1 Abbreviations

Abbreviation	Definition
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
DESI	Department of Environment, Science and Innovation
DO	Dissolved oxygen
DLGWV	Department of Local Government, Water and Volunteers
DRDMW	Department of Regional Development, Manufacturing and Water
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

Abbreviation	Definition
TSS	Total Suspended Solids
UWIR	Underground Water Impact Report
VWP	Vibrating Wireline Piezometer
WCM	Walloon Coal Measures
WMMP	Water Monitoring and Management Plan
WRMMP	Water Resource Monitoring and Management Plan
WMP	Water Management Plan
WMS	Water Management Strategy
UWIR	Underground Water Impact Report
WQO	Water Quality Objective

Appendix A SGP EIS / SREIS Commitments

Table A.1 presents Arrow's EIS/SREIS commitments that relate to groundwater and surface water, cross-referencing where each commitment is addressed in the WRMMP.

Table A.1 EIS / SREIS commitments cross -reference

Number	Description of commitment	Relevant WRMMP section
C053	Avoid disrupting overland natural flow paths and, where avoidance is not practicable, maintain connectivity of flow in watercourses.	Section 5.2 Appendix F
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 A of Appendix E
C124	Consider local biological, groundwater and surface water conditions when identifying sites for coal seam gas water dams and brine dams.	Attachment A of Appendix E
C125	Consider local groundwater conditions when identifying sites for the installation of buried infrastructure (e.g., gathering lines).	Attachment A of Appendix E
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 8.1
C129	Continue a program of aquifer testing in dedicated groundwater monitoring bores to increase the predictability of aquifer properties and groundwater movement.	Managed through the Joint Industry Framework (Section 4.1)
C130	Collect relevant geological and hydrogeological data from existing and future production wells, monitoring bores and registered third-party bores (where	Managed through the Joint Industry

Number	Description of commitment	Relevant WRMMP section
	possible) together with information collated collaboratively with other proponents and regulatory authorities.	Framework (Section 4.1)
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.	Managed through the Joint Industry Framework (Section 4.1)
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.	Managed through the Joint Industry Framework (Section 4.1)
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.	Managed through the Joint Industry Framework (Section 4.1)
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 5.1 Appendix E
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 5.1 Appendix E
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 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).	Section 7
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	Attachment A of Appendix E

Number	Description of commitment	Relevant WRMMP section
	conditions relating to dam design, construction, inspection and mandatory reporting requirements.	
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.	Managed through the Joint Industry Framework (Section 4.1)
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 5.2 Appendix F Attachment A of Appendix E
C154	Design coal seam gas water dams in accordance with relevant legislation, standards and guidelines.	Attachment A of Appendix E
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 5.2 Appendix F
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.	Managed through the Joint Industry Framework (Section 4.1)
C171	Develop and implement incident reporting, emergency response and corrective action systems or procedures. Include systems for reporting, investigation and communications of lessons learned.	Section 6.1 Section 9.2
C174	Maximise beneficial use of coal seam gas water.	Attachment A of Appendix E
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 A of Appendix E
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 A of Appendix E
C205	Identify strategies to minimise coal seam gas water surface storage and to promote increased efficiency.	Attachment A of Appendix E
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	Discharge is not proposed

Number	Description of commitment	Relevant WRMMP section
	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.	
C521	Ensure methods used to monitor groundwater levels and quality, together with monitoring frequencies and parameters are in accordance with approved regulatory standards.	Section 6.1.4
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 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.	Managed through the Joint Industry Framework (Section 4.1)
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.	Managed through the Joint Industry Framework (Section 4.1)
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 6.4 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 6.4 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	Section 5.1

Number	Description of commitment	Relevant WRMMP section
	Alluvium in the area of greatest predicted drawdown as a result of coal seam gas water extraction from the Walloon Coal Measures.	Attachment A of Appendix E

Appendix B WRMMP SGP Project Description

The SGP involves an expansion of Arrow's CSG production in the Surat Basin. As described in the Supplementary Report to the Environmental Impact Statement (SREIS), the SGP comprised an FDP based on 6,500 wells and total water production of 510 GL. This production has been subsequently revised, and this WRMMP is based on an updated FDP comprising 2,766 wells and total water production of 380 GL (down from 575 GL as forecasted in the Updated WMMP) over a 42 year duration, as included in the Office of Groundwater Impact Assessment (OGIA) 2021 Underground Water Impact Report for the Surat Cumulative Management Area (UWIR) model (OGIA, 2021).

Production under the SGP commenced in April 2022 and a total of 4,271.3 ML of water has been extracted up to October 2023.

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

Appendix C Surface Water and Aquatic Ecosystems

Appendix D Arrow CSG Water Management Plan

Appendix E Assessment of Impacts and Development of Management Measures

Appendix F Flood Risk Assessment

Appendix G Early Warning Monitoring System

Appendix H Subsidence

Appendix I Peer Review