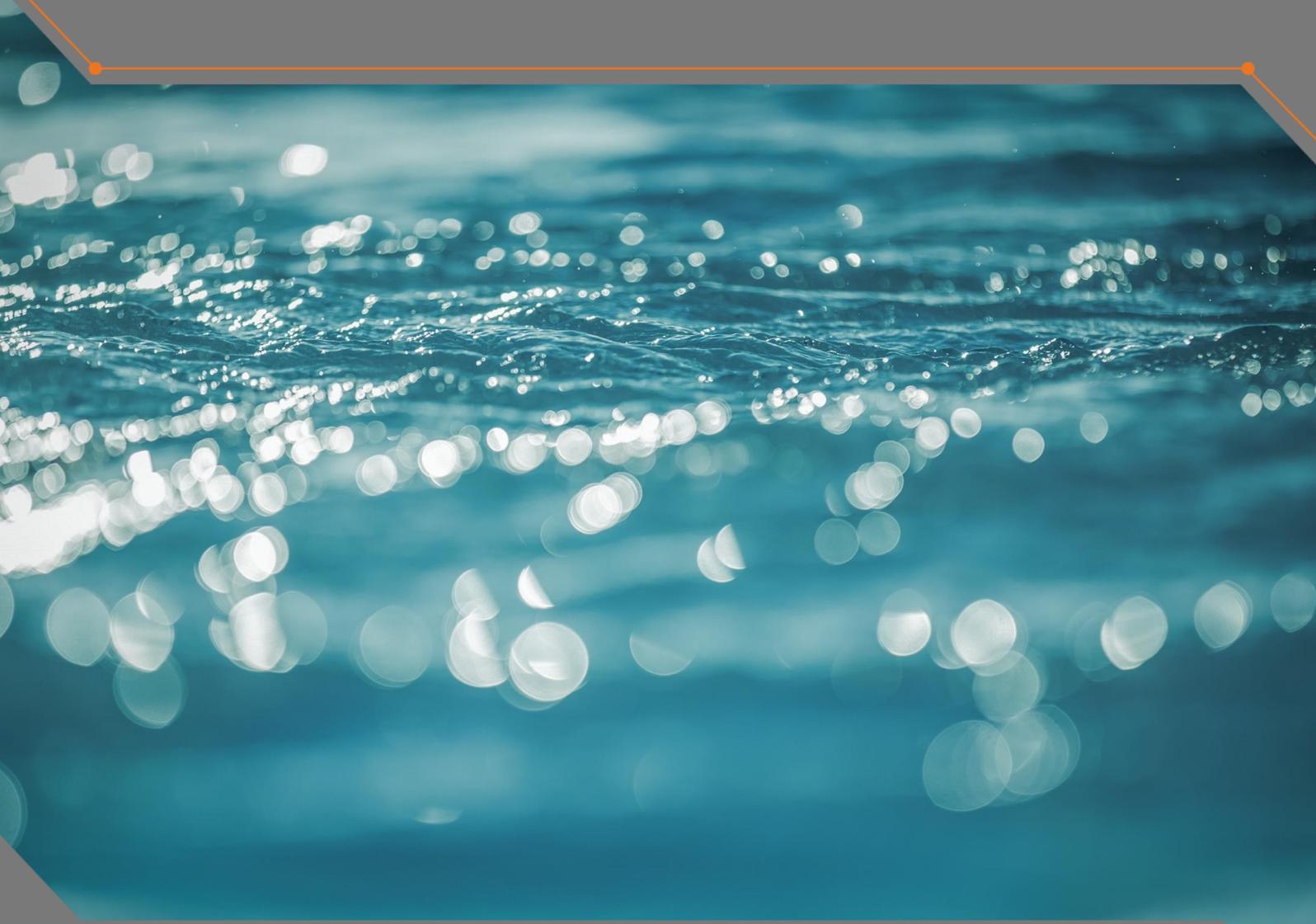


# Underground Water Impact Report 2021 for the Surat Cumulative Management Area

*A report on the assessment and management of cumulative impacts from coal seam gas, coal mining and conventional oil and gas development in the Surat and southern Bowen basins*



December 2021

Office of Groundwater Impact Assessment



Queensland  
Government

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Authorised to be released by Sanjeev Pandey, Executive Director, Office of Groundwater Impact Assessment on 31 March 2022.

The current version is as approved by the Department of Environment and Science on 17 March 2022 and includes minor amendments to the report originally submitted for approval on 17 December by the Office of Groundwater Impact Assessment.

This publication has been compiled by the Office of Groundwater Impact Assessment, Department of Regional Development, Manufacturing and Water.

**Bibliographic reference:**

OGIA, 2021. *Underground Water Impact Report for the Surat Cumulative Management Area*. OGIA, Brisbane.

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# **Underground Water Impact Report 2021 for the Surat Cumulative Management Area**

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**December 2021**

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## Key points

### Context

- An Underground Water Impact Report (UWIR) for the Surat Cumulative Management Area (CMA) is a statutory report prepared by the independent Office of Groundwater Impact Assessment (OGIA) every three years.
- The UWIR provides for the assessment and management of cumulative groundwater impacts resulting from the incidental extraction of groundwater by resource development activities – i.e. coal seam gas (CSG), conventional oil and gas, and coal mining.
- Incidental extraction of groundwater, also referred to as ‘associated water’, is groundwater that is primarily extracted in the process of depressurisation of coal measures for CSG production, dewatering of coal seams for safe operations of coal mines, and production of conventional oil and gas.
- CSG and coal mining target formations are layered within the aquifers of the Great Artesian Basin (GAB) and also underlie the Condamine Alluvium.
- Groundwater in the Surat CMA is also extracted for use by water bore owners, mainly for stock and domestic, irrigation, agricultural and town water supply purposes.

### Existing and proposed development

- CSG is the dominant, and expanding, resource development activity in the Surat Basin with five major operators – QGC, Santos, Origin Energy, Arrow Energy and Senex Energy.
- The existing and planned CSG production area has increased by 8% since 2019, with current projection of about 22,000 CSG wells – of which about 8,600 are already in place.
- Current associated water extraction by the CSG operators is around 54,000 megalitres per year and is likely to average around the same over the life of the industry.
- The coal mining footprint is less than two per cent of the CSG footprint in the Surat Basin and currently extracts less than 1,000 megalitres of associated groundwater per year.
- All coal mines in the Surat Basin are open-cut mines – four are operational, one is currently closed and three are proposed.
- There are approximately 8,000 water supply bores, half of which are in the GAB, within and in the immediate proximity of the CSG production areas, extracting 59,000 megalitres of groundwater per year for consumptive use.

### Existing impacts

- Declines of up to about 400 metres are observed from the groundwater level monitoring data in the Surat Basin CSG target formations and to a lesser extent in the Springbok Sandstone – consistent with the predictions in the previous UWIR.
- Impacts of up to 30 metres are noted in the Walloon Coal Measures surrounding the coal mines.
- No impacts are identified in the Hutton Sandstone, Precipice Sandstone or Condamine Alluvium at this stage.

## Predicted impacts

- Predicted impacts are broadly similar to the previous UWIR in 2019.
- For most areas, impacts of 450 metres or less are predicted in the CSG and coal target formations, and 80 metres in the Springbok Sandstone.
- Only minor impacts of less than 12 metres are predicted in the Hutton Sandstone and Precipice Sandstone.
- Predictions of groundwater loss from the Condamine Alluvium to the underlying Walloon Coal Measures have increased marginally to 1,270 megalitres per year. Impacts on groundwater levels remain less than a metre.
- Predicted CSG water extraction has increased marginally to 54,000 megalitres per year due to changes in development profile.
- A total of 702 water bores are predicted to be impacted in the long term, of which 108 are predicted to be impacted in the next three years (Immediately Affected Area (IAA) bores).
- The proportion of predicted cumulative impacts from coal mining is up to 55 metres in some localised areas around the mines but generally less than 10 to 20 metres.

## Impact management and monitoring

- For each of the 108 IAA bores, responsible tenure holders are assigned for follow up bore assessment and make good.
- IAA bores are progressively identified in each UWIR for make good purposes; of the 233 IAA bores from the previous UWIRs, make good has been executed for 135 and is in process for 98.
- The monitoring network is to be strengthened – from the existing network of around 617 groundwater level monitoring points and 90 groundwater chemistry monitoring points, to 724 and 100 respectively – a net increase of about 14%.
- Seven groups of springs are predicted to be impacted by more than 0.2 m of groundwater level decline in their source aquifers. Of these, mitigation strategies arising from the previous UWIR are in place for three groups where the unmitigated risk is medium or high.

## Subsidence

- Hundreds of metres of CSG depressurisation will result in a few centimetres of subsidence at the ground surface.
- OGIA's modelling of subsidence predicts that most of the cropping area around the Condamine Alluvium is likely to experience less than 100 mm of subsidence, with a maximum change in slope for most areas of less than 0.001% (10 mm per km) and up to 0.004% (40 mm per km) for some areas.
- Observations from satellite data indicate that about 100 mm of CSG-induced subsidence has occurred around the CSG fields near Condamine Alluvium. Natural movement of up to 25 mm/year is also observed away from CSG fields.
- The monitoring strategy comprises the establishment of baseline slope and trend monitoring using airborne and satellite data.

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## Abbreviations

°C .....	degrees Celsius
1D, 2D, 3D.....	one-dimensional, two-dimensional three-dimensional
AEM.....	airborne electromagnetic
AGL .....	AGL Energy Ltd (including subsidiaries and joint venture partners)
APLNG .....	Australia Pacific LNG (including subsidiaries and joint venture partners)
Armour.....	Armour Energy Ltd (including subsidiaries and joint venture partners)
Arrow .....	Arrow Energy Ltd (including subsidiaries and joint venture partners)
ATP .....	authority to prospect
Bridgeport.....	Bridgeport Energy Ltd (including its subsidiaries and joint venture partners)
CDMMR.....	cumulative deviation from mean monthly rainfall
CMA .....	cumulative management area
CSG .....	coal seam gas
DES .....	Department of Environment and Science (Queensland)
DNRME .....	former Department of Natural Resources, Mines and Energy (Queensland)
DoR .....	Department of Resources (Queensland)
DRDMW .....	Department of Regional Development, Manufacturing and Water (Queensland)
EA.....	environmental authority
EIS.....	environmental impact statement
EP Act .....	<i>Environmental Protection Act 1994</i>
EPBC Act .....	<i>Environment Protection and Biodiversity Conservation Act 1999</i>
EPP .....	Environmental Protection (Water and Biodiversity) Policy 2009
EV.....	environmental value
GAB .....	Great Artesian Basin
GDE.....	groundwater-dependent ecosystem
GWDB .....	DRDMW's groundwater database
GDR .....	Great Dividing Range
GL.....	gigalitres

IAA.....	immediately affected area
IESC .....	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
InSAR.....	Interferometric Synthetic Aperture Radar
km .....	kilometres
L .....	litres
L/s.....	litres per second
LAA.....	long-term affected area
LNG .....	liquefied natural gas
m .....	metres
mbgl.....	metres below ground level
mD.....	milliDarcy
MERLIN.....	Mineral and Energy Resources Location and Information Network
mg/L .....	milligrams per litre
ML .....	mining lease
ML/year .....	megalitres per year
MR Act.....	<i>Mineral Resources Act 1989</i>
mm .....	millimetres
MNES .....	matters of national environmental significance
OGIA .....	Office of Groundwater Impact Assessment
Origin .....	Origin Energy Ltd (including subsidiaries and joint venture partners)
P&G .....	petroleum and gas
P&G Acts.....	<i>Petroleum and Gas (Production and Safety) Act 2004 and Petroleum Act 1923</i>
PEST .....	model-independent parameter estimation and uncertainty analysis software
PL.....	petroleum lease
PLA .....	petroleum lease under application
psi.....	pressure, pound-force per square inch
QDEX .....	Queensland Digital Exploration Reports System
QGC .....	Queensland Gas Company Pty Ltd (including subsidiaries and joint venture partners)
RE .....	regional ecosystem
RTH.....	responsible tenure holder
S&D .....	stock and domestic
Santos .....	Santos Ltd (including subsidiaries and joint venture partners)
SAR .....	sodium adsorption ratio
Senex .....	Senex Energy Ltd (including subsidiaries and joint venture partners)
SIMS.....	Spring Impact Management Strategy
TGDE .....	terrestrial groundwater-dependent ecosystem
TDS .....	total dissolved solids
UWIR.....	Underground Water Impact Report
Water Act.....	<i>Water Act 2000</i>
WMS.....	Water Monitoring Strategy

## Chapter 1 Introduction

### 1.1 What is an Underground Water Impact Report?

An Underground Water Impact Report (UWIR) for a ***cumulative management area***<sup>1</sup> (CMA) is a statutory report to provide for:

- an **assessment of impacts** from existing and proposed associated water extraction by resource tenure holders – i.e. coal seam gas (CSG), conventional oil and gas, and coal mining – including establishing existing impacts and making predictions of future impacts on aquifers and groundwater assets
- **proactive strategies for managing** those impacts – such as make good of water bores ahead of actual impacts, a monitoring strategy and impact mitigation strategies for affected springs and connected watercourses
- **assignment of responsibilities** to individual tenure holders to implement strategies and for ongoing reporting.

The report for a CMA is prepared independently by the Office of Groundwater Impact Assessment (OGIA) **every three years** to iteratively update the assessment and management strategies in response to emerging data, information and issues (Figure 1-1). The report is finalised following consideration of submissions from stakeholders on a consultation draft. Once approved by the regulator, which is the Department of Environment and Science (DES), implementation of the management strategies in the report is a statutory obligation on the relevant tenure holders. Annual reporting provides an update on any changes in circumstances that would materially affect the UWIR.



Figure 1-1: The UWIR cycle

### 1.2 Water rights of resource tenure holders

In Queensland, the *Petroleum and Gas (Production and Safety) Act 2004* and the *Petroleum Act 1923* (collectively referred to here as the P&G Acts), along with the *Mineral Resource Act 1989* (MR Act), authorise resource tenure holders to undertake activities related to exploration and production. Tenure holders have a statutory right to take or interfere with underground water (**groundwater**) in the process of exploration and production. Water taken under this right is referred to as **associated water** and the right to take the water is referred to as an **underground water right**. This right has existed for petroleum and gas (P&G) tenure holders since 1923 and was extended to mining in 2016, through legislative amendments and some transitional arrangements. The right is subject to several responsibilities for ongoing assessment and management of groundwater impacts arising from the extraction of associated water. These responsibilities are collectively referred to as the **underground water obligation** and the entire framework is referred to as the **underground water management framework** under Chapter 3 of Queensland's *Water Act 2000* (Water Act).

The underground water right is provided to enable safe operating conditions in mines and to achieve the production of petroleum and natural gas. The right does not apply to other extraction of

<sup>1</sup> Italics denote statutory/legislative terms; bold denotes emphasis

groundwater by resource tenure holders specifically for purposes such as camp water supply or road construction. Groundwater extracted for such purposes is referred to as **non-associated water**, the taking of which requires a water licence or water entitlement under Chapter 2 of the Water Act. Extracted associated water, however, can be used for other purposes, in accordance with the Queensland Government CSG water management policy which encourages the beneficial use of CSG water.

The underground water management framework specifically provides for:

- periodic assessment of groundwater impacts on aquifers, including predictions of impacts on water bores and environmental values (EVs)
- a baseline survey of water bores in and around the tenures
- detailed assessment of potentially affected water bores to establish whether their capacity to supply water will be impaired
- an obligation for tenure holders to implement proactive **make good** measures for affected water bores
- development and implementation of a groundwater monitoring network
- development and implementation of a strategy for managing impacts on affected springs and watercourses
- preparation of the UWIR every three years to report the outcomes of the assessment and management arrangements.

### 1.3 Complementary frameworks

The framework complements overall environmental impact management under Queensland's *Environmental Protection Act 1994* (EP Act) and the Australian Government's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (Pigram, Pandey & Baker 2019). A major resource project's broad impacts on groundwater are considered through the environmental impact statement (EIS) process prior to the granting of environmental authorities (EAs) and tenure. A project proponent is required to develop an environmental management plan to support an application for an EA. All proposals for CSG developments that are likely to have significant impacts on water resources require approval under the EPBC Act; this requirement is known as the 'water trigger' and came into effect in June 2013. Such approvals are typically subject to a range of conditions for the assessment and management of impacts. The conditions are progressively being aligned to the UWIR framework.

### 1.4 Assessment and management of cumulative impacts

Impacts on groundwater level from two or more resource development activities can overlap. In these situations, it is not practical for individual tenure holders to assess cumulative groundwater impacts and to determine individual tenure holder responsibilities for monitoring and make good obligations. Therefore, to ensure that a comprehensive cumulative groundwater assessment is completed and to provide clarity on management responsibilities of the involved tenure holders, an area containing projects with overlapping impacts can be declared a CMA under Chapter 3 of the Water Act.

When a CMA is established, responsibility for preparing the UWIR rests with OGIA – an independent statutory office. OGIA becomes responsible for preparing a single UWIR for the whole area, undertaking assessments, establishing management arrangements and identifying responsible tenure

holders (RTHs) to implement specific aspects of those management arrangements (Pandey, Cox & Flook 2021). RTHs have a legal obligation to implement the management activities assigned in the UWIR. OGIA oversees the implementation of those arrangements, while DES remains the regulatory agency for compliance with those obligations.

## 1.5 The Surat CMA

### 1.5.1 Overview

The Surat CMA was established in 2011 in response to intense CSG development (Figure 1-2). The CMA covers the area of current and planned CSG development in the Surat Basin and the southern Bowen Basin, as described in detail in the next Chapter. The Surat CMA was amended in January 2020 to include coal mines in the Surat Basin, as they largely overlap with CSG impacts in the basin. It is to be noted that Bowen Basin mines within the Surat CMA boundary are not included in the CMA as they are relatively isolated operations.

The Surat CMA straddles the Great Dividing Range (GDR) and falls within a region covering various catchments of both the southern parts of Fitzroy River Basin and the northern parts of the Murray-Darling Basin. The GDR divides the Murray-Darling Basin river systems – which are dominated by the Condamine and Balonne rivers – from the northerly and easterly flowing Nogoa, Comet, Dawson and Boyne river systems. The Condamine-Balonne river system is the dominant surface drainage system in the south of the region.

The climate of the area is sub-tropical, with most rainfall occurring in summer, between November and February. Rainfall and run-off are highly variable and evaporation rates are high. Consequently, many of the watercourses in the area are ephemeral.

The predominant land use in the region is agriculture, including broadacre cropping, horticulture, grazing and lot-feeding. Other land uses include urban, industrial, CSG and conventional oil and gas extraction, mining (mainly coal) and conservation.

### 1.5.2 Geological and hydrogeological framework

Geologically, the Surat CMA incorporates parts of three large sedimentary basins: the southern part of the **Bowen Basin**, the northern part of the **Surat Basin** and the western part of the **Clarence-Moreton Basin**. Geological and structural maps of the Surat CMA are presented in Appendix A and more details are provided in a companion document (OGIA 2021a).

Geologic formations within the three basins mainly comprise layers of sandstone, siltstone and mudstone that were primarily deposited by rivers and lakes, with occasional marine influences.<sup>2</sup> OGIA has created videos illustrating the groundwater systems in 3D (section 14.4).

There are four primary groundwater systems in the Surat CMA as listed below, each including one or more aquifers:

- **Great Artesian Basin (GAB):** a Jurassic to Cretaceous hydrogeological basin comprising alternating aquifers and aquitards of various geologic formations of Surat Basin sediments and their equivalents.

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<sup>2</sup> The Surat Basin and the Clarence-Moreton Basin are geologically and hydrogeologically connected to each other. For simplicity, unless specifically stated, a reference to the Surat Basin in this report is a reference to both the Surat Basin and the Clarence-Moreton Basin.

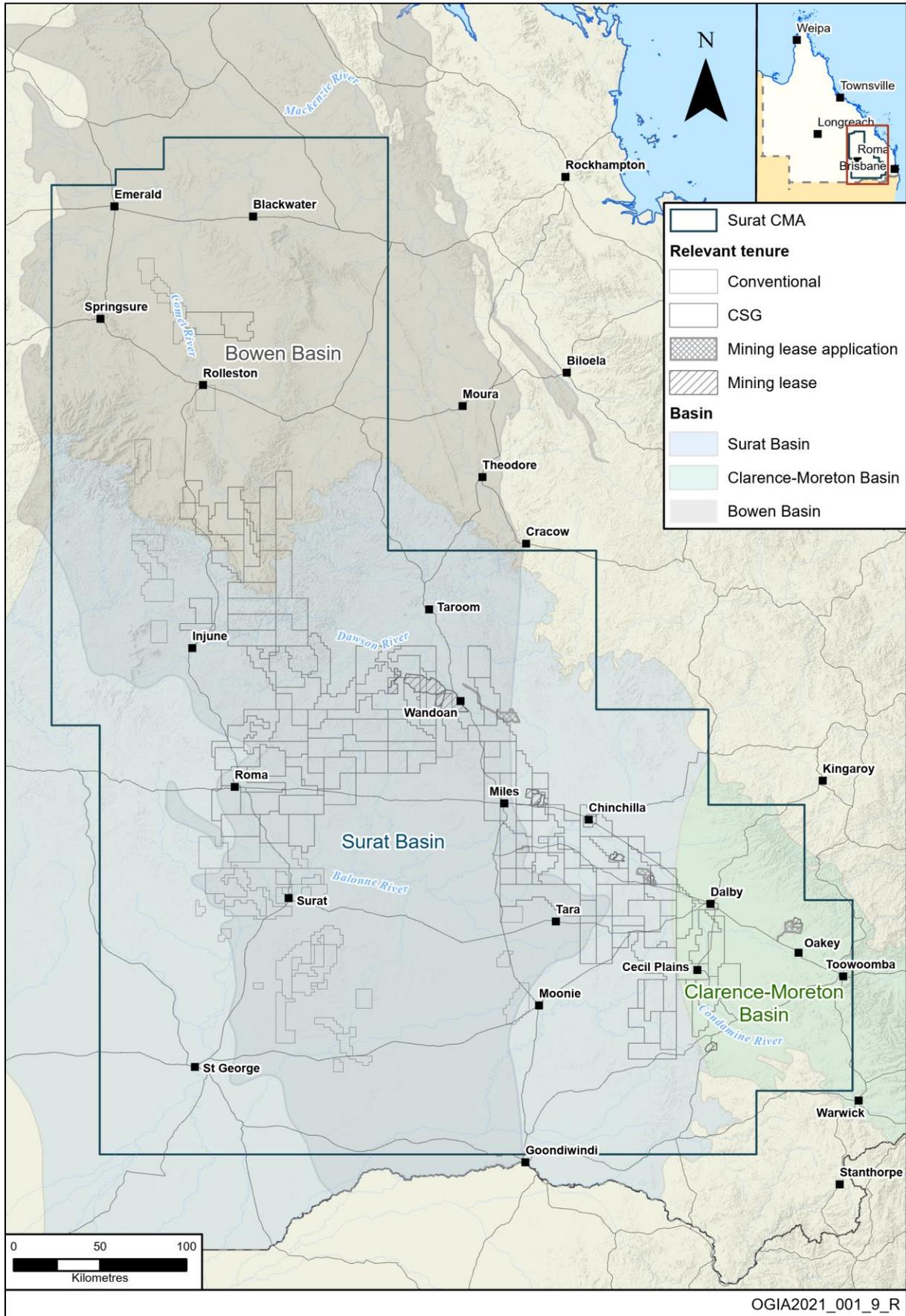


Figure 1-2: The Surat Cumulative Management Area (Surat CMA)

- **Bowen Basin:** Permian to Triassic aquifers and aquitards of the Bowen Basin formations underlying the Surat Basin.
- **Main Range Volcanics:** a Cenozoic consolidated surficial aquifer that mainly caps the Clarence-Moreton Basin along the GDR.
- **Alluvium:** Quaternary unconsolidated surficial aquifers; mainly the Condamine and St George alluviums.

These primary groundwater systems have the potential to interact with one another. In terms of productive groundwater supplies, the GAB, the Condamine Alluvium and the Main Range Volcanics are the three most significant groundwater systems in the Surat CMA. Generalised groundwater movement in these systems is shown in Figure 1-3. Details of groundwater flow conditions in each of the key aquifers are provided in a companion document (OGIA 2021b).

Most formations, including those which are sandstone-dominated, show significant proportions of fine-grained layers of mudstone, siltstones and shale that vary from place to place. This results in a high degree of lateral and vertical hydrogeological heterogeneity<sup>3</sup>, which determines if a formation has the overall characteristics of an aquifer or aquitard and also influences the mechanisms of interconnectivity between the formations.

A generalised characterisation is adopted for the purpose of the UWIR:

- **regional aquifer:** high transmissivity<sup>4</sup>, high bore yields that are vertically and laterally consistent at a regional scale, e.g. Precipice Sandstone
- **partial aquifer:** medium transmissivity, high to medium bore yields that are vertically and laterally inconsistent at a regional scale and exhibiting a high degree of heterogeneity, e.g. Hutton Sandstone
- **tight aquifer:** medium to low transmissivity, low bore yields that are regionally inconsistent and exhibiting a high degree of heterogeneity, e.g. Springbok Sandstone
- **interbedded aquitard:** similar to a tight aquifer but with thin, spatially limited but transmissive water-yielding zones interbedded in an otherwise tight aquitard, e.g. Walloon Coal Measures
- **tight aquitard:** predominantly low permeability, regionally extensive and thick formations.

A classification of geological formations based on the above definitions is presented in Appendix A.

Dominant recharge in the GAB is along the zones of increased permeability in outcrop areas through fractures and permeable beds. High-intensity rainfall events and high volume are required to provide sufficient saturation of the surficial sediments for effective diffuse recharge to occur. Similar to Kellett et al. (2003), OGIA has been using and updating a chloride mass balance approach to estimate surficial recharge for selected aquifers, which is then applied to the groundwater flow model and further adjusted in the model calibration process to get estimates of deep recharge. The majority of the surficial recharge discharges locally to streams and rivers, such that less than 10% of this recharge (about 18 GL per year) reaches the deeper confined aquifers.

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<sup>3</sup> Heterogeneity is a reference to the variations in aquifer parameters in different directions.

<sup>4</sup> In simple terms, transmissivity is the product of formation permeability and formation thickness and is used in representing an aquifer's capacity to yield water.

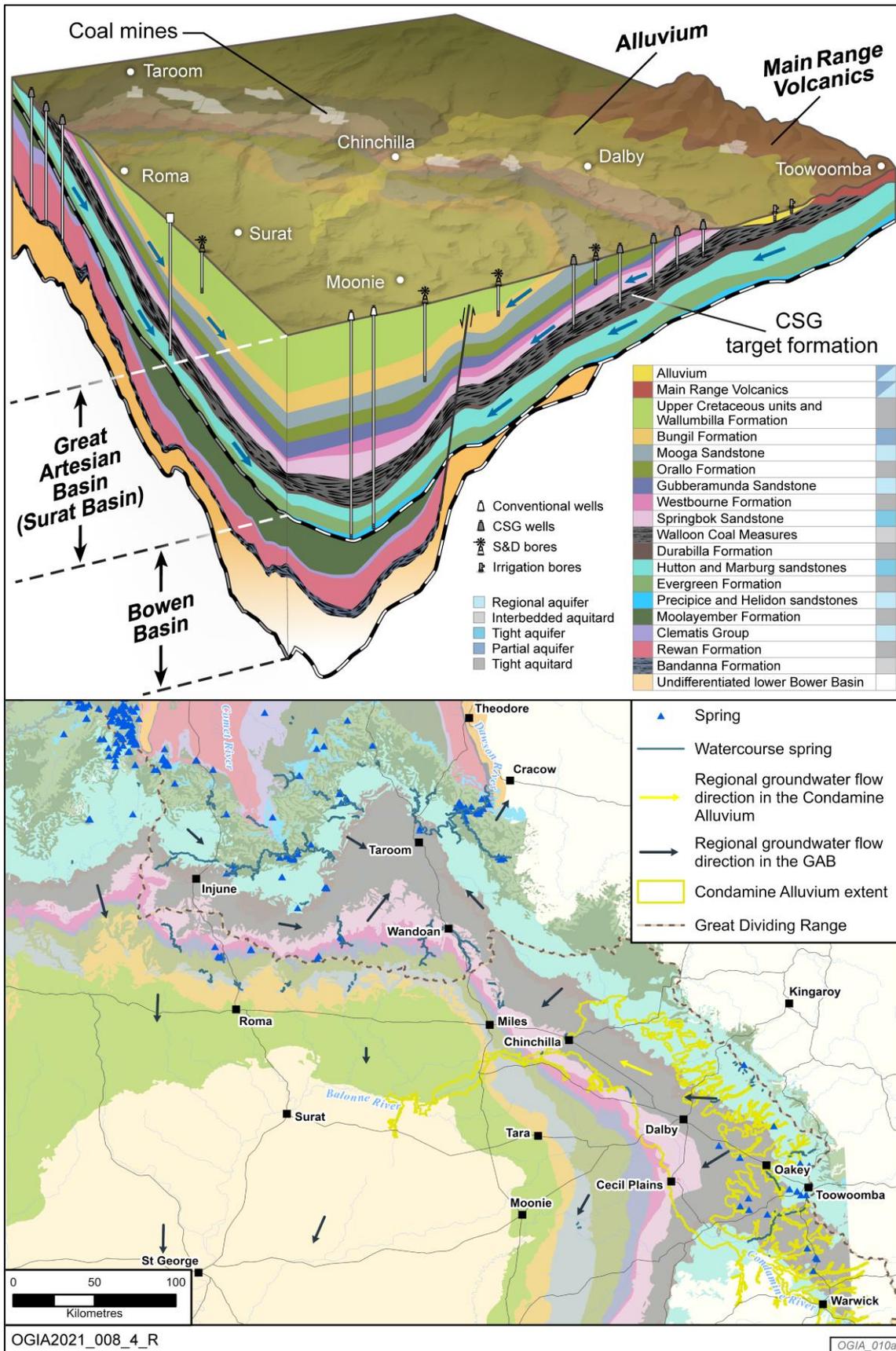


Figure 1-3: Representation of the main groundwater systems and geology in the Surat CMA

## 1.6 What is new in this UWIR

The first Surat UWIR was prepared by OGIA (then part of the Queensland Water Commission) in 2012, followed by two further iterations – UWIR 2016 and UWIR 2019. The UWIR 2019 remains in force until the UWIR 2021 (this UWIR) is finalised and approved by DES.

The UWIR is required to be updated every three years. However, as a consequence of an amendment to the Surat CMA in early 2020 to include coal mines in the Surat Basin, DES has required that a subsequent UWIR be submitted by the end of 2021 – which is effectively two years after the previous UWIR.

As a result of the inclusion of coal mining impacts and other emerging issues, some of the new elements, material updates and reporting in this UWIR – compared to the previous UWIR – are as follows:

- assessment and integration of cumulative impacts from existing and proposed coal mines in the Surat Basin – with corresponding integration of impact management strategies
- compilation of a large amount of relevant data accessed directly from coal mining tenure holders
- sub-regional-scale impact pathway conceptualisation in and around the coal mines
- two separate geological models developed for the eastern and northern Surat Basin to support impact assessment in those areas and refine understanding of shallow systems that may potentially have implications for CSG and coal mining impact propagation to some of the environmental assets
- refinement of the regional geological model in and around the coal mines using coal hole data to represent subdivisions of the Walloon Coal Measures across the whole model domain
- a new chapter (Chapter 4) on impact pathways that reflects the evolving philosophy to focus on conceptualisation of impact pathways
- regional model updates including refinement of the Horrane and Hutton-Wallumbilla faults based on new geological data, inclusion of coal mines in the regional cumulative impact model, improved calibration and more comprehensive uncertainty analysis
- increasing use of a suite of models instead of relying solely on the regional model, e.g. a separate model developed for the northern coal area, review and adoption of the model developed at New Acland, and the Condamine Alluvium model
- comprehensive modelling of CSG-induced subsidence including development of a 3D geomechanical model for part of the Condamine Alluvium and an analytical model across the Surat Basin
- developing and testing of monitoring methods for subsidence including field surveys, securing of remote-sensing data, and follow-up analysis to identify existing areas of subsidence
- integration of monitoring of groundwater conditions in and around the coal mines
- revision of trend analysis based on up-to-date monitoring data and contextual information.

Some structural changes to the UWIR and supporting assessment are detailed further in section 1.8.

## 1.7 Scientific assessments underpinning the UWIR

Each successive UWIR is supported by a combination of investigation, assessment and research from four broad sources:

- a range of focused and need-driven **in-house scientific assessments** and research by OGIA – e.g. groundwater flow and geological modelling, development of innovative and customised modelling methods, subsidence modelling and monitoring, conceptualisation of impact pathways – particularly the geological faults, evaluation of Condamine Alluvium connectivity, conceptualisation of springs, development of water use estimation methods and application of advanced data science methods
- **tenure holders' assessments** in the Surat Basin, such as Origin Energy's annual groundwater assessments and reinjection studies, assessments by QGC and Santos relating to watercourses and springs, and Arrow's Horrane Fault assessment and Condamine Alluvium connectivity assessment
- **collaborative assessments** by other organisations, such as water measurement, Springbok Sandstone characterisation and seismic data interpretation by the University of Queensland's (UQ) Centre for Natural Gas (UQCNG) and geomechanical modelling by Schlumberger
- **complementary studies** by other organisations, such as UQCNG's Surat Deep Aquifer Appraisal Project and Geoscience Australia's (GA) project on assessing the status of groundwater in the GAB.

A more comprehensive list of the assessments and studies is provided in Appendix B.

## 1.8 Structure of the report

The report is broadly structured in three parts – contextual background on resource development and groundwater assets (Chapters 1 to 3); assessment of impacts (Chapters 4 to 7); and strategies for managing those impacts (Chapters 8 to 14).

A significant amount of data and information continues to be generated in the Surat CMA. There is also an increasing expectation among stakeholders that the UWIR provide specific detail on various elements of the assessment. This poses a considerable reporting challenge for OGIA in maintaining a balance between the overall length and readability of the document, and inclusion of scientific details for a broad spectrum of readers.

To address this challenge, OGIA has taken a new approach in preparing this UWIR. A range of supporting and mutually independent technical reference documents have been prepared and compiled as **companion documents**. These provide additional contextual and technical information on approaches and methods, while only key information and results are included in the UWIR. OGIA intends to progressively update companion documents during UWIR cycles and make them available through an online interface.

## Chapter 2 Existing and proposed resource development in the Surat CMA

### 2.1 Preamble

This chapter provides contextual information about the development activities in the Surat CMA – CSG, conventional oil and gas, and coal mining. It includes production methods, as well as current and proposed production footprints. This information is used in developing conceptual understanding of groundwater impact pathways (Chapter 4) and trends (Chapter 5) and to prepare an **industry development profile**, which is a key input to the regional groundwater flow model for making predictions of impacts.

### 2.2 Terminology

**Target formation** – a general term used to refer to the formation from which CSG or coal is produced – also referred to as the reservoir in some instances.

**Relevant tenures** – all P&G tenures that are either granted (i.e. petroleum leases (PL)) or PLs under application (PLA) and all coal mining tenures that are either granted (mining leases (ML)) or are under application (MLA).

**Authorised tenure holder (ATH)** – a single entity assigned for ongoing dealings in relation to a tenure because tenures are often held by multiple entities and as joint ventures.

**Associated water** – the incidental extraction of groundwater during resource production or extraction processes which, in the Surat CMA, are depressurising of coal measures for CSG production, dewatering of coal seams during coal mining, and conventional oil and gas production.

**Production area** – the part of the PL or PLA where production is occurring or proposed.

**Development profile** – the production footprint with corresponding planned commencement, development sequencing and cessation.

### 2.3 Petroleum and gas (P&G)

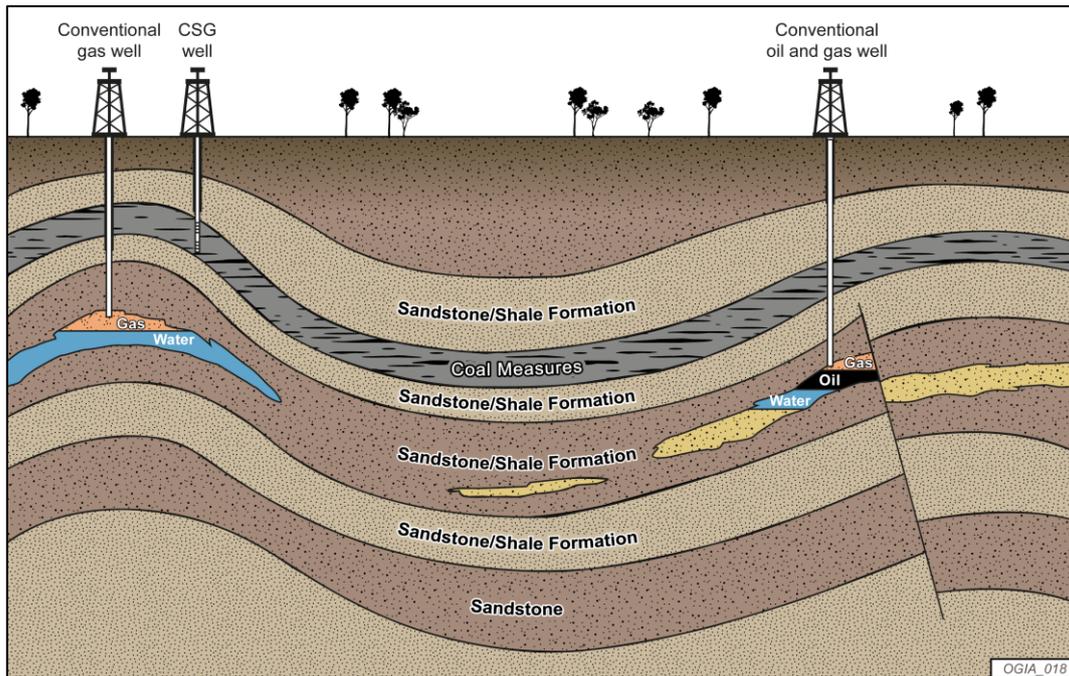
#### 2.3.1 Production methods

P&G is extracted from geological formations using conventional and unconventional methods. Conventional methods involve the direct extraction of P&G residing in porous rock formations, such as sandstone (**conventional oil and gas**). In recent decades, unconventional methods have been developed to extract gas from other formations (**unconventional gas**) including coal formations (CSG), low-porosity rock formations such as shale (shale gas) and low-permeability sandstone/siltstone (tight gas) (Figure 2-1). CSG is typically extracted from relatively shallower depths of 200 to 1000 m, while shale gas and tight gas are extracted from depths of 1,000 to 5,000 m.

In the Surat CMA, conventional oil and gas production dates back to the 1960s and is now approaching end of life. The main oil field is the Moonie field, which accounts for nearly half of total conventional production in the Surat CMA.

Compared to CSG, conventional development requires a relatively small number of production wells, because the gas tends to be localised and can move relatively easily through the porous rock towards the well. Although water is extracted along with the gas, it is a by-product and there is no need to

lower groundwater pressure over large areas to produce the gas. The volume of water extracted varies but is generally much less than for CSG.

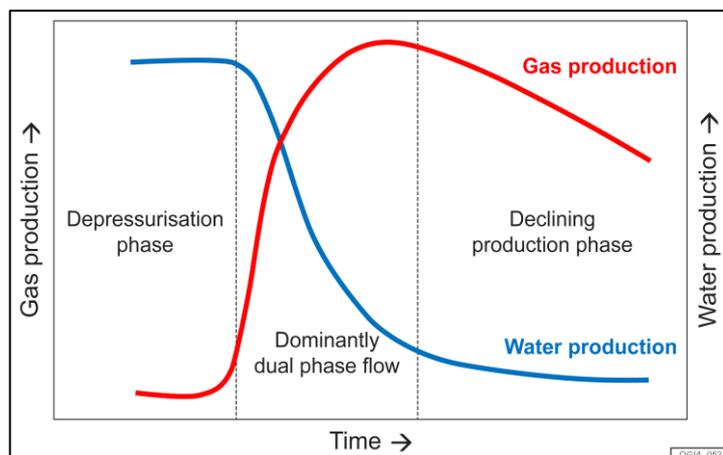


**Figure 2-1: Schematic of oil and gas accumulation types**

CSG is a natural gas attached to the surface of coal particles, along fractures and cleats, and is held in place by groundwater pressure. The gas is extracted by drilling a well into the coal formation and extracting groundwater to depressurise the formation. To produce gas, the groundwater pressure in the well is reduced to 35–120 psi, which is equivalent to 25–80 metres head of water.

Once the desired pressure is reached, pumping continues at the rate necessary to maintain the pressure, until gas production becomes uneconomical. Initially, as shown in Figure 2-2, groundwater alone is extracted; as the pressure drops, more and more gas is released and extracted together with water, leading to an increasing ratio of gas to water over time. The flow of water and gas together is known as ‘dual-phase flow’ (Morad, Mireault & Dean 2008).

In the context of groundwater, there are some fundamental differences between conventional and unconventional methods:



**Figure 2-2: Typical gas and water flow profile during CSG production**

- The volume of associated water extracted using conventional production methods is much less than the volume of water extracted during CSG production.
- Unlike in the conventional reservoirs, CSG is distributed over a relatively large area and requires a large number of production wells to extract gas.

- In the life of a CSG production well, water extraction peaks early, while for conventional production, water extraction increases over time before declining again in mature stages of development.

### 2.3.2 P&G tenures

The Queensland P&G Acts specify authorities that can be granted for activities related to P&G exploration and production. The authorities relevant to this report are those that provide associated water rights to the tenure holders: the authority to prospect (ATP) and the authority to operate a petroleum lease (PL). These authorities are referred to collectively in this report as **petroleum tenures**. Petroleum tenures provide rights in relation to gas and other petroleum products, such as oil. The use of the tenure is usually constrained by the EAs granted under Queensland's EP Act or by the development plans for the tenure approved under the P&G Acts.

The entities that hold petroleum tenures are referred to as **petroleum tenure holders**. As tenures are often held as joint ventures, a single entity is assigned as the **authorised tenure holder** when the tenure is granted. The authorised holder is the primary contact for the petroleum tenure and is legally responsible for dealing with served notices and other documents. All references to tenure holders in this report refer to the authorised holders.

Close to 20% of the CMA is covered by ATPs that have little or no activity in relation to water extraction. Therefore, in the context of this report, the term **relevant tenures** is used to refer to all tenures that are either granted PLs or PLs under application (PLAs). PLAs are relevant because they reflect parts of ATPs where tenure holders have intention to produce and where they have applied for EAs.

The distribution of relevant tenures is shown in Figure 2-3. For reference purposes, also shown are ATPs where environmental approval processes are completed, underway or intended. The relevant tenures are grouped in different colours to represent authorised tenure holders:

- AGL, its subsidiaries and joint venture partners (collectively referred to as AGL)
- Armour Energy, its subsidiaries and joint venture partners (collectively referred to as Armour)
- Arrow Energy, its subsidiaries and joint venture partners (collectively referred to as Arrow)
- Bridgeport Energy, its subsidiaries and joint venture partners (collectively referred to as Bridgeport)
- Origin Energy, its subsidiaries and joint venture partners including Australia Pacific LNG (collectively referred to as Origin)
- Queensland Gas Company, its subsidiaries and joint venture partners (collectively referred to as QGC)
- Santos, its subsidiaries and joint venture partners (collectively referred to as Santos)
- Senex Energy, its subsidiaries and joint venture partners (collectively referred to as Senex)
- other authorised holders.

Some tenure transactions have occurred in the Surat CMA since 2019. Most notable is Tri-Star Pty Ltd becoming the authorised tenure holder for the tenures collectively known as Gilbert Gully, located southwest of Cecil Plains.

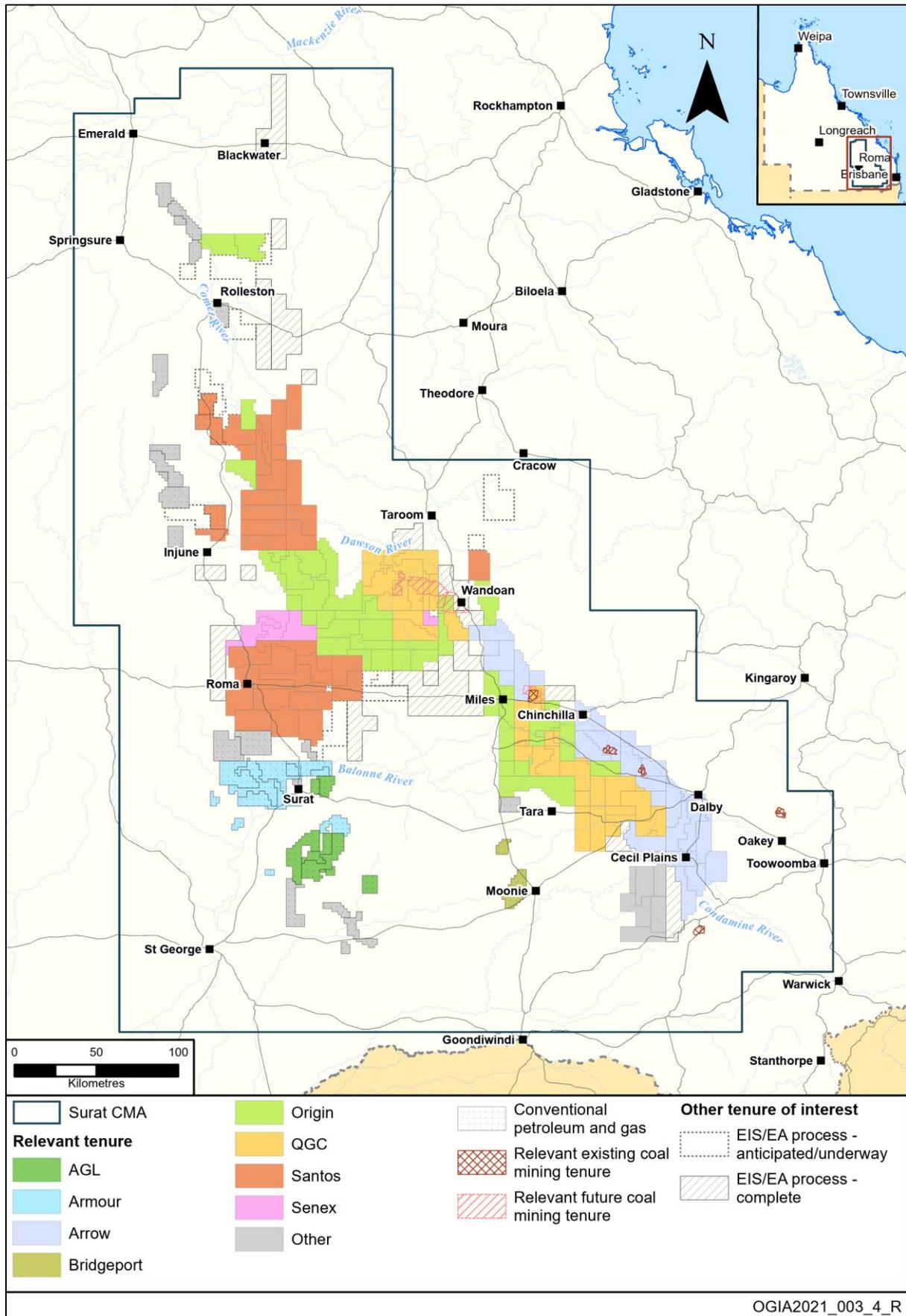


Figure 2-3: Distribution of relevant tenures and authorised tenure holders in the Surat CMA

The Department of Resources (DoR) records all mining and petroleum tenure information in MyMinesOnline, which is the system used to administer resource authorities in Queensland and used by resource authority holders to apply for, and manage, their tenure authorities. The Geological Survey of Queensland (GSQ) recently launched its Open Data Portal that now provides a single point of access for all data relating to tenures and geoscience that is primarily required to be submitted by tenure holders. The portal replaces previous systems such as the Queensland Digital Exploration (QDEX) Data system and the Mineral and Energy Resources Location Information Network (MERLIN). DoR has also established GeoResGlobe for searching and displaying the available data from the GSQ Open Data Portal and MyMinesOnline.

### 2.3.3 Production footprints and scheduling

A tenure area may be utilised by the tenure holder for production purposes and/or gas field development infrastructure. A tenure holder's plan for developing production fields in a tenure may vary over time due to emerging information about reservoir dynamics, availability of reserves and changing market conditions. Those changes to plans may affect the proposed development footprint, as well as the timing of production commencement and cessation. Typically, about 50 to 70% of the total tenure area is used for production purposes as some parts of a tenure may never be developed. The areas where production occurs at some stage is important in assessing the impact of development on groundwater resources. In the context of this report, the part of the PL or PLA where production is occurring or proposed is referred to as the **production area**. The production footprint – with associated planned commencement, development sequencing and cessation – is collectively referred to as the **development profile**.

On an annual basis, OGIA compiles a whole-of-life cumulative industry development profile based on information received directly from tenure holders and verified information available to DoR through various reporting arrangements. The development profile is used as the input scenario for the regional groundwater flow model for impact predictions and development of various impact-management strategies. The development profile used in this UWIR is based on information available as at late 2020 and is shown in Figure 2-4 as footprints where production was occurring at the time (shown in blue), and planned CSG production areas where production is proposed at any time in the future (gold). It also shows where active conventional oil and gas production is still occurring (brown). For comparison, the development profile as of 2018 (provided in the previous UWIR 2019) is also shown. More details are provided in Appendix C and in a separate companion document (OGIA 2021c).

The changes to the development profile since the UWIR 2019, in terms of both the CSG production footprint and planned timing of commencement, are shown in Figure 2-5. Key changes are as follows:

- The total production area (existing and planned) has increased by 8% to approximately 15,000 km<sup>2</sup> but remains within the scope of the approved plans – about 50% of the relevant tenure area.
- The total area that is in production ('existing CSG production area') has increased by 14%, as seen in areas between Dalby and Miles and east of Roma.
- The expansion of the planned CSG production area includes Origin's new Mahalo gas field, the reintroduction of Origin's Ironbark gas field, Santos's expansion for Arcadia and Arcadia West gas fields, and new area for the Arcadia field east of Rolleston.
- Senex's planned production schedule has undergone major change as the Rhea, Dione, Phoebe and Pandora gas fields have all been rescheduled to later commencement.

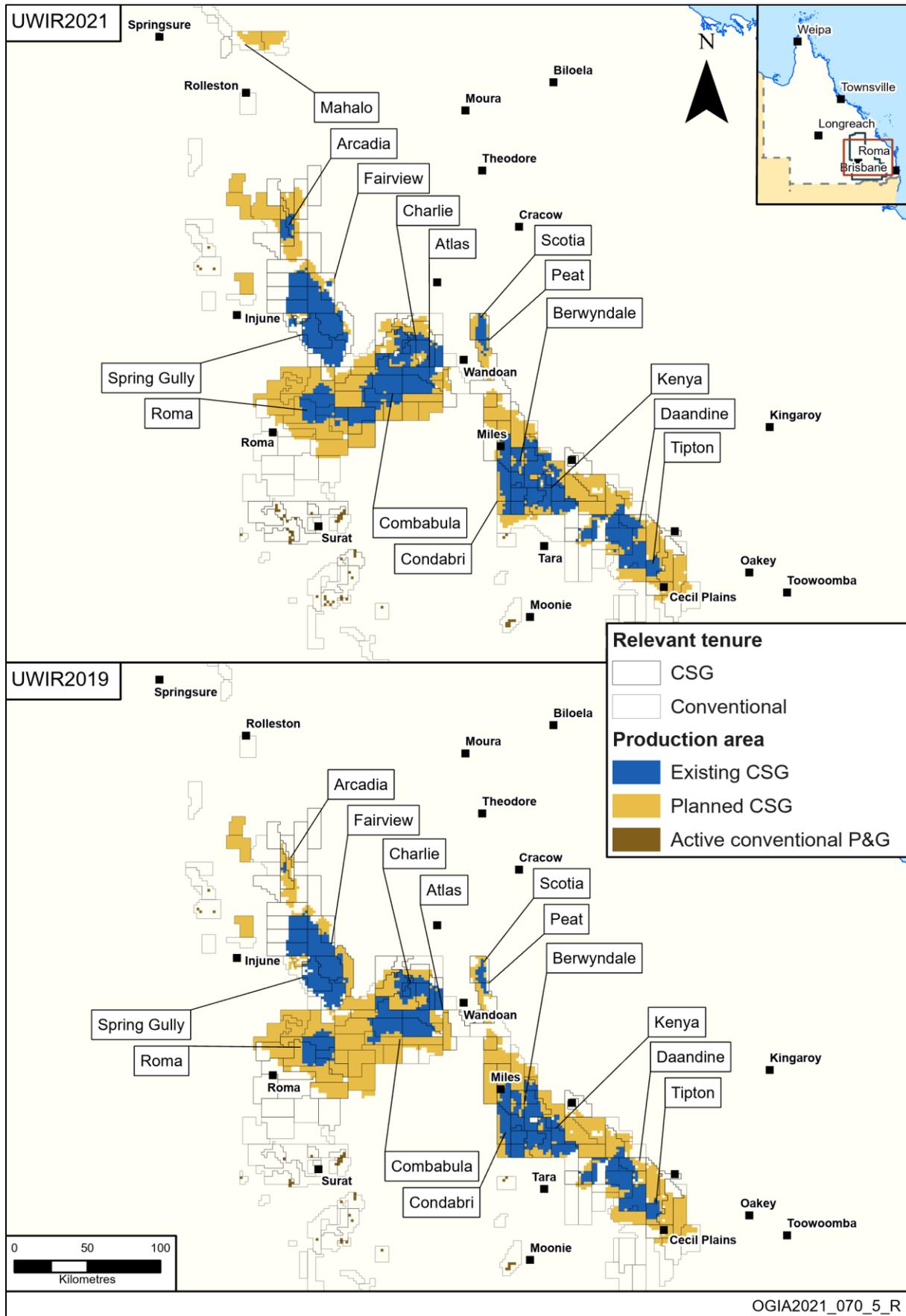
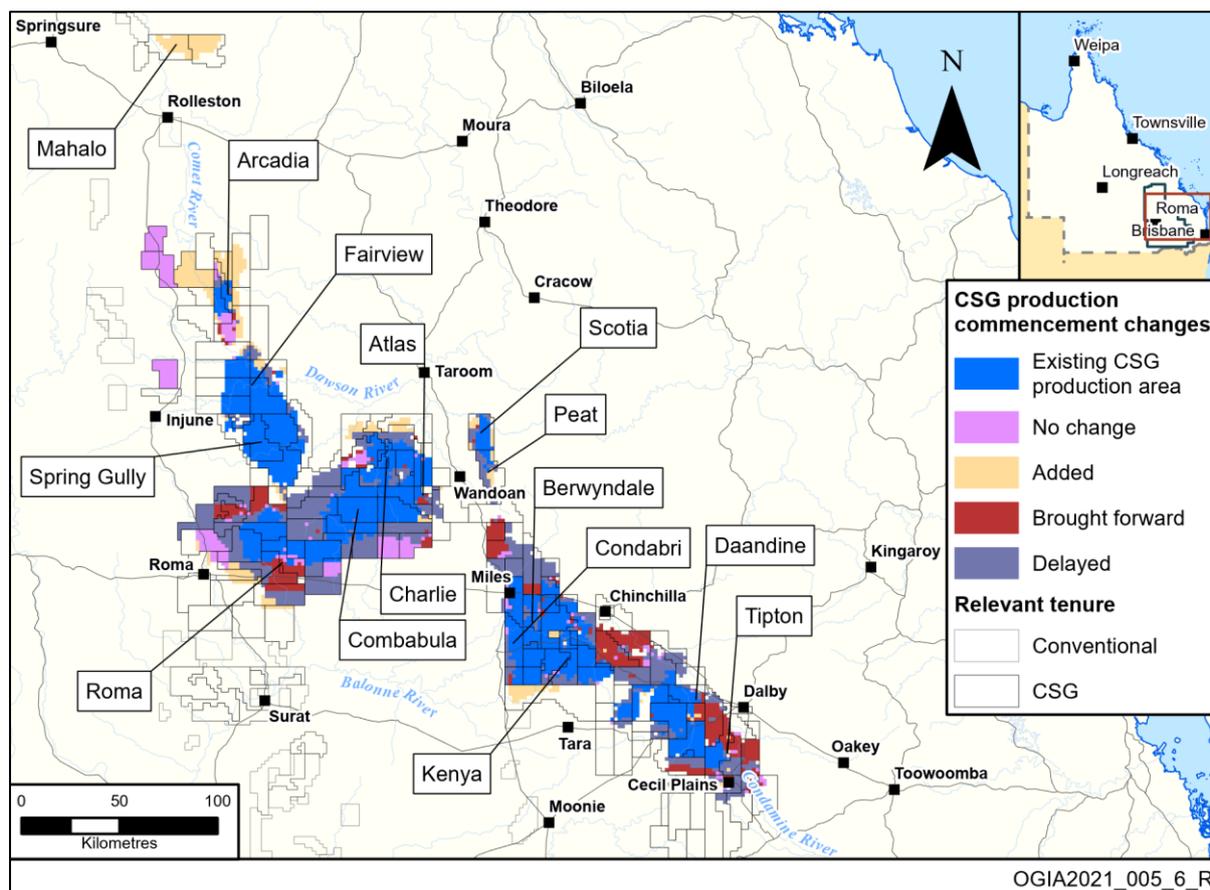


Figure 2-4: Distribution of production areas and their status (2020 and 2018)

- Development between Dalby and Cecil Plains has generally been brought forward, as has planned development south of Chinchilla while development area located north of Miles has generally been scheduled later, except for the northernmost part of this gas field which has been brought forward by up to 10 years.
- Despite an increase in the planned production area over time, there has been a net slowdown in the rate of development in the shorter term – likely to be in response to current market conditions related to the COVID-19 situation.



**Figure 2-5: Changes in planned commencement timing of production areas from 2018 to 2020**

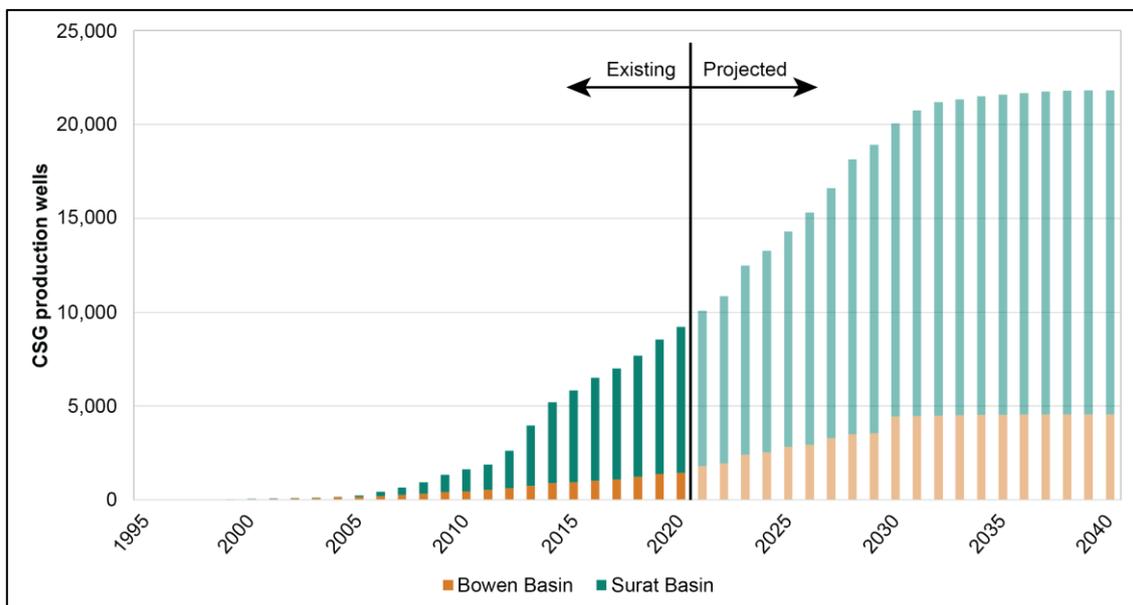
### 2.3.4 Current development trends

The dominant method for P&G production in the Surat and Bowen basins in Queensland is CSG. Conventional production only contributes about one per cent of the total production and is now approaching end of life.

As at the end of 2020, there were approximately 8,600 CSG wells in the Surat CMA that are either currently producing gas or have been completed as production wells and are yet to be brought into production. Of these, 84% are in the Surat Basin and the rest are in the southern Bowen Basin. There are also an additional 500 wells outside CSG production areas constructed for exploration or testing purposes.

The number of CSG wells has increased by about 1,800 wells since the UWIR 2019. With the increase in net production footprint, the total number of projected wells over the life of the industry has also slightly increased by about 5% to approximately 22,000 (Figure 2-6). There are approximately 730 directional or horizontal wells in 352 clusters – 314 in the Bowen Basin and 38 in the Surat Basin.

The average well density is about 1.5 wells per km<sup>2</sup>, although it varies from 1.2 to 1.7 wells per km<sup>2</sup> in the Surat basin, and 0.8 to 1.5 wells per km<sup>2</sup> in the Bowen basin. The average well completion rate is currently about 680 wells per year, substantially less than the peak rate of 1,000 wells per year in the earlier phases (2013 to 2015).



**Figure 2-6: Existing and projected CSG wells in production areas**

The number of P&G wells recorded in the GSQ Open Data Portal may be significantly higher than reported above because the portal includes non-operational, converted and abandoned wells. OGIA infers the type of wells and their status based on contextual information such as their location, depth, tenure types and reported water production.

### 2.3.5 Associated water extraction by CSG and conventional oil and gas

CSG water extraction is metered individually at each well in most instances. As the meters measure a combination of gas and water, there are often additional steps to calculate or calibrate the water-only component of the reading. Monthly extraction is reported to OGIA under the water monitoring strategy obligations (Chapter 9).

Total water production from existing CSG wells over time is shown in Figure 2-7, where the volumes are shown as rates in megalitres per year (ML/year), as derived from monthly volumes submitted to OGIA. There has been a significant increase in associated water extraction since 2014 to around 54,000 ML/year over the past three years. Overall, since 2016, the extraction rate has been progressively declining from a peak of around 67,000 ML/year – partially due to reduction in extracted water over time from existing wells and infilling of new wells in areas where partial depressurisation has already occurred. The majority (45,000 ML/year) of extracted water is in the Surat Basin. CSG water extraction in the Bowen Basin has remained relatively stable in recent years, at around 9,000 ML/year.

The spatial distribution of CSG water extraction in 2020 by tenure is also presented in Figure 2-8. This shows that the largest associated water extraction occurs from the Fairview, Talinga, Daandine, Kenya and Berwyndale gas fields (see Figure 2-4 for locations).

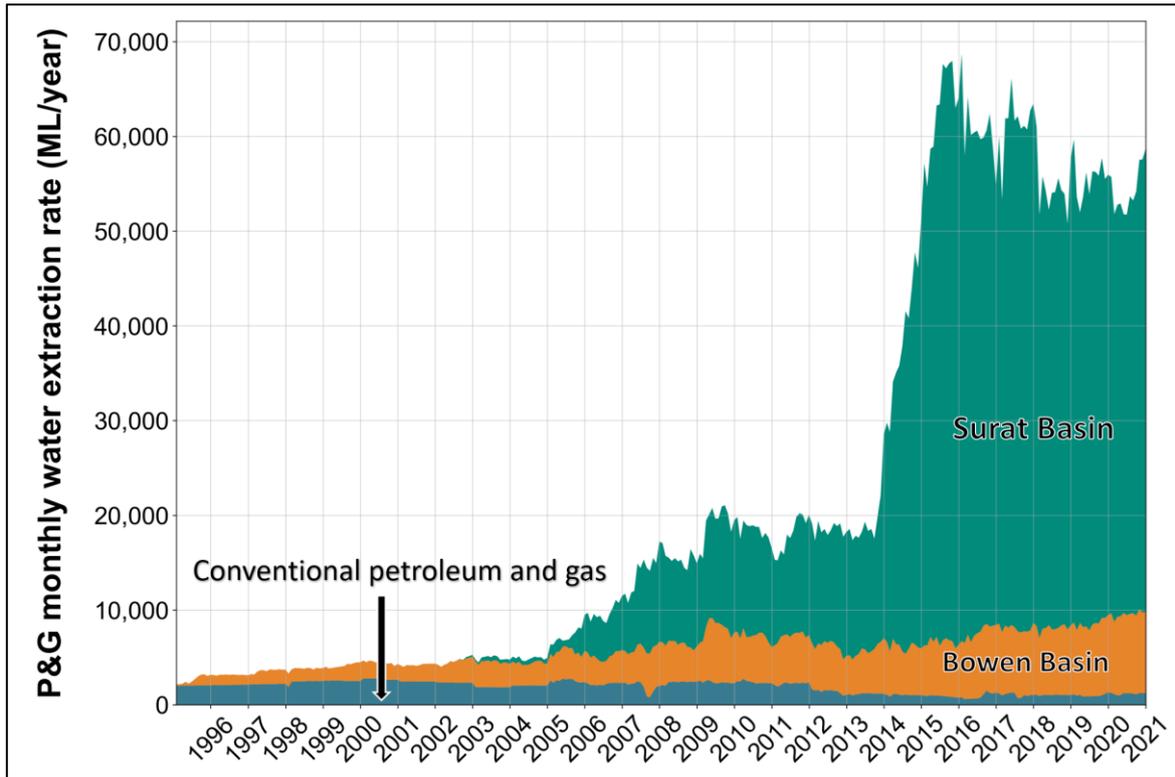


Figure 2-7: Historical associated water extraction by the P&G tenure holders in the Surat CMA

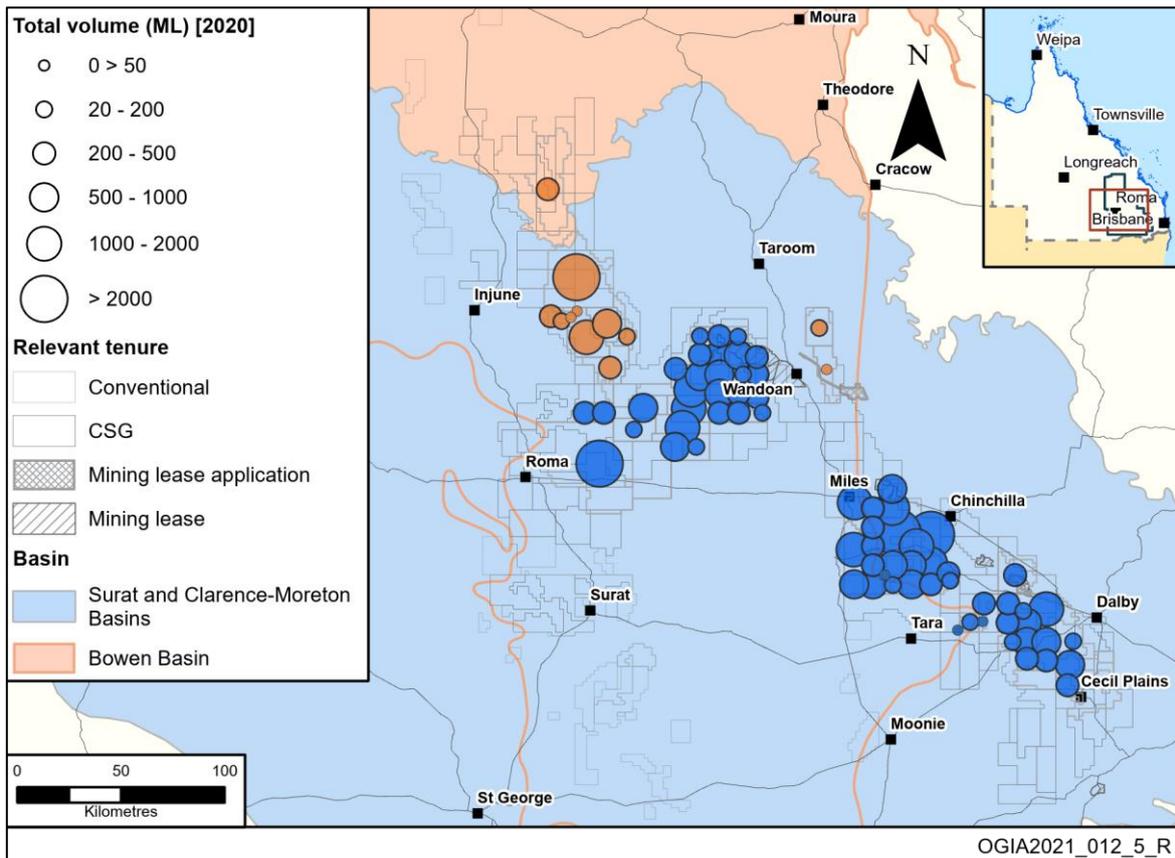


Figure 2-8: Spatial distribution of CSG water extraction

Conventional oil and gas production in the Surat CMA is in a mature phase, with water extraction declining significantly since 2011 to the current level of around 1,000 ML/year, corresponding with

declining oil production. About 95 per cent of conventional associated water extraction is from the Precipice Sandstone and Evergreen Formation in the Moonie oil field. There is also some minor extraction from the Clematis Sandstone.

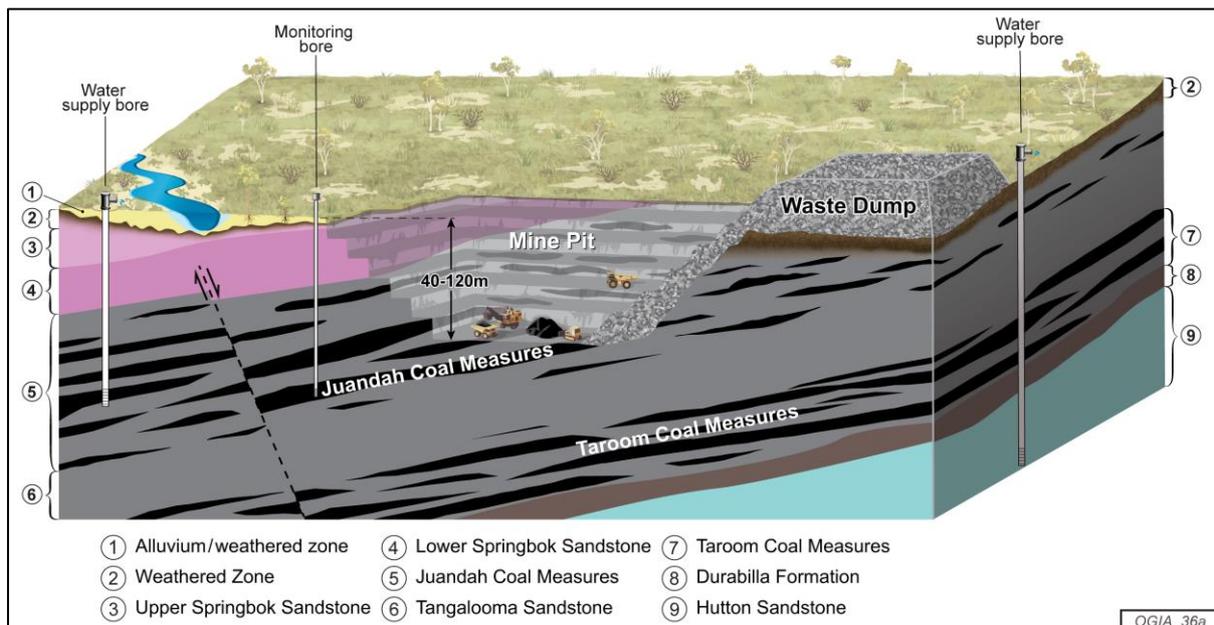
## 2.4 Coal mining

### 2.4.1 Mining methods in the Surat Basin

All existing and proposed coal mining operations in the Surat Basin are open-cut, which involves physical removal of overburden for direct access to coal seams (Figure 2-9). An open pit is normally commenced through excavation of a small pit where the coal seams are accessible at a shallow depth. The open pit is then progressively developed (as a box cut) first along the strike of the target formation, and then along the dip of the formation to access deeper coal seams. A typical open pit develops a series of benches as the depth of excavation increases.

Open pits are often developed below the water table, which results in the lowering of the groundwater level adjacent to the pit and consequential groundwater seepage into the pit. Groundwater seepage collected in the open pit is diverted via drains into artificial in-pit sumps in the first instance and then pumped out to the surface. Surface water and watercourses are diverted where necessary to avoid inflow of water to the open pit during rain events. Rainfall and run-off that occurs within the open pit and pit catchment is usually directed to the in-pit sump.

This groundwater seepage and incidental rainfall must be removed for safe operation of the mine – a process referred to as **dewatering**. In other provinces outside the Surat Basin where higher groundwater inflows need to be controlled, more proactive systems are required, such as dedicated dewatering bore fields, or the inclusion of vertical barriers to prevent excess water entering in the mine void. In the Surat Basin, groundwater seepage to the open pits is low and hence only in-pit sump pumping is used to manage dewatering.



**Figure 2-9: Schematic showing typical profile of an open-cut coal mine development**

The active mining phase for an open pit usually ranges from 5 to 30 years. Waste rock, known as ‘spoil’ or ‘overburden’, is initially dumped ‘out of pit’ in waste rock dumps until a sufficient pit area has been excavated to enable in-pit dumping (Liang, Ren & Ningbo 2017). At the end of the mining

operations, part of the open pit is left unfilled; this is usually referred to as the 'final void'. The shape and depth of the final void is based on several factors, including the economics of material handling, surface hydrology, topography, depth to water table, and other environmental factors.

### 2.4.2 Mining tenures

Authorities relating to the exploration and development of mines for extraction of minerals and coal are managed through the *Queensland Mineral Resources Act 1989* (the MR Act). Exploration permits (EP) are issued for five-year terms and allow for the assessment of the quantity and quality of coal resources. A Mineral Development Licence (MDL) is granted to allow tenure holders to evaluate the development potential of the defined resource. A Mining Lease (ML) allows for conducting larger scale mining operations. An appropriate EA is required before an ML can be granted.

### 2.4.3 Existing and proposed coal mines

There are eight existing and proposed open-cut coal mines in the Surat Basin (Figure 2-10) targeting coal seams in the Walloon Coal Measures. Four mines (New Acland (Stages 1 and 2), Cameby Downs, Kogan Creek and Commodore) are operational, one (Wilkie Creek) is currently closed. Extension is proposed for two existing mines (New Acland (Stage 3) and Cameby Downs), while approvals are in place, or under consideration, for the establishment of three new mines (Wandoan Coal Project, Elimatta and The Range). Key attributes of these mines are presented in Table 2. Further details on coal mines in the Surat Basin are also provided in a separate companion document (OGIA 2021d).

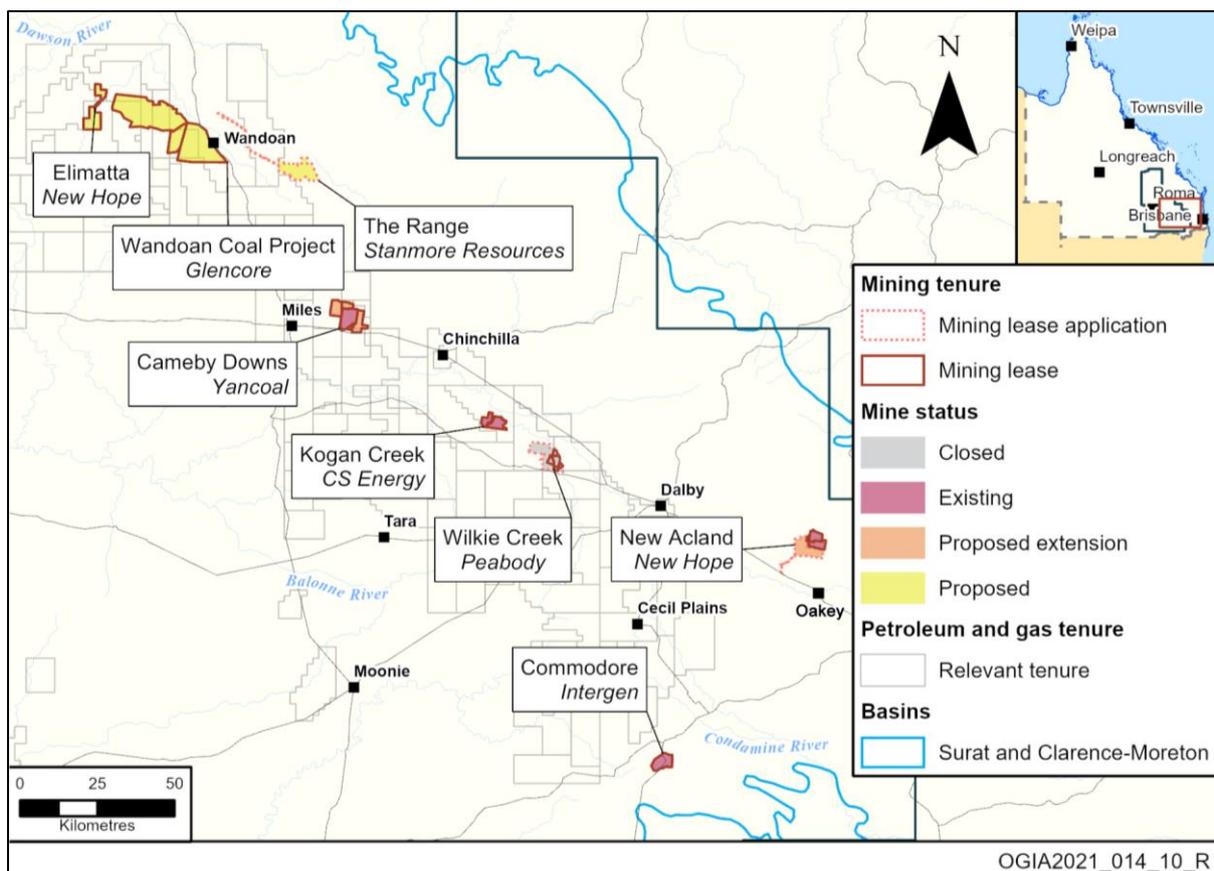


Figure 2-10: Location of coal mines in the Surat Basin

**Table 2-1: Status and key attributes of coal mines in the Surat Basin**

Mine	Status	Start–end	Target seam	Excavated overburden	Pit depth* (m)	
Wandoan Coal Project (Glencore)	proposed	2024–2056	Juandah CM (Kogan to Wambo)	Alluvium, Springbok Sandstone	24–60	
Elimatta New Hope (New Hope Group)	proposed	2029–2058	Juandah CM (Kogan to Wambo)	Alluvium, Springbok Sandstone	50–150	
The Range (Stanmore Resources)	proposed	2027–2051	Tangalooma Sandstone		20–120	
Cameby Downs (Yancoal)	operational	2009–2092	Upper Juandah CM (Kogan, Macalister and Nangram)	Springbok Sandstone	40–110	
Kogan Creek (CS Energy)	operational	2000–2040	Upper Juandah CM (Macalister and Nangram)		40–60	
Wilkie Creek (Peabody)	currently closed	1995–2015	Upper Juandah CM (Macalister)		30–60	
New Acland (New Hope Group)	Stages 1 & 2	operational	2001–2022	Taroom CM (Acland-Sabine, Waipanna and Balgowan)	Main Range Volcanics	30–60
	Stage 3	proposed	2022–2033	Taroom CM (Acland-Sabine)	Main Range Volcanics	35–55
Commodore (Queensland Power Company)	operational	2001–2037	Taroom CM (Commodore)	Alluvium	15–50	

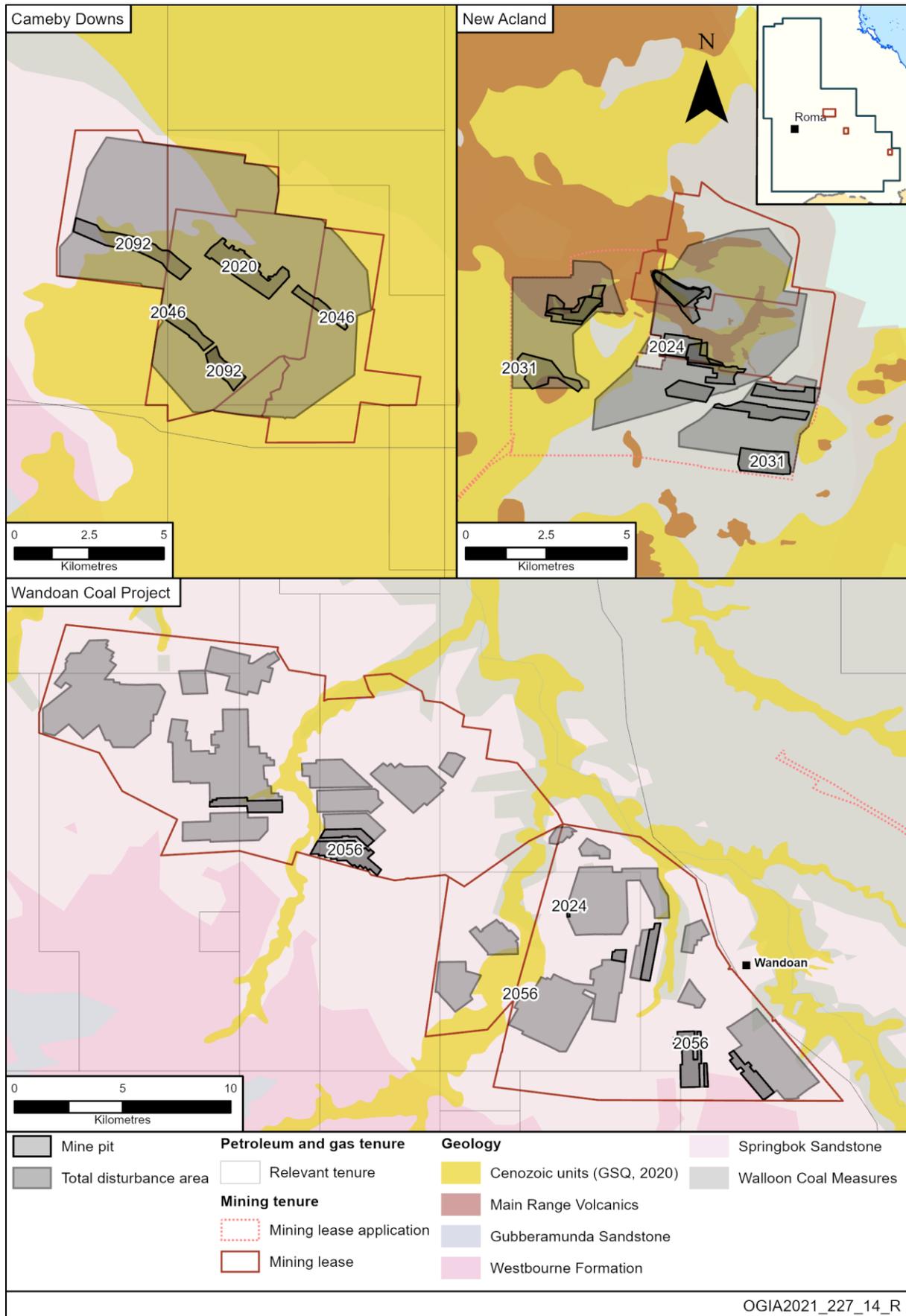
**Notes:**

CM = coal measures; \*estimated

Open-cut mining methods are employed because at the current level of development, coal mining in the Surat Basin is confined to areas where the Walloon Coal Measures is within 100 metres of the ground surface. The target coal seams for mining in the Surat Basin are within two subdivisions of the Walloon Coal Measures – the Juandah Coal Measures and Taroom Coal Measures. CSG extraction targets these same formations, although CSG development generally occurs at greater depths.

Mining operators continuously revise scheduling of pit progression based on the available coal resources and its quality, geotechnical considerations, necessary regulatory approval, operating costs, market factors, as well as engineering and logistical considerations. The plans are therefore dynamic and often subject to change. Scheduling of mine progression, excavation depths, backfilling and the final void provide a critical set of information for the purpose of assessing groundwater impacts, as it not only affects the extent of impacts but also the timing of those impacts.

For the UWIR 2021, up-to-date information was sought directly by OGIA from coal mining tenure holders and interpolated to provide an annual pit progression. As an example, Figure 2-11 shows the current and end of life mine plan for three mines – the Wandoan Coal Project, Cameby Downs and New Acland – noting that there is uncertainty around approvals relating to New Acland Stage 3.



**Figure 2-11: Mine development plans – Cameby Downs, New Acland and Wandoan Coal Project**

## 2.4.4 Associated water extraction by coal mines

Coal mining operations in the Surat Basin generally require minimal active dewatering. As detailed in the previous chapter, groundwater seepage, together with rainfall into the mine pits, is extracted by in-pit sump pumping.

A legislative requirement to report the annual take of associated water by coal mines was established in 2016. Considering mining practices and the practical difficulties in measuring dewatering volumes, guideline material was made available to assist resource tenure holders to estimate and report the volume of associated water (DNRME 2020) – comprising a water balance method, a numerical groundwater flow method and an analytical groundwater flow method.

OGIA compiled reported volumes for the four operational coal mines in the Surat Basin – Cameby Downs, Commodore, Kogan Creek and New Acland. OGIA also estimated associated water volumes using an analytical equation and historical mine pit areas, to verify reported volumes and modelled estimates. The results suggest that the total associated water use by coal mines in the Surat Basin in 2020 is less than 1,000 megalitres, which is less than two per cent of the total associated water extraction in the Surat Basin. Additional information on this assessment is available in OGIA (2021f).

## 2.5 Comparison between CSG operations and coal mining

Two fundamental differences that significantly influence the propagation of groundwater impacts are the resource extraction method and relative scale of operations. CSG extraction does not require the physical removal of formation material and relies upon large-scale depressurisation to extract the gas resource.

In comparison, coal mining requires the physical extraction of material (through open-pit development) at a much smaller scale, and depressurisation is limited by the relatively shallow depth of open cut pits. The volume of associated groundwater take during coal mining in the Surat Basin is therefore orders of magnitude smaller in comparison to CSG production. This results in an isolated and smaller impact footprint from coal mines. A summary of differences is presented in Table 2-2.

**Table 2-2: Differences between the coal mining and CSG development in the Surat Basin**

Element	Coal mining	CSG
Method	Excavation of overburden and coal seams through open pits	No excavation; resource extraction through gas wells
Development area and impact footprint	Local scale; largely isolated mines with little or no overlap of impacts	Sub-regional scale; connected gas fields with overlapping impacts
Associated water extraction	Dewatering of open pits and desaturation of surrounding coal seams for safe operation	Depressurisation to release gas; coal measures generally saturated
Aquifer conditions	Unconfined near the open pit; pit depths <100 mbgl	Confined; well depths range from 80 to 800 mbgl
Drawdown (m)	<100	>500
Impact pathway	Mainly lateral	Lateral and vertical
Associated water extraction	Low volume; passive drainage (in-pit sump pumping)	High volume during active depressurisation

Notes: mbgl = metres below ground level

## 2.6 Summary of existing and proposed development

- CSG is the dominant, and expanding, resource development activity in the Surat Basin from five major operators – QGC, Santos, Origin, Arrow and Senex.
- The existing and proposed production footprint has increased by about 8% compared to the previous UWIR but remains within the existing approvals.
- As at the end of 2020, there are approximately 8,600 CSG wells in the Surat CMA. This is likely to increase to 22,000 based on the current plans of approved development – about 5% higher than reported in the previous UWIR.
- There has been a significant increase in associated water extraction by CSG since 2014, to the current level of around 54,000 ML/year from about 8,600 wells.
- The majority (45,000 ML/year) of associated water extraction has been in the Surat Basin, while in the Bowen Basin it has remained relatively stable in recent years at about 9,000 ML/year.
- There are eight existing and proposed open cut mines coal mines in the Surat Basin with a footprint of less than two per cent of the CSG footprint.
- Four mines are operational – New Acland (Stages 1 and 2), Cameby Downs, Kogan Creek and Commodore – while another coal mine, Wilkie Creek, is currently closed. Extension of two existing mines – New Acland Stage 3 and Cameby Downs – is also under consideration and approvals are in place for the establishment of two large new coal mines – Wandoan Coal Project and Elimatta. Approval for The Range mine is under consideration.
- Total associated water extraction by coal mines in the Surat Basin in 2020 has been less than 1,000 ML/year, which is less than two per cent of the overall associated water extraction in the Surat Basin.
- OGIA has compiled information about the CSG and coal mining development footprint and timing for existing as well as proposed development. This information is used as input to the regional groundwater flow model to predict impacts and analysis of groundwater trends.

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## Chapter 3 Water bores and groundwater use

### 3.1 Preamble

This chapter provides a summary of water bores and groundwater extraction from those water bores for consumptive purposes in the Surat CMA. Information about water bores – such as their location, construction details, source aquifers and estimated groundwater use – supports the impact assessment in this report. This information is used in conceptualising pathways for groundwater impact (Chapter 4), calibration of the groundwater flow model (Chapter 6), identification of water bores likely to be impacted (Chapter 8) and development of a water monitoring strategy (WMS) (Chapter 9).

Section 3.3 provides details about water bores and their distribution in the Surat CMA. The subsequent sections describe groundwater use. Associated water extraction by the resource industry is provided in the previous chapter.

### 3.2 Terminology

**Groundwater use** – groundwater taken under a statutory authorisation, water licence or entitlement managed through Chapter 2 of the Water Act – e.g. agricultural, irrigation, industrial, town water supply and stock and domestic (S&D) purposes.

**Non-associated groundwater use** – the extraction of groundwater by resource tenure holders for consumptive purposes which now require water licences under Chapter 2 of the Water Act – e.g. for camp water supply, road construction, etc.

**Aquifer attribution** – an interpretation of the aquifer (or aquifers) from which a water bore may be accessing water.

### 3.3 Water bores

#### 3.3.1 Information about water bores

Information about a water bore's location, depth and construction is recorded by the water bore driller at the time of drilling and supplied, as required under their driller licence, to the bore owner and to the Department of Regional Development, Manufacturing and Water (DRDMW). The data is recorded in the DRDMW groundwater database (GWDB), which is Queensland's primary repository for water bore information.

Since the introduction of the underground water management framework in the Water Act, baseline and bore assessments (section 8.4.2) of potentially affected water bores have been progressively undertaken by resource tenure holders (refer to Chapter 8 for details on bore baseline assessment, bore assessment and its linkages to make good). Data and the outcomes from these assessments are provided to the bore owners and OGIA. In addition, bore data is also collected as part of various hydrogeological investigations by OGIA and the resource tenure holders, and is progressively updated in the GWDB as relevant.

#### 3.3.2 Verification of water bore information

In preparing the UWIR, OGIA initially compiles information about water bores from the GWDB, baseline assessments and bore assessments. Where there is ambiguity, OGIA cross-verifies this information through a desktop assessment and aerial photograph analysis, as well as field

investigations and discussions with bore owners where necessary. Bore identifiers – registered numbers (RN) – are matched with verified bore locations, source aquifers (section 3.3.4) and bore status. Given the large number of water bores in the Surat CMA, the level of effort in verifying the information is prioritised based on a bore’s proximity to existing and planned resource development. For example, priority is given to water bores that are located closer to CSG production areas and likely to be impacted sooner. The verified information is also progressively updated in the GWDB.

### 3.3.3 Tracking of physical status of a water bore

The status of water bores are recorded in the GWDB as either ‘existing (EX)’, ‘abandoned and destroyed (AD)’ or ‘abandoned but usable (AU)’. The physical status of a water bore may change over time but the status recorded in the GWDB may not be updated because there is no specific requirement for bore owners to provide updated bore status information to DRDMW. More contemporary bore status information may also be recorded elsewhere, such as DRDMW’s Water Management System (licensing and development permit database), decommissioning information provided by resource tenure holders directly to OGIA from their make good arrangements, and in some instances, from fields visits and verbal verification by OGIA.

Multiple sources of bore status information can lead to inconsistencies. OGIA has therefore developed a set of criteria and workflow to reconcile bore status information and determine the most contemporary status of a water bore for the purpose of the UWIR. This is important because a bore’s physical and legal status affects its eligibility for the follow-up make good arrangements that are described in Chapter 8. Some key criteria are listed below:

- Water bores with no status information available are taken to be in existence.
- Water bores with decommissioning information are taken to be abandoned.
- Water bore status recorded in a bore assessment is taken to be the most up-to-date status.
- The latest recorded status in the GWDB is adopted where no other status information is available.
- Where there is an inconsistency between a bore’s status in the GWDB and the baseline assessment, the latest reported status is taken to be the most up-to-date status.
- Where a bore is reported as ‘could not be found’ during a baseline or bore assessment, and the bore is a priority bore with respect to anticipated impacts, OGIA undertakes further desktop and verbal verification with the bore owner (where possible).

### 3.3.4 Attributing source aquifers to water bores

Identifying the aquifer tapped or sourced by a water bore is critical information required to support the assessment in the UWIR. It is used for identifying potentially affected water bores (section 8.5.1), estimating water use for model calibration (section 6.4.4), analysis of groundwater level trends (Chapter 5) and assigning groundwater levels to specific aquifers (section 6.4.4).

The process of aquifer attribution for a water bore is the determination of the aquifer tapped or sourced by a water bore. The process involves the compilation and verification of bore location and construction details to determine the portion of the bore that is ‘screened’ or open (intake depth), then intersecting this with the depths of the geological formations from the geological model at the same location. However, there are significant challenges in implementing this fundamental process, such as uncertainties in recorded bore locations and matching RNs; lack of information on bore depth and

screened depths (in the Surat CMA, there are about 1,100 water bores without recorded depth); and lack of sufficient construction information. In addition, near outcrop areas and along the fringes of the Condamine Alluvium, the boundaries between geological formations may be uncertain, which leads to uncertain aquifer attribution.

Given the large number of water bores – about 29,500 existing and abandoned water bores in the Surat CMA – OGIA has developed a methodology that is largely automated, complemented with a manual site-specific review in specific areas of interest, e.g. where impacts are anticipated in the short term. Assumptions are made where necessary, such as those listed below:

- Where no depth information is available, a bore is assumed to be screened in the aquifer that is frequently intersected by other water bores within five kilometres.
- Where information about the depth is available but not the screened depth, the screened depth is assumed to be the same as other water bores constructed to similar depths and at similar times.
- In areas where the geological model has very limited or no control points, aquifer attribution recorded in the GWDB or licensing information is retained.
- Where the bore is screened or open across multiple formations, the relative transmissivity (a product of intercepted thickness and permeability) of those formations is used to assign the dominant and secondary contributing aquifers.

Aquifer attribution does change over time because of the changes to input datasets, such as corrections to bore records, and the ongoing improvement to the geological model. OGIA's methodology for assigning aquifers has also continued to evolve since the UWIR 2012 to address the limitations of bore data and improvements in underlying information.

### 3.3.5 Distribution of water bores

In the previous UWIRs, the number of water bores was reported for the entire CMA (approximately 22,500 water bores). However, more than half of those are located away from CSG production areas, outside the impact footprint. To provide a more relevant contextual number of water bores, the number of water bores reported in this UWIR are within an **area of interest**. It is an area that captures the entire active resource development footprint and extends further to about 15 km from the development because impacts from development are unlikely to extend beyond this footprint.

Within the area of interest, there are approximately 8,000 water bores. About 4,000 of these access groundwater from the GAB formations (the Surat and Clarence-Moreton sub-basins) and the remaining access water from the Condamine Alluvium and the Main Range Volcanics. There are only about 100 water bores in the Bowen Basin. The distribution of water bores in the Surat CMA is presented in Figure 3-1.

The distribution reflects the availability of reliable groundwater supplies at the shallowest possible depths, and the demand for supplies. The majority of water bores are sub-artesian, meaning that the groundwater level in the bores is below the ground surface. Only a small proportion of water bores in the Surat Basin are recorded as artesian and these tend to be generally located away from CSG production areas.

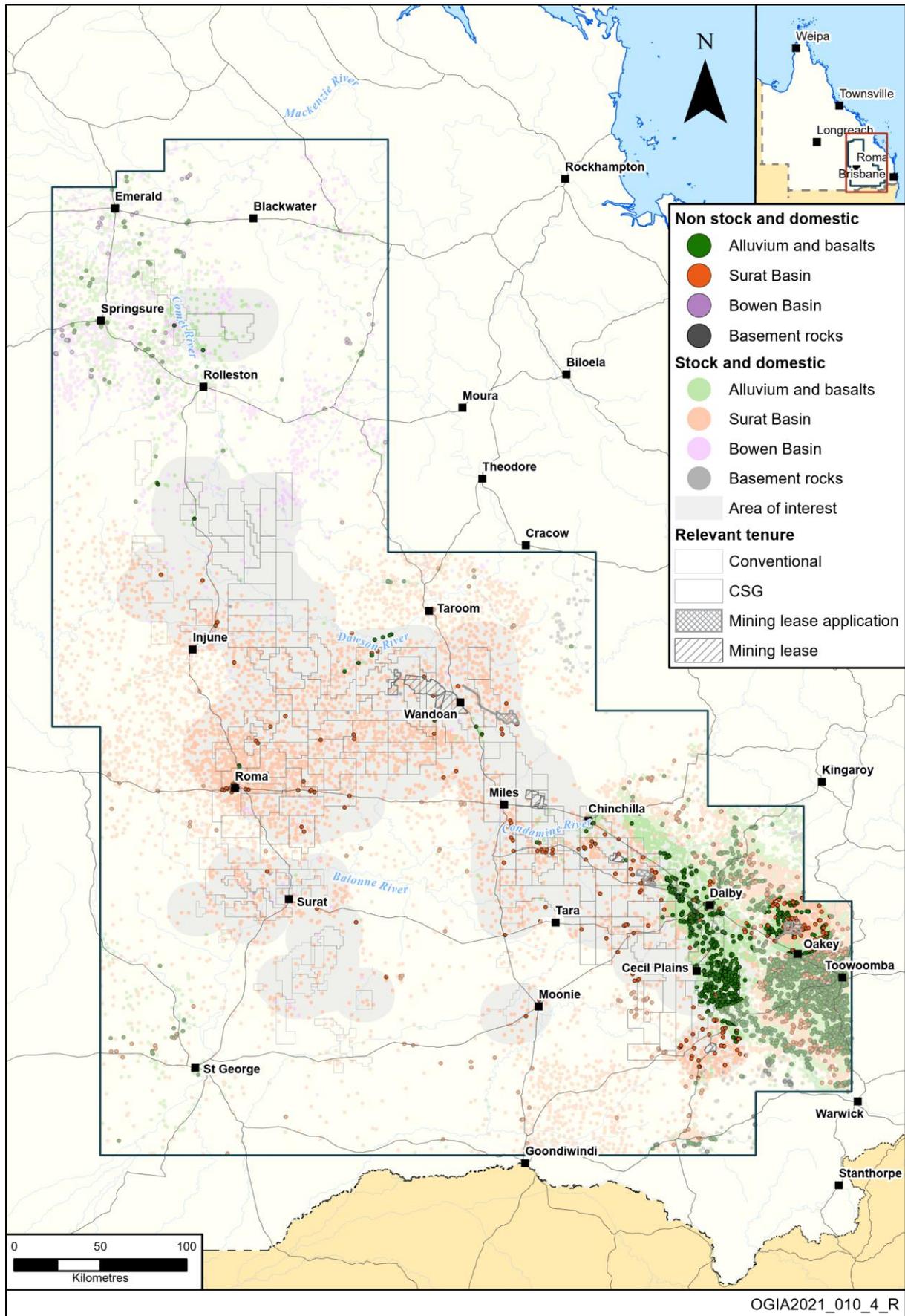


Figure 3-1: Distribution of water bores in the Surat CMA

Water bores in the GAB can be up to 1,000 m deep, although the majority are 200–500 m deep. By contrast, water bores in the alluvium, the Main Range Volcanics and the Bowen Basin are typically less than 200 m deep.

## 3.4 Groundwater use

Groundwater use is a reference to groundwater taken for agricultural, irrigation, industrial, town water supply and S&D purposes. This section provides an overview of the estimated groundwater use in the Surat CMA.

### 3.4.1 Authorisation and reporting

Licensing requirements and the volume of water that can be taken under an authorisation depend upon the purpose and the water resource management objectives for the specific water planning area where the bore is located. Relevant water plans within the Surat CMA are the GAB, Condamine and Balonne, Burnett, and the Border Rivers and Moonie catchments.

The majority of groundwater use in the area of interest is under the water plans for the GAB and Condamine and Balonne where authorisation requirements are as summarised below:

- A water licence is required to take groundwater in the Surat and Bowen basins for all purposes excluding domestic use and stock use in some areas (Eastern Downs sub area).
- Where a water licence is required for S&D purposes, a volumetric limit is not specified on the licence, because take is limited by the stock-carrying capacity.
- For all other purposes, including stock-intensive and town water supply, a water licence is required and includes a specified annual volumetric limit.
- Within the Condamine Alluvium and Main Range Volcanics, water licences are required for all purposes excluding S&D purposes.
- New water bores may only be constructed in accordance with the requirements of relevant water plans.

DRDMW administers the licensing provisions of the Water Act. Information about water licences, authorised volumetric limits and purposes are recorded in DRDMW's Water Management System. In some areas, water bores are metered; this information is also stored and maintained in DRDMW's Water Management System.

### 3.4.2 Estimated groundwater use

#### 3.4.2.1 Approach

The requirement to measure and report groundwater use in the Surat CMA varies – S&D water use does not require metering; for other purposes, there is limited (less than 1% of water bores) metering of water use outside of the Condamine Alluvium and Main Range Volcanics.

In the absence of metering data, indirect methods are required to estimate groundwater use. A method first developed by OGIA in 2012 has since been refined based on additional data and information. Some sporadic metering data is now also becoming available, which has helped in reconciling water use estimates and building uncertainty bounds around the estimates – together with other complementary studies undertaken by UQ in the Surat CMA (Keir et al. 2017), and Klohn Crippen Berger (Kent et al. 2020) to support the GAB water planning process.

For S&D water use, the underlying principle of OGIA's method is that the deficit between the demand for water and the availability of surface water sources is met by groundwater. Demand is estimated based on grazing potential (stock-carrying capacity), property size and climatic variability. Details of the method are provided in Singh et al. (2020).

Non-S&D uses, such as irrigation, town water supply and industrial, have annual volumetric extraction limits (entitlement volume). In those cases, metered data is used where available – such as in the Condamine Alluvium. However, metered data is rarely available in other areas and water use is estimated by applying a percentage to the entitlement volume derived from the available metering data. The data indicates that irrigation, agricultural and town water supply use is generally 70 to 90 per cent of the entitlement volume and industrial use is about 50 per cent of the entitlement volume. Estimates of groundwater use for stock-intensive purposes are based on 90 per cent utilisation of the entitlement.

Estimated volumes for individual water bores are assigned to the aquifers into which the bores are screened (section 3.3.4), which in some cases may be different to the formation identified in a water licence because of the updated information about the water bore.

Where a bore is screened across more than one formation, water use has been distributed to the intersected formations relative to their permeability and intercepted thickness. For example, a water bore screened across the Springbok Sandstone, Walloon Coal Measures and Hutton Sandstone is likely to be accessing most of the water from the Hutton Sandstone, because the permeability is higher in that formation.

In 2020, OGIA commenced a collaborative project with UQ to meter groundwater extraction at about 30 properties across the Surat Basin. This project builds upon an earlier metering project undertaken by UQ. The outcomes of the project will further assist in refining the methodology for estimating groundwater use for both S&D and non-S&D purposes. Ongoing improvements in the estimation of groundwater use will support improved characterisation of the groundwater system and assessment of impacts from resource development.

### **3.4.2.2 Results**

Estimated groundwater use for the area of interest (section 3.3.5) in the Surat CMA is summarised in Table 3-1. Spatial distribution of groundwater use across the Surat Basin is presented in Figure 3-2 and the change in estimated water use over time is presented in Figure 3-3.

There has been a slight increase in the estimates of groundwater use since the previous UWIR. The main changes relate to an increase in the number of property parcels included in the S&D estimate due to the construction of new water bores, refinement of the aquifer attribution for some water bores and more metering data, which has significantly increased the estimate for some formations, such as the Precipice Sandstone.

**Table 3-1: Estimated groundwater use in the area of interest**

Formation	Number of water bores				Water use (ML/year)*				
	S&D	Non-S&D	Non- assoc.	Total	S&D	Non-S&D	Non- assoc.	Total	
<i>Alluvium and basalt</i>									
Cenozoic Sediments	45	2	0	<b>47</b>	69	47	0	<b>116</b>	
Condamine Alluvium	1,903	503	0	<b>2,406</b>	1,784	29,696	0	<b>31,480</b>	
Main Range Volcanics	345	69	1	<b>415</b>	253	1,869	9	<b>2,131</b>	
Other Alluvium	510	46	0	<b>556</b>	2,995	1,780	0	<b>4,775</b>	
Other Basalts	63	2	0	<b>65</b>	69	203	0	<b>272</b>	
<i>Alluvium and basalt subtotal</i>	<i>2,866</i>	<i>622</i>	<i>1</i>	<i><b>3,489</b></i>	<i>5,170</i>	<i>33,595</i>	<i>9</i>	<i><b>38,774</b></i>	
<i>Great Artesian Basin (GAB)</i>									
Upper Cretaceous formations	90	3	0	<b>93</b>	141	153	0	<b>294</b>	
Wallumbilla Formation	35	1	0	<b>36</b>	83	4	0	<b>87</b>	
Bungil Formation	132	2	0	<b>134</b>	297	22	0	<b>319</b>	
Mooga Sandstone	376	4	0	<b>380</b>	625	147	0	<b>772</b>	
Orallo Formation	563	14	0	<b>577</b>	738	952	0	<b>1,690</b>	
Gubberamunda Sandstone	602	40	12	<b>654</b>	787	2,098	325	<b>3,210</b>	
Westbourne Formation	49	1	0	<b>50</b>	76	4	0	<b>80</b>	
Springbok Sandstone	157	6	3	<b>166</b>	190	151	28	<b>369</b>	
Walloon Coal Measures	Upper Juandah Coal Measures	150	8	0	<b>158</b>	179	369	0	<b>547</b>
	Lower Juandah Coal Measures	363	25	0	<b>388</b>	444	525	0	<b>969</b>
	Taroom Coal Measures	218	30	0	<b>248</b>	215	644	0	<b>859</b>
Durabilla Formation	45	1	0	<b>46</b>	42	11	0	<b>53</b>	
Hutton Sandstone	1,101	123	0	<b>1,224</b>	1,611	6,275	0	<b>7,886</b>	
Evergreen Formation	91	3	0	<b>94</b>	247	149	0	<b>396</b>	
Precipice Sandstone	164	15	7	<b>186</b>	299	1,742	184	<b>2,225</b>	
<i>GAB subtotal</i>	<i>4,136</i>	<i>276</i>	<i>22</i>	<i><b>4,434</b></i>	<i>5,974</i>	<i>13,246</i>	<i>537</i>	<i><b>19,757</b></i>	
<i>Bowen Basin</i>									
Moolayember Formation	11	0	0	<b>11</b>	29	0	1	<b>30</b>	
Clematis Group	26	0	0	<b>26</b>	28	0	0	<b>28</b>	
Rewan Group	38	0	0	<b>38</b>	24	0	0	<b>24</b>	
Bandanna Formation	14	0	0	<b>14</b>	27	0	0	<b>27</b>	
Cattle Creek Formation	0	0	0	<b>0</b>	0	0	0	<b>0</b>	
Upper & Lower Permian	12	0	0	<b>12</b>	15	0	0	<b>15</b>	
Metamorphic/ igneous/old basement rocks	11	0	0	<b>11</b>	12	0	0	<b>12</b>	
<i>Bowen Basin subtotal</i>	<i>112</i>	<i>0</i>	<i>0</i>	<i><b>112</b></i>	<i>135</i>	<i>0</i>	<i>1</i>	<i><b>136</b></i>	
<b>TOTAL</b>	<b>7,114</b>	<b>898</b>	<b>23</b>	<b>8,035</b>	<b>11,279</b>	<b>46,841</b>	<b>547</b>	<b>58,667</b>	

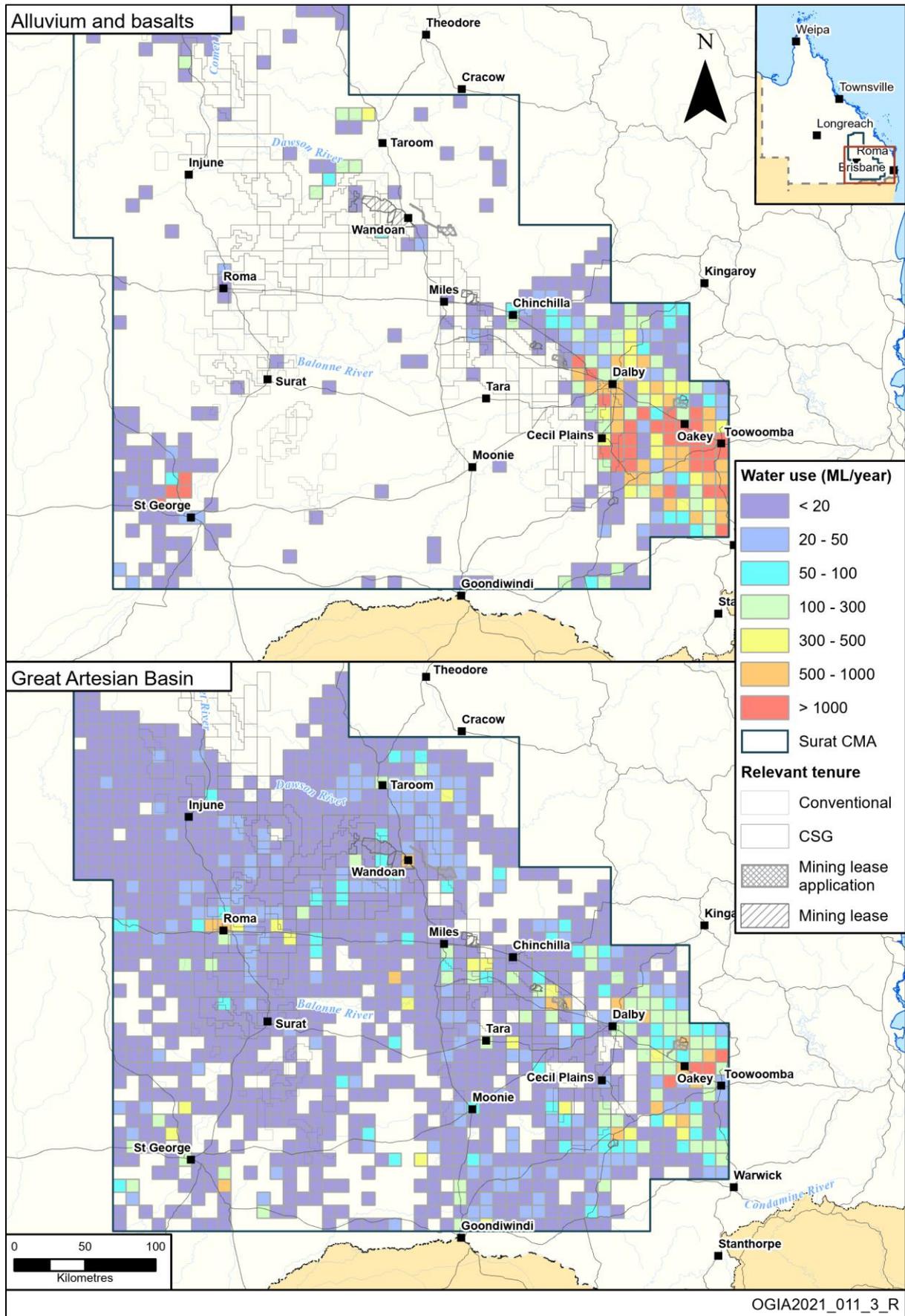
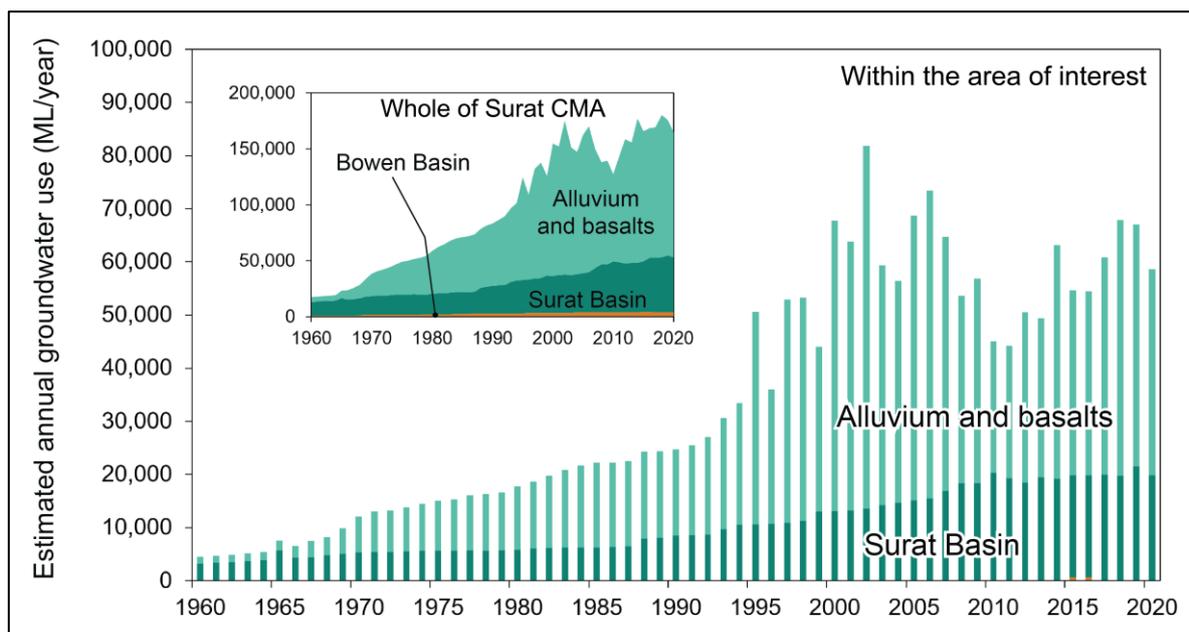


Figure 3-2: Spatial distribution of groundwater use in the Alluvium, Basalt and GAB (at a resolution of 75 km<sup>2</sup>)



**Figure 3-3: Growth in consumptive water use grouped by major groundwater systems**

Some relevant observations from the water use data are as follows:

- The current estimated groundwater use in the area of interest is about 59,000 ML/year, of which about 20,000 ML/year (34%) is from the GAB.
- The Hutton Sandstone is the most developed aquifer in the GAB by water use, followed by the Gubberamunda and Precipice sandstones.
- Although the water quality in the Walloon Coal Measures is not suitable everywhere, it is used as a water source where it is found at shallow depth with adequate water quality.
- Two-thirds of the water use in the GAB is for non-S&D purposes. Similarly, nearly 90% of the groundwater use from the alluvium and basalt is for non-S&D purposes (predominantly irrigation).
- The Precipice Sandstone has the highest average bore yield – about 12 ML/year, which is more than twice that of other GAB aquifers in this area – the Hutton and Gubberamunda sandstones. This is broadly consistent with the permeabilities of these formations relative to other formations.
- The Springbok Sandstone contributes only a very minor proportion of the water use with a very low average bore yield, comparable to aquitards or tight aquifers. This supports OGIA's classification of this formation as a tight aquifer at best (section 1.5.2).
- Estimated water use has been gradually increasing since 1910 but has been stabilising since about 2000. This coincides with the commencement of significant water planning initiatives in Queensland.

### 3.4.3 Groundwater quality

Groundwater quality varies within the major water supply formations. The primary factors influencing groundwater quality are formation mineralogy, proximity to areas where the formation is recharged and groundwater flow dynamics within the formation.

A summary of the groundwater chemistry for the major water supply formations across the Surat CMA is provided in Table 3-2.

**Table 3-2: Median values for key water quality parameters in the target formations and adjacent aquifers in the Surat CMA**

Formation	Samples	Concentration (mg/L)								pH	SAR	
		Calcium	Magnesium	Sodium	Potassium	Chloride	Sulphate	Bicarbonate	TDS			
Condamine Alluvium	4,206	40	32	217	2	200	30	408	867	7.9	7	
Springbok Sandstone	425	11	20	1,100	4	1,600	21	431	1,727	8	41	
Walloon Coal Measures	UJCM	147	29	33	1,840	6.5	3,070	2	397	2,442	8.1	31
	LJCM	46	29	25	605	4	820	19	432	1,952	8	23
	TCM	607	36	89	798	3.3	1,270	156	401	1,380	7.8	14
Hutton Sandstone	1,748	27	14	357	3	400	16	412	1,160	8	14	
Precipice Sandstone	662	3	1	47	2.1	15	1	125	184	7.5	8	
Bandanna Formation	496	14	8	84	12.8	54	4	236	454	7.9	3	

**Notes:**

LJCM = Lower Juandah Coal Measures, SAR = sodium adsorption ratio, TDS = total dissolved solids, TCM = Taroom Coal Measures, UCJM = Upper Juandah Coal Measures

Compared to other formations, those that are sandstone-dominated or permeable – such as the Precipice, Clematis and Hutton sandstones, Condamine Alluvium and Main Range Volcanics – generally contain better groundwater quality. For those formations, TDS tends to be less than 1,000 mg/L and SAR less than 10. For human drinking purposes, a TDS of less than 1,000 mg/L is required, whereas for stock purposes, up to 4,000 mg/L is acceptable.

In terms of the application of groundwater for irrigation, there are three key parameters: pH, TDS and SAR. The usual ranges for these parameters are pH between 6.5 and 8.4, TDS less than 2,000 mg/L and SAR less than 15. Where parameters are above these ranges, irrigation application would be detrimental for the majority of crops (Dewis, Freitas & others 1970).

### 3.5 Non-associated groundwater use and reinjection

Non-associated groundwater use by P&G tenure holders includes take for consumptive or operational purposes, such as camp supplies and construction. From 2021 onwards, a water licence will be required for non-associated groundwater use in the CMA.

Origin, QGC and Santos have reported non-associated take within the Surat CMA. The volume of use in 2020 was around 540 ML/year. Most of this water is extracted from the Precipice and Gubberamunda sandstones. Historically, this volume peaked at around 1,700 ML/year in 2013. The recent reduction is due to declining exploration and construction activities by the tenure holders.

Tenure holders also treat associated water to an appropriate standard and then use it, or make it available to others, for consumptive purposes or reinject it into the aquifer system. Origin and Santos have established reinjection facilities to inject treated associated water into aquifers, in accordance with the conditions of the relevant EAs.

Santos's reinjection facilities target the Gubberamunda Sandstone at the Roma gas field. Origin targets the Precipice Sandstone at Spring Gully and Reedy Creek/Combabula gas fields. At this stage, only the Origin facilities are operational where since commencement of the scheme in January 2015, more than 30,000 megalitres has been reinjected into the Precipice Sandstone. The current reinjection rate is around 4,500 ML/year.

### **3.6 Summary of water bores and groundwater use**

- There are approximately 8,000 water bores within and in the immediate proximity of the CSG production areas – about 4,000 of these access water from the GAB formations and the remainder access water from the Condamine Alluvium and the Main Range Volcanics.
- Total estimated groundwater use in the area of interest – i.e. in and around the resource tenures, is about 59,000 ML/year of which about 20,000 ML/year (34%) is from the GAB. It is estimated by OGIA because most use is not metered.
- The Hutton Sandstone is the most developed aquifer in the GAB, followed by the Gubberamunda and Precipice sandstones.
- Groundwater use is generally for agricultural, irrigation, industrial, town water supply and S&D purposes – two-third of the groundwater use in the GAB is for non-S&D purposes.
- Origin is also currently reinjecting around 4,500 ML/year of treated CSG water back into the Precipice Sandstone.
- Groundwater use and extraction is primarily used by OGIA in calibrating the groundwater flow model and assessing groundwater trends, amongst other assessments.

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## Chapter 4 Conceptualisation of groundwater impact pathways

### 4.1 Preamble

Groundwater systems are dynamic and constantly responding to inflows, outflows and changes in formation pressure. Under natural or pre-development conditions, the groundwater system is typically recharged through rainfall, which moves laterally and vertically through aquifers and then discharges out of the system through streams, springs and as evapotranspiration. Groundwater levels respond to the balance between these recharge and discharge processes – referred to as the water balance.

**Stressors** such as groundwater use and associated water extraction during the resource development process cause groundwater to move, from surrounding areas and aquifers to where pressure is lowered by that extraction. This may result in impacts on **receptors** such as water bores, springs and terrestrial groundwater-dependent ecosystems (TGDEs). The degree of impact on receptors depends upon the **impact pathway** and its characteristics, i.e. the mechanism or linkage through which groundwater impacts propagate from stressors to receptors. This is also loosely referred to as **connectivity** in groundwater systems. The conceptual understanding of impact pathways is important in assessing and managing impacts on receptors.

### 4.2 Terminology

**Groundwater level** – a generic term used in this chapter and the rest of the report to refer to groundwater level or groundwater pressure in an aquifer. The two terms are used interchangeably depending upon the context. This is the level to which groundwater is measured in a monitoring bore. In unconfined aquifers in outcrop areas, this is the level below which aquifers are saturated with water – also referred to as the water table. In confined areas, where a low-permeability clay or mudstone formation sits above an aquifer, the groundwater pressure in the aquifer is above the top of the aquifer – meaning that the groundwater level in a water bore completed in that formation will rise above the aquifer.

**Head gradient** – in the context of the UWIR, typically a vertical difference in groundwater level or groundwater pressure between two formations. It can also be a difference in groundwater level horizontally between two points. Head gradient drives the groundwater flow.

**Groundwater impact** or **impact** – primarily the change in groundwater pressure or groundwater level in response to associated water extraction (also termed **drawdown**). Like groundwater level and pressure, the terms impact and drawdown are used interchangeably depending upon the context.

**Formation** – a generic term used to refer to a geological formation.

### 4.3 Formation anisotropy

Permeability or hydraulic conductivity reflects the ease with which water or another fluid can flow through a medium, such as a consolidated rock or unconsolidated sediment. It is driven by interconnected pores in the formation – created either at the time of deposition (e.g. sandstone) or at later geological stages (e.g. fractures), and is one of the key parameters that affect impact pathways and connectivity. At the formation scale, each formation includes mixed assemblages of sandstone, siltstone, mudstone, coal and shale, configured in a complex three-dimensional layered arrangement (Figure 4-1).

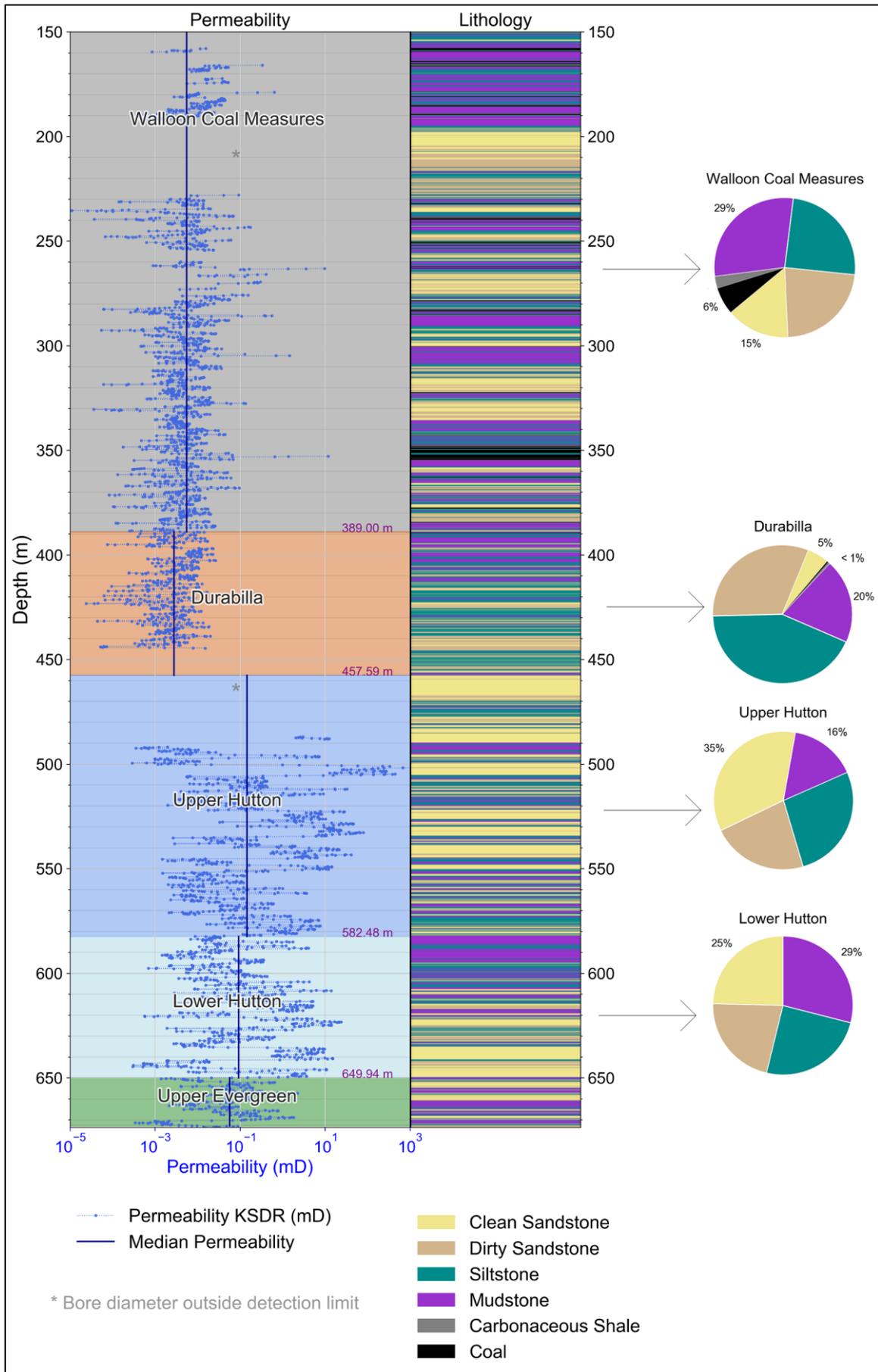


Figure 4-1: Continuous permeability profile from a water bore east of Chinchilla

This results in much lower effective permeabilities in the vertical direction than the horizontal direction – meaning that impacts will propagate faster and much further laterally than vertically. The ratio between vertical and horizontal permeability is referred to as the formation anisotropy.

This variation in vertical permeability is demonstrated using permeability profiling data for the Walloon Coal Measures and the Hutton Sandstone, in a water bore east of Chinchilla, commissioned by OGIA in 2018. Figure 4-1 shows a permeability trace for this bore, together with interpreted lithology. Due to higher sandstone proportions (yellow bands), the median permeability values for the upper and lower Hutton Sandstone are much higher compared to the overlying Durabilla Formation and Walloon Coal Measures, which contain higher proportions of mudstone and siltstone (purple and green bands). Layering of lower-permeability mudstone and siltstone also significantly reduces the effective vertical permeability. Calculations based on data for this bore suggest an anisotropy of around 1:1,000 for the Hutton Sandstone, further validating the model-derived values that are of the same order of magnitude.

## 4.4 Impact pathways – CSG

### 4.4.1 General

Understanding of the geology and hydrogeology of the Surat and southern Bowen basins continues to evolve and is reported progressively in each UWIR, with additional detail available in technical reports and companion documents (OGIA 2021a, 2021b).

As described in Chapter 2, depressurisation from CSG production creates a head difference between the target formation and adjacent aquifers and increased potential for groundwater to move from those aquifers towards the target formation. Depending upon the degree of connectivity, declines in groundwater levels and potential impacts on receptors may occur in those aquifers.

A generalised schematic showing groundwater conditions in and around a CSG production well, with some of the key factors that potentially influence impact pathways, is shown in Figure 4-2. This is also illustrated further in a video created by OGIA (section 14.4).

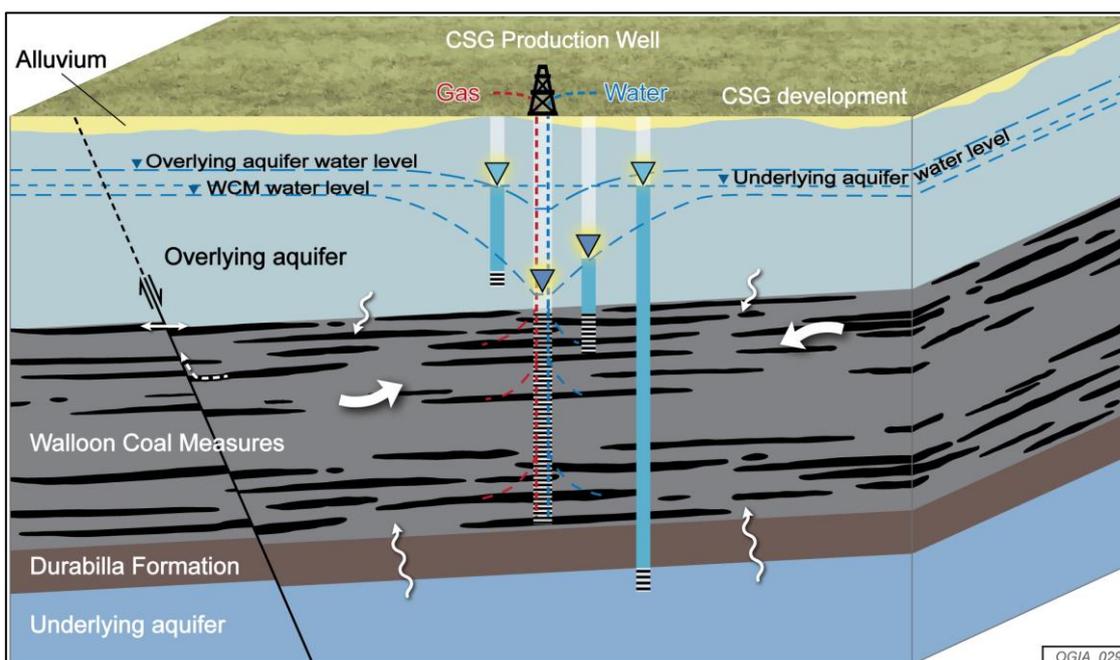


Figure 4-2: Impact pathways for from CSG development

As drawdown propagates laterally away from CSG production fields, vertical head gradients are induced relative to adjacent aquifers. Impacts can subsequently be transmitted to receptors in adjacent aquifers where this change in head gradient coincides with impact pathway, as well as the lateral propagation of impact within a formation due to gradient created towards the well.

The degree of vertical connectivity between two formations is controlled by the hydrogeological properties of the intervening material, the hydraulic gradient and the presence or absence of impact pathways to connect the two. Important geological factors that affect connectivity are as follows:

- the characteristics of intervening aquitards – primarily their thickness and vertical permeability, e.g. the Durabilla Formation (which separates the Hutton Sandstone from the Walloon Coal Measures) and the upper non-coal zone of the Walloon Coal Measures
- where an aquifer is in direct contact with a CSG target formation, the nature of the transitional material between them and vertical permeabilities of the formations, e.g. the contact between the Condamine Alluvium and the Walloon Coal Measures, and areas where the Precipice Sandstone is in contact with the Bandanna Formation
- geological faults that may reduce connectivity by physically disconnecting formations or laterally connect overlying and underlying formations with coal seams or potentially induce vertical flow in the damage zone, e.g. the Hutton-Wallumbilla and Horrane faults
- wells and water bores that may act as conduits to flow where they are screened across coal measures as well as adjacent formations/aquifers.

Connectivity is an inherent characteristic of all geological formations. Hydraulic connection alone is not sufficient to induce groundwater flow between two formations. A difference in groundwater pressure between the formations or head gradient is necessary for cross-formational flow to occur. While no flow will occur between well-connected formations if there is no pressure difference, there may be some flow between poorly connected formations if there is a large pressure difference.

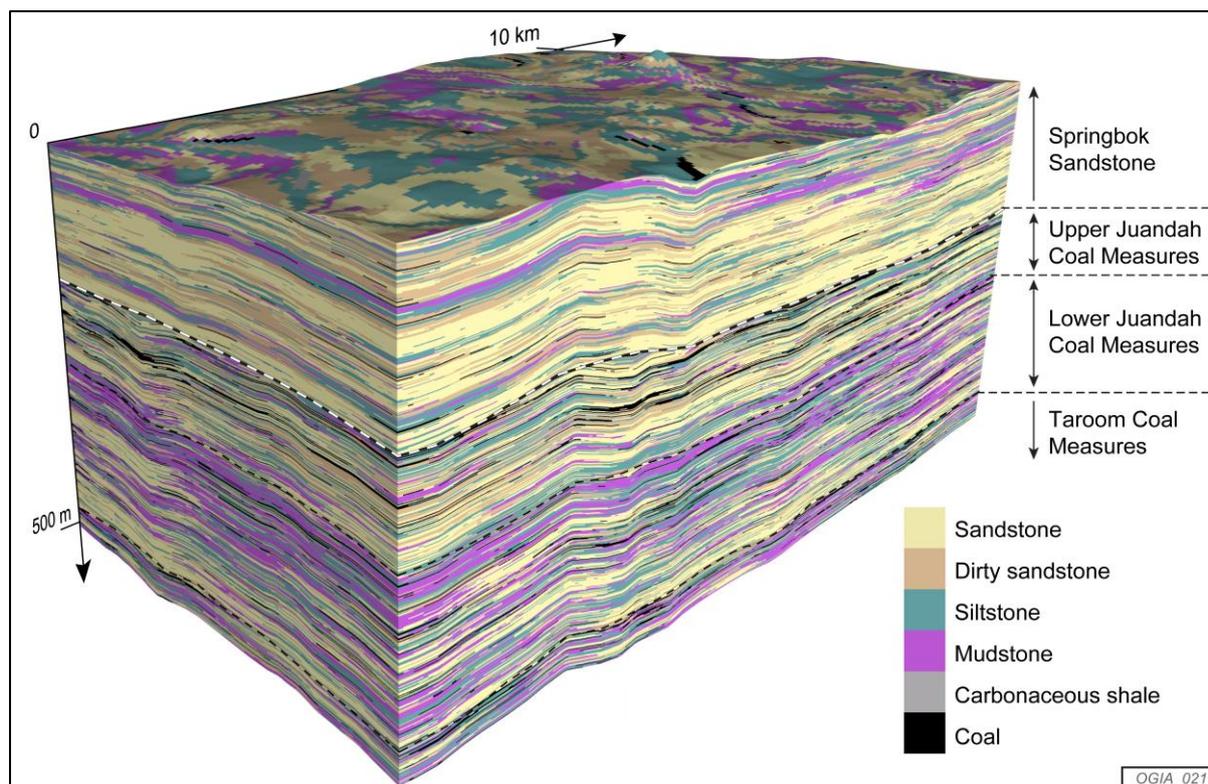
#### **4.4.2 Groundwater flow and lateral propagation of impacts within the coal measures**

The Walloon Coal Measures, Bandanna Formation and Cattle Creek Formation are the target coal sequences for CSG production in the Surat CMA. The Walloon Coal Measures is complex, comprising mostly thin, discontinuous coal seams or layers (Scott et al. 2004) as demonstrated in Figure 4-3, which presents a 3D lithology model of the Walloon Coal Measures derived from detailed geophysical log data for the eastern gas fields.

Comprising siltstone, mudstone, fine to medium-grained sandstone and coal, the Walloon Coal Measures was deposited over millions of years from rivers, lakes and swamps across the Surat and Clarence-Moreton basins (Scott et al. 2004). Most of the coal seams comprise numerous thin, non-continuous stringers or lenses (up to 45 individual coal seams can be recognised in places) separated by bands of low-permeability sediments often referred to as the interburden. Coal typically makes up less than 9% of the total thickness of the Walloon Coal Measures.

Within the Walloon Coal Measures, the two coal-dominated formations are the Juandah Coal Measures in the upper part and the Taroom Coal Measures in the lower part. These units are separated by the Tangalooma Sandstone, although not present everywhere, and is often lumped with the Lower Juandah Coal Measures.

At the base of the Walloon Coal Measures is the Durabilla Formation, which primarily contains low-permeability sandstone, siltstone and mudstone and is largely devoid of coal (Figure 4-3).



**Figure 4-3: Walloon Coal Measures visualisation showing the complexity of the geology (generated from CSG well data)**

Due to the presence of cleats and fractures, the coal seams are generally the more permeable units within the Walloon Coal Measures, with permeabilities in the range of 1 to 1,000 milliDarcy (mD), equivalent to a hydraulic conductivity of 0.001 metres to 1 metre per day (m/d). They sit within a sequence of mainly mudstones, siltstones or fine-grained sandstones (interburden), which typically have lower permeabilities in the range of 0.0001 to 0.01 mD, equivalent to a hydraulic conductivity of  $1 \times 10^{-7}$  to  $1 \times 10^{-5}$  m/d. Permeability in the Walloon Coal Measures also reduces with depth, as the cleats and fractures close up due to pressure from the overlying material. For every 300-m increase in depth, the coal permeability declines by about one order of magnitude. For other lithologies, it typically takes the weight of 1,300 m of overlying material to cause a similar reduction in permeability.

The thickness of the Bandanna Formation varies from 70 to 250 m. Ten individual coal seams can be identified within the formation. These coal seams tend to be slightly thicker (often less than two metres) and therefore more continuous than the coal seams in the Walloon Coal Measures. Coal seams typically account for less than 15% of total thickness of the Bandanna Formation.

The Cattle Creek Formation is present at depths of up to 1,800 metres below ground level (mbgl) and about 500 m below the base of the Bandanna Formation. Since only a few CSG exploration wells have extended into this formation, little is known at this stage about the nature, thickness and distribution of coal seams in this unit.

As detailed in 2.3.1, optimal conditions for CSG to flow to a well are typically achieved when groundwater pressure in the production well is equivalent to 25–80 metres of water. This implies that

if groundwater pressure in a CSG well before development is around 300 m, then it is to be depressurised by about 220–275 m to bring it to the operating level for CSG production.

As the coal seam permeabilities are 4–5 orders of magnitude higher compared to the interburden, the water is mainly contributed laterally from coal layers in the initial stage of depressurisation. Over time, drawdown radiates away from the well in a conical shape ('cone of depression'). In contrast, there is little contribution from the interburden, where some vertical flow occurs over time towards the coal layers in response to a pressure difference created between the two. The pressures across the two units gradually equilibrate over the lifetime of the well – typically 20 to 25 years in the Surat Basin. For the same reasons, the reduction in pressure also tends to be smaller near the formation top, i.e. in the Juandah Coal Measures, while greater reductions in pressure occur near its base, in the Taroom Coal Measures.

Another factor affecting groundwater flow in coal measures is the release of gas in response to depressurisation. As the coal seams are depressurised, both gas and water are released and dual-phase (or 'two-phase') flow occurs within the coal seam (section 2.3.1). The presence of gas within the coal seam provides additional resistance to the flow of water and effectively reduces the water permeability, compared to if water alone was present in the coal seam. As a result, the effective permeability also tends to reduce over time as depressurisation continues and more gas flows with the water. This contributes to the reduction in the rate of associated water extraction over time (Figure 2-2). During the latter stages of development, coal seams may become completely depressurised, such that the only sources of water entering the well are attributed to leakage from the surrounding interburden and slow recharge from outside the wellfield.

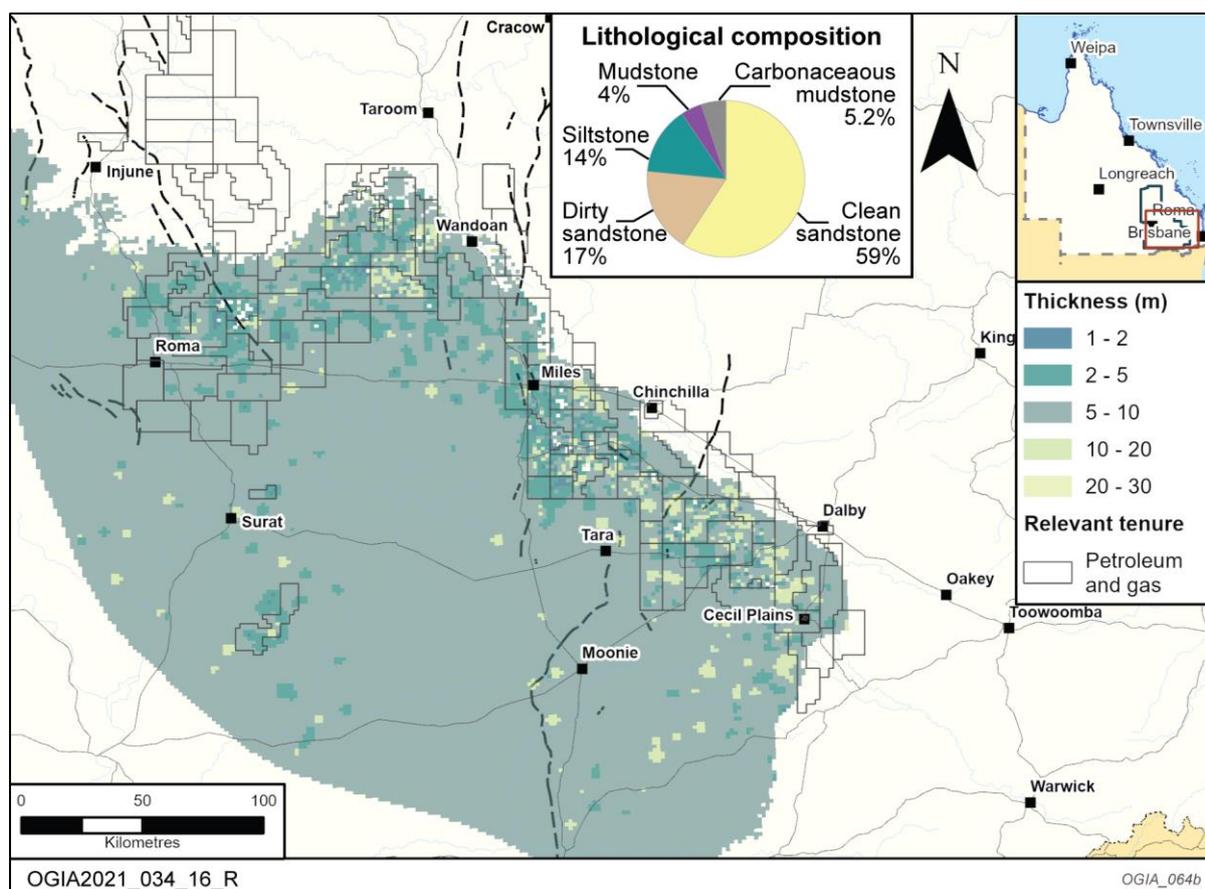
CSG wells are typically completed across multiple coal seams, connecting those coal seams through the wells themselves. When multiple CSG wells are drilled in close proximity, typically 700–1000 m from each other, the wells also potentially connect seams that would otherwise be disconnected from each other – leading to an effective increase in the formation-scale horizontal permeability of the coal measures and relatively more uniform distribution of pressure within the formation.

The processes of lateral and vertical impact propagation in the coal measures are represented in the groundwater modelling by OGIA through various customised modules of the MODFLOW-USG code.

#### **4.4.3 Impact pathways from the Walloon Coal Measures to the Springbok Sandstone**

In general, the uppermost part of the Walloon Coal Measures contains less coal than the rest of the formation and is dominated by low-permeability siltstone and mudstone. It is therefore not commonly targeted for CSG production and is screened off. This part of the formation is referred to as the 'non-coal zone', forming an effective aquitard that impedes vertical flow from the Springbok Sandstone. However, the contact between the two formations is erosional and there are areas where the productive coal seams are in direct contact with the Springbok Sandstone providing a relatively higher degree of connectivity in those areas, as is evident from the distribution of the thickness of this effective aquitard (Figure 4-4).

Also, while the Springbok Sandstone is highly heterogeneous, the lower part is characterised by a higher proportion of sandstone but permeabilities are generally low, with significant variability and some localised high-permeability zones. This may be related to the relatively high percentage of swelling clays commonly found in the sandstone matrix (Shell 2012).



**Figure 4-4: Thickness of the non-coal zone of the Walloon Coal Measures**

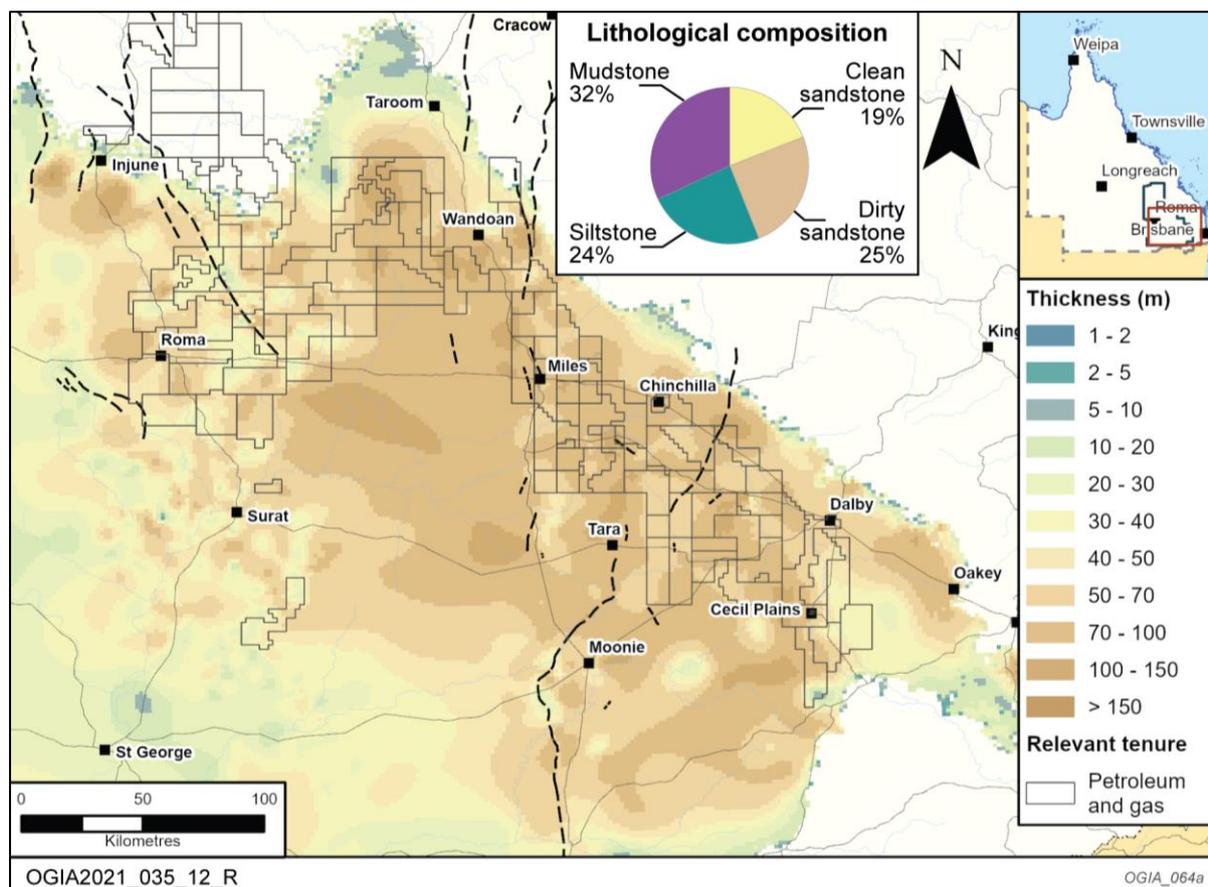
Low permeabilities are also supported by low water bore yields, as described in Chapter 3. Additionally, both the Walloon Coal Measures and the Springbok Sandstone are highly stratified and include significant proportions of siltstone and mudstone. As a result, the estimated vertical permeability, based on core permeability tests and formation-scale numerical permeameter results (6.4.3), is much lower than in the horizontal direction. Regional interconnectivity between these two units is therefore considered to be low. However, there may be local instances of connectivity caused by erosional contacts, CSG wells partially completed into the Springbok Sandstone (section 4.4.7) and geological faults (section 4.4.6).

Monitoring data collected in response to associated water extraction in the last 10 years or so suggests that despite a groundwater level difference of up to 265 m between the Walloon Coal Measures and the Springbok Sandstone, the majority of Springbok Sandstone monitoring points located close to active CSG production areas show little or no significant drawdown. The exceptions are those where the influence of faulting has affected local connectivity (section 4.4.6).

Complementary studies by QGC suggest that proportions of low-permeability clay present in the Springbok Sandstone may be even higher than previously thought, due to the presence of swelling clays leading to the over-estimation of sandstone from wireline logs (Gaede et al. 2020; Kieft et al. 2015). An area of active interest – for the industry, OGIA and UQ – is the characterisation of the Springbok Sandstone in terms of its petrophysical properties as well as the geological architecture across the Surat Basin.

#### 4.4.4 Impact pathways from the Walloon Coal Measures to the Hutton Sandstone

The Hutton Sandstone is physically separated from the Walloon Coal Measures by the Durabilla Formation, a unit commonly regarded as a major aquitard of the GAB (Ransley & Smerdon 2012). As shown in Figure 4-5, the Durabilla Formation is continuous across the current and proposed CSG footprint, with an average thickness of about 55 m across most of the area, although there are areas with less than 10 m thickness.



**Figure 4-5: Thickness of the Durabilla Formation – the aquitard between the Walloon Coal Measures and the Hutton Sandstone**

The Durabilla Formation predominantly comprises siltstone, mudstone and fine to medium-grained poorly sorted sandstones, with almost no coal, and has estimated vertical permeabilities in the range of  $10^{-6}$  to  $10^{-7}$  m/d – indicative of a very effective aquitard.

With the exception of portions of the Horrane and Hutton-Wallumbilla fault systems, there are no known faults with the potential to juxtapose coal seams at the base of the Walloon Coal Measures against sandstones in the upper parts of the Hutton Sandstone. Fault-induced lateral connectivity between these two formations is therefore also considered to be very low (see section 4.4.6 for more details).

While many CSG wells in the Surat Basin are drilled at least partially into the Durabilla Formation, very few wells are screened across the Durabilla Formation as it is not a CSG target formation. Due to its low permeability, impacts are not likely to be transmitted away from the wells (see section 4.4.7 for more details).

Therefore, overall interconnectivity between the Walloon Coal Measures and the underlying Hutton Sandstone is considered to be very low. This is supported by the analysis of monitoring data, which concludes that despite a pressure difference of up to 450 m between the Walloon Coal Measures and the Hutton Sandstone, there are no CSG-induced impacts in the observed groundwater levels in the Hutton Sandstone. Declining groundwater levels are attributed to non-CSG related factors (section 5.6.2.1).

#### **4.4.5 Impact pathways from the Walloon Coal Measures to the Condamine Alluvium**

The Condamine Alluvium is an important groundwater resource that overlies the Walloon Coal Measures. Since 2012, OGIA and Arrow have led research into connectivity between these formations, 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. Arrow complemented the study by coring, pump testing and drilling of monitoring bores. Details of the investigations, approach and outcomes were compiled in an investigation report (OGIA 2016a) and a peer-reviewed journal (Pandey et al. 2020) together with separate reports by Arrow (Viljoen et al. 2020).

OGIA 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 4-6). The degree to which flow is impeded therefore depends upon the combined thickness and vertical hydraulic conductivity of these two units (Pandey et al. 2020).

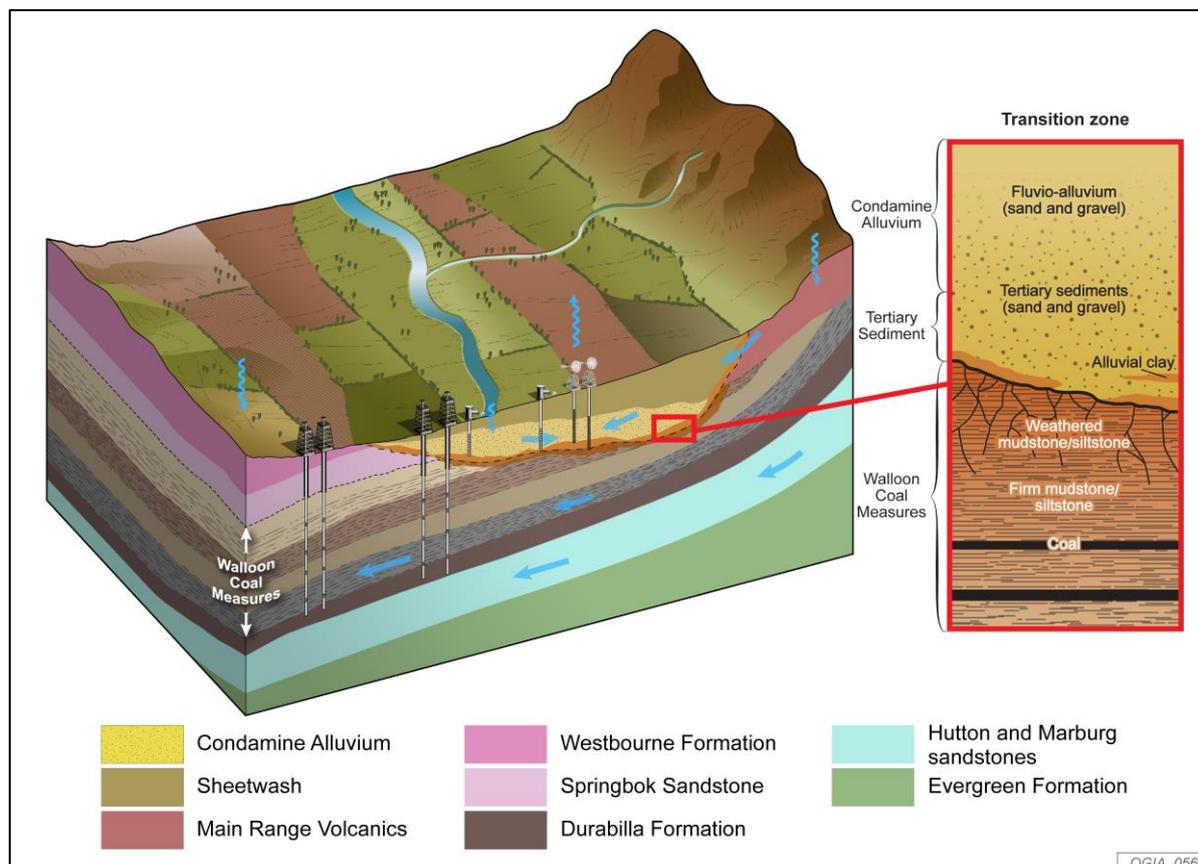
Data collected more recently from additional monitoring and test pump sites has reaffirmed the findings that the degree of connectivity is low. Updated mapping of the contact between the Walloon Coal Measures and the Condamine Alluvium in the geological model, from additional wireline and bore data,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

An emerging focus of update to the Condamine connectivity study is to improve understanding in two specific areas:

- the geological and hydraulic characteristics of the Horrane Fault
- the sub-cropping coal seams at the base of the Condamine Alluvium.

In 2020, OGIA remapped the geometry of the Horrane Fault from seismic data provided by Arrow. This work suggests that the fault is more laterally extensive and segmented than previously mapped (section 4.4.6). Arrow also undertook a comprehensive and separate investigation to evaluate the hydraulic characteristics of the fault across the Walloon Coal Measures (Viljoen et al. 2020). While these investigations provide an improved understanding of fault geometry in consolidated and deeper sediments, there is scope to further improve understanding of fault-induced connectivity at shallower depths. To advance this knowledge, OGIA is planning an airborne electromagnetic (AEM) survey in the next UWIR cycle. In the interim, OGIA has taken a conservative approach by assuming a higher level of connectivity in modelling the predicted impacts.

Under pre-CSG conditions, groundwater levels across most of the Condamine Alluvium were similar to or lower than those in the underlying Walloon Coal Measures and the Springbok Sandstone, therefore, there were only minor inflows to the Condamine Alluvium from these formations.



**Figure 4-6: Schematic of the regional hydrogeological setting around the Condamine Alluvium**

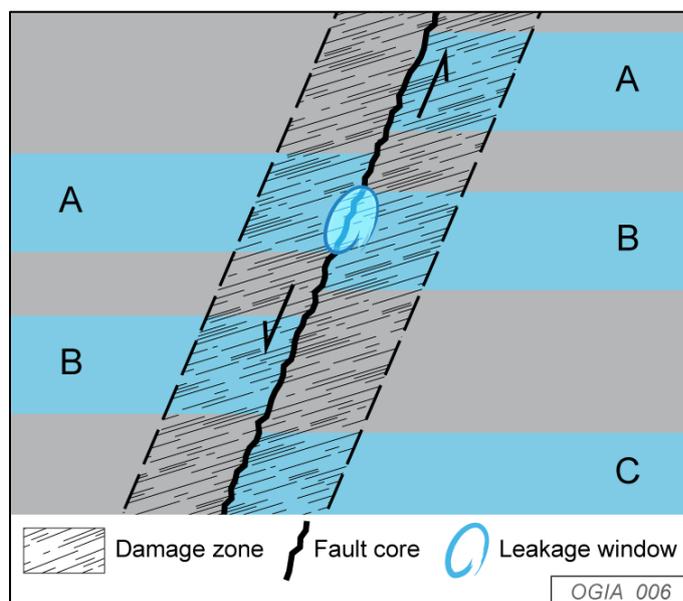
CSG depressurisation under the western Condamine Alluvium will result in either an increase or reversal of the pressure gradient towards the Walloon Coal Measures. As a result, while upward flow may still occur into the Condamine Alluvium in the east, the western Condamine Alluvium will lose some flow to the underlying Springbok Sandstone and Walloon Coal Measures. The interaction is likely to be greater where the coal seams are in direct contact with the base of the Condamine Alluvium and where the transition zone is either thin or absent. Model calibration suggests that the net average loss from the Condamine Alluvium is likely to be about 1,270 ML/year (section 6.5.2.5).

#### 4.4.6 Impact pathways through geological faults

A geological fault is a break along which rock formations have moved past each other by a distance, referred to as the fault ‘throw’ or ‘displacement’. Faults occur at a range of scales between local features with small displacements to regional fault systems comprised of several segments with often complex geometry.

Faults have the potential to create impact pathways and may impact both vertical and horizontal connectivity. As shown in Figure 4-7, faults may affect vertical connectivity by increasing the vertical permeability of the host rock through fractures in the damage zone. The fracture characteristics are controlled by the rock type (such as the presence or absence of swelling clays), in-situ stress conditions and the degree of mineralisation that has occurred since the fractures formed. These

factors collectively determine whether, and to what degree, a given fault will facilitate vertical groundwater flow.



**Figure 4-7: Schematic showing a generalised representation of a fault zone**

Faults may also induce horizontal connectivity by juxtaposing formations that would not otherwise be in direct contact. In the context of CSG, there is potential for lateral propagation of impacts where coal seams of the Walloon Coal Measures are juxtaposed against the Springbok Sandstone or the Hutton Sandstone.

For the Hutton Sandstone, such juxtaposition occurs where the throw of the fault is greater than the thickness of the intervening aquitard, the Durabilla Formation, however, even when the two are placed in direct contact, the smearing of clay along the fault plane can limit flow across the fault.

Faults may also reduce connectivity where the displacement creates a permanent disconnection and subsequent horizontal barrier to flow. Seismic survey data, supplemented with knowledge about the formation materials from well log data, provides a useful insight into the location and displacement of faults at a local and regional scale.

OGIA has been progressively improving the understanding of major and minor faults in the Surat CMA since 2013, using seismic data from more than 800 two-dimensional (2D) seismic surveys and 4 three-dimensional (3D) surveys. A total of 61 mappable faults and numerous fault intersections in and around the CSG fields were identified through this process. Details and findings of this research are documented in a separate report by OGIA (OGIA 2020). Key conclusions from the study are summarised as below:

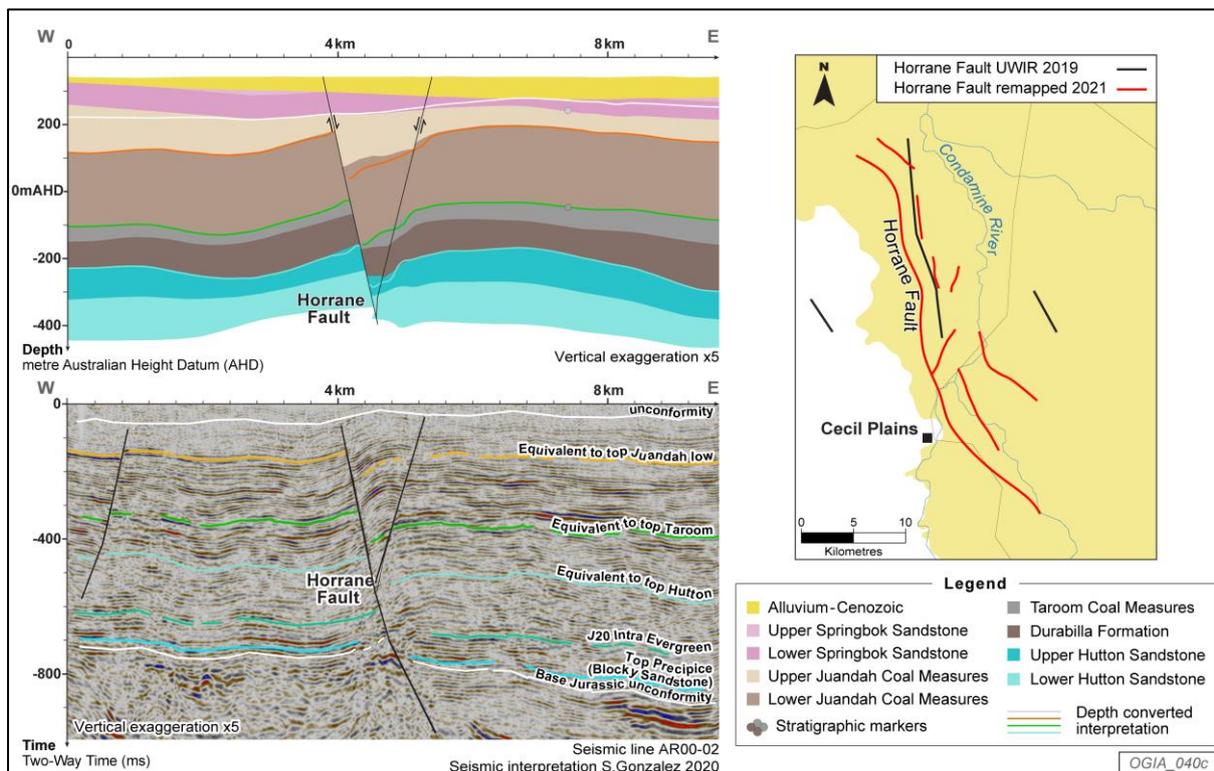
- Most regional-scale fault systems in the Surat CMA have displacements measuring several hundred metres but they predominantly affect the Bowen Basin sediments.
- Faults affecting the Surat Basin sediments often overlay regional fault systems in the Bowen Basin and have much smaller displacements, generally less than 50 m.
- The displacement of faults affecting the Springbok Sandstone and the Walloon Coal Measures was found to range between 10 and 20 m, with some exceptions of up to 60 m in places.
- Several local faults have sufficient displacement to place coal seams in the Walloon Coal Measures against the Springbok Sandstone and potentially increase connectivity – one example is in the Kenya East gas field, located between Chinchilla and Tara, where analysis of groundwater data suggests increased connectivity caused by a fault (section 5.6.2.2).
- Only two locations are identified where faults have sufficient displacement to bring the Walloon Coal Measures and the Hutton Sandstone into contact, both of which are simulated

in the groundwater model by OGIA: the Horrane Fault, near Cecil Plains, and a fault system overlying the Hutton-Wallumbilla Fault, north of Roma.

- Although numerous local faults have the potential to create connectivity (Figure 4-7) between the Walloon Coal Measures and the lower Springbok Sandstone – only a small number suggest enhanced connectivity.
- 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. The exception to this is around the Lucky Last and Abyss springs and east of Injune.

The above conclusions are integrated into OGIA’s impact assessment. A total of 32 major mappable faults are incorporated into the geological model and 22 of those are explicitly represented in the groundwater flow model. Faults are represented in a way that accounts for the juxtaposition of the formations, based on estimated fault displacement, and variations in permeability along the fault plane caused by clay smearing. Clay smearing was assessed on the basis of interpreted lithology from geophysical logs around the faulted formations. As examples, a summary of analysis of two major fault systems is provided below.

The **Horrane Fault** is a 40-km-long fault zone trending south to north with a maximum estimated displacement of 108 m. Analysis of depth-converted seismic data (3D) shows the juxtaposition of the Walloon Coal Measures with Hutton Sandstone at segments towards both ends of the fault zone (Figure 4-8).



**Figure 4-8: Schematic of Horrane Fault remapping (seismic data sourced from Arrow)**

Reservoir pressure monitoring data suggests a large pressure difference across the fault, indicating a barrier to horizontal flow within the Walloon Coal Measures. This is supported by Arrow’s separate investigations based on interference tests and coring (Viljoen et al. 2020). 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 **Hutton-Wallumbilla Fault** in the Bowen Basin has a displacement in excess of 1,000 m. The fault is considered to be a near-vertical thrust fault, dividing the Comet Ridge Platform from the lower Roma Shelf (Green 1997). Up to 3,000 m of subsequent erosion of Bowen Basin sediments resulted in deposition of the Precipice Sandstone (the Surat Basin) directly upon the Bandanna Formation. OGIA focused its investigations on the mechanisms by which springs occur around Injune (the Lucky Last spring complex) and impact pathways from CSG development in the Bandanna Formation (Flook et al. 2020).

Field investigations and analysis indicate that the springs occur along a north–south-orientated lineament controlled by the Hutton-Wallumbilla Fault. At this location, groundwater level data shows a substantial pressure difference in the Precipice Sandstone both across the fault and vertically to the overlying Hutton and Boxvale sandstones. This indicates that at this location, the fault constrains horizontal flow, however, there are isolated areas of vertical flow from the Boxvale Sandstone to the springs. More recent AEM data collected by Geoscience Australia (GA) shows that displacement in the Surat Basin is likely to be minor, with the sequence steeply dipping more broadly in this area.

#### 4.4.7 Impact pathways through CSG wells and coal holes

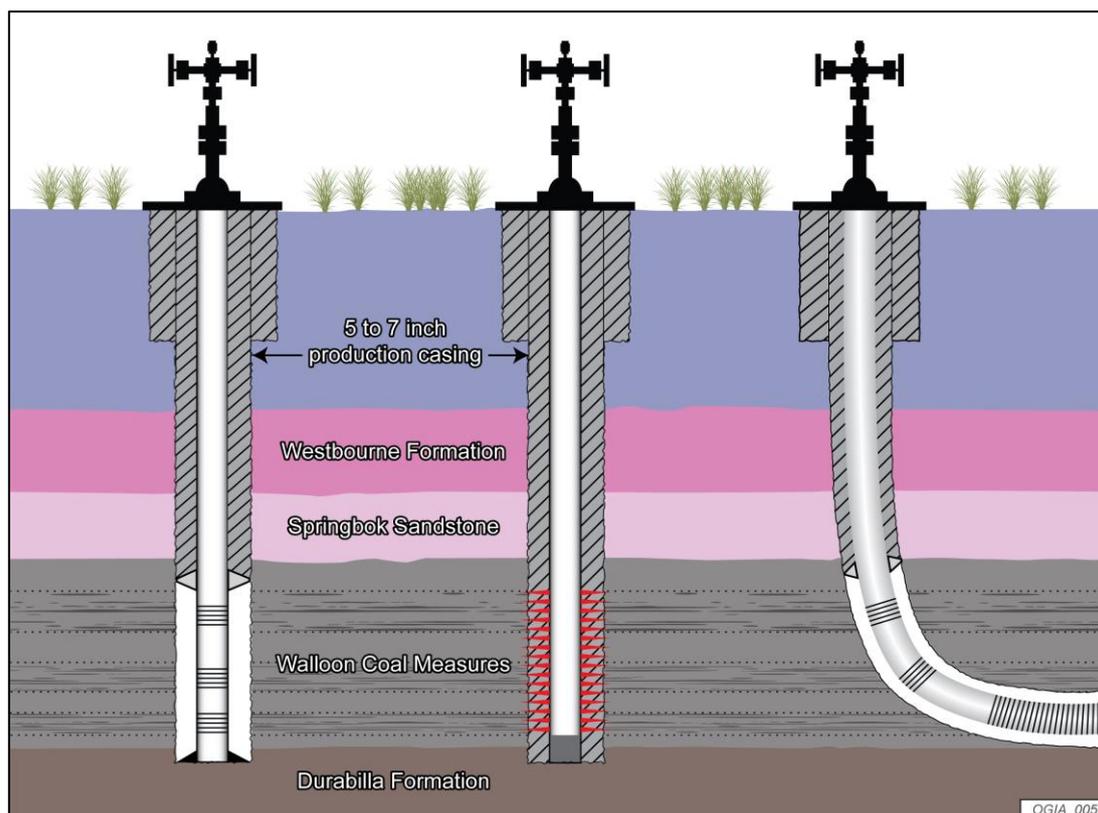
CSG wells are generally constructed as traditional vertical wells screened across the productive coal seams in the target coal formations. However, directional or horizontal wells are becoming increasingly common.

Vertical wells are constructed to a finished diameter of 5 to 7 inches with a production casing that is typically opened through the production zone within the coal formation, accessed either through pre-perforated casing across the coal seams or by shooting holes through the casing and cement grout across the productive coal seams (Figure 4-9). Both of these construction types result in effective inlet intervals to provide access to formation fluids (water and gas).

General industry practice for well construction is to establish a ‘set-back’ distance between permeable water-bearing zones and the top of the CSG production zone – in the case of Condamine Alluvium, this is about 30 m from the base. Where coal seams or gas flows are encountered in less permeable parts of the Springbok Sandstone, wells are completed to access those zones.

Well construction and abandonment have the potential to influence the timing and extent of impacts from CSG depressurisation to overlying and underlying aquifers. This may occur in three ways:

- extraction of associated water from production inlets, including inlets directly tapping formations above or below the Walloon Coal Measures
- indirect flow between formations via wells where well integrity may be compromised
- flow between formations through wells or exploration holes where they are not abandoned properly.



**Figure 4-9: Typical construction of a CSG well**

In Queensland, a code of practice (Department of Natural Resources Mines and Energy 2018) applies to P&G well construction, abandonment and conversion to water bores. The code primarily addresses safety and environmental issues and identifies measures to prevent cross-flow contamination between hydrocarbon-bearing formations and aquifers. In 2015, the Queensland Government's P&G Inspectorate undertook an audit of CSG well integrity and construction and found no evidence of subsurface leaks (GasFields Commission - Queensland 2015).

OGIA compared CSG well screen intakes against the geological formations to assess the potential for direct extraction of associated water from surrounding aquifers. Analysis suggests that about 16% of wells may be partially completed into the Springbok Sandstone, as reported in the previous UWIR. Those CSG wells will, to some extent, extract water directly from the part of the formation where the screens are placed. The amount of water extracted, and the magnitude of the resulting pressure drop in the Springbok Sandstone, will depend upon the permeability of the formation and the length of well screen above the top of the Walloon Coal Measures. To assess this further, OGIA compared water production from wells partially completed into the Springbok Sandstone against those solely completed in the Walloon Coal Measures, which indicated that 97% of wells partially completed into the Springbok Sandstone do not extract materially higher volumes. Nevertheless, partial completion of wells into the Springbok Sandstone is accounted for in the groundwater flow model and is one of the key reasons for the higher level of impact prediction in the Springbok Sandstone compared to other surrounding formations.

Similarly, analysis of well completion into the underlying Durabilla Formation and Hutton Sandstone suggests that nearly half of all the CSG wells do penetrate the Durabilla Formation by more than 5 m but remain separated from the Hutton Sandstone by an average thickness of about 70 m. There is

one exception – Condabri 363 – which is completed into the Hutton Sandstone and may draw some water from this formation.

Horizontal drilling is predominantly used in the Bowen Basin when conditions allow the wells to be drilled to run along the target coal seams. In the Surat CMA, deviated drilling is becoming common around the Condamine Alluvium to minimise surface impact in prime agricultural land. Multiple wells are drilled in different directions, from a single well pad or cluster, to access multiple seams at different depths. OGIA has compiled information on directional wells. In the context of assessing groundwater impacts, the primary focus is on well intake zones and their location in terms of depth and coordinates. This information is then used in determining where the groundwater is extracted from and how it may impact groundwater level.

There are also many coal explorations holes in the Surat Basin, to which varied construction and abandonment standards have applied over time. Available data on those holes, collated by OGIA from mining tenure holders in 2020, suggests that there are at least 18,000 coal exploration holes associated with the 8 mines. These coal holes are typically shallow in depth (less than 200 m).

Coal holes drilled prior to 2001 may not have been abandoned properly and have the potential to affect connectivity. However, most of these are in or near the outcrop areas of the Walloon Coal Measures, on the margin of the basin. A total of about 2,200 coal holes identified in the Springbok Sandstone outcrop areas could potentially provide a pathway to impact from the underlying Walloon Coal Measures, if they remain open over a longer period. Further analysis of potential flow from these holes, in response to CSG depressurisation, indicates that it is likely to be a minor proportion of the overall impact in the Springbok Sandstone. There are also a further 22 coal holes that are likely to connect the Hutton Sandstone to the overlying Walloon Coal Measures but the estimated impact is likely to be localised and less than one metre over a long period of time.

#### 4.4.8 Impact pathways from the Permian coal measures to surrounding aquifers

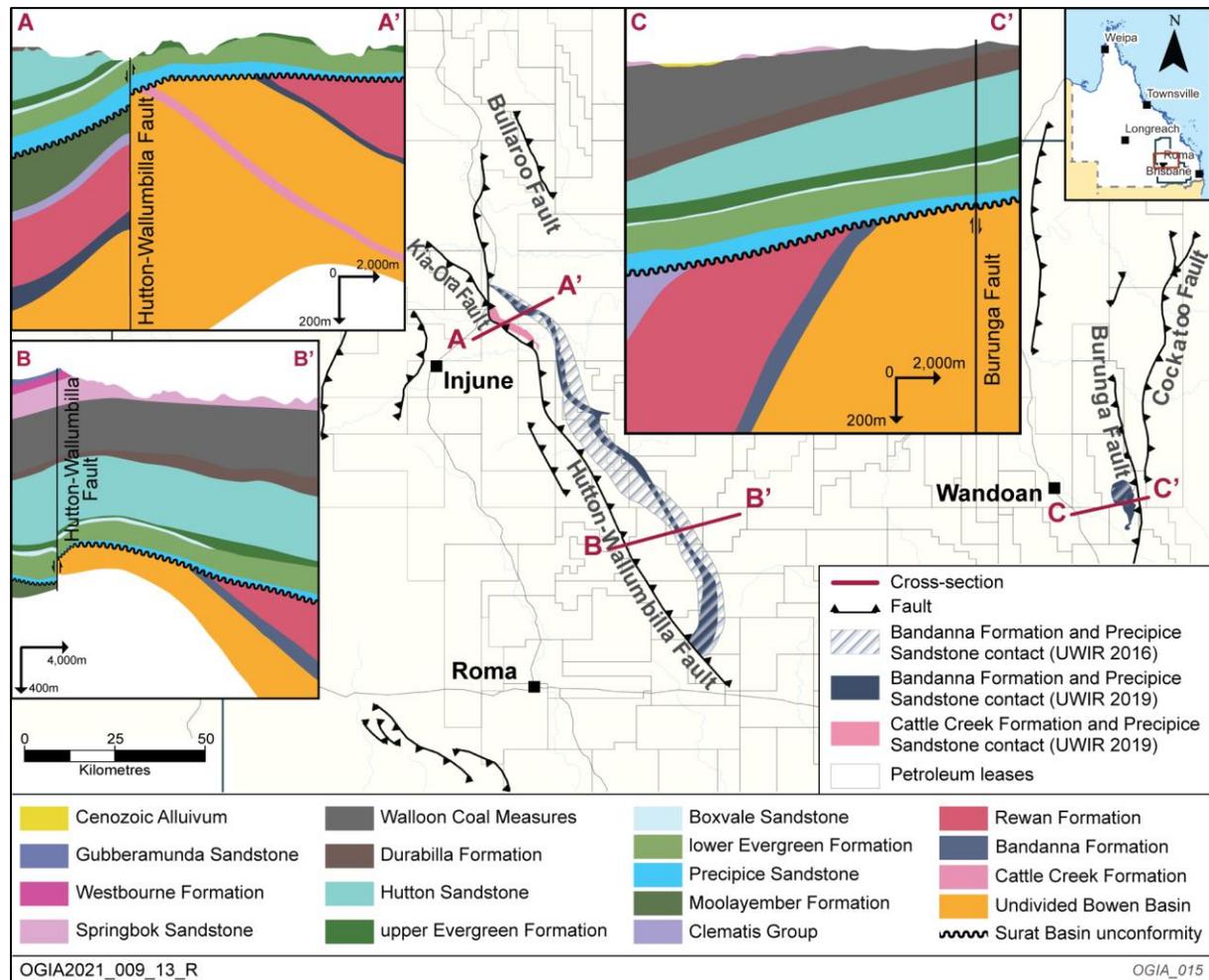
The Bandanna Formation is the main productive Permian CSG formation within the Bowen Basin. It is laterally isolated from the Rangal Coal Measures in the north due to erosion, and from the Baralaba Coal Measures in the east due to faulting (Figure 4-10). Depressurisation of the Bandanna Formation is therefore unlikely to affect aquifers to the north around Clermont and to the east around Biloela.

The Bandanna Formation is generally well isolated from productive aquifers. The underlying Permian formations have little permeability and the low-permeability mudstones of the Rewan Group separate the formation from the overlying aquifers. It is therefore unlikely that depressurisation of the Bandanna Formation will affect those surrounding formations. However, in some locations, the Surat Basin sediments were deposited over the erosional surface of the Bowen Basin and there is potential for the coal formations of the Bowen Basin to come in contact with the Precipice Sandstone (section 4.2.6).

Since the initial UWIR in 2012, OGIA has progressively refined understanding of the extent of the contact zones based on wells that intersect the contact zones directly, and as more seismic survey and drilling data has become recently available. There are two contact zones:

- an area immediately east of Injune near the Fairview and Spring Gully gas fields and parallel to the Hutton-Wallumbilla Fault (the **western contact zone**)
- an area immediately east of Wandoan, south of the Peat and Scotia gas fields and adjacent to the Leichhardt-Burunga Fault (the **eastern contact zone**).

In the western contact zone, there is potential for a high degree of interaction between the coal-bearing formations and the Precipice Sandstone in this area, as they are in direct contact. Some of the earliest CSG fields – Fairview developed in 1996 and Spring Gully in 2005 – have resulted in a decline of more than 200 m due to depressurisation of the Bandanna Formation.



**Figure 4-10: Contact zones between the Bandanna Formation and overlying Surat Basin**

From the available groundwater level data, there is limited evidence of discernible impact in the Precipice Sandstone (see section 5.6.2.4). Over the more recent period – since 2015 – the reinjection of treated associated water has dominated observed groundwater levels across the northern extent of the Precipice Sandstone, which may mask potential impacts. However, a comparison of groundwater and gas production volumes from the Fairview gas field is suggestive of some connectivity across the contact zone. The wells located closer to the contact zone produce higher water volumes, and maintain higher water-to-gas ratios, compared to other wells across the gas field.

The eastern contact zone occurs adjacent to the Leichhardt-Burunga Fault. At this location, similar to the western contact zone, the Bandanna Formation is overlain by the Precipice Sandstone. This area of potential connectivity is much smaller compared to the western contact zone and there is minimal data available on groundwater level or chemistry at this location from which to assess the degree of connectivity.

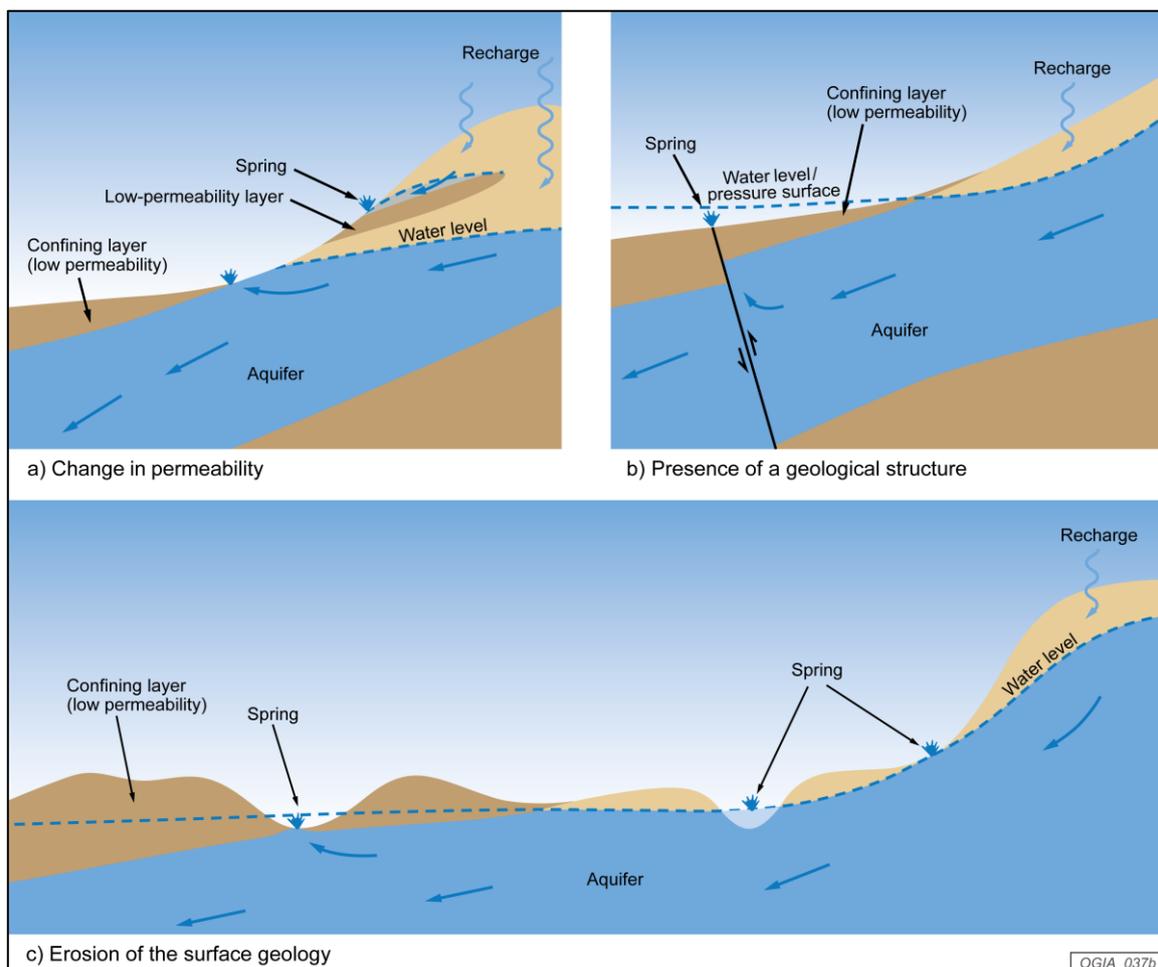
Origin has recently acquired new 3D seismic data in the area of the Peat gas field, providing new information on the eastern contact zone between the Precipice Sandstone and Bandanna Coal

Measures. OGIA has reviewed the new information and while the new data is consistent with the current conceptualisation, this data may be useful for future refinement of the geological models.

#### 4.4.9 Impact pathways to springs

Groundwater discharge to springs and watercourses occur across the central, northern and eastern margins of the Surat CMA (Chapter 10). The main aquifers where groundwater discharges to the surface are the Precipice, Hutton and Gubberamunda sandstones and the basalts. There are three key attributes that influence the potential for propagation of impacts to springs: the mechanism by which groundwater makes its way to the spring, the impact pathway to source aquifer for the spring (as described in previous sections), and the discharge environment. There are three hydrogeological mechanisms as shown in Figure 4-11:

- A spring can form where the hydraulic properties of the aquifer change – often referred to as a contact spring – where a higher permeability layer overlies a lower permeability layer, flow across the boundary is restricted. As a result, water tends to flow laterally. An example is the Spring Ridge spring complex.
- A geologic structure, such as a fault, can also provide a pathway to the surface along which water can flow, such as at the Lucky Last and Dawson River 8 spring complexes.
- Erosion and dissection of the landscape by surface water flows can provide opportunities for groundwater to reach the surface, such as along the Dawson River.



**Figure 4-11: Hydrogeological mechanisms for groundwater discharge to springs**

These mechanisms may also occur concurrently and their understanding provides important knowledge on how impacts may, or may not, affect spring discharge.

The Precipice Sandstone is the source aquifer for many springs in the northern part of the Surat Basin. There are two primary impact pathways to these springs – the contact zones with the Bandanna Formation (section 4.4.8) and conventional oil and gas development at Moonie. In both instances, for impact to occur at the spring, drawdown is required to propagate laterally within the Precipice Sandstone, from the contact zones or Moonie to the location of these springs. Springs fed by the Hutton Sandstone have a similar impact propagation pathway.

A variation to this is at the Lucky Last spring complex where the source aquifer is the Boxvale Sandstone. At this location, impacts propagating laterally in the Precipice Sandstone are then potentially propagating vertically along the Hutton-Wallumbilla fault, to the Boxvale Sandstone and then the spring.

Building upon these mechanisms, understanding how the springs – and supported wetlands – occur within the landscape, and characterising how they are likely to respond to a change in the groundwater regime, is important for the assessment of consequences. OGIA has developed a typology for springs, which is further discussed in section 10.5.4.

#### **4.4.10 Impact pathways – conventional oil and gas**

Although numerous conventional oil and gas fields have recorded some production in recent years, Moonie oil field is the primary field, accounting for nearly half the oil production and 95% of the associated water production from conventional methods within the CMA. The Precipice Sandstone (Surat Basin) and the Showgrounds Sandstone (Clematis equivalent of the Bowen Basin) are the two formations contributing almost all of the associated water. The Permian Bowen Basin sequences do not have any water contribution of significance.

Conventional oil and gas is found at much deeper depths than CSG, in porous rock formations such as sandstone. Gas and other petroleum products move upward until they are trapped by a combination of an impermeable layer (seal) and favourable structure or stratigraphy – such as anticlines or faults. Extraction of this oil and gas involves simultaneous extraction of groundwater but it does not require lowering of groundwater level over large areas. The volume of groundwater extracted is generally much less than for CSG.

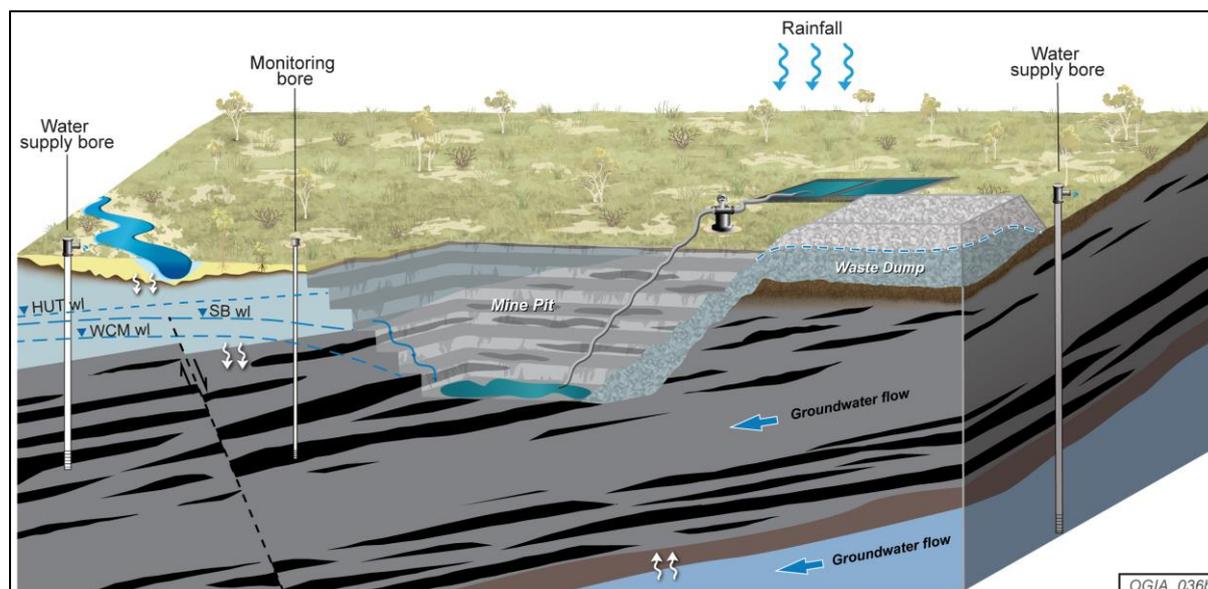
The impact propagation mechanism is best demonstrated in the Moonie field, which is primarily a compartmentalised ‘structure trap’ at a depth of about 1,700 mbgl in the Precipice Sandstone. Permeability of the formation and the confining pressure is high, which results in widespread lateral propagation of groundwater level declines. However, this pressure decline is unlikely to propagate upward to other formations because of the overlying seal from the Evergreen Formation – a regional aquitard. General integrity of the seal, particularly around the gas field, is demonstrated by the fact that it has trapped fluids (oil, gas and groundwater) over a long geological period.

UQ has been reviewing and investigating the hydrogeological conditions in and around the Moonie field in detail as part of a broader project on carbon sequestration. Interim review and findings shared by UQ suggest that the main producing reservoir is the “58 sand”, considered to be part of the Precipice Sandstone. The Moonie-Goondiwindi Fault system is complex; in some places, these faults may have almost no throw and the effect on flow might be limited, while in others, the Precipice Sandstone may be juxtaposed against much tighter parts of the Evergreen Formation, significantly

limiting flow. UQ also developed a sub-regional model from which simulated impact propagation is summarised in Chapter 6.

## 4.5 Impact pathways – coal mining

Current and proposed coal mining in the Surat Basin is carried out via open-cut methods as detailed in section 2.4.1. A generalised schematic showing the typical groundwater conditions in and around an open pit in the Surat Basin is shown in Figure 4-12. OGIA has also created a video to illustrate the coal mining impact pathways (section 14.4) with significant additional details in a separate companion document (OGIA 2021f).



**Figure 4-12: Generalised schematic of groundwater conditions around the open pits**

The groundwater regime around the mine pits may potentially be affected in three ways:

- *Physical removal* of overburden and coal, resulting in the removal of groundwater stored within the formation material. In relative terms, this is a small fraction of the groundwater resource but the resulting open pit creates a condition for ongoing loss of groundwater that flows into the open pit.
- *Direct extraction* of groundwater that flows and seeps into the open pit from exposed formations along the pit walls. Collecting within in-pit sumps, the groundwater is then pumped away from the open pit as part of the mine site water management system.
- *Indirect extraction* of groundwater through the evaporative loss of water from the exposed high and low walls of open pits and sumps.

In the Surat Basin, the coal seams are usually saturated with groundwater and allow free drainage once a seepage face is exposed but inflow is small and active dewatering bores are not required. Associated water extraction is by in-pit sump pumping, where groundwater seepage is managed along with rainfall run-off. A large portion of groundwater is either lost to evaporation from the pit face and floor (indirect extraction) or removed as entrained moisture within the mined coal and overburden (physical removal).

Lateral propagation of drawdown in coal seams extends in the order of a few kilometres – usually 5 to 10 km in the Surat Basin. As the coal seams are fully desaturated during mining, the magnitude

of drawdown is equivalent to the depth to base of the coal seam, minus the pre-mining depth to water table or groundwater level. In most instances, this magnitude of drawdown is in the order of tens of metres, reducing with distance from the open pit.

Drawdown around the open pit also creates a head gradient between the coal seams and the overlying and underlying formations in the vicinity of the mine. This creates a potential for groundwater flow from those formations towards the open pit and the mined coal seams. For those mines that extract (or propose to extract) coal from the lowermost Taroom Coal Measures – e.g. Commodore, The Range and New Acland – the vertical head gradient across the Durabilla Formation may induce some flow from the underlying Hutton Sandstone. However, as detailed in section 4.4.4, the Durabilla Formation is a very effective aquitard, significantly limiting any such flow. In addition to seepage through the pit wall, some vertical flow may also occur from the Springbok Sandstone to the Walloon Coal Measures where the Springbok Sandstone is intersected and remains saturated in the vicinity (e.g. Cameby Downs, Elimatta and Wandoan Coal Project mines).

Overburden may also comprise non-coal bearing and weathered parts of the Walloon Coal Measures and the Springbok Sandstone, near-surface fractured rock (such as the Main Range Volcanics), as well as thin alluvial cover where present. Groundwater seepage would occur into the open pits where they intersect the saturated overburden. Due to the lower permeabilities that are observed in much of the overburden material, the seepage contribution from the overburden is likely to be relatively low.

As stated in section 4.4.6, faults may provide a conduit to groundwater flow. To assess the potential for fault-induced connectivity around coal mines, OGIA completed an assessment of faults around coal mines using a similar methodology applied for CSG impact assessment (section 4.4.6). This assessment involved mapping of faults from seismic and coal holes data; determination of fault juxtaposition; and identification of high-priority faults based on connectivity risks. The assessment showed that faulting is generally subdued, with the interpreted throw insufficient to juxtapose coal seams with the underlying Hutton Sandstone. The exception to this is around the New Acland mine.

There is some risk of vertical transmission of both CSG and future coal mine impacts between the Walloon Coal Measures and the Springbok Sandstone or alluvium but it is likely to be a relatively minor proportion of the overall impacts.

## 4.6 Interaction between the CSG and coal mining impacts

Six of the eight operational and proposed coal mines in the Surat Basin overlap with (or are immediately adjacent to) tenure where CSG production is occurring or planned in the future. These operations are generally targeting the same coal seams of the Walloon Coal Measures.

The timing and sequencing of CSG development on overlapping tenure will determine whether the coal seams will be dry, partially saturated or fully saturated during mining. The levels of saturation in the coal seams will affect groundwater seepage (volumes and rates) to the open pits as well as the magnitude, extent and timing of potential drawdown from coal mining.

To conceptually understand this overlapping interaction of drawdown at each of the existing and proposed coal mines, OGIA estimated the level of saturation (groundwater level above the base of the pit) expected in and around the open pit, then compared this with the drawdown resulting from CSG development over the mining period. The analysis suggested that some level of interaction is occurring or is likely at all mines except New Acland and Commodore, both of which are further from CSG production areas.

## 4.7 Summary of impact pathway conceptualisation

- Overall, the understanding of inter-aquifer connectivity and impact propagation pathways has progressively improved since the UWIR 2012.
- Impacts from CSG depressurisation will propagate laterally within the target coal formations, including the Springbok Sandstone, where CSG wells are partially screened into the lower parts of this formation.
- Impacts will also propagate vertically to the overlying Springbok Sandstone and Condamine Alluvium, although the degree of connectivity for the Condamine Alluvium is low.
- Connectivity with the underlying Hutton Sandstone is also very low, due to the intervening Durabilla aquitard, which limits the potential for impacts to propagate.
- Additional minor faults continue to be mapped and there is some potential for faults to enhance connectivity through displacement that may place the Springbok Sandstone in contact with the Walloon Coal Measures in some areas
- There is insufficient fault displacement to create connectivity across the Walloon Coal Measures and the Hutton Sandstone, except at two locations.
- There is also direct connectivity between the Bowen Basin and the Precipice Sandstone in the north-eastern and north-western parts of the CMA where the Bandanna Formation and Precipice Sandstone are in direct contact.
- An open-cut coal mining pit creates a sink where groundwater will flow from the intersected coal seams and overlying formations. This creates groundwater drawdown or impact in the immediate vicinity of the coal mines but the level of impact is much smaller in magnitude compared to CSG.
- There is also some interaction between the CSG and coal mining activities, which often results in partial desaturation of coal mines by nearby CSG depressurisation.
- Understanding of impact pathways presented in this chapter is the foundation for the structure and set-up of the groundwater model. It has also contributed to design of the monitoring network and the spring impact management strategy (SIMS), presented in Chapter 9 and Chapter 10 respectively.

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## Chapter 5 Identifying impacts from monitoring data

### 5.1 Preamble

In most instances, impacts on groundwater levels that may have occurred from resource development cannot be measured directly. This is because monitoring data (groundwater level and chemistry) is influenced by a range of resource-related and non-resource-related activities. Further analysis is therefore required to separate out resource-related impacts from other influences.

This chapter provides a summary of the analysis of monitoring data by OGIA to identify impacts on groundwater levels that have occurred so far, including the overall scientific approach and the key conclusions. Additional details are available in a separate companion document (OGIA 2021g). The analysis has also supported conceptual understanding of impact pathways presented in the previous chapter, and the calibration of the groundwater flow model described in the next chapter.

### 5.2 Terminology

**Groundwater level** – groundwater level or pressure in an aquifer, as described in the previous chapter.

**Groundwater level trend** – change in groundwater level or pressure over a specified period of time. A trend can be either rising, declining or stable.

### 5.3 Typical influences on groundwater levels

At any given point in time, the groundwater level is a representation of a number of influences on the groundwater system. Under natural conditions, prior to development, the groundwater level represents a balance between natural recharge and discharge, or system input and output. For example, when the rate of recharge to an aquifer exceeds the rate of discharge, the groundwater level rises.

In an undeveloped aquifer, the primary groundwater input is via rainfall infiltration or leakage through stream beds (aquifer recharge). This typically occurs in outcrop areas where the aquifer is exposed at the surface. Once recharge enters the aquifer system, it moves from areas of higher groundwater elevation to areas of lower elevation and may discharge to springs and watercourses (aquifer discharge). All other factors being equal, if average recharge is maintained, then there is little or no variation in groundwater level, and discharge will be equal to recharge.

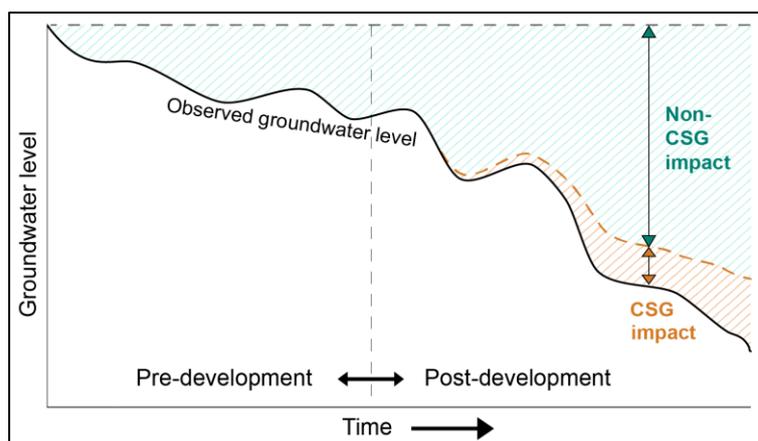
During extended periods of above-average recharge, the groundwater level will gradually rise. Similarly, periods of below-average rainfall will tend to result in a declining groundwater level trend. Monitoring points typically show a more defined response to variations in rainfall where they are closer to recharge areas. Monitoring points further from recharge areas typically show subdued and delayed responses to variations in rainfall. In a large groundwater system, such as the GAB – where recharge may be hundreds of kilometres from the monitoring point – responses to recharge are slow, delayed and often subtle, when compared to smaller groundwater systems, such as the Condamine Alluvium.

Groundwater use from water bores will cause the groundwater level to gradually decline until a new balance is achieved between extraction (aquifer discharge) and recharge. A highly transmissive aquifer, such as the Precipice Sandstone, will distribute this impact across a very large area, which

will result in small local impacts at the bore. A low-transmissivity aquifer/tight aquifer, such as the Springbok Sandstone, will create a strong local drawdown but impact will extend only a short distance from the pumping bore.

There are a number of other factors unrelated to recharge or discharge that can also influence changes in groundwater levels. These include loading and unloading effects – created by water being withdrawn from overlying formations (depressurisation) or added to overlying formations (rainfall) – and changes in atmospheric pressure. In most cases, these other factors are relatively minor components of groundwater level change.

Observed groundwater levels in formations surrounding the Walloon Coal Measures and the Bandanna Formation may show a combined effect of groundwater use and induced flow resulting from associated water extraction (Figure 5-1). Separating the two impacts in time series of observed groundwater levels is challenging because neither impact can be measured directly.



**Figure 5-1: Schematic showing the combined effect of resource development and water use on groundwater**

## 5.4 Data availability

Prior to 2010, the majority of groundwater monitoring infrastructure in the GAB was established by the Queensland Government (DRDMW) for reviewing aquifer performance and managing groundwater use. These monitoring sites are predominately located in areas close to outcrop away from CSG development, where groundwater was generally accessed at shallower depths for consumptive purposes. There is also substantial coal mine monitoring data available around some coal mining operations, which pre-date CSG commencement.

Since 2010, in the post-CSG-commencement era, there has been a significant increase in monitoring infrastructure in deeper formations around the CSG development areas, where tenure holders have established monitoring points in response to previous UWIR requirements and for their own specific purposes. This also includes a new obligation (from UWIR 2019) for tenure holders to collect environmental isotopes (strontium) to support the further investigation of inter-aquifer connectivity between the CSG target formations and adjacent aquifers. A summary of monitoring points with groundwater level, chemistry or strontium isotope ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) data is provided in Table 5-1.

## 5.5 Overall approach to analysis of monitoring data for impacts

The most common approach is to establish a pre-development background trend in groundwater level and compare with post-development trend to assess deviations that may indicate the onset of resource development impacts. The approach requires pre- and post-resource-development time-series groundwater level data. It also requires estimates of groundwater use and extraction of associated water, because of their potential influence on the observed groundwater levels.

**Table 5-1: Summary of monitoring points with data available for the analysis**

Formation	Pre-CSG commencement			Post-CSG commencement		
	Pressure	Chemistry	<sup>87</sup> Sr/ <sup>86</sup> Sr	Pressure	Chemistry	<sup>87</sup> Sr/ <sup>86</sup> Sr
Condamine Alluvium	762	253	2	73	56	3
Springbok Sandstone	22	13	0	47	34	9
Hutton Sandstone	115	71	2	40	47	18
Precipice Sandstone	41	51	3	71	30	5
Upper Juandah Coal Measures	20	3	0	97	6	0
Lower Juandah Coal Measures	10	4	0	69	0	0
Taroom Coal Measures	45	31	1	50	4	1
Bandanna Formation	42	0	0	18	0	0
<b>Total</b>	<b>1,057</b>	<b>426</b>	<b>8</b>	<b>465</b>	<b>177</b>	<b>36</b>

In the Surat CMA, considerable new monitoring data has become available since the onset of CSG development. From the pre-development period, however, data to establish background trends is limited, particularly with corresponding estimates of groundwater use.

In recent times, OGIA has been exploring the application of signal processing and modelling tools to support trend analysis. The primary drivers for this research are the quantification and complexity of the factors that can affect groundwater levels, the quantum of monitoring data and the need to streamline and apply increasing automation to the assessment process.

Conceptually, signal processing is the process of generating a set of responses (signals) from a range of individual influences – such as associated water production and cumulative deviation from mean monthly rainfall (CDMMR) – then combining these signals to match observed groundwater levels. This numerically extensive and demanding technique, is showing promising results, however, further research and development is necessary prior to broader application (OGIA 2021g).

For the assessment in this UWIR, OGIA has built further upon a multiple-lines-of-evidence approach applied in 2019 (OGIA 2019a) that included statistical and visual correlation of observed trends with a range of factors such as estimated rainfall recharge, estimated groundwater use and associated water extraction. This has been further enhanced to also include the analysis of hydraulic gradients, hydrochemistry and isotopes. For completeness and contextual purposes, spatial trend analysis also includes preparing and assessing potentiometric maps (groundwater level maps) that are presented in Appendix D together with selected hydrographs. Key steps applied are summarised as follows:

- Compile and quality-control the available monitoring data and generate time-series datasets.

- Generate groundwater level surfaces (or piezometric maps) for the Condamine Alluvium, the Springbok, Hutton and Precipice sandstones and the two target formations.
- Identify focus areas where there is potential for groundwater flow towards the coal formations and potential for impacts in surrounding formations.
- Within the focus areas, characterise the coal formation and adjacent aquifers to provide contextual information for the analysis – including the hydraulic properties of the aquifer, intervening aquitards and relevant connectivity features.
- Classify data as pre- or post-resource-development based on whether monitoring points are more than 10 km from an active CSG well. Data from monitoring points that were operational before a CSG well commenced within 10 km of the monitoring point is classified as ‘pre-development’ data. The amount of post development data changes over time as the resource development progresses. For the Walloon Coal Measures, a radius of 20 km is applied. These distances are based on the magnitude of observed declines in monitoring points in the Walloon Coal Measures, their distance to active CSG wells (Figure 5-2) and the potential for CSG impacts beyond 10 km.
- Calculate annual rate of change for both pre- and post-resource-development periods. Only those monitoring points with more than 10 records over more than 12 months have been included in this analysis.
- In conjunction with groundwater levels, the isotopes of strontium ( $^{87}\text{Sr}$  and  $^{86}\text{Sr}$ ) are now collected on a regular basis. The  $^{87}\text{Sr}/^{86}\text{Sr}$  isotope ratio (the ‘strontium ratio’) can provide useful insights into the connectivity between formations. If the strontium ratio for a coal formation differs from adjacent aquifers, then a coal formation strontium ratio close to that of an adjacent aquifer may be indicative of inflows from the adjacent aquifer. In parallel, major ion hydrochemistry of the coal formations and adjacent aquifers is also analysed to identify areas of potential connectivity.
- Finally, a site-specific analysis of trends and stressors at representative locations in the context of key water balance factors – groundwater use, associated water extraction (coal mines and P&G production) and climate – in combination with conceptualisation of key connectivity features and impact pathways as presented in the previous chapter.

## 5.6 Results and conclusions

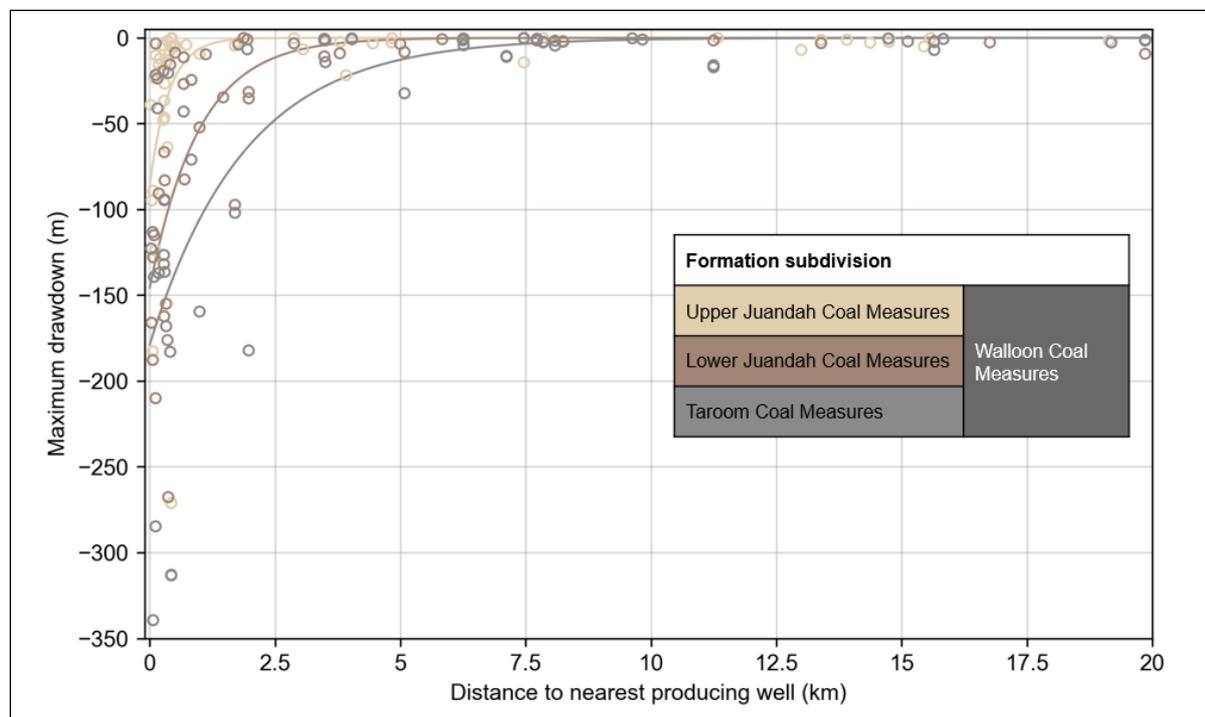
A summary of the spatial and temporal trends is provided here in two groups: the target formations (or the reservoirs), i.e. the formations that are directly subject to associated water extraction which are the Walloon Coal Measures and the Bandanna Formation; and the adjacent aquifers to which impacts from those target formations may propagate. Further details of the assessment are available in a separate companion document (OGIA 2021g).

### 5.6.1 Target formations

#### 5.6.1.1 Walloon Coal Measures

Consistent with other Surat Basin formations, the regional groundwater flow in the Walloon Coal Measures north of the GDR is generally northward, suggesting discharge into the Dawson River catchment. South of the GDR, groundwater flow directions are generally to the south and in the east, groundwater flow directions are broadly consistent with the dip of the formation (Appendix D).

Areas of extensive CSG development are reflected in the regional groundwater levels as local to sub-regional areas of depressed groundwater levels (OGIA 2021b). Comparison of observed groundwater level decline from all monitoring points in the Walloon Coal Measures, with distance to nearest active CSG well, is shown in Figure 5-2. The spatial distribution and magnitude of observed drawdown at monitoring locations for the upper Juandah and Taroom coal measures are shown in Figure 5-3.



**Figure 5-2: Observed groundwater level drawdown in the Walloon Coal Measures with distance to nearest CSG production well**

These figures provide valuable insights into the magnitude and extent of observed drawdown in the Walloon Coal Measures including the following:

- Drawdowns of more than 10 m are generally within 10 km of CSG production wells.
- The cone of groundwater level decline or drawdown (also referred to as the **cone of depression**) around the CSG field is very steep.
- CSG-induced drawdown increases with depth – being the highest in the Taroom Coal Measures (around 350 m), followed by the Lower Juandah Coal Measures (250 m) and the Upper Juandah Coal Measures (150 m).

The different magnitude of observed drawdown across the sub-units of the Walloon Coal Measures also reflects, in part, the differences between the sub-units in terms of connectivity between coal seams due to the differing proportion of intervening low-permeability interburden. This is demonstrated at several nested or closely located monitoring points within the development area. There are some rising groundwater level trends around the periphery of CSG production, which may be due to migration of gas.

Examples of groundwater level response to CSG and coal mine development at four representative locations (Figure 5-3) are shown in Figure 5-4, along with rainfall data (CDMMR). For comparison, the CSG associated water extraction within 20 km is shown on the same figures, together with mine associated water extraction within 5 km.

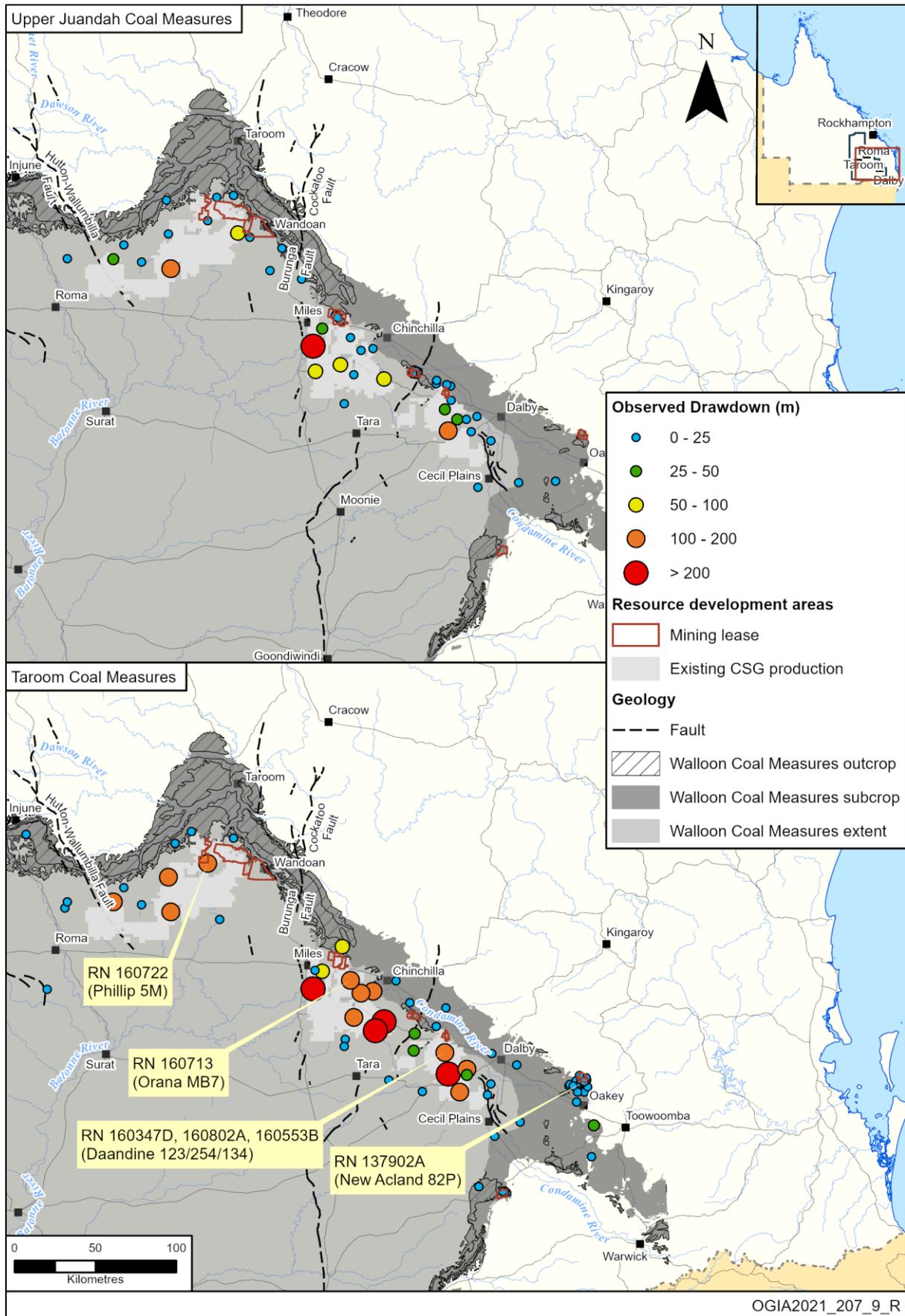


Figure 5-3: Observed drawdown in the upper Juandah and Taroom coal measures

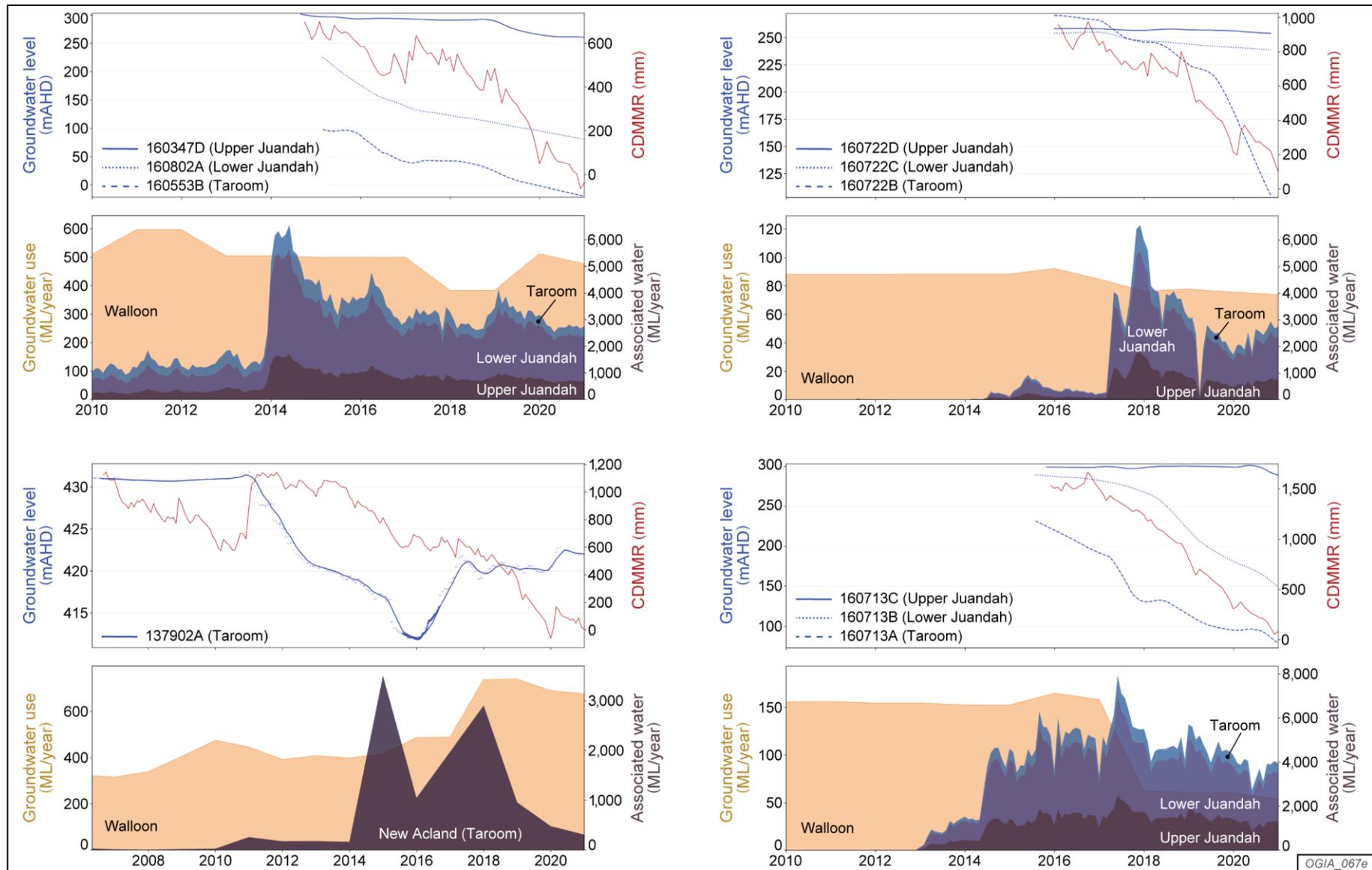


Figure 5-4: Groundwater level trends at selected sites in the Walloon Coal Measures

At the Daandine gas field immediately west of Dalby, a gradual decline in groundwater level of more than 100 m is observed in the Lower Juandah and Taroom coal measures (RN160802A, 160553B) with less than a 50-m decline observed in the Upper Juandah Coal Measures (RN 160347D).

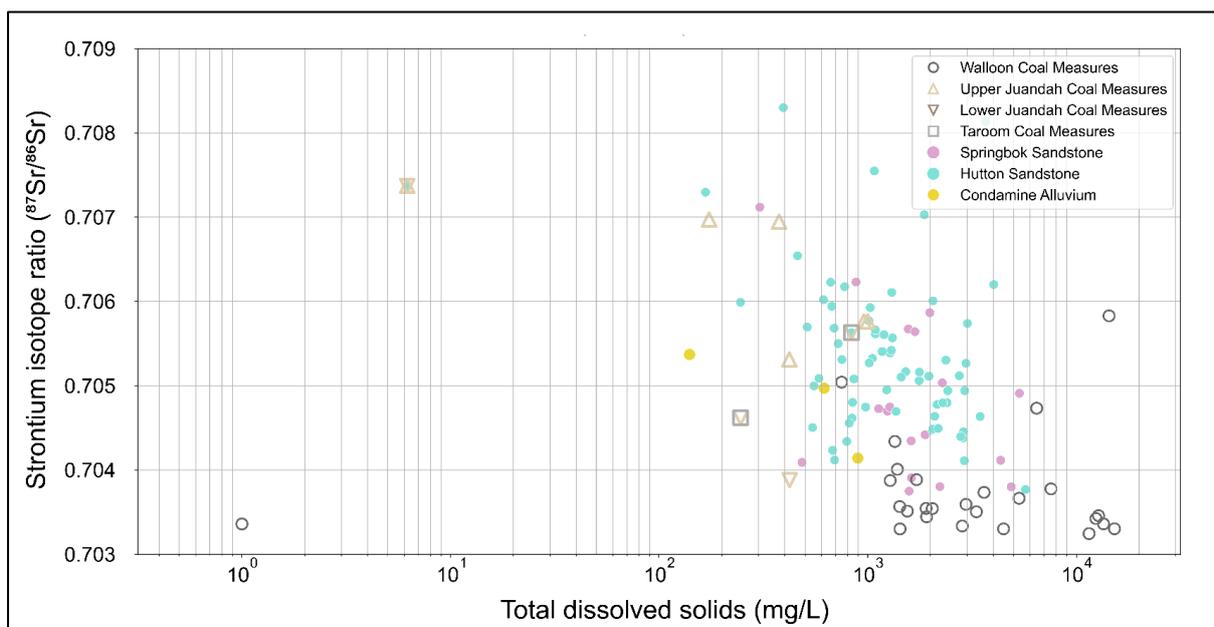
At Orana MB7 (RN 160713), around 20 km northwest of Chinchilla, the lower two sub-units of the Walloon Coal Measures show a decline in response to regional CSG production, prior to more local CSG development commencing in early 2017. As a result, a steady decline is observed in the Taroom Coal Measures (150 to 170 m), with progressive delays in the onset of drawdown in the upper parts of the formation such that significant drawdown in the upper Juandah only commencing in 2020 (currently less than 20 m).

In the northern development area south of Wandoan, CSG production commenced more recently than the southern development areas. A rapid and steep decline of up to 180 m is observed in the Taroom Coal Measures at Phillip 5M (RN160722) which is the lowermost sub-unit. This is likely due to the relatively recent commencement of development in the area but there has been little impact in the upper sub-units with currently less than 5 m in shallow Upper Juandah Coal Measures.

Groundwater use from the Walloon Coal Measures in and near the active development area is around 2,400 ML/year – about 4% of the associated water extraction by CSG. Therefore, almost all the decline in the Walloon Coal Measures in CSG development areas is related to CSG extraction.

New Acland 82P (RN137902A) is located adjacent to the New Acland coal mine north of Oakey. The impact of groundwater seepage into the mine pits is evident in this area where a decline of 10 to 20 m is observed in the Acland coal sequence (a unit of the Taroom Coal Measures) from 2011 onward.

The  $^{87}\text{Sr}/^{86}\text{Sr}$  isotope ratio for the Walloon Coal Measures and adjacent aquifer samples are shown in Figure 5-5. Samples from the Walloon Coal Measures generally have values below 0.704, while the adjacent aquifers (Hutton Sandstone, Springbok Sandstone, Condamine Alluvium) tend to have higher values. Strontium ratios greater than 0.704 in the Walloon Coal Measures, or lower than 0.704 in the Springbok or Hutton Sandstones, may be an indication of connectivity between aquifers.

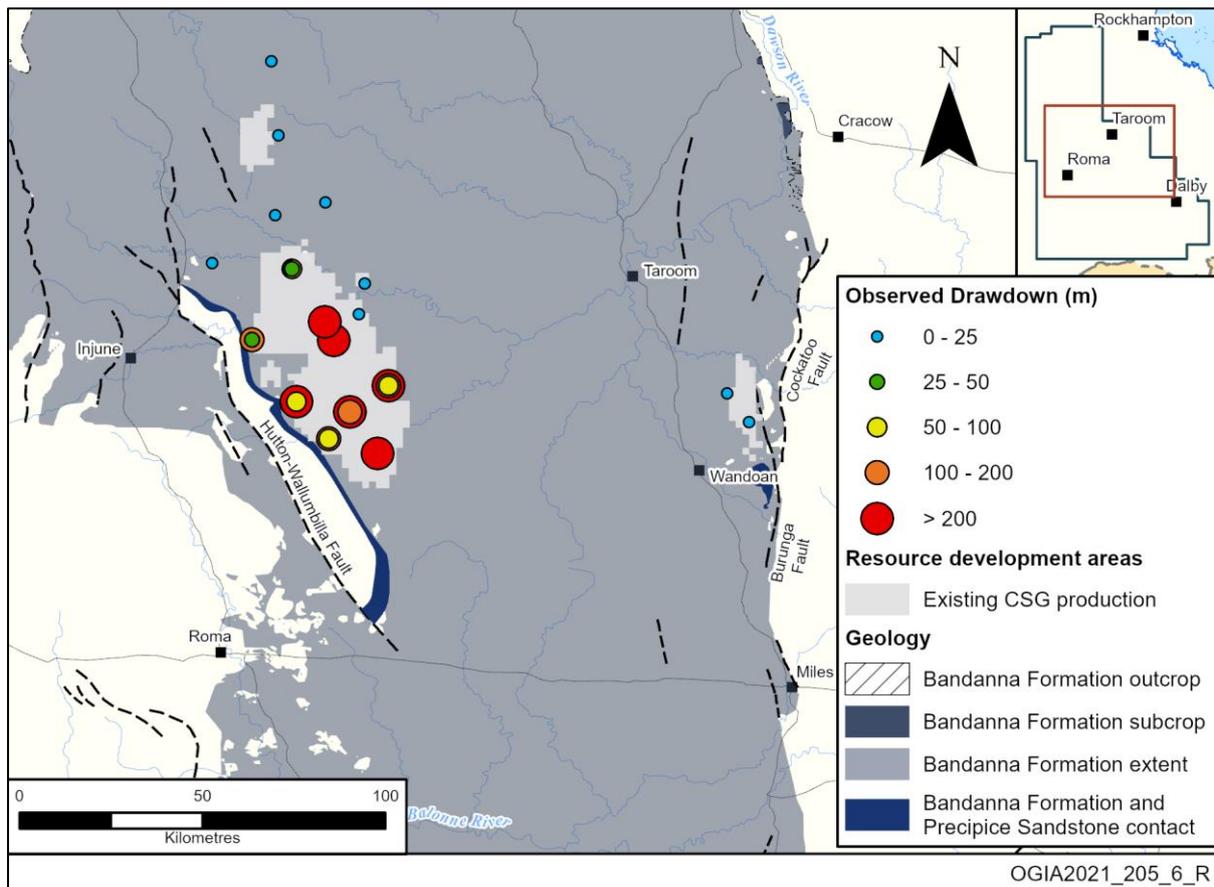


**Figure 5-5: Strontium isotope ratios ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) over total dissolved solids (TDS) for the Walloon Coal Measures, Springbok Sandstone, Hutton Sandstone and Condamine Alluvium**

### 5.6.1.2 Bandanna Formation

Development in the Bandanna Formation is concentrated at the Fairview and Spring Gully gas fields east of Injune, and in the equivalent Rangal and Baralaba coal measures at the Peat and Scotia fields around Wandoan. These production areas are separated by the Taroom Trough, where the Bandanna Formation is present at significant depths (>5,000 m).

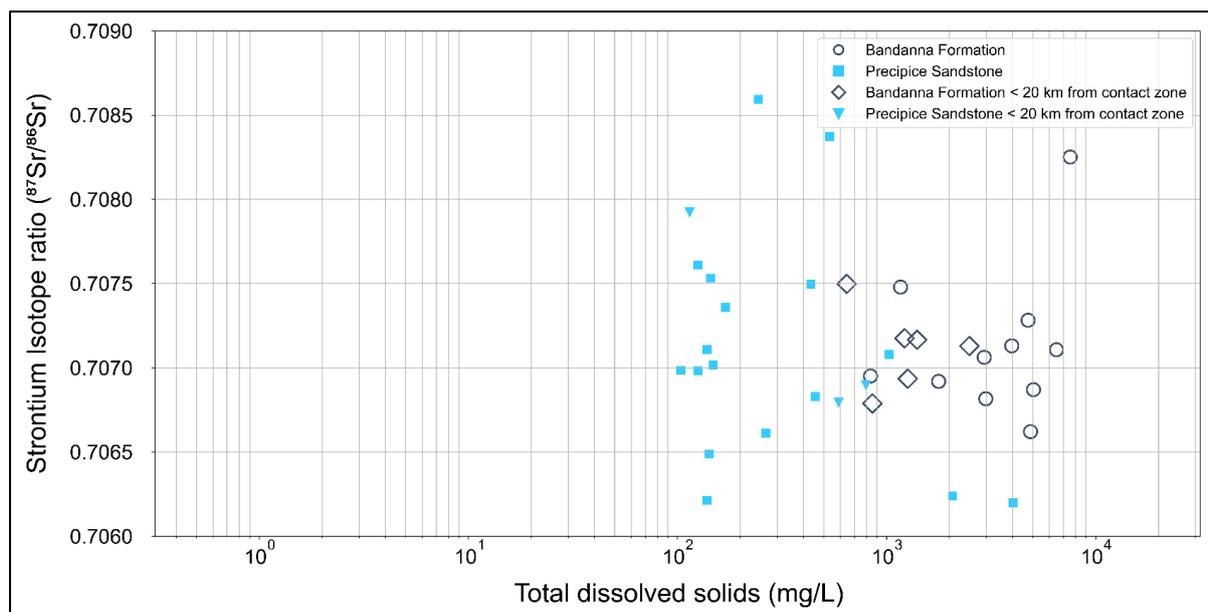
As is the case for the Walloon Coal Measures, there is significant observed drawdown in the Bandanna Formation (Figure 5-6). Although monitoring data is unavailable prior to production, observed drawdown since production are in excess of 400 m. Many of these locations are in close proximity to the interpreted contact zones (section 4.4.8) and therefore ongoing monitoring in these areas is important to assess connectivity.



**Figure 5-6: Observed drawdown in the Bandanna Formation**

At the Fairview gas field adjacent to the western contact zone, the Bandanna Formation is found at depths of around 600 m. In contrast, around the eastern contact zone, the equivalent Rangal and Baralaba coal measures are found at around 1,000 m.

Figure 5-7 shows the available strontium isotope data for the Bandanna Formation and its adjacent aquifer – the Precipice Sandstone. The currently available data indicates that the Precipice Sandstone has a wide range of values, and the values for the Bandanna Formation fall within this range. This suggests that strontium isotope ratios may not be able to indicate connectivity between these units in areas where they have locally similar strontium isotope ratios. This will be further evaluated as more monitoring data becomes available.



**Figure 5-7: Strontium isotope ratios (<sup>87</sup>Sr/<sup>86</sup>Sr) over total dissolved solids (TDS) for the Bandanna Formation and the Precipice Sandstone**

## 5.6.2 Adjacent aquifers

In this section, summary of the analysis for the pre- and post-resource-development period is provided for aquifers adjacent to the resource target formations – the Springbok, Hutton and Precipice sandstones and the Condamine Alluvium. For each aquifer, representative hydrographs and local water balance influences are used to support the analysis, including CDMMR as a proxy for variations in groundwater recharge, total CSG associated water extraction within 10 km, coal mine dewatering within 5 km, estimated groundwater use (from water bores) within 20 km, and reinjection volumes (Precipice Sandstone only).

### 5.6.2.1 Hutton Sandstone

There is a low level of connectivity between the Hutton Sandstone and the overlying Walloon Coal Measures in the Surat Basin, as described in section 4.4.4.

Groundwater level trends in the Hutton Sandstone are of particular interest as declining trends have been observed in CSG development areas, which causes some concern for water users. There are also a number of significant springs dependent on this aquifer in the northern parts of the Surat basin.

As shown in Appendix D, groundwater flow directions in the Hutton Sandstone are similar to other Surat Basin formations with an interpreted groundwater divide around the GDR, resulting in two dominant flow directions. North of the GDR, groundwater flows towards the northeast, suggesting discharge to the Dawson River, while south of the GDR, the flow is towards the south and southwest, consistent with the dip of the formation. This pattern is also consistent with earlier findings (Hodgkinson, Hortle & McKillop 2010; Ransley & Smerdon 2012; OGIA 2016a).

The location and estimated annual trends for the available data points are shown in Figure 5-8, with example hydrographs shown in Figure 5-9. These representative plots illustrate the local influences on the groundwater system in the vicinity of the monitoring point. Additional information is available for each site in the companion document (OGIA 2021g).

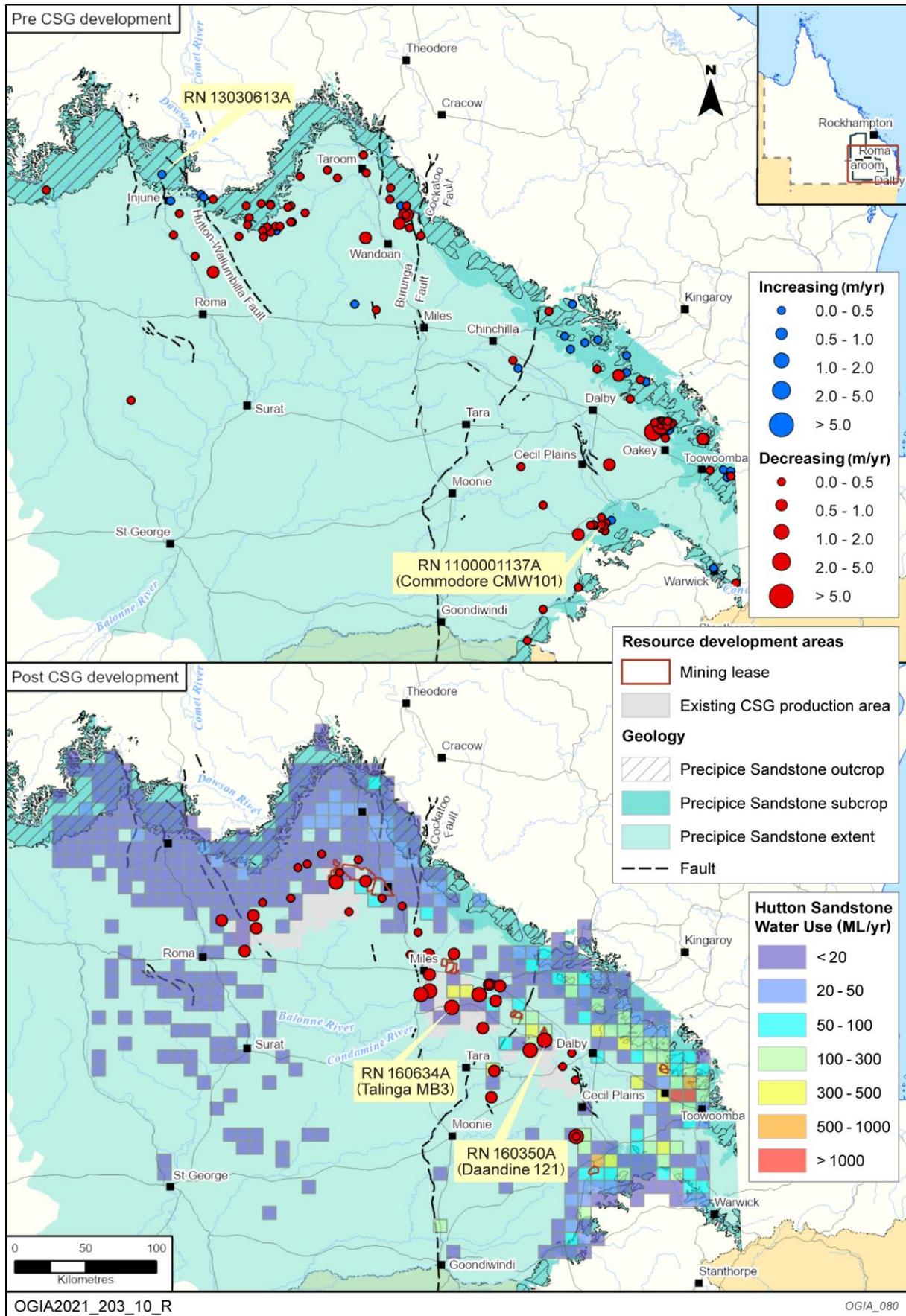


Figure 5-8: Summary of groundwater level trends in the Hutton Sandstone

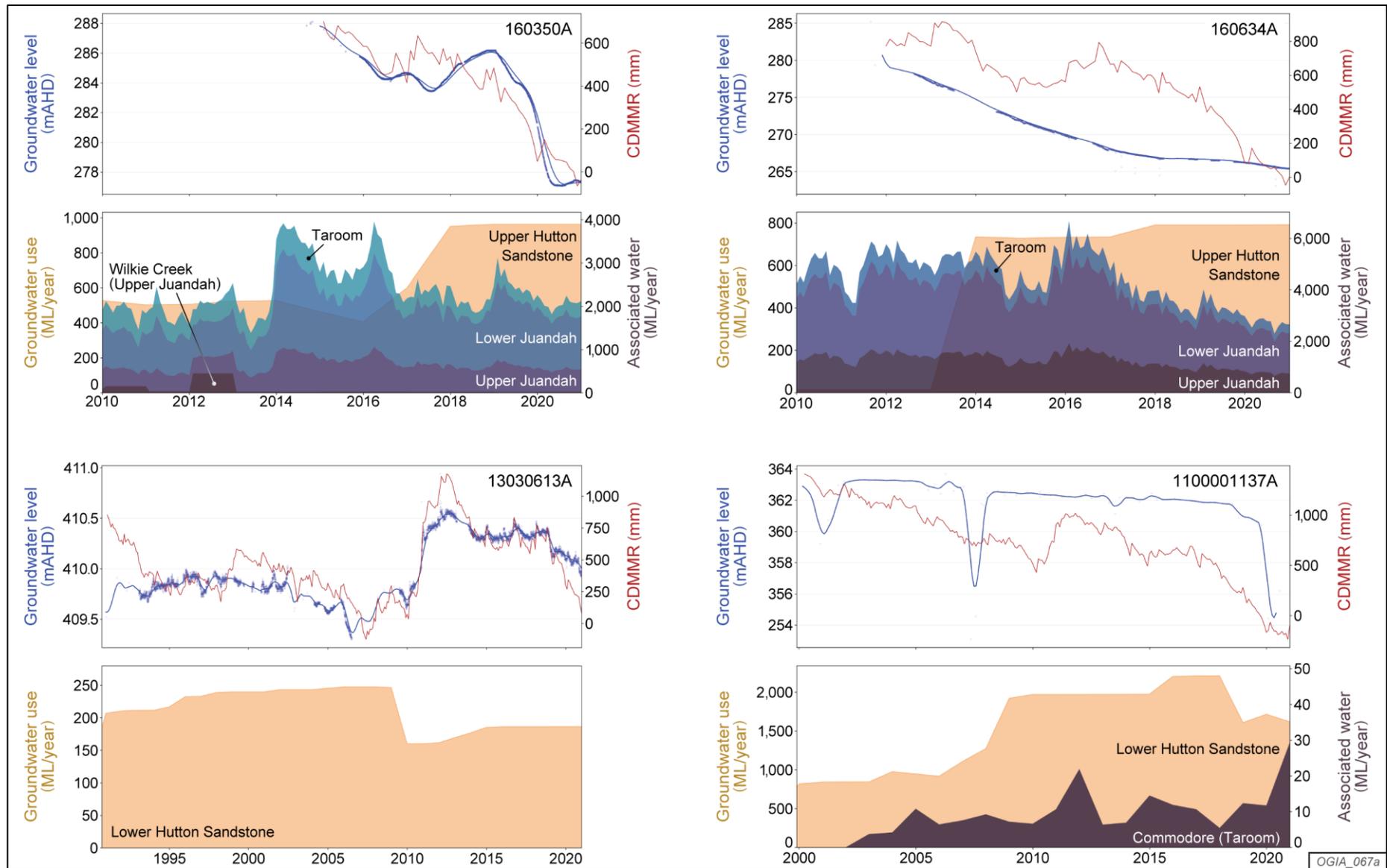


Figure 5-9: Example hydrographs showing trends in the Hutton Sandstone

Within and adjacent to the outcrop areas, observed groundwater levels are relatively stable and show a correlation with variations in rainfall and groundwater use directly from the aquifer. RN13030613A is within the outcrop of the Hutton Sandstone north of Injune (Figure 5-8). In this area, there is minimal groundwater use and the hydrograph shows a strong correlation with rainfall (Figure 5-9). In contrast, RN1100001137A (Commodore CMW101) is within the outcrop of the Hutton Sandstone southeast of Cecil Plains, near the Commodore coal mine. The observed groundwater level trend is generally stable but is influenced by nearby groundwater use for industrial purposes (Figure 5-9).

Away from aquifer outcrop, in deeper confined parts of the system, there is no obvious correlation with patterns of rainfall and likely recharge events. However, longer-term decadal trends in climate are evident in some observed trends (RN160350A and RN 160634A, Figure 5-9). This diminishing trend response with distance from the source of recharge is consistent with the response expected and described in earlier sections.

In the post-development period, the majority of sites – particularly in confined parts of the system – show generally declining trends of between 0.5 and 2.0 m per year. Declining trends are noted both within and outside of CSG production areas. However, north of the GDR where the groundwater flow direction is northward, observed trends show little variation, including within CSG production areas.

The distribution of groundwater use from the Hutton Sandstone (Figure 5-8) indicates extensive groundwater development in areas where the formation is either at outcrop or at depths of less than 500 m. The majority of groundwater use north of the GDR is for S&D purposes, while further south, around Toowoomba and Dalby, there is significant use for industrial, stock-intensive, town water supply and irrigation purposes – representing more than 30% of the total extraction from the Hutton Sandstone (about 6,200 ML/year). Between Dalby and Chinchilla, there are local areas of significant groundwater use for industrial and stock-intensive purposes (about 2,000 ML/year). These areas of extensive groundwater use correlate spatially with declining trends.

There is no discernible change in the rate of groundwater level decline following the commencement of CSG associated water extraction. Increased rates of decline are observed at some locations, such as RN160350A (Figure 5-9) in late 2019 and early 2020, which are due to below-average rainfall and increased groundwater demand. More recently, the groundwater levels have stabilised despite continued decline in the Taroom Coal Measures – suggesting little cross-formational flow. This conclusion is supported by the strontium isotope data discussed earlier.

Given the limited historical data, a sub-regional-scale groundwater model was developed during the last UWIR cycle to further evaluate whether CSG impacts may have occurred in the Hutton Sandstone, and to test different hypotheses that may explain the observed drawdown at RN160634A (Figure 5-8 and Figure 5-9) in the vicinity of Talinga and Condabri gas fields. The results suggested that CSG impacts are unlikely to propagate to the Hutton Sandstone unless the vertical permeabilities of the Durabilla Formation, which separates the Hutton Sandstone from the overlying Taroom Coal Measures, are uncharacteristically high (OGIA 2019a).

In conclusion, the available data indicates that declining trends in the Hutton Sandstone are unlikely to be related to CSG associated water extraction in the overlying Walloon Coal Measures. Groundwater use from the Hutton Sandstone aquifer is likely to be the primary cause of the observed declining trends. CSG depressurisation may be a contributing factor in some areas but there is no definitive evidence at this stage. However, some CSG impacts are predicted in the Hutton Sandstone in the longer term.

### 5.6.2.2 Springbok Sandstone

The Springbok Sandstone overlies the Walloon Coal Measures, separated by a non-coal zone. As discussed in section 4.4.3, the contact between the two formations is erosional and there are areas where the productive coal seams are in direct contact with the Springbok Sandstone.

Groundwater flow directions in the Springbok Sandstone are similar to other formations (Appendix D). Although somewhat limited, the available data north of the GDR suggests possible northward groundwater flow and discharge to the upper tributaries of the Dawson River and associated minor alluvium. South of the GDR, groundwater flow is generally to the south and south-west, consistent with the dip of the formation.

The location and estimated annual trend for the available data points are shown in Figure 5-10, with example hydrographs shown in Figure 5-11. Additional information is available for each site in the companion document (OGIA 2021g).

While considerable variation occurs in the observed groundwater levels in the Springbok Sandstone, there are spatially consistent trends. North of the GDR in shallower areas around the periphery of CSG production, groundwater levels are generally rising – potentially related to gas migration – whereas the groundwater levels within the confined areas are generally declining.

In deeper parts of the groundwater system in and around the gas fields, impacts from depressurisation are observed at Kenya East GW4 (RN160525A, Figure 5-10 and Figure 5-11) – around 30 km south of Chinchilla. At this location, a nearby fault has been identified (section 4.4.2) which has juxtaposed the Walloon Coal Measures against the Springbok Sandstone, enhancing connectivity and the potential for groundwater flow between the two formations. Groundwater levels in the Springbok Sandstone were stable until late 2014, after which a rapid fall commences, resulting in a total decline of around 20 m. The commencement of this decline correlates with a rapid increase in CSG production within 10 km of this site.

Groundwater chemistry for a number of CSG wells and monitoring points in this area also indicates potential mixing of water between the two formations. This is especially evident in the isotope analysis that suggests the strontium ratios are similar with values for both units around 7.04.

Declining trends outside CSG production areas are also noted – Glenburnie 18 (RN 160941E, Figure 5-10 and Figure 5-11) – but are unrelated to CSG development, as only limited pilot production has occurred in this area.

Rising trends are observed at a number of locations within the Springbok Sandstone on the periphery of CSG production (Figure 5-10) – for example, at the Talinga MB21 monitoring point (RN 160693A, Figure 5-10 and Figure 5-11). High concentrations of dissolved methane are also observed at this location. The cause of these rising trends is therefore likely due to the presence of gas migrating from the shallow Walloon Coal Measures into the Springbok Sandstone.

In summary, there are variable trends in the Springbok Sandstone. Consistent with previous predictions, there is evidence of CSG impact at some locations, particularly where connectivity may be enhanced due to local geological features, such as faults. There is also some groundwater use from the formation, which may be sufficient to cause localised groundwater level declines, particularly outside of CSG production areas. Observed impacts from CSG are generally less than those predicted due to the conservative approach taken in modelling and the potential influence of migrating gas in water levels. OGIA will further investigate this during the next cycle.

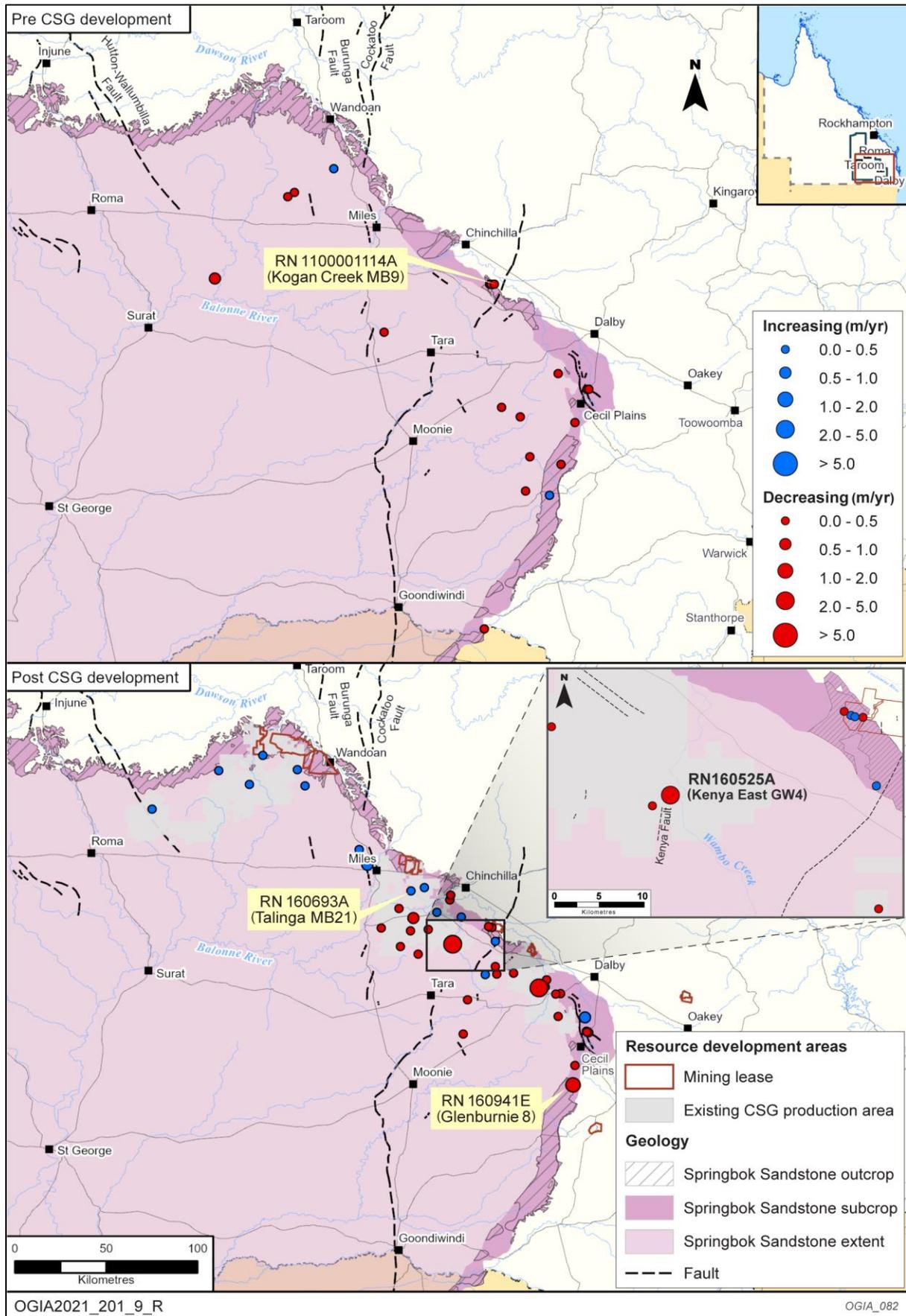


Figure 5-10: Summary of groundwater level trends in the Springbok Sandstone

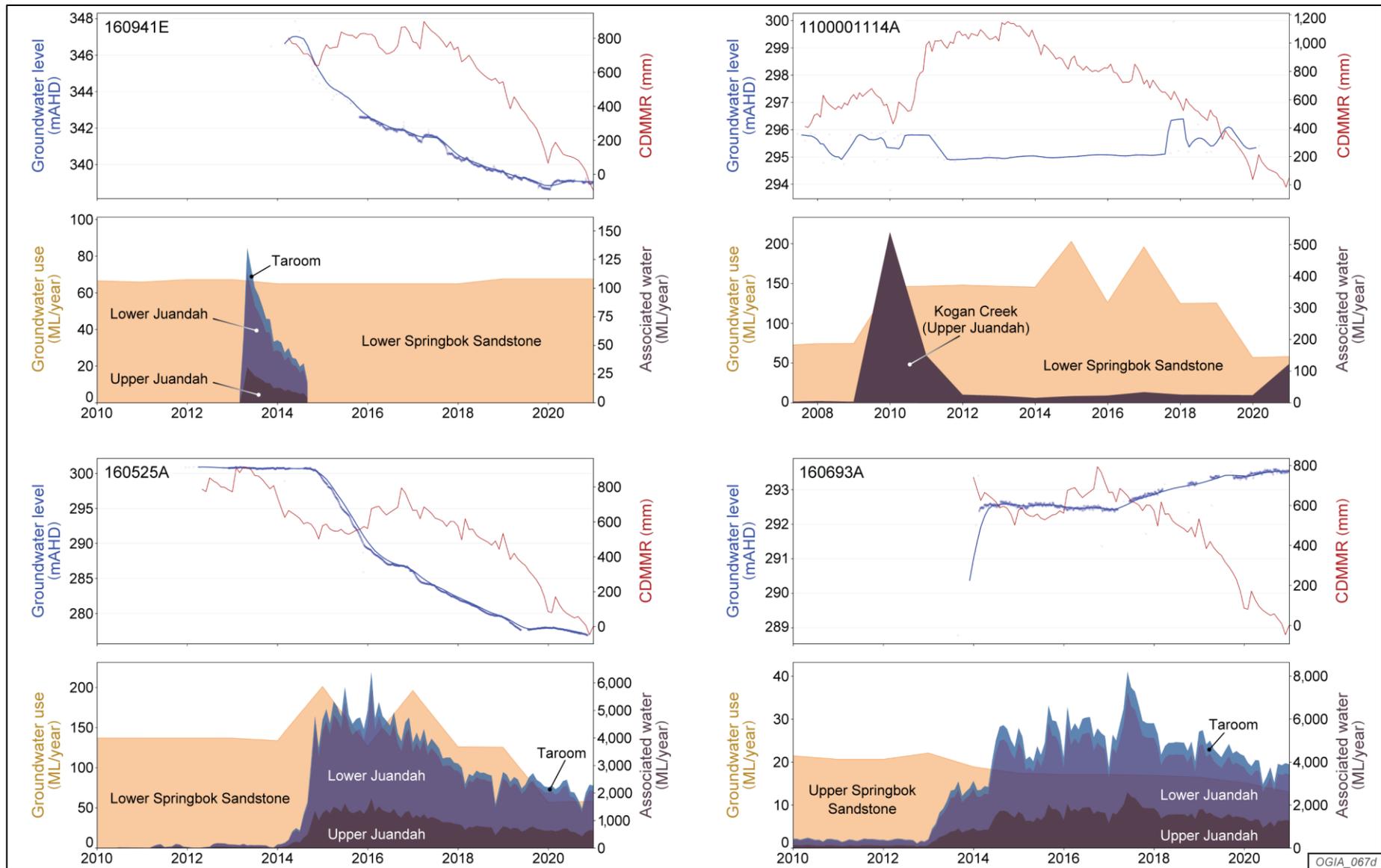
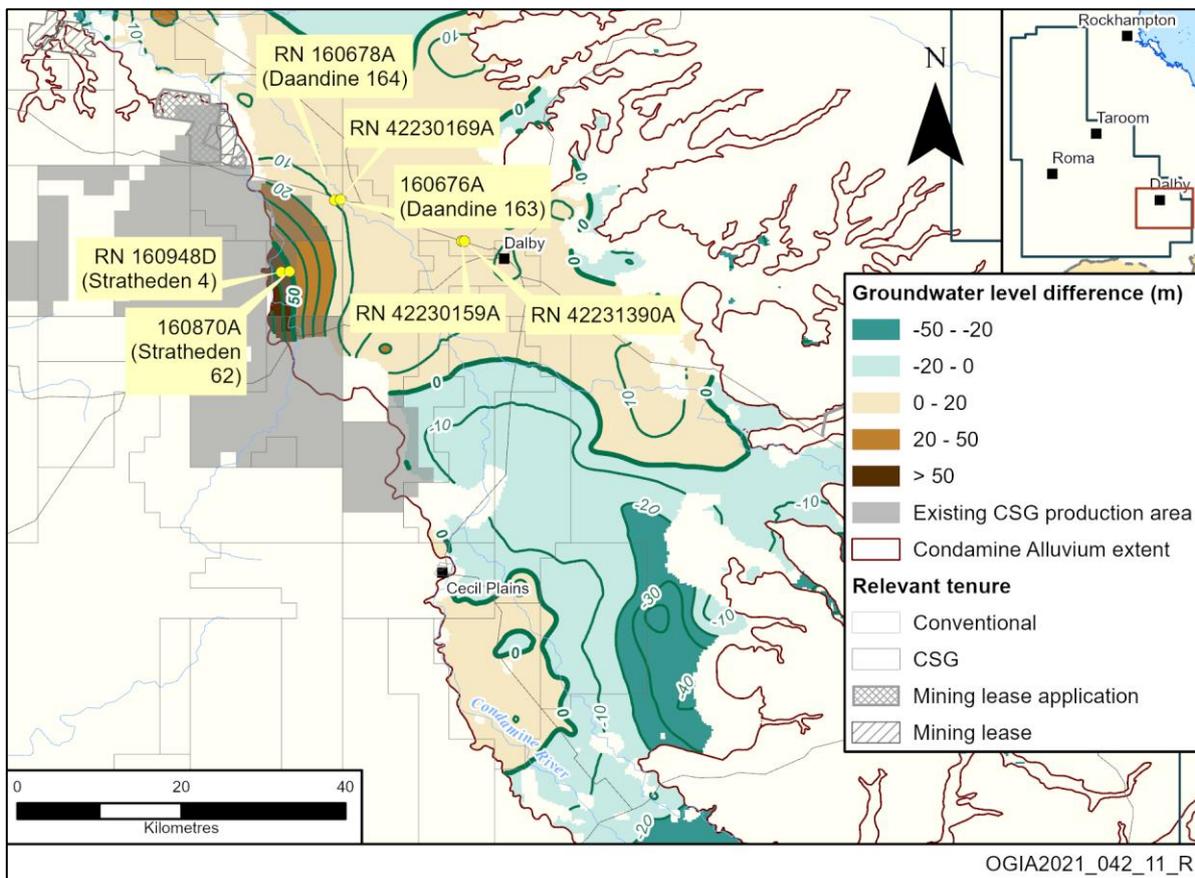


Figure 5-11: Example hydrographs showing trends in the Springbok Sandstone

### 5.6.2.3 Condamine Alluvium

The Condamine Alluvium overlies the Walloon Coal Measures along the eastern edges of the Surat Basin and has been heavily exploited for groundwater irrigation. This has reduced the groundwater level in the more developed parts of the Condamine Alluvium by up to 30 m over the past 60 years, significantly altering the flow pattern in the formation. Until recently, groundwater levels in the Walloon Coal Measures have not materially changed, resulting in an upward groundwater level gradient of 5 to 20 m between the formations across much of the central part of the Condamine Alluvium (OGIA 2016a).

Updated mapping of the groundwater level difference between the Condamine Alluvium and the Walloon Coal Measures, along the western flank of the alluvium where CSG development has occurred, is presented in Figure 5-12. The pattern is comparable to those previously reported and continues to suggest overall low connectivity between the two formations (section 4.4.5).



**Figure 5-12: Groundwater level difference – Condamine Alluvium to the Walloon Coal Measures**

In this area of close proximity to CSG development, temporal groundwater level trends are demonstrated through data from two monitoring sites – RN 42230159A east of the Condamine River away from CSG development, and RN 42230169A near the Daandine gas field (Figure 5-13).

Since 1990, the trends at these monitoring points correlate well with longer-term dry and wet periods and corresponding groundwater use within 10 km, particularly in the period 1990 to 2005. Nearby monitoring in the Lower Juandah Coal Measures, such as RN 42231390A and RN 160678A, shows clear declining trends that are not observed in the Condamine Alluvium, although it is important to note that the length of record is short.

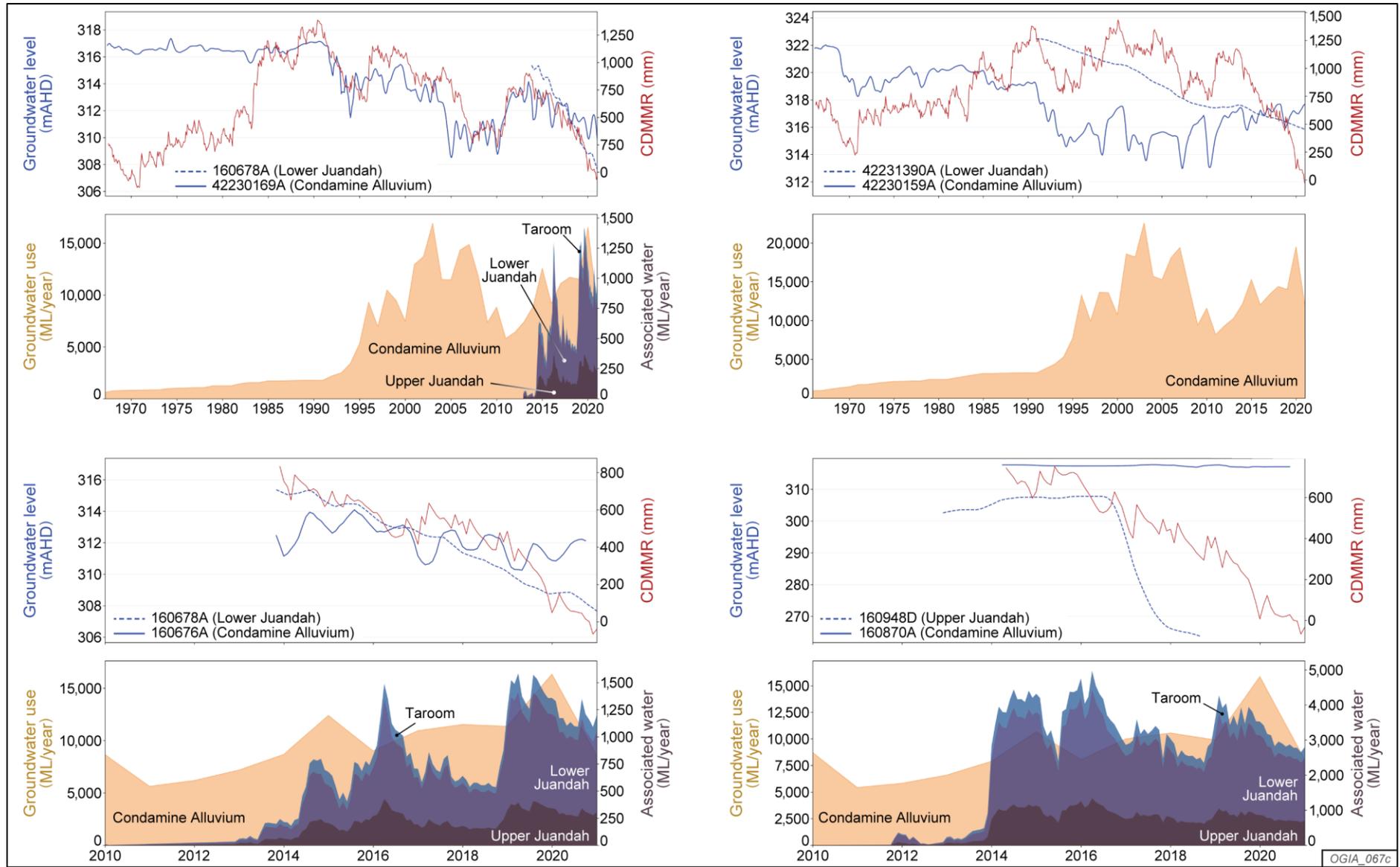


Figure 5-13: Example hydrograph showing trends in the Condamine Alluvium and the underlying Walloon Coal Measures

West of Dalby, at RN 160948 (Stratheden 4), significant drawdown is observed in the Walloon Coal Measures due to associated water extraction, creating a groundwater level difference of more than 30 m from the Condamine Alluvium to the underlying Upper Juandah Coal Measures. A similar relationship is beginning to emerge at other sites such as RN 160678 (Daandine 164), which was one of two pumping test sites investigated as part of the Condamine Connectivity study. At this stage, there are no discernible responses in the Condamine Alluvium at these locations. This is consistent with the findings from the Condamine Connectivity study which found that fluctuations in groundwater levels during the testing period at RN 160678 were attributed to the effects of mechanical loading and regional trends in the Walloon Coal Measures (OGIA 2016a).

In summary, consistent with previously reported findings, it is considered unlikely that the trends in the Condamine Alluvium are influenced by associated water extraction in the Walloon Coal Measures, which is consistent with groundwater modelling predictions in the previous UWIR.

#### **5.6.2.4 Precipice Sandstone**

The Precipice Sandstone is the basal unit of the GAB in the Surat CMA and while it is well isolated from the Walloon Coal Measures, there are isolated areas of connection in the north with the Bandanna Formation – the CSG target formation in the Bowen Basin. There is also substantial conventional oil and gas production from the Moonie oil field in the southern CMA, which has produced directly from the Precipice Sandstone since 1964 (section 4.4.10).

There are two dominant groundwater flow directions, broadly flowing either side of the GDR (Appendix D). Groundwater discharge – and pressure – support many significant springs (Chapter 10) and groundwater use in the northern and eastern Surat CMA (Chapter 4).

The location and estimated annual trends for the available data are shown in Figure 5-14, with example hydrographs shown in Figure 5-15. Associated water extraction and groundwater use are also shown, along with the aquifer reinjection profile from Reedy Creek and Spring Gully sites.

Similar to the UWIR 2019, the available data shows a mix of stable to moderately declining trends until 2015 and generally increasing trends thereafter (Figure 5-15). However, the observed trends broadly correlate with the location of groundwater use and reinjection and the commencement of those activities on the groundwater system. In the southern and south-eastern extent of the Precipice Sandstone, declining trends are generally attributed to groundwater use for town water supply, stock-intensive and industrial purposes, except near the Moonie oil field where declines are due to conventional oil and gas production.

Since the commencement of reinjection of treated CSG water into the Precipice Sandstone in 2015, significant groundwater level responses have been observed across the groundwater system. The magnitude of the groundwater level response to reinjection increases the complexity of identifying smaller CSG impacts on groundwater levels. At the Reedy Creek reinjection site, initial short-term groundwater level increases of up to 50 m have been observed (RN160966, Figure 5-15). Regionally, pressure responses are observed more than 80 km from the reinjection site (RN160474, Figure 5-15), highlighting the high permeability and transmissivity of this unit.

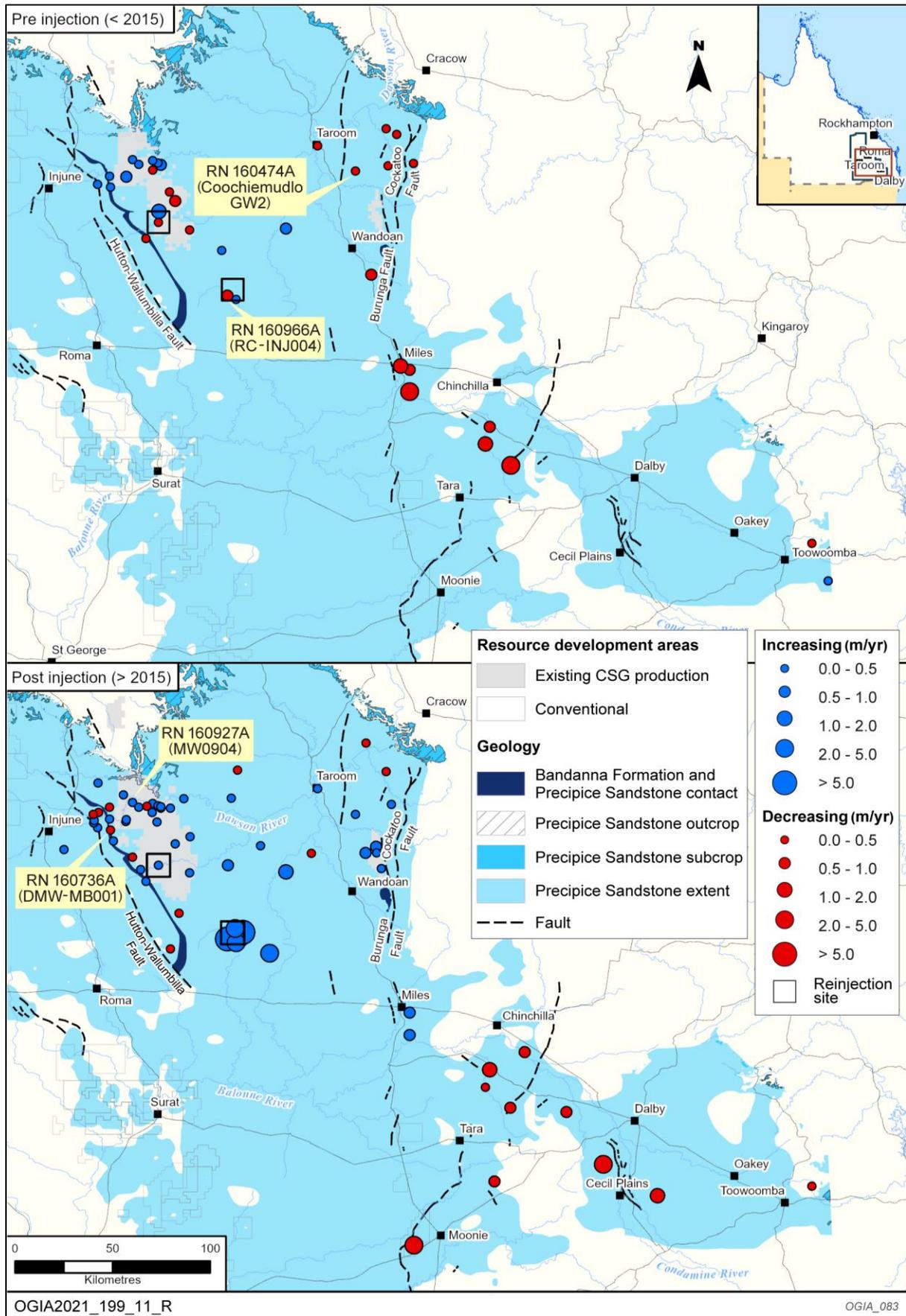


Figure 5-14: Summary of groundwater level trends in the Precipice Sandstone

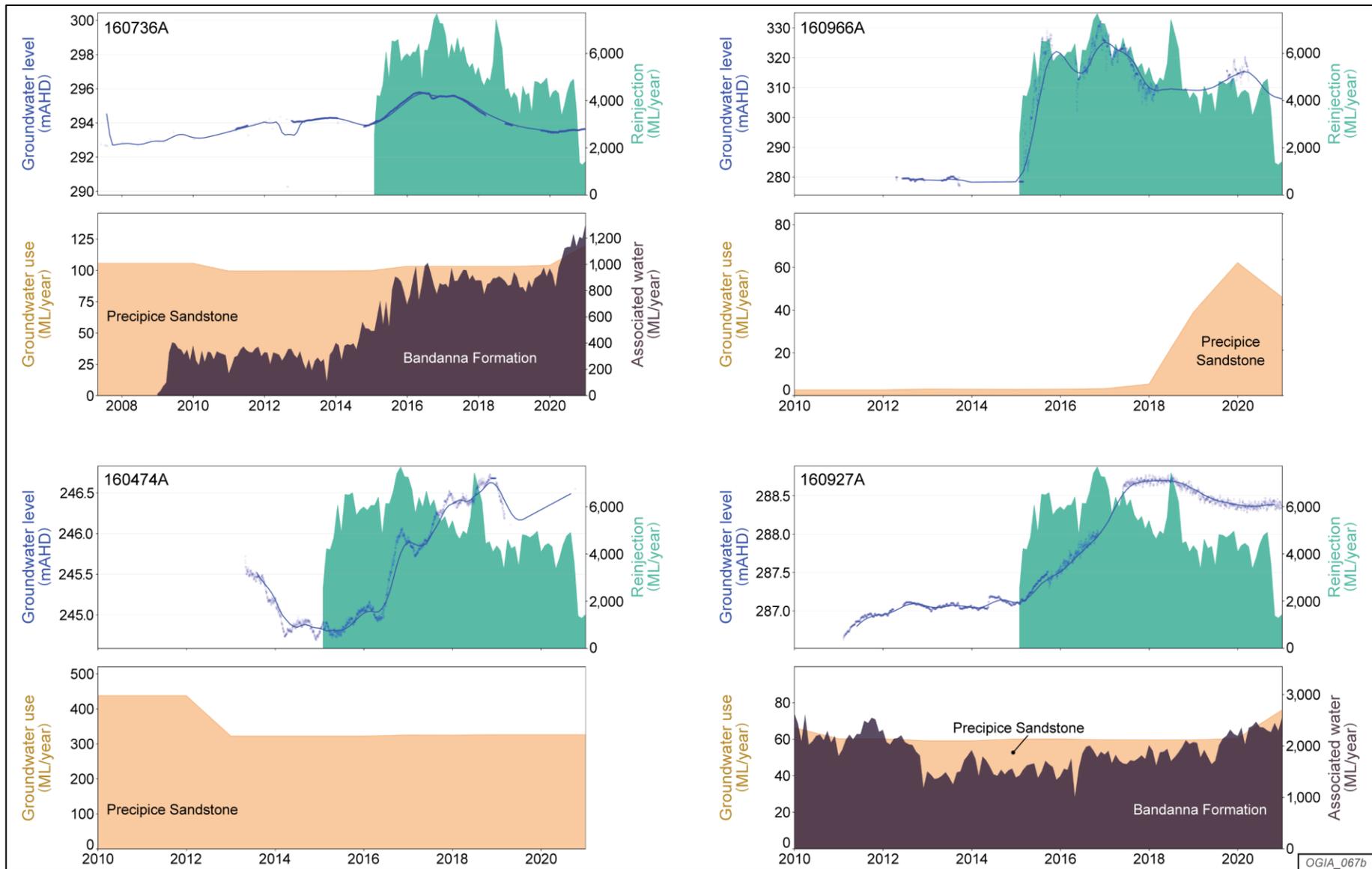


Figure 5-15: Example hydrographs showing trends in the Precipice Sandstone

Around the western contact zone, there are significant groundwater level decline in the Bandanna Formation. However, the majority of observed groundwater level trends in the Precipice Sandstone correlate with reinjection and climatic fluctuations and it is difficult to identify CSG impacts at this stage. The available strontium data for the Precipice Sandstone in this area has also been analysed to identify impact. As discussed (section 5.6.1.2), there is insufficient data to identify inter-aquifer mixing at this stage.

To support the further evaluation of the observed trends in this area, OGIA has analysed time-series water and gas production from CSG wells located within 10 km of the western contact zone adjacent to the Fairview gas field, as comparatively higher or sustained higher associated water extraction rates may be indicative of flow across the contact zone. This work is ongoing but preliminary results suggest wells located closer to the contact zone (within 6 km) produce higher associated water extraction volumes and maintain higher water-to-gas ratios, compared to other wells across the areas. However, while this may suggest that flow may be contributed from the Precipice Sandstone into the Bandanna Formation there is little evidence in groundwater levels in the Precipice Sandstone..

In summary, there is limited evidence of CSG impacts at the two contact zones at this stage. Aquifer reinjection is the dominant influence on groundwater levels in these areas. Further south, away from CSG production, groundwater levels in the Precipice Sandstone have been affected by groundwater use and associated water extraction from the Moonie oil field, although there is limited long-term groundwater monitoring data to confirm this conclusion.

#### **5.6.2.5 Main Range Volcanics**

In the south-eastern Surat CMA, the Main Range Volcanics is a significant groundwater system providing water supplies for some towns, S&D and irrigation. The Main Range Volcanics dominantly comprised of alkaline basalts that are commonly fractured with vesicular (honeycomb) and weathered zones, which may act as unconfined, semi-confined and confined systems. The Main Range Volcanics overlies the Walloon Coal Measures and Hutton Sandstone and is overlain by western Condamine Alluvium and tributaries in some areas. Groundwater flow directions in most areas are a subdued reflection of local topography.

The observed groundwater level trends are responsive and correlate well to both rainfall and local groundwater use. In terms of impacts from resource development, this is observed in the immediate vicinity of the New Acland mine, where parts of the formation overlie the Taroom Coal Measures – the target resource formation for the mine. As a result of dewatering, local groundwater level declines in the Main Range Volcanics have been observed in response to this associated water extraction.

#### **5.6.3 Other aquifers**

There are a number of other aquifers across the Surat CMA that are not immediately adjacent to the resource target formations. These include minor alluvium and other basalts, the Bungil Formation and the Mooga, Gubberamunda and Clematis sandstones. In the long term, although impacts are predicted in some of these formations, such as in the Gubberamunda Sandstone, observed trends are largely influenced by seasonal conditions and groundwater use.

## 5.7 Summary of identified impacts from monitoring data

- Since 2011, the groundwater monitoring network has continued to grow to meet OGIA's evolving assessment objectives in the Surat CMA. Initially, the focus was on system characterisation and understanding – but this has progressively shifted towards impact assessment.
- Impacts on groundwater levels that may have occurred from resource development cannot be measured directly. Therefore, OGIA has applied a multiple-lines-of-evidence approach to identify impacts from groundwater level, chemistry and isotope data.
- As expected, there is widespread CSG impact in the target formations (Walloon Coal Measures and the Bandanna Formation) where impacts of more than 400 m have been observed at some locations.
- In the overlying Springbok Sandstone, the trends are mixed, although there is evidence of CSG impact at some sites. There are substantial areas of rising trends around the north-eastern fringe of the development areas, likely to be caused by gas migration.
- No impacts are observed in the overlying Condamine Alluvium at this stage.
- In the underlying Hutton Sandstone, there is no evidence of CSG impact. Declining trends are attributed to groundwater use, although that trend appears to be somewhat stabilising in recent times.
- In the Precipice Sandstone, the basal unit of the Surat Basin, reinjection is the dominant influence on observed groundwater levels particularly in the north. This increases the complexity of identifying any minor impacts that may have occurred around its contact with the Bandanna Formation in the Bowen Basin.
- Surrounding operational coal mines, impacts in the Walloon Coal Measures are evident at short distances from operational mine pits, with drawdowns of up to 30 m observed in the available monitoring data.
- Interpreted impacts from monitoring data are broadly consistent with those modelled. The exception to this is the Springbok Sandstone, where observed impacts from CSG are generally less than those predicted due to the conservative approach taken in modelling and the potential influence of migrating gas in water levels.

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## Chapter 6 Predictions of groundwater impacts

### 6.1 Preamble

Predictions of groundwater impacts from the extraction of associated water are a product of:

- a numerical **groundwater flow model**, which is a customised computer-based code that mathematically represents geology and groundwater flow
- a resource **industry development profile** comprising the footprint and timing of existing and proposed CSG, coal mining and conventional oil and gas development.

A change to either of these will result in a change in impact predictions. More often than not, it is the changes in development profile that has the biggest influence in changes to predictions.

The conceptual basis underpinning the geology and groundwater flow is summarised in Chapter 4. A summary of the modelling methods employed by OGIA in making predictions are provided in this chapter, with additional details available in OGIA (2021h). The development profile that underpins the predictions in this UWIR is detailed in Chapter 2 of the UWIR.

### 6.2 Terminology

**Impact** – as defined in Chapter 4, the change in groundwater pressure or groundwater level in response to associated water extraction.

**Impact area** – a non-statutory term to define an area where groundwater level impacts are predicted to be more than one metre. This generally reflects the practical limit of impacts.

**Trigger threshold** – five metres for consolidated aquifers such as sandstone, and two metres for unconsolidated aquifers such as alluvium.

**Immediately Affected Area (IAA)** – defined in the Water Act as an area of an aquifer within which groundwater levels are predicted to fall by more than the trigger threshold within three years of the UWIR release (i.e. by 2024 for this UWIR) – also informally referred to as the **short-term impacts**.

**Long-term Affected Area (LAA)** – also defined in the Water Act, the maximum impacts at any time in the future based on the same trigger thresholds. It is an aquifer area within which groundwater levels are predicted to fall by more than the trigger threshold at any time in the future.

**The Regional Model** – the core groundwater flow model covering the entire Surat CMA and used in making predictions presented in the UWIR.

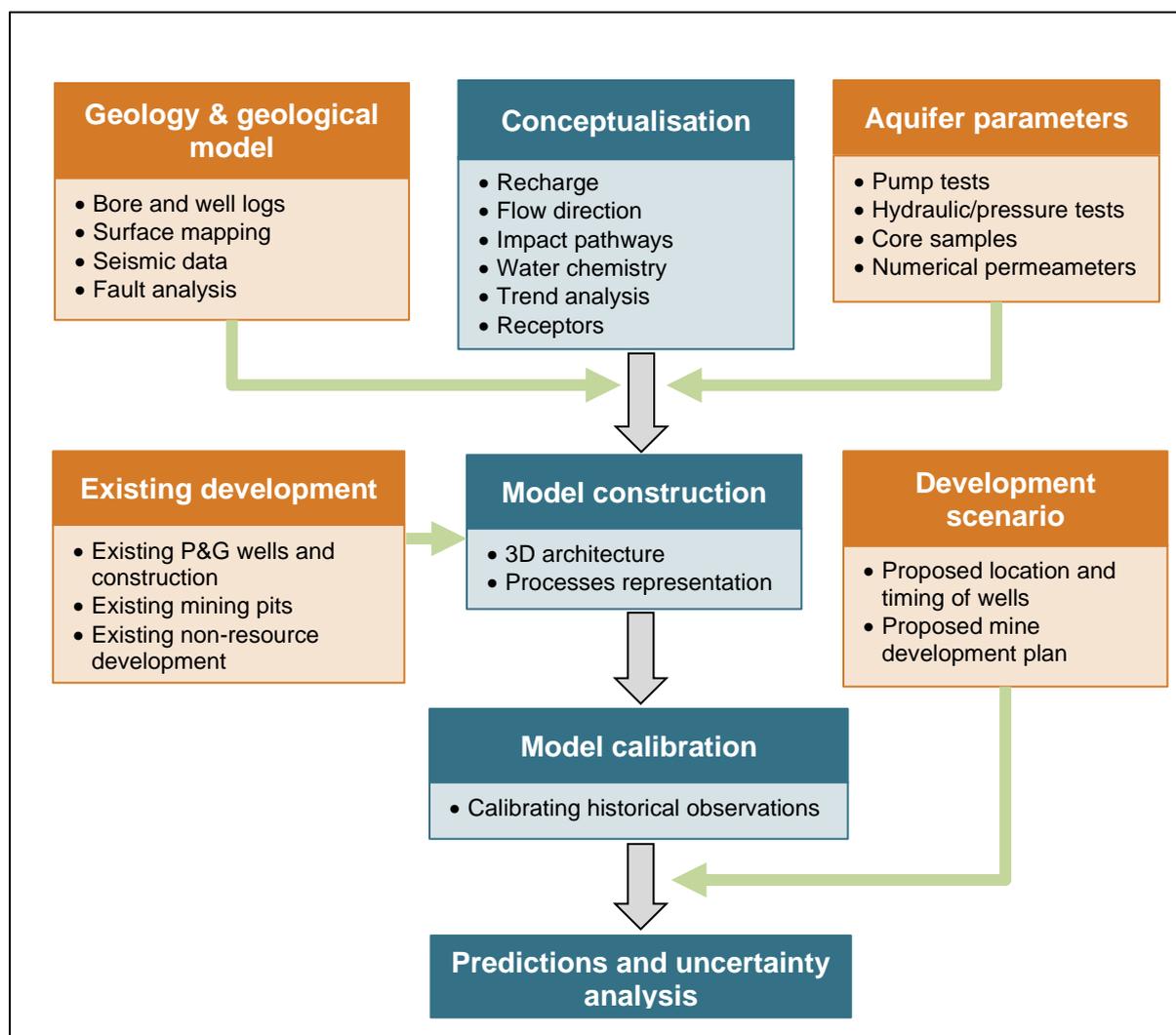
### 6.3 Modelling of impacts

#### 6.3.1 Purpose

In the context of the UWIR, the primary purpose of groundwater modelling is to predict changes in regional groundwater levels in aquifers within the Surat CMA in response to extraction of groundwater associated with CSG (primarily), coal mining and conventional oil and gas. More specifically, the purpose is to predict short-term and long-term impacts in surrounding aquifers, volumes of associated water extraction, and groundwater movement between formations in terms of both rate and volume.

#### 6.3.2 Key stages in modelling

A process flow diagram detailing the modelling stages is presented in Figure 6-1.



**Figure 6-1: Process flow diagram for groundwater flow modelling in the Surat CMA**

These elements can be grouped into four stages:

1. *Conceptualisation*. Available data, information and investigations are used to develop an understanding of geology, groundwater flow systems, inter-aquifer connectivity and impact pathways in response to stresses imposed by associated water extraction.
2. *Model construction*. The simplified conceptual representation of the system is converted into a groundwater flow model – a series of large computer files representing hydraulic parameters, boundary conditions, associated water extraction, groundwater recharge, ground surface and geological formation elevation, the model grid and other elements.
3. *Model calibration*. Once constructed, the model is then calibrated based on monitored groundwater levels, extraction rates and other available information, including expert knowledge. This calibration process typically involves adjusting the hydraulic parameters of each model layer until the best possible match is achieved between predicted and observation data.
4. *Predictions and uncertainty analysis*. The model is run with an input scenario, i.e. a development profile to derive predictions of groundwater level changes in response to that scenario. As more than one set of parameters can calibrate to a single set of observations

(mathematically referred to as ‘non-uniqueness’), a further analysis is performed called an uncertainty analysis. This typically involves creating a large set of models, each with different parameters that would still calibrate to the observation data. Predictions are then generated from each of those models for the same input scenario. This provides a set of predictions that are statistically processed to assess the most probable outcome (50th percentile, P50) and the upper (95th percentile, P95) and lower (5th percentile, P5) limits of potential outcomes.

## 6.4 Approach to modelling

### 6.4.1 Unique modelling challenges in the Surat CMA

The purpose of modelling in the context of assessing impacts in the Surat CMA is different to the modelling that is generally undertaken for groundwater allocation and aquifer sustainability studies, as the focus is on impact propagation to surrounding formations rather than to assess water allocation or sustainability. This places a greater emphasis on simulating vertical groundwater flow, i.e. between aquifers, rather than within aquifers. Predictions in this context require understanding of vertical hydraulic conductivities both within and between aquifers. These are often more difficult to assess than horizontal hydraulic conductivities, especially if the intervening aquitards have not yet been subjected to significant vertical head gradients induced by the associated water extraction.

The geology of the Surat CMA is complex, with more than 20 geological formations, erosional contacts and structural offsets with considerable lateral and vertical heterogeneity. This translates to a multi-layered aquifer system where individual aquifers can be exposed at the surface but can also be more than a kilometre deep at other locations – forming one of the biggest groundwater systems in the world, the GAB. CSG is produced from a coal formation that is layered within this complex system and within which there are multiple coal seams that are targeted for development. Hydrogeological properties and processes in areas of CSG extraction also exhibit small-scale complexities, e.g. the discontinuous nature of permeable coal seams and the presence of both gas and water phases in the CSG target formation.

An additional complexity added in this UWIR cycle is the integration of coal mining impacts in the Surat Basin. Coal mines are relatively isolated and located within outcrop areas but extract coal from the same target formation as the CSG.

### 6.4.2 Evolution of modelling approach

OGIA’s approach to modelling, and the numerical model itself, have evolved since the first regional model was developed for the UWIR 2012. The modelling philosophy has evolved with each iteration, supported by internal and external innovations. The first model was largely based on secondary information and developed using a standard version of MODFLOW 2005 modelling code. For the UWIR 2016, a new model was constructed in MODFLOW-USG with a number of code customisations to accommodate innovative modelling techniques developed by OGIA’s team, as well as a revised conceptualisation – such as a method developed to simulate water desaturation in and around CSG wells, as described in Herckenrath, Doherty & Panday (2015). The regional groundwater flow model for the UWIR 2019 included a number of further refinements, with the incorporation of additional major faults and simulation of CSG wells partially completed into the overlying Springbok Sandstone.

### 6.4.3 Current approach

Since the previous UWIR in 2019, OGIA has developed a long-term multi-UWIR-cycle strategy that incorporates simultaneous development of regional-scale and sub-regional-scale models combined

with researching and testing new approaches to modelling. In the current shorter UWIR cycle, OGIA has also implemented specific improvements to the modelling of impacts in terms of architecture, process representation and calibration methodology, including:

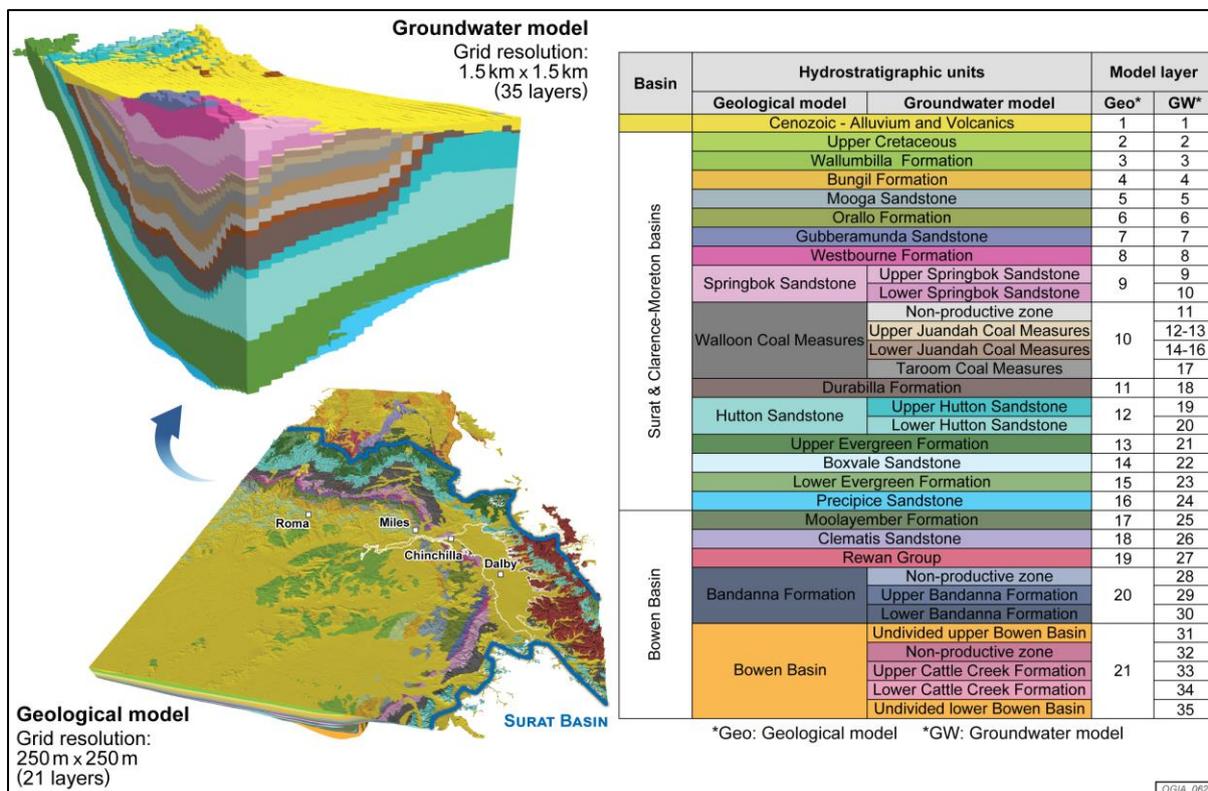
- updated layering of the Walloon Coal Measures subdivisions (Upper Juandah Coal Measures, Lower Juandah Coal Measures and Taroom Coal Measures) based on previously interpreted petroleum wells (drilled before 2017) and newly collected data from about 1,000 coal holes (OGIA 2021h)
- a further refined regional geological model
- development of a suite of models to inform, and integrate with, the regional model to better explore sub-regional and local processes
- refinement of the Horrane and Hutton-Wallumbilla faults based on new geological data
- revised extent of Cenozoic formations using detailed surface geology
- inclusion of coal mines in the regional groundwater flow model
- improved methodology for calibration and uncertainty analysis using PEST++ IES
- extension of the calibration dataset by an additional two years
- utilisation of increased computational capacity allowing expansion of predictive uncertainty by using 550 model sets.

A detailed description of the modelling methods utilised for the UWIR 2021 can be found in separate companion document (OGIA 2021h).

A suite of models now underpins the cumulative assessment, as summarised below:

- A **regional groundwater flow model** (the Regional Model) – the core model comprising 35 layers (Figure 6-2) at 1.5×1.5-km grid resolution, covering a domain of 650×450 km. The Regional Model represents unique features such as dual-phase flow approximation, permeability enhancement caused by connectivity through CSG wells, multiple depressurisation targets within the coal seams and geological faults. Coal mine stresses are now also included.
- **Numerical permeameters** – detailed lithology-scale groundwater models to make best use of lithology scale data and for upscaling hydrogeological parameters. These are generated using lithological data from CSG wells at 250×250-m resolution covering 21×21 km each (138,000 models in total).
- **Condamine model** – a modified version of the Condamine Alluvium model at a 500×500-m resolution, originally developed by Klohn Crippen Berger (KCB) for the then Department of Natural Resources, Mines and Energy (DNRME) for water allocation purposes and has since been updated collaboratively with KCB. Time-variant groundwater level conditions from the updated Condamine model were then imported into the regional model as boundary conditions.
- **New Acland model** (the Acland model) – developed by New Hope Group for the prediction of impacts from existing and proposed development at the New Acland mine. OGIA reviewed the model and determined that it was fit for the purpose of integrating coal mining impacts from the New Acland mine into the Regional Model.

- A **sub-regional groundwater model** for the Northern Coal Area (NCA) (the NCA Model) – to explore potential impacts from CSG and coal mining in an area where impacts are likely to significantly overlap. At this stage, this model was developed as a proof-of-concept (OGIA 2021h).



**Figure 6-2: Schematic representation of the regional geological and groundwater flow models**

The Regional Model remains the primary tool for the prediction of impacts for all P&G development, as well as most of the coal mines in the Surat CMA (Commodore, Kogan Creek, Wilkie Creek, Cameby Downs, Elimatta, Wandoan Coal Project and the Range). Coal mines are represented in the Regional Model by use of ‘drains’ (MODFLOW RIV package). Drain locations and elevations are set using time-variable mine development plans as provided by tenure holders.

The Acland Model is integrated by OGIA to assess impacts from the New Acland mine due to its detailed representation of the local geology and conservative hydrogeological assumptions, which are likely to result in higher predictions of impacts. This is consistent with the precautionary approach generally adopted by OGIA in modelling. OGIA is undertaking investigations to further constrain properties and processes relevant to these predictions for the future UWIRs.

In parallel with the integration of coal mine impacts outlined above, OGIA has developed a prototype sub-regional groundwater model for the NCA. The model has a 250-m grid resolution to assess near-surface cumulative impacts. It incorporates a number of novel improvements including an explicit representation of the weathered zone, a number of parameterisation improvements to capture the interaction between the near-surface and the deeper GAB system, as well as an updated calibration methodology commensurate with that of the Regional Model. Preliminary results are promising, and the methods developed may provide significant improvements for future near-surface impact modelling in the Surat CMA.

To support groundwater flow modelling and underlying conceptualisation, OGIA has also updated the regional geological model and created new geological sub-models as below:

- **Regional geological model update** – updated model based on additional CSG wells and newly collected data from about 1,000 coal holes (limited coal holes penetrate a full subdivision); revision of the alluvium with a more detailed extent (1:100,000 scale); and revision of the Horrane Fault trace.
- Development of **two sub-regional geological models** for the northern and eastern parts of the Surat Basin for better representation of the Walloon Coal Measures, its subdivisions and surficial units in these areas, i.e. Cenozoic and/or Main Range Volcanics.

#### 6.4.4 Calibration methodology

Calibration of the regional groundwater flow model involved three sub-stages as summarised in Table 6-1. An extensive array of monitoring data was considered in both the steady state and transient calibration phases, including but not limited to groundwater levels, vertical head gradients between key formations, measured associated water extraction volumes and formation-scale groundwater use. The Regional Model's scaled root mean squares (SRMS) value of 4.2% indicates a well-calibrated model (Barnett et al. 2012).

**Table 6-1: Stages in the Regional Model calibration**

Period	Type of calibration	Groundwater stresses	Outcome
End of 1947	Steady state	None	Pre-development
End of 1995	Steady state	Groundwater use	Pre-CSG conditions
1995–2020	Transient	Groundwater use + associated water extraction	Post-P&G (CSG and conventional) + coal mining

A key improvement to this Regional Model is the adoption of stochastic model calibration through the iterative ensemble smoother in PEST++ (White 2018) to improve efficiency of model calibration and predictive uncertainty processes, as they are undertaken simultaneously. Additional information on this approach is provided together with further details on model calibration in a separate companion document (OGIA 2021i).

#### 6.4.5 Predictive model setup

The model was set-up to run in predictive mode from 2020 onward. Two separate predictive runs were carried out to assess the cumulative impacts of CSG developments within the CMA:

- a **base run** that includes only groundwater use for non-P&G purposes, i.e. excluding all associated water extraction;
- and a **production run** that includes both groundwater use and associated water extraction based on the sequencing of development for each 1.8×1.8-km sub-block in production tenures (refer to Chapter 2 for details).

The difference in predicted groundwater levels between the base and production runs then provides the prediction of groundwater level changes resulting from past associated water extraction and planned resource development. Predictions are made on a quarterly basis from 2021 to 2070, then at progressively greater intervals from 2070 to the year 10000.

An advanced approach to uncertainty analysis consistent with the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) guidelines (Middlemis & Peeters 2018) is applied, whereby a total of 3,000 calibrated parameter sets (ensembles) were obtained from the stochastic calibration process. The top 550 parameter sets were then utilised for predictions, which were statistically compiled in terms of the P50 being the most probable outcome, P5 being a lower limit of potential outcomes, and P95 being an upper limit of potential outcomes. These statistics are presented to reflect the range of uncertainty associated with predictions. Predictions of median impacts from 550 model runs are extracted for each model layer at each of the 1.5x1.5-km model cells. For the purposes of determining impacts for the UWIR 2021, the P50 predictions are utilised.

The P5, P50 and P95 impacts are combined from both the Regional Model, the Condamine model and the Acland model to obtain estimates of potential cumulative impact.

## 6.5 Predictions of impacts

### 6.5.1 General

**Impacts** are predicted changes in groundwater level (or 'drawdown') in response to associated water extraction by CSG, conventional oil and gas, and coal mining. To clarify further, while the base run does take into account groundwater use for S&D, irrigation, town water supply purposes, as well as non-associated groundwater use by the resources industry for road construction, camp water supply, and reinjection, the 'impacts' derived from the production run explicitly represent impacts from the associated water extraction alone.

The Springbok Sandstone, Hutton Sandstone and Walloon Coal Measures are each represented by multiple layers in the model and impacts presented for a particular formation are the maximum impacts from its component layers. For the Walloon Coal Measures, impacts are also presented at the subdivision level – Upper Juandah, Lower Juandah and Taroom coal measures.

Impacts for all aquifers are presented in terms of the short-term impacts or IAAs, and the long-term impacts or LAAs as defined in the terminology at the beginning of this chapter. A time series of impacts at each bore location and at each spring of interest is derived from interpolation of impacts from nearby model cells. Predicted lumped-up associated water extraction and induced flow from one layer to another are derived as a time series.

### 6.5.2 Groundwater level impacts

The magnitude of impact in a formation varies spatially and diminishes exponentially away from production areas. While some areas around the centre of the development will experience larger impacts, for most areas the impacts will be much less. Table 6-2 shows the magnitude of maximum short-term and long-term impacts that most of the area (90% of the impact area for the respective formation) will experience. This is used as a measure of the typical magnitude of predicted impacts in a formation and the corresponding area. Key observations from the predicted pressure impacts are summarised in subsequent sections.

**Table 6-2: Summary of impacts in key formations (P50)**

Formation or subdivision	90% of the impacted area* will experience less than this impact	
	Short-term impact (m)	Long-term impact (m)
Condamine Alluvium	-	-
Main Range Volcanics	38	42
Springbok Sandstone	55	80
Upper Juandah Coal Measures	200	275
Lower Juandah Coal Measures	265	340
Taroom Coal Measures	425	450
Hutton and Marburg sandstones	3	7
Precipice Sandstone	10	12
Bandanna Formation	550	225
Cattle Creek Formation	300	300

**Note:**

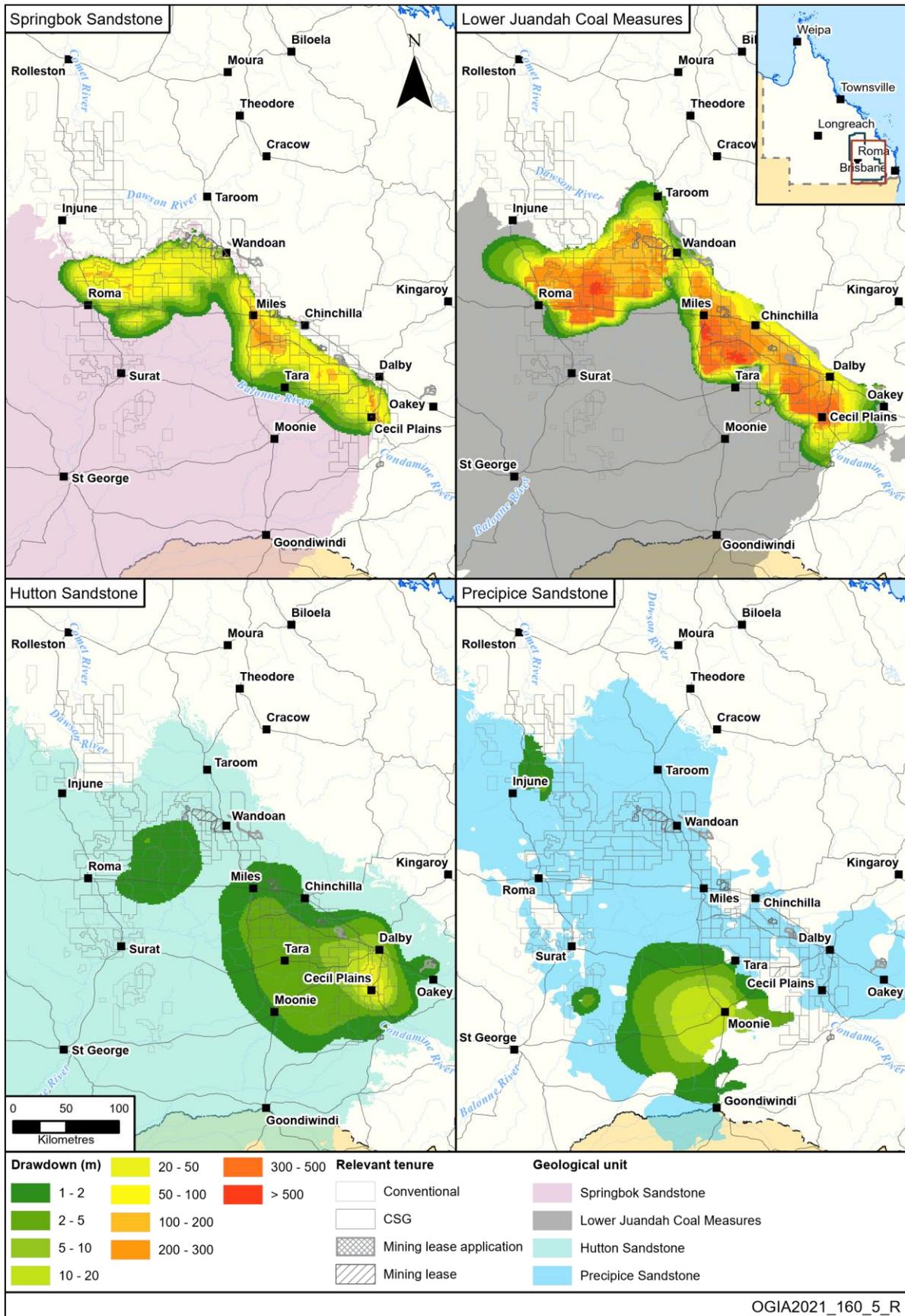
\* For the purpose of this table, the impact area is the extent of  $\geq 1$  m impact in the respective formation.

For each of the target formations and overlying or underlying aquifers, the P5, P50 and P95 groundwater level impacts over time, at a number of representative locations within the production areas, are presented as pixelated maps in Appendix E. As an example, the P50 impacts for the Springbok Sandstone, Upper Juandah Coal Measures, Hutton Sandstone and Precipice Sandstone are shown in Figure 6-3.

The IAAs and LAAs for the most affected target formations and aquifers are shown in Figure 6-4. Separate impacts are presented in this UWIR for the upper and lower Juandah Coal Measures and the Taroom Coal Measures. This approach is taken because of the significant differences in the levels of depressurisation in those sub-formations.

### 6.5.2.1 CSG target formation in the Surat Basin – the Walloon Coal Measures

- Short-term and long-term impacts are predicted in the Walloon Coal Measures – the target formation for CSG and coal mining in the Surat and Clarence-Moreton basins.
- There is little material change in LAA footprint compared to that reported in the previous UWIR, except some minor changes in magnitude and slight expansion of footprint to shallower areas including west and northwest of Roma resulting from recalibration of the model.
- Consistent with the depths of target sub-formations within the Walloon Coal Measures, the extent of depressurisation in the lowermost part (the Taroom Coal Measures) is likely to be about 450 m or less and in the upper most part (the Juandah Coal Measures) it is likely to be 340 m or less.



**Figure 6-3: Long-term groundwater level impact patterns (P50) – overlying Springbok Sandstone, Lower Juandah Coal Measures (coal target formation) and underlying Hutton and Precipice sandstones (detailed maps are in Appendix E)**

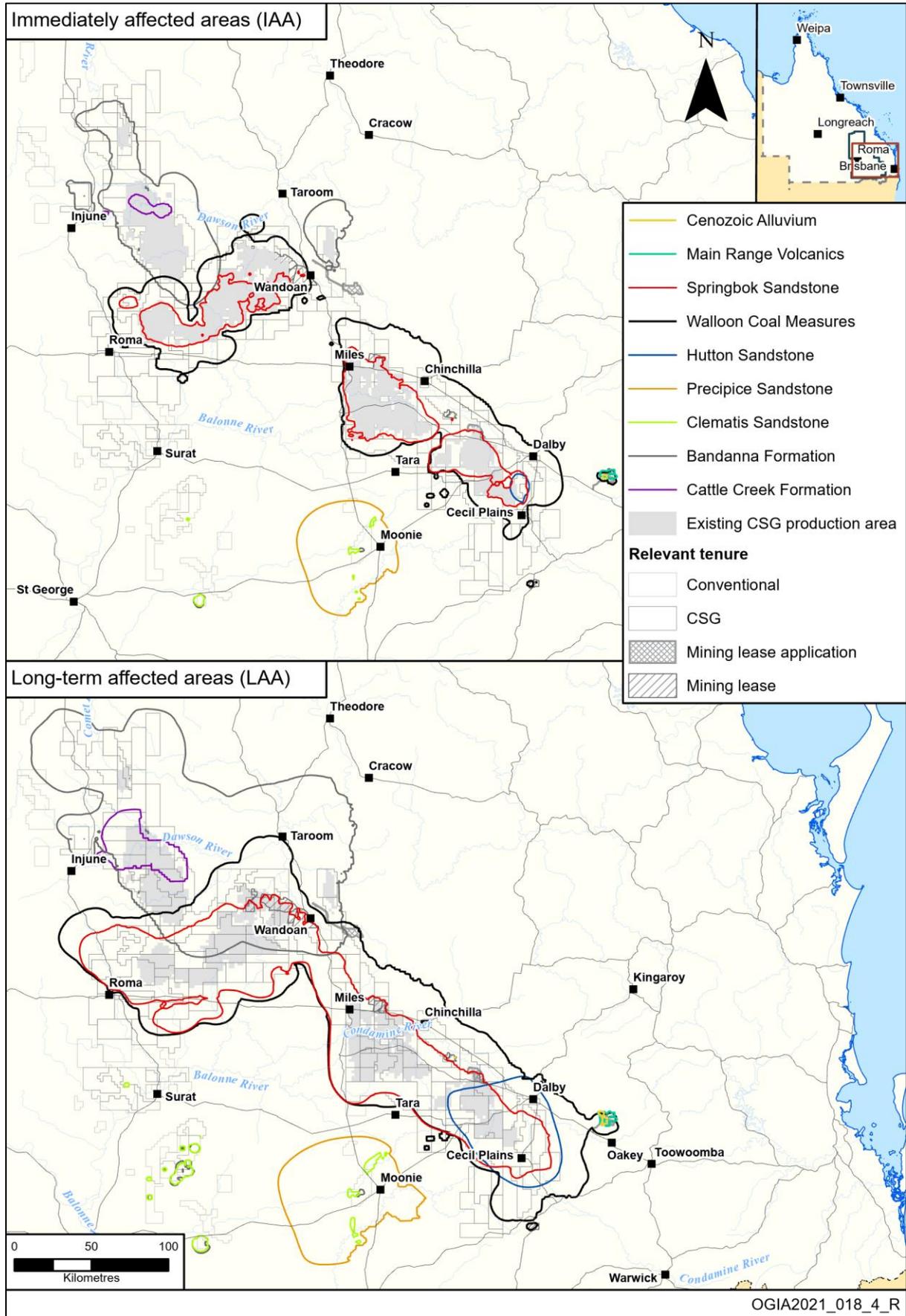


Figure 6-4: Extent of the immediately (IAAs) and long-term affected areas (LAAs)

- In some localised areas depressurisation may be up to 600 m but near Dalby where the target formation is shallower, the depressurisation is likely to be about 100–150 m.
- The LAA generally extends to about 15 km from the production wells, typically expanding further in the east and southeast where target coal seams are shallower and more permeable, under semi-confined to unconfined conditions.

#### **6.5.2.2 CSG target formation in the Bowen Basin**

- Short-term and long-term impacts are predicted in the Bandanna and Cattle Creek formations.
- Since the previous UWIR, there is material expansion of impacts in the Bandanna Formation further to the northwest. This is primarily due to the planned development of new CSG fields such as Mahalo.
- Development of the Cattle Creek Formation, located several hundred metres below the Bandanna Formation, is currently only proposed within the Fairview CSG field. A small number of pilot CSG wells have been drilled to date and depressurisation of this formation is currently limited.
- More impact is predicted in the vicinity of the Precipice-Bandanna contact zone. This is primarily a function of recalibration, whereby wider parameter bounds are explored in the Regional Model.

#### **6.5.2.3 Overlying aquifers and formations**

- Substantial short-term and long-term impacts are predicted in the Springbok Sandstone which overlies the Walloon Coal Measures, although the formation is only a minor source for water supply and does not materially support environmental assets, compared to the Walloon Coal Measures and the other aquifers.
- The predicted impacts are primarily due to the partial completion of CSG wells into the lower parts of the Springbok Sandstone (section 4.4.7), although the model may also be overpredicting in this formation.
- Although the impact footprint and pattern are very similar to those of the Walloon Coal Measures, the magnitude of predicted impact is much less – in the long-term 80 m or less in most of the area, and 55 m or less in the short-term.
- There is no LAA in the other overlying aquifers that are heavily utilised for water supply, such as the Condamine Alluvium, the Gubberamunda Sandstone and the Orallo Formation.

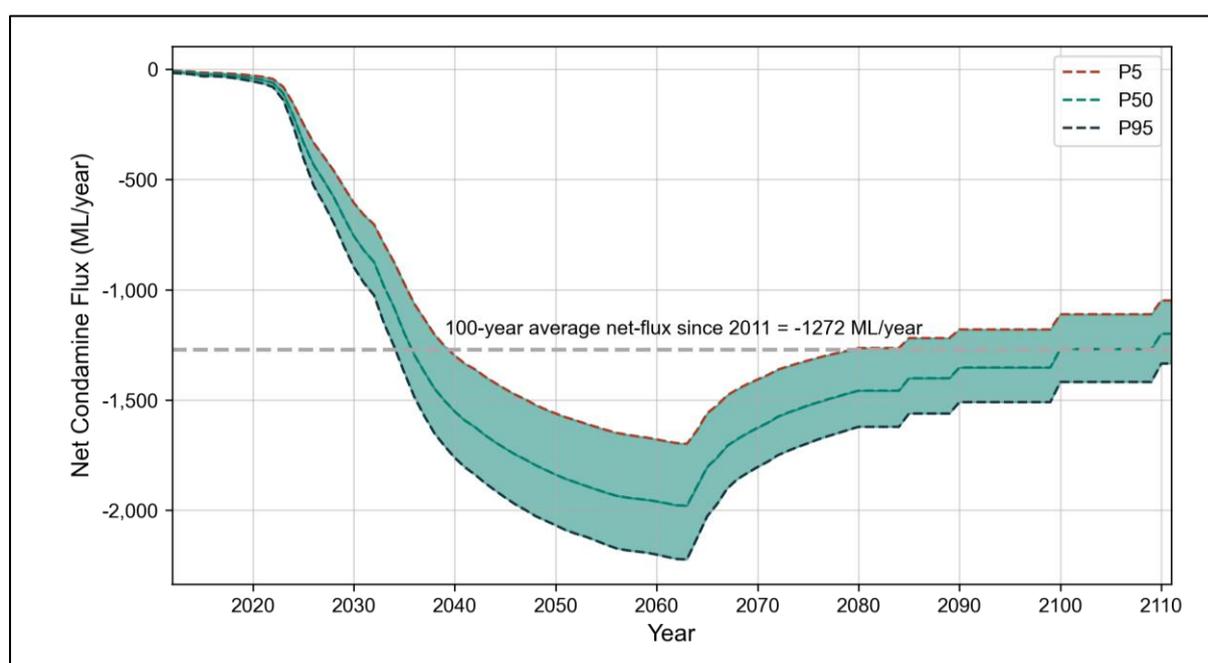
#### **6.5.2.4 Underlying aquifers and formations**

- Relatively smaller LAAs are predicted in the southern parts of the Surat Basin in three underlying aquifers – the Hutton Sandstone, the Precipice Sandstone and the Clematis Sandstone.
- LAAs in the Precipice and Clematis sandstones are from conventional oil and gas activities. Impacts in the Precipice Sandstone are primarily associated with the Moonie oil field.
- In the Precipice Sandstone the predicted impacts are relatively small along the northern edges of the Surat Basin in and around the contact zone with the Bowen Basin – resulting from groundwater extraction in the Bandanna Formation.

- Around the contact zone west of the Fairview gas field, the maximum predicted impact has increased marginally from 1.9 m in the previous UWIR to 2.6 m in this UWIR.
- The change in predictions around the contact zone is due to a combination of factors:
  - changes in the CSG development scenario
  - revised calibration from groundwater monitoring data in response to reinjection which has resulted in higher calibrated permeabilities in the Precipice Sandstone
  - updated geometry around the Hutton-Wallumbilla Fault based on recently acquired AEM survey data, undertaken by GA.

### 6.5.2.5 Condamine Alluvium

- Although the Condamine Alluvium overlies the Walloon Coal Measures, predicted long-term impacts continue to be less than the 2-m trigger threshold for unconsolidated aquifers. There is therefore no LAA or IAA in the Condamine Alluvium.
- The magnitude of impact is less than 0.3 m for most of the area and the footprint of predicted impact is similar to that in the previous UWIR, as shown in Figure E-8 (Appendix E). Predicted impacts have changed slightly due to changes in the development profile, and changes to model structure and calibration.
- It is to be noted that the drawdown pattern is very sensitive at lower resolution (10 cm interval), and to model recalibration. Therefore, given the small (<0.5 m) impacts predicted, a more reliable parameter for impact in the Condamine Alluvium is the net loss of water.
- The average net loss of water from the Condamine Alluvium to the Walloon Coal Measures is predicted to be about 1,270 ML/year over the next 100 years as shown in Figure 6-5. This is higher than predictions in the UWIR 2019 but comparable to predictions in the UWIR 2012 and UWIR 2016.



**Figure 6-5: A time series of predictions of net loss of water from the Condamine Alluvium to the Walloon Coal Measures**

### **6.5.2.6 Conventional oil and gas impacts**

- As noted earlier (section 6.5.2.4), predicted LAAs in the Precipice and Clematis sandstones are from conventional oil and gas activities. Predicted impacts in the Precipice Sandstone are associated with the Moonie oil field where production started in 1964 and is now in a declining phase, nearing end of life.
- Conventional production only contributes about one per cent of the total P&G production (less than 1,000 ML/year), the production occurs directly from aquifers under deep confining conditions (Precipice and Clematis sandstones).
- The predicted impact is at much greater depths compared to CSG formations, and is laterally extensive but is retracting progressively. Due to their depth, the impacted aquifers are generally not accessed for water supply in the areas of predicted impact.
- Modelling by UQ of the Moonie field is broadly consistent with predictions presented in this report. However, there are differences in the extent of impacts further west due to UQ using a different stratigraphic subdivision. OGIA is in discussions with UQ to review the current subdivision of the Precipice Sandstone for the entire Surat Basin.

### **6.5.2.7 Mining impacts**

- Mining impacts are integrated into the cumulative impacts summarised in the previous sections.
- As detailed in section 2.4.2, six of the eight existing and proposed coal mines in the Surat Basin overlap with (or are immediately adjacent to) CSG tenure. The timing and sequencing of CSG development around those mines will influence the level of any additional impacts that the mines may cause.
- A separate scenario run was carried out, to assess additional impacts from mining. The results suggest the following:
  - In northern areas, where large mines (Wandoan Coal Project and Elimatta) are proposed in the Juandah Coal Measures, the proportion of impacts from mining (additional to CSG impacts) are up to 55 m in localised areas near the mine pit but for most areas it is less than 10 m.
  - For mines in central areas, the additional impact depends upon the timing of pit progression and can be up to 50 m but is generally less than 20 m and limited to the immediate vicinity of the mine pits.
  - There is relatively little or no interaction with CSG impact in mines targeting the Taroom Coal Measures. Impact is expected at The Range mine, while relatively minor impacts are expected at Commodore.
  - Predicted impacts around the proposed Wandoan Coal Project mine are five metres or less and the impact is confined to within three kilometres of the mine pits.
- Impacts are predicted post-mining, as it is assumed that mine pits will remain largely open, unless there is data to suggest otherwise. This is a conservative approach as in practice, some pits are likely to be backfilled.

- Impacts from the New Acland mine are unlikely to substantially overlap with regional CSG impacts. This is partly due to the distance – the nearest CSG development being about 50 km away – and the timing of mining impacts in the nearby area being separated by more than a decade.
- IAAs and LAAs associated with the proposed activity at the New Acland mine are predicted for the Oakey Creek Alluvium, Main Range Volcanics, Lower Juandah Coal Measures and Taroom Coal Measures. No IAA or LAA is predicted for the Hutton Sandstone, noting that predictions are based on Stage 3 planned commencement.
- At the New Acland mine, predicted long-term impacts in the direct vicinity of the mine pits are typically less than 55 m. In the Main Range Volcanics, the LAA is constrained to less than 3 km, while in the Taroom Coal Measures, the LAA is predicted to extend up to 7 km west.

### 6.5.2.8 Timing of pressure impacts and recovery

- In areas located close to the edge of the predicted LAA in the Walloon Coal Measures, groundwater levels are expected to recover within five years. Groundwater levels within CSG production areas are predicted to take more than 1,000 years to fully recover.
- Compared to the underlying upper Walloon Coal Measures, impacts in the Springbok Sandstone tend to develop more slowly. Groundwater levels in the Springbok Sandstone will therefore also recover more gradually.

### 6.5.3 Associated water extraction and inter-formation induced flow

Predictions from the Regional Model of associated water extraction in the Bowen and Surat basins are presented in Figure 6-6. Average extraction over the life of the industry is approximately 46,000 ML/year, with a peak of about 120,000 ML/year in around 2027. The average from 2014 to 2065, during which most of the production will occur, is about 54,000 ML/year – compared to 51,000 which was predicted in the previous UWIR. Predicted extraction in the next three years is likely to be around 80,000 ML/year. Current actual associated water extraction is about 54,000 ML/year.

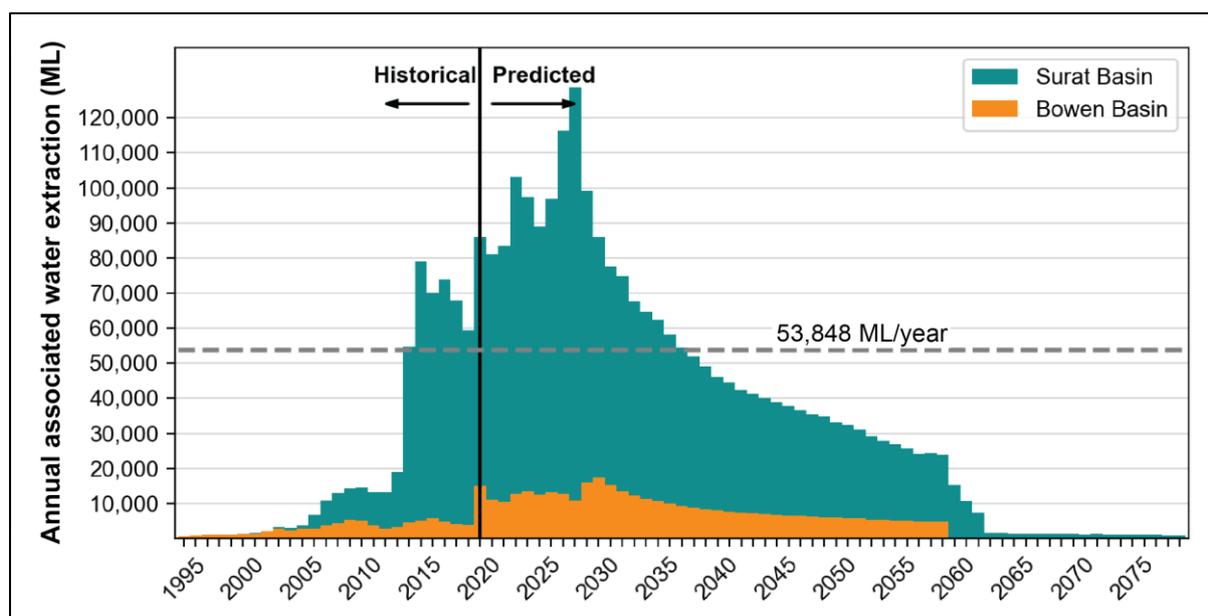


Figure 6-6: Predicted CSG water extraction

The timing and volumes of predicted associated water extraction will continue to vary in future due to the changes in planned commencement and cession of production areas and infilling of existing areas.

Over a 100-year period from the start of the CSG production, most groundwater extracted will be from the storage in the Walloon Coal Measures. Only about 8% of the water is predicted to be derived from cross-formational flow from the surrounding aquifers, including less than 2% from the Hutton Sandstone. This proportion will decline further over a longer period.

There is no direct relationship between the volume of associated water extracted and the magnitude of groundwater level impacts. This is because CSG operations aim to maintain a close-to-constant groundwater level (or pressure) in the gas fields. Consequently, whilst reductions in modelled permeability will tend to reduce predicted volumes of associated water extraction, this will not directly lead to a change in predicted groundwater level impacts.

## 6.6 Uncertainties in predictions

The subsurface geological environment is complex and the understanding is limited to observations and measurements from only some parts of the system. Groundwater models are therefore simplified constructs that are continuously refined to assimilate new data, improvements to conceptualisations and inherent uncertainties, to improve predictions and inform management options (of resource development, in this instance).

In the context of the UWIR, uncertainties can be grouped into the following categories:

- **conceptual** uncertainty arising from differences in understanding of the geological system and groundwater processes, e.g. geological layering
- **parameter** uncertainty arising from the ability to represent complex groundwater flow systems from limited datasets, e.g. aquifer parameters
- **scenario** uncertainty arising from changes in proposed development scenarios as provided by tenure holders.

As detailed in section 6.4.5, the regional groundwater flow model was set-up to explore parameter uncertainty to generate 550 predictions, of which the P50 is used in determining impacts as discussed in the earlier sections. Further scrutiny of the range of predictions indicates that impact footprints in the Walloon Coal Measures and the Springbok Sandstone may vary by about 10 to 15%, while for other formations it may be more. There is also greater uncertainty in the Bowen Basin, which reflects the comparatively less calibration data available in that basin. In addition to impact areas, the predicted average associated water extraction volumes may vary by about 12% for the same development profile.

For information purposes only, a 'maximum development scenario' was also run to explore potential uncertainties associated with changes in development profile, which may result in an increase in LAA bore numbers by about 3%.

## 6.7 How the predictions are used for managing impacts

Predictions of impacts are used directly and indirectly for proactively developing and implementing impact management strategies and to inform stakeholders about the magnitude, timing and implications of impacts. More direct use of the predictions is summarised below:

- IAAs are used to determine the water bores that are likely to be impacted in the short-term and require follow-up make good arrangements (Chapter 8)
- LAAs are used to flag water bores that may potentially require make good arrangements in future (Chapter 8)
- the magnitude and timing of impacts on springs are used for determining the risk to those environmental assets, developing a strategy for impact mitigation and monitoring, and scoping further assessments where required (Chapter 10)
- the magnitude and timing of impacts on TGDEs (Chapter 11)
- distribution of pressure impacts in the target formation as input to determining surface subsidence (Chapter 7)
- a strategy for ongoing monitoring to verify the predictions of impacts (Chapter 5), effectiveness of management strategies and ongoing improvements in assessing impacts (Chapter 9)
- assess impacts on EVs to support ongoing evaluation of EAs by the regulator (Chapter 12).

## **6.8 Summary of predicted impacts on aquifers and formations**

- Predictions of groundwater level impacts are made using the latest industry development profile as a key input – the footprint and timing of existing and proposed resource development. Change to the development profile is the primary reason for progressive changes to predicted impacts in UWIRs.
- Compared to the previous UWIR in 2019, the impacts predicted in CSG target formations and surrounding aquifers are broadly similar, except for some marginal increases associated with changes in the planned production footprint and the integration of coal mining.
- LAAs and IAAs are predicted in all target formations and some surrounding aquifers.
- The majority of the impact area in the Walloon Coal Measures will experience maximum impacts of about 200–425 m in the short term, and 275–450 m in the longer term.
- In the overlying Springbok Sandstone, predicted impacts are 55 and 80 m in the short and long term, respectively, for most of the area.
- Only minor impacts are predicted in the Hutton and Precipice sandstones, with less than 10 m in the short term and less than 12 m in the long term for most of the area.
- Impacts in the Condamine Alluvium will be less than 1 m and the net loss of groundwater is predicted to be about 1,270 ML/year.
- The average annual volume of associated water extraction by resource development is predicted to be about 54,000 megalitres over the life of the industry.
- The proportion of predicted cumulative impacts from coal mining is up to 55 m in some localised areas around the mines but generally less than 10 to 20 m.

## Chapter 7 Assessment of subsidence

### 7.1 Preamble

Hundreds of metres of CSG depressurisation in target formations will result in some compaction of coal seams and a few centimetres of subsidence at the ground surface.

Following legislative amendments in late 2016, DES amended guidance material for the preparation of UWIRs and included a requirement for risk-based assessment of impacts on EVs, that may result from subsidence caused by associated water extraction (Department of Environment and Science 2017). The UWIR is required to assess subsidence impacts that may have already occurred and are likely to occur in the future. Potential impacts to EVs that could result from land subsidence include changes to surface water flows that support aquatic ecosystems, impairment of aquifer integrity, and changes to landform.

Since late 2020, matters relating to subsidence have gained significant attention from landholders of cropping lands on the western edge of the Condamine Alluvium. In particular, there are concerns about how baseline conditions can be established in cultivated areas, whether subsidence may have already occurred as a result of CSG development and, where there is material change, how subsidence can be remediated or managed.

In response to these emerging concerns, OGIA, in collaboration with the GasFields Commission Queensland, established an ongoing engagement process with landholders and commenced several research initiatives to improve assessment methods and the collective understanding of subsidence. The improvements specifically relate to addressing the difficulty of establishing a baseline in cropping lands, developing a monitoring strategy to identify CSG-induced subsidence, and improving the predictions of subsidence.

This chapter provides a summary of the assessment of subsidence, including predictions of impacts and an update on the progress and future direction of OGIA's work on those matters. Additional technical details on the assessment are provided in a separate companion document (OGIA 2021j).

It should be noted that while the assessment of subsidence is within the legislative scope of the UWIR, management actions in response to subsidence are currently beyond that scope.

### 7.2 Terminology

**Ground movement** – also referred to as 'ground motion', the movement in ground surface elevation measured at surface, irrespective of the cause.

**Subsidence** – used in this report to refer to the component of ground movement that is induced by CSG depressurisation.

**Ground slope** – change in slope of the land at surface resulting from CSG-induced subsidence.

**Groundwater impact or impact** – as defined in Chapter 3, primarily the change in groundwater pressure or groundwater level in response to associated water extraction (also termed drawdown).

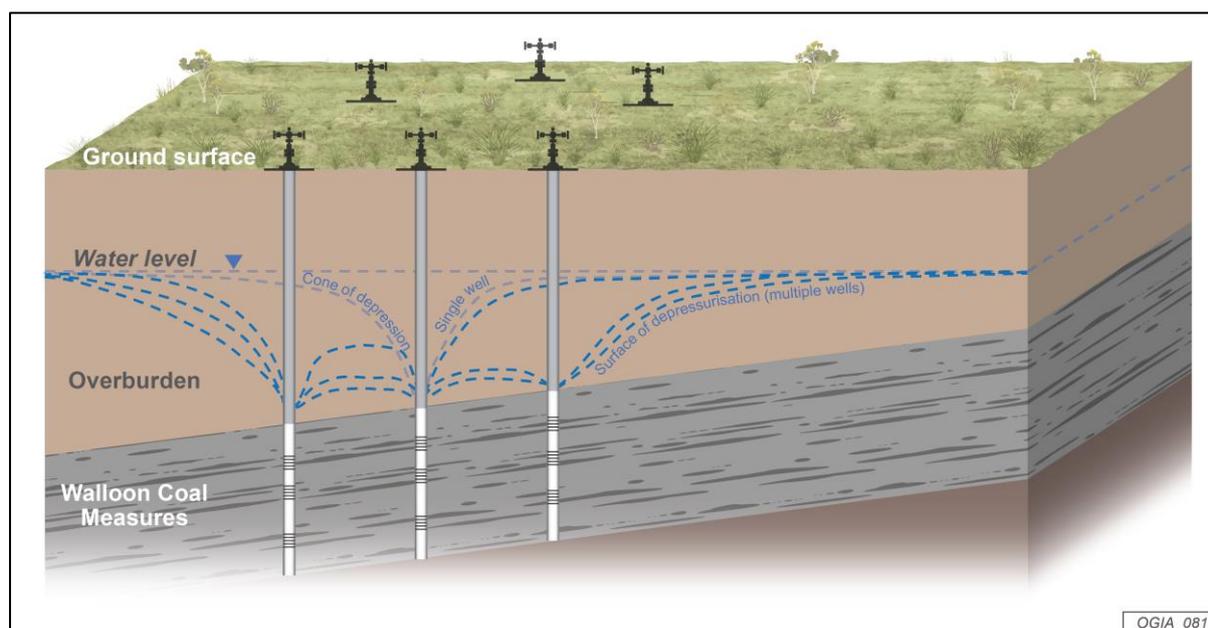
**Cone of depression** – the groundwater pressure (or level) pattern around a pumping well that has the shape of an inverted cone that develops around the well, where the slope is increasingly steeper closer to the well.



where upper parts of the coal measures are eroded away – such as underneath the Condamine Alluvium. This is considered in making predictions of groundwater impacts (or depressurisation) as detailed in Chapter 6 and modelling of subsidence (section 7.4).

Of all the factors described above, the one that has the greatest effect on CSG-induced subsidence is the magnitude of depressurisation, its pattern and how it develops over time across a gas field.

A typical gas field in the Surat Basin has vertical CSG wells completed about 750 m apart. There are also directional wells where well heads can be further apart, however, subsurface intakes of individual directional wells are less than 750 m apart. In both instances, the cones of depressions from nearby vertical or directional well intakes will interfere with each other. Since the maximum depressurisation at a well location is limited by the target pressure (section 2.3.1), the interference will gradually flatten depressurisation between the wells as depicted in Figure 7-2, achieving relative uniformity over time inside gas fields. This is intentional by CSG producers, to achieve relatively uniform depressurisation within a gas field and to optimise gas production. If sufficient pressure drop is not achieved between wells, the well spacing is often reduced or in-fill wells are drilled. However, away from the gas fields, the depressurisation will gradually taper away where slope of depressurisation surface also gradually declines away from the gas fields.



**Figure 7-2: Schematic showing the interference and resulting depressurisation within and outside a CSG field**

There is also a timing consideration. The cone of depression extends over time – at higher rates initially, before stabilising after a few years. Therefore, how soon the relative uniformity in depressurisation is achieved within a gas field will depend upon the timing of commencement of production from individual CSG wells and their spacing. Assuming the wells are completed in a configuration as described previously and the production commences somewhat simultaneously, the interference between the individual cones of depression will occur within months and depressurisation within the gas fields will become relatively uniform within a year. After the first year of production, depressurisation within the gas field will change little, however outside the gas fields, it will keep expanding.

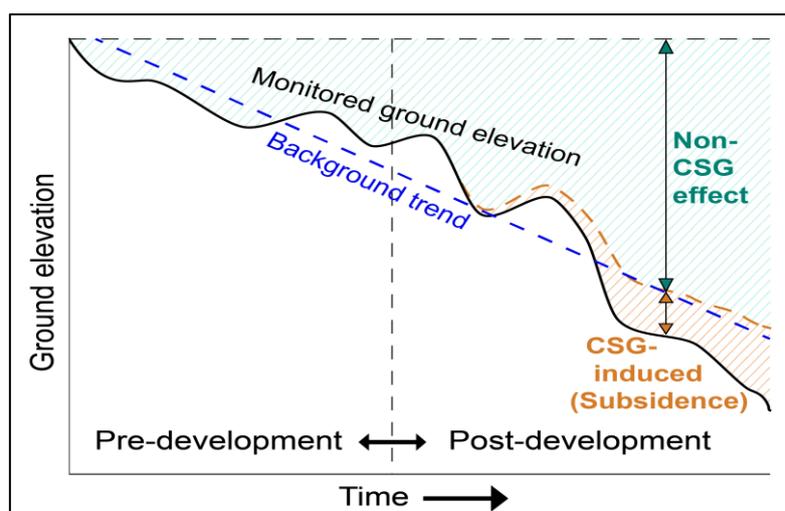
There is also natural ground movement – i.e. the ground movement caused by factors other than the CSG-induced subsidence – from the shrinking or expansion of high-clay-content soils due to changes in moisture content, depressurisation resulting from groundwater use in aquifers overlying the target coal formation and, land management practices, such as irrigation, tillage and land contouring. While it is not possible to measure subsidence directly, ground movement can be measured.

### 7.3.2 Implications for agriculture practices

There have been limited studies on CSG-induced subsidence and its consequences on surface infrastructure and the environment (Wu, Jia & Wu 2019; Jayeoba 2020). In late 2020, OGIA engaged with landholders of cropping land in the western part of the Condamine Alluvium, seeking their understanding of potential consequences of subsidence on farming activity. While there were diverse perspectives expressed, there was consensus that rather than the overall magnitude of ground movement, the main concern would be change to the ground slope and aspect of the land resulting from variation in ground movement at the farm scale. Such change could affect surface water drainage directions, which may have implications for irrigation and other farming practices.

### 7.3.3 The concept of baseline in subsidence

As detailed earlier, ground movement may be caused by a range of environmental and anthropologic factors. Most of these influences are seasonal, such as variations in soil moisture profile resulting from variations in rainfall and farming activities. It is therefore impractical to use a single point-in-time measurement of a farm's elevation and slope as a baseline. Instead, to eliminate seasonal effects, a baseline trend from data collected over a reasonable period is a more useful approach to establish CSG-induced subsidence (Figure 7-3). This is similar to the approach used in establishing groundwater level impacts from CSG development Chapter 5 (Figure 5-1).



**Figure 7-3: Schematic showing factors affecting trends in ground movement**

### 7.3.4 Inferred subsidence from the monitoring data

There are a range of methods and tools that can be used to measure ground movement (section 7.5.1). The most common and efficient is a remote-sensing technique called interferometric synthetic aperture radar (InSAR), whereby satellite-derived radar signals are processed to determine the change in ground elevation (i.e. ground movement).

InSAR data coverage is available since 2006 which also corresponds to commencement of CSG operations in the Surat Basin. From the period 2006-11, the data is available from ALOS satellite at an interval of 46 days, from Radarsat for the period 2012-17 at an interval of 24 days and from Sentinel since 2015 for at least every 12 days (6 days from 2017 onwards). Sentinel data is also available from points as close as 20 metres from one another – resulting in a 'point cloud'. The raw

data is processed by private companies using proprietary algorithms and software to convert it into change in ground elevation. This means that ground movement over every 6 to 12 days is available since 2015 – noting that not all data points can be converted to ground movement, such as in some heavily cultivated areas. OGIA has directly secured the processed data for further analysis from a company called TRE Altamira.

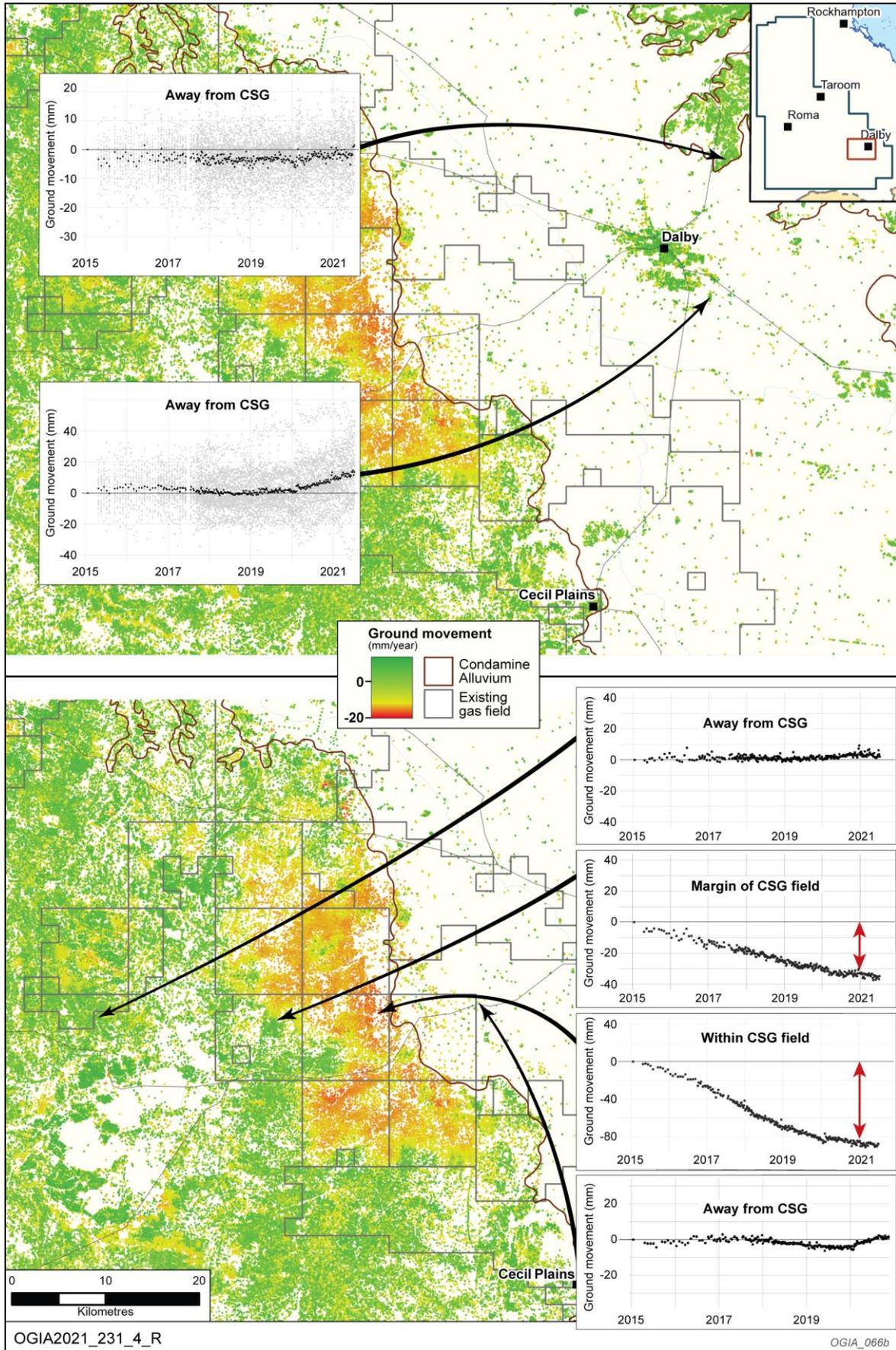
Figure 7-4 shows the available point cloud around the eastern gas fields and along the western edge of the Condamine Alluvium. This figure shows ground movement over a period from early 2015 to mid-2021 as mm/year in different colours (red – higher downward ground movement; yellow – medium downward ground movement; green – neutral or upward ground movement). Charts of ground movement over time at representative locations with respect to proximity to gas fields are also shown as insets. For example, the insets in the bottom figure are from four locations around a CSG field. Moving from east to west, these are: away from the field, margins of the field, centre of the field and then again away from the field. At those locations, ground movement is averaged from all data points within an area of about 250x250 m.

To demonstrate local-scale and natural variations in ground movement, similar data is also shown at a local scale at two different locations in and around the Condamine Alluvium – this time with and without averaging on the upper panel of Figure 7-4.

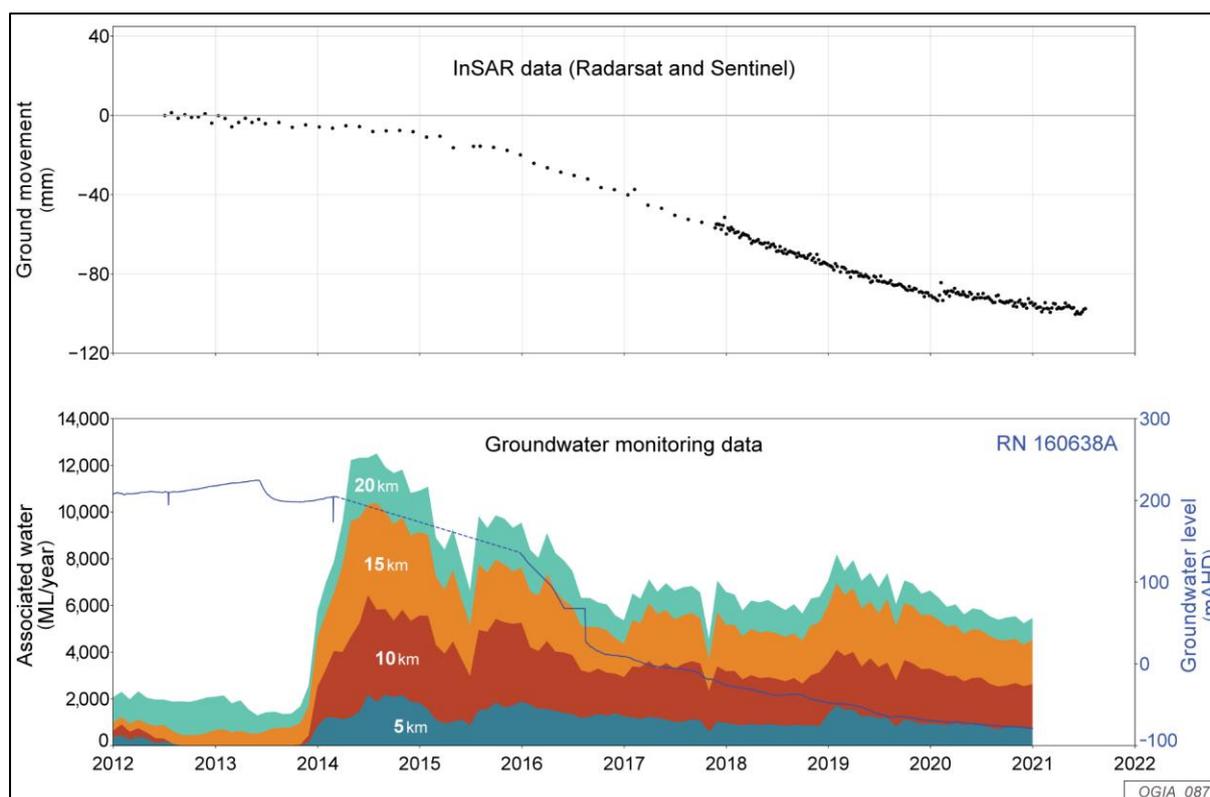
To capture the pre-CSG period, the stitched dataset incorporating Radarsat and Sentinel data from 2012 onward is presented in Figure 7-5. To demonstrate timing and extent of CSG development within 20 km of the location, nearby CSG water production (within 20 km) and groundwater pressure (depressurisation) monitoring in the Taroom Coal Measures is also shown for the corresponding period.

Some important observations from these two figures are as follows:

- Within the gas fields (concentration of red points), total ground movement of about 100 mm is noted so far and is attributed to CSG depressurisation as it correlates well with the commencement of CSG depressurisation around 2014, and corresponding depressurisation as shown in Figure 7-5.
- Ground movement gradually reduces at the margins of gas fields (yellow points), changing to a nearly flat rate (green points) further away from the gas fields.
- The rate of subsidence is higher in the early stages of development but is likely to stabilise to near zero in the later years as is suggested from the long-term predictions (Appendix F) described in later sections.
- 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.
- Despite local variations in the rate of movement, the average trend from all data points within a local area shows a more consistent pattern of observed ground movement (Figure 7-4).
- Rising trends are observed in some eastern parts of the Condamine Alluvium with multi-year trends in ground movement which appear to correlate with rainfall pattern. This is likely due to overall moisture content that influences ground movement through drying and swelling of soil.



**Figure 7-4: Spatial and temporal pattern of ground movement around the eastern gas fields in the Surat CMA as measured through InSAR (source data: TRE Altamira)**



**Figure 7-5: Ground motion, groundwater pressure and water production at various radiuses from the within the CSG field location as shown in Figure 7-4**

- Despite some limitations with InSAR data in cultivated areas, observed trends from the available data indicate ground movement within farms is highly variable, both spatially and temporally, apparently due to farming activities. Cultivated areas are therefore unsuitable for assessing changes in elevation, except in those parts of the farms that are less affected by these activities – such as near sheds, houses and other infrastructure.

## 7.4 Predictions of subsidence

### 7.4.1 Previous assessments

A preliminary regional assessment of subsidence was undertaken for the first time in the UWIR 2019. The approach incorporated an assessment of the likelihood of subsidence and a description of the EVs located within risk areas. The likelihood of subsidence was assessed using two risk factors: 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. On this basis, three subsidence risk classes were assigned and all areas containing EVs, except for Woleebee Creek near Wandoan, were found to be at low to moderate risk of subsidence.

CSG tenure holders have estimated the potential risk of subsidence as part of their EIS and EA processes. These assessments applied a similar approach – coupling the results of their groundwater flow models with analytical methods to estimate compaction for each geological unit. A monitoring program was also developed across tenements, using various monitoring techniques such as InSAR and permanent survey markers to measure actual ground movement at local and regional scales.

The previously reported industry predictions of subsidence vary between tenure holders. Arrow's long-term predicted subsidence was up to 150 mm (Coffey Environments 2018). Santos estimate a maximum subsidence of up to 280 mm around the Roma gas field and 150 mm for Arcadia and Fairview gas fields (Santos 2013). QGC estimate 80 mm in the central gas fields, increasing to 145 mm in the south and 180 mm in the north (QGC 2012).

### 7.4.2 Approach to the prediction of subsidence in this UWIR

OGIA developed an advanced approach to the prediction of subsidence to support the assessment for this UWIR. The approach incorporated three stages which are described in the following sections.

#### 7.4.2.1 Numerical (geomechanical) model in the Condamine Alluvium

A 3D geomechanical model for the Condamine Alluvium and adjacent CSG production areas was built, incorporating all available data on local geomechanical properties and lithological distribution. Predicted groundwater level impacts from the groundwater model (section 6.5) were used as an input to the geomechanical model for making predictions of subsidence.

The geomechanical model was developed by OGIA in collaboration with Schlumberger using the Visage™ Finite Element Geomechanics Simulator. The model has 88 vertical layers and a model grid ranging from 250x250-m to 750x750-m to account for variations in lithology (including coal). Rock properties were derived from 41 wells within the model extent (Figure 7-6) and detailed geology was derived from OGIA's regional geological model for the relevant units – including the subdivisions of the Walloon Coal Measures.

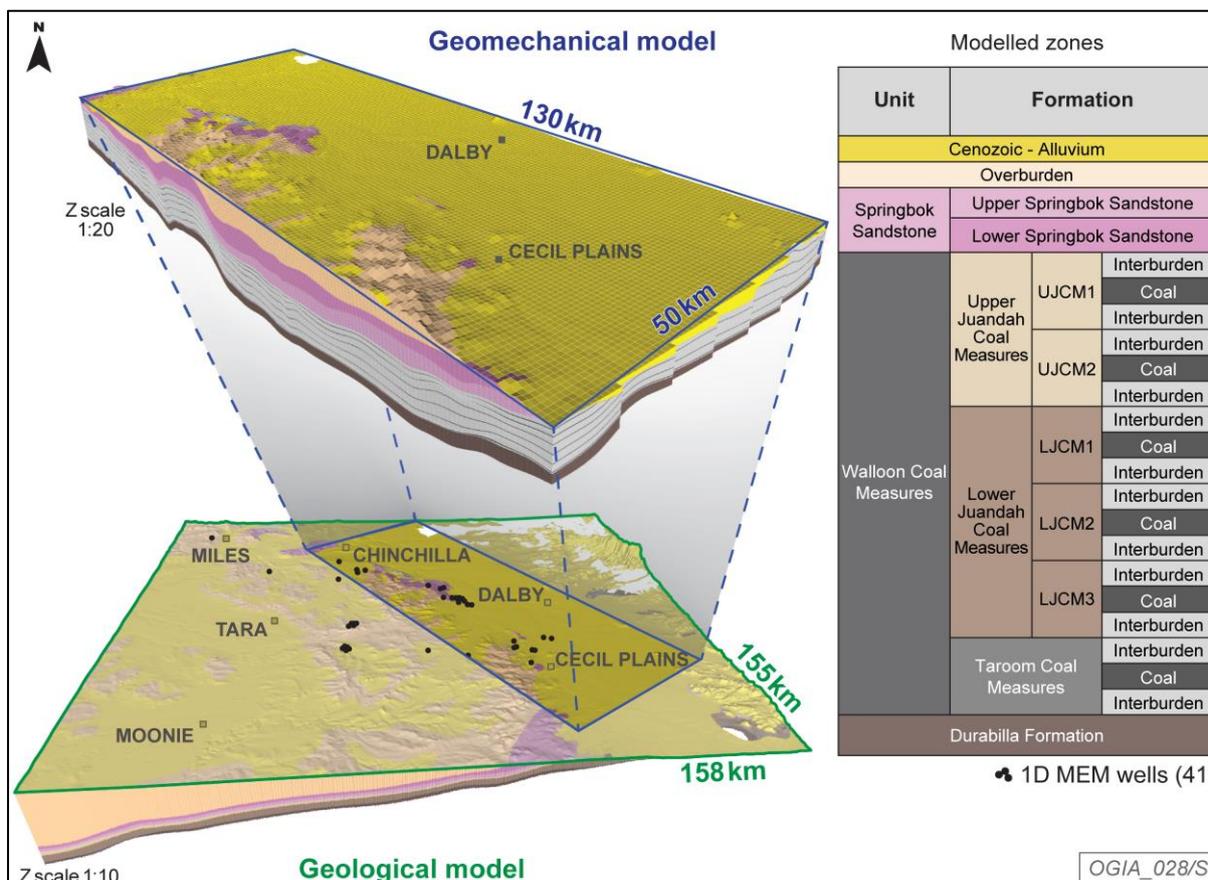


Figure 7-6: Geomechanical model architecture

The geomechanical model provided prediction of subsidence in response to predicted groundwater depressurisation in the Condamine Alluvium footprint. In addition to predictions, the modelling process also revealed two important findings; that subsidence is largely controlled by linear elastic compaction within the coal portion of the Walloon Coal Measures; and that there is negligible arching of overburden material. These findings provided the foundation for a simplified analytical model for the whole of the Surat Basin in the CMA as detailed in the next section.

#### **7.4.2.2 Analytical model for the Surat Basin**

An analytical model was developed for the entire Surat Basin using an analytical equation integrating geomechanical rock properties and predicted depressurisation. The model calculates compaction in the Walloon Coal Measures as a function of the change in pressure resulting from depressurisation, the thickness of the formation prior to compaction and the properties of the lithological units derived from downhole geophysical logs.

Comparison of the results from the two models (i.e. the geomechanical model and the analytical model) in the Condamine Alluvium footprint highlighted that for the same geomechanical properties and pressure distribution, the analytical model was able to approximate predictions of subsidence from the numerical model. It also offered significant advantages over the geomechanical model as comparatively short runtime of this model enabled history matching to InSAR data as well as estimates of predictive uncertainty.

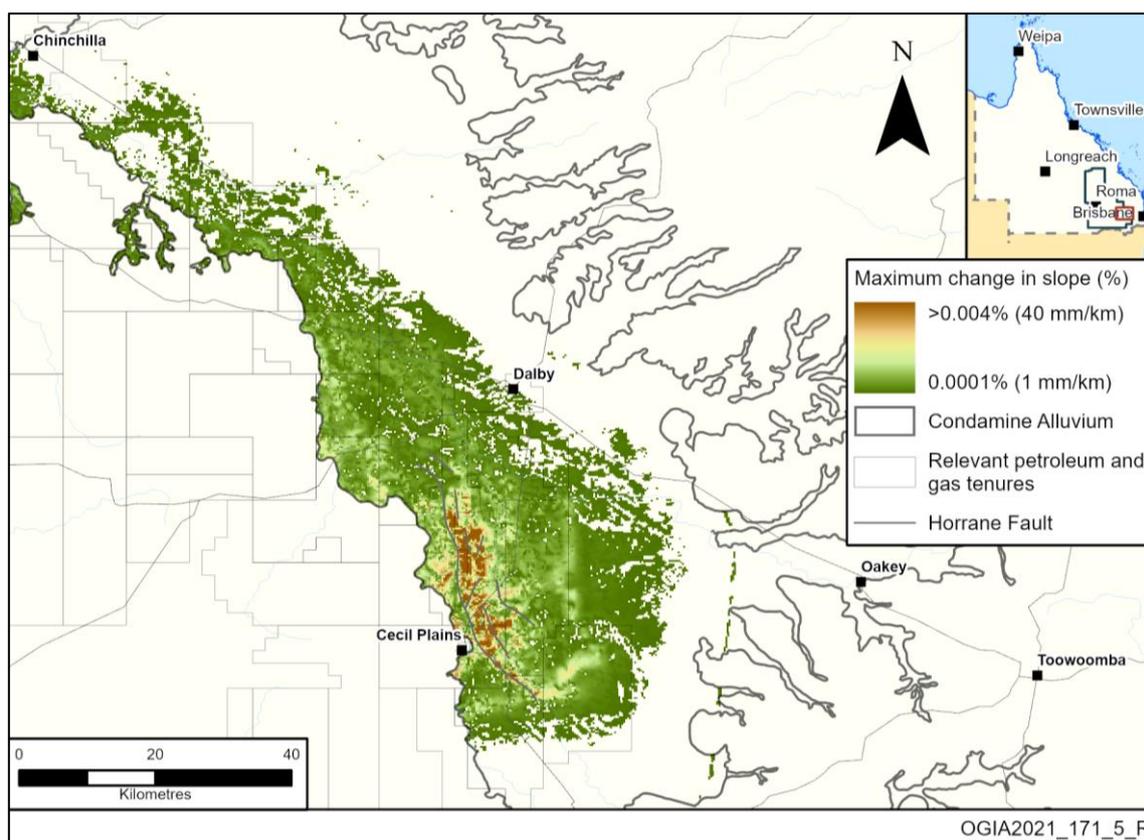
#### **7.4.2.3 Predictions**

Predicted groundwater impacts from the groundwater flow model were used as an input to the subsidence model for making a prediction of CSG-induced subsidence in the Walloon Coal Measures. To explore the range of uncertainty in predictions, a set of 1,000 models were generated from stochastic realisations of geomechanical properties. Each of these models was then compared to the available InSAR data in the vicinity of the Condamine Alluvium, with the 50 best fitting models selected to generate predictions of subsidence.

Predictions were derived as change in ground movement (i.e. predicted subsidence). A change in slope was also calculated within the cropping land in the Condamine Alluvium. Predicted subsidence and change in slope are reported statistically as a median (P50) prediction derived from those 50 model runs. The predicted magnitude of subsidence for the entire Surat Basin is shown in Appendix F, and the change in ground slope is shown in Figure 7-7 for the cropping areas in and around the Condamine Alluvium.

Outputs from the uncertainty analysis are processed to derive probability of certain magnitude of subsidence and slope occurring at each model cell (OGIA 2021j). As an example, maps of the probability of 0.001% and 0.005% slope change, together with probability of 100 mm and 150 mm subsidence occurring around the Condamine Alluvium, is also presented in Appendix F. The maps suggest that in a very small area north of the Cecil Plains, there is about 80% probability of change in slope of 0.005%, while most of the area between the Dalby and Cecil Plains is likely to experience 0.001% change in slope. Similarly, in terms of the magnitude, some localised areas west of Cecil Plains are predicted to have a 50% chance of 150 mm of subsidence occurring.

Within the Condamine Alluvium, the greatest change in slope is predicted across the Horrane Fault. This is driven by differential drawdown patterns either side of the fault which is facilitated by disconnection of layers through juxtaposition as well as the resistance to horizontal flow caused by fault core.



**Figure 7-7: Predicted maximum change in ground slope from CSG-induced subsidence**

### 7.4.3 Conclusions from subsidence predictions

Key conclusions from subsidence modelling and predictions are as follows:

- As is the case for groundwater level decline, the rate of subsidence is likely to be higher in the initial stages of development, gradually stabilising over the following few years.
- By the end of 2060, predictions of subsidence are mostly less than 100 mm across the cropping lands, with some exceptions around the heavily developed CSG fields where the maximum subsidence is likely to be up to around 175 mm.
- The maximum change in ground slope from CSG-induced subsidence in most areas is predicted to be less than 0.001% (10 mm over 1 km) but is up to 0.004% (40 mm over a km) in some areas.
- Uncertainty analysis suggests that in a very localised area north of Cecil Plains, there is 80% probability of the maximum change in slope exceeding 0.005%, while most of the area between Dalby and Cecil Plains has nearly 90% probability of experiencing greater than 0.001% change in slope.
- Predictions are broadly consistent with observed ground movement in and around the western margins of the Condamine Alluvium.

### 7.4.4 Implications for EVs

As stated previously, the EVs that could potentially be affected by subsidence are changes to landform and surface water flow (which supports aquatic ecosystems), cropping lands and aquifer integrity.

There are aquatic ecosystems associated with surface watercourses in the Surat Basin. Depending upon the magnitude, subsidence may change the slope of tributaries, resulting in changes in flow and direction that would affect aquatic systems. However, as detailed in previous sections, observed and predicted subsidence is very small and unlikely to materially change surface flows to watercourses.

Subsidence may, depending upon the magnitude and rate of change over time, potentially affect the ground slope of irrigated cropping land and hence the irrigation practices. A key parameter for this assessment is the change in ground slope resulting from subsidence, as presented in Figure 7-7.

The process of depressurisation of the target formation has the potential to alter the porosity and permeability of the formation through compaction. Compaction resulting from associated water extraction occurs primarily within coal seams in the target formation, resulting in a corresponding reduction in permeability. This effect is likely to be inconsequential in surrounding aquifers, as they have practically no coal and hence less prone to compaction compared to the CSG target formation.

## 7.5 Monitoring strategy for subsidence

Monitoring of ground movement is required to:

- establish baseline and background trends in ground movement
- identify CSG-induced subsidence that may have already occurred
- continuously improve the model for making predictions of CSG-induced subsidence.

Some ground movement monitoring is necessary in areas away from CSG production, where subsidence would not be a component of ground movement. That data would assist in understanding background movement unrelated to CSG.

As detailed in the following sections, there are four elements to the monitoring strategy:

- tools and techniques
- baseline slope (spatial monitoring)
- trend monitoring (temporal monitoring)
- conditional monitoring (a safety net).

### 7.5.1 Tools and techniques

A range of tools exist to monitor ground movement at either a local or regional scale. Some methods measure relative change in elevation, while others are better at measuring absolute ground elevation. In the context of CSG-induced subsidence, important considerations for monitoring ground movement are: the accuracy of the measurement (millimetre accuracy when measuring changes over time); the need for minimal disturbance in and around the measurement points; and cost-effectiveness in data collection. Given the regional scale of CSG development in the Surat CMA, satellite or aerial survey-based methods are more practical. A summary of techniques and methods is provided in Table 7-1.

Despite its limitations, InSAR is a commonly applied and practical technique for monitoring regional-scale ground movement. There is InSAR data available in the Surat Basin as far back as 2006. Industry has been purchasing this data since 2014 for individual tenure areas. From more recently deployed satellites (since 2017), data is available at a frequency of six days, with data points on a 4x20-m grid. To address tenure boundary limitations and extend knowledge, OGIA has now acquired

data directly from TRE Altamira for the broader Condamine Alluvium and Chinchilla area, covering a period from 2006 to July 2021.

Geoscience Australia, Origin and QGC have separately established a network of around 140 geodetic markers, which are permanent survey installations. Additional installations are currently under construction by other tenure holders.

In general terms, a difference between measurements within a time series indicates ground movement. As previously discussed, further evaluation of the potential influences on ground movement is then necessary to distinguish the CSG-induced impact from other influences on ground movement.

There are also other methods, such as tiltmeters and extensometers, that are sometimes used for local investigations but their application is limited at a regional scale.

**Table 7-1: Methods for measuring ground movement**

Method	Mode and frequency	Measured parameter	Suitability and practicality
InSAR	Satellite based, every 6 days	Change in elevation	<ul style="list-style-type: none"> <li>Measuring change over time (temporal monitoring)</li> <li>Not suitable for establishing a digital terrain model</li> <li>Some limitations in cultivated areas</li> </ul>
Airborne LiDAR	Flight survey, when tasked	Absolute elevation	<ul style="list-style-type: none"> <li>Establishing digital terrain model and slopes (spatial measurement)</li> <li>Not suitable for comparing absolute elevation from two different surveys at two different time periods</li> <li>Some limitations in heavily vegetated areas</li> </ul>
Drone LiDAR	Above-surface survey, when tasked	Absolute elevation	<ul style="list-style-type: none"> <li>Very similar to airborne LiDAR but with higher density of data points</li> <li>More expensive than airborne LiDAR</li> <li>Some limitations in heavily vegetated areas</li> </ul>
Terrestrial survey	Physical on-ground survey, when tasked	Absolute elevation	<ul style="list-style-type: none"> <li>Similar to Drone LiDAR but most expensive</li> <li>Some limitations in vegetative areas</li> </ul>

**Notes**

LiDAR = light detection and ranging

### 7.5.2 Establishing baseline slopes

Establishing land slope requires measurement of elevation at different points around the same time, to a high level of relative accuracy. As listed in Table 7-1, there are multiple ground survey and aerial methods for establishing ground elevation, which can then be used to establish ground slope at a farm scale.

In early 2021, in collaboration with interested landholders, OGIA selected representative properties to compare and test the suitability and viability of two different methods to establish ground elevation and slope – drone LiDAR and ground-based GPS survey. OGIA then further compared these products with regional airborne LiDAR data acquired and provided by Arrow. Results thus far conclude that the surface drainage pattern across a paddock, derived from an aerial LiDAR survey, is the most suitable and cost-effective method to establish background slope, as it also helps in

identifying minor slopes and depressions. As drone and airborne LiDAR show a broadly similar drainage pattern, airborne LiDAR is therefore considered a cost-effective method for slope analysis and assessing changes over time at both a regional and property scale.

The strategy for establishing baseline is therefore as follows:

- In cropping lands in and around the Condamine Alluvium, the RTH (Arrow in this instance) will undertake at least one airborne LiDAR survey (or an alternate method that can provide similar or higher accuracy) each year, preferably during the dry season when leaf coverage is minimal and there is no ponding of water, within 5 km of CSG development. The first survey should be carried out prior to the commencement of production, as far as practical.
- RTH will provide the data to OGIA within three months of survey.
- OGIA will analyse the data on an ongoing basis and report the findings annually.
- OGIA will also make the data and analysis available to stakeholders.

### 7.5.3 Trend monitoring

As stated in earlier sections, InSAR is the most appropriate technique for ongoing monitoring of change in ground elevation for the purpose of establishing trends and subsequent identification of subsidence. Trend monitoring will therefore be undertaken as follows:

- OGIA will acquire InSAR data directly from a supplier and make this dataset available to industry and stakeholders.
- OGIA will select specific locations, as a network of high-quality reliable monitoring locations, for ongoing assessment and reporting.
- OGIA will report the trends on an annual basis and make data available through a web interface for easy public access.

In parallel, OGIA will continue to evaluate best practice techniques for processing InSAR data which are currently being explored by research organisations. OGIA is also in discussions with TRE Altamira to explore extraction of additional ground movement data at specific points of interest, such as the CSG well heads.

### 7.5.4 Additional monitoring

Additional monitoring is proposed where the observed trend in ground movement shows a decline of more than 10 mm/year over a 12-month period and there is CSG production within 2.5 km of the monitoring location. This will provide additional data in instances where ground movement deviates from the predicted rate of decline. This additional monitoring will consist of the following:

- OGIA assesses the trends on an ongoing basis and notifies RTH (Arrow in this instance) where additional monitoring may be required.
- RTH then captures more frequent LiDAR (or similar) data within 12 months and undertakes additional verification at agreed ground control points to further improve accuracy of the survey data.
- RTH provides raw and processed data to OGIA for further analysis.

## 7.6 Summary of the subsidence assessment

- Hundreds of metres of CSG depressurisation in the coal seams will typically result in a few centimetres of subsidence at the surface.
- The rate of subsidence is higher in the initial development stages, before gradually stabilising in the following few years. This may cause minor changes to the ground slope and potentially affect farming practices and EVs.
- The available data indicates about 100 mm of CSG-induced subsidence has occurred since 2015 in some mature gas field areas near the Condamine Alluvium.
- OGIA's predictions of subsidence are based on a combination of geomechanical and groundwater flow modelling, accounting for all existing and proposed development. The subsidence model is history-matched to ground movement data. Predictions of subsidence within the Condamine Alluvium footprint suggest that most of the cropping area is likely to experience less than 100 mm of subsidence by the end of 2060 with some exceptions around the heavily developed CSG fields where the maximum subsidence is likely to be around up to 175 mm.
- The maximum change in ground slope from CSG-induced subsidence in most areas is predicted to be less than 0.001% (10 mm over 1 km) but can be up to 0.004% (40 mm over a km) in some areas.
- Uncertainty analysis suggests that in a very localised area north of Cecil Plains, there is 80% probability of the maximum change in slope exceeding 0.005%, while most of the area between Dalby and Cecil Plains has nearly 90% probability of experiencing greater than 0.001% change in slope.
- Natural or 'background' ground movement unaffected by CSG development is in the order of  $\pm 25$  mm/year.
- Remote sensing (InSAR) is the most effective tool for monitoring regional-scale ground movement over time (trend monitoring), which is then used to assess subsidence.
- Airborne LiDAR survey data is effective in establishing and monitoring slope and mapping out drainage at the farm scale.

## Chapter 8 Management of impacts on water bores

### 8.1 Preamble

A central part of the underground water management framework in Queensland (Chapter 1) is to provide for the proactive management of impacts on water bores that are predicted to be impacted due to the exercise of underground water rights by a resource tenure holder – i.e. by the extraction of associated water.

Chapter 6 presents impacts on groundwater levels in aquifers and Chapter 3 provides a profile of water bores and their aquifers in the Surat CMA. This chapter presents how those two sets of information are used to identify water bores that are predicted to be impacted in the short and long terms, and how that underpins the **make good of water bores**.

### 8.2 Terminology

**Bore trigger thresholds** – thresholds used to identify water bores that are likely to be impacted and require further bore assessment. The Water Act defines bore trigger thresholds as a decline in the groundwater level in an aquifer of five metres in a consolidated aquifer (such as sandstone) and two metres for an unconsolidated aquifer (such as alluvium).

**Make good arrangements** – an informal term used in this report to collectively refer to provisions under Chapter 3 of the Water Act designed for the proactive management of impacts on water bores. These include establishing existing and future impacts on water bores through the UWIR (s. 376 of the Water Act), identifying responsible tenure holders (RTHs) (s. 376), and subsequent make good obligations (ss. 408–437).

**Make good obligations** – a statutory term comprising four obligations of a tenure holder: bore assessment, entering into a make good agreement, complying with that agreement and varying it if necessary.

**Make good agreement** – a statutory term referring to a legally binding agreement between the tenure holder and the water bore owner to reflect the outcome of bore impairment assessment and make good measures negotiated between the tenure holder and the bore owner.

**Make good measures** – a statutory term referring to specific make good actions.

**IAA bores** – a statutory term referring to water bores determined to be accessing water from an aquifer within the IAA for that aquifer – meaning the water bores that are predicted to be impacted by more than the trigger threshold in the next three years (i.e. 2021–2024 for this UWIR).

**Net IAA bores** – IAA bores identified in the current and previous UWIRs (2011–2024) including any additions and subtractions resulting from changes to bore information in the post-UWIR period.

**LAA bores** – a statutory term referring to water bores where impacts of more than the trigger thresholds are predicted at any time in the future.

**Existing bore** – a statutory term referring to a water bore that was in existence before the first UWIR took effect (1 December 2012).

**New bore** – a statutory term referring to a bore that was constructed in the Surat CMA after the first UWIR took effect (1 December 2012).

**Replacement bore** – a water bore constructed within 10 metres of the originally authorised water bore and tapping the same aquifer, or where the authorised replacement location was granted through a relevant water licence/development permit.

**Responsible tenure holder (RTH)** – an authorised tenure holder responsible for implementing a specific obligation assigned to it in the UWIR, as per the provisions of s. 369 of the Water Act.

### 8.3 A water bore and its authorisation

Under the Water Act, a water bore is an artesian or sub-artesian bore that taps an aquifer. Relevant definitions in the Water Act imply that a water bore accesses water from an aquifer and has an appropriate authorisation for its construction. For the purpose of the make good arrangements, a water bore is considered a water bore unless there is sufficient information to demonstrate that it either was not authorised for construction, was dry when constructed, or has insufficient yield for at least domestic purposes.

The Water Act requires that the construction of a water bore be authorised. There is a separate requirement regarding the purpose for which the water bore can be used, and how much water can be taken from the bore, as detailed in section 3.4.1.

Authorisation to construct a water bore is currently provided through the *Planning Act 2016*. The requirements vary depending upon whether there is a water plan that applies to groundwater, or whether there is a declared groundwater management area established under the Water Regulation 2016, and whether groundwater in the area is managed through general provisions in the Water Act. More broadly, all artesian bores require development permits regardless of their location. The permit requirements for sub-artesian bores can be divided into three categories:

- Assessable development – prior to the construction of a water bore, a development permit is required and is assessed through an application process.
- Accepted development (self-assessable) – a development permit is not required but the water bore must be constructed in accordance with a self-assessment code, including the requirement for construction by a licensed water bore driller in accordance with minimum construction standards.
- Not assessable (exempt development) – a development permit is not required for the water bore to be drilled and constructed, although the water bore must be constructed by a licensed water bore driller in accordance with minimum construction standards.

In the Condamine Alluvium, sub-artesian water bores for S&D purposes are exempt developments, unless the proposed bore location is within 200 m of a property boundary or within 400 m of another water bore. Water bores for all other purposes require development permits. In the GAB, development permits are required for all water bores with the following exceptions: those for domestic use only; those for S&D use in the Eastern Downs management area; and replacement bores (self-assessable). Sub-artesian bores in the Bowen Basin do not require authorisation to construct.

Construction requirements have evolved and changed over time. A water bore may not have held a development permit at the time of construction or may not have been required to comply with self-assessment code but would still be 'deemed authorised' if it was constructed to the requirements of the time.

A licensed water bore driller must be engaged for drilling and constructing any water bore in Queensland. All water bores must be completed in accordance with the minimum construction standards, which specify both construction materials and minimum design standards (Department of Natural Resources Mines and Energy 2017). This requirement only came into effect in 2000 – including a requirement to provide data for recording in the GWDB. Importantly, a water bore’s presence or absence in the GWDB does not determine the legal status of the water bore – meaning that a bore not registered in the GWDB (often referred to as ‘unregistered’ bore) may still be a legally constructed water bore.

Historically, water bores were constructed to maximise supply for the intended purpose. In some cases, water bores were screened across multiple aquifers to achieve a desired yield and quality. The introduction of the minimum construction standards in the 1990s changed this practice by requiring, amongst other things, that each water bore be completed in a single aquifer.

## 8.4 Make good arrangements

### 8.4.1 General

As stated in the terminology, the make good arrangements include establishment of existing and future impacts on water bores through the UWIR, identification of RTHs, and subsequent make good obligations.

The make good obligations are also summarised in various guidance material prepared by DES and specifically comprise the following:

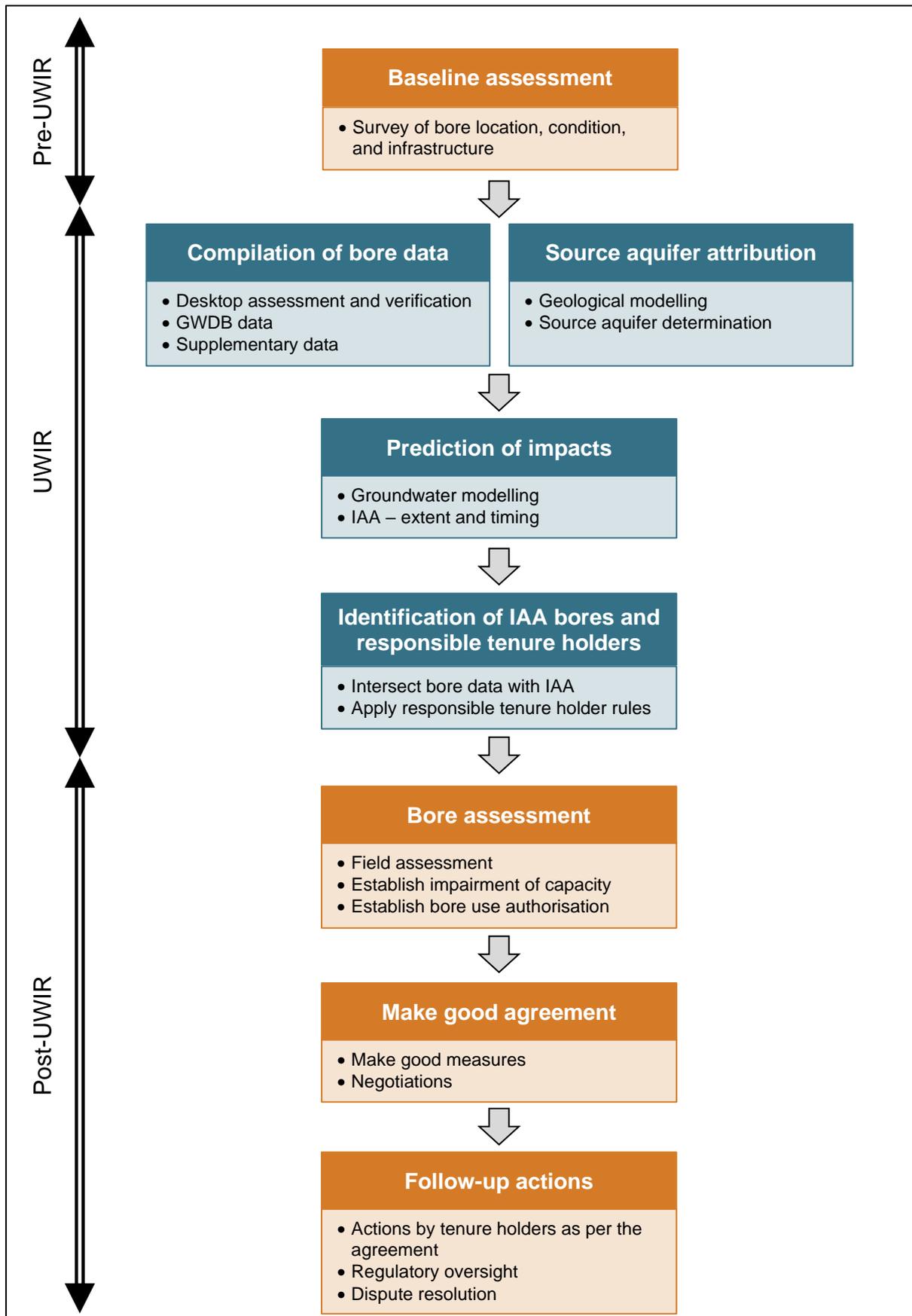
- bore assessment
- entering into a make good agreement and, if the water bore is (or is likely to be) impaired, providing make good measures for that impairment
- compliance with the make good agreement
- if asked to vary the make good agreement in specified circumstances, negotiation of variation to the make good agreement.

Implied in these arrangements are two key principles:

- **proactive action** – i.e. for a water bore that is predicted to be impacted, a make good agreement is in place for that water bore prior to any impairment of water supply from that bore
- **adaptive and flexible** – i.e. the actual make good measures are based on specific circumstances relating to the affected water bore and may include one or more elements, such as ongoing monitoring, additional local-scale assessment, rework/modification of existing water bore infrastructure, drilling of a replacement water bore in a non-affected formation, provision of an alternate water supply and financial compensation.

### 8.4.2 Process and key components

Details on the legislative processes relating to make good arrangements are provided in the DES guidelines. A more detailed flow diagram for some of the steps relevant to the UWIR is provided in Appendix G. Key elements in terms of steps that occur pre- and post-UWIR, and their interlinkages, are presented in Figure 8-1 and summarised in subsequent sections.



**Figure 8-1: A simplified flow diagram showing the key steps of make good arrangements for water bores**

#### **8.4.2.1 Baseline assessment**

There is a legislative requirement for a resource tenure holder to collect data on the condition of a water bore prior to commencement of resource production. For a water bore located on tenure, a baseline assessment plan is submitted to DES by the tenure holder. The UWIR also identifies additional water bores located off tenure for which baseline assessment is required to be carried out by the tenure holders. Information typically collected in a baseline assessment includes its location, groundwater level and quality, construction, and pumping infrastructure. Information must be collected, or certified, by an independent third party, with the outcome of the assessment provided to the landholder and submitted to OGIA.

#### **8.4.2.2 Compilation of water bore data and aquifer attribution**

This step is to establish the source aquifer for a water bore and its physical status, as detailed in section 3.3.4. This involves verifying and synthesising water bore information, which in turn involves desktop assessment supplemented with aerial photos and scrutiny of site-specific information in priority areas. This information is then used in identifying the aquifer or aquifers that supply water to the water bore. This step also determines whether the water bore is considered an existing water bore for the purpose of make good arrangements.

#### **8.4.2.3 Prediction of impact**

The outcome of model predictions of impact in aquifers (Chapter 6) is presented in the UWIR in the form of a map, for each aquifer, showing the areas where impacts are predicted to be greater than the trigger threshold (five metres for consolidated aquifers and two metres for unconsolidated aquifers) within the next three years – the end of 2024 for this UWIR. This is known as the IAA for the aquifer.

#### **8.4.2.4 Identification of IAA bores and RTH**

Water bores sourcing water from an aquifer within its IAA are referred to as IAA bores. They are identified in the UWIR by intersecting available water bore information – such as water bore location, physical status and source aquifer – with the corresponding IAA. The outcome is a list, in the UWIR, of IAA bores with corresponding RTHs that then become responsible for completing water bore assessment and entering into make good agreements. While IAAs are only established through an approved UWIR and remain unchanged until the next update of the UWIR, the list of IAA bores can change between UWIRs as new information on water bores becomes available.

#### **8.4.2.5 Bore assessment**

After a UWIR is approved, the first step is for a bore assessment to be undertaken by the RTH for each of the identified IAA bores. The RTH must establish whether a water bore has, or is likely to have, impaired capacity due to the exercise of underground water rights. This typically involves a site visit and investigations (such as hydrogeological measurements, pump tests, etc.) by the RTH to amalgamate local-scale hydrogeological information that may impact on the water supply from the bore and establish the water bore's authorised use and purpose. The outcome may result in a change to the aquifer attribution for the water bore. Bore assessment outcomes are provided to landholders and submitted to OGIA to update relevant information and datasets.

#### **8.4.2.6 Establishment of water bore impairment**

The main purpose of bore assessment is the establishment of water bore impairment, which is undertaken by the RTH to assess whether, because of the exercise of underground water rights, the water bore will be unable to provide a reasonable quality or quantity of water for its authorised use or

purpose. Make good obligations distinguish between an '**existing bore**', a '**new bore**' and a '**replacement bore**', for which all obligations relating to make good are deemed to be transferred from the original water bore to the replacement water bore.

#### **8.4.2.7 Make good agreement**

A make good agreement is a legally binding agreement between the RTH and the water bore owner. The agreement must include the outcome of a bore assessment, assessment of impaired capacity and make good measures negotiated between the RTH and the water bore owner. Make good measures may include actions such as ongoing monitoring, additional local-scale assessment, rework/modification of existing water bore infrastructure, drilling of an alternate water bore in a non-affected formation, provision of an alternate water supply or financial compensation. To provide for ongoing monitoring and periodic review, a make good agreement is required for all water bores for which bore assessments have been undertaken, not just those that are likely to be impaired.

#### **8.4.2.8 Implementation of make good measures**

This is subject to the details of make good measures and other actions agreed upon by the RTH and the water bore owner. Oversight and compliance of implementation is provided by DES as the responsible regulator and facilitated by government agencies responsible for managing and coordinating natural resources, such as the Engagement and Compliance Unit within DoR and the GasFields Commission Queensland.

If a water bore is not located within an IAA but is experiencing impairment, including due to the release of free gas derived from a resource tenure holder's activity, the chief executive of DES may direct the resource tenure holder to undertake a bore assessment, regardless of whether the water bore is identified as an IAA bore. In those circumstances, the subsequent steps of establishing impairment and make good agreement are the same as summarised above.

### **8.4.3 Responsibilities of various parties**

Responsibilities of various stakeholders involved in relation to make good arrangements are summarised as follows:

- **Water bore owners** – provide access to the water bore, and information about the water bore, to the RTH and OGIA when requested.
- **RTHs** – undertake baseline and bore assessments including all supporting field investigations; establish water bore authorisation, purpose and impairment; negotiate and enter into make good agreements with water bore owners; and comply with agreements.
- **OGIA** – compile and verify water bore information and status; develop and maintain geological and groundwater flow models; make predictions of IAAs; update and report predictions and IAA bores in the UWIR every three years; review predictions and IAA bores every year, reported through an Annual Report; receive and maintain baseline and bore assessment information from the RTHs; and support implementation of make good arrangements.
- **DES** – provide overall regulation of make good arrangements; develop and provide guidelines/forms in relation to make good arrangements and obligations; maintain relevant data; and oversee compliance.
- **DRDMW and DoR** – support engagement, support compliance and maintain the GWDB.

- **GasFields Commission Queensland** – support engagement and facilitate coexistence.

## 8.5 IAA bores

### 8.5.1 Process for determining IAA bores in the UWIRs

As summarised in the previous sections, three sets of information are required to determine if a water bore is an IAA bore:

- The water bore's **location and physical status** – compiled and verified from the GWDB, supplemented with baseline assessment and bore assessment where available and, for some priority areas, field visits and discussions with water bore owners.
- The aquifer(s) from which the water bore sources water (**aquifer attribution**) – determined primarily from water bore construction details, assumptions about screening and depths where construction information is not available, and the geological model.
- Short-term impacts (next three years) in the source aquifer(s) at the location of the water bore – derived from predictions of impacts which establish the **IAA footprint** for each aquifer, as presented in section 6.5.2.

In the Surat CMA, OGIA compiles and verifies water bore location and status information for the purpose of the UWIR (Chapter 3). In some instances, this results in changes to previously recorded location data and the addition of water bores that have not previously been recorded in the GWDB. A higher level of effort is applied in the verification of water bores that are located closer to CSG production areas and likely to be impacted sooner. The GWDB is also progressively updated with the verified information.

Section 3.3.3 also details a process by which the physical status of a water bore is compiled and verified. This is then used to derive a list of water bores that physically exist and require further make good consideration, by excluding the following:

- water bores that are reported to be abandoned and/or destroyed
- water bores that are reported in the bore baseline assessment as 'could not be found or located' – subject to OGIA's desktop verification and discussions with water bore owners, where possible
- water bores that are recorded in the GWDB as decommissioned
- water bores for which make good agreements have already been settled between the tenure holders and the water bore owners – either for water bores that were previously identified as IAA bores (refer next section), or for other water bores where voluntary agreements may have been settled
- water bores for which there is no authorisation to drill and construct – noting that water bores are considered to be authorised by default, unless there is sufficient information to conclude otherwise
- water bores where multiple aquifers are accessed and for which the impacted aquifer is contributing less than 10 per cent of the water bore yield.

The filtered dataset from the above process is then intersected with the IAA for the corresponding aquifer to determine which of the water bores tapping the aquifer are IAA bores.

IAA bores are determined on a rolling basis in each successive UWIR for the following three years. This is because the areas affected by groundwater level declines continue to expand as new development areas are added, leading to additional water bores being identified as IAA bores. Also, industry's development plans are more stable in immediate term and therefore predicted IAA bores are also likely to be relatively more certain and need proactive make good.

### 8.5.2 IAA bores in this UWIR

Applying the process described in the previous section, there are 108 water bores that are identified in this UWIR for the first time as IAA bores – i.e. predicted to be impacted by more than five metres in next three years (2021–2024). These are in addition to the 233 IAA bores from the previous UWIRs (from 2011 to 2021), which are detailed in the later section. Table 8-1 provides a summary of these IAA bores and a full list of water bores is provided in Appendix G.

**Table 8-1: Summary of identified IAA bores in the UWIR 2021 for the period 2021–2024**

Formation/subdivision		Water bore purpose			
		Agriculture	TWS	S&D	Total
Springbok Sandstone		-	-	14	14
Walloon Coal Measures	Upper Juandah Coal Measures	-	-	19	19
	Lower Juandah Coal Measures	3	-	64	67
	Taroom Coal Measures	1	1	6	8
<b>Total</b>		<b>4</b>	<b>1</b>	<b>103</b>	<b>108</b>

**Note:**

TWS = town water supply

Of the 108 IAA bores, 94 are in the Walloon Coal Measures, the primary target for CSG production. They are largely located along the Dalby–Chinchilla Highway, where the Walloon Coal Measures is accessible at relatively shallower depths. There are also some water bores in and around the Dalby township accessing the coal formation below the Condamine Alluvium for S&D purposes.

Eighty-nine (89) of the 108 IAA bores are assigned to Arrow for the follow-up bore assessment and make good arrangement. The relatively higher number of water bores assigned to Arrow is due to its tenure location in relation to impacted water bores, rather than the magnitude of impacts (Chapter 13). Arising from the integration of coal mining impacts, three water bores are assigned to mining tenure holders, for which New Hope Group is the RTH.

Adding the 233 water bores determined as effective IAA bores in the previous UWIRs (next section) results in a total of 341 water bores that have been effectively determined as IAA bores since 2011, as shown in Figure 8-2 and summarised in Table 8-2. Again, the majority are in the Walloon Coal Measures and are for S&D purposes. Only a handful (less than eight per cent) are in the other aquifers.

### 8.5.3 IAA bores identified in previous UWIRs

As detailed earlier, IAA bores are progressively identified on a rolling basis for the following three years. In the post-UWIR period, more up-to-date information may become available that may lead to additional water bores being determined to be IAA bores, even though the extent of the IAA remains

unchanged until the next update of the UWIR. For those additional water bores, OGIA will continue to notify the water bore owners as well as the RTHs for those water bores for follow-up actions. DES may also issue a direction notice to a tenure holder under s. 418 of the Water Act, triggering a bore assessment and subsequent make good agreement.

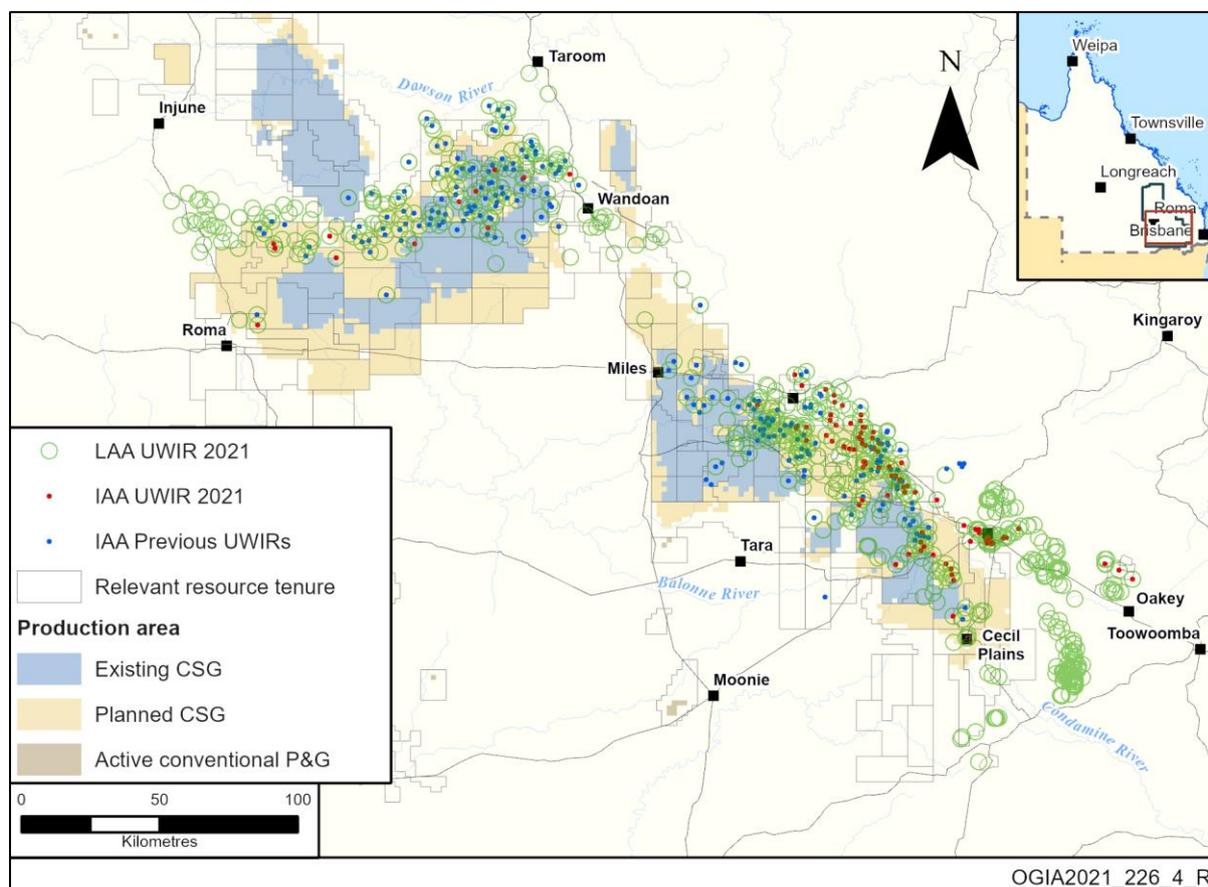


Figure 8-2: Map showing location of IAA bores

Table 8-2: Tracking of changes to IAA bores

Period	Added	Removed	Net IAA bores (running total)
UWIR 2012	85	-	85
Post-UWIR	10	25	70
UWIR 2016	57	-	127
Post-UWIR	1	6	122
UWIR 2019	100	-	222
Post-UWIR	13	2	233
UWIR 2021	108	-	341

For tracking IAA bores, the term 'net IAA bores' is used to define the group of bores that have become IAA bores as a result of being identified and listed in a UWIR, or post-UWIR changes. Table G-3 in the UWIR 2019 separately listed 48 water bores where there was insufficient data to reliably identify them as IAA bores, although they were predicted to experience an impact of more than the

trigger threshold of five metres within three years (i.e. end of 2022). Further investigations in the post-UWIR period determined 12 of these water bores to be IAA bores. OGIA notified the outcome of the assessment to affected tenure holders, water bore owners and DES.

In some instances, an IAA bores listed in the previous UWIRs may no longer be an IAA bore in this UWIR because of changes to bore information, attributed source aquifer, or changes in predictions resulting from a combination of revised production scheduling and model calibration. These bores are identified in Table G-2.

Of the 341 net IAA bores, about 80% are within relevant tenure area boundaries and the remainder are outside. Also, only about 25% of the IAA bores are within the existing production footprint where CSG wells are already operating.

Prior to this report, 233 water bores had been identified as net IAA bores in the previous three UWIRs or from changes to water bore information in the post-UWIR periods. A summary of those water bores is presented in Table 8-2 and a full list of bores is provided in Appendix G. Of the 233 net IAA bores:

- Bore assessments have so far been completed for 170 water bores as the first step towards make good agreements, while 45 bore assessments are outstanding.
- Make good has so far been executed for 135 water bores<sup>5</sup>. In some instances, make good arrangements were reached without bore assessments.
- There are 45 water bores for which make good is currently under negotiation.
- A total of 117 water bores have so far been decommissioned or agreed to be decommissioned primarily as a result of make good agreements.

There are also about 90 water bores – primarily in the Walloon Coal Measures – that have been proactively decommissioned by the industry. Tenure holders have also advised that in addition to IAA bores, agreements for make good measures have been proactively entered into with the owners of approximately 100 water bores. These are water bores that would likely be identified as IAA bores at a later stage of development but have been attended to earlier on a voluntary basis, at the mutual convenience of the water bore owner and the tenure holder. The available information from DRDMW and tenure holders also suggests that about 16 alternate water bores may now be completed into the Hutton Sandstone as a result of make good arrangements.

#### **8.5.4 Post-UWIR process for IAA bores**

Once the UWIR is approved and takes effect, the RTH listed against each IAA bore in Appendix G is required to undertake a bore assessment to establish whether the water bore has, or is likely to have, impaired capacity due to a decline in groundwater level in the water bore resulting from the exercise of underground water rights – as detailed in section 8.4.2. This will include, among other things, establishing the water bore's authorised use and purpose, and whether it is an existing water bore.

### **8.6 LAA bores**

LAA bores are those water bores where impacts of more than the trigger thresholds (five metres for consolidated aquifers and two metres for unconsolidated aquifers) are predicted at any time in the future. They are determined using a process similar to IAA bores, the only difference being that the

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<sup>5</sup> This potentially includes some in-principle agreements.

water bore information and source aquifer is intersected with LAAs (section 6.5.2) rather than IAAs. Table 8-3 provides a summary of LAA water bores.

The total number of LAA bores stands at 702, of which 515 physically exist and are usable water bores, while 187 have now been decommissioned or proactively entered into make good agreements. These are included to enable ongoing comparison of effective LAA bores.

The number of LAA bores is higher than that presented in the previous UWIR. This increase is due to a combination of factors:

- integration of coal mining impacts – 15 LAA bores that are directly assigned to coal mining tenure holders
- changes to development profile (Chapter 2)
- changes to water bore information as a result of ongoing verification and reattribution of source aquifers, including about 23 water bores that had not been registered in the GWDB
- about 18 water bores that have come into existence since the last UWIR.

**Table 8-3: Water bores in LAAs**

Formation/subdivision		Agriculture	S & D	Town water supply	Industrial	Total
Main Range Volcanics		1	2	-	-	3
Springbok Sandstone	Upper Springbok Sandstone	1	44	-	-	45
	Lower Springbok Sandstone	2	37	-	-	39
Walloon Coal Measures	Upper Juandah Coal Measures	3	63	-	-	66
	Lower Juandah Coal Measures	21	246	2	-	269
	Taroom Coal Measures	8	78	1	1	88
Hutton Sandstone	Upper Hutton Sandstone	-	1	-	-	1
	Lower Hutton Sandstone	-	2	-	-	2
Lower Bandanna Formation		-	1	1	-	2
<b>Total number of water bores that physically exist</b>		<b>36</b>	<b>474</b>	<b>4</b>	<b>1</b>	<b>515</b>
LAA bores that are decommissioned or where a make good agreement has been reached proactively						187
Total						702

About 92% of the LAA bores are for S&D purposes and 98% are in the CSG and coal mining target formation including the Springbok Sandstone. LAA bores do not trigger any further actions for tenure holders. These water bores are identified for information purposes only, until such time as they are identified as IAA bores in subsequent UWIRs. Of note, there may be water bores that are located within the geographic extent of an LAA for an aquifer but are not identified as LAA bores because they may be extracting water from another non-impacted aquifer.

## 8.7 Accessing water bore information

Information about a water bore in the Surat CMA can be accessed from a number of sources:

- Details about prediction of impacts for a water bore located within the Surat CMA – including whether the water bore is an IAA or LAA bore, along with magnitude and timing of impacts – are provided by OGIA in a web-based ‘Bore Search Tool’ (<https://www.resources.qld.gov.au/business/mining/surat-cma/bore-search>).
- Key information compiled by OGIA (Chapter 3), such as the verified water bore location, physical status and source aquifer, is also provided through the Bore Search Tool.
- Bore baseline assessments and outcomes of bore assessments are statutorily collected by the RTHs and provided to OGIA. Due to confidentiality reasons, this data is only made available on a case-by-case basis when requested. Relevant information from this data is extracted by OGIA for verification purposes and progressively incorporated into the GWDB.
- Information about the status of IAA bores that have been identified so far, and progress on implementation of make good agreements – compiled by OGIA using data from tenure holders and DES (provided in Appendix G).
- Detailed data about water bores, in terms of water bore location, construction details, etc., are maintained in the GWDB and accessible through Queensland Globe (<https://qldglobe.information.qld.gov.au>).

## 8.8 Summary of impacted water bores and their management

- A total of 702 water bores are likely to be impacted in the long term (LAA bores), based on a trigger threshold of five metres of predicted impact for consolidated formations and two metres for unconsolidated formations.
- About 92% of the water bores predicted to be impacted are for ‘stock and domestic’ purposes. The majority are in the CSG target formations or the Springbok Sandstone. Fewer than one percent are in recognised aquifers of the GAB and none are in the Condamine Alluvium.
- Of the LAA bores, 108 are short-term impacted water bores (IAA bores) that are likely to be impacted within the next three years (2021–2024). These will now require follow-up bore assessments by the RTHs to assess impairment of capacity. If a water bore’s water supply is likely to be impaired, then the tenure holder will negotiate and implement an appropriate make good measure with the water bore owner.
- OGIA has assigned an RTH for each of the 108 water bores based on rules established in this UWIR (section 13.4.3).
- IAA bores are identified in each UWIR on a rolling basis for the next three years. A net 233 water bores had been identified as IAA bores from the previous three UWIRs, of which make good is completed for 135. The total number of IAA bores to date is now 341.
- Details about prediction of impacts for a water bore located within the Surat CMA, including whether the water bore is an IAA or LAA bore, along with magnitude and timing of impacts, is provided by OGIA in a web-based ‘Bore Search Tool’ (<https://www.resources.qld.gov.au/business/mining/surat-cma/bore-search>).

## Chapter 9 Water Monitoring Strategy

### 9.1 Preamble

The purposes of the Water Monitoring Strategy (WMS) are to:

- identify past groundwater impacts from P&G and coal mining development
- improve knowledge about the groundwater flow system, which improves OGIA's ability to predict impacts
- support the evaluation of UWIR impact management strategies.

The WMS includes the specification of a groundwater monitoring network, tenure holder obligations for implementation of the network and reporting of data to OGIA. A key change to the monitoring strategy established in the previous UWIR is the integration of coal mining impacts in the Surat Basin.

### 9.2 Terminology

**Monitoring point** – a groundwater piezometer or bore constructed to monitor groundwater level or groundwater chemistry (Figure 9-1).

**Monitoring network** – a collection of groundwater monitoring points.

### 9.3 Components of the monitoring strategy

There are three core components of the WMS:

1. design, installation and maintenance of a **monitoring network** including:
  - a groundwater **level** network
  - a groundwater **chemistry** network
  - a groundwater **quantity** network (i.e. groundwater extraction volumes)
2. a program for **baseline assessment**
3. tenure holder **reporting** of the data and activities relating to the above components.

Each of these components is detailed in the subsequent sections of this chapter.

Individual tenure holders are responsible for specific monitoring obligations, which are assigned in accordance with the rules outlined in Chapter 13. Sections 9.5, 9.6 and 9.7 provide the details of each component of the WMS and additional information is available in the WMS companion document (OGIA 2021i).

### 9.4 Groundwater monitoring network

#### 9.4.1 Evolution and ongoing review of the network

The WMS groundwater monitoring network has grown progressively since its initial specification in the UWIR 2012. Changes since then reflect the availability of existing infrastructure at the time of review, groundwater system conceptualisation and data needs, and the progressive deterioration of early network installations.

The initial monitoring network specified in the UWIR 2012 incorporated 106 existing monitoring points. The network has since grown to about 700 groundwater level and chemistry monitoring points in this

UWIR despite recent delays to some of the planned maintenance and installations due to the COVID-19 situation (Figure 9-2). This growth has provided important continuity of historical monitoring data.

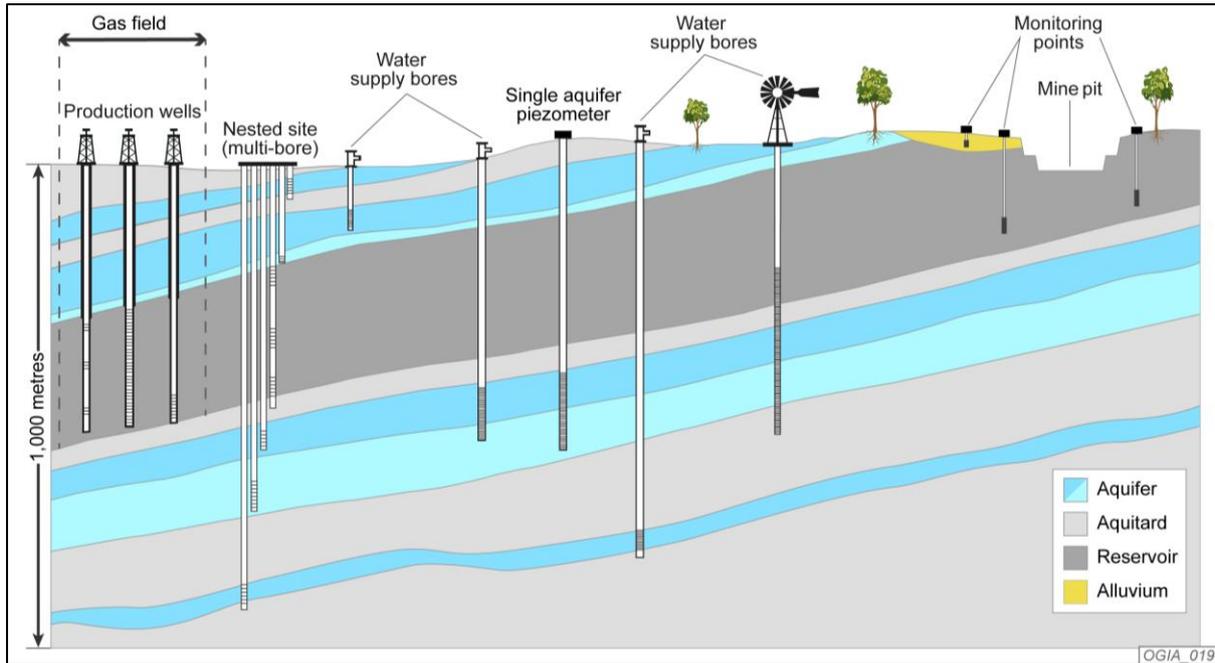


Figure 9-1: Schematic of monitoring installation types in the Surat CMA

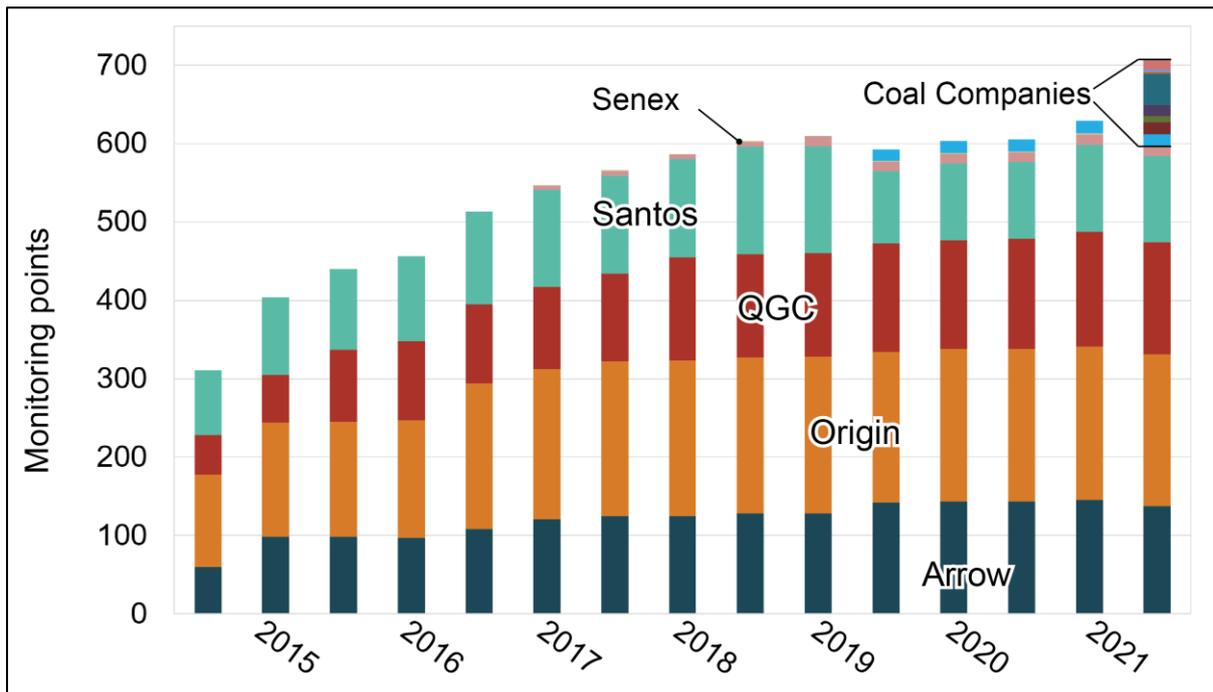


Figure 9-2: Growth of WMS monitoring points

There has also been growth in complementary networks including Groundwater Online and Groundwater Net (Jamieson et al. 2020). This data provides water bore owners with useful information about the condition of their water bores as well as changes in groundwater levels. These networks continue to provide additional data to support OGIA’s assessment.

As the groundwater monitoring network has evolved, additional challenges have emerged relating to new hydrogeological understanding and the performance of monitoring infrastructure. These include variability in groundwater systems, change to development plans, new techniques for the analyses of data, upkeep of existing installations, and keeping pace with technological advances.

A key additional consideration for the monitoring network in the current UWIR is to integrate monitoring of groundwater level and associated water extraction around coal mines.

### 9.4.2 Network objectives and rationale

Consistent with the purpose of the WMS, the following objectives (broadly consistent with those in the previous UWIRs) have informed the design of the network:

1. **Establish background trends** due to climatic variability and groundwater use. This then allows separation of the impacts of resource development from other contributing factors and understanding of the functioning of groundwater systems.
2. **Identify pressure changes near areas of resource development** to enable understanding of the vertical and lateral propagation of impacts within the target formations, as well as overlying and underlying formations.
3. **Understand groundwater flow near connectivity features** in areas where there is high potential for connectivity between coal formations and other aquifers, such as those areas where regional faults and associated fracture zones have been identified and in areas where formations separating reservoirs from other aquifers are either thin or absent.
4. **Understand groundwater flow near high value assets** such as springs and water bores where impacts are predicted that will enable understanding of groundwater level conditions and effectiveness of management strategies.
5. **Improve conceptual understanding and future groundwater flow modelling** by collecting and securing data for model calibration and validations of modelling.
6. **Assess groundwater conditions around the coal mining pits** to improve understanding of impact pathways and saturation level at the mine pits.

### 9.4.3 Guiding design principles

Consistent with the objectives, the review and design of the monitoring network has followed the following guiding principles:

- The part of the monitoring network specified in the UWIR 2019 that was not constructed by June 2021 has been reassessed as part of the current WMS. The revised network specification replaces the UWIR 2019 network specification. Such changes are more significant in this UWIR cycle due to logistical challenges associated with the COVID-19 situation affecting network implementation and maintenance.
- In general, a higher density of monitoring points is required inside and near existing and planned CSG development areas (e.g. Daandine 123 (RN160347)) compared to more distant areas, where background monitoring is the primary focus (e.g. Tipton 206 (RN 160789)).
- Where practicable, monitoring points are located in close proximity for multiple formations, providing information on groundwater level differences between formations – following the concept of nested monitoring points (Figure 9-1).

- In some formations, such as the Springbok and Hutton sandstones, separate monitoring is required for the upper and lower parts immediately overlying and underlying the CSG target formations (Glenburnie-18 (RN 160941)).
- A lead time is necessary to allow collection of sufficient data ahead of resource development in areas where impacts are predicted in the future so that a background trend can be established. For this reason, implementation timeframes are earlier in areas where impacts are predicted in the short term.
- The monitoring network allows for ongoing review in keeping with the ongoing changes to the development profile within the UWIR cycle. There are, however, certain monitoring points that are designed for ambient background conditions that will therefore continue to be required regardless of any changes to development profile (e.g. Dione 12M).
- The use of suitable existing tenure holder monitoring points – such as the existing coal monitoring networks or the conversion of exploration wells – is maximised so that the drilling of new dedicated monitoring points can be focused in areas of greatest need.
- The network seeks to primarily comprise groundwater level monitoring points that are dedicated, i.e. monitoring points that are not also used for water extraction or installed with pumping equipment (excluding sampling equipment) – except where there is sufficient contextual data to interpret monitoring data for the specific purpose.
- Monitoring points should reasonably represent groundwater level and groundwater chemistry at the formation or sub-formation scale. Monitoring points constructed as cemented vibrating wire piezometers (VWPs) or screened across multiple formations are being progressively transitioned out of the UWIR network (e.g. Meenawarra 5 (RN160732A)).
- The monitoring network maximises the use of existing monitoring points and requirements are commensurate with the level of relative impacts from (and development by) CSG, conventional oil and gas, and coal mining (e.g. Moonie 35 (RN22939A)).
- Tenure holder groundwater monitoring obligations under project approval conditions are considered in developing an integrated monitoring network. Rather than eliminating monitoring obligations under other requirements, integration with the WMS network improves efficiency and increases transparency. For example, OGIA liaised directly with mining companies to access information and data about their operational monitoring network consistent with their environmental approval conditions and has included these in the WMS where they align with the WMS objectives.
- As far as practicable, an integrated single monitoring network is established over time that meets the requirements of UWIR and other State and Commonwealth approval conditions.

## 9.5 Groundwater level network

A summary of groundwater level monitoring points is provided in Table 9-1. This network includes 724 groundwater level monitoring points – comprising 617 existing points and 107 proposed (i.e. yet to be installed). For each monitoring point, a status ('WMS status') is assigned as follows:

### Existing monitoring points:

- *Operational* – constructed, operational and collecting data.

- *Repair* – constructed but requiring instrumentation or repair to continue to operate.
- *Replace* – constructed but the installation is unlikely to be repaired and therefore a replacement point is required in the proximity.
- *Integrate* – constructed, operational and collecting data but have not previously been included in the WMS. These monitoring points meet the objectives and have been integrated into the WMS – predominately coal mining monitoring points.

**Proposed monitoring points:**

- *Reschedule* – proposed in previous UWIR but are yet to be installed and have been rescheduled.
- *New* – new monitoring points required in the current UWIR (2021).

**Table 9-1: Summary of the WMS groundwater level network (P&G and mining)**

Formation	Existing				Proposed		Total
	Integrate	Operational	Repair	Replace	New	Reschedule	
<i>Alluvium, basalt and mine spoil</i>							
Mine spoil	1	0	0	0	0	0	1
Condamine Alluvium	0	23	1	0	3	1	28
Other formations (Cenozoic)	19	5	0	0	3	4	31
<i>Surat Basin (GAB)</i>							
Springbok Sandstone	6	61	4	3	3	13	90
Upper Juandah Coal Measures	27	57	11	1	1	9	106
Lower Juandah Coal Measures	2	57	13	2	0	8	82
Taroom Coal Measures	25	67	11	2	0	8	113
Walloon Coal Measures	1	3	1	0	3	5	13
Hutton Sandstone	13	52	8	2	2	21	98
Other Surat Basin formations	7	92	12	1	3	12	127
<i>Bowen Basin</i>							
Bandanna Formation	0	16	1	3	1	5	26
Other Bowen Basin formations	0	5	2	0	0	2	9
<b>Total</b>	<b>101</b>	<b>438</b>	<b>64</b>	<b>14</b>	<b>19</b>	<b>88</b>	<b>724</b>

The design specifications of the groundwater level monitoring points are summarised in Table 9-2. The network has expanded since the UWIR 2019, primarily due to integration of monitoring points for coal mining. A list of the individual monitoring points with corresponding status and required timeframes is available from the OGIA website and in the WMS companion document (OGIA 2021i).

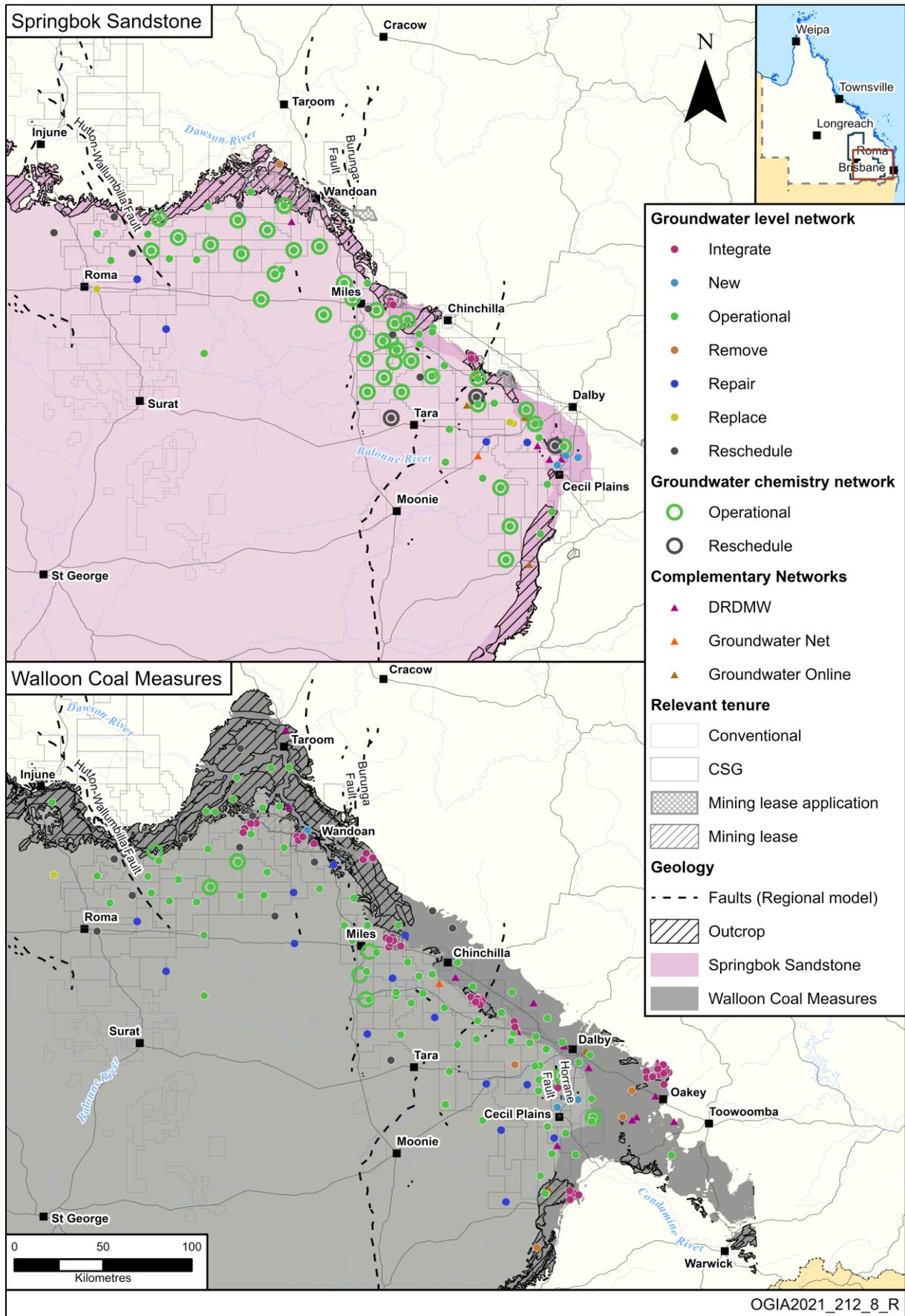
The locations of the monitoring points in key formations – the Walloon Coal Measures and Springbok, Hutton and Precipice sandstones and Condamine Alluvium – are shown in Figure 9-3 and Figure 9-4.

**Table 9-2: Design specification of the groundwater level network**

Design element	Specification
Location	<ul style="list-style-type: none"> <li>• Specific coordinates for individual monitoring points are provided in the WMS companion document (OGIA 2021i)</li> </ul>
Parameter	<ul style="list-style-type: none"> <li>• Groundwater level</li> </ul>
Frequency	<ul style="list-style-type: none"> <li>• Daily for CSG installations</li> <li>• Monthly for coal mining installations at operational coal mines</li> </ul>
Installation type	<ul style="list-style-type: none"> <li>• To suit the formation types</li> </ul>
Installation guidelines	<ul style="list-style-type: none"> <li>• As detailed in the WMS companion document (OGIA 2021i)</li> </ul>
Installation timing	<ul style="list-style-type: none"> <li>• For new points, generally within 3 years and for replacement points within 12 months. Of note, some points are linked to the commencement of resource development. Specific timing for each individual point is provided in the WMS companion document (OGIA 2021i)</li> <li>• OGIA will review the timing in each Annual Report and inform DES and tenure holders for follow-up actions</li> </ul>
Maintenance and replacement	<ul style="list-style-type: none"> <li>• RTH must maintain each monitoring point and notify OGIA if a point fails, within 3 months of becoming aware of the failure</li> <li>• Monitoring points must be repaired or replaced within a timeframe agreed with OGIA</li> </ul>
Contextual information	<ul style="list-style-type: none"> <li>• For all new constructions, the RTH must provide a summary of the planned design of monitoring points to OGIA prior to construction for endorsement</li> <li>• A monitoring bore completion diagram must be provided to OGIA within six months of completion</li> </ul>
Measurement type	<ul style="list-style-type: none"> <li>• Data loggers – where daily measurements required</li> <li>• Manual – where monthly measurements are required (at minimum)</li> </ul>
Installation, maintenance, data collection and provision	<ul style="list-style-type: none"> <li>• The RTH as specified in the WMS companion document (OGIA 2021i)</li> <li>• Data provision by RTH to OGIA on 1 April and 1 October</li> </ul>

The main features of the groundwater level network are as follows:

- There are 617 existing monitoring points, of which 539 (87%) are operational and the remaining 78 (13%) are to be repaired or replaced.
- The network has been growing steadily since the first UWIR in 2012 and maturing to the extent that only 19 new points are proposed in this UWIR.
- About 86% of points are for CSG tenure holders and about 14% are for coal tenure holders.
- There are only four (4) monitoring points proposed at mines that are not yet operational, which are required when these mines commence. Of the remaining proposed points, 88 are rescheduled from the previous WMS requirement and 15 are newly proposed.



**Figure 9-3: Groundwater monitoring networks in the Walloon Coal Measures and the Springbok Sandstone**

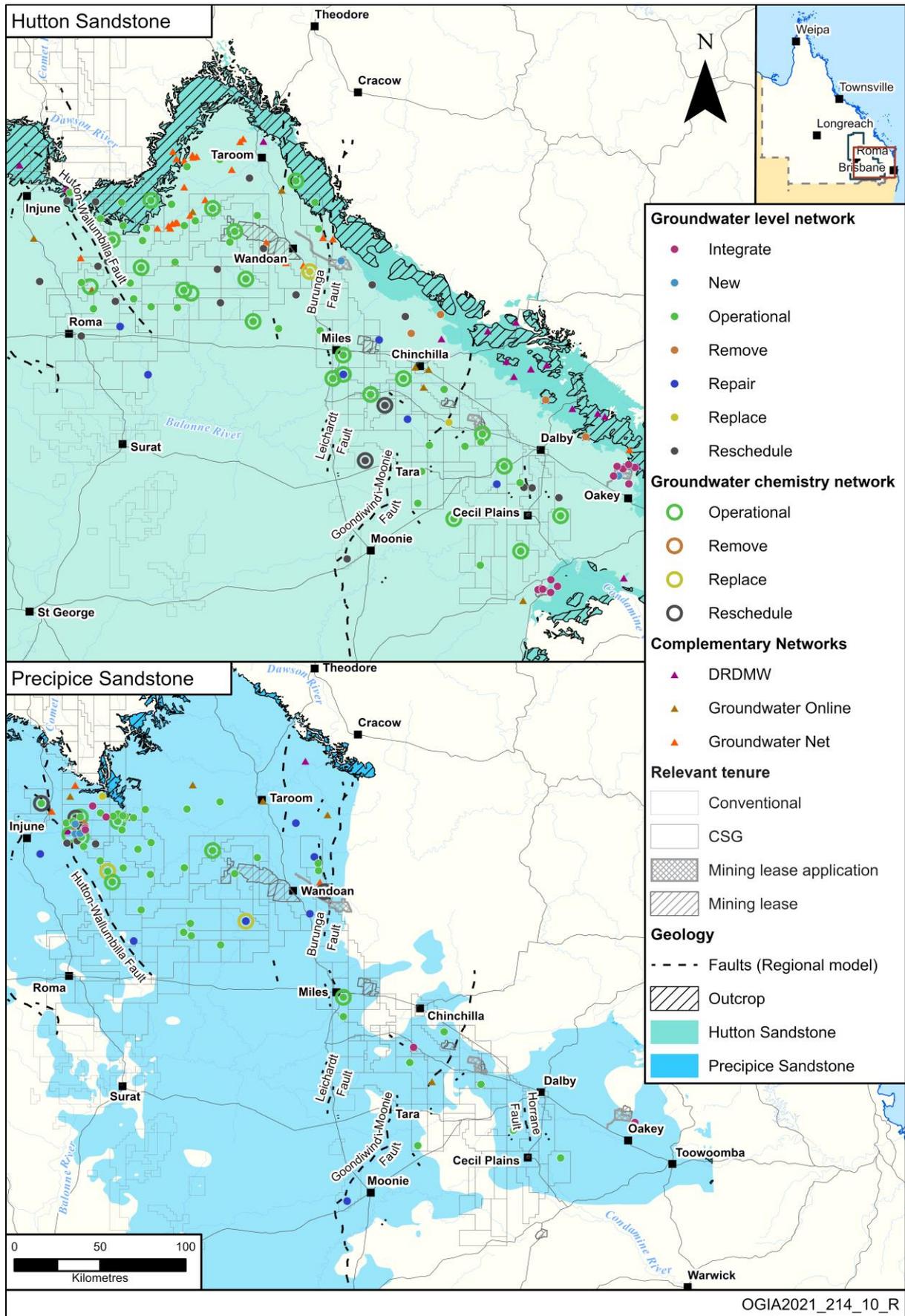
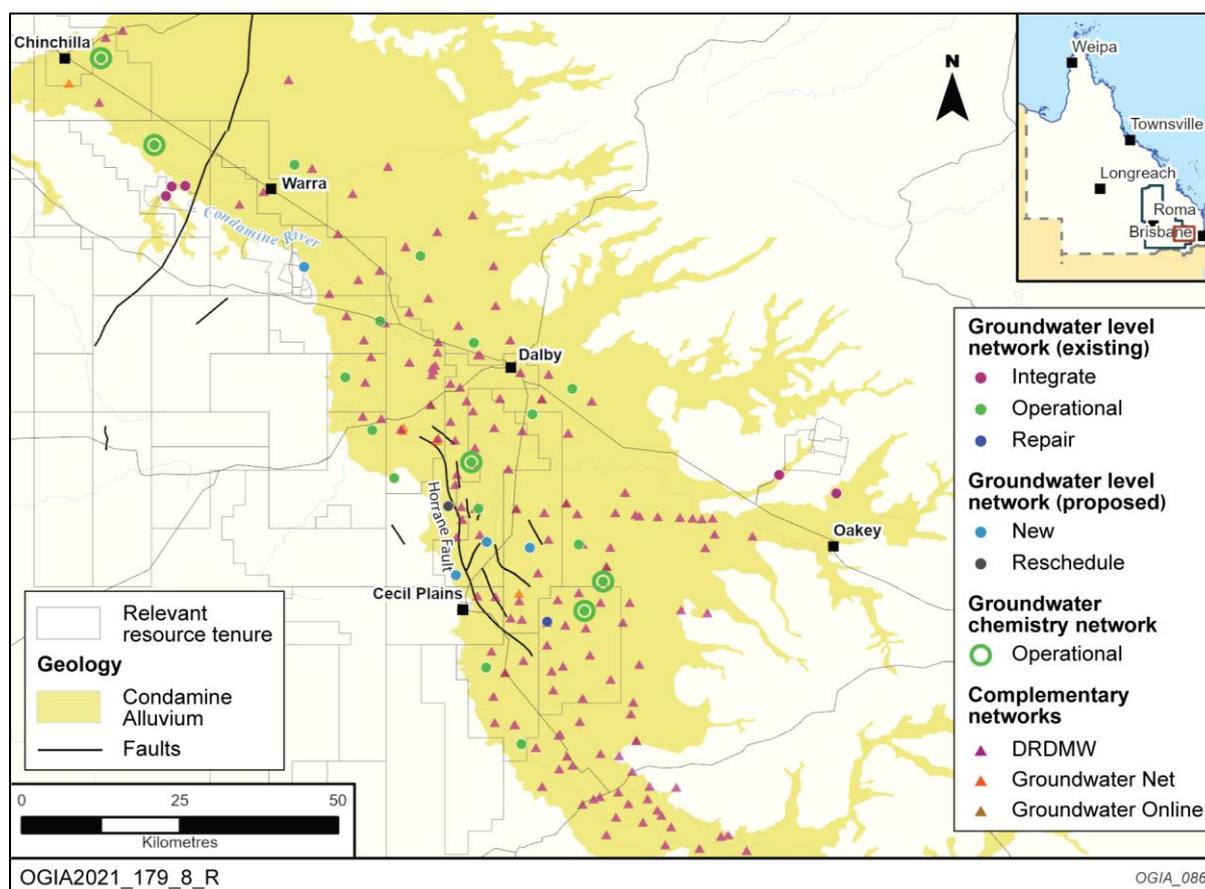


Figure 9-4: Groundwater monitoring networks in the Hutton and Precipice sandstones



**Figure 9-5: Groundwater monitoring networks in the Condamine Alluvium**

- About 43% of points are in the Walloon Coal Measures in the Surat Basin and 4% are in the coal formations of the Bowen basin – leaving 53% in surrounding formations.
- There are 176 nested monitoring locations, at which monitoring is specified in the coal formation and one or more adjacent aquifers at the same location.
- About 90% of the monitoring points are in formations and locations where CSG impacts on groundwater level of more than five metres are predicted in the long term (LAA). The other 10% are located outside areas of impact.
- The frequency of monitoring varies. Daily groundwater level measurements are required at most locations; for some monitoring points in and around the coal mines, the required frequency is monthly.

There are two broad categories of monitoring installations: **single aquifer piezometers** with similar construction to water bores; and **multiple monitoring points** within a single well. Where there is potential for interaction with gas either within the CSG reservoir or in formations below the reservoir, the monitoring points are constructed in accordance with the P&G Acts to manage risks associated with the presence of flammable gas under pressure.

OGIA acknowledges the difficulties for tenure holders to install and maintain monitoring points off tenure and away from production areas, particularly those that are some distance from tenure. OGIA therefore intends to engage with industry to explore alternative approaches to gather monitoring data in those areas.

## 9.6 Groundwater chemistry network

The groundwater chemistry network has also evolved since its initial specification in the UWIR 2012. Similar to the groundwater level network, a WMS status has been assigned to each monitoring point.

A summary of WMS groundwater chemistry monitoring points is provided in Table 9-3. The network includes 100 monitoring points, of which 90 are existing and operational and 10 are proposed to be rescheduled. About 16% of the points monitor the CSG target formations, however, additional groundwater chemistry monitoring from production wells is specified in section 9.7. The design specification of the groundwater chemistry network is summarised in Table 9-4.

**Table 9-3: Summary of the WMS groundwater chemistry network**

Formation	Existing		Proposed	Total
	Operational	Replace	Reschedule	
<i>Alluvium</i>				
Condamine Alluvium	5	0	0	5
<i>Surat Basin (GAB)</i>				
Springbok Sandstone	37	0	3	40
Upper Juandah Coal Measures	2	0	0	2
Lower Juandah Coal Measures	2	0	0	2
Walloon Coal Measures	4	0	0	4
Hutton Sandstone	21	1	2	24
Other formations (Surat)	10	2	3	15
<i>Bowen Basin</i>				
Bandanna Formation	6	0	2	8
<b>Total</b>	<b>87</b>	<b>3</b>	<b>10</b>	<b>100</b>

**Table 9-4: Design specification of the groundwater chemistry network**

Design element	Specification
Location	<ul style="list-style-type: none"> <li>• Specific coordinates for individual monitoring points are provided in the WMS companion document (OGIA 2021i)</li> </ul>
Parameter	<ul style="list-style-type: none"> <li>• Field parameters, laboratory analysis (Suite A) and isotope samples (Suite B)</li> <li>• Specific requirements for each monitoring point are specified in the WMS companion document (OGIA 2021i)</li> </ul>
Frequency	<ul style="list-style-type: none"> <li>• Suite A – where specified, one sample every 12 months for CSG wells and every six months until at least five complete samples are secured for all other points</li> <li>• Suite B – where specified, a strontium isotope sample is required once only in non-reservoir formations and annually in the CSG reservoirs and production wells</li> </ul>
Installation type	<ul style="list-style-type: none"> <li>• To suit the formation and conditions</li> </ul>

Design element	Specification
Installation guidelines	<ul style="list-style-type: none"> <li>As prescribed in the WMS companion document (OGIA 2021i)</li> </ul>
Installation timing	<ul style="list-style-type: none"> <li>Generally, new monitoring points are required within 2 years and replacement points required within 1 year. Of note, some points are linked to the commencement of resource development. Specific timing of each point is provided in the WMS companion document (OGIA 2021i)</li> <li>OGIA to review the timing each year in the Annual Report and inform DES and tenure holders for follow-up actions</li> </ul>
Maintenance and replacement	<ul style="list-style-type: none"> <li>RTH must maintain each monitoring point and notify OGIA if a point fails, within 3 months of becoming aware of the failure</li> <li>Monitoring points must be repaired or replaced within a timeframe agreed with OGIA</li> </ul>
Measurement type	<ul style="list-style-type: none"> <li>Sampling in accordance with (OGIA 2021i)</li> </ul>
RTH	<ul style="list-style-type: none"> <li>The tenure holder responsible for the monitoring obligation</li> </ul>
Installation, maintenance, data collection and provision	<ul style="list-style-type: none"> <li>The RTH as specified in the WMS companion document (OGIA 2021i)</li> <li>Data provision by RTH to OGIA on 1 April and 1 October</li> </ul>

The suites for groundwater chemistry include both major ions and isotopes to support identifying impacts from resource development. The water chemistry network also requires annual monitoring of groundwater chemistry from 154 production wells. Some of these are not yet in production and monitoring is therefore only required once production commences. A list of these wells is provided in the WMS companion document (OGIA 2021i). The density of these sites is generally one per production block, with higher density specified in areas where there is higher potential for connectivity.

## 9.7 Monitoring of associated water extraction

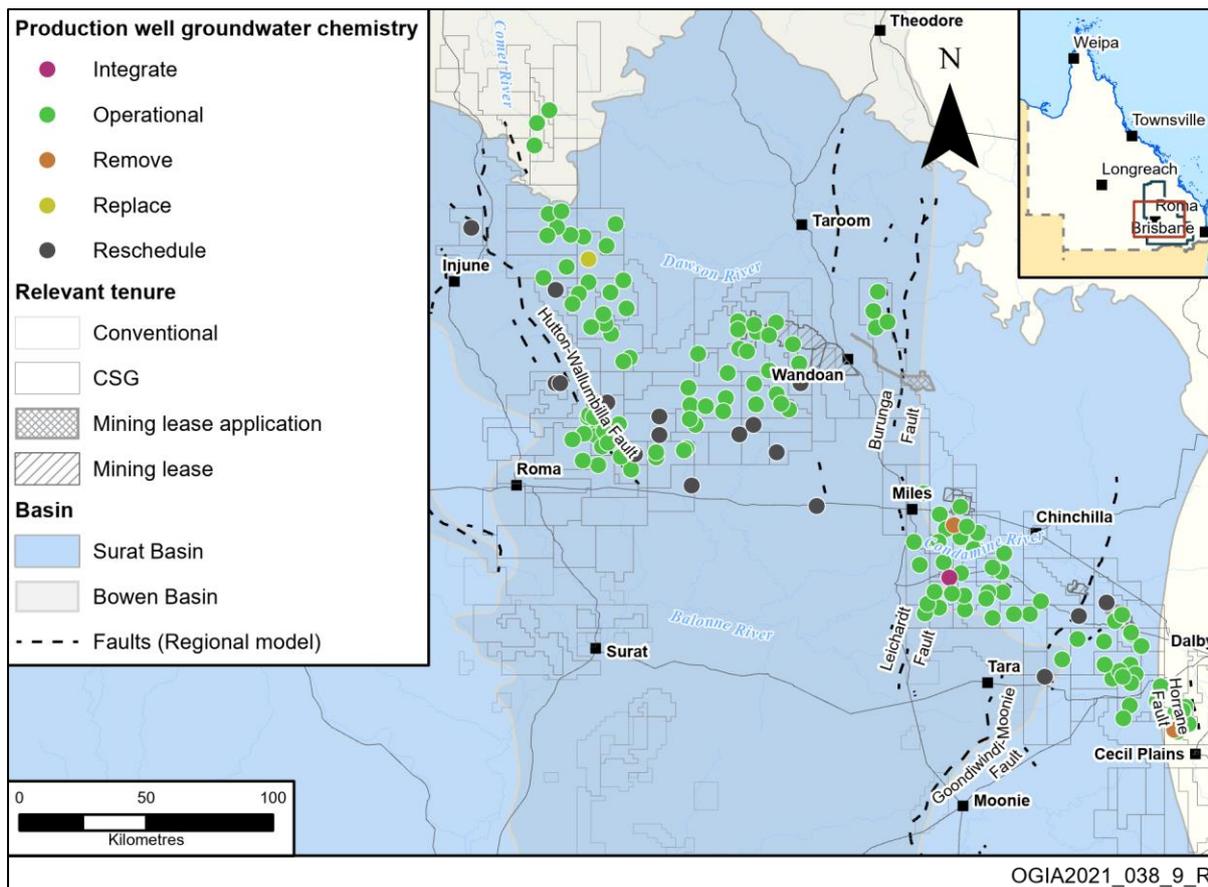
As detailed in sections 2.3.5 and 2.4.4, associated water is extracted by tenure holders during the production of P&G or to safely operate coal mines. This water extraction is subject to following statutory reporting requirements:

- Under section 42 of the Petroleum and Gas (General Provisions) Regulation 2017, tenure holders are required to report production volumes on a six-monthly basis to DoR.
- Under section 334ZP of the MR Act, since December 2016, MDL and ML holders are required to report annual associated water volumes to DoR if the annual volume is greater than two megalitres.

There are guidelines from DoR for reporting and processing of associated water extraction data where direct measurements are not available (DNRME 2020).

Monitoring of associated water extraction volumes is critical to overall understanding of groundwater level and chemistry changes in response to associated water extraction. The data is also used to support the calibration of groundwater models. While annual and six-monthly measurements provide useful information, more frequent measurements and recording is necessary in some instances. Complementary monitoring is therefore required for water chemistry in the Surat CMA as part of the WMS. The locations of groundwater chemistry monitoring points for CSG production wells are shown

in Figure 9-6. Table 9-5 provides a summary of the specification for the associated water extraction network.



**Figure 9-6: Groundwater chemistry monitoring points for CSG production wells**

Recent discussions with CSG tenure holders have identified some discrepancies at the wellfield scale between the volumes measured through meters at wells and the bulk volumes estimated from water balances at water processing facilities (section 2.3.5). This is understood to result from a combination of two factors – increasing presence of gas over time and the ability of meters to measure low flow volumes. OGIA will be exploring these issues during the next UWIR cycle.

**Table 9-5: Specification of the associated water extraction monitoring**

Item	Legislative reporting requirements	Additional and complementary monitoring under the UWIR WMS
Location	<ul style="list-style-type: none"> <li>All P&amp;G wells that are extracting associated water</li> <li>All coal mines extracting more than 2 ML/year</li> </ul>	<ul style="list-style-type: none"> <li>None</li> </ul>
Frequency	<ul style="list-style-type: none"> <li>Six monthly volumes for individual CSG wells</li> <li>Permit scale for conventional wells</li> <li>Annual frequency for mines</li> </ul>	<ul style="list-style-type: none"> <li>Monthly volumes for P&amp;G wells</li> </ul>

Item	Legislative reporting requirements	Additional and complementary monitoring under the UWIR WMS
Measurement method	<ul style="list-style-type: none"> <li>• P&amp;G – not specified</li> <li>• Coal mines – methods specified in guidelines (DNRME 2020)</li> </ul>	<ul style="list-style-type: none"> <li>• Individual metering of P&amp;G wells as far as practicable</li> </ul>
Contextual information	<ul style="list-style-type: none"> <li>• Perforation, stratigraphy, lithological, remarks</li> </ul>	<ul style="list-style-type: none"> <li>• Measurement methods</li> </ul>
Responsibilities	<ul style="list-style-type: none"> <li>• RTH for data collection</li> </ul>	<ul style="list-style-type: none"> <li>• RTH for data collection</li> </ul>
Data provision	<ul style="list-style-type: none"> <li>• Annual submission for coal and 6-monthly for P&amp;G tenure holders</li> <li>• Data provided via the GSQ lodgement portal</li> </ul>	<ul style="list-style-type: none"> <li>• P&amp;G RTHs to provide data to OGIA on 1 April and 1 October</li> <li>• OGIA to maintain data, QA/QC for on-going analysis and make data available to stakeholders</li> </ul>

## 9.8 Complementary monitoring

In addition to data sourced from the UWIR monitoring network, OGIA also integrates groundwater level and chemistry data available through the Queensland Government's ambient groundwater monitoring network, community-based monitoring and from other monitoring undertaken by tenure holders.

- *Other state government monitoring.* Within the Surat CMA, there are around 650 monitoring points with contemporary data and sufficient time series for analysis. These sites are generally located in shallower parts of the formations, where groundwater use is more concentrated.
- *Groundwater Online and Groundwater Net.* Since 2014, DRDMW has progressively grown two monitoring programs that focus on increasing community understanding of groundwater system responses within resource development areas. 'Groundwater Online' represents a subset of the Queensland Government's monitoring network and includes a combination of landholder and dedicated monitoring infrastructure. In the Surat CMA, there are about 70 landholder water bores monitored through this program. 'Groundwater Net' is a community-based initiative that encourages landholders to monitor their own water bores and submit their information to the GWDB. This currently includes around 100 monitoring points within the Surat CMA.
- *Other tenure holder monitoring.* In the Surat CMA, resource tenure holders have provided data for around 400 additional monitoring points beyond those required by the WMS. These monitoring sites are typically on tenure and have been established for operational reasons or to meet other State or Commonwealth approval conditions.

## 9.9 Monitoring of groundwater use

There is significant non-resource related development for groundwater use (Chapter 3), mainly in aquifers adjacent to the target formation. Metering of such use is limited in the Surat CMA and OGIA relies on this data from the relevant regulatory agencies, where such data is available. OGIA will continue to liaise with stakeholders to explore ways to increase data coverage.

## 9.10 Baseline assessment program

A baseline assessment is a field survey of a water bore by a tenure holder to obtain information about water bore construction, groundwater levels and groundwater quality (section 8.4.2.1). The information provides a baseline of a water bore's condition and performance, ahead of any predicted impacts occurring at the water bore. Baseline assessments are carried out in accordance with baseline assessment plans approved by DES and in accordance with guidelines prepared by DES.

The Water Act includes baseline assessment exemptions for mining lease (ML) holders where they have water licences or permits for associated water (including associated water licences) or where they were entitled to take associated water prior to the inclusion of coal mining under Chapter 3 of the Water Act in December 2016. This exemption is limited to water bores located on tenure.

There are three criteria for when baseline assessment is required:

1. water bores located on tenure prior to production commencement
2. water bores for which the tenure holders are directed by DES to undertake baseline assessment
3. any other water bores within LAAs for which the WMS in a UWIR contains a program for baseline assessment.

Triggers for baseline assessment in criteria 1 and 2 are directly provided in the primary legislation (ss. 397 and 402 of the Water Act). In relation to the third criteria, the baseline assessment requirements are to be stated in a UWIR and are as follows:

- The baseline assessment area for an aquifer is the area where a groundwater level fall of more than one metre is expected within three years (2021–2024, Figure 9-7). This is because baseline assessments are most effective when they are undertaken immediately before impacts are expected to occur.
- RTHs must carry out baseline assessments for a water bore that taps an aquifer within the baseline assessment area for that aquifer.
- If a baseline assessment has already been carried out in accordance with other obligations arising under the Water Act, no further assessment is required.
- Assessments are to be carried out in accordance with the current guidelines for baseline assessments from DES.
- Assessments must be completed, and the results reported to OGIA within 12 months of the UWIR being approved. A list of water bores that require a baseline assessment is provided in Table G-3 in Appendix G.

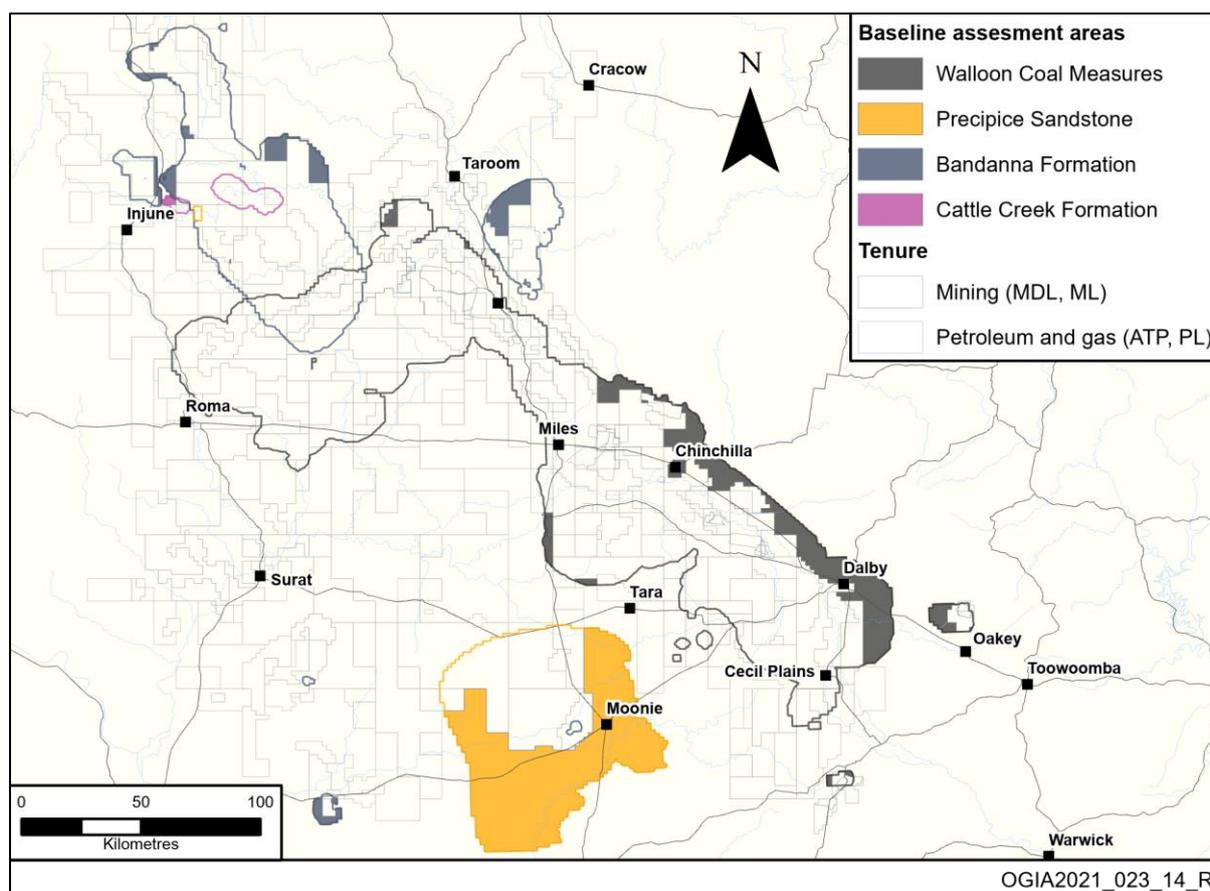


Figure 9-7: Baseline assessment areas

## 9.11 Timeframe for implementation

The WMS identifies RTHs for the installation and maintenance of monitoring infrastructure including groundwater level, groundwater chemistry and a groundwater quantity network (i.e. groundwater extraction volumes). The timeframe for implementation is summarised in sections 9.5, 9.6 and 9.7. Specific details for timing of installation of each individual monitoring point are provided in the WMS companion document (OGIA 2021i).

A program for baseline assessment is specified in section 9.10. This must be completed within 12 months of the UWIR being approved.

## 9.12 Summary of tenure holder WMS obligations

Rules for assigning RTH obligations are specified in Chapter 13. The RTH obligations in relation to the WMS are summarised as follows:

- installation and maintenance of groundwater level and chemistry monitoring points at locations and within the timeframe listed in the WMS companion document (OGIA 2021i)
- repair and replacement of monitoring points in accordance with those specified in the WMS companion document (OGIA 2021i)
- submission of the following on 1 April and 1 October of each year:
  - a WMS network implementation report to OGIA that must include the current status of groundwater monitoring points, planned installation of monitoring points, emerging

implementation issues and proposed changes to the location or timing of any installations, for OGIA endorsement

- a WMS water monitoring report that must include details about the monitoring point or production well construction, and an explanation of any gaps or changes in the monitoring record associated with maintenance issues or failure of a monitoring point
  - the data collected for each monitoring location including groundwater level, groundwater chemistry, associated water volumes and reinjection volumes where applicable – in accordance with OGIA’s data dictionary
  - if a tenure holder needs to amend monitoring data previously submitted in a water monitoring report as a result of tenure holder quality assurance processes, a data correction report providing an explanation of the corrections.
- where a new monitoring point is required under the WMS, the RTH must provide, for endorsement by OGIA:
    - prior to construction, the planned design of monitoring points
    - upon completion, a monitoring bore completion diagram.

### 9.13 Availability of monitoring and baseline data

Since the UWIR 2012, implementation of the WMS has progressively built a substantial groundwater monitoring network across the Surat CMA. OGIA has a statutory obligation to maintain the database of monitoring data in the Surat CMA.

Data is received by OGIA from the RTHs under the WMS every six months, reviewed and then made publicly available on the GWDB and the Queensland Globe. Data from the WMS has improved knowledge about the groundwater flow system and has helped to identify where further improvements are required.

OGIA has a statutory obligation to maintain a database of the baseline assessment information collected by tenure holders. The database currently holds close to 4,800 completed assessments, of which 4,100 are in the Surat CMA.

The quality of the information and data collected during baseline assessment varies. The information collected by a tenure holder at the time of visiting a water bore is often heavily reliant on existing information available on the GWDB. Since 2017, in collaboration with DRDMW, OGIA has undertaken a project to verify the registered number assigned during baseline assessments completed by tenure holders. This subset of the more than 3,500 baseline assessments was reviewed as a priority, as they are located within the IAA and LAA footprints and may have a material influence on the identification of affected water bores.

The project involves a desktop check to validate the registered number assigned at the time of the baseline assessment. The process includes a cross-check of data, photos and other information provided by tenure holders with data held in various DRDMW databases (GWDB, Water Management System, GSQ Open Data Portal, MyMinesOnline). Where available, field reports and photos are matched with aerial imagery.

Thus far, the verification process has identified that 3% of baseline assessments have incorrectly assigned RNs, about 11% were unable to be assigned RNs during the baseline assessment, with

around 10% of those water bores subsequently linked to existing RNs by OGIA. The water bores that remain without RNs are processed by DRDMW and allocated new RNs. Once water bores are verified, the associated non-confidential information from the baseline assessment is progressively uploaded to the GWDB.

## 9.14 Summary of WMS

- The objectives of the WMS are to identify groundwater impacts from resource development, improve knowledge about the groundwater flow system, support model calibration and evaluate effectiveness of impact management strategies.
- The WMS strategy includes a groundwater monitoring network and tenure holder obligations for implementation of the network and reporting. The network comprises groundwater level, groundwater chemistry and associated water extraction monitoring.
- As a result of the WMS in previous UWIRs, there are now 617 groundwater level monitoring points and 90 water chemistry monitoring points commissioned and operating.
- This UWIR proposes expansion of the network to about 724 groundwater level monitoring points and 100 water chemistry monitoring points – a net expansion of the network by about 14%, and ongoing metering of associated water extraction. An important part of the strategy is the progressive replacement and maintenance of monitoring points.

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## Chapter 10 Spring Impact Management Strategy

### 10.1 Preamble

The Spring Impact Management Strategy (SIMS) is developed for managing impacts on springs and reaches of watercourses that are fed by groundwater within the Surat CMA. The SIMS is specified to achieve the following key outcomes:

- enhance hydrogeological knowledge about springs, including assessment of the connectivity to underlying aquifers
- improve the prediction and assessment of potential impacts on springs
- prescribe actions for the management of predicted impacts where necessary.

Since 2012, there has been significant research by OGIA and tenure holders to improve understanding about the springs in the Surat CMA including the way springs respond to seasonal climatic conditions, non-groundwater related stresses, groundwater use and associated water extraction.

This chapter provides an update to the SIMS in response to the revised predictions of groundwater impact as well as new knowledge acquired since the UWIR 2019.

### 10.2 Terminology

**Watercourse spring** – section of a watercourse where groundwater from an aquifer enters the stream through the streambed.

**Spring** – includes both spring vents and watercourse springs unless the context requires otherwise.

**Spring vent** – a single location in the landscape where groundwater discharges at the surface.

**Spring complex** – a collection of spring vents with the same source aquifer and geological setting.

**Spring group** – a collection of spring complexes and watercourse springs sharing the same source aquifer, location and impact propagation pathway.

**Springs of interest** – springs overlying aquifers with predicted impact of more than 0.2 metres drawdown at any time.

**Source aquifer** – for a spring, the aquifer providing the flow of water to the spring.

### 10.3 Components of the strategy

The SIMS includes the following components:

- characterisation of springs and assessment of **connectivity to underlying aquifers**, including identification of source aquifers
- identification of the **springs of interest**
- **assessment of risks** to springs from current and planned resource development in the Surat Basin impacting on the source aquifers of the springs of interest
- a **spring impact mitigation strategy** for preventing or mitigating impacts on springs where predicted impacts on source aquifers are more than 0.2 metres

- a **spring monitoring program** identifying monitoring sites, appropriate techniques and frequency.

The monitoring and mitigation strategies identified in the SIMS are implemented by tenure holders in accordance with their individual responsibilities as assigned in Chapter 13.

## 10.4 Evolution of knowledge

Since the CMA was established in 2011, there has been significant investment in research to improve knowledge about the location, ecological values and seasonal dynamics of springs in the Surat CMA. Together with output from the revised modelling (Chapter 6), this new knowledge has enabled ongoing improvement to the assessment of risk and management actions.

The UWIR 2012 provided the first assessment of cumulative impacts on springs in the Surat CMA. Five spring complexes were predicted to be impacted by more than 0.2 metres in the long term. As a result, detailed desktop and field investigations were undertaken by OGIA and tenure holders at these locations. In parallel, quarterly seasonal monitoring across 17 spring complexes was completed by CSG tenure holders, in accordance with the UWIR 2012 and their EPBC approval conditions.

In early 2015, OGIA collated and analysed these datasets to build local-scale conceptualisations at each of the monitored spring complexes (OGIA 2015). These local conceptualisations improved the collective understanding of the springs' source aquifers and likely responses to changes in groundwater level.

In 2017, OGIA remapped and field-verified a number of watercourse springs (OGIA 2017). This information identified areas where impacts may occur. Tenure holders have also undertaken investigations since the UWIR 2019 to verify areas of potential surface water–groundwater connectivity identified by OGIA's desktop assessment.

Between 2017 and 2018, OGIA led a pilot project on new methods to evaluate which spring attributes and monitoring tools are most appropriate for ongoing monitoring. The outcomes from that project have guided the specification of monitoring in this UWIR.

Since the UWIR 2019, the focus has shifted towards: firming up mitigation action plans, as the predicted timing of impacts greater than 0.2 m comes nearer (section 10.7); and ongoing work on improvements to understanding of impact propagation pathways around the western contact zone (section 4.4.8) in the Precipice Sandstone, which is a source aquifer for springs in the area.

## 10.5 Springs of interest in the Surat CMA

This section provides a summary of knowledge about springs of interest in the Surat CMA. Additional information is available in a companion document (OGIA 2021k).

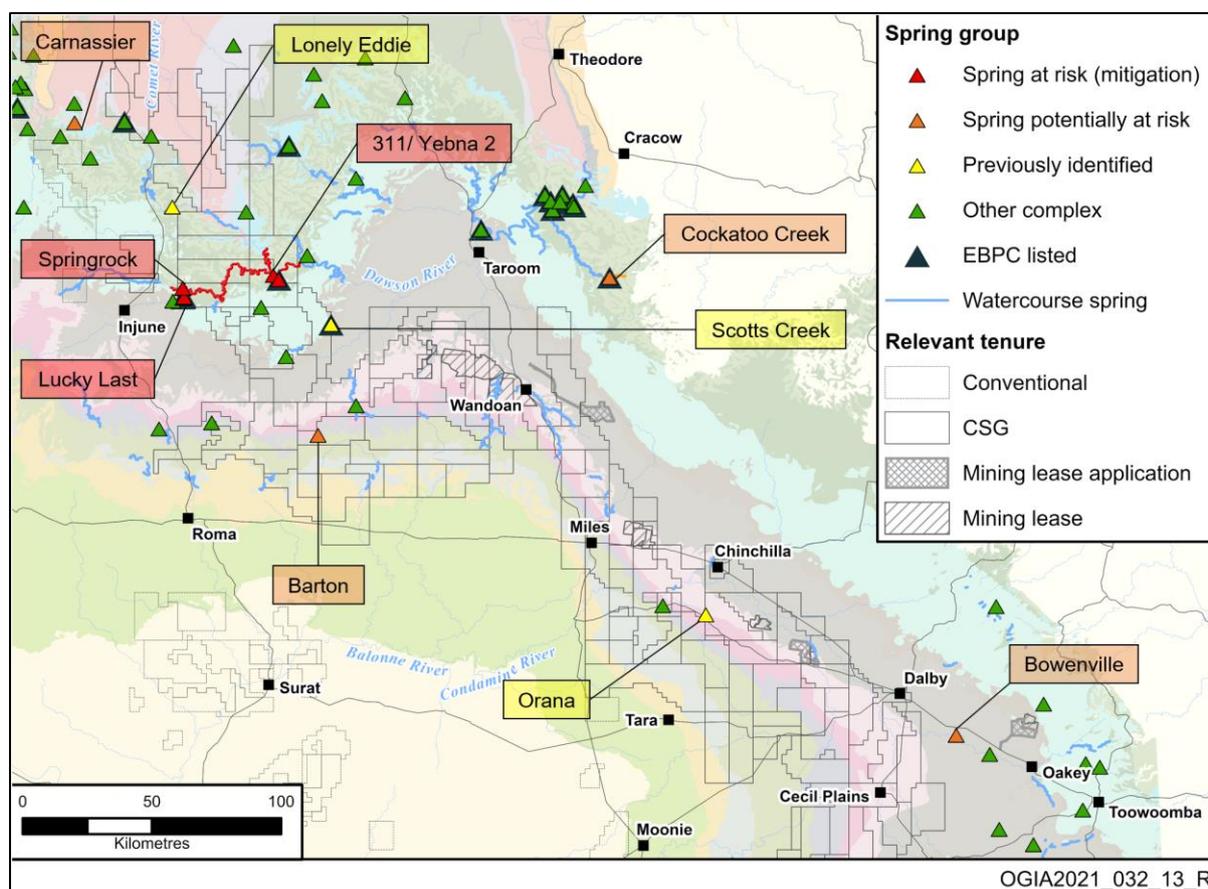
### 10.5.1 Distribution and occurrence

In the Surat CMA, the majority of springs are located along the northern and central outcrop areas of the Surat and Bowen basins (Figure 10-1). The occurrence and distribution of springs is primarily driven by regional and local geology, topography and groundwater flow regimes.

There are three fundamental hydrogeological mechanisms by which springs occur (OGIA 2016b, 2016c) (Figure 4-11):

- where *changes in formation permeability* result in flow laterally to the surface (a)

- where a *geological structure* provides a path to the surface along which water can flow (b)
- where erosion of the landscape by surface water flows can provide opportunities for groundwater to reach the surface (c).



**Figure 10-1: The location of springs of interest in the Surat CMA**

## 10.5.2 Source aquifer

Understanding the connection between a spring and underlying aquifer is necessary to assess the risk to the spring from groundwater level impacts. The source aquifer could be the same geological formation in which the spring occurs, or it could be a deeper formation from which groundwater flows along a fault to the spring.

The source aquifer for each spring complex was assessed as part of detailed conceptualisation work in 2015 (OGIA 2015; Flook et al. 2020). The key aquifers which feed springs in the Surat CMA are the Clematis, Precipice, Hutton and Gubberamunda sandstones. An important outcome from detailed assessment is that some springs are fed by both local and regional flow systems.

Following the identification of a spring's source aquifer, OGIA then improved the understanding of risk by developing a classification of springs based on wetland features. This provides a better understanding about a wetland ecosystem's dependency on groundwater and its likely response to change in the groundwater regime.

Using the new knowledge, a wetland typology was developed to support the assessment of risks and specification of monitoring under the UWIR (2016b, 2016c). The wetland types are based on how and

where the wetlands occur within the landscape, as springs of a given type will have a similar hydrogeological response to a change in the groundwater regime.

### 10.5.3 Ecological and cultural values

In parallel with their hydrogeological characteristics, springs support unique ecological assemblages and are often culturally significant sites. In terms of cultural values, the connection between Aboriginal people and water (including springs) is recognised as a holistic and interconnected relationship – one connected system with spiritual, cultural, environmental, social and economic values. Water is vital for many aspects of Aboriginal life, such as fishing, hunting, swimming, storytelling, family gatherings, ceremonies and other sacred activities (Department of Natural Resources Mines and Energy 2019). In many cases, springs are permanent sources of water in semi-arid environments and are often associated with cultural values.

Information about the cultural significance of specific springs is available at some locations following studies undertaken to support project approval processes or development activities. Information and data recorded in relation to indigenous cultural heritage studies and sites are maintained on the Queensland Aboriginal and Torres Strait Islander Cultural Heritage Database and Register. For the purposes of the risk assessment in the SIMS, it is assumed that all springs support cultural heritage values and that the maintenance of groundwater discharge is necessary to maintain those values. Understanding cultural heritage values associated with high-risk springs is an area identified for future research during the next UWIR cycle (section 14.5).

A number of spring complexes support species and ecosystems recognised under the Australian Government's EPBC Act and Queensland's *Nature Conservation Act 1992* (NC Act). Watercourse springs may also play an important role in maintaining stream ecosystem functions, particularly during dry periods.

Information on the conservation significance of springs has been used in assessing the risks to springs (section 10.6.2). Table 10-1 shows the numbers of springs in the Surat CMA recognised for their conservation significance under the EPBC Act.

**Table 10-1: Springs in the Surat CMA**

Spring type	Total	Subset of springs associated with the EPBC Act listing	Springs of interest*
Spring complexes (spring vents)	88 (389)	19 (138)	53 (223)
Watercourse springs	96	-	93
Spring groups	59	13	39

**Notes:**

\* Springs of interest are those springs overlying aquifers where the long-term predicted reduction in groundwater level exceeds 0.2 metres (section 10.6.1).

To sustain ecological assemblages and functions, springs and watercourses have an ecological water requirement. Essentially, this is the water regime necessary to sustain the values of water-dependent ecosystems at a low level of risk (Richardson et al. 2011). Springs by definition require discharge above ground level to sustain wetlands. The available pressure at each spring varies and depends on

a range of factors including the source aquifer and the elevation of the spring within the landscape. In the Surat CMA, available pressures at springs vary from more than 20 m to less than 1 m above ground level.

As previously stated, in addition to regional groundwater flow, the water requirements of some spring wetlands are also met from local inflows, such as groundwater in shallow alluvium, surface water flows, rainfall and overland flow. At some locations, springs expand and contract in response to the presence or absence of these additional inflows and changes in evapotranspiration, resulting in distinct seasonality in wetland extent and floristic composition.

### 10.5.4 Conceptual response to a change in groundwater level

While hydrological responses at springs and ecological impacts in wetlands are likely to be complex, the extent of free water in the wetland will likely contract in response to declining groundwater levels. The contraction will depend upon the available pressure, the wetland type (OGIA 2021k) and the magnitude of the predicted impact. In response, the composition of the ecological community would be expected to transition from aquatic to more terrestrial-dominated assemblages. Changes in groundwater level are likely to be a more significant influence on impact than changes in groundwater chemistry.

To support the evaluation of hydrological change on the wetland, OGIA has developed a classification for springs based on wetland features. The classification system groups springs based on the wetland ecosystem’s likely dependence on groundwater and its likely response to change in the groundwater regime. The landscape setting and hydrological processes for each wetland type are shown in Figure 10-2 and further described in OGIA (2016c).

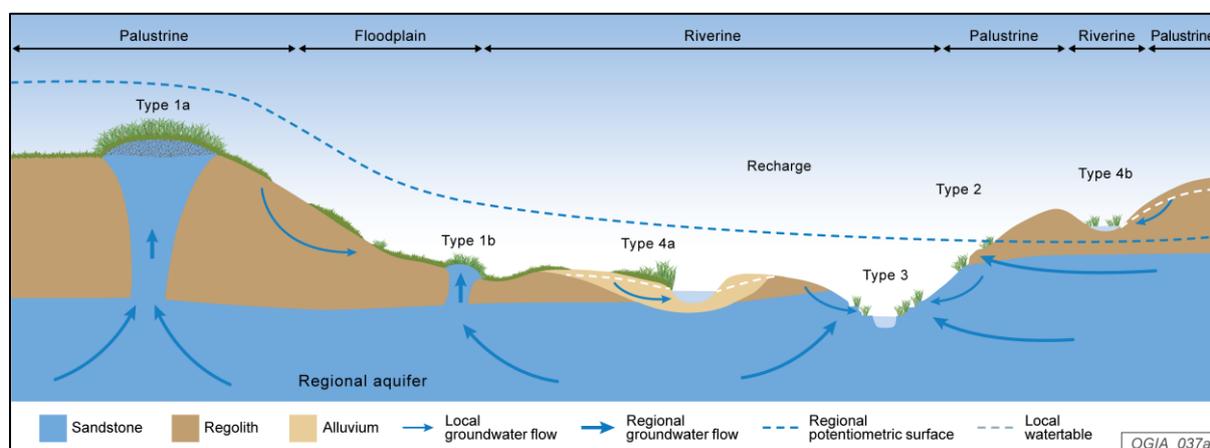


Figure 10-2: Wetland types in the Surat CMA

## 10.6 Predicted impacts on springs in this UWIR

### 10.6.1 Springs of interest

Under the Water Act, the UWIR is required to assess the potential for groundwater impacts on **springs of interest**. These are springs overlying aquifers with predicted impact of more than 0.2 metres drawdown at any time. Predictions are derived from the regional groundwater flow model (Chapter 6) to identify springs of interest (Figure 10-1 and Table 10-1).

## 10.6.2 Risk assessment

As in the previous UWIRs, an assessment of risk to springs is derived from the intersection of likelihood and consequences. The risk assessment then drives the specification of spring impact mitigation and monitoring strategies and ensures actions are commensurate with the overall risk.

The risk assessment criteria relate to the following:

- the likelihood and timing of the predicted impact on groundwater level
- the uncertainty associated with the magnitude in change predicted
- the consequence for the spring, should the groundwater level decline.

The likelihood of the groundwater level decline in source aquifer is assessed using the regional groundwater flow model. The consequence of a groundwater level decline in the source aquifer is evaluated using a combination of factors, including the estimated magnitude of change in groundwater level in the spring's source aquifer and the conservation significance of the spring.

Additional information on the risk assessment methodology and outcomes for all springs of interest in the Surat CMA is available in a separate companion document (OGIA 2021k). Table H-1 in Appendix H provides a summary of current and previous risk assessments at springs where more than 0.2 m drawdown has been predicted in either 2012, 2016, 2019 or 2021. The risk assessment also presents residual risk because of the proposed mitigation actions, as outlined in section 10.7.

Compared to the UWIR 2019, the number of springs of interest has increased, primarily as result of the expansion of the predictions of impact in the Precipice Sandstone. There are seven spring groups where impacts of more than 0.2 m are predicted in the springs' source aquifers at any time in future. At the majority of these springs, predicted impacts are less than 1 m.

## 10.7 Spring impact mitigation strategy

### 10.7.1 General

The UWIR is required to include a strategy, including the actions to be taken, for preventing or mitigating the predicted impacts on the springs. This section provides an overview of locations where mitigation actions are required following the risk assessment and provides an update on progress where actions have been taken or are planned.

The risk assessment incorporates predictions of impact in the spring's source aquifer, spring condition and ecological value. The outcomes are used to determine locations for which plans for mitigation actions are required.

Since a group of springs in a close proximity may share the same impact pathway and mechanism, actions to mitigate those impacts may also be similar. The term **mitigation group** is used to refer to a collection of such springs where, on the basis of current knowledge, actions are likely to be required at some stage to avoid, mitigate or offset future impacts at the springs. The mitigation strategy is reviewed and updated considering the following:

- revisions to risk profile resulting from updated predictions in this UWIR for springs that have more than 0.2 m predicted impact (Table H-1, Appendix H)
- conceptual understanding and uncertainties in relation the propagation of drawdown a significant distance from resource development

- residual risks from agreed mitigation actions (section 10.7.3.1) and flow-on benefits from other actions such as Origin's ongoing reinjection of treated CSG water into the Precipice Sandstone.

## 10.7.2 Mitigation actions required in the previous UWIR

Six groups of springs were identified in the UWIR 2019 with medium or high residual risk, four of which (Springrock, 311/Yebna 2, Lonely Eddie and Lucky Last) were assigned to Santos to prepare a Spring Impact Mitigation Plan (SIMP). Mitigation plans were not required for the other two – Horse Creek and Cockatoo – as there remained some conceptual uncertainties. Since then, further assessment by QGC has confirmed that the Horse Creek group is disconnected from groundwater and is not a watercourse spring, and further assessment – characterisation of the impact propagation pathway – is still underway for the Precipice Sandstone, which is the source aquifer for the Cockatoo group.

Santos initially submitted a SIMP for the four springs groups for which it is the RTH in June 2020. Following a number of iterations and discussions between Santos, OGIA and DES, the SIMP was approved by OGIA in June 2021 and took effect through an amendment to the UWIR in August 2021. The SIMP comprises three parallel streams:

1. **Mitigation actions** to bring the residual risk to low based on the risk profile and predictions identified in the UWIR 2019. Mitigation actions (section 10.7.3) are to be triggered by the likelihood of CSG impacts occurring at early warning indicator sites and to come into force within one to two years of being triggered.
2. **Trigger monitoring** and reporting based on OGIA's ongoing assessment of trends in groundwater level monitoring data. Santos will undertake monitoring and provide data to OGIA. OGIA will undertake a biannual assessment of the data to identify the likelihood of CSG impacts occurring at early warning indicator sites and notify Santos and DES of the outcome and if actions are required. These sites and complementary monitoring are listed in Table H-3, Appendix H.
3. **Ongoing investigations** at a number of spring groups to further improve knowledge about impact pathways and spring response to groundwater level impacts. These investigations will occur in parallel with the mitigation actions and trigger monitoring.

## 10.7.3 Updated mitigation strategy

The updated strategy is summarised into three categories in the following section: springs where the current unmitigated risk is medium to high and mitigations actions are required; springs where risks were previously identified but actions are no longer required; and springs that have been identified as at risk for the first time but mitigation actions are not required until further investigations are completed.

### 10.7.3.1 Springs currently at risk

#### Springrock (Precipice Sandstone)

This group was assigned high risk in the UWIR 2019. Santos has committed to implementing a flow augmentation scheme by extracting water from the Precipice Sandstone some distance away from the spring and providing flow directly into the spring wetland. Once triggered, the action will

commence between one and two years, depending on the early warning monitoring location where CSG impacts are confirmed by OGIA.

In the current assessment, there is a slight increase in maximum impact but the residual risk profile is low because of the proposed actions.

#### **Lucky Last (Boxvale Sandstone Member)**

Compared to the previous assessment, there is a slightly higher level of predicted source aquifer impact for this mitigation group – maximum impact of about 0.6 m (P50) – therefore the risk profile has increased. The increase in predicted impacts in the source aquifer is due to a range of factors relating to changes in the groundwater model and to the development profile. There is some ongoing ambiguity around the impact pathway for this mitigation group, leading to likely overestimation of risk. OGIA plans to investigate this further in the next UWIR cycle.

Until investigations suggest otherwise, Santos's mitigation actions are based on the current risk profile. The actions include to offset the source aquifer impact by retiring the landholder's groundwater use from the source aquifer and also by introducing stock control measures to improve wetland condition and resilience to any potential impacts on the wetland.

The action will commence between one and two years from when the trigger is activated, depending on the early warning monitoring location, and confirmation by OGIA of CSG impacts. Santos will be providing, by the end of 2022, evidence of an agreement with the landholder.

#### **311/Yebna 2 (Precipice Sandstone)**

The unmitigated risk for this mitigation group is high, as in the previous UWIR. In accordance with the SIMP, Santos will undertake two mutually exclusive mitigation actions: offset of the predicted drawdown with Origin's reinjection scheme until around 2030, followed by the retirement of Santos's groundwater extraction licence; and stock control measures to improve wetland condition and resilience to the predicted impact.

Since the reinjection by Origin is already occurring, no further trigger is required for immediate actions; however, Santos will enter into a firm agreement before the end of 2022 to retire groundwater extraction from a nearby location, so that this action can be triggered within a year of the reinjection scheme ceasing operation or failing.

### **10.7.3.2 Springs potentially at risk**

This section details springs where some risk is identified, however, improvements to conceptual understanding of impact pathways are necessary to better assess risk before the need for mitigation is considered.

#### **Cockatoo Creek (Precipice Sandstone)**

A medium risk was assigned to this spring in the previous UWIR but no RTH was identified because of the conceptual uncertainty and a low residual risk due to reinjection by Origin into the Precipice Sandstone, which would reduce impacts to less than the 0.2-m trigger threshold. The risk profile for this spring effectively has not changed. Ongoing investigations include a detailed evaluation of the Surat–Bowen basin contact zone near Wandoan, which is the potential impact propagation pathway in this area.

## Other springs

At some springs, along the very fringe and well away from resource development, some risk is identified because of predicted impacts between 0.2 and 0.4 m in the Precipice Sandstone, which is the likely source aquifer. One example is the **Carnassier** spring group. However, there are conceptual uncertainties in the area. The strategy for these springs is to improve conceptualisation as part of a broader project into the contacts of the Precipice Sandstone (section 14.5). In the interim, reinjection by Origin continues to significantly reduce any unforeseen risk to the springs.

Similarly, impacts are predicted at the **Barton** spring complex, which is fed by local groundwater flow from the Gubberamunda Sandstone. Predicted impacts are up to about 0.8 m and are not predicted to occur for more than 50 years, therefore no action is required until connectivity is better understood.

The **Bowenville** spring complex, fed by the Main Range Volcanics, is identified for the first time in this UWIR. At this location, predicted impacts are small – just over 0.2 m (P50) – and there is conceptual uncertainty, therefore no actions are required at this stage. Further investigations are necessary prior to identifying any need for mitigation actions.

### 10.7.3.3 Springs previously at risk

This section details springs where some risk was identified in the past but where subsequent revisions in conceptual understanding or impact predictions have reduced or eliminated the risk.

#### Lonely Eddie (Precipice Sandstone)

This site was assessed as high risk in the UWIR 2019 and therefore a mitigation plan was required. However, field investigations by Santos since then show that the spring is fed by local flows in an isolated portion of the Precipice Sandstone, disconnected from the aquifer in which drawdown was predicted. Consequently, mitigation is not required.

#### Horse Creek (Springbok Sandstone)

This watercourse spring group was assessed as moderate risk in the UWIR 2019 but did not require a mitigation plan at that time as there remained some uncertainty relating to the connectivity of Horse Creek with impacted aquifers. Since then, QGC investigations show that this creek is disconnected from groundwater, therefore, no risk is now assigned to this spring and a mitigation plan is not required at this location.

#### Scotts Creek (Hutton Sandstone)

This spring group is no longer considered at risk due to changes to the predictions of impact – primarily relating to refinement of the representation of the Durabilla Formation in the groundwater flow model, which resulted in a reduction in predicted impacts in the Hutton Sandstone.

## 10.8 Spring monitoring and investigations

Spring monitoring is necessary to understand the natural variability in spring discharge. Similar to understanding influences on observed groundwater levels (Chapter 5), this information provides the basis for establishing the background conditions, for correlation with seasonal conditions, groundwater use and potential impacts from resource development.

This section specifies the monitoring required at springs to assess changes in groundwater discharge, that may be related to changes in groundwater levels in the aquifers that feed springs. Collectively, monitoring at springs and in the springs' source aquifers supports correct identification of any future

impacts from associated groundwater extraction. At many locations, groundwater monitoring in the spring's source aquifer is also included in the WMS (Chapter 9).

### 10.8.1 Spring vent monitoring network

Springs vary considerably in terms of their ecological values, physical condition and suitability for monitoring. Site suitability and the outcomes from the risk assessment have been used to guide site selection. Each RTH is to carry out monitoring at the sites to which it is assigned according to the requirements specified in Table 10-2.

**Table 10-2: Design specification of the spring vent monitoring network**

Design element	Specification
Location	<ul style="list-style-type: none"> <li>Spring monitoring sites are provided in Table H-4, Appendix H.</li> </ul>
Frequency	<ul style="list-style-type: none"> <li>Six-monthly (April and November)<sup>1</sup></li> </ul>
Wetland discharge	<ul style="list-style-type: none"> <li>Required at sites specified in Table H-4, Appendix H</li> <li>Details of the method are specified in Table H-6, Appendix H.</li> </ul>
Water chemistry	<ul style="list-style-type: none"> <li>Required at sites specified in Table H-4, Appendix H.</li> <li>Monitoring suite as per Table H-7, Appendix H.</li> </ul>
Flora	<ul style="list-style-type: none"> <li>Required at sites specified in Table H-4, Appendix H.</li> <li>Presence or absence of species listed in Table H-8, Appendix H.</li> </ul>
Wetland condition	<ul style="list-style-type: none"> <li>Photographs and descriptions of the wetland from all aspects. Additional details of this requirement and prompts for monitoring are provided in Table H-6, Appendix H.</li> </ul>
Data collection and provision	<ul style="list-style-type: none"> <li>Collected by RTH and provided to OGIA on 1 April and 1 October each year.</li> </ul>

**Note:**

1. A higher frequency is required for an initial 12-month period at some locations.

### 10.8.2 Watercourse spring monitoring network

Based on the outcomes from the risk assessment, in parallel with monitoring at spring vents, monitoring is also required at a small number of watercourse springs – gaining streams – such as certain reaches of the Dawson River and Hutton Creek. Tenure holder monitoring requirements for watercourse springs are specified in Table 10-3.

**Table 10-3: Design specification of watercourse spring network**

Design element	Specification
Location	<ul style="list-style-type: none"> <li>Watercourse spring monitoring sites are listed in Table H-5, Appendix H.</li> </ul>
Discharge	<ul style="list-style-type: none"> <li>Low-flow sampling at sites and frequency specified in Table H-5, Appendix H.</li> </ul>
Water chemistry	<ul style="list-style-type: none"> <li>Field water chemistry at sites and frequency as specified in Table H-5, Appendix H.</li> </ul>
RTH	<ul style="list-style-type: none"> <li>The tenure holder responsible for the monitoring obligation.</li> </ul>
Data collection and provision	<ul style="list-style-type: none"> <li>Collected by RTH and provided to OGIA on 1 April and 1 October each year.</li> </ul>

### 10.8.3 Watercourse spring verification

In accordance with the UWIR 2019, tenure holders have undertaken field verification of some reaches identified by OGIA to confirm groundwater discharge. The outcomes from these investigations have been incorporated into the UWIR 2021 by either removing these reaches (where they were identified as losing streams) or changing the attribution of source aquifers (where the investigations demonstrated change).

There remain three unverified reaches of watercourses which require field verification by tenure holders. These reaches and the RTHs are identified in Table H-2, Appendix H. The action required is a dry season longitudinal survey of the reaches to assess where groundwater is discharging to stream and to identify the source aquifer. The survey must include surface water chemistry, stream gauging, and the measurement of groundwater levels and chemistry in nearby shallow water bores. Where a reach is verified as a watercourse spring, OGIA will specify monitoring and mitigation actions, where appropriate. The annual report will provide an update on the progress and outcomes from these activities.

## 10.9 Timeframe for implementation and reporting

The SIMS identifies RTH for monitoring, investigations, mitigation actions and reporting at spring complexes and watercourse springs. The timeframe for implementation is summarised in sections 10.7 and 10.8, with additional detail provided in Appendix H.

## 10.10 Summary of SIMS

- Springs are locations in the landscape where groundwater is naturally discharged at the surface – including ‘watercourse springs’, which are sections of a watercourse where groundwater from an aquifer enters the stream through the streambed.
- There are a total of 88 spring groups and 96 watercourse springs in the Surat CMA, generally located around the edges of the Surat Basin and are fed by the Precipice, Hutton and Gubberamunda sandstones.
- Impacts are predicted at seven of the spring groups but they are less than 1 m in most instances, and at four sites there is uncertainty about the current conservative assumption that the source aquifer may be impacted at the location of the spring.
- A follow-up risk assessment, accounting for consequences, suggests that unmitigated risks for three of these spring groups – Springrock, Lucky Last and 311/Yebna 2 – are moderate to high. Santos is the RTH for all three and has a statutory plan in place, resulting from the previous UWIR, which will bring the risk to low.
- Other springs where risk was identified in the past are no longer at risk, due to updated investigations about their connectivity or revised predictions of impacts on groundwater levels.
- OGIA will undertake investigations for some other springs where some level of risk has been identified for the first time, before assessing potential mitigation actions, if necessary.
- Monitoring is specified at 26 spring vents and 5 watercourses on the basis of the risk assessment. The data collected, in combination with water level monitoring data, will provide a basis for understanding background trends and potential impacts on springs.

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## Chapter 11 Assessment of impacts to terrestrial groundwater-dependent ecosystems

### 11.1 Preamble

Terrestrial groundwater-dependent ecosystems (TGDE) occur where vegetation requires access to groundwater, either intermittently or permanently, to maintain ecological composition and function – typically where aquifers outcrop at the surface or underlie shallow alluvium associated with watercourses, and where the water table is shallow enough to be accessed by roots. TGDEs were included as EVs for the first time in the UWIR 2019.

In contrast to springs, which are generally localised features, TGDEs may be extensive and may integrate with non-TGDE vegetation communities, depending on variations in surface geology, landform and soil.

This chapter provides a summary of the conceptual understanding of TGDEs in the Surat CMA, predictions of impact resulting from the exercise of underground water rights, and monitoring requirements.

### 11.2 Terminology

**Regional ecosystem (RE)** – groupings of vegetation communities that are associated with a particular combination of geology, landform and soil type. Each RE has a biodiversity status, reflecting its condition and remaining extent of the RE.

### 11.3 Description of TGDEs

#### 11.3.1 TGDE mapping

In the Surat CMA, areas of potential groundwater-dependent vegetation have been mapped by the Queensland Herbarium and attributed with a level of confidence indicating whether the assigned dependency on groundwater is based on field data or expert opinion. Field-verified areas are attributed higher confidence. The distribution of potential TGDEs within the Surat CMA is shown in Figure 11-1.

#### 11.3.2 Conceptualising groundwater use by vegetation

The relationship between a TGDE and its source aquifer depends on botanical characteristics (such as root morphology), the groundwater regime, proximity of surface water, and rainfall patterns. These characteristics and attributes allow ecological water requirements of particular REs to be hypothesised (Doody, Hancock & Pritchard 2018).

Water levels in unconfined aquifers fluctuate at a variety of time scales, including daily, and in response to rainfall events. The ability of vegetation to switch water sources is a key adaptation in areas of highly variable rainfall and soil moisture conditions. As a result, vegetation may only use groundwater for short periods or opportunistically during dry periods. The ecological water requirement of terrestrial vegetation may not only be volumetric but importantly may have a timing component. Access to groundwater during dry periods may have a crucial role in the maintenance of aspects of plant life cycles, such as sapling establishment and growth.

The ability to access groundwater is conferred by the root architecture and rooting depth. Processes affecting root architecture are complex and depend on a range of site-specific variables. A widely

adopted rule of thumb is that vegetation use of groundwater is likely where the depth-to-water is less than 10 metres below ground level (mbgl), possible at 10 to 20 mbgl, and unlikely at >20 mbgl (D Eamus et al. 2006; OGIA 2019b).

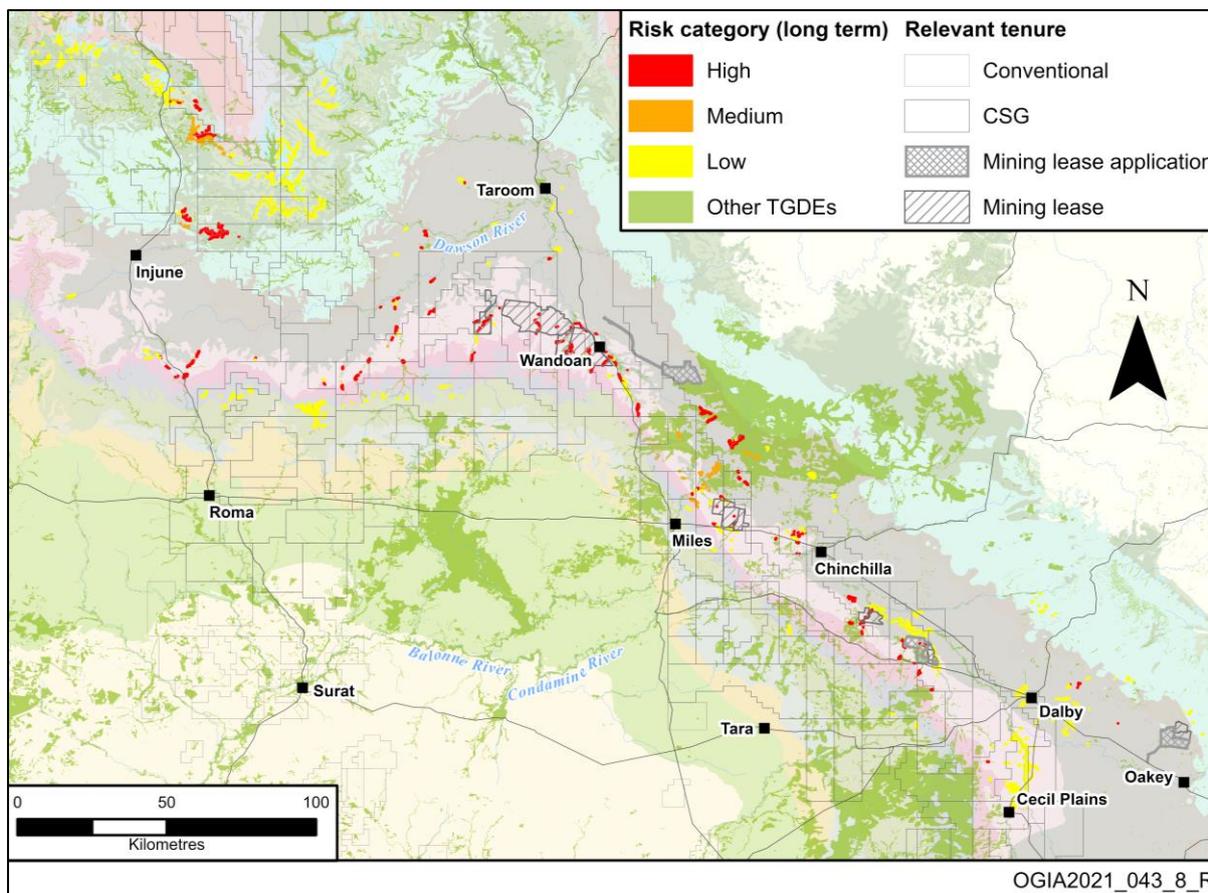


Figure 11-1: The location of potential TGDEs and risk assessment outcomes (long term)

### 11.3.3 Response to a change in the groundwater regime

Where potential TGDEs are confirmed through field investigation, response to impacts are conceptualised into three categories: productivity and growth; biodiversity; and reproduction and recruitment. In the short term, decreased availability of groundwater is more likely to be evident in changes in the productivity of vegetation. Drawdown is associated in the short term with reduced leaf production and in the longer term with an absence of saplings, loss of biodiversity and changes in community structure and composition (Figure 11-2).

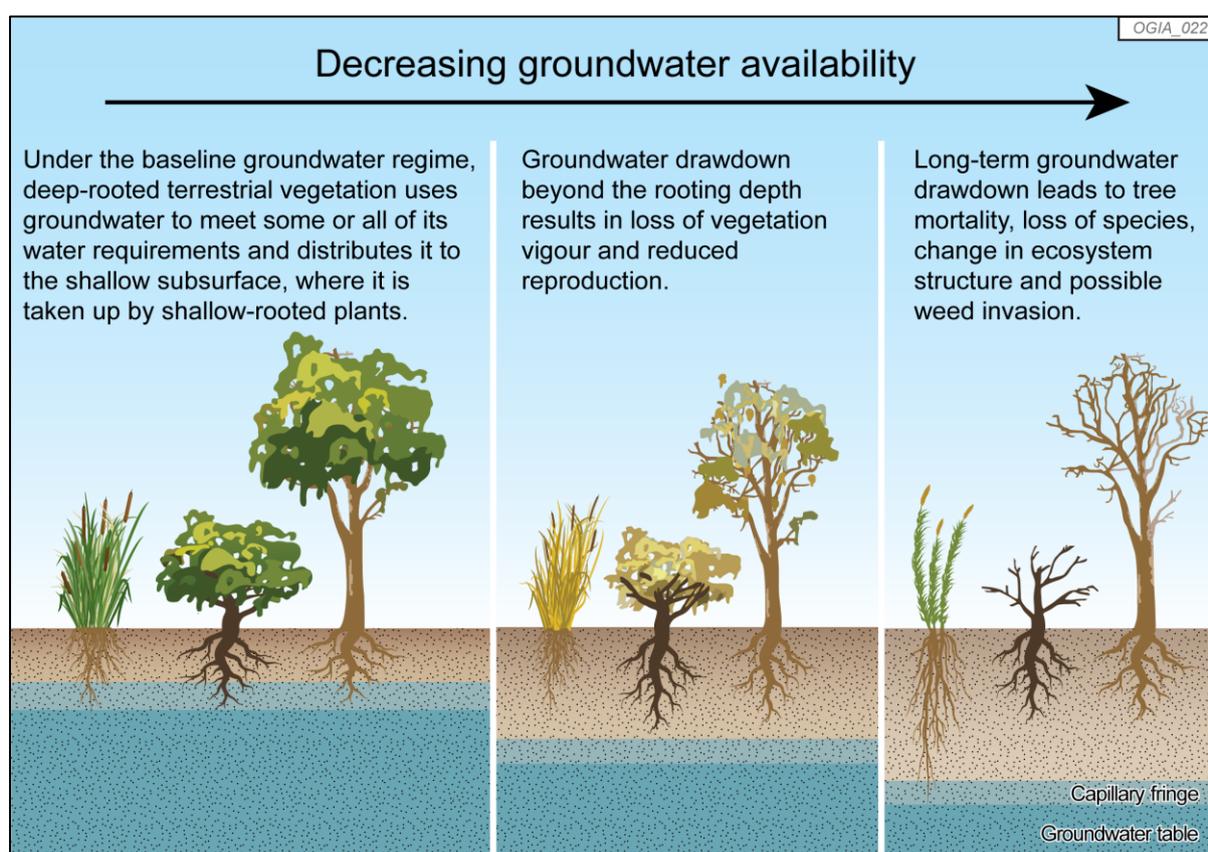
Where predicted impacts are minor and the rate of change in the groundwater level is slow, some vegetation communities may have the ability to adapt to the new groundwater level. Within the outcropping aquifers, when groundwater levels are impacted, TGDEs may be sustained by infiltrating rainfall. Given the seasonality of the rainfall, however, this may only provide a short-term buffer and may not compensate for a reduction in groundwater level during dry periods. Further research into responses is required to clarify the resilience of these TGDEs.

## 11.4 Predictions of impact

### 11.4.1 Previous assessments

As part of project approval conditions, a number of tenure holders have undertaken project-scale assessments and field investigations to conceptualise and evaluate the risk of impacts to TGDEs. In many cases, these investigations are ongoing and inform tenure holders' Groundwater Monitoring and Management Plans, which include the development of early warning indicators and trigger thresholds for TDGEs. In parallel, CSG tenure holders have also developed a Joint Industry Framework with the Australian Government to ensure a consistent post-approval groundwater management framework, including TGDEs and springs.

For the UWIR 2019, OGIA completed a regional-scale desktop assessment. In December 2020, OGIA provided an update on this assessment to DES which specifically identify impacts over the three statutory timeframes – past, within the next three years and over the life of the industry.



**Figure 11-2: Conceptual model of TGDE response to a reduction in groundwater level, after Eamus et al. (2006) and Rohde et al. (2017) (after OGIA 2019b)**

### 11.4.2 Approach to assessment for the UWIR 2021

A flow diagram showing the workflow for the assessment for the UWIR 2021 is provided in Appendix I. The overall approach to the assessment is consistent with the previous assessment in 2019 and includes the following:

- identifying TGDEs of interest – located within the area of 0.2 m predicted drawdown within the outcrop of affected aquifers

- undertaking a risk assessment as a function of the likelihood and consequence of groundwater drawdown in the target formation for a TGDE – this considers biodiversity status and the magnitude and timing of impacts, to assess the consequence of any change in the groundwater regime.

In terms of the TGDEs considered in the assessment, there has been a change to the previous approach due to the inclusion of coal mines. In the previous assessment, TGDEs reliant on perched aquifers were excluded, as CSG depressurisation is unlikely to affect these perched aquifers. In the case of coal mines, however, perched aquifers may be affected by the exercise of underground water rights, and they are therefore included in the assessment where they are located on mining leases.

### 11.4.3 Magnitude of predicted impacts

As presented in Chapter 6, the magnitude and timing of predicted impacts is different for each formation and varies spatially within impacted formations. Prior to 2021, at the location of potential TGDEs, predicted changes to groundwater levels in the Walloon Coal Measures are generally less than 10 metres. In the longer term, as TGDEs are located within the unconfined aquifers, the majority of impacts are less than 15 metres.

Where TGDEs are confirmed to be accessing groundwater in affected formations, there is potential for impacts to TGDE's ecological water requirements and resultant condition.

## 11.5 Risk assessment

A risk assessment is applied which builds upon the previously described impact assessment. Three risk categories are identified as follows:

- areas of low risk, where predicted impacts on REs range between 0.2 and 1 m regardless of the biodiversity status
- areas of medium risk, where predicted impacts on REs are greater than 1 m and the biodiversity status is 'no concern at present'
- areas of high risk, where predicted impacts are greater than 1 m and the biodiversity status is 'of concern' or 'endangered'.

The assessment is conservative because it is applied to vegetation that has been classified, mostly through desktop study, by the Queensland Herbarium as a potential TGDE. Therefore, this includes vegetation that may not be dependent on groundwater. Further field investigations are necessary to confirm this assumption. This additional work will provide an understanding of site-specific characteristics – such as rooting depths – and likely responses to a change to the groundwater regime.

### 11.5.1 Outcomes from the risk assessment

The risks of impact are identified in terms of the three statutory timeframes: prior to the UWIR 2021; predicted to occur in the next three years (2021–2024); and over the life of the industry. Outputs are presented as an extent of TGDEs in three risk categories – summarised in Table 11-1 and shown in Figure 11-1 for over the life of the industry. Risk assessment for pre-2021 and short-term impacts are presented in Appendix I. Similar to the concept of springs of interest, TGDEs of interest are those TGDEs overlying aquifers with predicted impact of greater than 0.2 m – although these aquifers may not be the source aquifers for the TGDEs.

**Table 11-1: Summary of risk assessment for TGDEs (area of interest)**

Risk category	Area of TGDEs predicted to be affected		
	Past	2021–2024	Long-term
Low	0.4 % (2,543 ha)	0.6 % (4,067 ha)	0.7 % (4,641 ha)
Medium	0.1 % (842 ha)	0.1 % (886 ha)	2.3 % (15,529 ha)
High	0.3 % (1,845 ha)	0.3 % (1,885 ha)	0.3 % (1,766 ha)

**Note:**

TGDE percentages relate to the total extent of TGDEs of interest. The percentages in later time periods (i.e. 2021–2024 and long-term) include the area identified in the earlier time periods.

Some of the key observations are as follows:

- In the long term, impacts exceeding 0.2 m occur within the outcrop areas of Precipice Sandstone, Walloon Coal Measures, Evergreen Formation (including the Boxvale Sandstone Member), Springbok Sandstone and the Condamine Alluvium, with smaller areas of impact predicted within the Hutton and Gubberamunda sandstones.
- About 27 per cent of the total area of likely TGDE has been confirmed with high confidence through field investigation as being TGDE. In the longer term, around 3.3 per cent of TGDEs of interest immediately overlie an aquifer predicted to be impacted by more than 0.2 m.
- The majority of TGDEs are remnant vegetation associated with watercourses where there is a higher potential for connectivity with groundwater.

Figure 11-1 presents a regional-scale snapshot of the outcomes of the risk assessment in the long term. Digital files providing higher resolution information are available from OGIA.

## 11.6 Potential uncertainties and monitoring

There are uncertainties regarding the identification of source aquifers for TGDEs and uncertainties resulting from the scale and the level of confidence of TGDE mapping. Large error terms are associated with estimation of the ecohydrological relationship between groundwater and vegetation. The conceptual models, estimated ecological water requirements, hypothesised ecological responses and resilience are drawn from the available literature, including Queensland Herbarium products, and are associated with high uncertainty. Ongoing monitoring is important to test, validate and refine this assessment.

The Queensland TGDE mapping has been developed using available datasets and engagement with subject matter experts (Glanville et al. 2016). Of the potential TGDEs identified, only a small percentage have been field-verified. Consistent with the national TGDE toolbox (Richardson et al. 2011), effective management of TGDEs requires three key knowledge components – location, groundwater dependency and characterisation of their likely response to changes in the groundwater regime. Validation and confirmation of TGDE mapping and associated REs, combined with conceptualisation of the identified TGDEs, will therefore greatly improve the future assessment.

## 11.7 Summary of TGDE assessment

- TGDEs occur where vegetation requires access to groundwater, either intermittently or permanently, to maintain ecological composition and function.
- The relationship between a TGDE and its source aquifer depends on root morphology, the groundwater regime, proximity of surface water, and rainfall patterns – essentially the availability of other water sources.
- Risk assessment is based on intersecting the area of 0.2 m predicted impacts in outcrop areas with mapped groundwater-dependent REs and their biodiversity status.
- Only a very small area is identified as at some risk, which is 3.3 per cent of the total TGDEs within the area of interest.

## Chapter 12 Synthesis of impacts on environmental values

### 12.1 Preamble

A change to the Water Act in 2016 extended the scope of the UWIR to include a description of impacts on EVs from the exercise of underground water rights. The intent of the change is to provide consistency between the Water Act and the EP Act – which defines EVs – and ensure that there is ability to review EAs in response to potential impacts on EVs that may occur during the operational phase of resource projects.

The characterisation and assessment of most of the environmental assets supported by groundwater in the Surat CMA – such as aquifers, springs and water bores – are explicitly included in other parts of the UWIR. Additional components relating to EV assessment – such as subsidence and TGDEs – are provided in Chapter 7 and Chapter 11. This chapter provides a synthesis of those various elements to summarise impacts on EVs from the exercise of underground water rights by the resource tenure holders.

### 12.2 Context

#### 12.2.1 Definitions of environmental values (EVs)

The EP Act defines an EV as a quality or physical characteristic of the environment that is conducive to ecological health, public amenity or safety, or another quality of the environment identified or declared to be an EV under an environmental protection policy or regulation.

In the context of the UWIR, the relevant policy is the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 (EPP). The EPP identifies specific EVs that are to be protected, with corresponding water quality objectives (WQOs). Under the EPP, all Queensland waters, including groundwater, have identified EVs and WQOs. Within the area of predicted impacts, more specific EVs and WQOs have been established in the Murray-Darling and Bulloo region and the Fitzroy Basin.

#### 12.2.2 Scope

Aquatic ecosystems and human use of groundwater are dependent on three primary attributes of groundwater – groundwater level, quality and quantity. The characteristics of a groundwater system can be affected by a range of resource development activities – such as the consumptive use of groundwater for camp supply, the loss of construction fluids to shallow aquifers, or changes to land use that may influence recharge to the groundwater system.

The scope of assessment of impacts to EVs in a UWIR is limited to only those impacts resulting from the exercise of underground water rights by P&G and coal tenure holders – i.e. impacts directly related to the depressurisation of coal seams or the dewatering of coal mines. Impacts on groundwater or EVs related to other activities are not assessed as part of the UWIR but are instead considered by other legislative provisions in the Water Act and the EP Act.

In this context, the exercise of underground water rights has the potential to impact:

- groundwater level, quantity and quality, which could affect the following EVs:
  - biological integrity of aquatic ecosystems
  - cultural, spiritual and ceremonial values of water

- groundwater quality, which could affect the following EVs:
  - the suitability of water for water supply (i.e. S&D and town water supply)
  - the suitability of water for irrigation, farms supply and aquaculture
  - the suitability of water for industrial use
- formation integrity affecting aquifer characteristics.

### **12.2.3 Scale and extent of the assessment**

The assessment of impacts to EVs for the Surat UWIR is a regional-scale assessment. As the long-term predictions of impact on groundwater from P&G and coal mining activities are not in all areas of the CMA, the assessment is limited to the extent of the LAA (Chapter 6).

The primary purpose of this assessment is to support decision-making by DES in relation to granting or amending EAs. The assessment is cumulative, in consideration of all resource development, and does not provide an assessment of impacts at a project-specific scale. Further site-specific assessments may therefore be required of individual proponents by DES to support project-specific applications for EAs or amendments.

### **12.2.4 Conceptual linkages between impacts and EVs**

Groundwater impact pathways for CSG and coal mining operations are described in Chapter 4. Two primary mechanisms by which groundwater level may be affected are lateral propagation (within a formation) and vertical propagation – through structures, poorly constructed water bores or wells, or intervening aquitards over longer timeframes.

In terms of impacts to groundwater quality, the impact pathways are similar to those described in relation to groundwater level. In general, the potential for changes in water quality in surrounding aquifers is considered low, because the pressure gradients generated across aquifers due to CSG depressurisation result in flow towards the target formations (i.e. the coal measures). This is likely to change the water quality in the reservoir, as water will move into the reservoir from adjacent formations. However, for those formations adjacent to the coal measures, minor water quality changes may result from the lateral and vertical flow induced through impact propagation into those formations. For formations overlying the coal measures, gas migration has the potential to result in changes to water quality, which is an area of ongoing research for OGIA.

### **12.2.5 Methods and tools for the assessment**

Schedule 1 of the EPP and supporting documents provide a list of groundwater management zones, water quality objectives and the EVs provided by the groundwater resource. In the Fitzroy Basin, there are two groundwater management zones based on a vertical subdivision – above and below 30 metres. In contrast, in the Murray Darling and Bulloo Basin, there are many groundwater management zones and aquifer groups within each zone. In addition, multiple hydrogeological units are amalgamated for the purposes of the EPP.

For each groundwater management zone, the supporting documents summarise the available groundwater quality data to define the 20th, 50th and 80th percentiles for each water quality parameter. The water quality objectives, national guidelines and percentiles provide a basis for assessing change since the commencement of resource development. Supporting guidance material recommends a minimum of eight samples at each site should be used in the comparison of water

quality (DES 2021). There are limited locations where there is sufficient data for a regional analysis. Using a similar approach to that applied in Chapter 5 (see section 5.5), data has been partitioned into pre- and post-CSG based on the timing and distance to the nearest CSG well.

Beyond water quality, an assessment of impacts on EVs has been made for changes in groundwater pressure (level) and subsidence, and their implications for the groundwater uses listed in the EPP. In some cases, data can be measured and evaluated. In other situations, there are data limitations, knowledge gaps and it is not always possible to quantify impacts that have occurred or are likely to occur in future. In these circumstances, a narrative based on conceptual understanding of potential impacts is provided.

## **12.3 Impacts to environmental values**

The following section provides a summary of the impacts to EVs in the Surat CMA, at three statutory timeframes – with linkages to previous sections of the UWIR.

### **12.3.1 Summary of data and analysis**

Across the EPP groundwater management zones where there are CSG wells, the regional analysis indicates water quality parameters have not changed significantly since CSG commencement – the available data largely remains within the 20th and 80th percentiles detailed in the EPP.

There is pre-CSG data outside the 20th and 80th percentiles provided in the EPP. This is likely to reflect either non-CSG influences or an increase in the data availability (since the EPP was established) changing the distribution of available data in the groundwater management zone. This is likely, given the substantial amount of new data since 2012 in the Surat CMA.

Given the hydraulic gradient following CSG development is from adjacent aquifers towards the reservoir, changes in water quality are unlikely in the adjacent aquifers. However, in areas where there is gas migration, there is potential for change in groundwater quality. This is an area of ongoing research for OGIA (OGIA 2021g).

### **12.3.2 Water supply**

Groundwater is accessed directly for use where there is no reticulated water supply. As detailed in Chapter 3, S&D use accounts for about 20% of groundwater use. Around half of the S&D use is from GAB formations, with the remainder from the alluvium and basalt.

There are 646 S&D (134 AD) and 6 town water bores (1 AD) predicted to be affected by the exercise of underground water rights over the life of the industry (Chapter 8). These water bores are accessing supplies from the Walloon Coal Measures, Springbok Sandstone, Bandanna Formation, Hutton Sandstone and Main Range Volcanics. In the short term – the next three years – 103 S&D water bores and 1 town water supply are predicted to be impacted in the Springbok Sandstone and the Walloon Coal Measures.

Due to the movement of water into the target formations from adjacent aquifers, there is unlikely to be any impact on water quality of water bores used for S&D purposes in the short and long terms.

### **12.3.3 Irrigation, farms supply and aquaculture**

Groundwater is accessed to support a range of agricultural activities across the Surat CMA, including as the primary source for some irrigation, aquaculture and stock-intensive operations (Chapter 3). Stock-intensive use occurs across all three groundwater systems – Alluvium and basalt, Surat and

Bowen basins (section 3.4) – and accounts for around 12% (about 7,200 ML/year) of groundwater use.

In contrast, irrigation development is primarily from the Condamine Alluvium and the Main Range Volcanics (about 11,200 ML/year), accounting for around 23% of water use in the area of interest. In addition to these licences, many water licences are issued for ‘agricultural purposes’, which are likely to include a high proportion of use for irrigation. When combined, irrigation and agricultural use accounts for around 56% of the use. Water quality requirements for cropping mean that the majority of take for this purpose is from the Alluvium and the Main Range Volcanics.

Over the life of the industry, it is predicted that 46 agricultural water bores – 32 stock-intensive (4 AD), 9 irrigation (1 AD) and 5 other agricultural water bores (1 AD) – will be affected by more than the trigger threshold (Chapter 8). These water bores access supplies from the Walloon Coal Measures, Springbok Sandstone, Bandanna Formation, Hutton Sandstone and Main Range Volcanics. In the short term – the next three years – 4 agricultural water bores in the Lower Juandah Coal Measures are predicted to be impacted. There are no agricultural water bores predicted to be affected in the Condamine Alluvium.

Due to the movement of water into the target formations from adjacent aquifers, there is unlikely to be any impact on water quality of water bores used for agricultural purposes in the short and long terms.

In parallel with impacts on groundwater level, subsidence has occurred and is predicted in areas adjacent to CSG development (Chapter 7). There is consequently potential for impacts to irrigation due to changes in landform and drainage, particularly in the western Condamine Alluvium as described in Chapter 7.

#### **12.3.4 Industrial use**

Around 4% of groundwater use (about 2,150 ML/year) is for industrial purposes including power stations and mining operations (Chapter 3). This use is predominantly from the Gubberamunda and Hutton sandstones – about 70% of industrial take in the area of interest.

Over the life of the industry, there are three industrial water bores (1 AD) predicted to be affected by more than the trigger threshold (Chapter 8). These water bores access supplies from the lower Juandah and Taroom coal measures. There are no industrial water bores affected in the short-term.

Due to the movement of water into the reservoirs from adjacent aquifers, there is unlikely to be any impact on water quality which may have implications on industrial use in the short and long terms.

#### **12.3.5 Cultural and spiritual values**

As noted in Chapter 10, Aboriginal people have a holistic and interconnected relationship with water – one connected system with spiritual, cultural, environmental, social and economic values. While springs are likely areas of significance, water more broadly is vital for many aspects of Aboriginal life, such as fishing, hunting, swimming, storytelling, family gatherings, ceremonies and other sacred activities (Department of Natural Resources Mines and Energy 2019).

Impacts on aquifers and springs are presented in Chapter 8 and Chapter 10, while impacts on TGDEs are presented in Chapter 11. The maintenance of groundwater pressure, quality and flow is highly likely to be important to maintain the many cultural values including mythological, ritual and ceremonial, economic and subsistence values across the Surat CMA. As such, any changes in groundwater discharge are likely to have implications on the cultural and spiritual values of water.

Additional site-specific assessments and engagement with traditional owners is necessary to understand the implications of any predicted impacts on cultural values. This is identified as an area of research during the next UWIR cycle (section 14.5).

### **12.3.6 Aquatic ecosystems**

Groundwater level, quality and movement support the biological integrity of aquatic ecosystems associated with spring vents and watercourses across the Surat CMA (Chapter 10). The key aquifers that feed springs in the Surat CMA are the Clematis, Precipice, Hutton and Gubberamunda sandstones, and basalts. Details of groundwater pressure impacts in the short and long terms are provided in Chapter 10 and Appendix H.

Where changes in groundwater pressure and a reduction in discharge occur, there is potential for impacts on water quality. For example, where there is reduced discharge, evapotranspiration will become a more significant component of the wetland water balance and may alter the water quality – such as increasing the salinity of the wetland (OGIA 2021k). The significance of any change will depend upon the initial conditions and magnitude of change.

### **12.3.7 Formation integrity**

The process of CSG production has the potential to alter the porosity and permeability of rocks through compaction. Compaction occurs primarily within coal seams in the Walloon Coal Measures; as such, a corresponding reduction in permeability will occur within the formation. This effect is likely to be inconsequential in surrounding aquifers, as these rocks are less prone to compaction and pressure declines are much lower, compared to the CSG target formation.

Subsidence modelling (Chapter 7) also predicts negligible compaction in aquifers surrounding the Walloon Coal Measures, due to the consolidated nature and geomechanical properties of these rocks and the lower predicted pressure declines, compared to the reservoir. The large area of compaction in the Walloon Coal Measures is also likely to be transferred to overlying aquifers as relatively uniform downward motion, resulting in shallow lateral gradients that are unlikely to affect the physical characteristics of aquifers and confining layers.

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## Chapter 13 Responsible tenure holder obligations

### 13.1 Preamble

As detailed in section 1.2, resource tenure holders' rights to take associated water is subject to several obligations relating to the management of impacts caused by the exercise of those rights, including the make good of impairment of supply from water bores.

In a CMA, where impacts from more than one tenure holder may overlap, the responsibilities of an individual tenure holder for specific obligations are assigned in the UWIR, to ensure there is clarity on impact management actions (s.369 of the Water Act). This chapter provides rules for determining individual RTHs for those obligations arising from the impact management strategies detailed in previous chapters.

### 13.2 Terminology

- **Responsible tenure holder (RTH)** – as also defined in Chapter 8, an authorised tenure holder responsible for implementing a specific obligation assigned to it in the UWIR, as per the provisions of s. 369 of the Water Act.
- **Relevant petroleum and gas tenure** – land over which a petroleum lease (PL) has been applied for or granted, as defined in section 2.3.2.
- **Relevant future coal mining tenure** – land over which a mining lease (ML) for coal has been granted and either the statutory right to take associated water has not yet been exercised or, where an associated water licence (AWL) is required, no water has been taken (section 2.4.2).
- **Relevant existing coal mining tenure** – land that is not a 'relevant future coal mining tenure' but over which an ML has been granted (section 2.4.2).
- **Authorised tenure holder** – the primary contact legally responsible for dealing with served notices and other documents in relation to a tenure, i.e. a PL or an authority to prospect (ATP) under the P&G Acts; or an ML or mineral development licence (MDL) under the MR Act.

### 13.3 Underground water obligations for RTH

Underground water obligations can be grouped into two categories:

1. **Make good obligations** for management of impairment of a bore's water supply – such as baseline assessment, bore assessment and make good agreement (section 8.4).
2. **Report obligations** that are much broader and primarily relate to water monitoring obligations, spring impact management obligations (Chapter 9 and Chapter 10) and any other obligations specified in the previous chapters of this report.

In the following sections of this report, the assignment rules are defined separately for each of the above two categories of obligation. All obligations are triggered from the day the UWIR takes effect. The take-effect day is advised by DES with the notice of approval of the report and made available on its website.

## 13.4 Assignment of underground water obligations

### 13.4.1 General

The locations of current and planned P&G production tenures and coal mining tenures are shown in Figure 2-3. For the tenures identified in section 2.3.2, details about the current authorised tenure holders, as of April 2021, are listed in OGIA (2021c). Since the RTH for an underground water obligation is directly linked to tenure ownership, an incoming authorised tenure holder resulting from change of tenure ownership will become the RTH for underground water obligations relevant to the tenure.

### 13.4.2 Changes compared to previous rules

As detailed in Chapter 1, all previous UWIRs applied to only P&G tenures (primarily CSG), therefore the rules for assigning RTHs were developed in the context that tenure footprints were often adjacent to each other but did not overlap, even though the P&G impacts resulting from activities on adjacent tenures often overlapped.

This is the first time that coal mining impacts are integrated with P&G impacts in the UWIR. Section 2.5 summarises some of the key differences between the operations of coal mining and CSG. With regard to the specification of assignment rules, the three important considerations are as follows:

- Coal mining tenures often overlap with P&G tenures.
- While P&G tenures in the Surat CMA tend to be adjacent to each other, coal mining tenures tend to be isolated from each other.
- The impact of coal operations are shallow and localised in.

In this context, some changes are made to the assignment rules compared to previous UWIRs to distribute obligations between the P&G and coal mining tenure holders where impacts are likely to overlap.

### 13.4.3 Assignment rules

#### 13.4.3.1 'Make good' obligations

The following rule assigns responsibility for make good obligations.

Rule 1: The RTH for a make good obligation relating to a water bore located within a relevant existing mining tenure is the authorised tenure holder of that tenure.

For the purpose of Rule 1, a relevant future coal mining tenure becomes a relevant existing mining tenure from the day the relevant future mining tenure holder exercises its associated water right or commences taking water under an AWL applicable to that tenure.

Rule 2: The RTH for a make good obligation relating to a water bore located within a relevant P&G tenure but outside any relevant existing mining tenure, is the authorised tenure holder of the relevant P&G tenure.

Because groundwater level impacts can extend outside a tenure boundary (off tenure), there may be make good obligations for water bores outside the lands covered by Rules 1 and 2. Therefore, the following rule assigns responsibility for make good obligations for those off-tenure water bores.

Rule 3: For a make good obligation relating to a water bore to which neither Rule 1 nor Rule 2 applies, the RTH is the authorised tenure holder of a relevant P&G tenure or relevant existing mining tenure that is closest to the water bore.

There are also instances where a tenure holder may have a pre-existing make good agreement with a landholder. The following rule applies in those instances.

Rule 4: Irrespective of Rules 1, 2 and 3, if a make good agreement under Chapter 3 of the Water Act has been executed between an authorised tenure holder and a water bore owner before the consultation day of this UWIR, then that authorised tenure holder continues to be the RTH for make good obligations relating to the water bore.

### 13.4.3.2 Baseline assessment

A baseline assessment is an assessment of a water bore by a resource tenure holder to obtain information about water bore construction, groundwater level and groundwater quality. As detailed earlier (in Chapter 8), under the Water Act, tenure holders are required to carry out baseline assessment of water bores on tenures before production or production testing begins on the tenures, and also in accordance with a program for any additional water bores required under a UWIR. The program is detailed in Chapter 8 and the rules for assignment are prescribed in this section.

Rule 5: The RTH for a water bore requiring baseline assessment under Chapter 8 is the authorised tenure holder of a relevant P&G tenure or relevant existing mining tenure that is closest to the water bore.

### 13.4.3.3 Reporting obligations – WMS, SIMS and others

Obligations relating to the WMS and SIMS are specified in Chapter 9 and Chapter 10, and relating to subsidence in Chapter 7 – primarily for implementing a monitoring network and spring impact monitoring and mitigation measures. These typically require actions such as installation of monitoring points, ongoing investigations and mitigation actions. The following rules apply to those and any other reporting obligations.

Rule 6: The RTH for a reporting obligation requiring actions within a relevant P&G tenure is the authorised tenure holder of that tenure.

Rule 7: The RTH for a reporting obligation requiring actions outside any relevant P&G tenure is the authorised tenure holder of the relevant P&G tenure that is closest to those actions.

The above rules imply that in some instances, reporting obligations may be assigned to P&G tenure holders within a mining tenure. This is intended because of the regionally extensive impacts caused by the P&G (primarily CSG) operations. In the instances where a reporting obligation and action – such as installation of a monitoring point or management of an impacted watercourse – is primarily required for mining purposes, the following rules will apply.

Rule 8: Irrespective of Rules 6 and 7, for a reporting obligation that is specifically attributed to mining activities and for which actions relating to the obligations are required within a relevant existing mining tenure, the RTH is the authorised tenure holder of that tenure.

Rule 9: Irrespective of Rules 6 and 7, for a reporting obligation that is specifically attributed to mining activities and for which actions relating to the obligations are required outside any relevant existing mining tenure, the RTH is the authorised tenure holder of the relevant existing mining tenure that is closest to those actions.

#### 13.4.3.4 Transfer of obligations

There are instances where a tenure holder other than the one identified as the RTH has taken, or intends to take, responsibility for some underground water obligations, through mutual agreement with the RTH. In a P&G context, this has generally occurred where, through application of the rules, monitoring or baseline assessment obligations had been assigned to a tenure holder over land where another tenure holder has held an ATP. Similarly, where P&G and mining tenures overlap, tenure holders may have pre-existing agreements in relation to various make good and monitoring obligations outside the Water Act framework. To facilitate such arrangements that are mutually practicable, the following rules applies.

Rule 10: An RTH may apply to OGIA for transfer of an underground water obligation to another authorised tenure holder, with the written consent of that other tenure holder. OGIA may approve or refuse the application with consideration to the effectiveness of the implementation of the actions relating to the obligation.

To provide transparency, OGIA will provide the outcome of any approved transfers in the annual report and will also notify DES and the affected tenure holders within 30 days of transfer approvals.

Assignment rules have evolved through the UWIR cycles in consultation with affected tenure holders. The applicable rules have been used in identifying the RTHs for underground water obligations in the UWIR effective at the time. Therefore, to provide certainty, RTHs and underground water obligations from previous UWIRs will continue to be maintained, based on the following rule.

Rule 11: Irrespective of Rules 1 to 10, a RTH's underground water obligations arising from assignment under previous UWIRs, continue unless and until the tenure holder transfers the obligation to another tenure holder under Rule 10.

### 13.5 Determination of RTH and their obligations

RTHs for various UWIR obligations are determined based on the rules detailed in the previous section and are listed in the following parts of the UWIR and supporting documents:

- Follow-up bore assessment and make good arrangements for each of the IAA bores – column 'RTH', Table G-1, Appendix G
- Bore baseline assessment as per section 9.10 – column 'RTH', Table G-3, Appendix G
- Installation and maintenance of monitoring points and implementation of monitoring strategy – various parts of Chapter 9; 'RTH' column in Table A-2, A-3, and A-4 in a separate companion document (OGIA 2021i)
- Monitoring and mitigation of relevant spring groups – section 10.7, section 10.7.3, 'RTH' column in Table H-1, Table H-4 in Appendix H
- Monitoring of subsidence – sections 7.5.2 and 7.5.4

A summary of each RTH's obligations is also provided in Appendix J.

It is also acknowledged that there is uncertainty around the approvals relating to New Acland Stage 3 development. The cumulative impact predictions and UWIR obligations emerging from that assessment are based on Stage 3 scheduled production, which assumes commencement of production from 2021 onwards. Therefore, UWIR obligations relating to New Acland will require a review if the approval process materially affects the scheduled production.

### 13.6 Linkages between an AWL and UWIR obligations

AWL requirements for mining tenure holders came into force following the amendment to the Water Act in December 2016, when associated water rights were extended to mining activities. The intent of an AWL within a CMA has been to provide a transitional arrangement until such time when a UWIR for the CMA takes effect. In this context, there are three potential scenarios within a CMA (subject to any requirement under the Coordinator-General's conditions in assessing the project to which the AWL may relate):

- If an AWL is already in place when a UWIR applicable to the mining activity comes into effect, then both obligations will coexist until the AWL conditions relating to the management of groundwater impacts align with the UWIR requirement and are potentially removed from the AWL.
- If an AWL application is under consideration when the UWIR takes effect, then the decision on the AWL will consider the UWIR findings and align with obligations to avoid potential duplication.
- If an AWL application is lodged after the UWIR takes effect, then the proponent is expected to consider and reference UWIR findings in its application. Similar to previously, the AWL will then be aligned to UWIR obligations.

### 13.7 Summary of RTH obligations

- In a CMA, where impacts from more than one tenure holder may overlap, the responsibilities of an individual tenure holder (the RTH) for specific obligations relating to management strategies in the UWIR are assigned to ensure there is clarity on impact management actions.
- This is the first time that coal mining impacts are integrated with P&G impacts in the Surat UWIR. Coal mining tenures are isolated from each other and often overlap with P&G tenures. Assignment rules are accommodated to account for this.
- Primarily, the rules assign tenure holders to be responsible for the UWIR-identified obligations within their own tenures and for those closest to their tenures.
- In some instances, specific coal mining obligations are required where mining tenures do not overlap with P&G tenures. For coal mines that are yet to commence operations, obligations will not apply until the extraction of associated water commences.
- Tables showing the assigned tenure holder for each make good bore, monitoring point and other obligation are available in the UWIR.

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## Chapter 14 Periodic reporting and review

This chapter describes the arrangements for ongoing reporting on matters relating to this UWIR and the subsequent revisions of the UWIR.

Once approved, the UWIR becomes a statutory instrument and provides a basis for ongoing management of groundwater impacts in line with the strategies specified in the report.

### 14.1 Annual reporting

An annual report is prepared to provide an update on changes to circumstances that would materially impact on the predictions reported in the UWIR, and to provide updates on the implementation of management strategies specified in the UWIR.

OGIA will continue to provide annual reports to DES for the UWIR 2021. These reports will be published on the OGIA website and will include the following:

- changes to the list of IAA bores resulting from ongoing verification of water bore status, authorisation and aquifer attribution for water bores referred to in Appendix G where follow-up bore assessment may be triggered
- overarching commentary on and summary of groundwater impacts from associated water extraction observed from monitoring data
- reporting of inferred CSG impacts at specific locations for the purpose of triggering actions specified in the SIMS in Chapter 10
- reporting of inferred CSG-induced subsidence where more than the anticipated subsidence is observed, for the purpose of follow-up actions specified in Chapter 7.

### 14.2 Other reporting and publications

OGIA's strategy on reporting its research and technical findings continues to evolve. OGIA intends to publish findings between the UWIR cycles, as they become available. OGIA will also progressively update the companion documents published on the OGIA website to reflect research outcomes.

A range of stakeholders have also expressed a view that technical and research work presented in the UWIRs should be shared with the broader scientific community through journal articles and conference presentations. OGIA has recently published some of its work in journals and intends to continue the practice, following the publication of the UWIR.

### 14.3 Access to information and data management

OGIA is the custodian of the following datasets that are reported by tenure holders in relation to implementation of the UWIR in the Surat CMA:

- monitoring data under the WMS (Chapter 9) including groundwater level, groundwater chemistry and associated water extraction data
- bore baseline assessment data reported under s. 405 of the Water Act and under Chapter 9 of the UWIR
- outcomes of bore assessments
- any other information collected and acquired under s. 460 of the Water Act.

The primary purpose of the data collection is to enable OGIA to undertake impact assessment activities and develop management strategies for the UWIR.

Following a quality control process, the majority of data received by OGIA is made available through the DRDMW GWDB and Queensland Globe. Tenure holder reports, including data about the construction of CSG wells and water extraction, are also available from the GSQ Open Data Portal.

Information about predicted impacts on individual water bores and water bore status at the time of preparing the UWIR is available through a 'Bore Search Tool' on OGIA's website ([www.resources.qld.gov.au/business/mining/surat-cma/bore-search](http://www.resources.qld.gov.au/business/mining/surat-cma/bore-search)).

OGIA is currently also progressing a project to develop a web-based portal for making the additional data and outputs that are presented in the UWIR available online.

## 14.4 Communication videos

OGIA has produced communication videos to support understanding of some fundamental elements of the impact assessment. These are available on OGIA's website ([www.business.qld.gov.au/industries/mining-energy-water/resources/landholders/csg/surat-cma/location-geology](http://www.business.qld.gov.au/industries/mining-energy-water/resources/landholders/csg/surat-cma/location-geology))

- *Introduction to the Surat CMA* ([www.youtube.com/watch?v=DSZh\\_aXOIy0](http://www.youtube.com/watch?v=DSZh_aXOIy0)) introduces the Surat CMA and some of the key groundwater assets in the CMA.
- *Geology of the Surat CMA* ([www.youtube.com/watch?v=0dhZPngCShc](http://www.youtube.com/watch?v=0dhZPngCShc)) shows the geological basins and formations, geological layers, groundwater systems, and what data OGIA has used to build this understanding.
- *Groundwater impact mechanism from CSG development* ([www.youtube.com/watch?v=pn8Ah03uB9E](http://www.youtube.com/watch?v=pn8Ah03uB9E)) explains how groundwater impacts may occur in aquifers surrounding the CSG formations in the Surat Basin.
- *Groundwater impact mechanism from coal mining* ([www.youtube.com/watch?v=QIVNkr6WdqM](http://www.youtube.com/watch?v=QIVNkr6WdqM)) explains how groundwater impacts may occur in aquifers surrounding the coal mines in the Surat Basin.

## 14.5 Revising the UWIR and future research directions

Queensland's regulatory framework requires revision of the UWIR every three years unless the chief executive of DES requires an earlier amendment. The revision incorporates new data and knowledge generated from research work in the preceding three years.

Understanding of the groundwater flow system continues to improve as data accumulates and is used to build knowledge through targeted research. OGIA's work program in the lead-up to the next update of the UWIR will include research in the following key areas:

- **Groundwater flow modelling** – continued development of the long-term modelling strategy as detailed in Chapter 6, exploration and development of new modelling techniques to maximise the use of available data, and further development and exploration of sub-regional models in specific areas of interest in relation to associated water impacts.
- **Subsidence** – continued improvement of understanding of subsidence from the monitoring data across the Surat Basin.

- **Monitoring and trend analysis** – exploration of new monitoring techniques for reliable and effective monitoring of groundwater levels affected by dual-phase flow, ongoing analysis of additional groundwater monitoring data to identify impacts associated with resource development, and discrepancies between the volumes measured through meters at CSG wells and the bulk volumes estimated from water balances at water processing facilities.
- **Hydrogeological conceptualisation** – further targeted assessment of the Horrane Fault, improving groundwater use estimates based on monitoring data, aquifer interconnectivity, regional groundwater flow patterns and groundwater flow in the Precipice Sandstone.
- **Cultural heritage values of springs** – integration of indigenous knowledge and furtherance of understanding of the cultural heritage values associated with high-risk springs in the Surat CMA.

OGIA will also continue to collaborate with research organisations and other government agencies to explore synergies in research and data/information management.

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