Queensland Government

Office of Groundwater Impact Assessment
Department of Local Government, Water and Volunteers

Consultation draft of the

Underground Water Impact Report 2025 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

Ver 1.2

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Summary

Headline summary

- The Underground Water Impact report (UWIR) provides for iterative assessment of cumulative impacts from past and future development, and proactive strategies for managing those impacts.
- The report is a statutory report prepared by the independent Office of Groundwater Impact Assessment (OGIA) every three years.
- Coal seam gas (CSG) is the predominant resource activity in the Surat Cumulative Management Area (CMA) with 11,000 operational CSG wells, expected to increase to 21,000 by 2060.
- CSG groundwater extraction has stabilised to around 52,000 megalitres per year (ML/year) and expected to average around 46,000 ML/year in the long run, compared to 58,000 ML/year that is currently extracted for consumption purposes by other users in the same area.
- Monitored impacts are broadly progressing as predicted in the previous UWIRs, reaching to 280 and 550 m, respectively, in the coal measures of the Surat and Bowen basins and extending to about 5-10 km from the gas fields.
- Implementation of management strategies for impacted water bores and groundwater-dependent ecosystems (GDEs) is also progressing as designed, with some room for ongoing improvements.
- As anticipated, groundwater pressure impacts from CSG development have started to manifest in some surrounding aquifers, such as the Precipice Sandstone and the Springbok Sandstone, while no impacts are observed in other aquifers as yet, including the Condamine Alluvium.
- Although predictions further into the future have changed due to changes in industry's development plans, those changes are broadly consistent with the previous predictions.
- Based on the statutory thresholds, a total of 747 water bores are likely to be impacted in the long term (referenced as LAA bores), of which 76 are identified to be impacted in the short term (the next three years) – referenced as immediately affected area (IAA) bores.
- IAA bores will now require make-good arrangements by the identified tenure holders in this report.
- IAA bores are identified on a rolling basis in each UWIR, resulting in 350 IAA bores from the previous four UWIRs, of which make good has been completed for 212 bores, while the remainder are in various stages of the process.
- An average net loss of water of about 920 ML/year is predicted to occur from the Condamine Alluvium to the underlying CSG target formation – marginally less compared to the predictions in the last UWIR.
- A dedicated monitoring network has been in place through the previous UWIRs and is now extended to 888 water level and water chemistry monitoring points, in addition to a complementary network of 3,100 monitoring points in the Surat CMA.
- Some springs and GDEs are likely to be impacted, for which mitigation actions resulting from previous UWIRs are already in place or are required under this UWIR.
- The regional-scale CSG-induced subsidence is likely to remain less than 100-150 mm over the life of the industry for most areas but in some localised areas it could be more than 250 mm.

The UWIR and the groundwater management framework

- 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.
- This UWIR represents the fifth iteration of the cumulative groundwater impact assessment and adaptive management cycle for the Surat CMA since its inception in 2010.
- The UWIR provides for the assessment and management of cumulative groundwater impacts resulting from the incidental extraction of groundwater by resource development activities – CSG, conventional oil and gas, and coal mining.
- Incidental extraction of groundwater, also called 'associated water', refers to groundwater that is primarily extracted in the process of either depressurising of coal measures for CSG production, dewatering of coal seams for safe operation of coal mines, or production of conventional oil and gas.
- The UWIR is finalised by OGIA and approved by the Department of Environment, Tourism, Science and Innovation following statutory consultation on the draft report.
- Once approved, implementation of the management strategies in the UWIR is a statutory obligation on the relevant tenure holders until the next iteration of the UWIR.
- The iterative UWIR cycle allows for the accommodating of new scientific understanding and changes in industry's development plans, to support ongoing adaptive management.
- OGIA holds, and uses, necessary statutory powers to seek any data and information that may be relevant for the assessment in the UWIR.

Resource development in the Surat CMA

- CSG and coal mining target formations are layered within some important aquifers of the Great Artesian Basin (GAB) – the Precipice Sandstone and the Hutton Sandstone – and also underlie the Condamine Alluvium.
- CSG is the dominant, and expanding, resource development activity in the Surat Basin from five major operators – QGC, Santos, Origin, Arrow and Senex – with a collective existing and proposed production footprint of about 14,000 km^2.
- The production footprint varies from year to year in response to tenure holders' plans, resource availability and business investment decisions.
- As at January 2025, the existing and proposed production footprint is about 5% less compared to the previous UWIR in late 2021.
- There are currently about 11,000 CSG wells in the Surat CMA, likely to increase to 21,000, well within the total 24,000 approved wells so far.
- CSG associated water extraction has stabilised to around 52,000 megalitres per year (ML/year) – 82% of which is from the Surat Basin – and less than 1,000 ML/year from the conventional oil and gas production.
- There are also seven existing and proposed open-cut coal mines in the Surat Basin with a combined footprint of less than two per cent of the CSG footprint.

Groundwater assets in the Surat CMA

- Groundwater in the Surat CMA is extracted for use by water bore owners, mainly for stock and domestic, irrigation, agricultural and town water supply purposes.

- Of the approximately 11,900 water supply bores that are in use, or usable, within 15 km of the relevant tenure footprint (the area of interest), about 7,000 access water from the GAB formations.
- Approximately 500 new water bores are drilled and completed every year in the Surat CMA.
- Estimated groundwater use within the area of interest is about 58,000 ML/year, of which about 22,000 ML/year (38%) is from the GAB.
- Origin is currently reinjecting around 4,500 ML of treated CSG water per year back into the Precipice Sandstone.
- Aquifers of the GAB also support a number of springs, watercourses and terrestrial vegetation – referred to as groundwater-dependent ecosystems (GDEs) – particularly in the northern part of the CMA.
- There are 86 spring complexes, 391 spring vents, 94 watercourse springs and 59 spring groups in the Surat CMA, located mainly along the northern and central boundaries of the Surat and Bowen basins.

Conceptualisation and modelling of impact propagation

- Depressurisation from CSG production creates a pressure difference between the target formation and adjacent aquifers that, depending upon the degree of connectivity, may potentially induce groundwater flow (impact) from those aquifers towards the target formation.
- CSG depressurisation also causes some underground compaction of coal seams that manifests as subsidence at the surface together with other influences on ground motion.
- Connectivity depends on intervening geological material and the presence of structures.
- Connectivity with the Hutton Sandstone and the Condamine Alluvium has been assessed to be low, while for the Precipice Sandstone, there are some localised zones of higher connectivity – similar to previous estimates.
- Impacts from CSG depressurisation propagate much further horizontally, along permeable coal seams, than they do vertically through low-permeability interburden.
- The groundwater levels observed from the monitoring data are a composite representation of multiple influences acting on the groundwater system, requiring further analysis to separate out impacts from CSG and coal mining development.
- There are an estimated 18,000 exploration coal holes, which pose only a minor to negligible risk of groundwater connectivity.
- Re-evaluation of connectivity with the Condamine Alluvium – through new airborne electromagnetic surveys and hydrochemistry assessment by OGIA – has reaffirmed the previous assessment that, while regional connectivity with the Condamine Alluvium is low, it is focused along specific localised pathways.
- OGIA has developed innovative tools and further improvements in the current modelling, particularly integration of groundwater flow and a geomechanical model to simultaneously calibrate to both groundwater and ground motion data.
- The regional model is calibrated using groundwater use data from about 30,000 bores, CSG water production, 40,000 records from more than 600 monitoring bores and several other datasets.
- Predictions are made through to hundreds of years and include past impacts from impacts from existing development as well as the future approved development – taking into account the impacts from non-CSG activities.

Results of cumulative impact assessment

- Since the previous UWIR, impacts from existing CSG development have started to manifest in the Springbok Sandstone and the Precipice Sandstone – as expected – while predictions in this UWIR are broadly similar.
- Changes in predictions are driven primarily by corresponding changes to planned development footprint and timing, and to some extent by underlying changes in the models and modelling tools.
- Maximum observable impacts so far are within the extents of gas fields in the Walloon Coal Measures and the Bandanna Formation, with magnitudes of up to 280 m and 550 m, respectively.
- Predicted impact in the lowermost part of the Walloon Coal Measures is relatively greater (about 420 m) compared to the middle and the upper parts, which will experience 350 m and 200 m respectively, although more than 500 m of depressurisation is expected towards the centre of some gas fields.
- Predicted material impacts in the CSG target formations generally extend to about 5–10 km from the gas fields.
- Substantial impacts are predicted in the Springbok Sandstone, which overlies the Walloon Coal Measures, compared to the underlying Hutton Sandstone.
- The Precipice Sandstone has started showing some impacts, as expected, despite the reinjection of about 4,500 ML/year, and the footprint of one metre or more of impact is significantly wider, needing further verification through more focused modelling in future.
- Declining trends observed throughout the Hutton Sandstone are attributed to groundwater take for water supply, with some indications of localised impacts from CSG development.
- The Springbok Sandstone, which overlies the Walloon Coal Measures and is little used for water supply, continues to show evidence of CSG impact where connectivity is enhanced due to local geological features, such as faults.
- Groundwater levels in the Condamine Alluvium are primarily influenced by local groundwater use and climate, with no identifiable CSG impacts yet, and the predicted impact is broadly similar to the previous UWIR, with an average net loss of water of about 920 ML/year – marginally less compared to the predictions in the last UWIR.
- The average annual volume of associated water extraction by resource development is predicted to be about 46,000 ML/year over the life of the industry, marginally less than the previous prediction.
- For most parts, the CSG-induced subsidence is likely to remain less than 100–150 mm but in some localised areas it may be more than 250 mm.
- The maximum change in regional ground slope from CSG-induced subsidence in most areas is predicted to be less than 0.001% (10 mm over 1 km), reaching up to 0.004% (40 mm over 1 km) in some areas around the Horrane Fault within the Condamine Alluvium footprint.
- The ground motion influenced by CSG-induced subsidence around the western edges of the Condamine Alluvium is showing a rate of movement of 10 to 15 mm/year, with some instances of 20 mm/year.
- A total of 747 water bores – about 7% greater than the UWIR 2021 – are likely to be impacted in the long term, based on a trigger threshold of five metres for consolidated formations and two metres for unconsolidated formations.
- About 92% of the water bores predicted to be impacted are used for stock and domestic purposes and are in the CSG target formations or the Springbok Sandstone, with less than one percent in recognised aquifers of the GAB and none in the Condamine Alluvium.
- Impacts of more than 0.2 m are predicted in one or more of the underlying aquifers at 51 spring groups and 84 watercourse locations.

Impact management and monitoring strategies

- Of the 747 long-term affected area (LAA) bores, 76 are likely to be impacted within the next three years (2026–2028), requiring follow-up statutory bore assessment by the responsible tenure holders identified in this UWIR to proactively establish impairment of water supply, and to implement make good measures.
- This adds to the 350 IAA bores from progressive UWIRs since 2012 on a rolling basis, of which make good is completed for 212.
- The monitoring strategy includes establishing and maintaining a groundwater monitoring network of groundwater levels, quality and quantity, and tenure holder obligations for implementation of the network and reporting.
- So far, 705 groundwater level monitoring points are established as part of the strategy from the previous UWIRs, proposed to increase by 57 further points for to a total 762 in this UWIR.
- Overall, the groundwater level and water chemistry network will increase to a total of 888 monitoring points – an increase of 10%.
- About 42% of all monitoring network points are in the Walloon Coal Measures in the Surat Basin, 4% are in the coal formations of the Bowen Basin and 54% are in surrounding formations.
- Monitoring of CSG water extraction includes monthly volumes reported to OGIA every six months.
- Several other formal and informal monitoring networks have important complementary datasets that are available for OGIA, and others, to use.
- A risk assessment based on the intersection of impact likelihood and consequences has identified 18 spring groups and watercourses with medium or high risks, where mitigation actions may be required at some stage.
- Three sites at very high risk, with mitigation plans in place through an approved Spring Impact Management Plan (SIMP) under previous UWIRs, now require updates based on the assessment in this UWIR.
- An additional two sites now require mitigation plans under this UWIR, while all other sites need further investigations and assessment before firming up the risk assessment and subsequent action plans.
- Monitoring is specified at 34 spring vents and 7 watercourses, on the basis of the risk assessment, to provide data for understanding background trends and identifying potential impacts on springs.
- Monitoring of CSG-induced subsidence comprises ground motion trends over time at various locations through InSAR, along with monitoring of landform changes in slopes and drainage through airborne LiDAR.
- Specific statutory actions and responsibilities resulting from the water bores make good, GDE mitigation plans and monitoring are attributed to individual tenure holders and specified in the UWIR schedules.
- Annual reporting on implementation and ongoing improvements to assessments of groundwater impacts will continue.

Table of contents

List of figures

List of tables

List of schedules – separate document

Abbreviations

1D, 2D, 3D........one-dimensional, two-dimensional three-dimensional
AEM..................airborne electromagnetic
AGL ....AGL 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
CSIRO ....Commonwealth Scientific and Industrial Research Organisation
DETSI ....Department of Environment, Tourism, Science and Innovation (Queensland)
DNRME ....former Department of Natural Resources, Mines and Energy (Queensland)
DNRMMRRD....Department of Natural Resources and Mines, Manufacturing and Regional and Rural Development (Queensland)
DLGWV ....Department of Local Government, Water and Volunteers (Queensland)
EA.....................environmental authority
EIS....................environmental impact statement

EP Act ....*Environmental Protection Act 1994*

EPBC Act ....*Environment Protection and Biodiversity Conservation Act 1999*

EPP ....Environmental Protection (Water and Biodiversity) Policy 2009

EV.....................environmental value

GAB ....Great Artesian Basin

GDE..................groundwater-dependent ecosystem

GWDB ....groundwater database

GWAN ....Groundwater Ambient Network

GDR ....Great Dividing Range

GL.....................gigalitres

IAA....................immediately affected area

IESC ....Independent Expert Scientific Committee on Unconventional Gas Development and Large Coal Mining Development

InSAR ....Interferometric Synthetic Aperture Radar

km ....kilometres

L ....litres

L/s.....................litres per second

LAA...................long-term affected area

LiDAR ....light detection and ranging

LNG ....liquefied natural gas

m ....metres

mbgl..................metres below ground level

mD ....milliDarcy

mg/L ....milligrams per litre

ML ....mining lease

ML/year ....megalitres per year

MR Act.............*Mineral Resources Act 1989*

mm ....millimetres

MNES ....matters of national environmental significance

NC Act ....*Nature Conservation Act 1992*

NDVI ....normalised difference vegetation index

OGIA ....Office of Groundwater Impact Assessment

Origin ....Origin Energy Ltd (including subsidiaries and joint venture partners)

P&G ....petroleum and gas

P&G Acts..........*Petroleum and Gas (Production and Safety) Act 2004* and *Petroleum Act 1923*

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
UQ ....University of Queensland
UWIR................Underground Water Impact Report
Water Act..........*Water Act 2000*
WMS.................Water Monitoring Strategy

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Part I Context

Chapter 1 Introduction

1.1 Target audience

The report is targeted to a broad audience with direct or indirect interest in the management of cumulative groundwater impacts, primarily from coal seam gas (CSG) development in the Surat Basin. It is a statutory report for ongoing proactive management of impacts but also serves as a single source of information about the existing and future impacts, and ongoing monitoring and management, in the Surat ***cumulative management area***[1] (CMA). It is expected that readers have a basic understanding and background knowledge of the CSG production processes, groundwater and geology of the Surat Basin.

1.2 What is an Underground Water Impact Report?

An Underground Water Impact Report (UWIR) for a CMA is a statutory report to provide for:

- an **assessment of impacts** on aquifers and groundwater assets from existing and proposed associated water extraction by resource tenure holders – i.e. CSG, conventional oil and gas, and coal mining – including determining existing impacts and making predictions of future impacts through modelling
- **proactive strategies for managing** those impacts – such as to *make good* water supply bores before actual impacts occur, a strategy for monitoring, and strategies for mitigating impacts on affected springs and connected watercourses
- the **assignment of responsibilities** to individual tenure holders for implementing strategies and ongoing reporting.

1.3 Who has prepared the report?

The UWIR for the Surat 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) following the principle of adaptive management. The UWIR is finalised following consideration of submissions from stakeholders in relation to a consultation draft. Once approved by the regulator, which is the Department of Environment, Tourism Science and Innovation (DETSI), implementation of the management strategies in the report becomes a statutory obligation on the relevant tenure holders. Further updates on any changes in circumstances that would materially affect

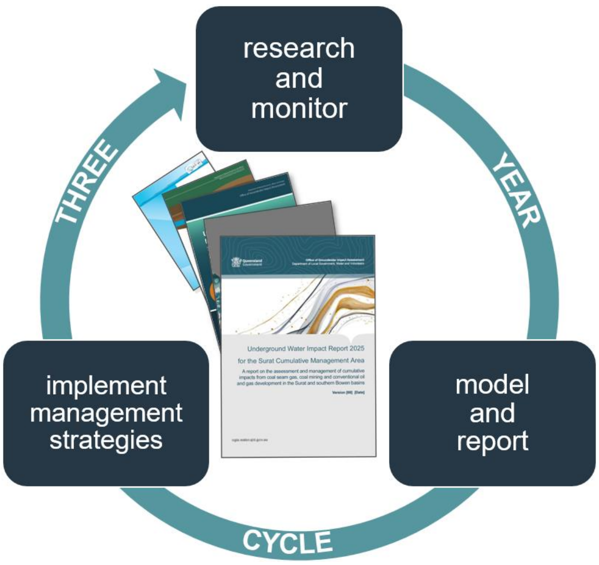

Figure 1-1: The UWIR cycle

[1] Italics denote statutory/legislative terms; bold denotes emphasis.

the UWIR are provided through an annual review. In addition, iterative assessments also provide a basis for ongoing review of environmental authorities (EA), if needed.

1.4 What constitutes this UWIR?

The report, for statutory purposes, comprises the main body of report, its appendices, and a separate schedule of listings of water bores and monitoring information for statutory implementation. The report refers to a range of supporting documents, reports, journal papers and background papers published by OGIA on the underlying scientific methods, prepared for a technical and scientific audience. Those supporting documents do not necessarily constitute parts of the UWIR.

1.5 Underground 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. The right to take the water is referred to as an **underground water right** and water taken using this right is referred to as **associated water**. This right has existed for petroleum and gas (P&G) tenure holders since 1923 and was extended to mining, through legislative amendments and some transitional arrangements, in 2016. The right is subject to various management and make good obligations and does not apply to other extraction of 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 Queensland's *Water Act 2000* (Water Act). Extracted associated water can, however, be used for other purposes, in accordance with the Queensland Government CSG water management policy[2], which encourages the beneficial use of associated water.

1.6 Underground water management framework

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 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 the Water Act.

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
- a baseline survey of water bores in and around the tenures
- detailed assessment of potentially affected water bores to establish whether their capacities to supply water will be impaired

[2] www.business.qld.gov.au/industries/mining-energy-water/resources/landholders/csg/environment-water/management

- 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.

1.7 Complementary frameworks

The underground water management 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). Prior to the granting of EAs and tenure, major resource projects' broad impacts on groundwater are considered through the environmental impact statement (EIS) process. A project proponent is required to develop an environmental management plan to support an application for an EA. EAs are granted and conditioned in consideration of the complementary underground water management framework so that statutory obligations are not duplicated. 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 have also been progressively aligned to the UWIR framework to minimise duplication.

1.8 Assessment and management of cumulative impacts and the role of OGIA

Impacts on groundwater level from multiple separate 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. To ensure that a comprehensive cumulative groundwater assessment is completed and to provide clarity on the management responsibilities of the involved tenure holders, an area containing projects with potentially overlapping impacts can be declared a CMA under Chapter 3 of the Water Act (Pandey, Cox & Flook 2021). Currently, there is only one CMA in Queensland – the Surat CMA, which was declared in 2010 and covers the petroleum and gas tenures in the Surat and the Southern Bowen basins.

When a CMA is established, the responsibility for preparing the UWIR for the CMA rests with OGIA, which is 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 DETSI remains the agency responsible for regulating compliance with those obligations.

1.9 The Surat CMA

The Surat CMA was established in 2011 in response to intense CSG development (Figure 1-2). Covering the area of current and planned CSG development in the Surat Basin and the southern Bowen Basin (as described in detail in Chapter 3), the Surat CMA was amended in January 2020 to include coal mines within 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. Straddling the Great Dividing Range (GDR), the Surat CMA falls within a region covering various catchments of both the southern parts of the Fitzroy River Basin and the northern parts of the Murray-Darling Basin. The GDR divides the Murray-Darling Basin river systems (dominated by the Condamine and Balonne rivers) from the northerly and easterly flowing Nogoa, Comet, Dawson and Boyne river systems. In the south of the region, the Condamine-Balonne river system is the dominant surface drainage system.

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.

1.10 Structure of the report

The report is broadly structured in four parts:

- **Part I:** Contextual background on resource development (Chapters 1 to 3)
- **Part II:** Description of groundwater assets in the CMA (Chapters 4 to 6)
- **Part III:** Assessment of impacts (Chapters 7 to 10)
- **Part IV:** Strategies for managing impacts (Chapters 11 to 16).

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 for a broader audience, and inclusion of scientific details. To address this challenge, the UWIR focuses on presenting key information, results and methodology summaries – written for a non-technical audience, to the extent possible. Further technical details are available in a range of supporting and mutually independent reference documents in the form of reports, research update papers and journal articles published by OGIA over time. These are available on the OGIA website and referenced in the UWIR, where applicable.

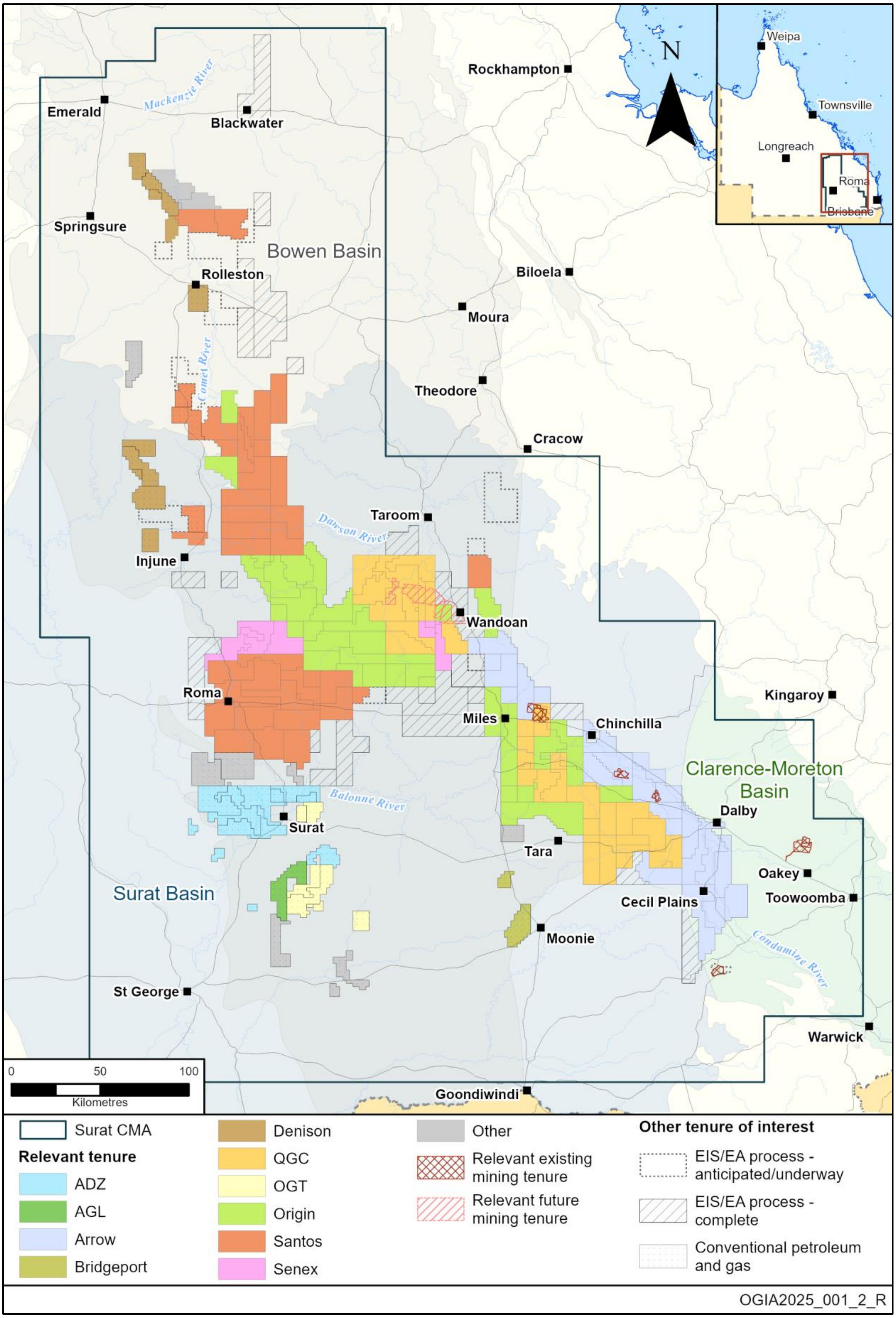

Figure 1-2: The Surat Cumulative Management Area (Surat CMA)

1.11 Summary of the impact management framework

- In Queensland, resource tenure holders have a statutory right to take or interfere with groundwater (associated water) in the process of exploration and production to provide for safe extraction of resources.
- The right to take water, however, is subject to various obligations on periodic assessment, reporting and management comprising make good, monitoring and mitigation measures through an underground water management framework.
- The framework allows for declaring a cumulative management area (CMA), which is an area of extensive development with adjoining or overlapping tenures, such as the Surat CMA, which was declared in 2010 in response to extensive CSG and coal mining development.
- In a CMA, the periodic assessment of impacts and development of management strategies is undertaken by the independent Office of Groundwater Impact Assessment (OGIA) and reported every three years in a statuary Underground Water Impact Report (UWIR).
- The UWIR also assigns statutory responsibilities for various elements of the management strategies to relevant tenure holders.
- The UWIR 2025 is the fifth such report since 2012.

Chapter 2 The UWIR development process

2.1 The UWIR process and its implementation

The UWIR for the Surat CMA is required every three years, commencing with the very first UWIR in 2012. The statutory process involves releasing a draft UWIR for public consultation, inviting and receiving submissions on the draft report, finalising the report after considering submissions and then submitting the final report to the regulator (DETSI) for approval, together with a summary of submissions. OGIA notifies affected bore owners and relevant tenure holders in the process.

Once approved, implementation of the management strategies in the UWIR is a **statutory obligation** on the relevant tenure holders until the next iteration of the UWIR. OGIA also liaises with tenure holders, bore owners and the regulator to support implementation of the management strategies in the UWIR, including collection and maintenance of the monitoring data. Increasingly, the data and information are made available online.

Each successive UWIR is supported by a combination of investigations, assessments and research to generate and accommodate new data, focused and needs-driven scientific assessment research by OGIA's in-house team, which comprises several hydrogeologists, modellers, geologists, hydrochemists, hydrologists, data scientists and supporting team members. OGIA also draws relevant aspects from review of tenure holders' own assessments in the Surat Basin, and collaborative and complementary assessments by other organisations, such as by the University of Queensland (UQ), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Geoscience Australia (GA). A comprehensive list of the assessments and studies is provided in Appendix A.

The iterative UWIR cycle allows accommodating new scientific understanding and changes in the industry's development plans. As the resource developments progress over time, more and more P&G wells are completed and logged, and groundwater system responses to development are monitored. All of this provides valuable data to improve understanding of the groundwater connectivity and to continuously calibrate the modelling of impacts.

2.2 The UWIR cycle

In some instances, the typically three-yearly UWIR cycle can be longer or shorter, to accommodate additional information or significant changes that could affect the assessment. For example, the cycle was shortened to two years when coal mines were added after the UWIR 2019, resulting in the next UWIR being prepared in 18 months. On the other hand, the current cycle is extended to four years, to allow for additional investigation in the Condamine Alluvium to be completed.

2.3 An overview of the UWIR preparation methodology

An overview of the methodology for the preparation of the UWIR is presented as a schematic in Figure 2-1. Broadly, the methodology's major and somewhat sequential steps are split into four parts, which the structure of this report follows: context setting (Part I), description of groundwater assets (Part II); assessment of impacts on those assets (Part III); and finally monitoring and management strategies for those impacts (Part IV).

Contextual information is about synthesising information on geology and groundwater, resource development processes, and the location and timing of existing and proposed development that may impose stresses on the groundwater system, in the context of impact assessment.

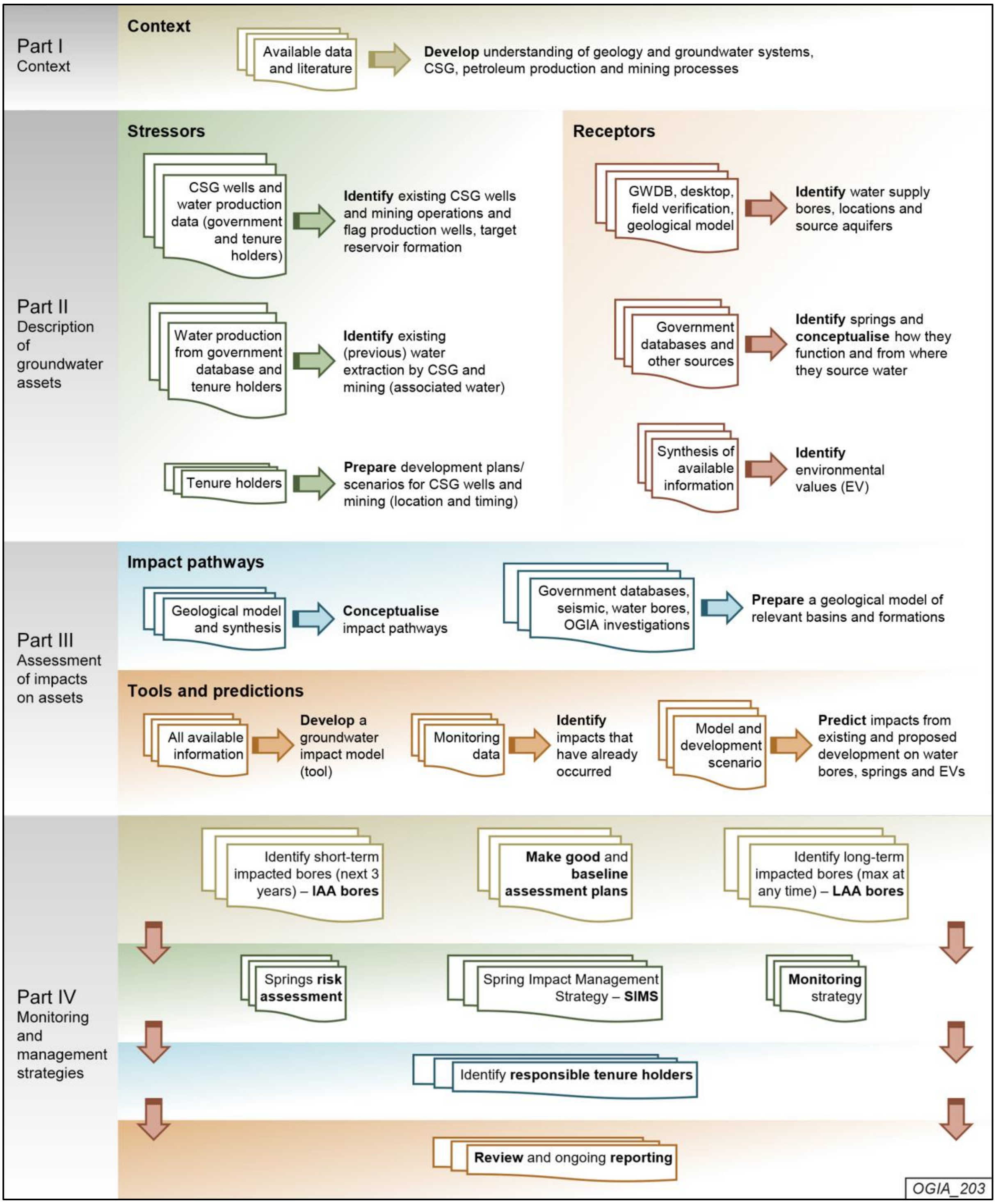

Figure 2-1: Schematic representing the methodology and workflow for preparation of the UWIR

Groundwater receptors, or assets, are the aquifers, water bores, springs and groundwater-dependent ecosystems (GDEs). Aquifers are characterised based on geological information and groundwater monitoring. Water bores are identified based on information available in the Queensland Government's groundwater database (GWDB). Due to inaccuracies and incompleteness in historical data, bore information is updated based on other sources, such as additional data collection and field verification of priority bores. Methods are developed to attribute source aquifers to each of those water bores, and to assign groundwater uses, because most use in the Surat CMA is not metered. Springs and GDEs are also mapped and verified, through a range of field investigations.

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 the extraction. This may result in impacts on **receptors** such as water bores, springs and terrestrial GDEs (TGDEs). The degree of impact on a receptor depends upon the impact pathway and its characteristics – that is, 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.

An initial step in the **conceptualisation of impact pathways** is to interpret depths of geological formations and structures – from information recorded during the drilling and completion of CSG wells, exploration wells and water bores, as well as from seismic and airborne electromagnetic (AEM) surveys, including many investigations run by OGIA. This is synthesised to develop a detailed geological model of the Surat CMA, which then forms the basis for aquifer attribution, impact pathway conceptualisation and modelling of impacts. From a dedicated monitoring network established through previous UWIR cycles and other sources, recorded data is analysed to evaluate emerging trends and interpret impacts that may have already occurred. All of this information, together with information about groundwater assets and resource development, is collectively synthesised to develop a conceptual understanding of how, and to what extent, groundwater systems are connected with each other – particularly those that are connected to the formations targeted to extract resources.

Development of **predictive tools** is the next major step, which involves developing and implementing a modelling strategy consistent with the purpose. Increasingly, a set of models is developed, instead of a single model. Several world-leading techniques have been developed and published by OGIA in peer-reviewed scientific journals. These are continuously improved upon through successive UWIRs since 2012. Underpinned by OGIA's geological models and conceptual understanding of impact pathways, models are calibrated to historical and updated monitoring data on groundwater levels, water production and ground movement, along with several other datasets. Once developed, the models then receive inputs of development profiles (the location and timing of existing and future CSG wells, mine pits and so on) to make transient **predictions of cumulative impacts** on each relevant aquifer. This includes predictions of impacts from development that has already occurred, as well as the future development. Changes in the development profile can have significant influence on the predictions.

Predictions, in combination with conceptual understanding and information about the groundwater receptors, lead to the development of statutory and **proactive management and monitoring strategies.** Water bores predicted to be impacted in the short term (the next three years) – based on specified impact triggers (5 m for consolidated formations and 2 m for unconsolidated formations) – are identified as immediately affected area (IAA) bores and flagged for follow-up statutory processes on bore assessment, then leading to 'make good arrangements', if needed. Long-term affected area (LAA) bores, which are predicted to eventually become IAA bores in future UWIRs, are identified for information purposes. A risk assessment methodology is developed and implemented for springs and TGDEs. The effectiveness of previous mitigation measures is evaluated, and mitigation plans are updated as necessary; a synthesis of impacts on other EVs is also presented. A monitoring strategy is developed – including a network of groundwater level, water chemistry and baseline monitoring – to ensure that impacts are proactively identified, system understanding is progressively improved, and effectiveness of management strategies can be evaluated. As the strategies are based on cumulative impacts, obligations of tenure holders to implement actions are identified and rules are developed to distribute individual obligations clearly. The strategy also identifies OGIA's own commitment to implement certain actions relating to monitoring, further research and the dissemination of information.

Guidelines by DETSI also require a risk-based assessment of impacts on EVs that may result from **CSG-induced subsidence** (Department of Environment and Science 2017). The UWIR 2021 presented a cumulative assessment of CSG-induced subsidence across the whole of the Surat and southern Bowen basins, as well as the Condamine Alluvium footprint (OGIA 2021a). The purpose of that assessment was to evaluate potential impacts on EVs and not on farming practices. Evaluation of impacts on farming practices requires a different scale of assessment outside the scope of the UWIR. The Queensland Government is currently considering a framework for the assessment and management of farm-scale CSG-induced subsidence impacts, for which OGIA is tasked with developing and testing tools and techniques for farm-scale assessment through a pilot project. To this end, OGIA has undertaken a number of research initiatives and investigations between 2022 and 2024, which are documented separately.

2.4 Source of data and information

OGIA has necessary statutory powers to seek any data and information that may be relevant for the assessment in the UWIR. Information about CSG wells and complementary geology and geophysical survey data – submitted by tenure holders to the Queensland Government through the Geological Survey of Queensland (GSQ) Open Data Portal[3] – is accessed by OGIA, including data that may not be publicly available. This is supplemented by data acquired directly from resource tenure holders, if and when needed, such as water production data at monthly intervals and reservoir parameters. Receiving similar data from multiple sources allows valuable quality-assurance and quality-checking (QA/QC) processes to verify and correct errors.

As tenure holders' proposed development plans are dynamic, this information is sought directly from tenure holders on an annual basis, then reconciled with regulatory approvals and compared for changes.

Water bore information is acquired from the GWDB – the Queensland Government's repository of water bore location and construction details, recorded at the time of drilling and as supplied by drillers. Some recorded information, particularly for historical bores, may be missing or incorrect. This information is therefore supplemented and verified through comparison with other information from tenure holders' bore baseline assessments; information collected directly by OGIA through various project investigations; information from the Department of Local Government, Water and Volunteers (DLGWV); and information from OGIA's field verification of priority bores. A range of monitoring data is sourced from a dedicated network established through previous UWIR cycles, along with other sources, such as the GWDB and monitoring by tenure holders.

Underlying data, such as monitoring, bore baseline, tenure status and development profile data, is continuously changing and updated. In most instances, further QA/QC steps are necessary, at various stages, to improve and prepare the data for the assessment. Some of those stages are sequential; for example, monitoring data feeds to conceptualisation, which then feeds to model development and calibration. Various datasets may therefore have different 'cut-off' times for

[3] https://geoscience.data.qld.gov.au

incorporating into the assessment. Some of those critical datasets and their cut-off times for the UWIR 2025 are summarised below:

- CSG well log and water bore log data, for geological modelling and conceptualisation – drilled up to October 2023
- Monitoring data, for analysis of trends and identifying existing impacts – October 2024
- Monitoring data on groundwater level and water production, for groundwater flow model calibration – December 2022
- Industry development profile (planned location and timing of future wells and planned cession of existing wells), for making predictions – January 2025

2.5 Peer review of scientific methods

As stated earlier, OGIA has developed a range of innovative techniques, tools and methods that are continuously improved upon since 2012 for progressive UWIRs. A peer-review strategy is employed for core elements of OGIA's scientific assessment to ensure that underlying scientific methods and techniques are robust and fit for purpose. The process includes publication of innovative methods and research in peer-reviewed scientific journals and the separate establishment of a Technical Advisory Group, through which OGIA seeks endorsement on specific assessment methods.

2.6 Key improvements and updates in this UWIR

The first UWIR was prepared by OGIA (then part of the Queensland Water Commission) in 2012, followed by three further iterations – UWIR 2016, UWIR 2019 and UWIR 2021. The UWIR 2021 remains in force until this UWIR (UWIR 2025) is finalised and approved by DETSI. Some of the key updates and new elements compared to the previous report (UWIR 2021) are summarised below.

Major research investigations and innovations

- An integrated groundwater flow and geomechanical model simultaneously calibrated to groundwater and ground motion data was developed and implemented – allowing concurrent predictions of groundwater impacts and subsidence, as well as maximising the value of calibration datasets.
- Significant focus was put on understanding CSG-induced subsidence processes, monitoring and modelling with multiple research initiatives and data gathering, particularly for assessing farm-scale impacts. This is not directly within the scope of the UWIR but has contributed to regional-scale CSG-induced subsidence assessment in the UWIR.
- An AEM survey in the western Condamine Alluvium was commissioned by OGIA in May 2023 to advance understanding of the shallow sub-surface geology and groundwater system in this area, with a particular focus on the Horrane Fault system.
- A new high-resolution 3D sub-regional geological model for the Condamine Alluvium footprint was developed, integrating recent AEM data with a comprehensive reinterpretation of existing seismic, petroleum well, coal holes and water bore datasets. This geological model serves as the architecture for a sub-regional groundwater impact model for the Condamine Alluvium.
- Multiple field investigations, sampling and verifications were undertaken for inflow zones and source aquifers for watercourses potentially connected with the Precipice Sandstone.

Improvements and updates

- A new recharge estimation workflow, to generate a unique and transient recharge model for each outcrop zone, based on daily rainfall and evaporation sequences pertinent to each outcrop, incorporates more precipitation data into the model calibration process.
- The representation of deviated CSG wells in the groundwater modelling workflow is refined.
- The calibration period is extended to December 2022, using additional and up-to-date monitoring data, and the water production calibration is refined, for better performance.
- Aquifer attribution has been updated for all water supply bores based on the revised geological model and updated bore information.
- Trend analysis methods for determining existing impacts from the monitoring data are modified, including re-classification of monitoring data into pre-development and post-development periods, extensive verification of data for quality control, and review of trends in environmental tracers.
- The methodology for estimating unmetered groundwater use is significantly improved to allow for temporal variation and inputs from a collaborative project with UQ.
- The workflow for identifying and verifying producing CSG wells is improved and implemented.
- The monitoring network was reviewed to refine and update the network and the strategy.

2.7 Summary of the UWIR process

- The statutory process for preparing the UWIR involves releasing a consultation draft first to seek feedback and submissions, then considering submissions and finalising the report for the regulator (DETSI) for approval.
- Once approved, implementation of the management strategies in the UWIR become statutory obligations on the relevant tenure holders until the next iteration of the UWIR.
- Each successive UWIR is supported by a combination of investigations, assessments and research by OGIA to generate and accommodate new data, allowing accommodation of new scientific understanding and changes in the industry’s development plans, to support ongoing adaptive assessment.
- The methodology broadly involves building contextual information such as the industry development profile, characterisation of groundwater assets such as water bores and GDEs, assessment of impacts on those assets through conceptualisation and modelling and, finally, monitoring and management strategies for those impacts.
- OGIA holds, and uses, statutory powers to seek any data and information that may be relevant for the assessment in the UWIR.

Chapter 3 Existing and proposed resource development in the Surat CMA

3.1 Preamble

This chapter provides information about the resource development activities in the Surat CMA – CSG, conventional oil and gas, and coal mining. Including production methods, as well as current and proposed production footprints, this information is used in developing conceptual understanding of groundwater impact pathways (Chapter 7) and groundwater level trends (Chapter 9), and to prepare an **industry development profile**, which is a key input to the regional groundwater flow model for making predictions of impacts.

3.2 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 petroleum leases (PL) or PLs under application (PLA) and all coal mining tenures that are either granted mining leases (ML) or mining leases under application (MLA).

Authorised tenure holder – 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 groundwater incidentally extracted during resource production or extraction processes; in the Surat CMA, these are the depressurising of coal measures for CSG production, dewatering of coal seams during coal mining, and production of conventional oil and gas.

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

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

3.3 Petroleum and gas (P&G)

3.3.1 Production methods

P&G is extracted from geological formations using both conventional and unconventional methods (Figure 3-1). 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 or siltstone (tight gas). CSG is typically extracted from relatively shallower depths of 200 to 1,000 m, while shale gas and tight gas are extracted from depths of 1,000 to 5,000 m.

Conventional oil and gas production in the Surat CMA dates back to the 1960s and is now approaching end of life. The main field is the Moonie oil field, which accounts for more than half of total conventional oil production in the Surat CMA, and the majority of groundwater produced by conventional oil and gas fields in the Surat CMA.

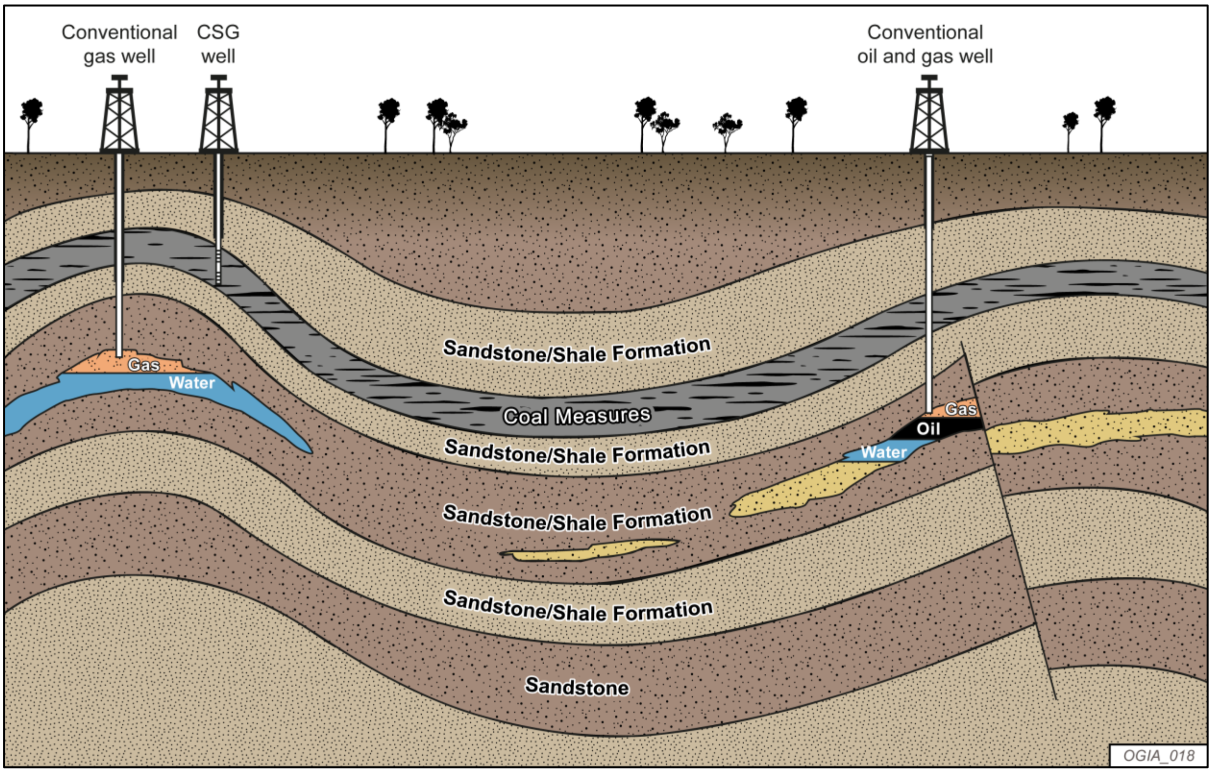

Figure 3-1: Schematic of oil and gas accumulation types

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 a rate that is necessary to maintain the pressure, until gas production becomes uneconomical. Initially, as shown in Figure 3-2, groundwater alone is extracted. Over time as the pressure drops, more and more gas is released and extracted together with water, leading to an increasing ratio of gas to water. The flow of water and gas together is known as 'dual-phase flow' (Morad, Mireault & Dean 2008).

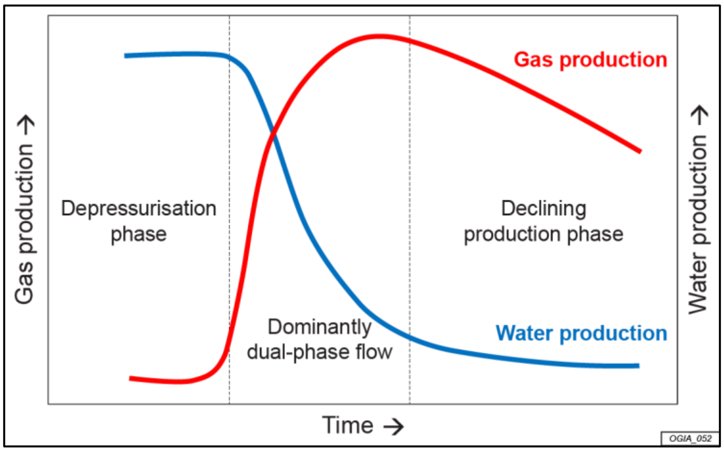

Figure 3-2: Typical gas and water flow profile during CSG production

In the context of groundwater, there are some fundamental differences between conventional and unconventional methods. The volume of associated water extracted using conventional production methods is much less than the volume of water extracted during CSG production and, 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 also peaks early, while for conventional production, water extraction increases over time before declining again in mature stages of development.

3.3.2 P&G tenures

The Queensland P&G Acts specify authorisations that can be granted for activities related to P&G exploration and production. The authorisations 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 tenure 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 relate to the authorised tenure holders.

Close to 18% of the CMA is covered by ATPs that have little or no activity in relation to water extraction. In the context of this report, the term **relevant tenures** is therefore used to refer to all tenures that are either granted PLs or 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 Department of Natural Resources and Mines, Manufacturing and Regional and Rural Development (DNRMMRRD) records all mining and petroleum tenure information in MyMinesOnline, which is the system used to administer resource authorities in Queensland; it is also used by resource authority holders to apply for, and manage, their tenure authorities. The GSQ Open Data Portal currently provides a single point of access for all data relating to tenures and geoscience that is primarily required to be submitted by tenure holders. DNRMMRRD has also established GeoResGlobe[4] for searching and displaying the available data from the GSQ Open Data Portal and MyMinesOnline.

The distribution of relevant tenures is shown in Figure 1-2; also shown, for reference purposes, are ATPs where environmental approval processes are completed, underway or intended. There are five major tenure holders operating CSG together with other tenure holders for conventional oil and gas production in the Surat CMA. The relevant tenures are grouped in different colours to represent authorised tenure holders:

<u>CSG</u>

- Arrow Energy, its subsidiaries and joint venture partners (collectively referred to as Arrow)
- Origin, its subsidiaries and joint venture partners including Australia Pacific LNG (collectively referred to as Origin)
- QGC, its subsidiaries and joint venture partners (collectively referred to as QGC)
- Santos, its subsidiaries and joint venture partners (collectively referred to as Santos)
- Senex, its subsidiaries and joint venture partners (collectively referred to as Senex)

[4] https://georesglobe.information.qld.gov.au

Conventional

- AGL, its subsidiaries and joint venture partners (collectively referred to as AGL)
- ADZ Energy, its subsidiaries and joint venture partners (collectively referred to as ADZ)
- Bridgeport, its subsidiaries and joint venture partners (collectively referred to as Bridgeport)
- Denison Gas, its subsidiaries and joint venture partners (collectively referred to as Denison)
- OGT Energy, its subsidiaries and joint venture partners (collectively referred to as OGT)
- other authorised tenure holders.

There have been several tenure transactions within the conventional tenures in the Surat CMA since the UWIR 2021. Most notably, Armour Energy tenures have been acquired by ADZ and OGT has acquired some of AGL's tenures in the southern CMA area. A notable CSG tenure transaction since the UWIR 2021 is Tri-Star becoming the tenure holder for the tenures collectively known as Gilbert Gully, located southwest of Cecil Plains. The PL applications for Gilbert Gully have also been withdrawn; however, the respective ATPs remain in place.

3.3.3 Production footprints and scheduling

A tenure holder may utilise a tenure area for production purposes and/or gas field development infrastructure. A tenure holder's plan for developing production fields within a tenure may vary over time, due to emerging information about reservoir dynamics, availability of reserves or changing market conditions. 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; some parts of a tenure may never be developed. The areas where production occurs at some stage are important in assessing the impact of the 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 as well as verified information that is available to DNRMMRRD 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 early 2025 and is shown in Figure 3-3. Footprints of production occurring at the time are shown in blue and planned CSG production areas, where production is proposed at any time in the future, are gold; also shown are areas where active conventional oil and gas production is currently occurring (brown) based on production information. For comparison, the development profile as of 2020 (provided in the previous UWIR 2021) is also shown. Further details are available in a separate document OGIA (2025).

The changes to the development profile since the UWIR 2021, in terms of both the CSG production footprint and planned timing of commencement, are shown in Figure 3-4.

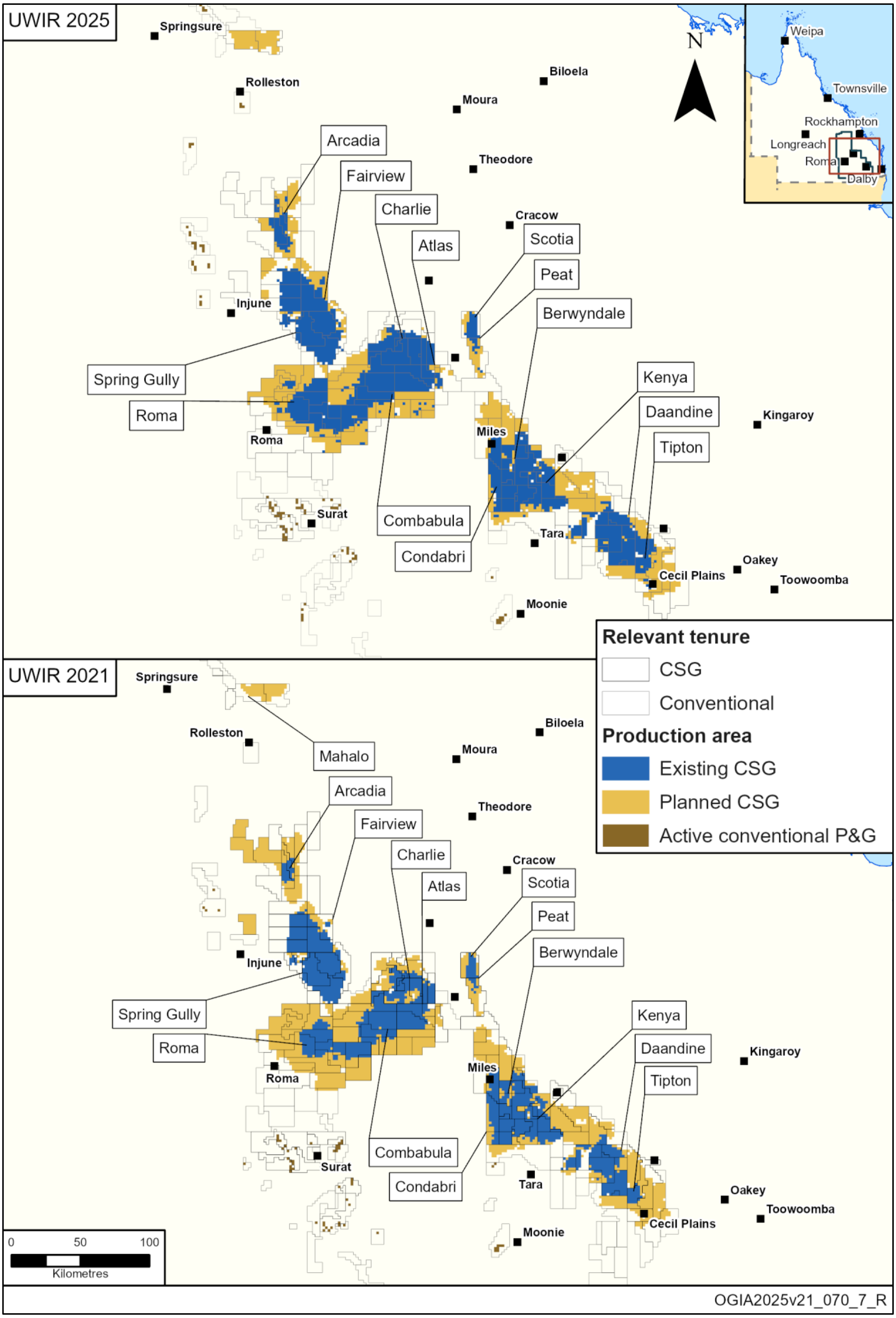

Figure 3-3: Distribution of production areas and their status (2025 and 2020)

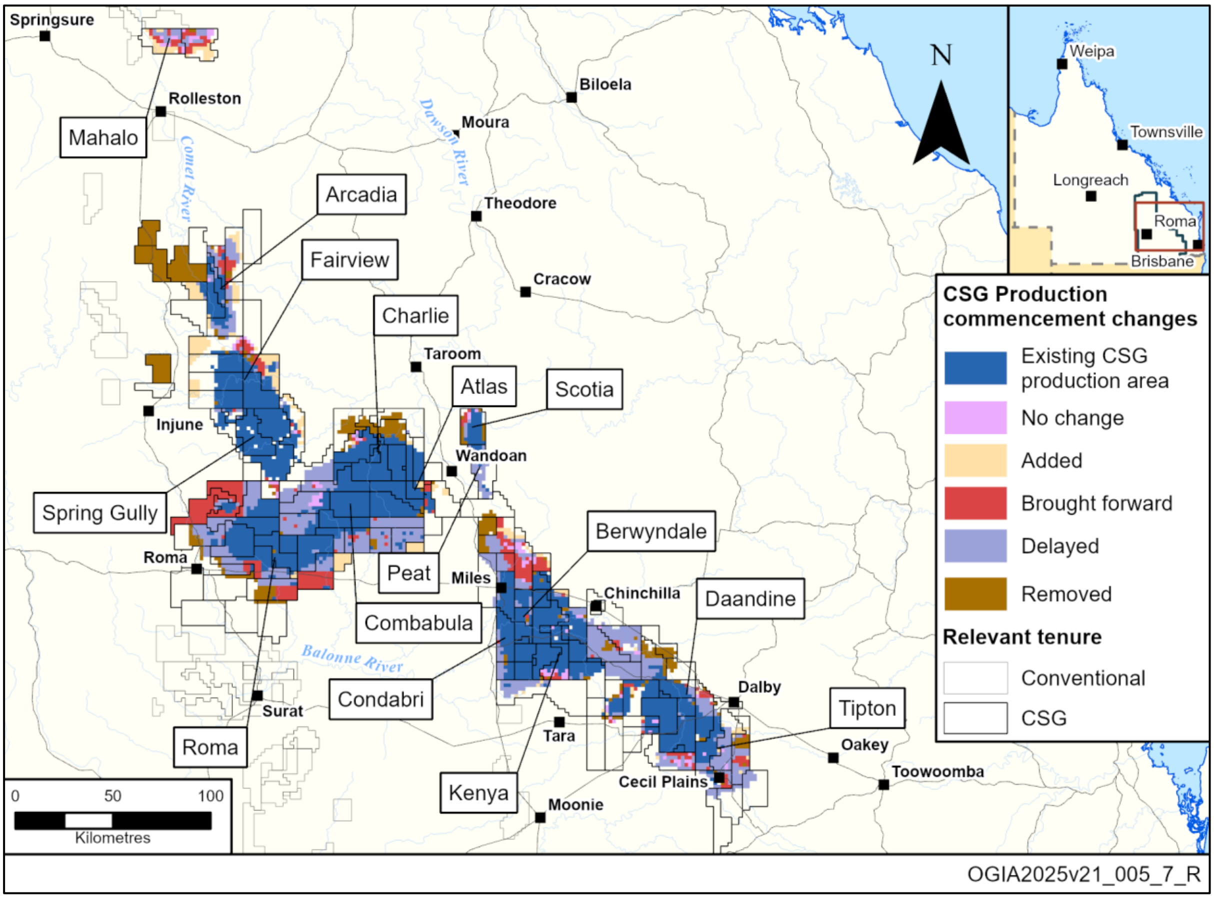

Figure 3-4: Changes in planned commencement timing of production areas from 2020 to 2025 with locations of key gasfields

Key changes are as follows:

- The total production area (existing and planned) has decreased by 5% to approximately 14,000 km^2.
- The total area that is in production ('existing CSG production area') has increased by 20% as more wells are brought online, mostly between Roma and Wandoan, and west of Dalby.
- Planned CSG production area has slightly reduced in the Santos gas fields north of Injune, in the QGC gas field northwest of Wandoan, and along the eastern flank of Arrow's development areas around the Condamine Alluvium footprint.
- Senex's planned production schedule has undergone major change – the commencement of western gas fields within the Roma North project have been brought forward while others have been rescheduled to later.
- Development across the CMA has generally been delayed, compared to previous scheduling. Some isolated pockets of development are brought forward, in three notable areas: Senex's gas fields in the Roma North area; the south-eastern portion of Santos's Roma gas field; and Arrow's gas fields north of Miles have all been brought forward by about 10 years.

Within the approved tenures, industry's actual development plans and scheduling change frequently in response to a multitude of factors relating to evolving understanding of the resources, reservoir conditions, business decisions and market conditions. These factors also affect the CSG well density and placement, as is reflected in Figure 3-5, which shows the changes in production area footprint and total number of existing and CSG wells reported in each UWIR since 2012.

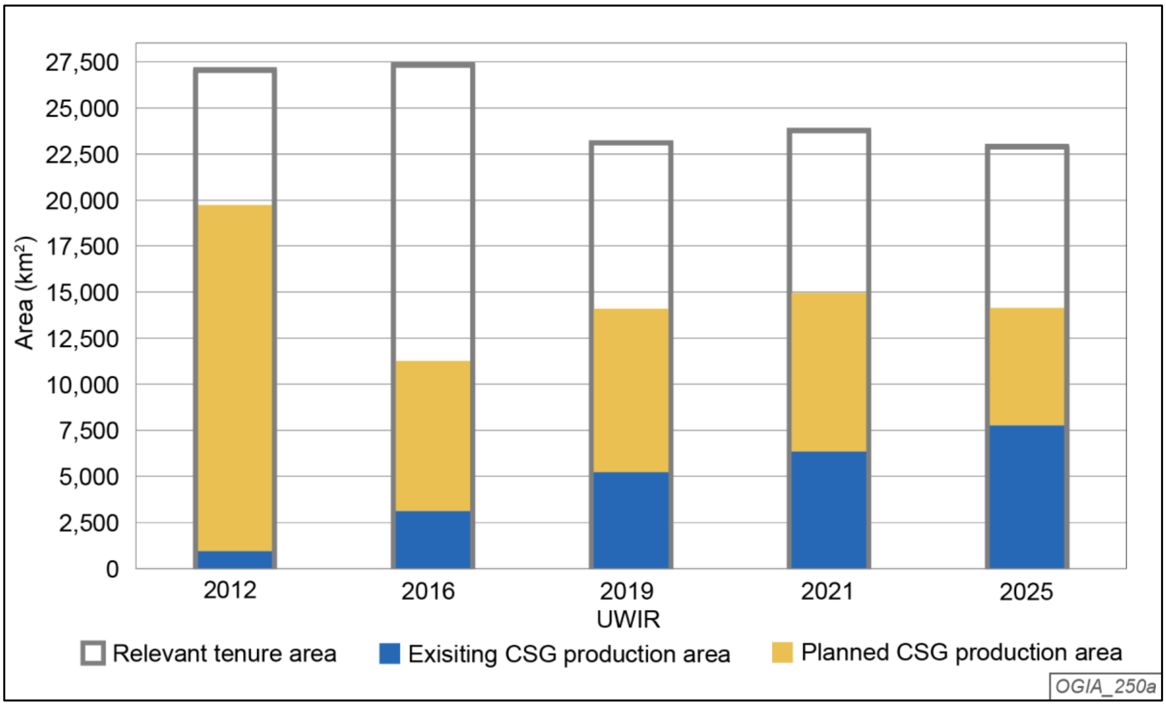

Figure 3-5: Trends in existing and planned production area over time

3.3.4 Number of CSG wells

CSG remains the dominant method for P&G production in the Surat and Bowen basins while conventional production is in decline, contributing about one per cent of the total production. As at the end of 2024, there were a little more than 11,000 CSG wells in the Surat CMA that either were producing gas or had been completed as production wells, waiting to be brought into production; 80% of these are in the Surat Basin and the rest are in the southern Bowen Basin. There are also 650 additional wells outside existing CSG production areas, constructed for exploration or testing purposes.

The number of existing CSG wells has increased by about 2,400 since the UWIR 2021. With the decrease in projected net production footprint, the total number of projected wells over the life of the industry has slightly dropped to 21,000 (Figure 3-6). This projected number is within the current overall approved number of wells of about 24,000 wells. The average well density is about 1.5 wells per km^2, although it varies from 1.2 to 2 wells per km^2 in the Surat basin, and 0.9 to 1.6 wells per km^2 in the Bowen Basin. The average scheduled production time for a well is currently about 30 years.

A 'cluster' is where multiple wellheads of directional wells appear on the surface – typically within 50 m of one another. There are approximately 1,000 directional or horizontal wells, of which 342 are single directional wells and the remainder are in 278 clusters of two or more well heads on the surface.

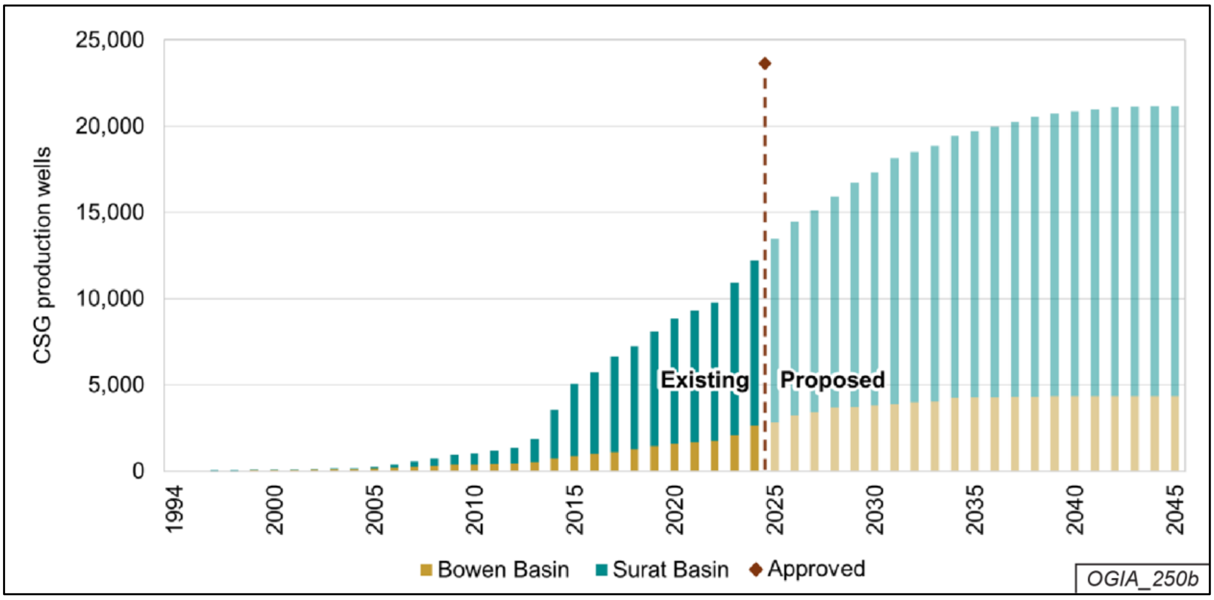

Figure 3-6: Existing and projected CSG wells in the Surat CMA

The number of P&G wells recorded in the GSQ Open Data Portal may be significantly greater than indicated 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 location, depth, tenure type and reported water production.

3.3.5 Associated water extraction by CSG and conventional oil and gas

Under the water monitoring strategy obligations (Chapter 12), monthly associated water extraction volumes are reported to OGIA for each well on a six-monthly basis. Total water production in the Surat CMA from existing CSG and conventional wells over time is shown in Figure 3-7, where the volumes are shown as rates in megalitres per year (ML/year).

Associated water production has remained around 52,000 ML/year over the past three years. Overall, the extraction rate has been progressively declining from a peak of around 67,000 ML/year in 2016 – partially due to reduction in extracted water over time from existing wells and the infilling of new wells in areas where partial depressurisation has already occurred. The majority (43,000 ML/year) of extracted water is in the Surat Basin. CSG associated water extraction in the Bowen Basin has remained relatively stable in recent years, at around 9,000 ML/year. The spatial distribution of CSG associated water extraction in 2024, presented in Figure 3-8, shows that the largest associated water extraction occurs from the Fairview, Talinga, Longswamp, Orana North, Tipton, Stratheden, Roma and Argyle gas fields.

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 760 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.

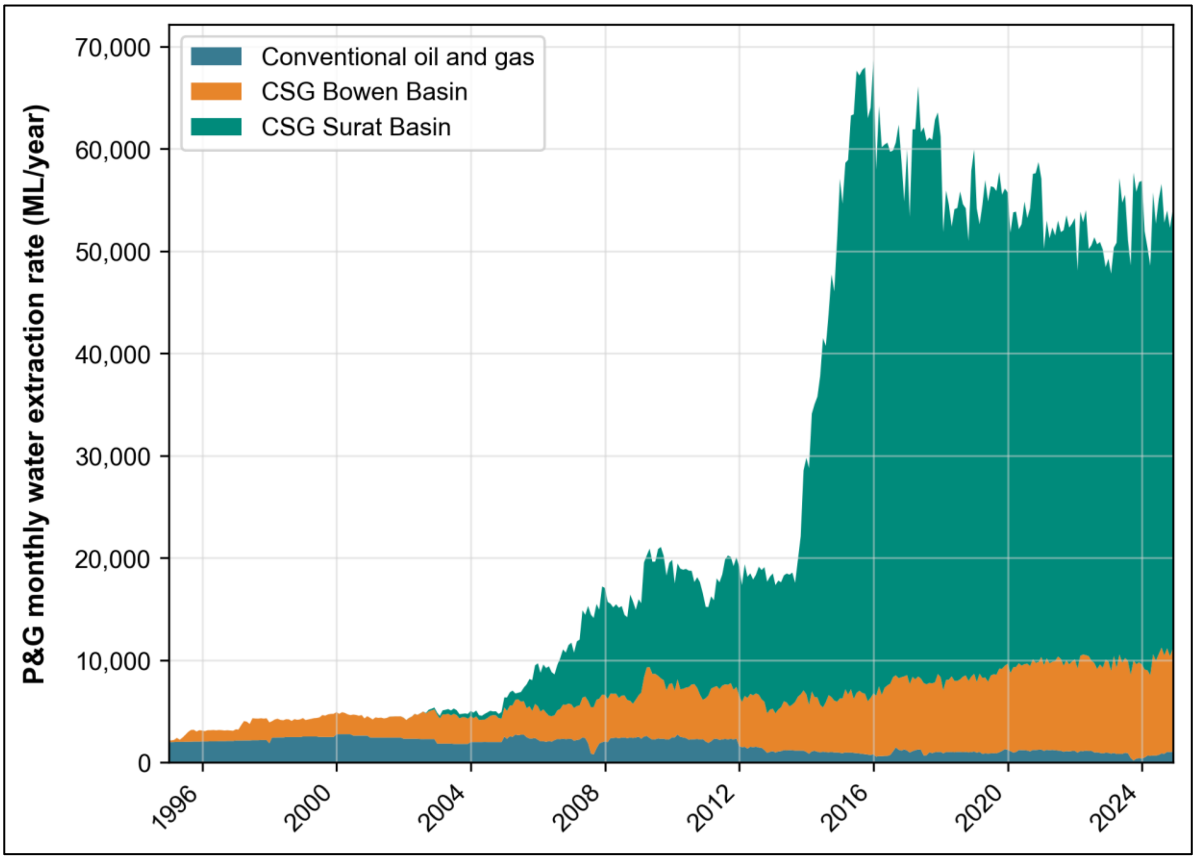

Figure 3-7: Historical P&G associated water extraction in the Surat CMA

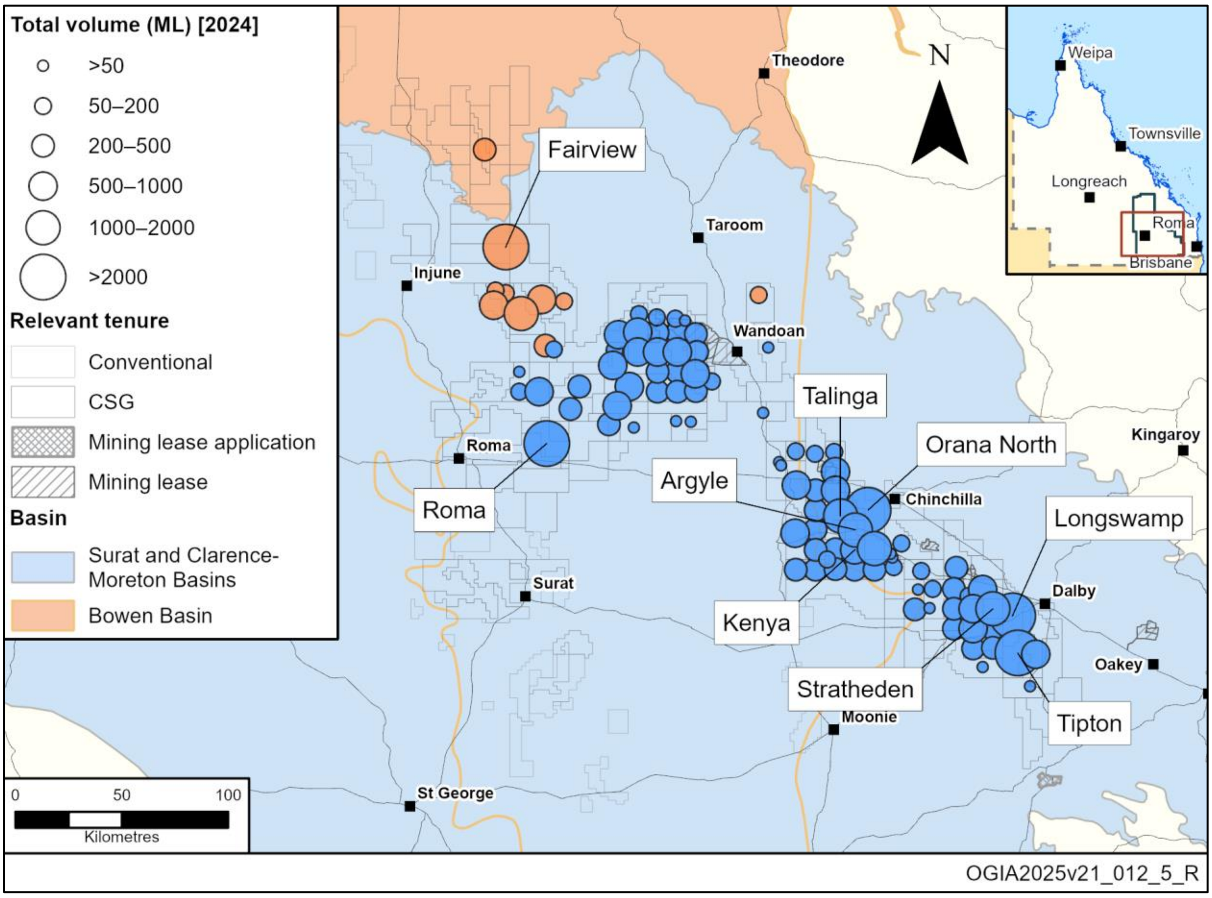

Figure 3-8: Spatial distribution of CSG associated water extraction

Between 2023 and 2024, OGIA undertook an initial desktop assessment of measurement methods, involving a review of the available data and interviews with tenure holders. Preliminary results suggest that almost all of the wells currently have magnetic flow (‘magflow’) meters to measure the volumes of water being extracted from each CSG well. The magflow meters assist the tenure holders to understand the gas-to-water ratio, which is beneficial to the tenure holder; they also provide accurate water extraction volumes.

3.4 Coal mining

3.4.1 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 3-9). An open pit is normally commenced through excavation of a small pit where the coal seams are accessible at shallow depth. The open pit is then progressively developed (as a box cut), first along the strike of the target formation, 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, 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.

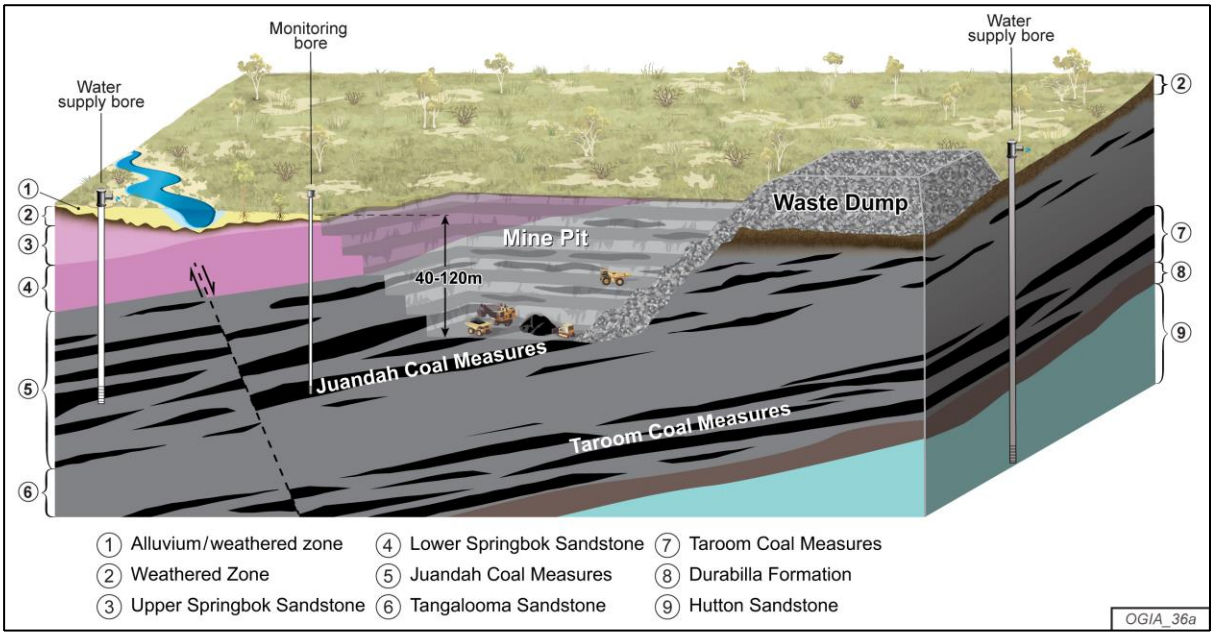

Figure 3-9: Schematic showing typical profile of an open-cut coal mine development

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 greater volumes of groundwater inflow 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 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.

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 mining operations, part of the open pit is left unfilled; this is 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.

3.4.2 Mining tenures

The *Queensland Mineral Resources Act 1989* (the MR Act) manages authorities relating to the exploration and development of mines for extraction of minerals and coal. 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 a defined resource. An ML allows for conducting larger scale mining operations. An appropriate EA is required before an ML can be granted.

3.4.3 Existing and proposed coal mines

There are seven existing and proposed open-cut coal mines in the Surat Basin, targeting coal seams in the Walloon Coal Measures (Figure 3-10). Four mines (New Acland, Cameby Downs, Kogan Creek and Commodore) are operational and one (Wilkie Creek) is currently in 'care and maintenance' mode. Approvals are either in place, or under consideration, for the establishment of two new mines (Wandoan Coal Project and Elimatta).

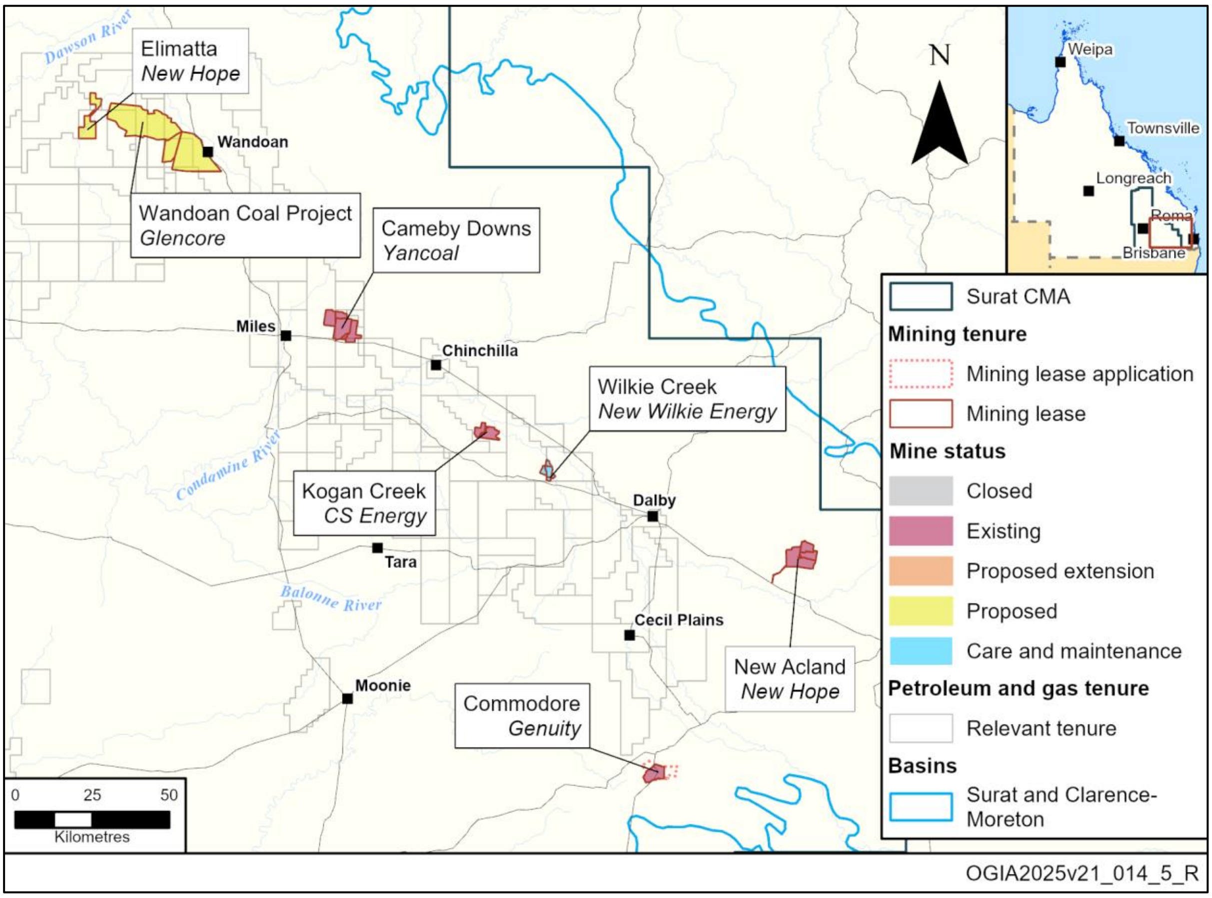

Figure 3-10: Location of coal mines in the Surat Basin

The Range, a proposed mine that was included in the UWIR 2021, has since been withdrawn. Key attributes of the seven existing and proposed mines are presented in Table 3-1.

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 pit progression scheduling based on the available coal resource and its quality, geotechnical considerations, necessary regulatory approvals, operating costs and market factors, as well as engineering and logistical considerations. The plans are therefore dynamic and often subject to change. Progression scheduling, excavation depth, backfilling and the final void comprise a critical set of information for the purpose of assessing groundwater impacts; this dataset not only affects the extent of impacts but also the timing of those impacts.

Table 3-1: Status and key attributes of coal mines in the Surat Basin

Mine	Status	Start–end	Target seam	Excavated overburden	Pit depth (m)[1]
Wandoan Coal Project (Glencore)	Proposed	2031–2105	Juandah Coal Measures (Kogan to Wambo)	Alluvium, Springbok Sandstone	24–60
Elimatta New Hope (New Hope Group)	Proposed	2029–2058	Juandah Coal Measures (Kogan to Wambo)	Alluvium, Springbok Sandstone	50–150
Cameby Downs (Yancoal)	Operational	2009–2053	Upper Juandah Coal Measures (Kogan, Macalister and Nangram)	Springbok Sandstone	40–110
Kogan Creek (CS Energy)	Operational	2000–2042	Upper Juandah Coal Measures (Macalister and Nangram)	-	40–60
Wilkie Creek (New Wilkie Energy)	Care and maintenance	1995–2030	Upper Juandah Coal Measures (Macalister)	-	30–60
New Acland (New Hope Group)	Operational	2001–2037	Taroom Coal Measures (Acland-Sabine, Waipanna and Balgowan)	Main Range Volcanics	30–60
Commodore (Genuity)	Operational	2001–2037	Taroom Coal Measures (Commodore)	Alluvium	15–50

Note:
1. Estimated pit depth

For the UWIR 2025, up-to-date information was sought by OGIA directly from coal mining tenure holders and interpolated to provide annual pit progressions. As an example, Figure 3-11 shows the current and end-of-life mine plan for two mines – Cameby Downs and New Acland.

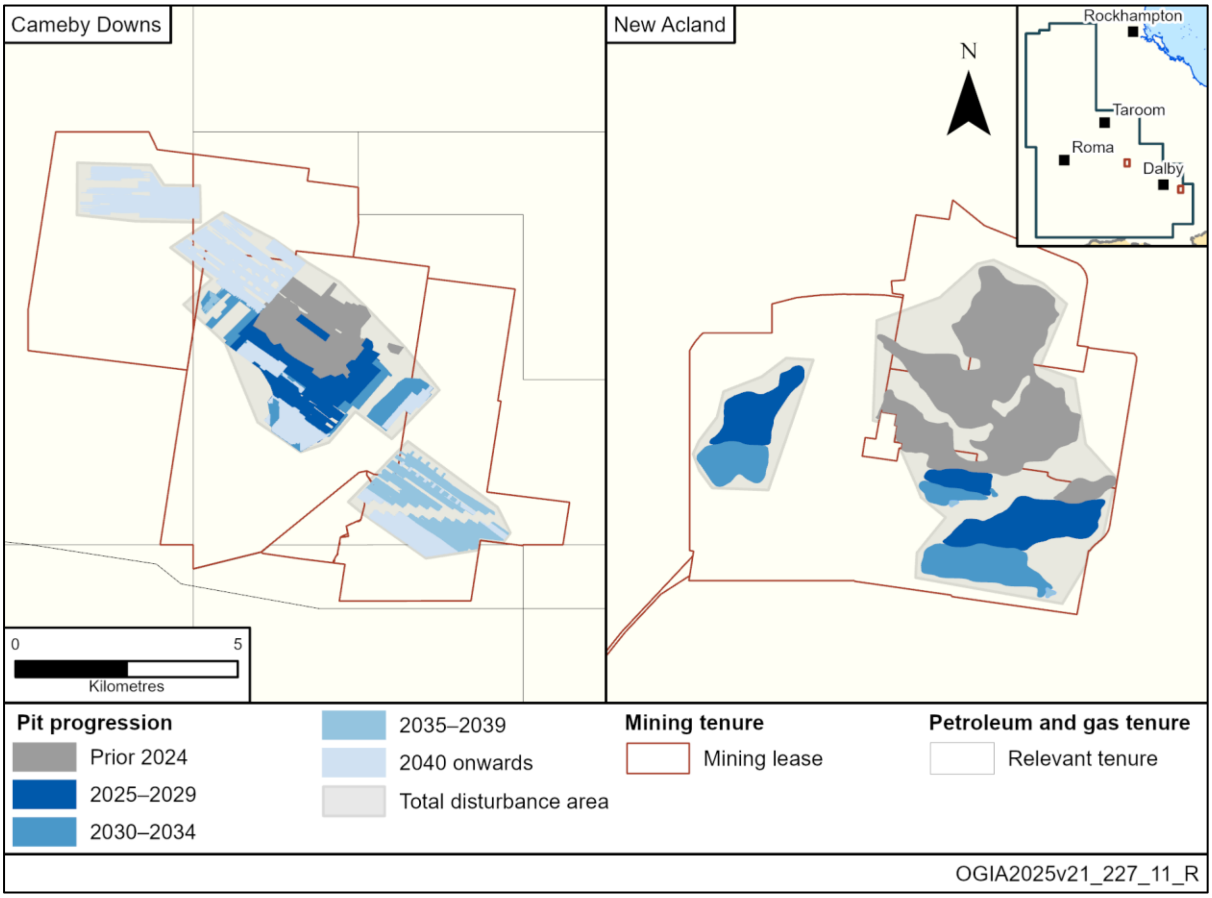

Figure 3-11: Cameby Downs and New Acland coal mining development plans

3.4.4 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 and rainfall into the mine pits are 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 – comprising a water balance method, a numerical groundwater flow method and an analytical groundwater flow method (Department of Natural Resources Mines and Energy 2020).

For the UWIR 2021, OGIA compiled reported volumes for the four operational coal mines in the Surat Basin – Cameby Downs, Commodore, Kogan Creek and New Acland. To verify reported volumes and modelled estimates, OGIA also estimated associated water volumes using an analytical equation and historical mine pit areas. The results suggest that the total associated water use by coal mines in the Surat Basin in 2020 was 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 (2023a). More recent associated water reporting held by DLGWV indicates the total volume for the four mines has averaged around 600 megalitres per year for 2022 to 2024.

3.5 Comparison of 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 3-2.

Table 3-2: Differences between 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 <150 mbgl[1]	Confined; well depths range from 80 to 800 mbgl[1]
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

Note:
1. mbgl = metres below ground level

3.6 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 is about 14,000 km^2 and has decreased by about 5% compared to the previous UWIR.
- As at the end of 2024, there are a little more than 11,000 CSG wells in the Surat CMA. This is likely to increase to 21,000 based on the current plans of approved development – about 5% less than reported in the previous UWIR.
- Current CSG water extraction (associated water) is around 52,000 ML/year.
- The majority (43,000 ML/year) of associated water extraction is from the Surat Basin, while in the Bowen Basin it has remained relatively stable in recent years at about 9,000 ML/year.
- The volume of associated water extracted using conventional production methods is much less than the volume of water extracted during CSG production.

- 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.
- There are seven existing and proposed open cut coal mines in the Surat Basin with a combined footprint of less than two per cent of the CSG footprint.
- Four mines are operational – New Acland, Cameby Downs, Kogan Creek and Commodore – while another, Wilkie Creek, is currently in ‘care and maintenance’ mode. Approvals are in place for the establishment of two large new coal mines – Wandoan Coal Project and Elimatta.
- Total associated water extraction by coal mines in the Surat Basin in 2024 has been less than 1,000 ML/year.
- Information about the CSG and coal mining development footprint and timing for existing as well as proposed development is compiled from the information provided by tenure holders as of January 2025. This information is used as input to the regional groundwater flow model to predict impacts and for the analysis of groundwater trends.

Part II Groundwater assets and environmental values

Chapter 4 Aquifers of the Surat CMA

4.1 Preamble

This chapter provides background information about the geological and hydrogeological systems in the Surat CMA. It includes definitions and descriptions of the key aquifers present. These references serve as the foundation for the rest of the document.

4.2 Geological context

Geologically, the Surat CMA incorporates parts of three large sedimentary basins: the southern part of the **Bowen Basin**, which contains some of the deepest units, the northern part of the **Surat Basin**, which sits on top of the Bowen Basin, and the western part of the **Clarence-Moreton Basin**, which is laterally continuous with the Surat Basin**.** Geological extents of these basins are shown in Figure 4-1.

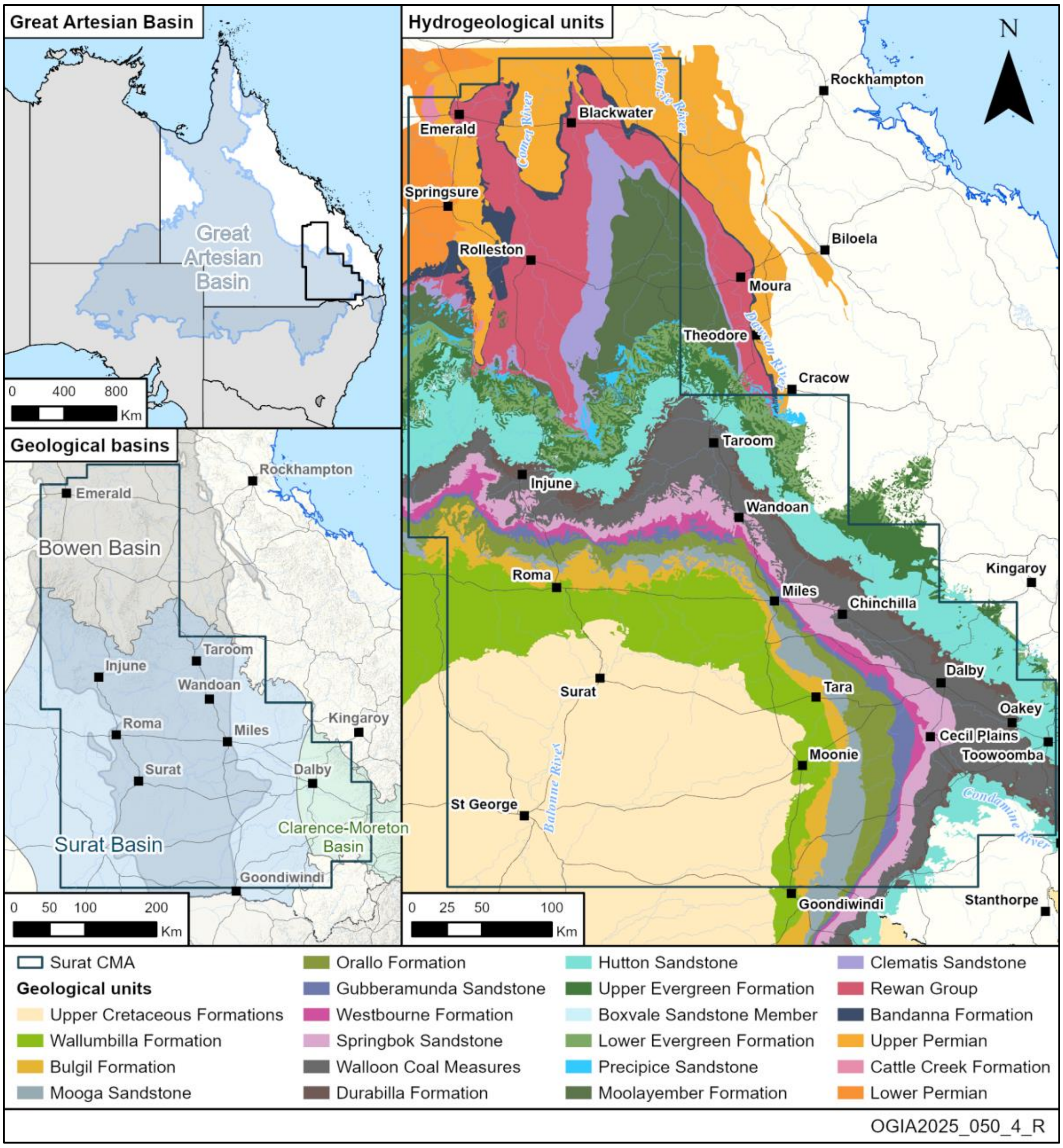

Figure 4-1: Great Artesian Basin (GAB), geological basins and subcropping hydrogeological units in relation to the Surat CMA

Detailed geological and hydrogeological context and boundaries are available in separate documents (OGIA 2019a, 2021b). Geological formations within the three basins primarily comprise layers of sandstone, siltstone and mudstone, deposited by rivers and lakes, with occasional marine influences. In contrast to a geological basin, a hydrogeological basin represents a set of aquifers that are somewhat connected in terms of groundwater flow.

A hydrogeological basin, or system, may span multiple geological basins, may combine more than one geological formation, or may split a single formation into two separate aquifers. For this reason, and in the context of the groundwater impact assessment, the rest of this report refers to groundwater systems and aquifers as hydrogeological formations, rather than as geological formations.

4.3 Geological formation vs aquifers

In the Water Act, an **aquifer** is a geological structure, a formation or formations that hold(s) water in sufficient quantity to provide a source of water that can be tapped by a bore. In the Surat CMA, most geological formations, including those that 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 variability in the formations' hydraulic properties (permeability and storage capacity).

In general, formations yielding high rates of water flow in bores have greater permeability and thickness (represented together as transmissivity) and those formations with relatively greater water level declines in response to groundwater extraction have lesser storage capacity. The variability determines if a formation has the overall characteristics of an aquifer or aquitard along a spectrum, characterised as follows in this report based on a similar classification by GA:

- **regional aquifer:** high transmissivity[5], high bore yields that are vertically and laterally consistent at a regional scale – for example, the 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 – for example, the Hutton Sandstone
- **tight aquifer:** medium to low transmissivity, low bore yields that are regionally inconsistent and exhibiting a high degree of heterogeneity – for example, the 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 – for example, the Walloon Coal Measures
- **tight aquitard:** predominantly low permeability, regionally extensive and thick – for example, the Westbourne Formation and Rewan Group.

A classification of all geological and hydrogeological units within the Surat CMA for the aquifer types is presented in Figure 4-2.

[5] 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.

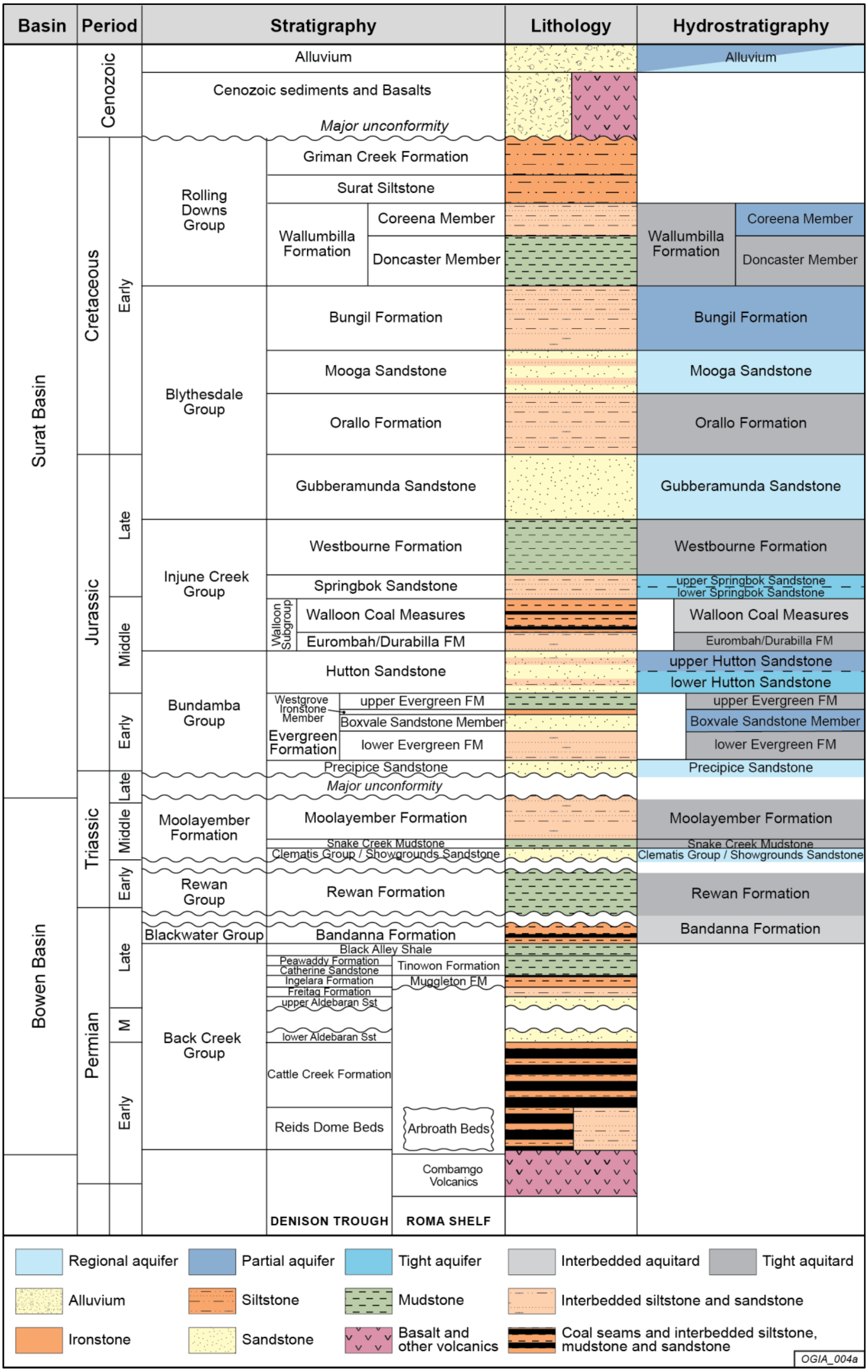

Figure 4-2: Generalised hydrostratigraphic classification in the Surat CMA

Consistent with the statutory definition of an aquifer in the Water Act, a more conservative and broader definition for aquifer is adopted in this report, for the purpose of assigning management strategies and the making good of water supply bores. This definition includes regional aquifers, partial aquifers, tight aquifers and interbedded aquitards, as described above. Interbedded aquitards are included because a number of water supply bores have historically been accessing water for stock and domestic (S&D) water supplies in formations considered interbedded aquitards.

4.4 Groundwater systems in the Surat CMA

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

- **Great Artesian Basin (GAB):** a Jurassic to Cretaceous hydrogeological basin comprising alternating aquifers and aquitards of various geological formations of Surat Basin sediments and their equivalents (4.4.1).
- **Bowen Basin:** Permian to Triassic aquifers and aquitards of the Bowen Basin formations underlying the Surat Basin (4.4.2).
- **Main Range Volcanics:** a Cenozoic consolidated surficial aquifer that mainly caps the Clarence-Moreton Basin along the Great Dividing Range (GDR).
- **Alluvium:** Quaternary unconsolidated surficial aquifers; mainly the Condamine and St George alluviums (4.4.3).

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 4-3.

4.4.1 The Great Artesian Basin

The GAB is the world's largest and deepest underground water system, comprising multiple layers of alternating sequences of aquifers and aquitards. Rather than being a single geological basin, the GAB is a hydrogeological basin comprising several component basins. These are collectively spread across 1.7 million km^2, covering four states and nearly one-fifth of Australia (Smerdon & Ransley 2012) (Figure 4-1).

In Queensland, the GAB covers about 65% of the state, with thickness ranging from less than 100 m near the basin's edge to more than 3,000 m in the centre. **Groundwater** in the GAB **moves very slowly** – 1 to 5 metres per year and is mostly under pressure (artesian). Isotopic validation by CSIRO using OGIA's groundwater flow model in 2016 indicates that, across most of the Surat CMA, the age of groundwater exceeds 1 million years (Siade et al. 2018).

In the Surat CMA, two geological basins – the Surat Basin and its equivalent, the Clarence-Moreton Basin – are hydraulically interconnected and are considered a single connected hydrogeological system. For reporting purposes, references to the Surat Basin encompass both sub-basins, unless otherwise specified. The main aquifers within the Surat CMA are the **Precipice Sandstone**, **Hutton Sandstone**, **Gubberamunda Sandstone**, **Mooga Sandstone**, **Bungil Formation** and their stratigraphic equivalents. These units are generally laterally continuous, have significant groundwater storage and permeability and are extensively used for groundwater extraction.

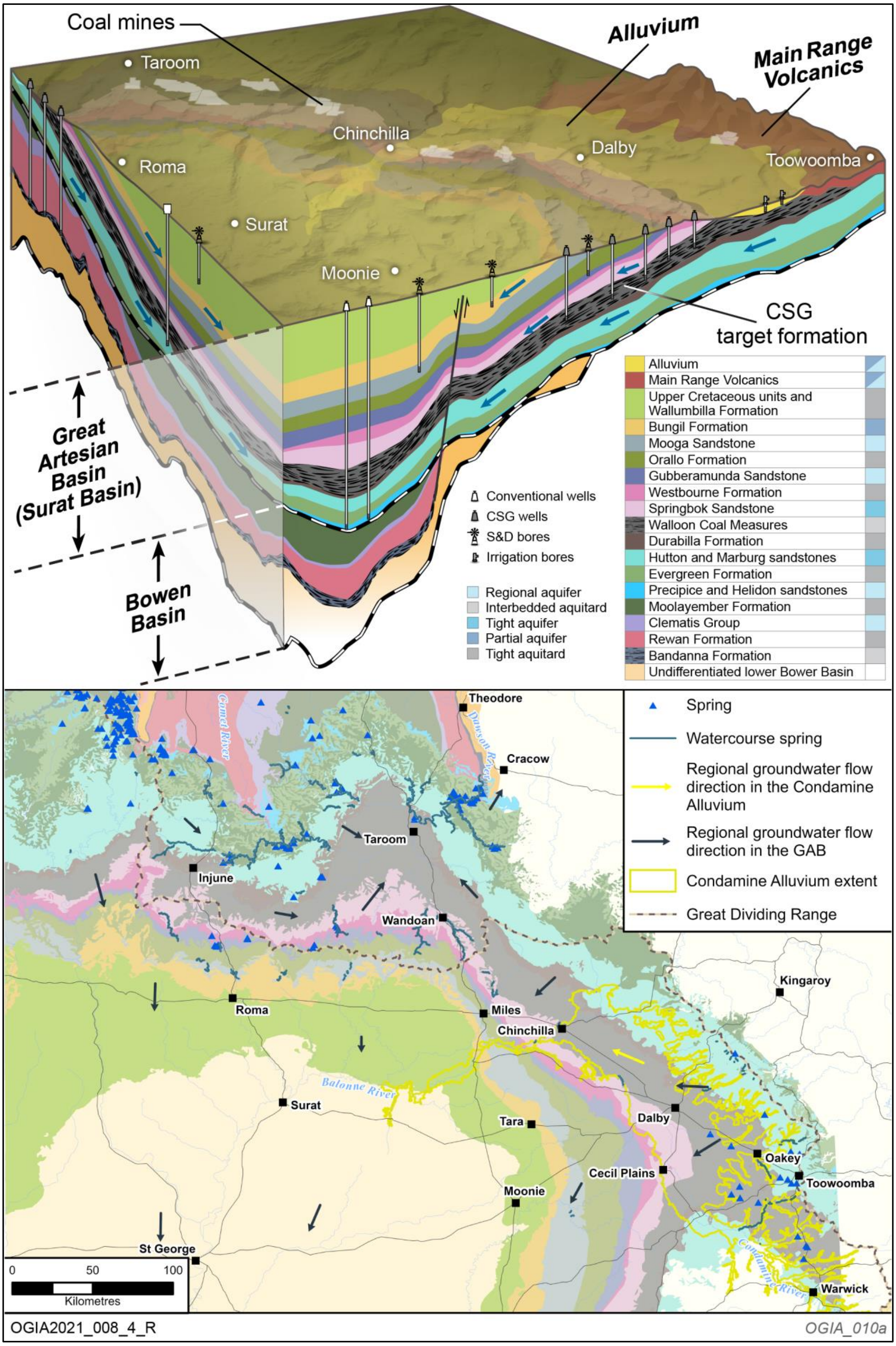

Figure 4-3: Representation of the main groundwater systems and geology in the Surat CMA

Recharge to aquifers primarily occurs by infiltration of rainfall and streams leakage into outcropping sandstone, mainly along the eastern margins of the basin, near the GDR. In the classical conceptual model of the GAB, groundwater recharge was understood to occur in outcrop areas, where formations were exposed to the surface. Groundwater flowing primarily along the formation towards the south, southwest and west, discharging naturally via springs and watercourses or, in some cases, flowing into the deeper system of the GAB to the southwest.

Recent studies by GA, OGIA and other research organisations, such as UQ, indicate more complex flow dynamics in the eastern GAB. North of the GDR, **groundwater flows** towards the northeast, discharging into the Dawson River catchment – a flow direction consistent with the topography but contrary to the south-westward dip of the stratigraphy. This pattern of flow continues to be represented in OGIA's groundwater assessment. The generalised groundwater movement within the GAB aquifers is shown in Figure 4-3, and groundwater flow directions for each key hydrogeological unit are presented in Chapter 9 and further details can be found in Erasmus et al. (2025).

Groundwater quality in most aquifers is generally fresh to brackish and suitable for stock purposes, with salinity averaging 1,520 milligrams per litre (mg/L). The Walloon Coal Measures generally has higher salinity of about 600 mg/L to more than 12,000 mg/L, with the median around 3,000 mg/L. Groundwater quality is spatially variable, due to the lateral and vertical variability in the lithology of the formation, variations in groundwater recharge and variations in the length of time the groundwater has resided in the formation.

4.4.2 The Bowen Basin

The sandstones of the **Clematis Group** are the primary aquifers for water supply bores in the Bowen Basin. While historically considered part of the GAB due to their artesian pressure and potential connection with Jurassic aquifers, recent studies (Smerdon & Ransley 2012; Ransley et al. 2015) suggest they are no longer classified within the GAB, though hydraulic interconnection with overlying GAB aquifers is still acknowledged. In Queensland, both the Bowen and Surat basins are jointly managed under the *Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017.*

The fine-grained siltstone and mudstone **Moolayember Formation**, where present, acts as a hydraulic barrier between the Bowen and Surat Basin sediments. The **Rewan Group**, a regional aquitard of low-permeability siltstone and mudstone, separates the Clematis Sandstone from the **Bandanna Formation**, which is targeted for **CSG** extraction. Deeper CSG targets, such as the **Cattle Creek Formation**, have limited data, but these units are generally fine-grained, well-cemented, and low in permeability.

4.4.3 Alluvial systems

The **Condamine Alluvium** is the most significant and most extensively developed alluvial aquifer system within the Surat CMA, primarily utilised for irrigation and town water supply, with minor use for domestic and other purposes. Bore yields are mostly around 10 L/s but vary significantly and can reach up to 60 litres per second (L/s) (Department of Environment and Resource Management 2009; KCB 2010a). Incised into the underlying Surat and Clarence-Moreton basin sediments by up to 120 m in the central area, the Condamine Alluvium comprises gravels and fine to coarse-grained channel sands interbedded with clays. The productive part of the alluvium is composed of individual channel sand and gravel units that are typically less than 20 m thick. In the east, a thick, clayey sequence of sheetwash deposits overlies the productive granular alluvium, causing the aquifer to be semi-confined in nature.

Recharge primarily occurs via infiltration from the Condamine River, with minor lateral contributions from adjacent bedrock and tributary alluvium. A widespread layer of low-permeability black soil, up to 10 m thick, restricts direct rainfall recharge.

Groundwater quality within the Condamine Alluvium is generally good, though salinity increases toward the alluvium margins and downstream areas due to longer residence times and potential interaction with basement formations. TDS concentrations range from 40 mg/L to over 16,000 mg/L, with an average of 1,500 mg/L (KCB 2010b).

There are **other shallow alluvial** groundwater systems – such as the St George Alluvium and the Dumaresq River Alluvium – that cover a large footprint. These systems are well outside of the CSG development areas or are vertically isolated from other formations by hundreds of metres and hence are of little significance for the impact assessment in this UWIR.

4.4.4 Basalts

The **Main Range Volcanics** represents the most significant aquifer within the Tertiary basalt systems, widely utilised for irrigation, S&D and town water supply purposes. These basalt units typically range in thickness from 10 to 30 metres, with bore yields varying considerably – from 5 to 50 L/s, averaging around 20 L/s. Groundwater quality is generally good, with TDS averaging 900 mg/L and ranging between 50 and 4,000 mg/L.

Tertiary basalts are also present in the northern parts of the region, where they overlie Bowen Basin sediments. Aquifers in these northern basalt units tend to be less productive, however, compared to those within the Main Range Volcanics.

4.5 Summary of groundwater systems and aquifers

- The Surat CMA incorporates parts of three large sedimentary basins: the deepest southern part of the Bowen Basin, the northern part of the Surat Basin, and the western part of the Clarence-Moreton Basin.
- Geological formations forming the GAB primarily comprise layers of sandstone, siltstone and mudstone, which are classified – based on their groundwater characteristics – as regional aquifers, partial aquifers, tight aquifers or interbedded aquitards.
- The Precipice Sandstone, the Hutton Sandstone and the Gubberamunda Sandstone are some of the major aquifers in the Surat Basin.
- The Walloon Coal Measures which is the target for CSG and coal mining in the Surat Basin, is an interbedded aquitard with relatively saline but often usable water.
- The Condamine Alluvium sits on top of the GAB and is the most significant and most extensively developed alluvial aquifer system within the Surat CMA, primarily utilised for irrigation and town water supply, with minor use for domestic and other purposes.

Chapter 5 Water bores and groundwater use

5.1 Preamble

Water bores are key groundwater assets and receptors potentially impacted by resource development activities. This chapter provides a summary of where those water bores are in the Surat CMA, how many there are, and how much groundwater they have been extracting for water supply. Information about water bore location, construction details, source aquifers and estimated groundwater use supports the subsequent assessments presented in this report, including conceptualising pathways for groundwater impact (Chapter 7), calibration of the groundwater flow model (Chapter 8), and identifying water bores likely to be impacted (Chapter 11).

5.2 Terminology

Aquifer attribution – the aquifer(s) from which a water bore may be accessing water. Also referred as the 'source aquifer', it is an interpretation of the aquifer(s) intersected by the bore screen and hence providing a source of water for that bore.

Associated water – groundwater extracted from CSG wells and dewatering of mines: in the process of depressurisation of coal measures for coal seam gas production, for production of conventional oil and gas, or from coal seam dewatering bores for the safe operation of coal mines. It can be considered a byproduct of the extraction of the main economic resource.

Groundwater use – groundwater taken under a statutory authorisation, water licence or entitlement managed through Chapter 2 of the Water Act; examples include 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; for example, camp water supply and road construction.

5.3 Source of information about water bores

In Queensland, information about a water bore's location, depth and construction is recorded by the water bore driller at the time of drilling and is supplied, as required under their driller licences, to the bore owner and to DLGWV. The data is recorded in the 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 of potentially affected water bores have been progressively undertaken by resource tenure holders (refer to Chapter 11 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 to OGIA. In addition, bore data is collected as part of various hydrogeological investigations – by OGIA and resource tenure holders – and is progressively updated in the GWDB, as relevant.

5.4 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 photography analysis, as well as field investigations and discussions with bore owners where necessary. Bore identifiers – registered numbers (RN) – are matched with verified bore locations, bore status (section 5.5) and source aquifers (section 5.6). Given the large number of water bores in the Surat CMA, the level of effort in verifying the information is prioritised based on the proximity of bores to existing and planned resource development. For example, priority is given to water bores located closer to CSG production areas and likely to be impacted sooner. The verified information is also progressively updated in the GWDB.

There are some inherent and major challenges in verifying a water bore's depth, its unique identifier (ID) and construction – all of which are critical to establishing its purpose, operational status, groundwater extraction and source aquifer. Since water bores are subsurface features with only the 'bore heads' or 'well heads' visible on the surface, that set of information relies upon the data collected at the time of drilling. If the information is not available or is missing, particularly for the older bores, then it is nearly impossible to determine it later unless machinery is physically mobilised to the location. This procedure may also involve removal of existing pumping infrastructure and logging or imaging of the bore, which is a cost-prohibitive exercise. Verification is also difficult if a bore ID is missing or incorrectly recorded. Both of these circumstances – missing depth and construction information, bore ID or incorrect locations recorded – are common occurrences for water bores in the Surat CMA, which leads to some significant inherent ambiguities in water bore information.

5.5 Tracking physical status of water bores

The status of each water bore is recorded in the GWDB as either 'existing (EX)', 'abandoned and destroyed (AD)' or 'abandoned but usable (AU)'. It can be that the physical status of a water bore may change over time while 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 DLGWV. More contemporary bore status information may also be recorded elsewhere: in DLGWV's Water Management System (licensing and development permit database); in decommissioning information provided by resource tenure holders directly to OGIA from their make good arrangements; or, in some instances, in data collected directly by OGIA through field visits or verbal communications.

Receiving bore status information for a single bore from different sources can lead to inconsistencies. OGIA has consequently developed a set of criteria and a 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 11. Key criteria include the following:

- Water bores with no status information available are taken to be in existence.
- Water bores with decommissioning information are taken to be abandoned.
- A 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 if no other status information is available.
- Where there is an inconsistency between a bore's status in the GWDB and in 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).

5.6 Attributing source aquifers to water bores

Correct identification of the aquifer tapped by a water bore is critical information required to support the assessment in this UWIR. It is used for identifying potentially affected water bores within impacted aquifers (section 11.4.1), as an input for calibration of the numerical model (section 8.9), for analysis of groundwater level trends (Chapter 9) and for assigning groundwater levels to specific aquifers.

The process of *aquifer attribution* is the determination of the aquifer tapped by a water bore. The process involves the compilation and verification of bore location and construction details to determine the section of the bore (in terms of the depth or 'elevation') that is 'screened' or open, then intersecting this underground elevation with the geological formations from the geological model at the same location. There are significant challenges in implementing this fundamental process, such as: uncertainties in recorded bore locations and matching RNs; lack of information on bore depths and screened depths (in the Surat CMA, there are about 1,100 water supply bores without depth information); 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, leading to uncertainty in aquifer attribution.

There is a large number of water bores in the Surat CMA – about 31,000 that are either existing (EX) or abandoned but useable (AU). OGIA has therefore developed a methodology that is largely automated, complemented with manual site-specific review for specific areas of interest, such as where impacts are anticipated in the short term (refer to Smallacombe et al. (2024) for more details). Assumptions are made where necessary, such as those listed below:

- Where information about the depth is available but not specifically the screened depth, the screened depth is assumed to be the same as other water bores constructed to similar depths and drilled at similar times in that area.
- Where no depth information is available, a bore is assumed to be screened in the aquifer that is most frequently intersected by other water bores within five kilometres.
- 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.

Given the constant improvement to input datasets, such as bore records and the geological model, aquifer attribution has changed over time. OGIA's methodology for aquifer attribution has also continued to evolve since 2012 to address the limitations of the data and evolving knowledge, which has gradually improved the estimation of the source aquifers over time, subject to some inherent ambiguities arising from the underlying data as described in the earlier sections.

For the UWIR 2025, the aquifer attribution workflow has been updated to incorporate the new and more detailed Condamine geological model as an input. Another change implemented across the whole of the Surat CMA is to apply an assumption that where no bore construction information is available, neighbouring bores with similar depths tap the same aquifer.

5.7 Distribution of water bores

As bores are continuously being drilled and reported in the GWDB, the total number of water bores keeps increasing with each successive UWIR. A total of about 6,000 bores have been drilled and completed in the Surat CMA since the first UWIR in 2012, while about 1,000 have been decommissioned during the same period (Figure 5-1).

In earlier UWIRs, the number of water bores was reported for the entire CMA – approximately 29,500; however, more than half of those bores were distant from CSG production areas or located outside the impact footprint. Beginning with the UWIR 2021, the number of bores is now reported within an **area of interest**, providing more relevant information about potentially affected bores. In the UWIR 2021, the area of interest covered the entire active resource development footprint, with a 15-km buffer around it because impacts from development are considered unlikely to extend beyond this buffer. A similar approach is used for this UWIR.

The updated development footprint means that a total of about 11,900 existing or abandoned but useable water bores are within the area of interest, compared to the 8,000 reported in the UWIR 2021. Of those 11,900 bores, about 7,000 are accessing groundwater from the GAB formations (the Surat and Clarence-Moreton sub-basins), 4,200 from the Condamine Alluvium and the Main Range Volcanics and the remainder sourcing water from the Bowen Basin. The distribution of water bores in the Surat CMA is presented in Figure 5-2.

The spatial distribution of water bores reflects the availability of reliable groundwater supplies at the shallowest possible depths, combined with the demand. 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; these tend to be generally located away from CSG production areas. 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.

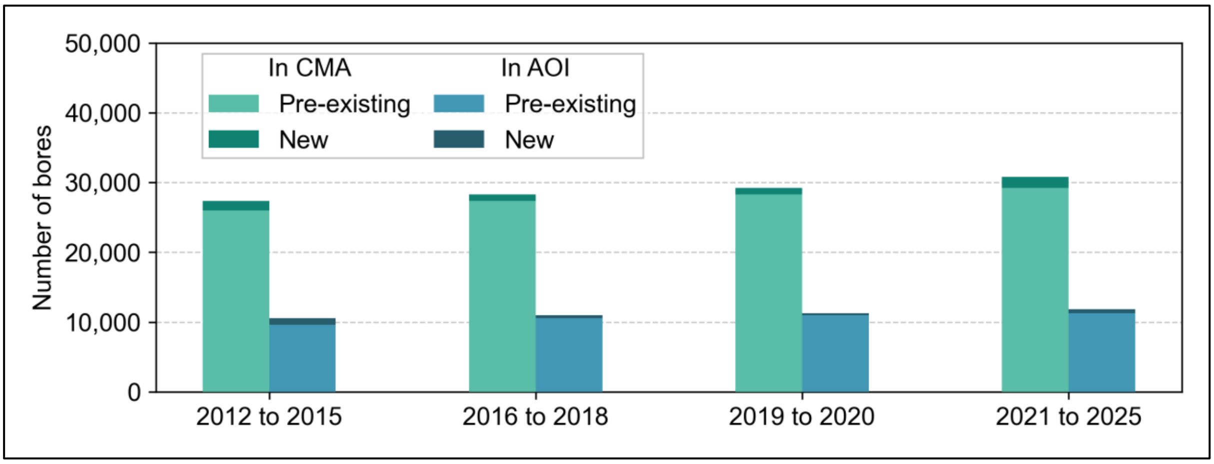

Figure 5-1: Water bores drilled and completed in the Surat CMA between UWIRs

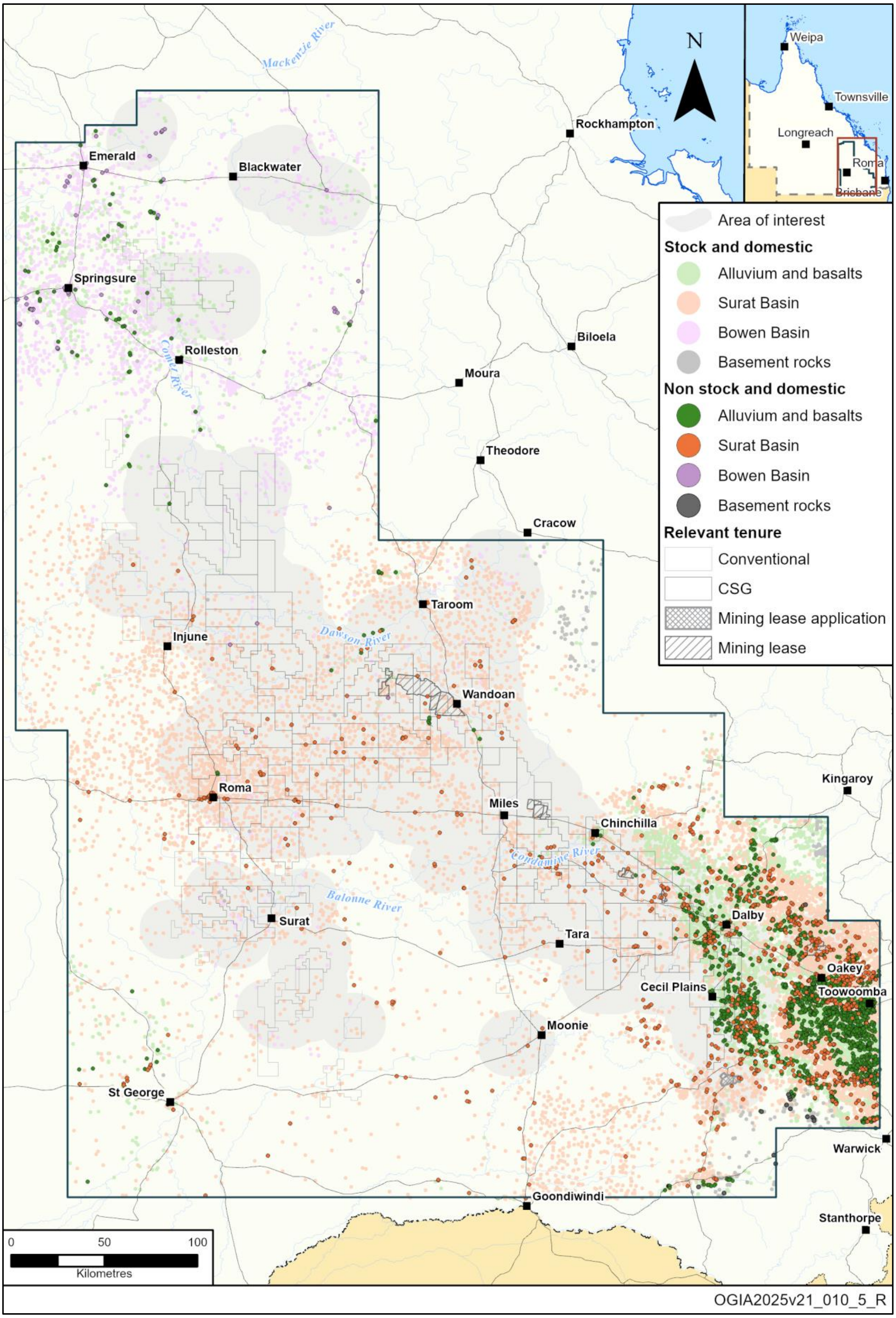

Figure 5-2: Distribution of water bores in the Surat CMA

5.8 Groundwater use from water bores

Groundwater use is a reference to water that is taken for agricultural, irrigation, industrial, town water supply and S&D purposes from water bores. This section provides an overview of the estimated groundwater use in the Surat CMA. It is estimated because the majority of the water bores are not metered.

5.8.1 Authorisation and reporting

Licensing requirements and the volume of water that can be taken under an authorisation depend on the purpose of the bore and the water planning area in which it is located. Water resource management priorities may differ between water planning areas. Within the Surat CMA, relevant water plans are for the GAB, Condamine and Balonne, Burnett, and the Border Rivers and Moonie catchments.

In the area of interest, the majority of groundwater use is under the *Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017* and the *Water Plan (Condamine and Balonne) 2019*, for which the authorisation requirements are summarised as below:

- In the Surat and Bowen basins, a water licence is required to take groundwater, except for domestic use.
- Stock and domestic uses are both exempt from licencing in some areas such as the Eastern Downs sub area, within the Condamine Alluvium and the Main Range Volcanics.
- For stock use, there is no volumetric limit because the volume ('take') is considered to be limited by the stock-carrying capacity.
- For all other purposes, including stock-intensive, a water licence has a specified annual volumetric limit ('entitlement volume').
- New water bores may only be constructed in accordance with the requirements of relevant water plans.

DLGWV administers the licensing provisions of the Water Act. Information about water licences, authorised volumetric limits and purposes are recorded in DLGWV's Water Management System, along with metered uses, where recorded.

5.8.2 Estimated volumes of groundwater use

5.8.2.1 Approach

The requirement to measure and report groundwater use in the Surat CMA varies. S&D water use does not require metering, while for other uses, the metering is still limited; consequently, metering data is available for fewer than 1% of all water bores.

In the absence of metering data, indirect methods to estimate groundwater use are applied. A method first developed by OGIA in 2012 has since been progressively refined based on additional data and information. Available metering data was initially used to reconcile groundwater use estimates and build bounds of uncertainty in the estimation. OGIA has since invested significant effort to improve the method for the estimation, as published in Singh et al. (2020) and Smallacombe et al. (2024).

The underlying principle for estimating S&D use 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.

For non-S&D uses such as irrigation, town water supply and industrial use, metering data is used where available – such as in the Condamine Alluvium. Where metering data is not available, groundwater use is estimated by applying a percentage to the entitlement volume derived from the metering data from bores with available metering data. This indicates that use is generally 70–90% of the entitlement volume for irrigation, agricultural and town water supply, generally 90% of the entitlement volume for stock-intensive, and about 50% of the entitlement volume for industrial use.

OGIA's recent improvements to the method (OGIA 2024) enhanced spatial and time-varying estimates, utilising the data and analysis from a collaborative bore-metering program run by UQ and OGIA (Smallacombe et al. 2024) and incorporating a spatiotemporal rainfall dataset. As part of the bore-metering project, water meters were installed on a total of 48 bores on 34 properties. Data collected from the meters was processed to produce annual volumes. Interview with bore owners revealed information on surface water availability, livestock numbers, bore usage and de-stocking rates. The metered volumes and interview data were analysed and compared with OGIA's estimates, resulting in an improved alignment between estimated and measured time-varying use.

Estimated volumes for individual water bores are assigned to the aquifers into which the bores are screened (section 5.6), which in some cases may be different from 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, most of the water accessed by a bore screened across the Springbok Sandstone, Walloon Coal Measures and Hutton Sandstone is likely to be from the Hutton Sandstone, because the permeability is higher in that formation.

5.8.2.2 Results

The estimated groundwater use and the number of water bores for the area of interest in the Surat CMA are summarised in Appendix B (Table B-1 and Table B-2) and presented as a chart in Figure 5-3. The spatial distribution across the Surat Basin, averaged for every 75 km^2, is presented in Figure 5-4 and the estimated total water use over time, grouped by major groundwater system, is presented in Figure 5-5.

Slight differences in water use estimates, compared to the UWIR 2021, reflect the updated methodology used for the estimation, as detailed earlier. Some relevant observations from the water use data are as follows:

- Estimated groundwater use within the area of interest in the last two decades has averaged around 58,000 ML/year, of which about 32,000 ML/year (55%) is from the alluviums and about 22,000 ML/year (38%) from the GAB.
- The Hutton Sandstone is the most developed aquifer in the GAB by water use volume, followed by the Precipice and Gubberamunda 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 80% of the groundwater use from the alluvium and basalts is for non-S&D purposes (predominantly irrigation).

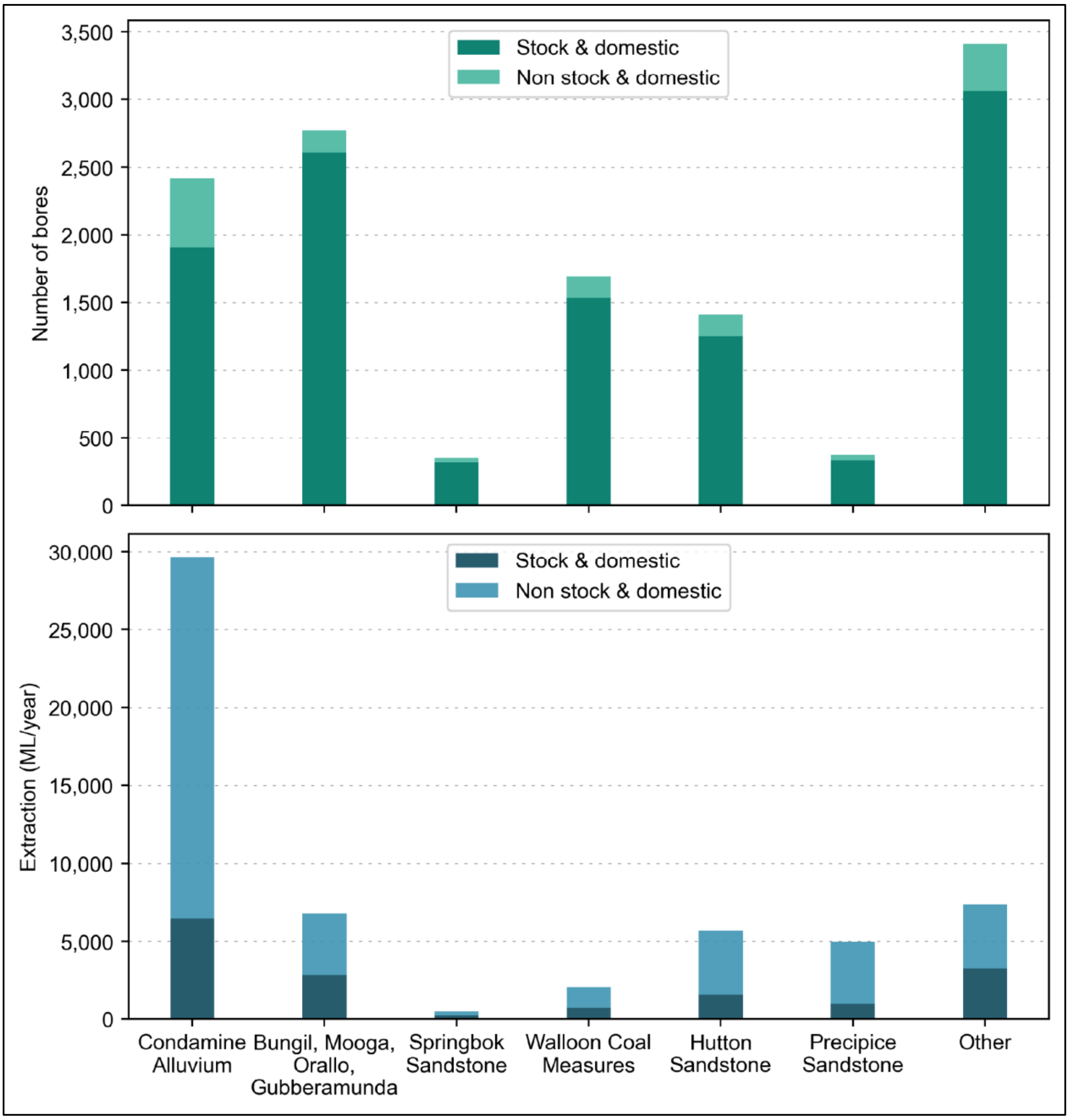

Figure 5-3: Number of water bores in the area of interest (top) and groundwater use from those bores (averaged 2004-2024)

- 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 (section 4.3).
- 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.

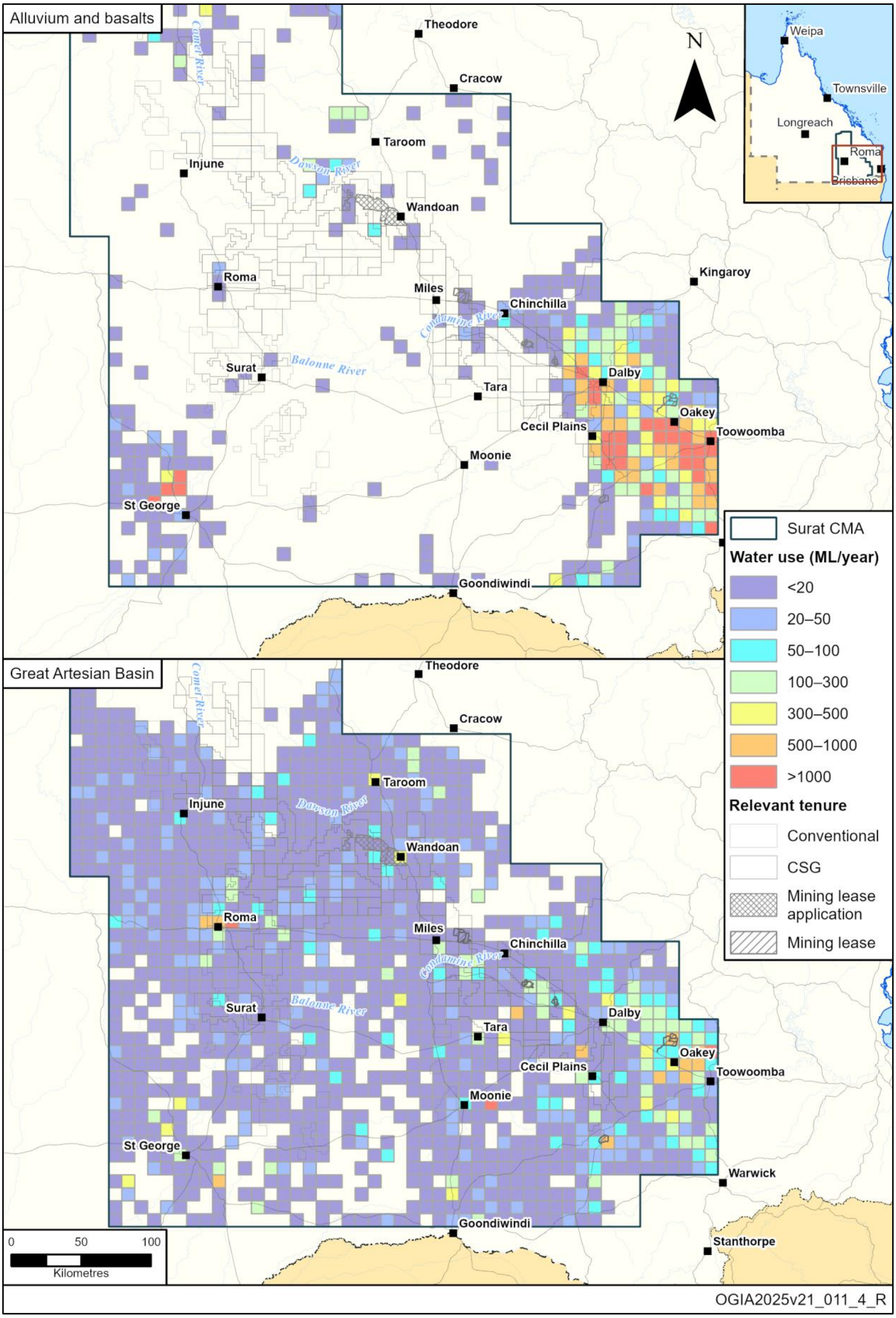

Figure 5-4: Spatial distribution of groundwater use in the alluvium, basalts and GAB (averaged 2004-2024)

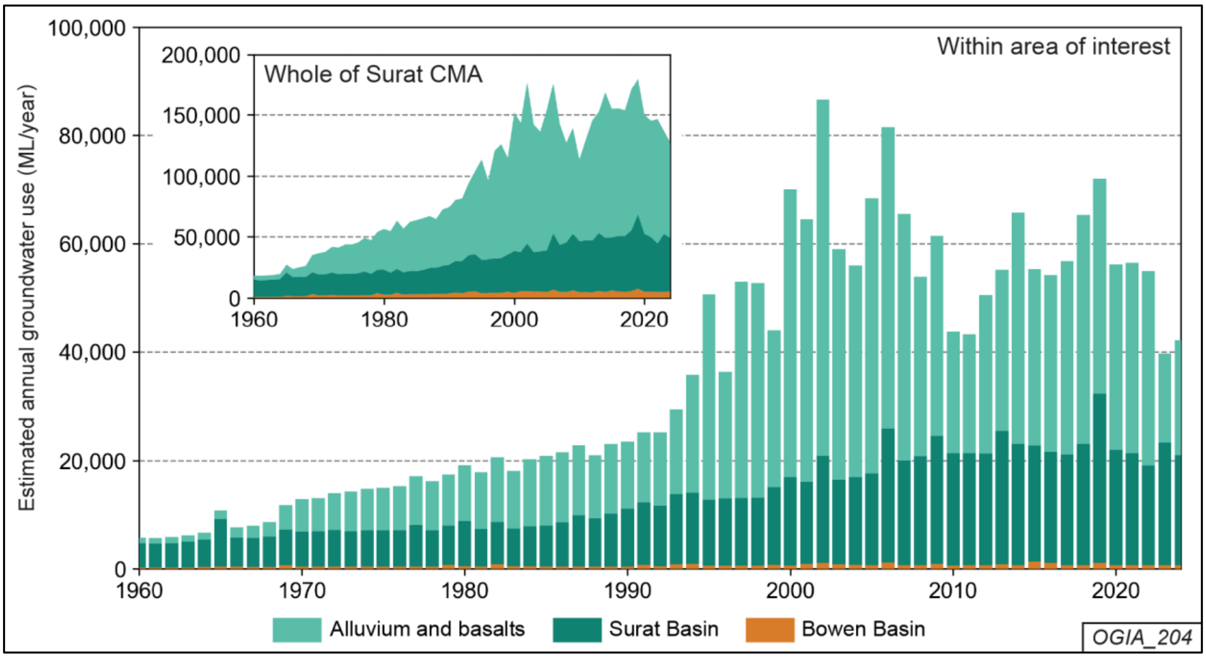

Figure 5-5: Growth in consumptive water use, grouped by major groundwater systems

5.8.3 Groundwater quality

Groundwater quality varies within the major water supply formations. The primary influencing factors are formation mineralogy, proximity to areas where the formation is recharged and groundwater flow dynamics within the formation. A summary of the up-to-date groundwater chemistry data for the major water supply formations across the Surat CMA is provided in Appendix B (Table B-3) and shown in Figure 5-6.

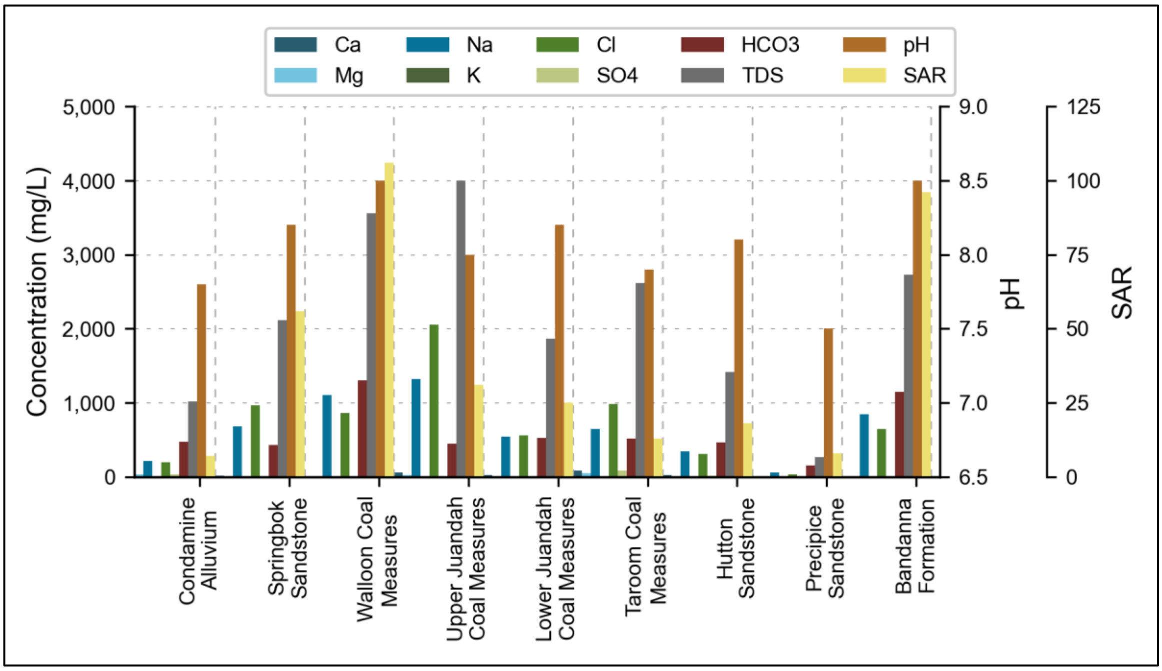

Figure 5-6: Typical (median) water quality of water bores in the Surat CMA

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

1,500 mg/L and sodium adsorption ratio (SAR) less than 20. 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 outside these ranges, irrigation application would be detrimental for the majority of crops (Dewis & Freitas 1970).

5.9 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. Since 2021, a water licence has been 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 2023 was around 400 ML/year, with a declining trend. Most of this water is extracted from the Precipice and Gubberamunda sandstones. Historically, the volume peaked in 2013, at around 1,700 ML/year. 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. Since commencement of the scheme in January 2015, more than 48,000 ML has been reinjected into the Precipice Sandstone. The reinjection rate has declined to the current level of about 4,500 ML/year.

5.10 Summary of water bores and groundwater use

- Information about water bores is compiled from Queensland Government's GWDB, bore baseline, field surveys, desktop surveys and further verification by OGIA using data from multiple sources.
- Critical information about the water bores such as the ID, location, construction and water use is often incomplete and is therefore indirectly inferred based on certain assumptions and methods.
- Metering data is unavailable for most bores and therefore OGIA has developed and applied methods for indirect estimation of groundwater use from the bores.
- There are approximately 11,900 water supply bores in use, or usable, within a 15-km area from the relevant tenure footprint (the area of interest).
- About 7,000 water bores in the area of interest access water from the GAB formations and most of the remainder access water from the Condamine Alluvium and other formations.
- Estimated groundwater use within the area of interest in the last two decades has averaged around 58,000 ML/year – about 32,000 ML/year (55%) from the alluviums, 22,000 ML/year (38%) from the GAB and the remaining 4,000 ML/year from other formations.

- The Hutton Sandstone is the most used aquifer in the GAB, followed by the Precipice and Gubberamunda sandstones. The Condamine Alluvium is the most significant non-GAB aquifer.
- Groundwater use is generally for agricultural, stock-intensive, irrigation, industrial, town water supply and S&D purposes – two thirds of the groundwater use in the GAB is for non-S&D purposes.
- Origin is currently reinjecting around 4,500 ML/year of treated CSG water back into the Precipice Sandstone.
- Approximately 500 new water bores are drilled and completed every year in the Surat CMA.
- Groundwater use and extraction is primarily used by OGIA in calibrating the groundwater flow model and assessing groundwater trends, amongst other assessments.

Chapter 6 Groundwater-dependent ecosystems

6.1 Preamble

Groundwater-dependent ecosystems (GDEs) are ecosystems that rely on groundwater to sustain all or part of their ecological processes or biota where groundwater may be the primary or a supplementary water source. A broad term that may include springs, watercourses, wetlands and vegetation accessing groundwater, GDEs are also groundwater assets and receptors of potential impacts from resource development.

In the context of the GAB, the underground water management framework in Queensland specifically identifies spring complexes and watercourse springs (watercourses that receive groundwater flow) for the assessment of impacts and a management strategy. In addition, impacts on EVs, such as terrestrial GDEs (TGDEs) – vegetation requiring access to shallow subsurface groundwater – are also required to be identified. TGDEs were included for the first time in the UWIR scope as EVs in 2019.

This chapter provides an overview of what the GDEs are in the Surat CMA, their locations and their likely source aquifers, leading into the conceptualisation of impact pathways to those GDEs (Chapter 7), risk assessment and the management strategy (Chapter 13).

6.2 Evolution of knowledge

Since the Surat 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 CMA. Together with output from the revised modelling, this new knowledge has enabled ongoing improvement to the assessment of risk and commensurate management actions as reflected in progressive UWIRs.

The UWIR 2012 provided the first assessment of cumulative impacts on springs in the Surat CMA, with five spring complexes 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 the period afterwards. In parallel, quarterly seasonal monitoring across 17 spring complexes was also completed by tenure holders, in accordance with the UWIR 2012 and EPBC Act approval conditions.

In early 2015, OGIA collated and analysed these datasets to build local-scale conceptualisations at each of the monitored spring complexes (OGIA 2016a). 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 2017a). This information identified areas where impacts to watercourses may occur and was included in the UWIR 2019. Following this, OGIA led a pilot project on new methods to evaluate which spring attributes and monitoring tools were most appropriate for ongoing monitoring. The outcomes from that project guided the specification of monitoring in the UWIR 2021.

Tenure holders have since undertaken additional investigations to verify areas of potential surface water–groundwater connectivity, which had been identified as being at risk in the UWIR 2019 and UWIR 2021. In several cases, the watercourses were found to be disconnected from groundwater and therefore removed from the 'at-risk' listing.

Since the UWIR 2021, ongoing investigations have focused on improvements to understanding of impact propagation pathways around both the eastern and western contact zones of the Precipice

Sandstone, which is a source aquifer for springs in the area. OGIA also conducted field investigations in 2023 and 2024 to better understand the source aquifers for selected watercourse springs as detailed in section 6.3.3.

6.3 Springs

As shown in Figure 6-1, there are different hydrogeological mechanisms by which springs occur (OGIA 2016b; QWC 2012):

- A spring can form where the hydraulic properties of the aquifer change – this is often referred to as a contact spring. For example, where a layer of higher permeability overlies a layer of lower permeability, flow across the boundary is restricted and, as a result, water tends to flow laterally, such as in the Spring Ridge spring complex.
- Where the overlying low-permeability unit thins or gets more permeable and water can seep through – such as mound springs and Cockatoo Creek vents
- A geological structure, such as a fault, can provide a pathway to the surface along which water can flow. Examples are 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. This also includes thinning of a low-permeability layer, providing a pathway for groundwater to reach the surface; for example, Cockatoo Creek and Boggomoss spring complexes

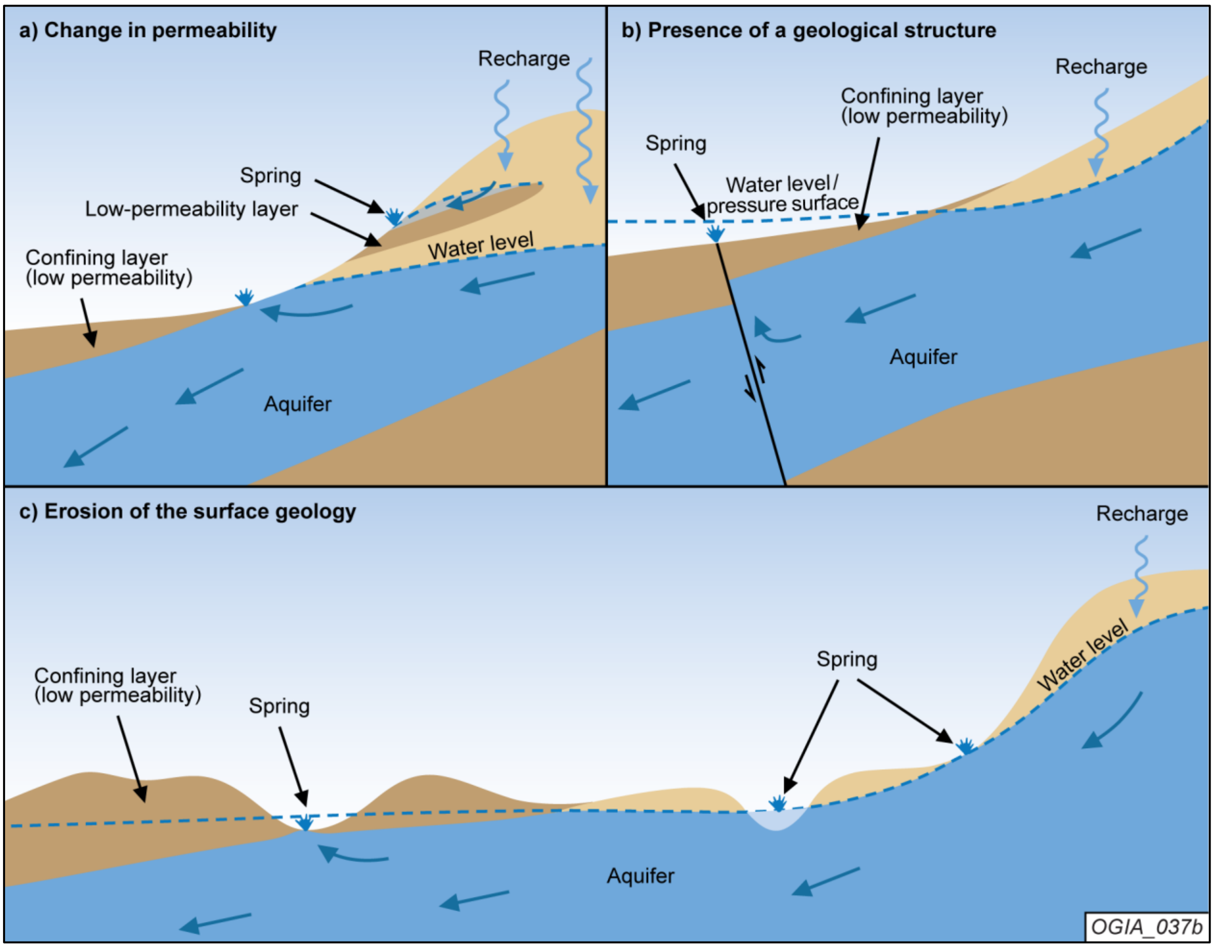

Figure 6-1: Hydrogeological mechanisms for groundwater discharge to springs

OGIA developed 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 this new knowledge, a wetland typology was developed to support the assessment of risks and specification of monitoring under the UWIR (OGIA 2016b; QWC 2012). The wetland types are based on how and where the wetlands occur within the landscape, since springs of a given type will have similar hydrogeological response to a change in the groundwater regime. The landscape setting and hydrological processes for each wetland type are shown in Figure 6-2 and further described in OGIA (2016b).

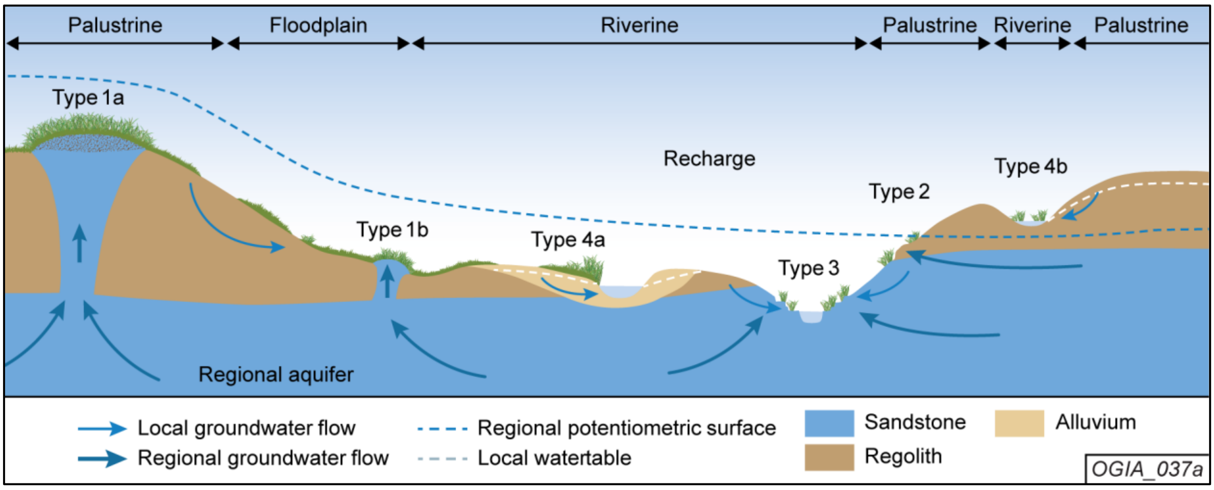

Figure 6-2: Wetland types in the Surat CMA

6.3.1 Distribution and occurrence of springs

There are 86 identified spring complexes, 391 spring vents, 94 water course springs and 59 spring groups in the Surat CMA (section 13.4). The majority of springs are located along the northern and central outcrop areas of the Surat and Bowen basins (Figure 6-3). The occurrence and distribution is primarily driven by regional and local geology, topography and groundwater flow regimes.

6.3.2 Source aquifer

Understanding the connection between a spring and an 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 to the spring along a fault or through a thinning of the low-permeability surface formation.

Detailed conceptualisation work in 2015 assessed the source aquifer for 17 spring complexes (OGIA 2016a; Flook et al. 2020). The key aquifers that feed springs in the Surat CMA are the Clematis, Precipice, Hutton and Gubberamunda sandstones. An important outcome from the detailed assessment was the knowledge that some springs are fed by both local and regional flow systems.

The 2015 conceptualisation reports (OGIA 2015a) focused on identifying the source aquifers for spring vents. Conceptual uncertainties remained around the locations and source aquifers for a number of potential watercourse springs (Type 3, Figure 6-2). Field verification of selected reaches to confirm groundwater discharge and verify initial assessment resulted in the removing of some of the reaches as watercourse springs (where they were identified as losing streams) or changing the attribution of source aquifers (where the investigations demonstrated change).

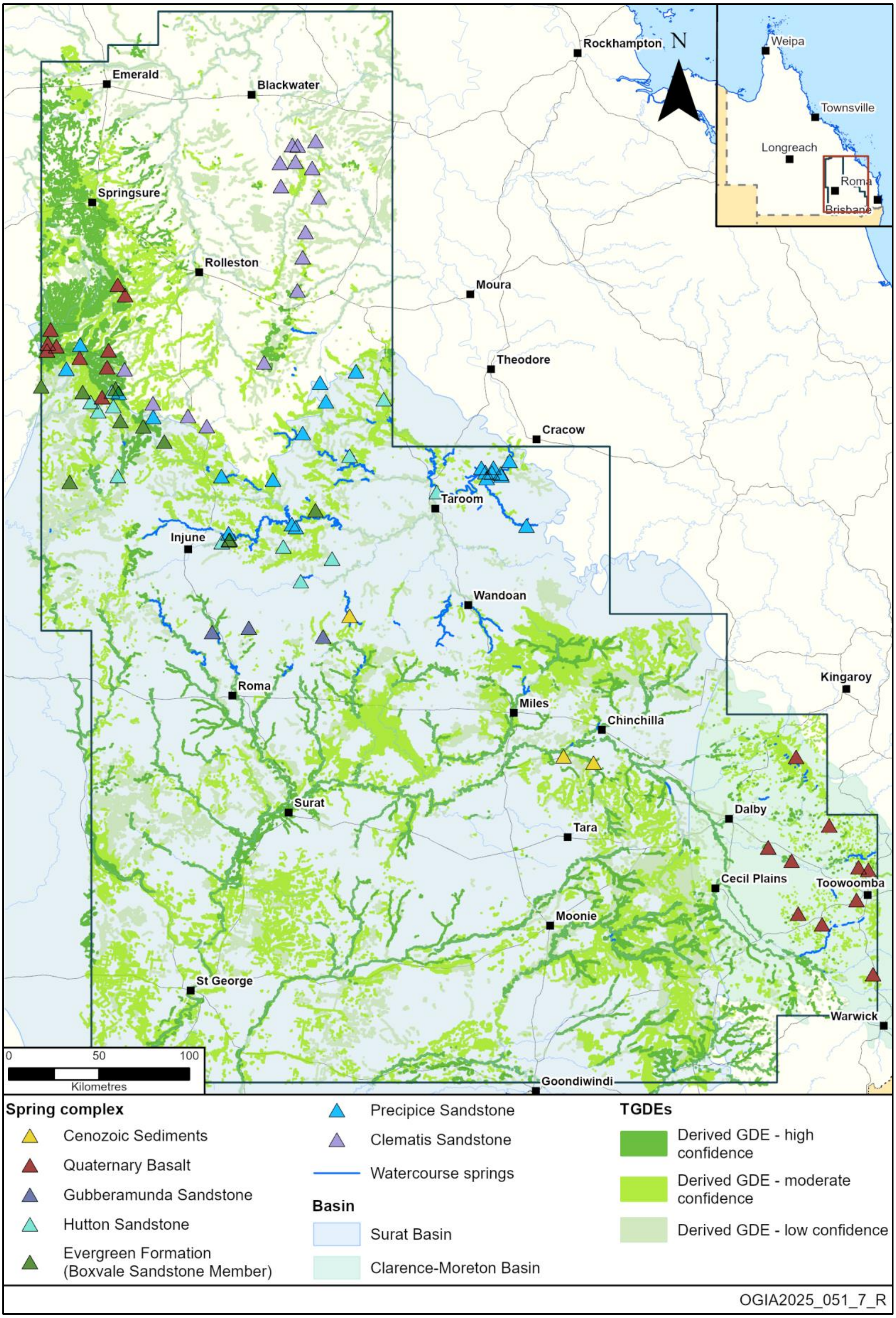

Figure 6-3: Locations of springs and terrestrial GDEs within the Surat CMA

6.3.3 Validation of at-risk watercourses

A key area of focus in the last three years has been on refining the characterisation of at-risk watercourse springs, primarily at Hutton Creek and the Dawson River (on the western margins of the Surat Basin) as well as Cockatoo Creek (on the eastern margin of the basin). This involved field investigations and desktop assessments in 2023 and 2024 to refine the inflow zones and source aquifers for these selected sites. Bringing together multidisciplinary datasets including hydro-geo-chemistry, light detection and ranging (LiDAR), flow gauging, geological mapping, AEM survey and conventional hydrogeological datasets, OGIA has refined the gaining extents for these key watercourses and verified the source aquifers in order to validate the risk assessment for these important regional GDEs.

The assessments identified that the primary gaining reach along the upper Hutton Creek (Springrock spring group) aligns with a small area of slightly artesian groundwater pressures within the Precipice Sandstone, limiting the gaining reach to a shorter stretch than the remapped geological outcrop of the Precipice Sandstone. Hydrochemical water sampling confirmed the source aquifer is consistent with the Precipice Sandstone, although the initial inflow zones appear to be sourcing water from an older, more regional groundwater source than the downstream sampling sites, which had a higher proportion of more modern water. In contrast, the lower Hutton Creek and Dawson River (311/Yebna 2 spring group) have a longer gaining reach and higher discharge volume. Hydrochemical sampling again indicates that the source aquifer is likely the Precipice Sandstone, with older groundwater inflows more common in the downstream sampling sites. As the field investigations have confirmed a connection to the regional groundwater system at both sites, they remain at high risk from the predicted groundwater level drawdown.

Cockatoo Creek was understood to be sourcing water from the Precipice Sandstone. Further investigations by OGIA in late 2024, however, suggest that it could instead be sourcing water partly from the Precipice Sandstone and partly from the sandstone-dominated layers of the Evergreen Formation. The groundwater inflow zone is also mapped further west, compared to pre-investigation mapping, and along a smaller tributary (Sandy Creek) that has now been added to the watercourse springs listings. Geological observations across the area concluded that the outcropping geology was likely to be sandstone-rich lower Evergreen Formation, rather than Precipice Sandstone as was historically mapped. Water chemistry samples identified that the initial seepage zones along both creeks had a composition and age similar to the bores in the area (likely Precipice Sandstone), while downstream flows have signatures of the Evergreen Formation.

Figure 6-4 below shows the updated mapping and gaining reaches for the three sites investigated. Outcomes of these verifications are incorporated in the assessment of risk and development of management strategies as detailed in Chapter 13.

6.3.4 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 wetlands will likely contract in response to declining groundwater levels. The contraction will depend upon the available pressure, the wetland type 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 have a more significant influence on impacts than are changes in groundwater chemistry.

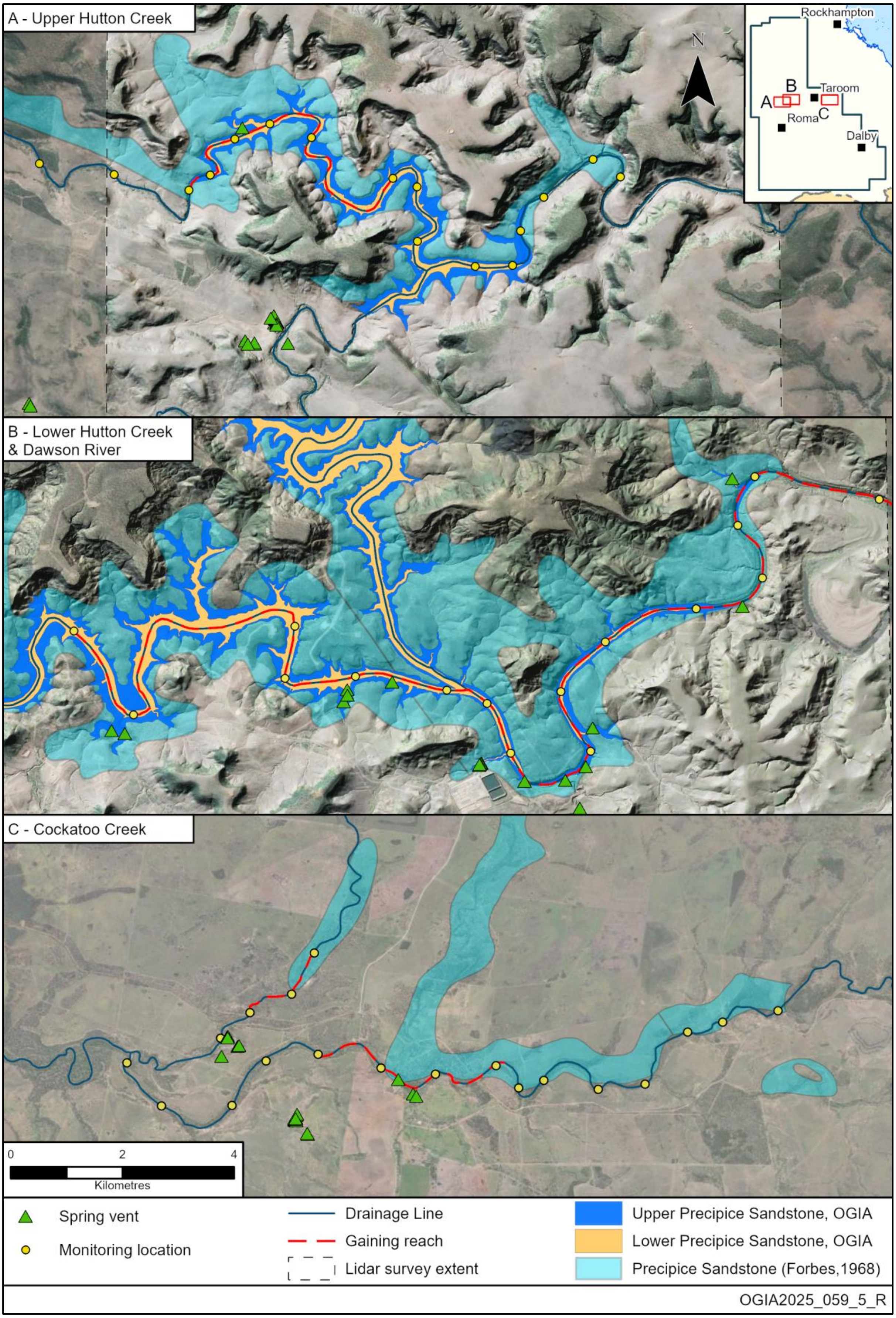

Figure 6-4: Revised mapping and gaining reaches at Hutton Creek (A), the Dawson River (B) and Cockatoo Creek (C)

6.3.5 Ecological and cultural values of springs

In parallel with their hydrogeological characteristics, springs support unique ecological assemblages and are often culturally significant sites. In terms of cultural values, the relationships between indigenous peoples and water (including springs) are recognised as holistic and interconnected – 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). Springs are permanent sources of water in semi-arid environments, in many cases, and are often associated with cultural values.

Information about the cultural significance of specific springs at some locations is available, following studies undertaken to support project approval processes or development activities. Information and data recorded in relation to indigenous cultural heritage studies and sites is maintained on the Queensland Aboriginal and Torres Strait Islander Cultural Heritage Database and Register[6]. For the purposes of the risk assessment in the Spring Impact Management Strategy (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 (section 16.5).

A number of spring complexes also 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 13.5). To sustain ecological assemblages and functions, springs and watercourses require water; this is essentially the water regime necessary to sustain the values of water-dependent ecosystems that have a low level of risk (Richardson et al. 2011). Springs by definition require discharge above ground level to sustain wetlands. The available pressure varies from spring to spring 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 less than 1 m to more than 20 m above ground level.

As previously stated, the water requirements of some spring wetlands are met from local inflows – such as groundwater in shallow alluvium, surface water flows, rainfall and overland flow – in addition to regional groundwater 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.

6.4 Terrestrial groundwater-dependent ecosystems

Terrestrial groundwater-dependent ecosystems (TGDEs) occur where vegetation requires access to the subsurface presence of groundwater, either intermittently or permanently, to maintain ecological composition and function. They occur typically around aquifer outcrops or shallow subcrops, or 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, when the scope of the UWIR assessment was expanded.

[6] www.culturalheritage.qld.gov.au

In contrast to springs – which are classified as aquatic GDEs and are generally localised features – TGDEs may be spatially extensive and may integrate with non-TGDE vegetation communities in addition to aquatic or other GDEs, depending on variations in surface geology, landform and soil.

6.4.1 TGDE mapping

In the Surat CMA, areas of potential groundwater-dependent vegetation have been mapped by the Queensland Herbarium (DSITI 2015) and attributed with a level of confidence that indicates whether the assigned dependency on groundwater is based on a field survey ('known GDE') or expert opinion ('derived' with high, moderate, or low confidence). Given the extensive spatial footprint, only a small number of priority TGDEs in the Surat CMA have been field surveyed by tenure holders and OGIA. Figure 6-3 shows the distribution of potential TGDE areas within the Surat CMA.

6.4.2 Conceptualising groundwater uses by vegetation

The relationship between a TGDE and its groundwater source can be complex and influenced by factors including botanical characteristics (such as plant rooting depth and morphology), depth to groundwater, proximity to surface water, and rainfall patterns. The ecological water requirements of particular regional ecosystems (REs) can be hypothesised using these characteristics (Doody, Hancock & Pritchard 2018).

Groundwater levels in shallow unconfined aquifers can have relatively quick fluctuations (including daily), in response to rainfall, run-off recharge events, or dry seasons. The ability of vegetation to switch water sources is a key adaptation in areas of highly variable rainfall and soil moisture conditions. During dry periods, vegetation may only use groundwater intermittently. In some cases, although groundwater dependence is temporary, it may still be essential in the life cycle of particular plant communities – such as while fruiting or for sapling establishment and growth.

The ability to access groundwater is conferred by the rooting depth and architecture. Processes affecting the development of roots are complex and depend on a range of site-specific variables. A simple rule of thumb is that vegetation use of groundwater is likely where the depth-to-water is less than 10 mbgl, possible at 10 to 20 mbgl, and unlikely at more than 20 mbgl (Eamus et al. 2006; OGIA 2019b).

6.4.3 Response to a change in the groundwater regime

Where potential TGDEs are confirmed through field investigation, responses to impact 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 6-5).

Some vegetation communities may have the ability to adapt to declining groundwater levels, especially where impacts are minor and the rate of change in the groundwater level is slow. Infiltrating rainfall may also sustain impacted TGDEs but rainfall is generally considered a short-term source that may not compensate for a reduction in groundwater level during dry periods. Further research into ecological responses is required to clarify the resilience of these TGDEs to changes in both hydrological and hydrogeological conditions.

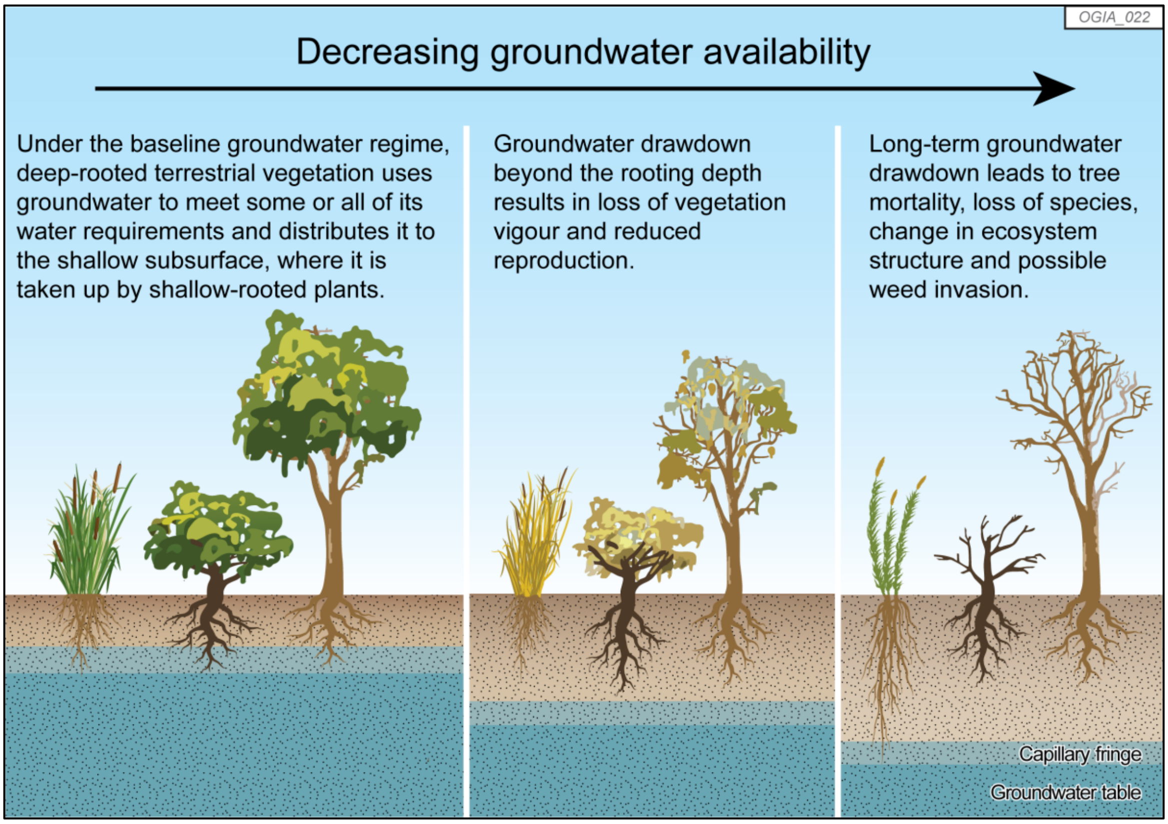

Figure 6-5: Conceptual model of TGDE response to groundwater level reduction (OGIA 2021a)

6.5 Summary of GDE characterisation

- 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.
- Terrestrial GDEs (TGDEs) are vegetation requiring access to shallow subsurface groundwater, generally less than 10 metres below ground.
- There are 86 spring complexes, 391 spring vents, 94 water course springs and 59 spring groups in the Surat CMA, located mainly along the northern and central boundaries of the Surat and Bowen basins.
- OGIA has been driving significant ongoing research to improve knowledge about the location, ecological values and seasonal dynamics of springs in the CMA since 2011, including a classification of springs based on wetland features.
- Most of the GDEs are supported by the Precipice Sandstone and the Hutton Sandstone – the two important aquifers of the GAB in the Surat basin.
- Springs also support unique ecological assemblages and are often culturally significant sites.
- The water requirements of some spring wetlands are met from local inflows in addition to regional groundwater flow causing springs to seasonally expand and contract in response.
- TGDEs occur where vegetation requires access to the subsurface presence of groundwater, either intermittently or permanently, to maintain ecological composition and function. They occur typically around aquifer outcrops or shallow subcrops, or where the water table is shallow enough to be accessed by roots.

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Part III Impact assessment

Chapter 7 Conceptualisation of groundwater impact pathways

7.1 Preamble

This chapter provides a summary of the impact pathways and mechanisms that can cause impacts on groundwater systems and receptors. Groundwater systems are dynamic and constantly responding to inflows, outflows and changes in formation pressure. Under natural or pre-development conditions, groundwater systems are typically recharged through rainfall, which moves laterally and vertically through aquifers and then discharges out of the system through streams and springs and as evapotranspiration. Groundwater levels respond to the balance between these recharge and discharge processes – this is 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 TGDEs. The degree of impact on receptors depends upon the **impact pathway** and its characteristics – the mechanisms and linkages through which groundwater impacts propagate from stressors to receptors. The conceptual understanding of impact pathways is important in assessing and managing impacts on receptors. A broad and general term, **connectivity**, is also used to describe the impact pathways and the degree to which groundwater can move from one formation to another.

7.2 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 this report, 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.

7.3 Impact mechanism from different resource activities

7.3.1 Coal seam gas

As described in Chapter 3, depressurisation from CSG production creates a head difference between the target formation and adjacent aquifers and increases 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 of groundwater conditions in and around a CSG production well, with some of the key factors that potentially influence impact pathways, is shown in Figure 7-1 and is illustrated further in a conceptual video created by OGIA (section 16.4).

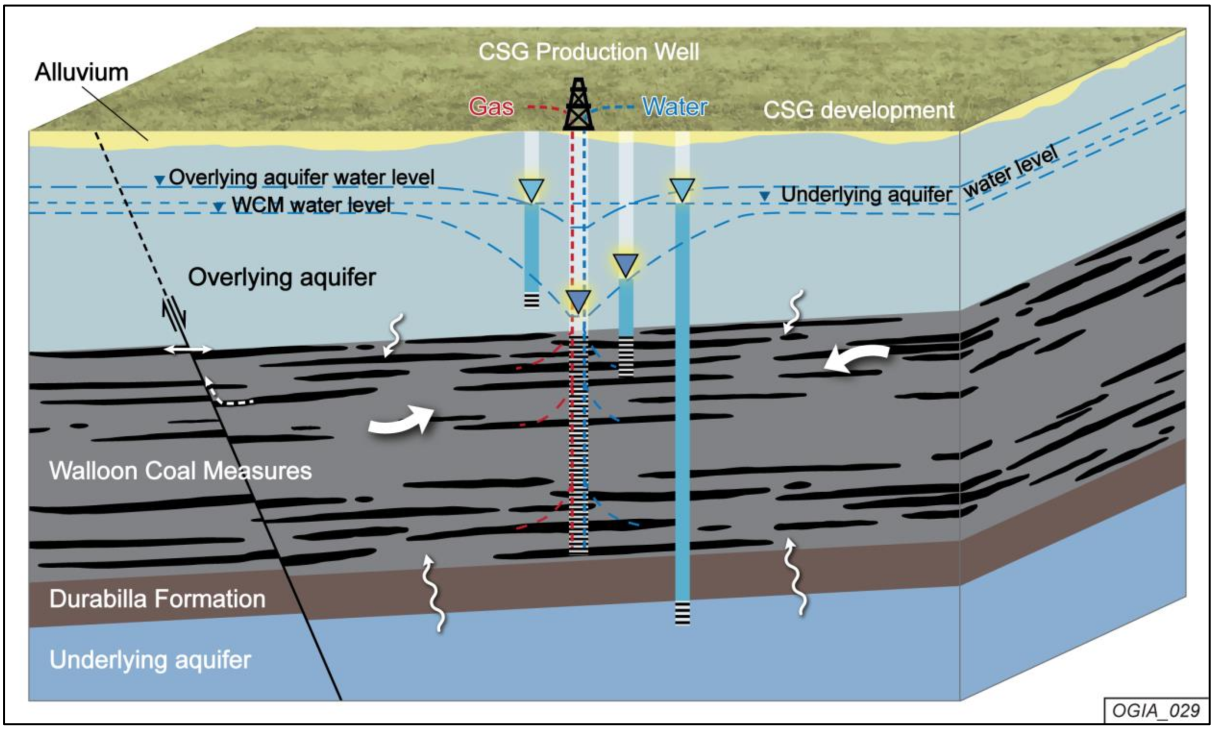

Figure 7-1: Impact pathways from CSG development

As drawdown propagates laterally away from CSG production fields, it creates vertical pressure difference (head gradients) relative to adjacent aquifers. This pressure difference then induces flow of water from the adjacent aquifers to the depressurised CSG formations. The amount of water loss from the adjacent aquifers depends on the impact pathway and the degree of vertical connectivity between the two formations.

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 even poorly connected formations if there is a large pressure difference.

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

- the characteristics, primarily the thickness and vertical permeability, of intervening aquitards – such as 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 – such as 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 – such as the Hutton-Wallumbilla and Horrane faults (section 7.4.2)
- wells and water bores that may act as conduits to flow where they are screened across coal measures and adjacent formations or aquifers.

7.3.2 Conventional oil and gas

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 the lowering of groundwater level over large areas; the volume of groundwater extracted is generally much less than for CSG.

Although numerous conventional oil and gas fields have recorded some production in the Surat CMA in recent years, Moonie oil field is the primary field, accounting for nearly half the oil production and 96% of the associated water production from conventional methods within the CMA. The Precipice Sandstone (Surat Basin) and the Showgrounds Sandstone (Clematis Sandstone 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.

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

7.3.3 Coal mining

Current and proposed coal mining in the Surat Basin is carried out via open-cut methods as detailed in section 3.4.1. A generalised schematic of the typical groundwater conditions in and around an open pit in the Surat Basin is shown in Figure 7-2. OGIA has also created a video to illustrate the coal mining impact pathways (section 16.4) with more additional details available in OGIA (2023b).

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.

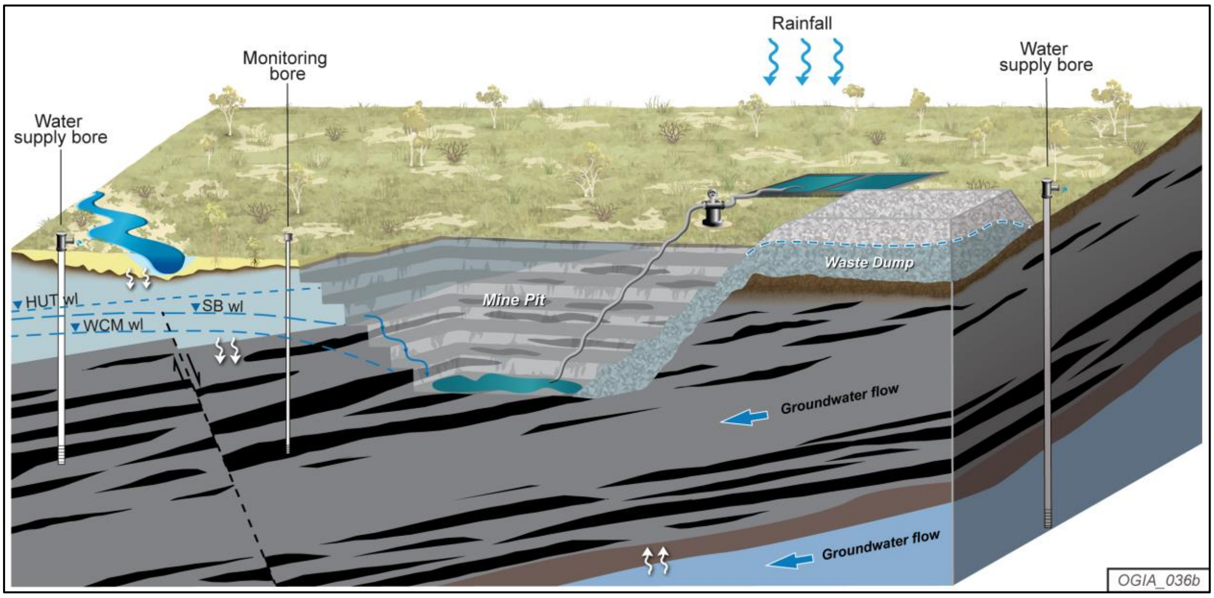

Figure 7-2: Generalised schematic of groundwater conditions around an open mine pit

- *Direct extraction* of groundwater that flows and seeps into the open pit from exposed formations along the pit walls. Collected 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 is 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 results in 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 – such as Commodore and New Acland – the vertical head gradient across the Durabilla Formation may induce some flow from the underlying Hutton Sandstone. As detailed in section 7.5.3, however, 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 (for example, at Cameby Downs).

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 earlier, 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 to that applied for CSG impact assessment, including the mapping of faults from seismic and coal holes data, determining of fault juxtaposition, and identifying of high-priority faults based on connectivity risks (OGIA 2020). 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.

7.3.4 Interaction between CSG and mining

Operational mines in the Surat Basin overlap with (or are immediately adjacent to) tenure where CSG production is occurring or planned in the future. These CSG and mining 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, during mining, the coal seams will be dry, partially saturated or fully saturated. 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 to occur, at all mines except New Acland and Commodore, both of which are further from CSG production areas.

7.3.5 CSG-induced subsidence

Gas wells depressurise the coal seams by up to a few hundred metres to release the gas that is otherwise trapped within coal matrix and coal cleats in various forms. This causes some compaction of the underground coal seams. As a result of this compaction, overlying formations may subside, resulting in some downward changes to ground surface – referred to as CSG-induced subsidence (Figure 7-3).

In the Surat Basin, some of the primary factors that affect the magnitude of CSG-induced subsidence are the magnitude and extent of depressurisation, geomechanical properties of the coal and overlying sediments, and the total thickness and distribution of coal where depressurisation occurs. Of all those factors, 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.

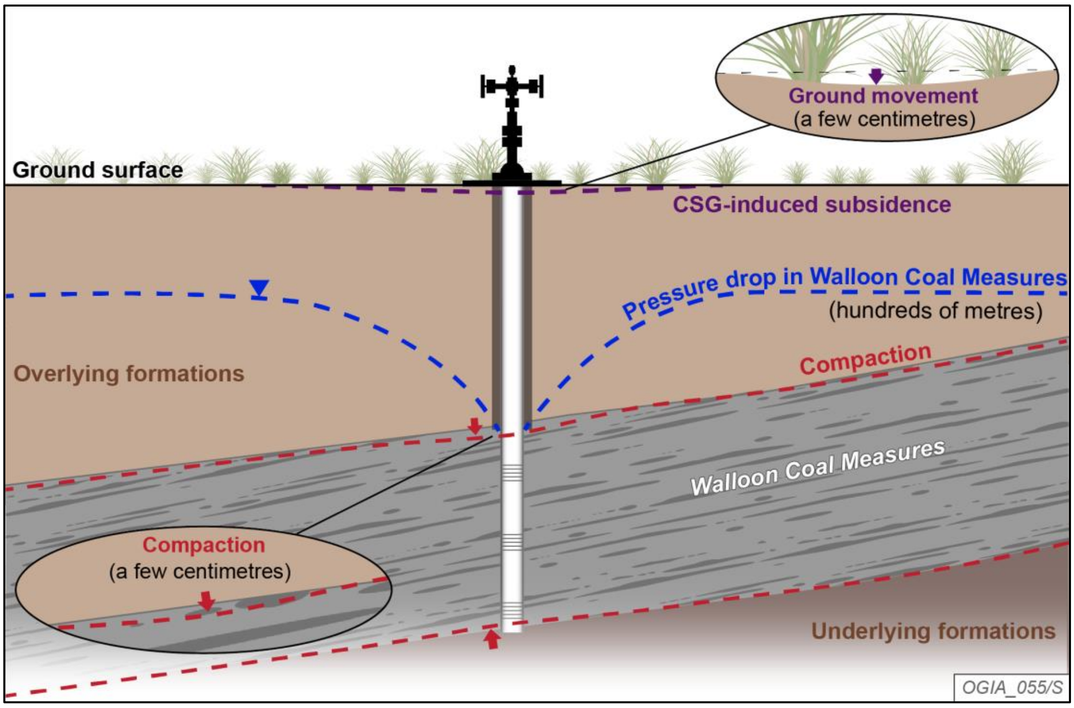

Figure 7-3: Schematic of the CSG-induced subsidence process

Coal seams are dual-porosity systems consisting of macropores (mainly cleats) and micropores within the matrix. Two relevant processes contributing to the total compaction of coal measures: poromechanical compaction, which happens through a decrease in macropore space; and coal shrinkage due to gas desorption from the coal matrix. Shrinkage only occurs in coal whereas poromechanical compaction happens in coal cleats (Aghighi, Cui, Schöning, Espinoza, et al. 2024; Cui, Schoning, et al. 2025).

To optimise gas production, the depth of depressurisation surface roughly follows the top of the target coal formation. In the Condamine Alluvium, where this depressurisation surface can be close to the alluvium base, Arrow Energy applies an additional criterion whereby well intakes are at least either 150 m deep from the ground surface or 30 m below the base of the Condamine Alluvium.

The subsurface depressurisation pattern is complex and changes over time; at any given point, its shape is a result of complex interference between individual well intake volumes, location and depths of well intakes, and timing of production commencement from those wells. At a regional scale, the depressurisation surface within the gas fields typically gets flatter over time as production matures, until the target surface – the top of the target coal formation – is reached. Away from the gas fields, the depressurisation surface gently slopes towards the gas fields and, over time, spreads away from the gas fields like a wave. Generally, the effect of >5 m of depressurisation – a proxy to the practical limit of CSG-induced pressure impacts – extends to about 5–10 km away from a well field within 2–3 years of production.

It is to be noted that ground motion is triggered by a range of environmental and anthropologic factors regardless of CSG-induced subsidence. Ground moves naturally, and frequently, from a range of factors such as: the shrinking or expansion of high-clay-content soils in response 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. CSG-induced subsidence, where it occurs, is another addition to this ground motion. However, natural movement (other than from land use practices) is typically in an up-and-down, oscillating pattern, along a seasonally variable background trend while the CSG-induced subsidence develops more gradually and is unidirectional.

As shown in a schematic in Figure 7-4, observed ground motion is a net effect of combined non-CSG and CSG-related factors. For this reason, the CSG-induced subsidence cannot be measured or monitored directly – it is only the observed ground motion that can be directly measured or monitored. Further scientific assessment is necessary to separate out, or estimate, CSG-induced subsidence from the ground motion after accounting for the noise in data, natural variations, background trends and so on. At best, observed or monitored ground motion can be attributed to CSG-induced subsidence only very close to CSG wells and if there are no other land use changes.

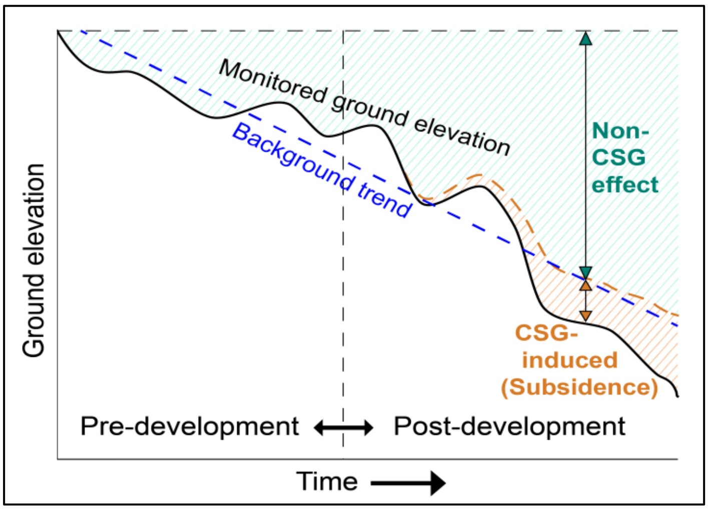

Figure 7-4: Schematic showing factors affecting trends in ground motion

7.4 Controls on groundwater connectivity

The movement of groundwater and the propagation of impacts are governed by some fundamental controls: the properties of the geological formations themselves, the presence of larger geological structures like faults, the influence of manmade pathways through poorly constructed wells and bores, and the existence of hydraulic head gradients. These controls are described in more detail in the following sections.

7.4.1 Formation properties

The most basic control on groundwater flow is the permeability of the rock. Permeability (or hydraulic conductivity) is a measure of how easily water can move through a formation's interconnected pores and fractures. Formations composed of sandstone, with many connected pore spaces, generally have higher permeability than formations containing mudstone or siltstone, which have much smaller, less connected pores.

At the formation scale, each formation includes mixed assemblages of sandstone, siltstone, mudstone, coal and shale, in different layered arrangements. This layering means it is typically much easier for water to flow horizontally along the more permeable layers, than to flow vertically through the less permeable layers. The rate of vertical flow between different layers is always controlled by the layer that is least permeable, which effectively acts as a hydraulic bottleneck.

Variation in vertical permeability and its effect on horizontal and vertical flow is demonstrated using permeability data logged from a water bore, east of Chinchilla, that is screened in the Walloon Coal Measures and the Hutton Sandstone – presented along with interpreted lithology in Figure 7-5. 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).

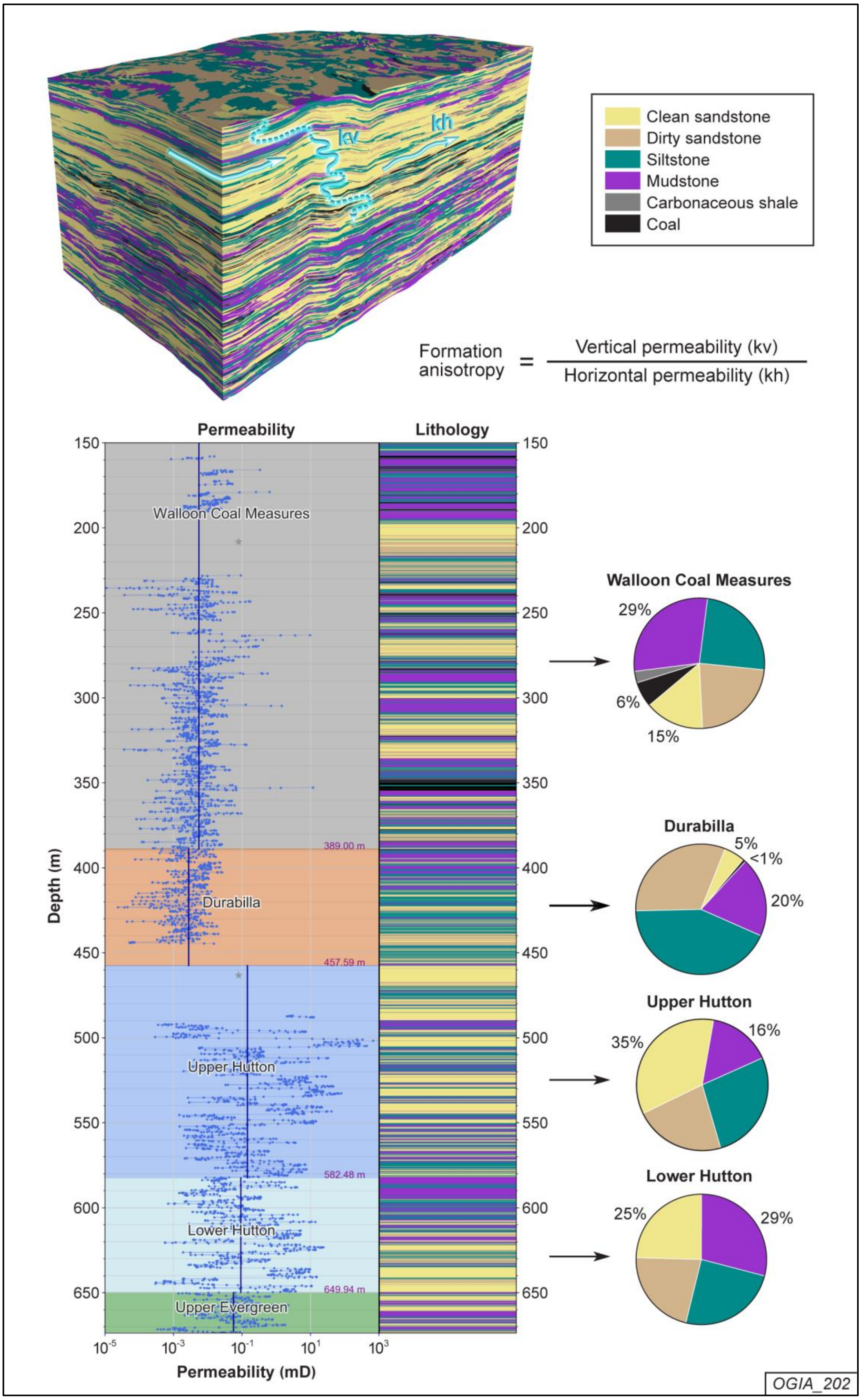

Figure 7-5: Continuous permeability profile from a water bore east of Chinchilla and a schematic of formation anisotropy

Layering of lower-permeability mudstone and siltstone also significantly reduces the effective vertical permeability. The ratio of horizontal to vertical permeability is known as formation anisotropy. Calculations based on data for this bore suggest an anisotropy of around 1:1,000 for the Hutton Sandstone, implying that water will flow laterally along the formation 1,000 times more easily than in the vertical direction (Figure 7-5).

Anisotropy represents an important measure of a formation's capacity to influence the propagation of impacts from one formation to another. For example, even though the Condamine Alluvium is highly permeable, any vertical water movement between it and the underlying Walloon Coal Measures is restricted by the latter's much lower permeability and anisotropy. This is similar to a clay-lined dam built on top of sand; the slow seepage through the clay controls the water loss, not the fast-draining sand underneath.

Similarly, a formation's water storage capacity – measured as a storage coefficient for confined systems (typically deeper formations) or specific yield for unconfined systems (typically the topmost formation) – also has some influence on impact propagation, particularly in terms of the water quantity. In the previous example, the Condamine Alluvium has a storage capacity 100 to 1,000 times that of the Walloon Coal Measures. This implies that for the same amount of water extraction, the pressure in the Walloon Coal Measures will drop much more, and in a relatively narrower area, compared to the Condamine Alluvium, where the groundwater level drop will be minimal but will spread wider.

7.4.2 Geological faults

Faults are breaks in rock formations where geological material has displaced along the break line, which is referred to as a fault plane. This displacement, or 'throw', can range from a few metres to hundreds of metres and can have a major influence on how groundwater moves.

Faults can either increase or decrease groundwater connectivity. They can increase connectivity in two main ways: firstly, the fractured 'damage zone' around a fault can enhance vertical permeability, creating a pathway for vertical flow through otherwise low-permeability layers. Secondly, fault movement can place permeable formations directly next to each other (juxtaposition), creating new horizontal pathways (Figure 7-6). For example, a fault with a large throw could place coal seams of the Walloon Coal Measures directly against the Hutton Sandstone. Conversely, faults can also decrease connectivity and act as barriers; this often occurs when soft, clay-rich rock is smeared along the fault plane during movement, creating a low-permeability layering that blocks horizontal flow. Faults may also reduce connectivity where the displacement creates a permanent disconnection and subsequent horizontal barrier to flow.

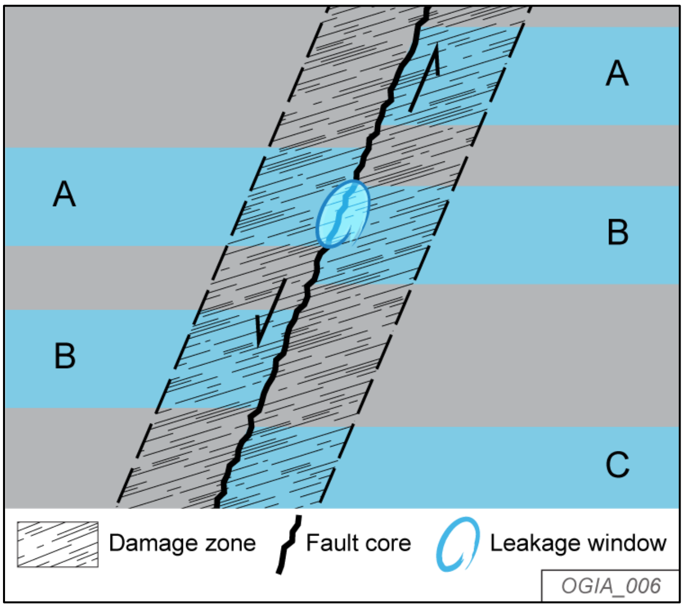

Figure 7-6: Schematic showing a generalised representation of a fault zone

For faults affecting the Walloon Coal Measures and the Hutton Sandstone interface, if the throw of the fault is greater than the thickness of the intervening aquitard (the Durabilla Formation), the coal seams may come in direct contact with the Hutton Sandstone. Even when the two are placed in direct contact, however, the smearing of clay along the fault plane can still limit flow across the fault.

OGIA has been progressively improving the understanding of major and minor faults in the Surat CMA since 2013, using seismic data from more than 300 two-dimensional (2D) seismic surveys, 12 three-dimensional (3D) surveys and four AEM surveys. A total of more than 200 mappable faults and numerous fault intersections in and around the CSG fields and coal mines were identified through this process. Since the previous UWIR in 2021, GA also acquired and interpreted regional AEM data to improve recharge assessment for the GAB and found a potential relationship between faults and groundwater compartmentalisation (McPherson et al. 2022). OGIA has integrated this data into its fault mapping.

Improved mapping of faults by OGIA is integrated into the impact assessment. A total of 32 major faults are incorporated into the regional geological model, with 22 explicitly represented in the regional groundwater flow model. At the sub-regional scale, additional faults are incorporated into the Condamine geological model as a result of remapping the Horrane Fault system, integrating both seismic and AEM surveys with geophysical logs (see section 7.5.4).

7.4.3 Anthropogenic pathways

In addition to natural geology, manmade structures can potentially create or alter groundwater pathways. These fall into two main categories: CSG wells and historical coal exploration holes.

CSG wells are drilled through multiple formations to reach the target coal seams. While traditional vertical wells are common, directional or horizontal wells are increasingly being drilled to achieve better efficiency in gas extraction, such as in the deeper Bowen Basin, or to minimise surface footprint, such as in the Condamine Alluvium. Wells are typically constructed with 5-to-7-inch diameter production casing, which is then opened to the coal seams either through pre-perforated sections or by creating holes through the casing and cement (Figure 7-7).

Well construction and abandonment can influence impacts in three main ways:

- Direct extraction of water from inlets that tap formations above or below the target coal measures.
- Indirect flow between formations if a well's integrity is compromised.
- Flow between formations through wells that are improperly abandoned.

To manage these risks, well construction in Queensland is governed by a Code of Practice, which is recently updated (Resources Safety & Health Queensland 2022). The code primarily addresses safety and environmental issues and identifies measures to prevent cross-flow contamination between hydrocarbon-bearing formations and aquifers. There is also an industry practice to establish a 'set-back' distance to separate production zones from sensitive aquifers – such as the 30 m of separation from the base of the Condamine Alluvium – or 150 m from the surface, whichever is greater. Regardless, the risks posed by the CSG and P&G wells need to be assessed and monitored regularly.

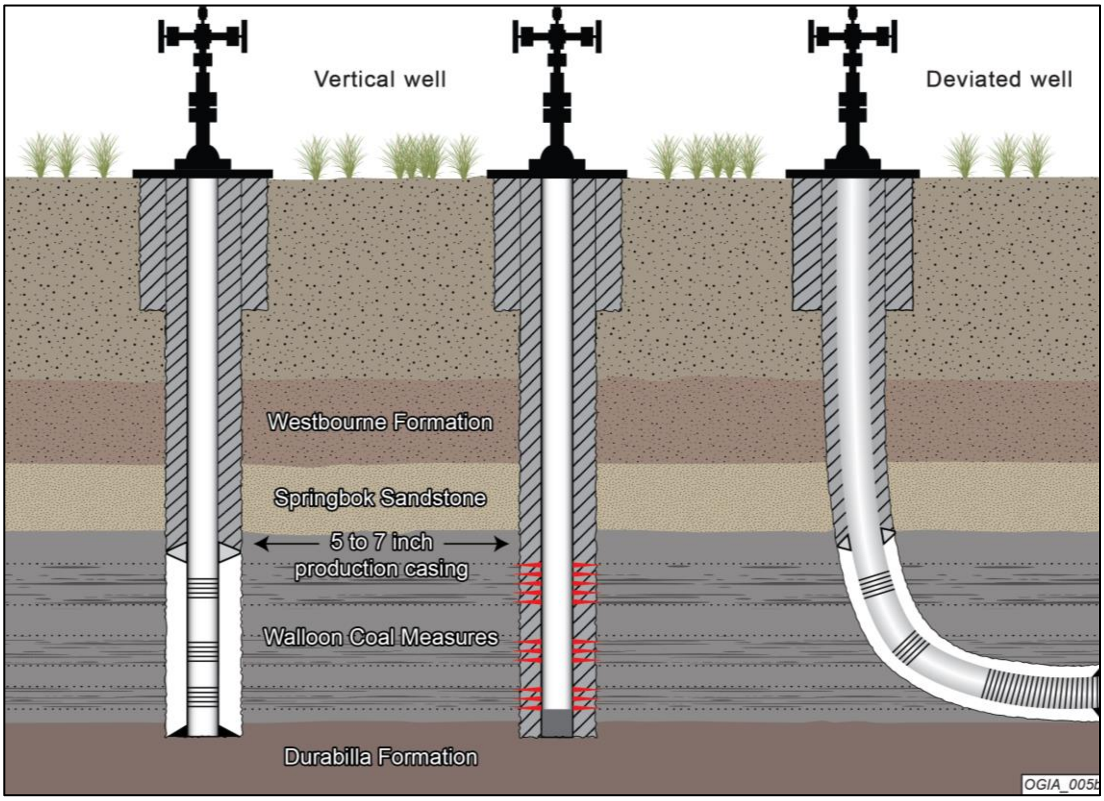

Figure 7-7: Typical construction of a CSG well targeting the Walloon Coal Measures

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. 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, sourced from mining tenure holders and collated by OGIA in 2020, suggests that there are at least 18,000 coal exploration holes associated with the eight mines. These coal holes are typically shallow in depth (less than 200 m).

Coal holes drilled prior to 2001 may have been abandoned improperly and have the potential to affect connectivity. Most of these are in or near the outcrop areas of the Walloon Coal Measures, on the margin of the basin. The implications of connectivity caused by poorly CSG wells and coal holes is further discussed in section 7.6 for the respective aquifers.

7.5 Impact pathways

7.5.1 Within the target coal sequences

The Walloon Coal Measures, Bandanna Formation and Cattle Creek Formation are the target coal sequences for CSG production in the Surat CMA. 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 $1x10^{-7}$ to $1x10^{-5}$ 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, within which, ten individual coal seams can be identified. These coal seams tend to be slightly thicker (often a little 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.

The complex internal structure of the target formations creates a distinct and anisotropic set of impact pathways that govern how pressure impacts from CSG production propagate, resulting in differing mechanisms for impact propagation in the horizontal versus the vertical direction (Scott et al. 2004).

The primary pathways for the lateral propagation of impacts are the natural fracture networks, or cleats, within the coal seams. Since the seams are thousands of times more permeable than the surrounding rock, they act like conduits that transmit pressure changes rapidly and over large distances horizontally. In contrast, the thick layers of interburden that separate the coal seams act as significant barriers to vertical flow.

The stark permeability contrast effectively vertically isolates the horizontal pathways from each other, forcing the initial drawdown from a production well to spread outwards, primarily along the targeted coal seams. Observations suggest that groundwater level declines of more than 10 m generally spread about 10 km from CSG production wells, with steep hydraulic gradients near the CSG development areas – creating a cone-like feature (‘cone of depression’), as shown in Figure 7-8.

Vertical impact propagation is far more restricted. The primary pathway is the slow leakage of water across the low-permeability interburden, which is only activated after a significant pressure difference has been established between a depressurised coal seam and the adjacent rock layers.

A more direct and significant vertical pathway is provided by the CSG wells themselves. Each well acts as a direct vertical conduit, creating a connection between the various horizontal pathways (the coal seams) that it intersects. This allows pressure changes to be transmitted vertically, at the well bore, between otherwise separated layers.

At the scale of a whole gas field, the network of production wells creates a larger, interconnected system of pathways. By linking multiple, previously isolated coal seams, the well field effectively increases the formation-scale horizontal connectivity. This allows pressure impacts to be distributed more broadly and uniformly across the entire production area.

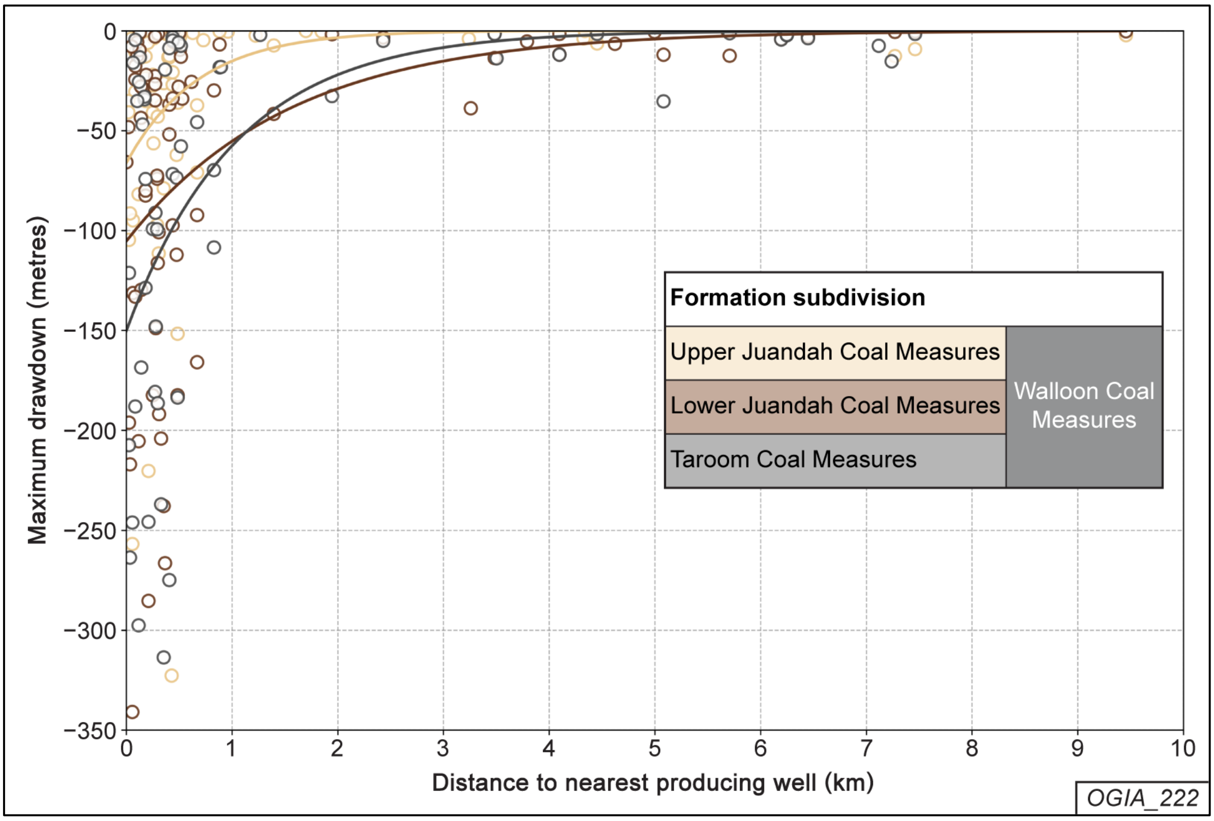

Figure 7-8: Observed groundwater level drawdown in the Walloon Coal Measures with distance to nearest CSG production well

These pathways' efficiency for water movement tends to decrease over time. As pressure drops and gas is released from the coal, the presence of gas bubbles in the fractures creates additional resistance to water flow. This phenomenon, known as two-phase or dual-phase flow, can partially impede the propagation of pressure impacts through the water phase as the gas field matures.

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.

7.5.2 Walloon Coal Measures to Springbok Sandstone

The connectivity between the Walloon Coal Measures and the overlying Springbok Sandstone is complex. While regional hydraulic connection is low, several lines of evidence confirm that impacts propagate through a combination of localised geological features and CSG wells partially screened into the Springbok Sandstone, activated by the change in pressure from CSG development.

In the pre-CSG period, the pressure gradient was directed upwards, from the deeper Walloon Coal Measures to the Springbok Sandstone. CSG depressurisation has reversed this gradient, creating a downward pressure difference of more than 200 metres in some areas (Figure 7-9). This downward hydraulic gradient creates the potential for water to flow from the Springbok Sandstone into the Walloon Coal Measures wherever a pathway exists (Erasmus et al. 2025).

The primary pathways are geological in nature. The boundary between the two formations is an erosional unconformity, which in some locations allows the sandy base of the Lower Springbok Sandstone, as shown in Figure 7-10, to be in direct physical contact with the coal seams of the Walloon Coal Measures, creating a natural conduit for flow. In addition to this natural contact, site-specific analysis confirms that faults can act as significant pathways.

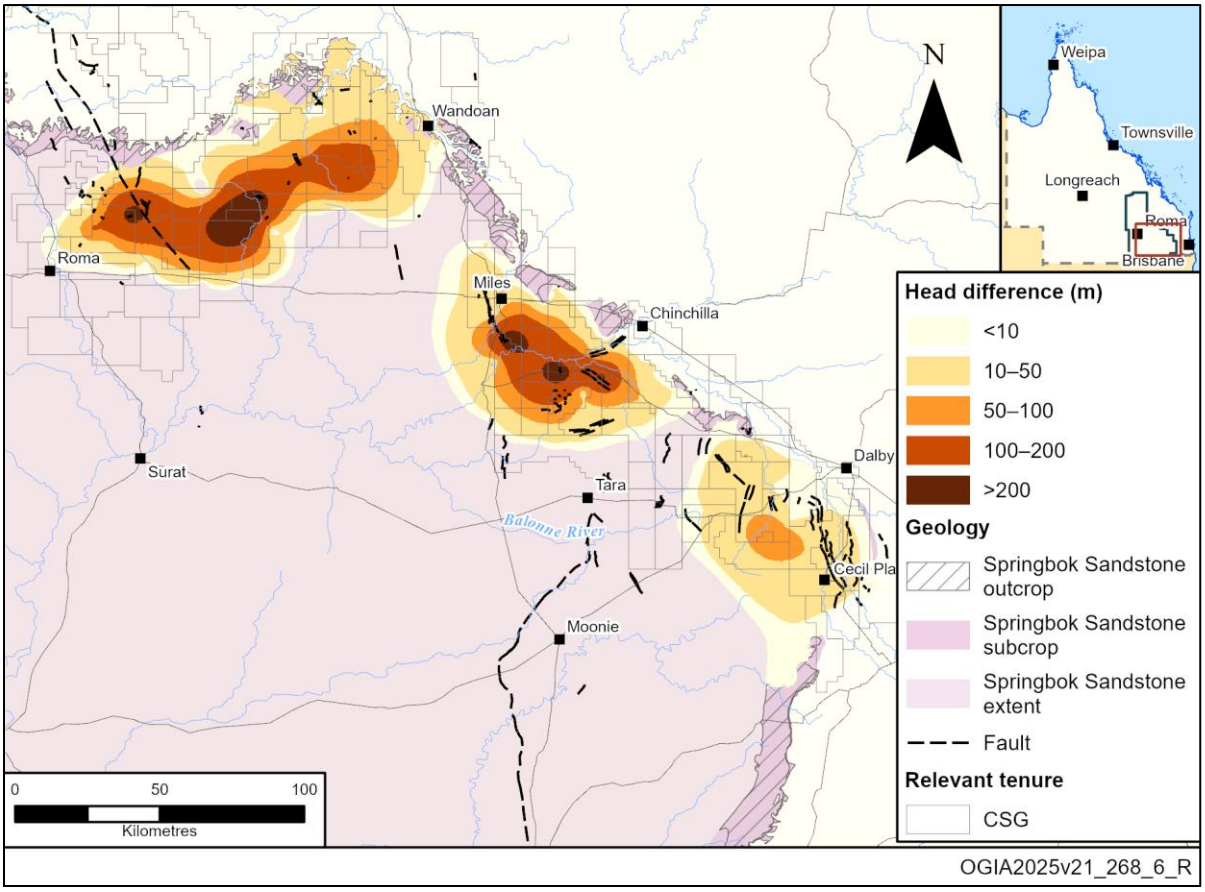

Figure 7-9: Vertical head gradient from the Springbok Sandstone to the Walloon Coal Measures

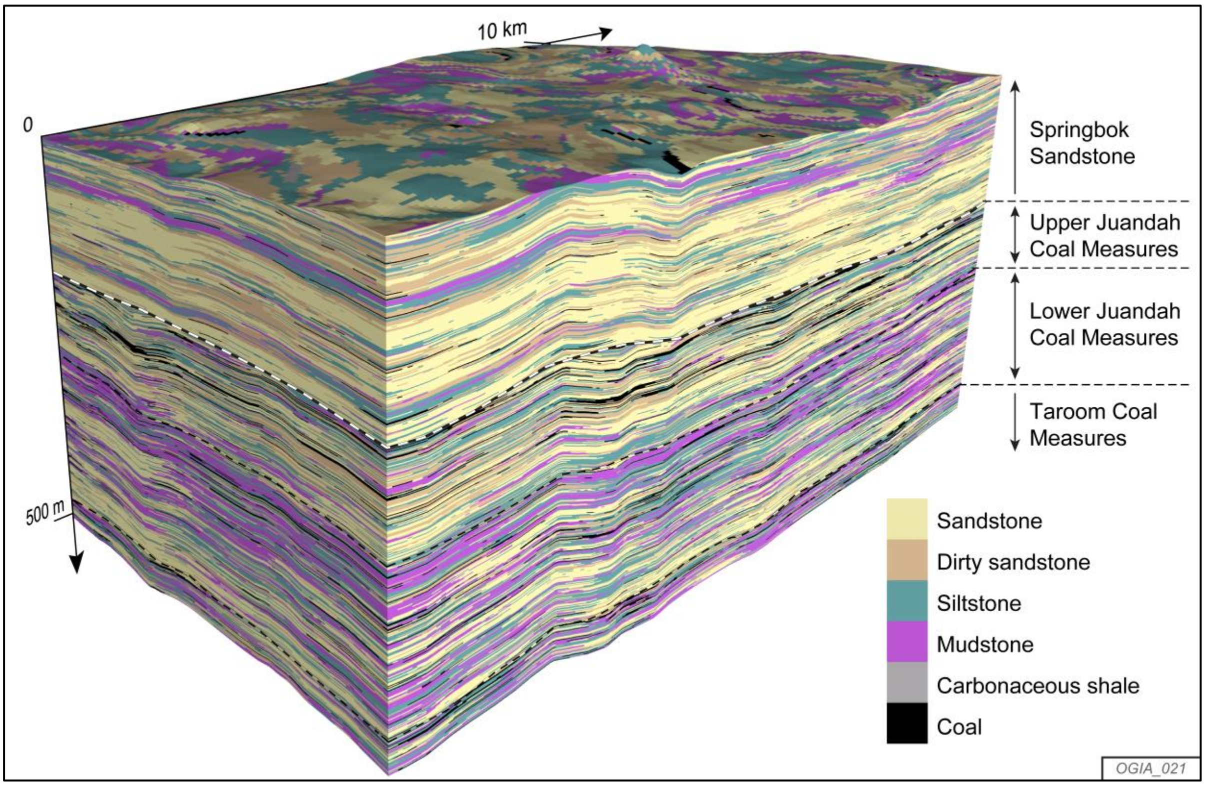

Figure 7-10: Walloon Coal Measures visualisation showing the complexity of the geology (generated from CSG well data)

The physical characteristics of the Springbok Sandstone control how impacts manifest. It is considered a tight aquifer, with generally low permeability due to a high percentage of swelling clays in the rock matrix. Low permeabilities are also supported by low water bore yields, as described in Chapter 5. 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 (Gaede et al. 2020; Kieft et al. 2015).

Because of these properties, impact drawdowns are typically localised and steep, rather than widespread, and Walloon Coal Measures connectivity is primarily with the more permeable Lower Springbok Sandstone. Variability in the connectivity is demonstrated in monitoring data in the Kenya East Gas field south of Chinchilla (Figure 7-11), which shows that a bore screened in the Lower Springbok Sandstone can experience significant drawdown, while a nearby bore in the Upper Springbok Sandstone, only 60 metres shallower, shows negligible impact (Erasmus et al. 2025).

In areas like the Kenya East gas field, a fault with sufficient displacement has connected the Walloon Coal Measures directly to the Lower Springbok Sandstone, resulting in a direct pressure response in monitoring bores (Erasmus et al. 2025). The displacement of faults affecting the Springbok Sandstone and Walloon Coal Measures was found to range between 10 and 20 m, with some exceptions of up to 60 m in places. Although numerous local faults have the potential to create connectivity between the Walloon Coal Measures and the Lower Springbok Sandstone, only a small number suggest enhanced connectivity (OGIA 2020).

To assess the implications of CSG wells on the connectivity, OGIA analysed well screen placement, which suggested that about 16% of wells may be partially completed into the Springbok Sandstone and may therefore have the potential to extract water directly from the part of the formation where the screens are placed. Further comparison of water production indicated that 97% of the wells partially completed into the Springbok Sandstone do not extract materially higher volumes compared to those that are screened into the Walloon Coal Measures alone. 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.

With regard to implications, of the 2,200 coal holes identified in the Springbok Sandstone outcrop areas (Figure 7-12) that could potentially also provide pathways to impact from the underlying Walloon Coal Measures, most old coal holes are likely to be collapsed. Induced leakage of flow in response to the CSG depressurisation – from those that remain open over a longer period – is likely to be a minor proportion of the overall impact in the Springbok Sandstone.

As shown in Figure 7-12, the non-coal zone of the Walloon Coal Measures is variable across the current and proposed CSG footprint, with an average thickness of about 5–10 m across most of the area, although there are areas where it is absent. The non-coal zone predominantly comprises sandstone and siltstone and provides some resistance to flow between the Springbok Sandstone and Walloon Coal Measures.

Monitoring data for groundwater level and chemistry suggests that, despite a pressure difference of up to 265 m between the Walloon Coal Measures and the Springbok Sandstone, the majority of monitoring points located close to active CSG production areas show little or no impact; the exceptions are those where the influence of faulting has affected local connectivity or where rising trends are potentially attributed to gas migration – further evidence of localised connectivity.

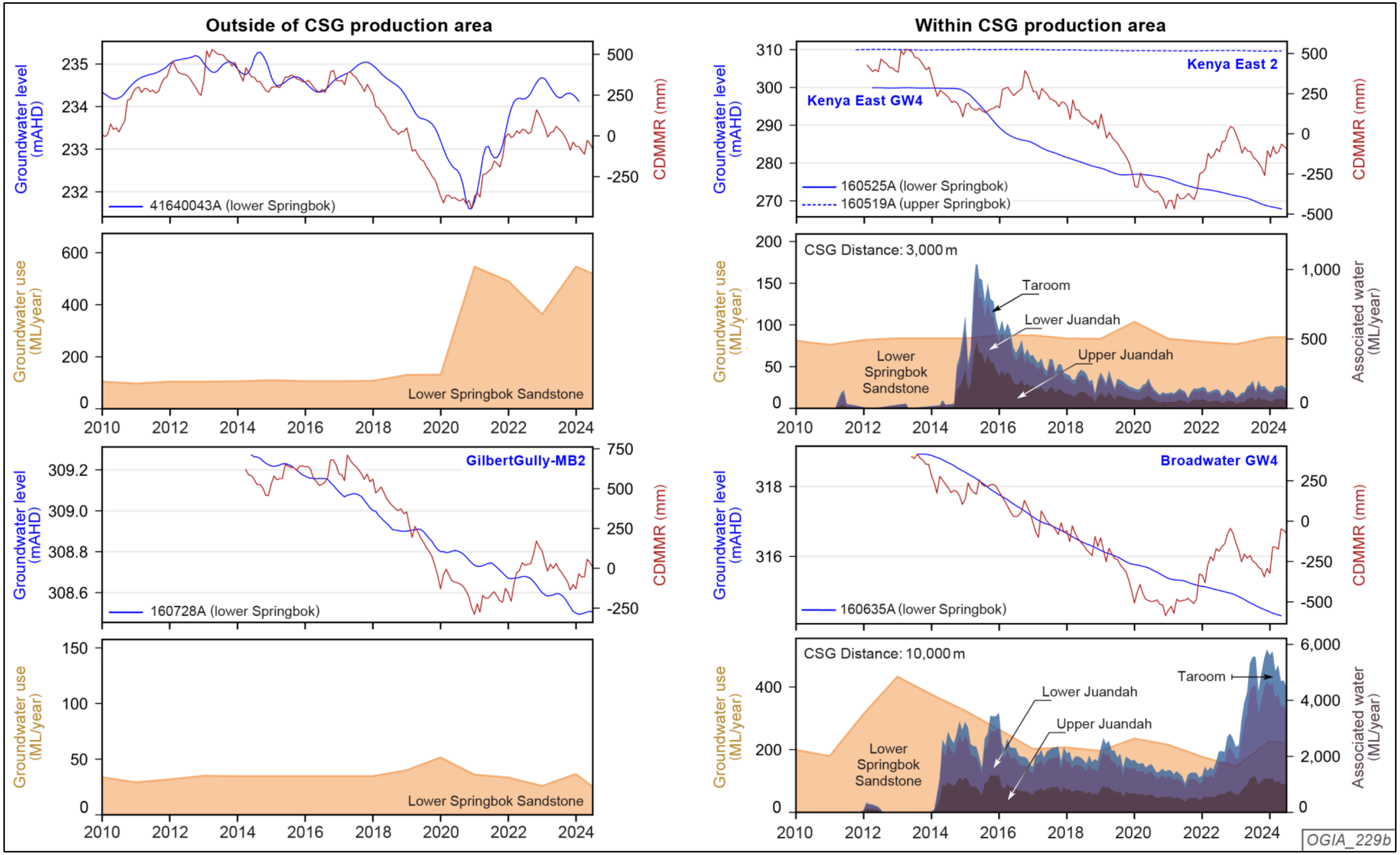

Figure 7-11: Example hydrographs in the Springbok Sandstone, outside (left) and inside (right) the CSG production area

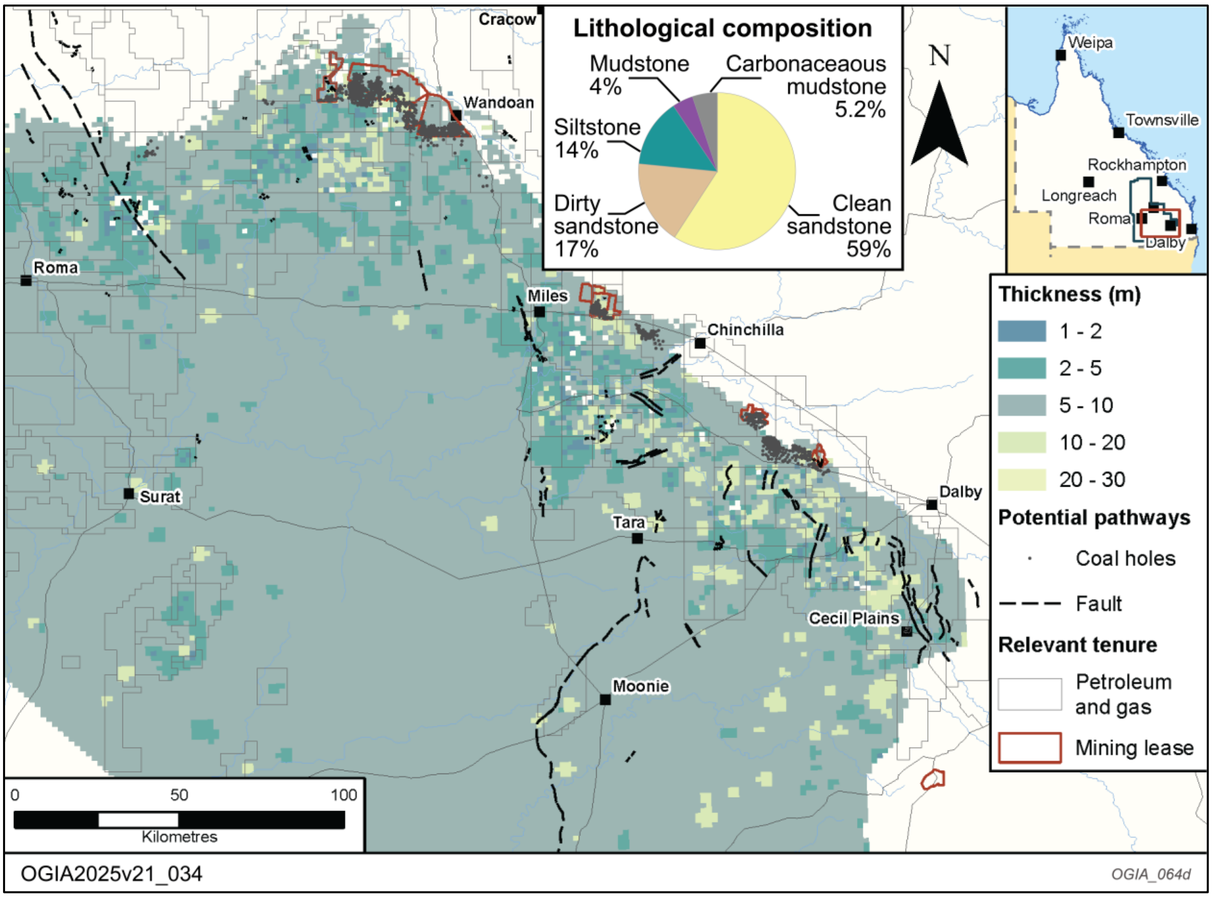

Figure 7-12: Thickness of the non-coal zone of the Walloon Coal Measures

7.5.3 Walloon Coal Measures to Hutton Sandstone

The overall hydraulic connectivity between the Walloon Coal Measures and the Hutton Sandstone is very low. This is primarily because they are separated by a thick, continuous, low-permeability geological unit – the Durabilla Formation, which acts as a major barrier to vertical groundwater flow and is commonly regarded as a major aquitard of the GAB (Ransley & Smerdon 2012).

As shown in Figure 7-13, 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. 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.

Because of this effective barrier, the main impact pathways of concern are features that could potentially bypass or compromise the Durabilla Formation, such as specific geological faults or poorly constructed CSG wells (Figure 7-13). Faults can create pathways if their displacements are large enough to place the coal seams of the Walloon Coal Measures directly alongside the permeable sandstone layers of the Hutton Sandstone – a phenomenon known as juxtaposition.

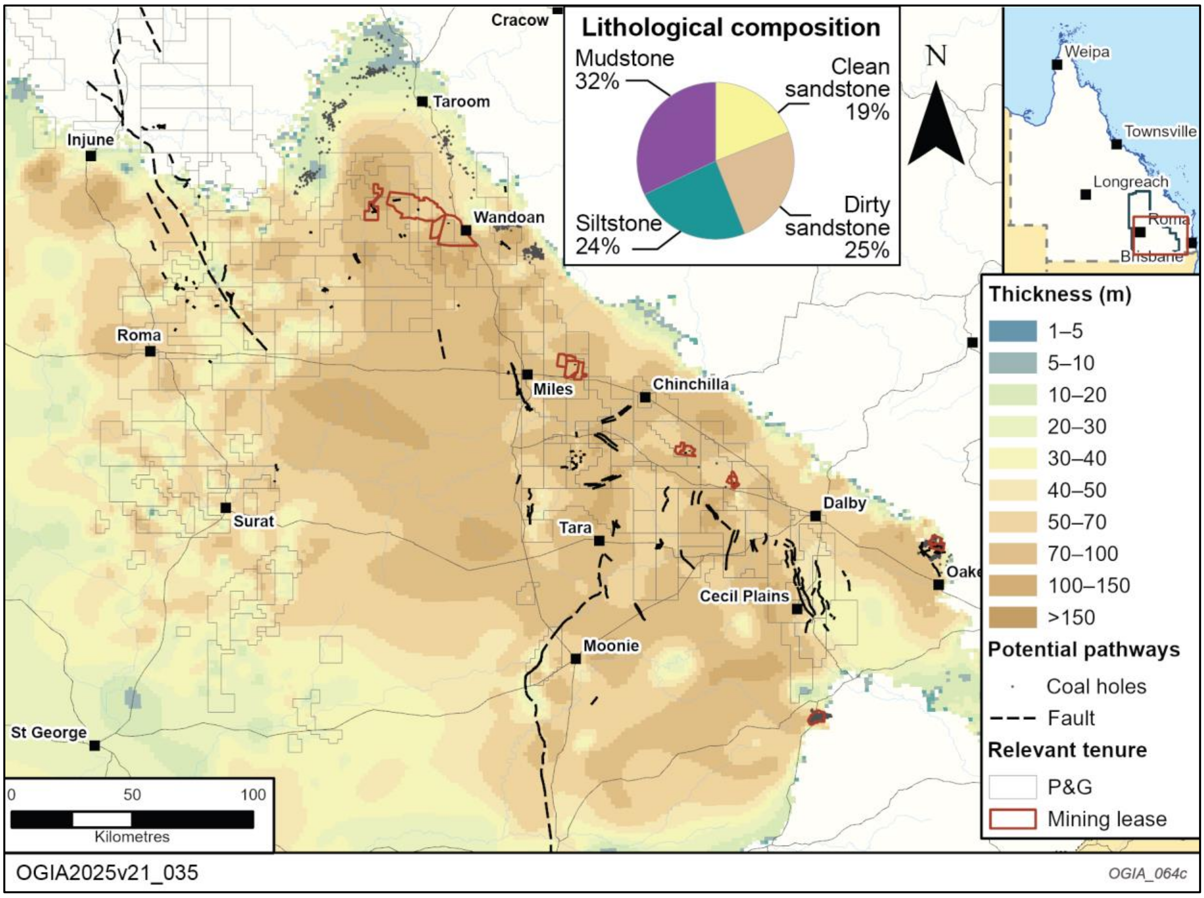

Figure 7-13: Thickness of the Durabilla Formation

Regionally, most faults do not have sufficient displacement to create this connection. The primary exceptions are portions of the Horrane and the Hutton-Wallumbilla fault systems. In specific segments of these major structures, geological assessment indicates that the Walloon Coal Measures has been placed in direct contact with the Hutton Sandstone, creating a potential – albeit localised – conduit for groundwater flow (OGIA 2020) (Figure 7-14). These are included in the groundwater model structure for impact assessment.

A significant factor increasing the potential for impact is the change in the hydraulic gradient, or pressure difference, between the two formations. Naturally, the deeper Hutton Sandstone is under higher pressure than the overlying Walloon Coal Measures, creating a natural upward hydraulic gradient. Depressurisation of the Walloon Coal Measures for gas production significantly lowers the pressure within that formation, which in turn substantially amplifies the pre-existing upward gradient. The pressure difference between the two formations in some established gas fields now exceeds 400 metres, creating a strong driving force for water to move from the Hutton Sandstone into the depressurised Walloon Coal Measures (Figure 7-15). Since the UWIR 2021, the spatial extent and magnitude of head gradients in the northern production areas have increased considerably.

In 2021, OGIA conducted an analysis of well completion into the underlying Durabilla Formation and Hutton Sandstone, the results of which suggest 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 and are not screened into the Hutton Sandstone. There is one exception – Condabri 363 – which is completed into the Hutton Sandstone and may draw some water from this formation.

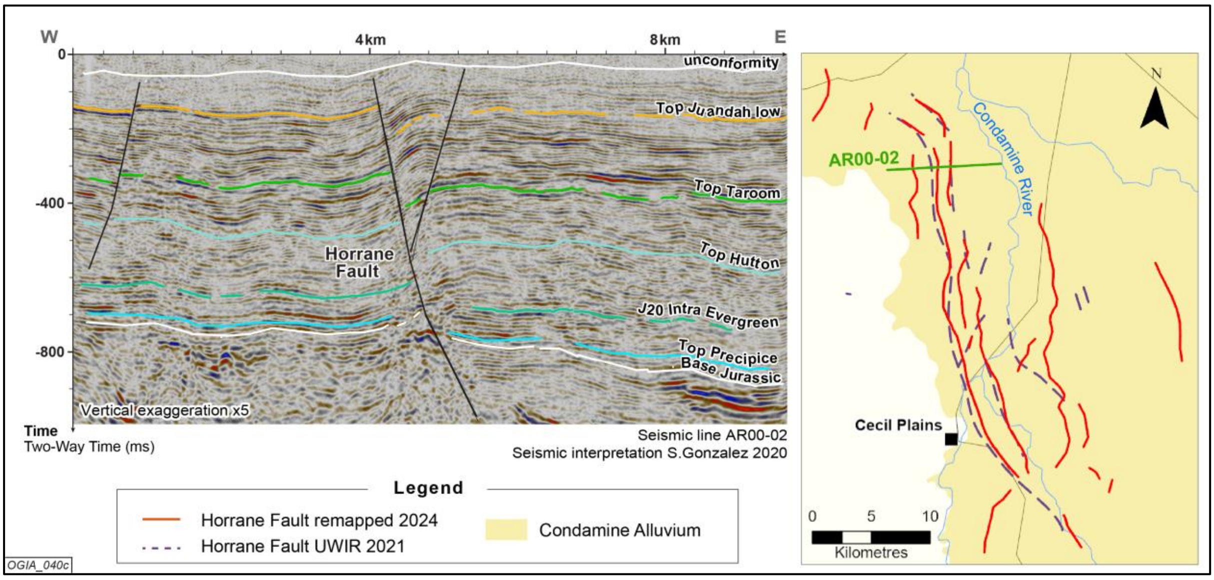

Figure 7-14: Horrane Fault revised mapping and interpretation

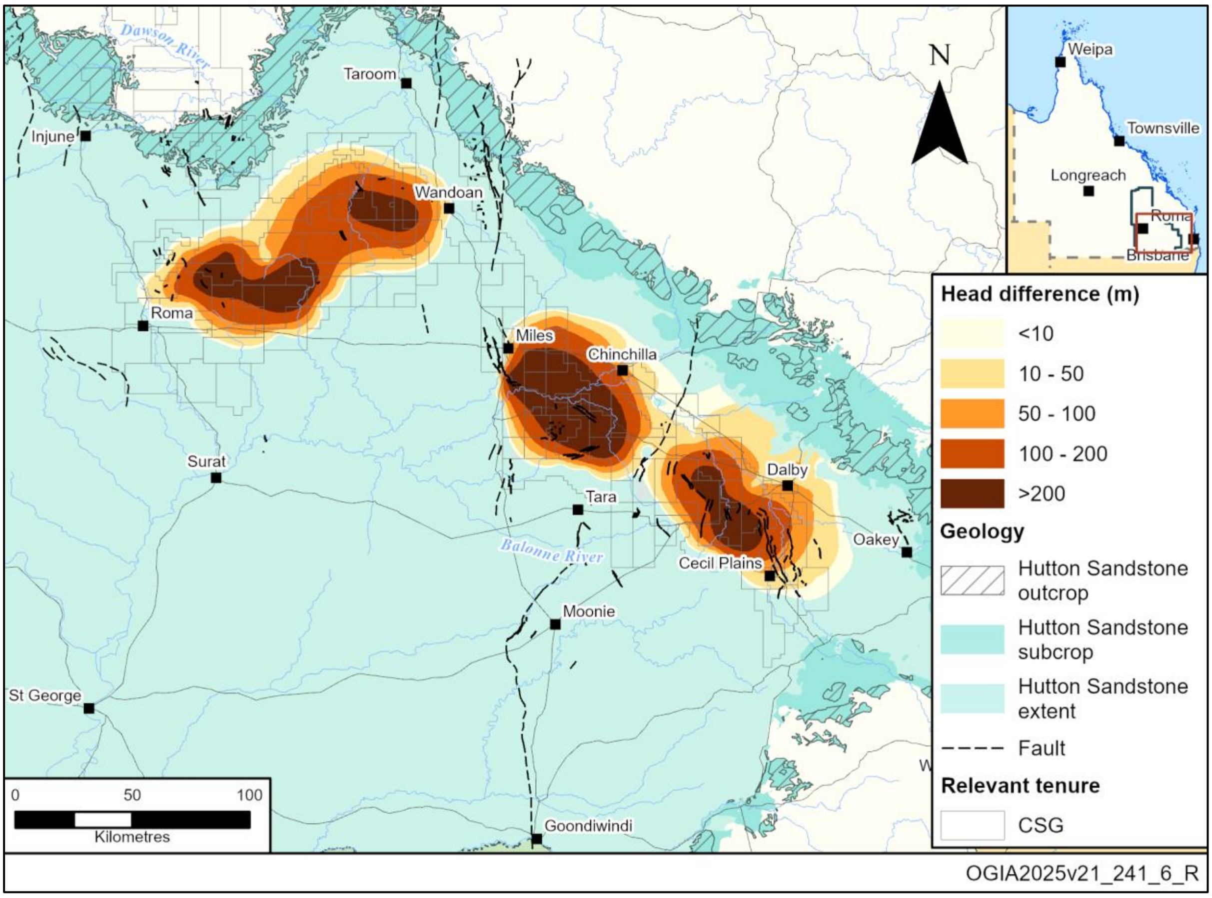

Figure 7-15: Vertical head gradient from the Hutton Sandstone to the Walloon Coal Measures

In addition to production wells, an estimated 22 historical coal exploration holes are noted to have been drilled deep enough to connect the Hutton Sandstone to the overlying Walloon Coal Measures; however, the potential impact from these holes is considered to be highly localised and minor, likely resulting in less than one metre of drawdown over a very long period.

Despite the significant pressure differential between the Walloon Coal Measures and the underlying Hutton Sandstone, overall hydraulic connectivity between the two formations is considered low.

Monitoring data support this, showing only localised, potential CSG-related impacts on groundwater levels in the Hutton Sandstone, with broader declines in groundwater levels attributed to non-CSG factors (Erasmus et al. 2025) – consistent with the findings reported in the previous UWIR.

7.5.4 Permian coal measures to Precipice Sandstone

The Precipice Sandstone is an important aquifer of the GAB, particularly in the northern parts of the Surat CMA, where it is potentially connected to the underlying Permian CSG reservoirs. It supports numerous GDEs, including culturally significant springs and watercourses, as well as a variety of water supply bores. Understanding the pathways for potential impacts therefore continues to be a key focus of assessment.

The primary Permian CSG target, the Bandanna Formation, is generally well-isolated from the overlying Precipice Sandstone. It is typically overlain by the low-permeability mudstones of the Rewan Group, which act as a regional aquitard, or barrier, limiting the potential for vertical impact propagation; however, in specific zones where geology has created a direct connection, impact pathways may occur.

The main pathway for impacts is where major geological uplift and subsequent erosion have removed the protective Rewan Group, allowing the Precipice Sandstone to be in direct physical contact with the Bandanna Formation. This direct contact bypasses the regional aquitard and forms the primary pathway for hydraulic connection. The pathway is enhanced by the properties of the Precipice Sandstone in the northern region, where it is highly permeable making the aquifer capable of propagating pressure changes over large distances. Since the initial UWIR in 2012, OGIA has progressively refined its understanding of the extent of the contact zones, informed by drilling data and seismic surveys (2D and 3D) as data becomes 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**).

The eastern contact zone occurs adjacent to the Leichhardt-Burunga Fault. At this location, similar to the western contact zone, the equivalent of the Bandanna Formation is overlain by the Precipice Sandstone, but the area of potential connectivity is much smaller compared to the western contact zone (Figure 7-16). While acquisition of a 3D seismic survey in 2018 – around the Peat gas field by Origin, and around the Scotia gas field by Santos – provide new insights and have confirmed the current conceptualisation, revised mapping from the seismic data is yet to be reflected in the geological model.

The western contact zone has been refined since the UWIR 2021, with the acquisition of the West Spring Gully 3D seismic survey by Origin in 2022, which enhances the delineation and interpretation of the contact zone area (Figure 7-16). Near the western contact zone, there is potential for a high degree of interaction between the coal-bearing formations and the Precipice Sandstone because they are in direct contact. Some of the earliest CSG fields – Fairview developed in 1996 and Spring Gully in 2005 – have already caused more than 200 m of depressurisation in the Bandanna Formation around the area and have created conditions for potential loss of water from the Precipice Sandstone. Some of the recent evidence increasingly indicates that some loss of water likely has started to occur from the Precipice Sandstone, as anticipated.

One such piece of evidence is from the CSG water production data in the area: CSG wells located closer to the contact zone exhibit consistently higher water production volumes and maintain higher water-to-gas ratios over time. This suggests these wells are drawing water from the connected Precipice Sandstone (Erasmus et al. 2025) consistent with the previous reporting by OGIA. In addition, the groundwater level monitoring data from within the contact zone indicates that positive groundwater levels trends in the northern Precipice Sandstone – influenced by the reinjection of treated CSG water – have started to reverse, despite continuation of reinjection at the same rate (section 9.6.2). This combination of evidence suggests the pathway in the western zone is likely active. Decomposition of signals to separate and quantify the reinjection and CSG impact components, however, is yet to be undertaken. OGIA is committing to undertake further work in this space in the next UWIR cycle, together with refinement of the modelling of impacts and hypothesis testing. This is particularly important and of high priority, given the significance of potential risks to GDEs that are supported by the Precipice Sandstone in the region.

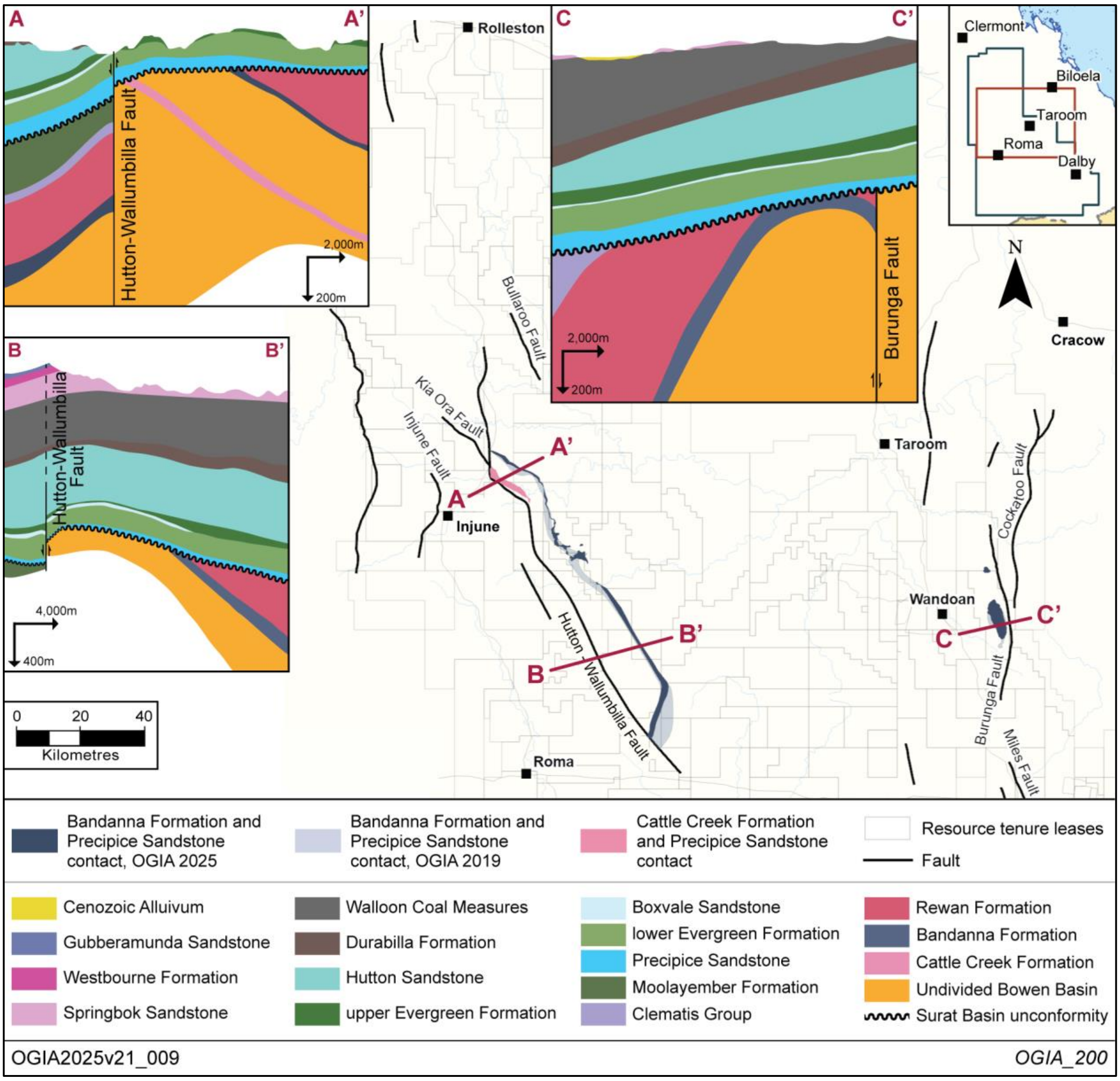

Figure 7-16: Contact zones between the Bandanna Formation and overlying Surat Basin

7.5.5 Walloon Coal Measures to Condamine Alluvium

7.5.5.1 Evolution of connectivity assessment

The Condamine Alluvium is a significant groundwater source supporting agriculture on the Condamine floodplain. It sits directly on top of the Walloon Coal Measures and hence a large pressure reduction in the coal seams from CSG production has the potential to induce some loss of water from the Condamine Alluvium to the underlying formations. Understanding the degree of connectivity between these two systems is therefore critical for assessing the impact (Figure 7-17).

Since 2012, OGIA and Arrow have separately undertaken research into connectivity between the Condamine Alluvium and the underlying formations. OGIA led research involving multiple lines of investigation: reinterpreting geology, mapping regional groundwater level differences, analysing hydrochemistry, drilling, conducting pumping tests, and numerical analysis. Details of the investigations, approach and outcomes were compiled in an investigation report (OGIA 2016c) and a peer-reviewed journal (Pandey et al. 2020).

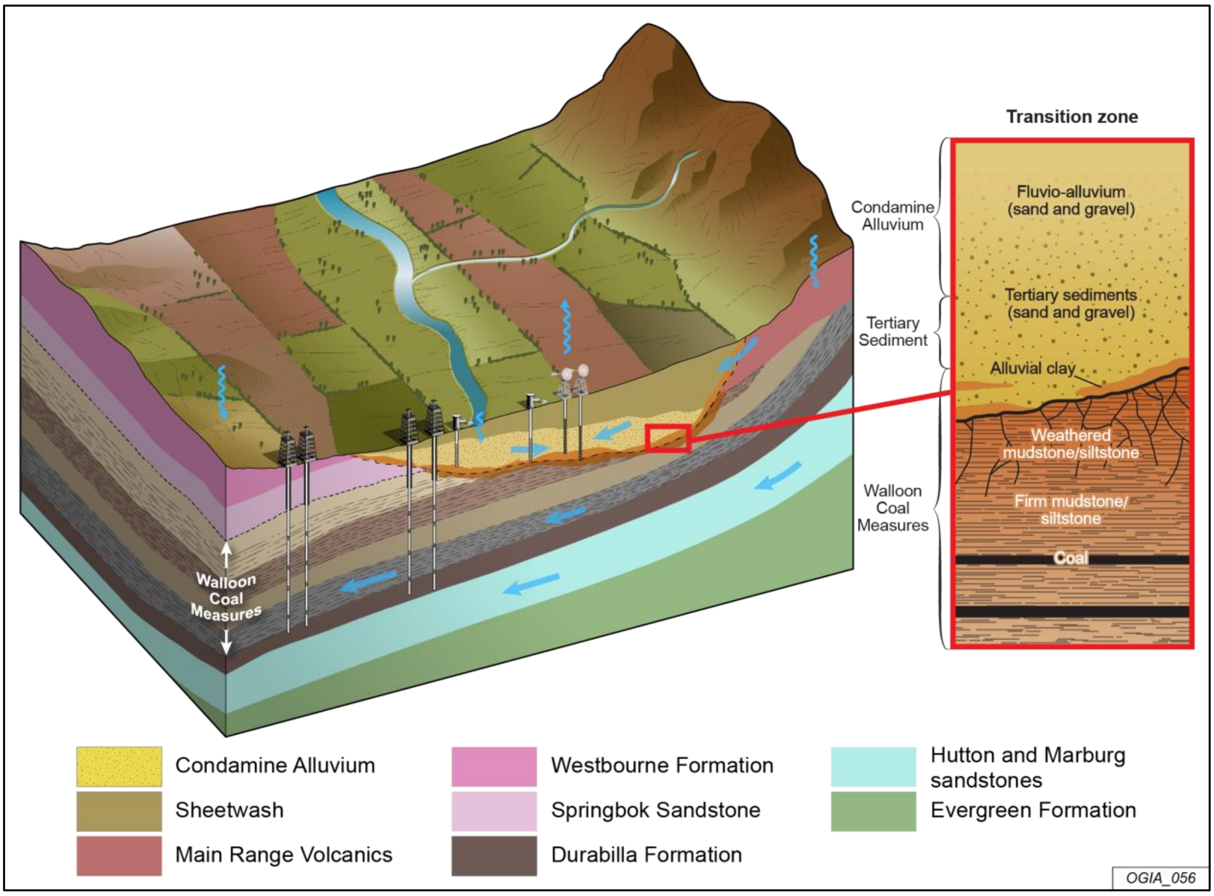

Figure 7-17: Schematic of the regional hydrogeological setting around the Condamine Alluvium

The investigations concluded that the degree of connectivity is low and that groundwater movement is impeded by an undifferentiated clay-dominated transition zone at the base of the Condamine Alluvium, where present.

This conceptual understanding of the connectivity, combined with target calibration datasets, has been integrated into groundwater impact modelling in successive UWIRs since 2015. The resulting predictions of net CSG-induced leakage from the Condamine Alluvium have subsequently ranged between 700 and 1,200 ML/year.

OGIA has committed to regularly updating the connectivity assessment through ongoing investigations and in response to emerging monitoring data. In 2019, OGIA conducted a regional assessment of fault-induced connectivity across the Surat CMA. As part of this, the Horrane Fault (along the western edge of the Condamine Alluvium) was remapped and assessed to bear potential implications for connectivity between the Walloon Coal Measures and Hutton Sandstone (underlying the Condamine footprint) (OGIA 2020). A targeted industry study also provided the direct hydrogeological data of the fault's sealing behaviour at depth (Viljoen et al. 2020).

7.5.5.2 Investigations for revaluation of connectivity since 2021

To further improve the understanding of the fault's near-surface expression and behaviour that could have more direct implications for the connectivity, OGIA undertook a major re-evaluation between 2023 and 2025 – focusing on refining the understanding of two key areas where localised pathways might exist: the geological characteristics of the Horrane Fault; and better characterisation of the subcropping geology at the base of the Condamine Alluvium. More specifically, the investigations included the following which are further detailed in separate documents, particularly a synthesis of the connectivity in Schöning et al. (2025):

- an AEM survey covering more than 2,000 km of flight survey lines, providing high-resolution geophysical data to improve geological mapping and resolve the near-surface expression of key structural features, like the Horrane Fault system (Schöning et al. 2025); the AEM survey is also able to be visualised using an interactive tool on OGIA's website[7]
- development of a new sub-regional 3D geological model that integrates the new AEM data with a comprehensive re-interpretation of existing seismic, petroleum well, coal bore and water bore datasets (Bui Xuan Hy et al. 2025)
- re-evaluation of hydrogeological datasets, including a new groundwater level trend analysis (Erasmus et al. 2025)
- a comprehensive hydrochemical re-assessment to identify potential evidence of connectivity pathways (Harris-Pascal, Flook, et al. 2025 in prep.)
- a probabilistic estimate of the potential leakage through historical coal exploration bores ('coal holes'), in order to guide and constrain future assessments
- refined conceptual understanding of the relationship between the Condamine Alluvium and the Walloon Coal Measures, with a particular focus on characterising the near-surface expression of the Horrane Fault system.

7.5.5.3 Current hydrodynamic conditions

Historically, water pressures in the deep bedrock were higher than in the alluvium, further exacerbated by groundwater extraction in the Condamine Alluvium for consumptive use over several decades. This implied that the natural head gradient had been predominantly upward across most of the alluvium footprint (Figure 7-18, left panel). As anticipated, CSG depressurisation over the last few years is gradually reversing that gradient (Figure 7-18, right panel), creating conditions for potential

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[7] www.ogia.water.qld.gov.au/products-tools

leakage of water from the Condamine Alluvium. For the impact to occur, however, a pathway through which water can flow must also occur.

Groundwater levels in the Condamine Alluvium show complex trends, influenced by several factors including climate, river leakage and consumptive water use. Long-term trends generally show a decline in groundwater levels coinciding with the commencement of groundwater pumping for agricultural use, stabilising or rising from the 2010s as water management practices changed, with a further recent increase from early 2020s in response to increased rainfall. Impacts to groundwater levels in the Condamine Alluvium resulting from CSG production have not yet been identified, despite depressurisation of the underlying Walloon Coal Measures at a number of locations and the reversal of hydraulic gradients identified in the previous section (Figure 7-18). A more detailed analysis of groundwater levels and trends can be found in Chapter 9 (section 9.7.4) and Erasmus et al. (2025).

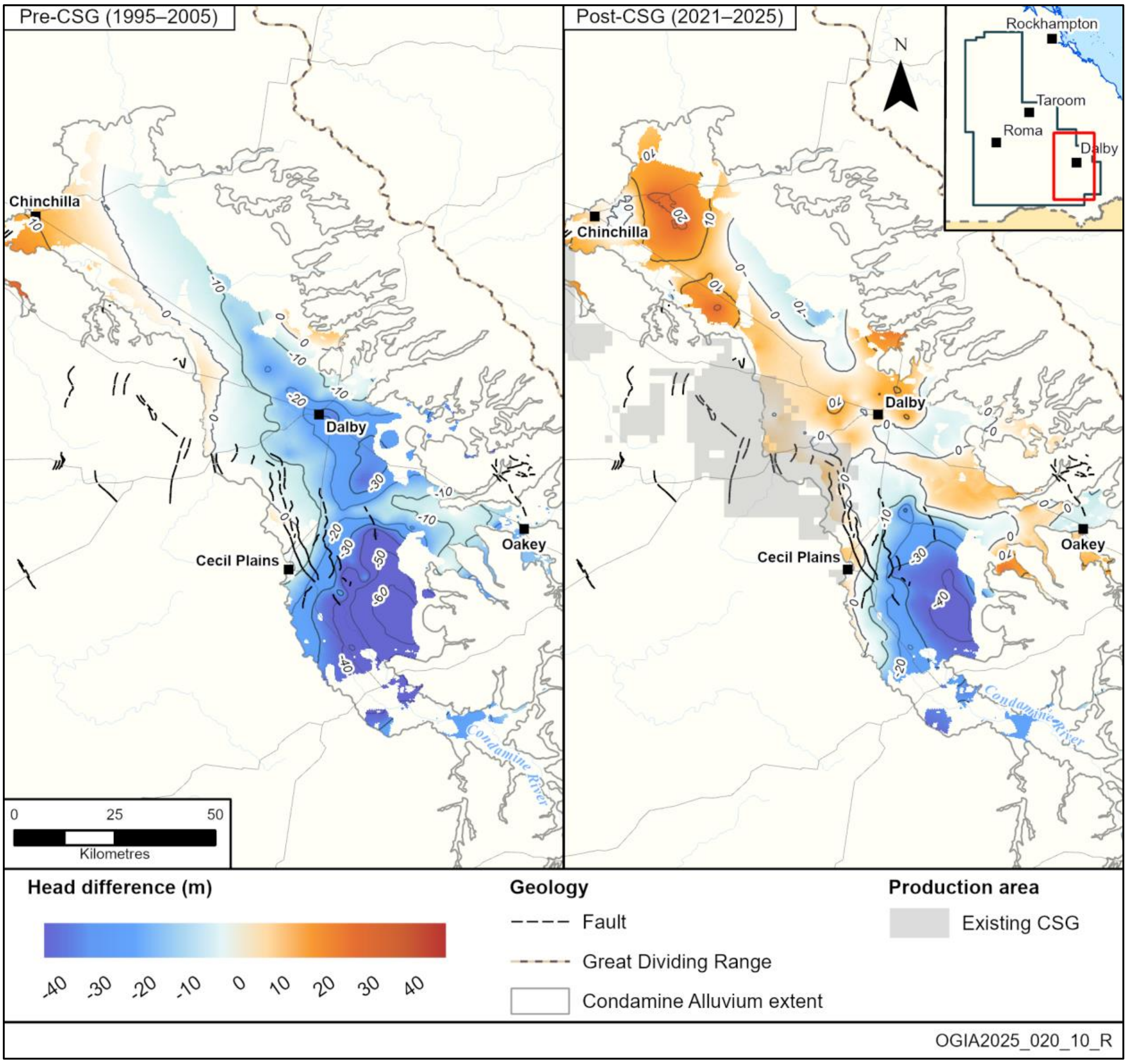


Figure 7-18: Pre-CSG and post-CSG hydraulic head difference – Springbok Sandstone and Walloon Coal Measures to Condamine Alluvium

7.5.5.4 Results of the re-evaluation

The AEM survey provided valuable new insights into the shallow subsurface, enhancing geological mapping to a depth of 200 m for a more refined mapping of the Horrane Fault system's near-surface expression (Schöning et al. 2025) and successfully resolving the fault system's complex near-surface geometry, identifying a greater number of faults than previously mapped. It also enabled the mapping of potential 'geological windows', at the base of the alluvium, where different bedrock units subcrop instead of the Walloon Coal Measures – providing an extra layer for impediment of flow, as illustrated in Figure 7-19. More refined mapping of these various features from the AEM survey has contributed to revised geological mapping, which also lays the foundation for a more detailed groundwater flow model for the Condamine Alluvium in the future.

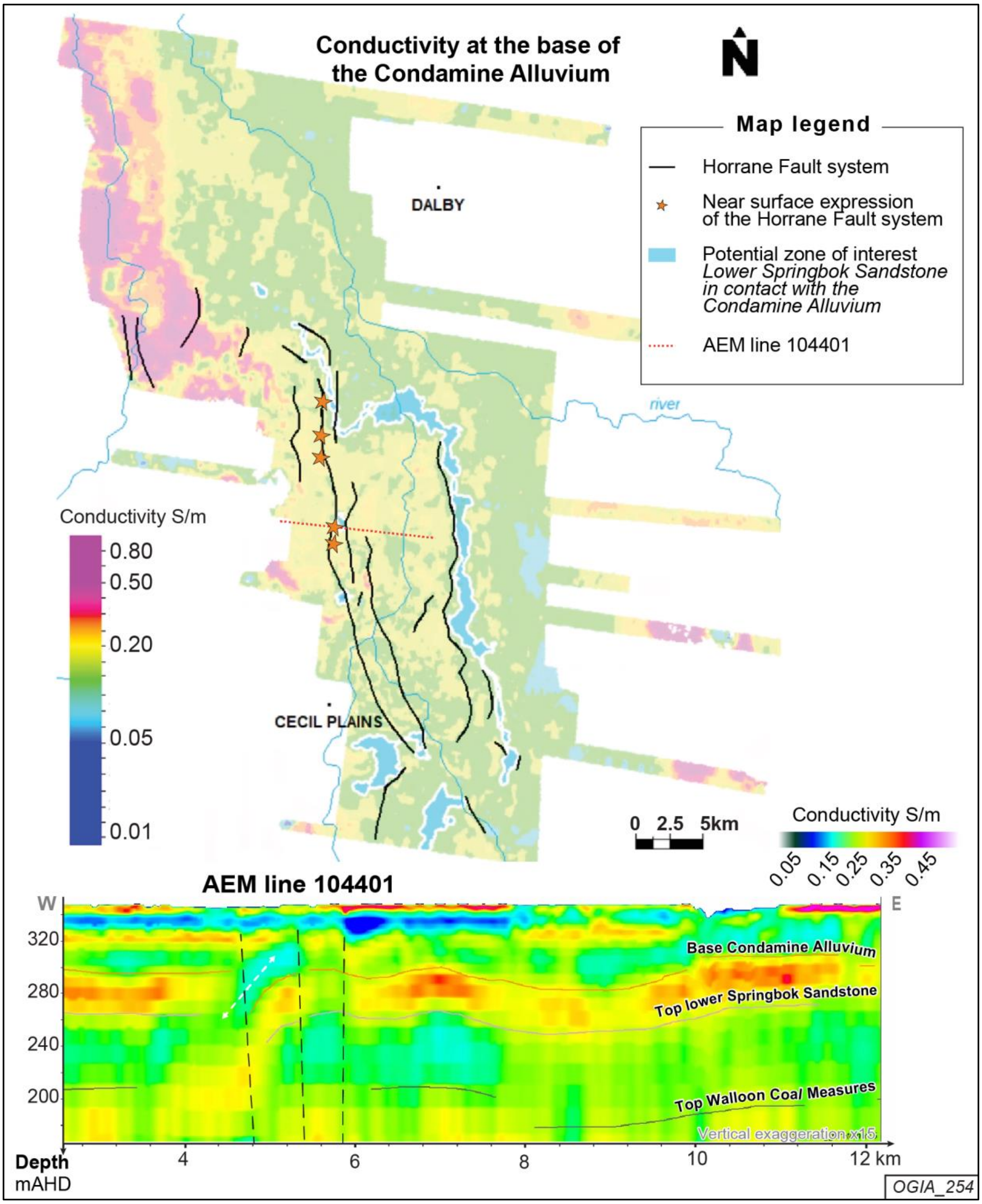


Figure 7-19: Potential features of locally enhanced connectivity at the base of the Condamine Alluvium (top) and AEM line across the Horrane Fault system (bottom)

The hydrochemistry re-evaluation has affirmed that there is no widespread connection between the two systems; it did, however, find chemical signatures of bedrock influence in some localised areas, particularly near the Horrane Fault or where the protective transition zone is mapped as thin or absent. For instance, elevated methane levels were found near the Horrane Fault, indicating that gas may be migrating upward through this structure at some places. While these chemical indicators confirm the existence of localised pathways, they do not provide information about the magnitude of water movement, or flux, between the units.

An analytical assessment of net flux change that may have already occurred due to CSG-induced depressurisation in the Condamine Alluvium is estimated to be around 300 ML/year. This probabilistic estimate, which includes all system drivers, is broadly consistent with model predictions in the previous UWIRs. An explicit and probabilistic assessment of potential leakage induced by historical coal exploration holes concluded that their impact on the total flux is relatively small compared to the natural geological pathways – most likely comprising less than 10% of the total net flux in the post-CSG period.

Overall, the new information has reinforced the primary conclusion that while regional connectivity between the Condamine Alluvium and the Walloon Coal Measures remains low, a more detailed understanding now shows that connectivity is focused along specific structural (faults) and geological features (windows). This new information provides a foundation for the next generation of predictive numerical groundwater modelling and the strategic design of targeted future monitoring programs. Instead of generalised, regional risk management and monitoring, these can now be focused on the specific areas that have the highest potential for connectivity. More details are available in Harris-Pascal et al. (2025).

7.5.6 Impact pathways to groundwater-dependent ecosystems

7.5.6.1 Springs and watercourse springs

Groundwater discharge to springs and watercourses occurs across the central, northern and eastern margins of the Surat CMA (Chapter 6). 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
- the discharge environment.

Springs typically form through three main hydrogeological mechanisms: changes in aquifer hydraulic properties that restrict vertical flow and promote lateral movement; geological structures, such as faults, that create pathways for groundwater to reach the surface; and landscape erosion or dissection by surface water that exposes subsurface flow paths. These mechanisms may also occur concurrently and the understanding of them 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 7.5.4) and conventional oil and gas development at Moonie. In both cases, for impact to occur at the springs, drawdown is required to propagate laterally within the

Precipice Sandstone as illustrated in Figure 7-20. Springs fed by the Hutton Sandstone have a similar impact propagation pathway.

The Lucky Last spring complex is an exception, where the source aquifer is the Boxvale Sandstone. At this location, impacts are likely to propagate laterally in the Precipice Sandstone and then vertically along the Hutton-Wallumbilla Fault zone to the Boxvale Sandstone.

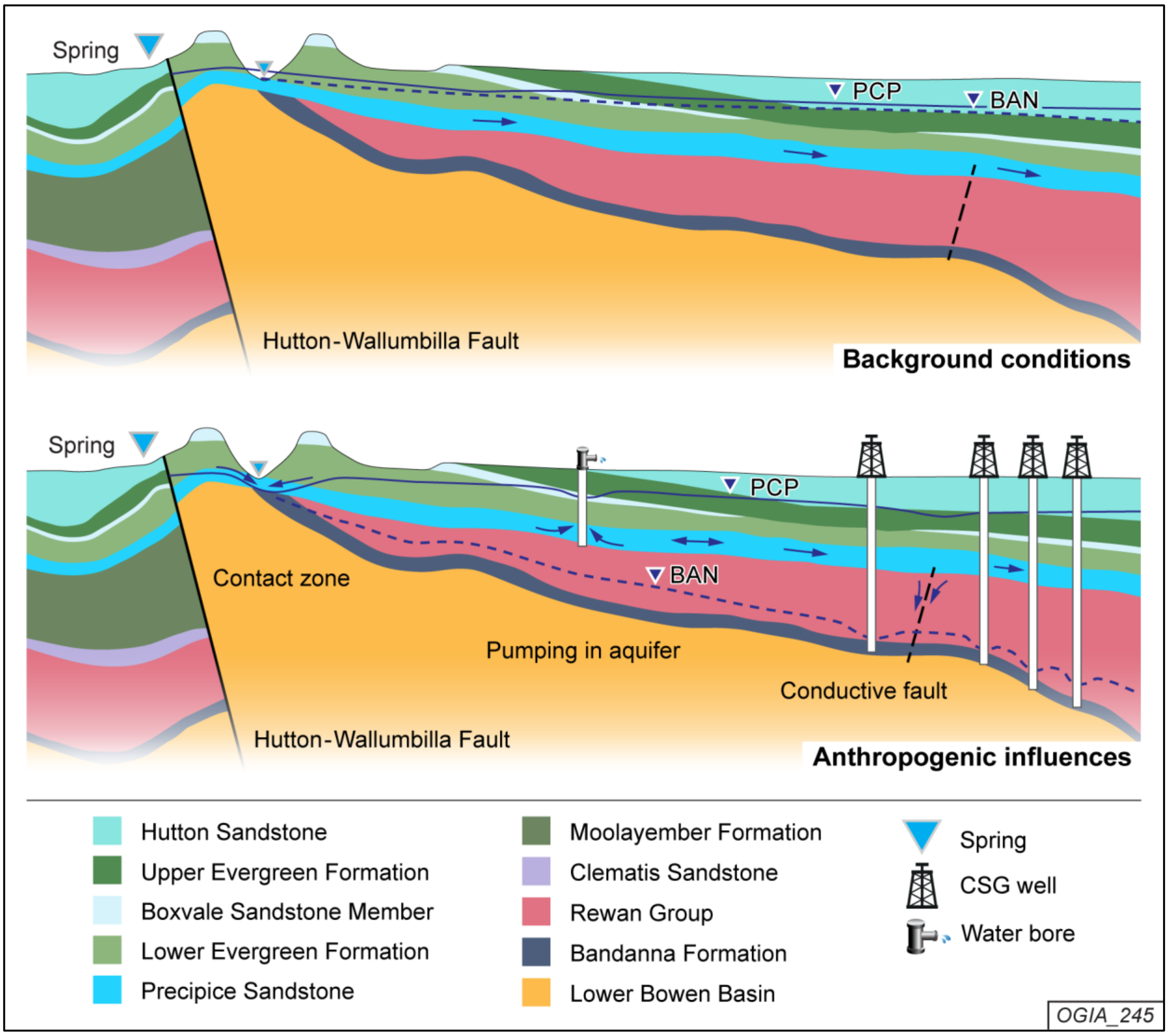


Figure 7-20: Potential impact pathway mechanisms using the western contact zone area as an example

7.5.6.2 Terrestrial GDEs

TGDEs are areas where vegetation depends on groundwater, either seasonally or year-round, typically found near aquifer outcrops, shallow subcrops, or where the water table is close enough for roots to access.

The main mechanisms by which TGDEs may be impacted are similar to those affecting springs and watercourses, as shown in Figure 6-1. The primary concern is a decline in groundwater levels from the source aquifer – whether confined or unconfined – that can affect vegetation productivity, biodiversity and reproduction. These impacts may first appear as reduced growth in the short term, with longer-term drawdown potentially leading to biodiversity loss and changes in ecosystem structure.

7.6 Summary of impact pathways

- Depressurisation from CSG production creates a pressure difference between the target formation and adjacent aquifers that may induce groundwater flow (impact) from those aquifers towards the target formation.
- The quantum of impact primarily depends on the pressure difference between the two formations created by depressurisation, and the degree of connectivity, which is influenced by geological characteristics.
- Impacts from CSG depressurisation propagate much further horizontally, along permeable coal seams, than they do vertically through low-permeability interburden.
- Open-cut coal mining creates more localised drawdown impacts compared to the widespread depressurisation from CSG development, though there can be interaction between drawdown from the two activities where they overlap.
- CSG depressurisation also causes some underground compaction of coal seams that may manifest as subsidence at the surface.
- The connectivity between the Walloon Coal Measures and the overlying Springbok Sandstone is complex, with localised connectivity enhanced by faults in some areas – as reported previously.
- There are an estimated 18,000 exploration coal holes but they pose only a minor to negligible risk to groundwater connectivity.
- Connectivity between the Walloon Coal Measures and the underlying Hutton Sandstone is very low due to the highly effective Durabilla Formation barrier, also as reported previously.
- In the northern part of the CMA, there is a high degree of connectivity between the Permian coal measures and the Precipice Sandstone in two specific contact zones, eastern and western.
- Revaluation of the connectivity between the Condamine Alluvium and the underlying Walloon Coal Measures through new major AEM and hydrochemistry investigations have reaffirmed the previous assessment that while regional connectivity between the Condamine Alluvium and the Walloon Coal Measures is low, it is focused along specific localised pathways such as the Horrane Fault and 'geological windows'.
- This detailed conceptual understanding of impact pathways is the foundation for the structure of OGIA's groundwater models, the design of the monitoring network, and the development of impact management strategies.

Chapter 8 Development of modelling tools

8.1 Preamble

OGIA has developed and continues to develop a range of tools to support conceptualisation, assess and decompose trends from historical data, and make predictions. Tools and methods include the estimation of unmetered water use and trend analysis, as described in Chapter 5 and Chapter 9, respectively. A summary of the modelling methods employed by OGIA in making predictions is provided in this chapter, with additional details available in the UWIR modelling report (Cui, Gallagher, et al. 2025). The development profile that underpins the predictions in this UWIR is detailed in Chapter 3.

8.2 Terminology

Impact – the change in groundwater pressure or groundwater level in response to associated water extraction by the resource development activities – CSG, coal mining and conventional oil and gas.

Model – a set of computer codes prepared for a specific groundwater system, using mathematical equations to represent complex geological systems and groundwater flow, so that it can receive input – such as when and where groundwater is extracted (or planned) – and generate output in response, such as groundwater level changes.

Regional model – the groundwater flow model covering the entire Surat CMA to underpin the making of predictions presented in the UWIR.

8.3 Purpose of the modelling

The specific purpose of each modelling exercise drives the scale, structure, calibration approach and uncertainty analysis of the model. For example, a model can be designed to assess sustainable extraction, allocation and management of groundwater for consumptive use, to test groundwater processes/conceptualisation, or to assess and manage impacts from a development. Separate modelling methods and tools are required to suit different purposes, and it is rarely the case that a single model can fulfil all those purposes.

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

8.4 Key stages in modelling

A process flow diagram detailing critical stages of UWIR groundwater modelling is presented in Figure 8-1. These elements can be grouped into four, somewhat sequential, stages:

1. *Conceptualisation.* Available data, information and investigations are used to develop a conceptual understanding of geology, groundwater flow systems, inter-aquifer connectivity and impact pathways in response to stresses imposed by associated water extraction, such as the conceptualisation presented in Chapter 7.

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 elevations, the model grid and other elements – as described in this chapter.
3. *Model calibration.* Once constructed, the model is then calibrated based on monitored groundwater levels, extraction rates, estimated ground motion 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 observed data – as detailed in section 8.9.
4. *Predictions and uncertainty analysis.* The model is run with an input scenario – a development profile – to derive predictions of changes of groundwater levels, flux between different units and ground motion, in response to that particular scenario. As more than one set of parameters can calibrate to a single set of observations (mathematically referred to as 'non-uniqueness'), there could be multiple valid models. Further uncertainty analysis is therefore undertaken to create a large set of models that would still calibrate to the observation data. Predictions for the same input scenario are then generated from each of those models to provide a set of valid predictions to derive the most probable outcome (50th percentile, P50) as well as the upper limit (95th percentile, P95) and lower limit (5th percentile, P5) of potential outcomes.

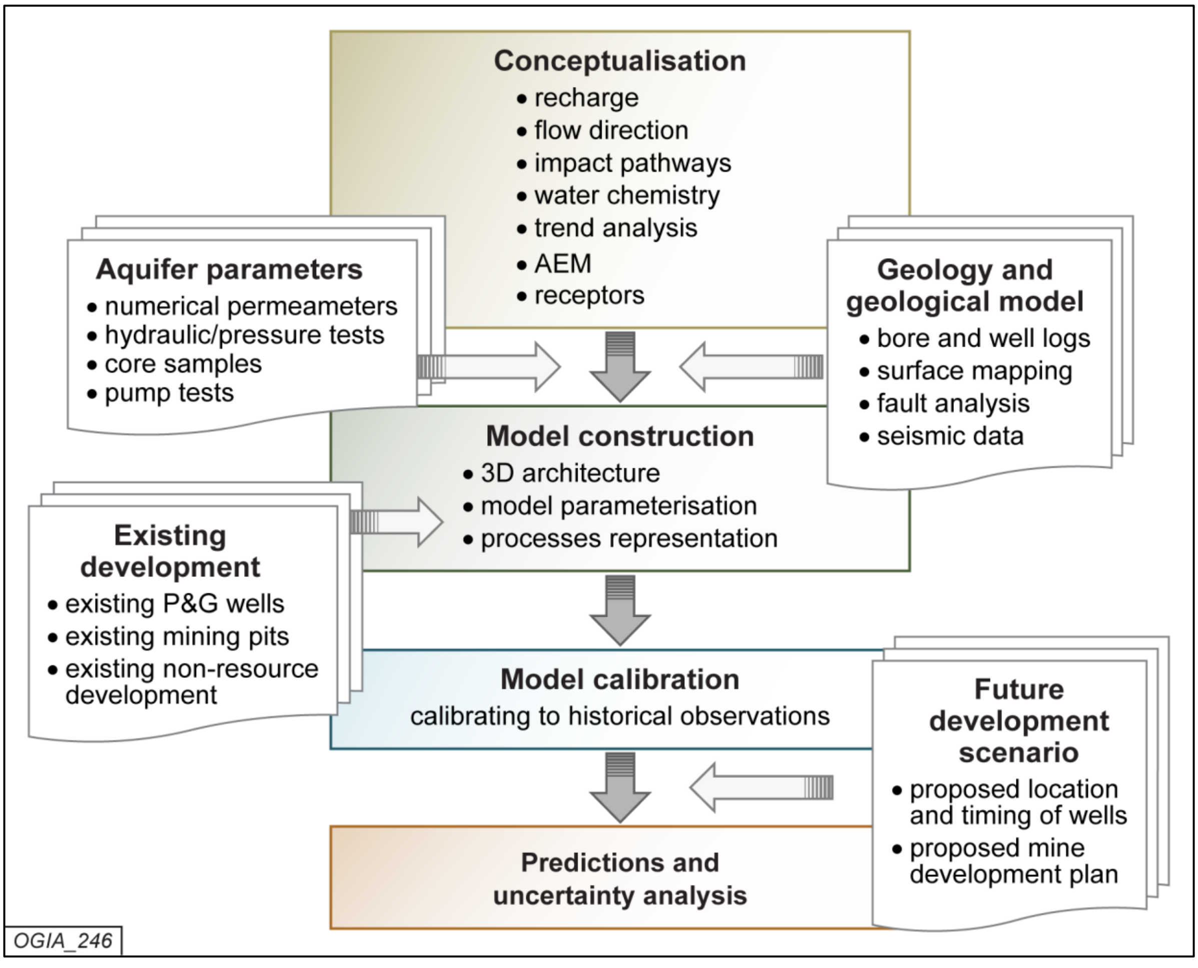


Figure 8-1: Process flow diagram for groundwater flow modelling in the Surat CMA

8.5 Unique modelling challenges in the Surat CMA

The UWIR modelling is for the assessment of impact in surrounding formations in a multi-aquifer system. As discussed in Chapter 4, the geology of the Surat CMA is complex, comprising more than 20 geological formations, erosional contacts and structural offsets with considerable lateral and vertical heterogeneity. Most individual aquifers of the multi-layered system are exposed at the surface and can also be more than a kilometre deep at other locations. CSG is produced from coal formations layered within this complex system, within which there are also multiple coal seams that are targeted for CSG development. In this context, some of the key modelling challenges are as below:

- a large-scale model domain covering an area of about 650×450 km (almost 300,000 km^2) and tens of geological formations
- a significant period over which CSG and mining development is expected to occur – spanning more than 75 years; the model needs to predict the long-term future impact in thousands of years
- critical vertical hydraulic connections both within and between aquifers; these are often more difficult to assess than horizontal hydraulic connections due to the limitation of data availability and slow response of the intervening aquitards
- coal measures comprising numerous thin coal seams and interburden units; due to the lack of information about individual seams and the long computational time required to simulate individual seams, these are often impossible to model as separate layers in groundwater models
- integration of coal mining impacts with CSG impacts; while coal mines are relatively isolated and located within outcrop areas that interact more with shallow hydrogeological processes, CSG development targets the same formation in the deeper part
- dual-phase flow effects near CSG-wells during coal seam depressurisation must be considered with a regional groundwater flow model
- representation of geological faults that extend into both the Surat and Bowen basins
- definition of upscaled parameters that are commensurate with the regional scale of the assessment, conditioned to available borehole measurements
- history-matching the model to a large quantity and various types of monitoring data, such as groundwater levels, water production and ground motion
- CSG-induced subsidence comprising multiple interactive processes, including poromechanical compaction of coal and interburden materials, and coal shrinkage that cannot be handled in subsidence packages designed for standard groundwater modelling.

8.6 Modelling approach

8.6.1 Historical approach

OGIA's approach to modelling has evolved, as has the numerical model itself, since the first regional model for the UWIR 2012 as summarised below:

- 2012: the first model was largely based on secondary information and developed using a standard version of MODFLOW 2005 modelling code.

- 2016: a fundamentally new approach was developed, supported by significant research, testing and development of innovative tools by the OGIA team – particularly in relation to the representation of dual-phase flow. The model was constructed in MODFLOW-USG with a number of code customisations and a revised conceptualisation (Herckenrath, Doherty & Panday 2015).
- 2019: the regional groundwater flow model included a number of further refinements, with the incorporation of additional major faults and simulation of Walloon Coal Measures CSG wells partially completed into the overlying Springbok Sandstone.
- 2021: the approach shifting to representation of more localised features of interest, significant refinement of the underlying geological model, integration of coal mining and development of regional CSG-induced subsidence models.

8.6.2 Current approach (2025)

In the current UWIR cycle, OGIA has implemented specific improvements to the modelling of impacts in terms of process representation and calibration methodology. Major updates of the current modelling include the following:

- development and implementation of a regional and **integrated groundwater flow and geomechanical model** that is simultaneously calibrated to groundwater and ground motion data – allowing concurrent predictions of groundwater impacts and subsidence, as well as maximising the value of calibration datasets
- development of a new high-resolution sub-regional geological model for the Condamine Alluvium footprint, integrating recent AEM data with a comprehensive reinterpretation of existing seismic, petroleum well, coal bore and water bore datasets (Bui Xuan Hy et al. 2025)
- development of a new recharge estimation workflow that generates a unique and transient recharge model for each outcrop zone based on daily rainfall and evaporation sequences pertinent to each outcrop – the new workflow also incorporates more precipitation data into the model calibration process
- refinement of the representation of deviated CSG wells, to improve impact and water production assessment
- extension of the calibration period to December 2022 using additional and up-to-date monitoring data, and refinement of the water production calibration, for better performance.

A detailed description of the modelling methods is available in OGIA (2025).

8.6.3 Approach to modelling CSG-induced subsidence

Modelling of CSG-induced subsidence for the current UWIR is specifically for the purpose of predicting regional-scale subsidence to support assessing impacts on environmental values, as required in the DETSI guideline (Department of Environment, Tourism, Science and Innovation 2025). For the avoidance of doubt, subsidence modelling is not for assessing farm-scale impacts; OGIA has developed and tested separate tools and models for a pilot project outside the UWIR scope.

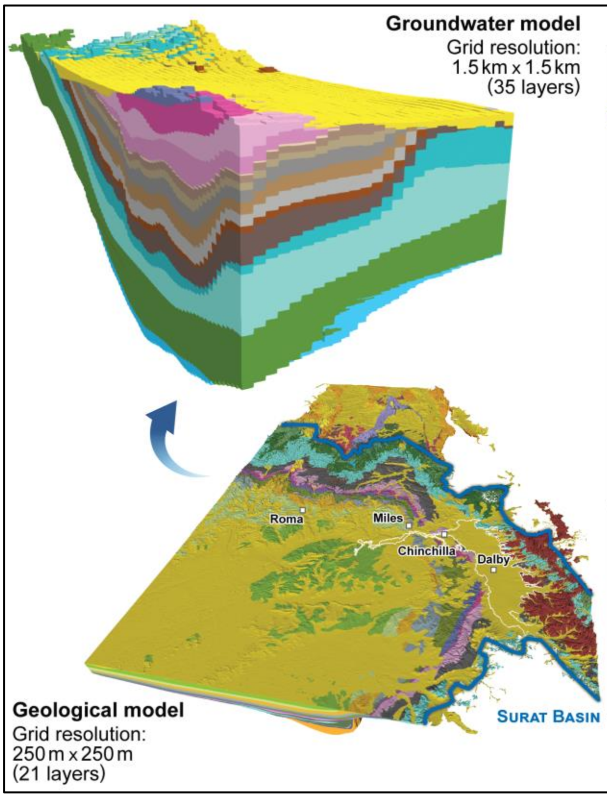
For this UWIR, groundwater flow and geomechanical models are coupled and simultaneously calibrated, in an innovative approach developed by OGIA. Peer-reviewed and accepted for journal publication (Cui, Schoning, et al. 2025), the approach allows concurrent predictions of groundwater impacts and subsidence. The primary novelty of the approach is its ability to efficiently model pressure changes and CSG-induced subsidence at the regional and sub-regional scales, although not necessarily through a single model. This is achieved by integrating pseudo-dual-phase flow formulation, dual-domain flow parameterisation and shrinkage modelling based on the Langmuir equation. This approach also allows simultaneous calibration to groundwater levels, water production and ground movement, to maximise the use of available data.

8.7 The modelling suite

A suite of models forms an integrated framework that underpins the UWIR impact assessment. A brief summary of these models is provided in this section, with more technical details of these models available in OGIA (2025).

- A **regional groundwater flow model** (the regional model) – the foundation groundwater flow model comprising 35 layers at 1.5×1.5-km grid resolution, covering a domain of 650×450 km (Figure 8-2). 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, geological faults and subsidence calculation. 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). Used to derive prior distribution of key model parameters including hydraulic conductivity and specific storage, these models play a critical role in model calibration and predictive uncertainty analysis.
- **New 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.
- **Recharge model** – an ensemble of transient recharge models for each of the 24 outcrop zones. The models are calibrated to long-term recharge estimation from chloride mass balance analysis and generate recharge time series for different outcrop zones.
- **Regional geological model** – at a scale of 1.5 km, the geological model provides the structural framework for the groundwater flow model, representing all the major formations of the Surat and Bowen basins in 21 layers (Figure 8-2), based on seismic data, water bore drill logs, CSG well logs, and surface and solid geology.
- **Condamine geological model** – a new high-resolution 3D sub-regional geological model for the Condamine Alluvium footprint, at a scale of 250 m (Figure 8-3), integrating recent AEM data with a comprehensive reinterpretation of existing seismic, petroleum well, coal hole and water bore datasets.

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, and Wandoan Coal Project). 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.



Basin	Hydrostratigraphic units		Model layer	
	Geological model	Groundwater model	Geo*	GW*
	Cenozoic - Alluvium and Volcanics		1	1
Surat & Clarence-Moreton basins	Upper Cretaceous		2	2
	Wallumbilla Formation		3	3
	Bungil Formation		4	4
	Mooga Sandstone		5	5
	Orallo Formation		6	6
	Gubberamunda Sandstone		7	7
	Westbourne Formation		8	8
	Springbok Sandstone	Upper Springbok Sandstone	9	9
		Lower Springbok Sandstone		10
	Walloon Coal Measures	Non-productive zone	10	11
		Upper Juandah Coal Measures		12-13
		Lower Juandah Coal Measures		14-16
		Taroom Coal Measures		17
	Durabilla Formation		11	18
	Hutton Sandstone	Upper Hutton Sandstone	12	19
		Lower Hutton Sandstone		20
	Upper Evergreen Formation		13	21
	Boxvale Sandstone		14	22
	Lower Evergreen Formation		15	23
	Precipice Sandstone		16	24
Bowen Basin	Moolayember Formation		17	25
	Clematis Sandstone		18	26
	Rewan Group		19	27
	Bandanna Formation	Non-productive zone	20	28
		Upper Bandanna Formation		29
		Lower Bandanna Formation		30
	Bowen Basin	Undivided upper Bowen Basin	21	31
		Non-productive zone		32
		Upper Cattle Creek Formation		33
		Lower Cattle Creek Formation		34
		Undivided lower Bowen Basin		35

*Geo: Geological model *GW: Groundwater model

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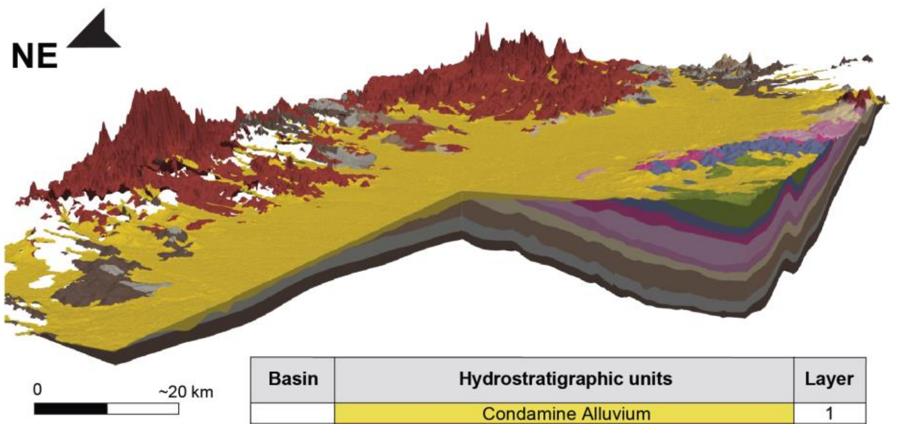
Figure 8-2: Schematic representation of the regional model layering



Geological model
Grid resolution:
250 m x 250 m
(11 layers)

Basin	Hydrostratigraphic units		Layer
	Condamine Alluvium		1
Surat & Clarence-Moreton basins	Main Range Volcanics		2
	Orallo Formation		3
	Gubberamunda Sandstone		4
	Westbourne Formation		5
	Springbok Sandstone	Upper Springbok Sandstone	6
		Lower Springbok Sandstone	7
	Walloon Coal Measures	Upper Juandah Coal Measures	8
		Lower Juandah Coal Measures	9
		Taroom Coal Measures	10
	Durabilla Formation		11

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Figure 8-3: Schematic representation of the Condamine geological model

The 2023 updated New Acland model is integrated by OGIA to assess cumulative impacts from the New Acland mine. A significant update of the 2018 New Acland model used in UWIR 2021, the updated New Acland model aims to be more in line with the current standard modelling practices and calibrated with more recent observations. The model is designed to assess the potential impact of the New Acland coal mine and has detailed representation of the local geology and hydrogeology. OGIA has conducted sensitivity analysis to ensure the predicted impact is conservative and precautionary.

8.8 Data availability

From developing model architecture to model parameterisation and calibration, significant volumes of data have been collected and assimilated. While not an exhaustive list of data used for UWIR groundwater modelling, Table 8-1 provides a high-level summary of such datasets and their application in the modelling process.

Table 8-1: A list of the key datasets processed to support the UWIR groundwater modelling

Dataset category	Volume/Note	Use in UWIR modelling
Geology	Seismic data from more than 300 (2D) and about 12 (3D) surveys; more than 20,000 water bore drill logs; about 7,700 CSG well logs; and surface and solid geology from GSQ and Cranfield (2017)	Model architecture
Hydrodynamics	Annual estimates of groundwater use from about 30,000 bores; monitoring bore data; monthly volumes for more than 10,000 wells; and about 40,000 records from more than 600 monitoring bores	Processes (non-CSG and CSG extraction); calibration targets
Development plans	CSG development plans and mine development plans	Processes (river package)
Recharge	Precipitation and evapotranspiration data between 1995 and 2023 from 24 stations; long-term recharge based on more than 12,000 chloride samples; reinjection volumes	Processes (recharge)
Hydraulic properties	Drill stem tests, pumping tests and core tests from about 12,000 measurements; methane adsorption tests	Parameterisation
Ground motion	InSAR measurements from about 400 million records at around 1 million sites	Calibration target

8.9 Calibration and uncertainty analysis methodology

There is a significant difference between traditional model calibration, which aims to produce an optimal calibrated model, and uncertainty analyses that generate stochastic samples of the posterior parameter distribution. The former attempts to suppress all parameter heterogeneity that is not required for a model to reproduce historical system response, while ensuring that any heterogeneity that does arise in this process adheres to known geological precepts. Calibration-constrained uncertainty analysis conversely attempts to express all heterogeneity in a manner that is geologically sensible, provided it remains compatible with historical system response. The extent to which parameter uncertainty is reduced from its prior uncertainty for a particular parameter depends on the information content of the calibration dataset with respect to that parameter.

In the current UWIR, to leverage the strength of both methods, a calibration strategy was implemented by combining PEST_HP (Doherty 2024) and PESTPP-IES (White 2018). Calibration of the regional groundwater flow model involved three sub-stages as summarised in Table 8-2.

Table 8-2: Stages in the regional model calibration

Period	Type of calibration	Groundwater stresses	Outcome
End of 1947	Steady state	None	Pre-development conditions
End of 1995	Steady state	Groundwater use	Pre-CSG conditions
1995–2022	Transient	Groundwater use + associated water extraction	Post-P&G (CSG and conventional) + coal mining

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, InSAR-estimated ground motion and formation-scale groundwater use. The overall performance of the calibrated regional model for transient groundwater levels in the key stratigraphic units, as measured by rooted mean square (SRMS), is 4.8% – indicating a well-calibrated model (Barnett et al. 2012).

8.10 Predictive model setup

The model was set-up to run in predictive mode for 2023 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 (excluding all associated water extraction)
- a **production run** that includes both groundwater use and associated water extraction, based on the sequencing of development for production tenures (refer to Chapter 3 for details).

The difference in predicted groundwater levels between the base and production runs then provides the prediction of groundwater level and flux changes resulting from past associated water extraction and planned future resource development. Predictions are made on a quarterly basis from 2023 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 Unconventional Gas Development 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 500 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 500 model runs are extracted for each model layer at each of the 1.5×1.5-km model cells. For the purposes of determining impacts (IAA bore identification) for the UWIR 2025, the P50 predictions are utilised. Results of predictions are presented in Chapter 10.

8.11 Summary of modelling tools

- The modelling tools are designed for the specific purpose of predicting changes (impacts) in in response to the extraction of groundwater by CSG, coal mining and conventional oil and gas development.

- Modelling is complex, with significant challenges associated with a multi-layered groundwater system, faulting, a large model domain, dual-phase flow processes and representation of vertical hydraulic connections across multiple formations.
- OGIA's approach to modelling has evolved to include development of several innovative modules to represent dual-phase flow, faults, complex lithology and geomechanical processes.
- Significant further improvements in the current modelling include integration of groundwater flow and a geomechanical model to simultaneously calibrate to groundwater and ground motion data – allowing concurrent predictions of groundwater impacts and subsidence, as well as maximising the value of calibration datasets.
- A suite of models is used for the cumulative impact predictions, including a 35-layer regional groundwater flow model covering a domain of 650×450 km, underlying numerical permeameters for detailed lithology-scale groundwater models, integration of the New Acland model, a recharge model, a regional geological model and a more detailed separate geological model for the Condamine Alluvium.
- The regional model is calibrated using groundwater use from about 30,000 bores, CSG water production, 40,000 records from more than 600 monitoring bores and several other datasets.
- The overall measure of the performance of the calibrated regional model classifies this as a well-calibrated model.
- Predictions are made on a quarterly basis from 2023 to 2070, then at progressively greater intervals from 2070 to the year 10000.
- Uncertainty analysis using a total of 500 calibrated parameter sets is compiled to derive the most probable outcome (P50) as well as the upper and lower bounds (P95 and P5).

Chapter 9 Assessment of existing and historical impacts from monitoring data

9.1 Preamble

Fluctuations and trends in groundwater levels and chemistry, as reflected in monitoring data, are collectively influenced by multiple stresses including resource development, non-resource activities – such as groundwater use for agriculture and town water supply – and climatic factors. Analysis of monitoring data is therefore essential to isolate resource-related effects (impacts) from those other influences. This chapter summarises the analysis approach and results to determine impacts that have occurred so far from CSG and coal mining in the Surat CMA. Additional technical details are available in a separate document (Erasmus et al. 2025).

9.2 Terminology

Groundwater level – groundwater level or pressure in an aquifer, as described in previous chapters.

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

Hydraulic gradient – change in groundwater level over a certain distance. This gradient is the primary driving force for groundwater flow, causing water to move from areas of higher elevation, or higher pressure, to areas of lower elevation or pressure.

9.3 What affects groundwater levels

The observed groundwater level in an aquifer at any point in time is a composite representation of multiple influences acting on the groundwater system, as illustrated in Figure 9-1. In its natural state, prior to development, the groundwater level signifies a dynamic equilibrium between natural recharge (inputs) and discharge (outputs). When recharge rates exceed discharge, groundwater levels rise; conversely, when discharge is greater, they fall.

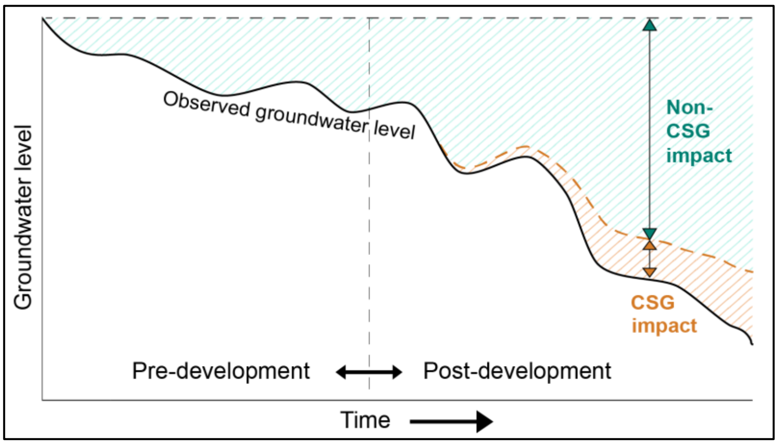

Figure 9-1: Schematic showing the combined effect of resource development and water use on groundwater levels

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 or 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 recharge will tend to result in a declining groundwater level trend. Monitoring points closer to recharge areas typically show a more defined response to variations in rainfall. Further from recharge areas, monitoring points 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, compared to smaller groundwater systems, such as the Condamine Alluvium.

Highly permeable aquifers (such as the Precipice Sandstone) allow water to flow easily, distributing the impact of water extraction over a very large area, resulting in drawdown that is shallow but widely spread. On the other hand, low-permeability aquifers (such as the Springbok Sandstone) impede water flow, resulting in smaller areas of influence with relatively deeper drawdown.

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

Disaggregating the impacts of climate variability, general groundwater use, and induced flow from resource-related water extraction is a significant challenge, as none of these individual components can be measured directly. While other minor factors, such as barometric pressure changes and loading effects, can also influence groundwater levels, they are typically negligible compared to the primary drivers of recharge and discharge.

9.4 Data availability

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

Since the commencement of CSG development around 2010, there has been a steady increase in monitoring infrastructure in deeper formations around the CSG tenures, where tenure holders have established monitoring points in response to UWIR requirements or for their own specific purposes.

Table 9-1 provides the number of monitoring sites with data that is available to OGIA for the purpose of the analysis presented in this chapter. In general, the number of sites with water pressure monitoring suitable for trend analysis has increased across most formations. Strontium isotope monitoring has expanded, with 90 new time-series sites added across the Bandanna Formation and Walloon Coal Measures.

Table 9-1: Groundwater monitoring sites with data suitable for trend analysis, 2021 and 2025

Formation	Groundwater level monitoring sites			Hydrochemistry monitoring sites		
	UWIR 2021	UWIR 2025		UWIR 2021	UWIR 2025	
		Total	With new data*		Total	With new data*
Condamine Alluvium	426	411	216 (53%)	297	202	5 (2%)
Springbok Sandstone	61	95	80 (84%)	51	34	6 (18%)
Walloon Coal Measures	268	492	327 (66%)	623	654	104 (16%)
Hutton Sandstone	150	166	126 (76%)	122	78	17 (22%)
Precipice Sandstone	80	93	67 (72%)	85	81	29 (36%)
Bandanna Formation	31	81	49 (60%)	59	80	28 (35%)
Total	**1,016**	**1,338**	**865 (65%)**	**1,237**	**1,129**	**189 (17%)**

Note:
* = subset of UWIR 2025 monitoring points with water pressure or hydrochemistry records updated since 2021.

9.5 Approach to analysis of monitoring data

The primary approach involves a comparative analysis of trends before and after the commencement of a specific resource activity – particularly CSG depressurisation. This requires establishing a pre-development baseline trend in groundwater level and chemistry, then comparing it with the post-development trend to detect deviations that may signal the onset of impacts.

The analysis is built upon a multiple-lines-of-evidence framework, which integrates statistical and visual analysis to correlate observed trends with key influencing factors, such as groundwater use, extraction of associated water, climate data – particularly rainfall as the cumulative deviation from mean monthly rainfall (CDMMR), which is a good indicator of relatively wetter or drier periods – and reinjection of groundwater. A significant general challenge in the Surat CMA is a lack of sufficient historical data from the pre-CSG period to establish robust background trends. A comprehensive description of the technical approach and methodology is available in a separate report (Erasmus et al. 2025). Some of the key features of the methodology are as below.

To estimate the rate of change and direction (increasing or decreasing) in groundwater level data, two methods were applied: the average annual rate of change, and the non-parametric Mann-Kendall test combined with Sen's slope. A modified version of the Mann-Kendall test was used to provide a reliable measure of statistical significance. A key methodological adaptation was required for the Precipice Sandstone, where trend analysis relied on the annual rate of change for both pre-development and post-development periods. For all other monitoring points, the Mann-Kendall test was applied.

To assess the likelihood of different drivers behind groundwater trends, the proximity of monitoring sites to potential impact pathways (such as faults, subcrop, abandoned bores) and in-aquifer stressors (water use, recharge zones, reinjection wells) was evaluated. Potentiometric maps and selected hydrographs were used to interpret regional pressure trends and produce head difference maps (Chapter 7), which are key to understanding vertical groundwater flow and potential CSG impacts.

9.6 Trends in target formations

This section provides a summary of the analysis for the pre-development and post-development periods for target formations – the Walloon Coal Measures and Bandanna Formation.

9.6.1 Walloon Coal Measures

Groundwater levels and flow directions in the Walloon Coal Measures are now primarily driven by depressurisation from CSG development, as shown in Figure 9-2 (for the Upper Juandah and Lower Juandah coal measures) and Figure 9-3 (for the Taroom Coal Measures). While natural groundwater flow is generally consistent with the geological dip of the formation, extensive CSG operations have created significant drawdown, altering these natural gradients. The extent of this impact is linked to the duration and intensity of CSG operations: larger and more extensive declines are observed in the eastern Surat Basin, where development commenced earlier, compared to the more recent development in the northern regions.

A consistent pattern observed across all development areas is that impacts are consistently more pronounced in the deeper subunits of the Walloon Coal Measures – the Taroom Coal Measures – because they are depressurised more, in order to lower the bottom-hole pressure sufficiently for gas to desorb from the coal matrix.

Hydrographs (Figure 9-4) from four representative locations (Figure 9-2) illustrate the current state of CSG-induced depressurisation in the Walloon Coal Measures:

- Tipton-197/RN160751, located south-west of Dalby, represents the southern end of development. A sharp groundwater level decline began in 2023, with drawdown of about 165 m in the deep Taroom Coal Measures, compared to only 11 m in the Upper Juandah Coal Measures. This has created a strong downward gradient at this location.
- Orana MB9-W/RN160710, located further southwest of Chinchilla, demonstrates a progressive impact, where an initial decline from regional pressure changes was accelerated by local CSG production starting in mid-2018. The drawdown is most advanced in the deepest layer (up to 225 m), with significant impacts only beginning to appear in the Upper Juandah Coal Measures in 2023 (currently ~40 m).
- At Glenora-4M/RN160989, located northeast of Roma, a steep decline in groundwater levels coincided directly with the peak of local CSG production in late 2019, leading to drawdown of up to 185 m in the deep Taroom Coal Measures, which has begun to stabilise since 2023.
- Phillip 5M/RN160722, located to the west of Wandoan and representing the newer northern development area, experienced a rapid and steep decline of around 280 m in the deep Taroom Coal Measures, correlating with the start of nearby production in late 2017. In contrast, the impact on the shallower Upper Juandah Coal Measures has been moderate (<15 m).

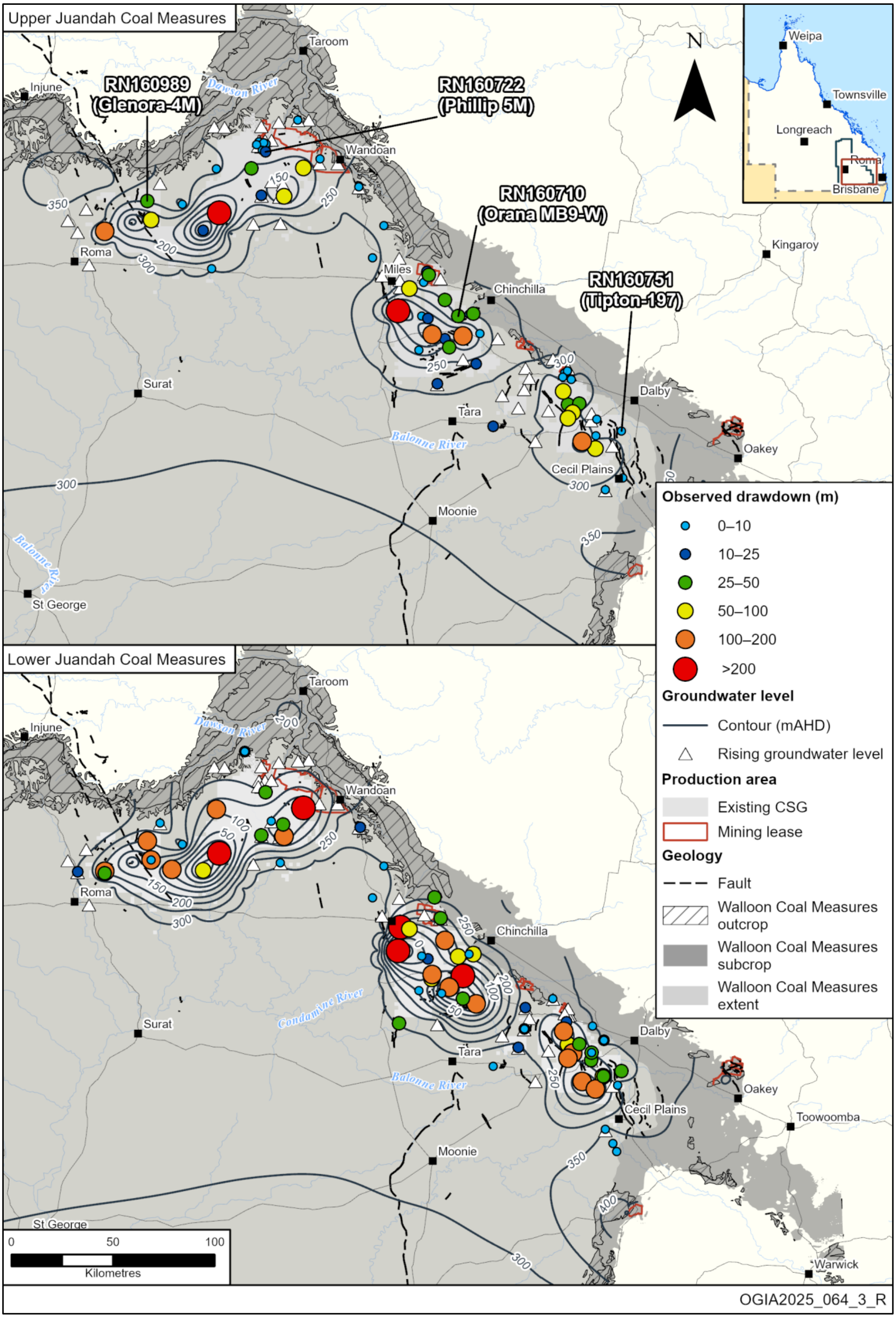

Figure 9-2: Current groundwater levels and observed drawdown in the Upper Juandah and Lower Juandah coal measures

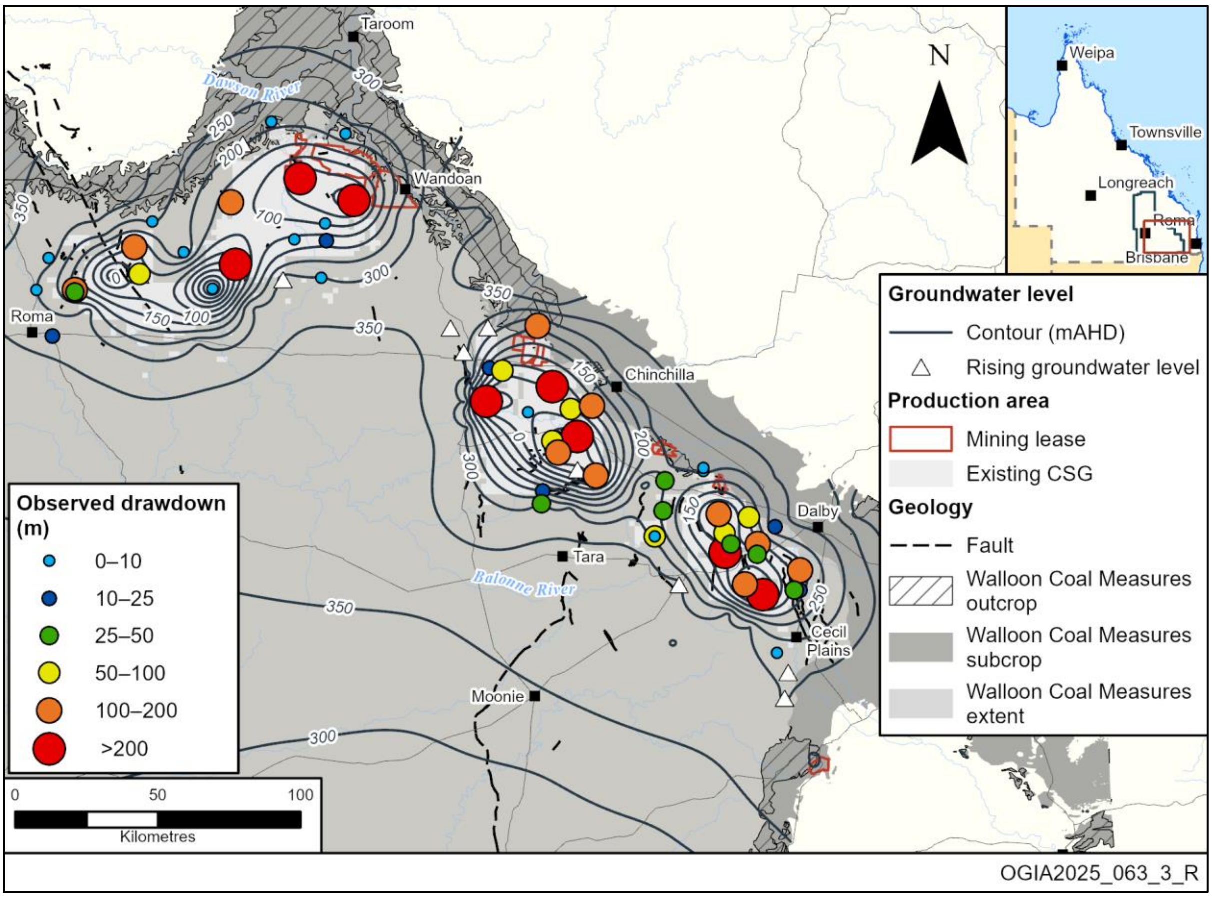

Figure 9-3: Current groundwater levels and observed drawdown in the Taroom Coal Measures

In areas where coal mines and CSG development overlap – such as Cameby Downs, Kogan Creek, and Wilkie Creek – groundwater level trends indicate that CSG is the dominant driver of depressurisation. Representative hydrographs (Figure 9-5) highlight the contributions of mining and CSG activities to groundwater level trends. Overall, CSG impacts vary across the mines, with moderate effects at Kogan Creek and Cameby Downs, minor impacts at Wilkie Creek, and no interaction at Commodore and New Acland.

Detailed hydrochemistry was assessed at 152 pre-CSG and 525 post-CSG sites with suitable data. In addition to major cations and anions, two key indicators – chloride (Cl) and strontium isotope ratios ($^{87}Sr/^{86}Sr$) – were selected as indicators of potential mixing between aquifers. Typically, Walloon Coal Measures groundwater has higher Cl concentrations and lower $^{87}Sr/^{86}Sr$ ratios compared to adjacent aquifers, as shown in Figure 9-6, though Cl levels vary significantly across sub-regions. A decrease in Cl and an increase in $^{87}Sr/^{86}Sr$ are considered indicative of groundwater ingress, although this may not occur in regions where the Walloon Coal Measures groundwater is already similar to that of adjacent aquifers.

A declining Cl concentration alongside increasing $^{87}Sr/^{86}Sr$ trends in structurally complex areas around the Undulla Nose/Anticline suggests groundwater inflow from adjacent aquifers into the Walloon Coal Measures, as expected.

Regionally, a large number of declining alkalinity trends are present in the post-CSG period, which confirms broad-scale depressurisation of the Walloon Coal Measures. Cl trends following production include approximately similar numbers of increasing and decreasing trends.

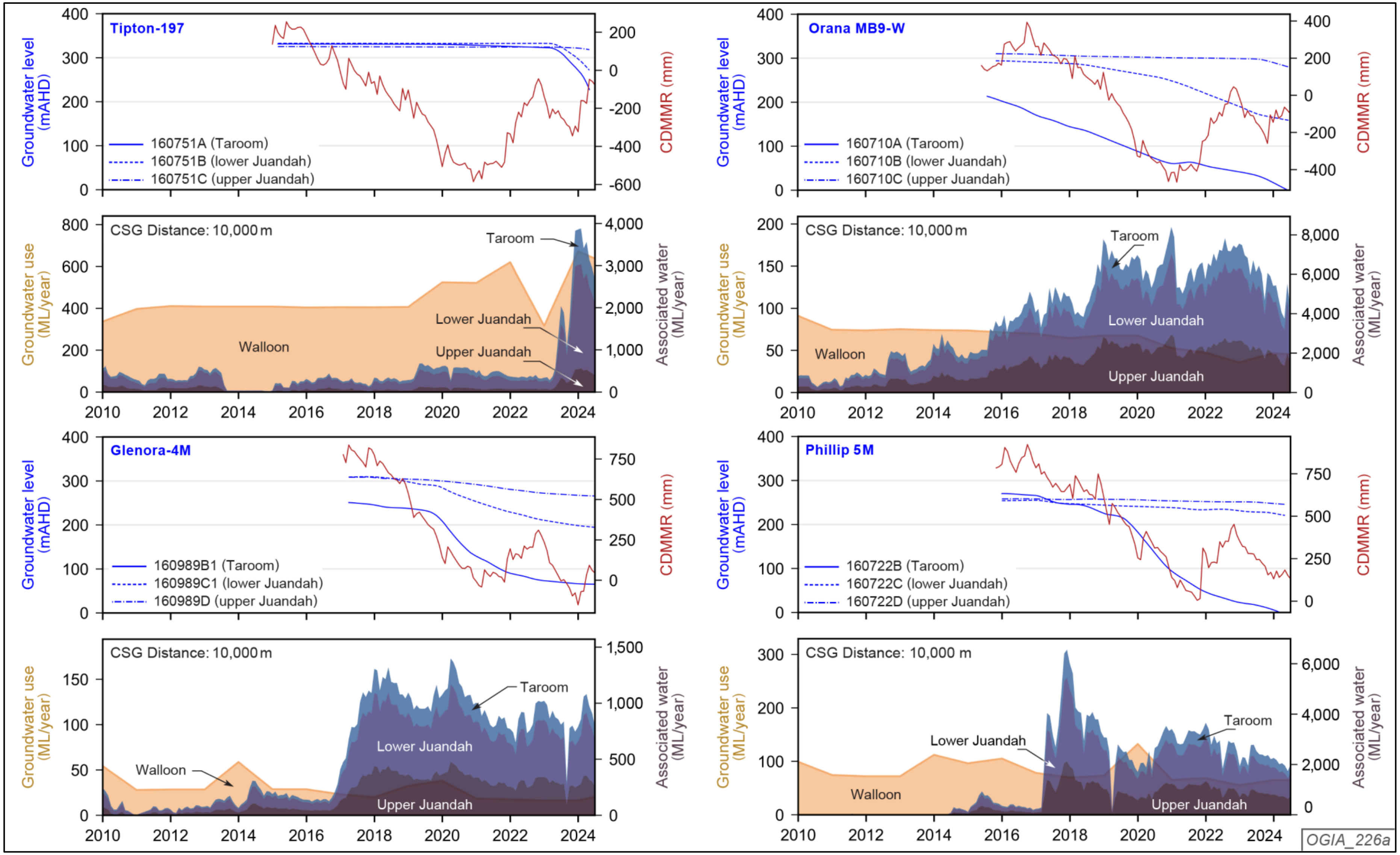

Figure 9-4: Groundwater level trends at selected sites in the Walloon Coal Measures

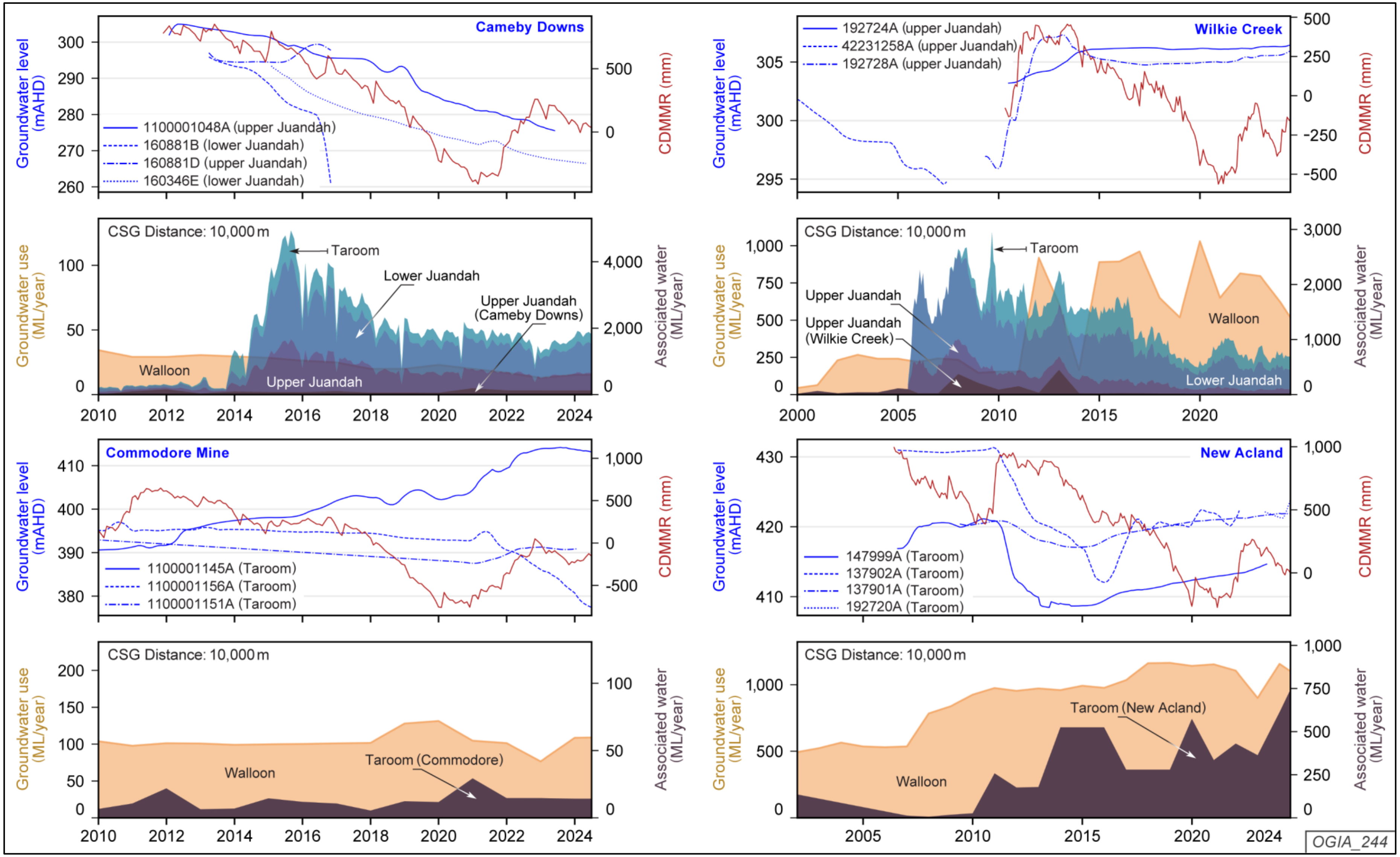

Figure 9-5: Groundwater level trends at selected coal mines in the Walloon Coal Measures

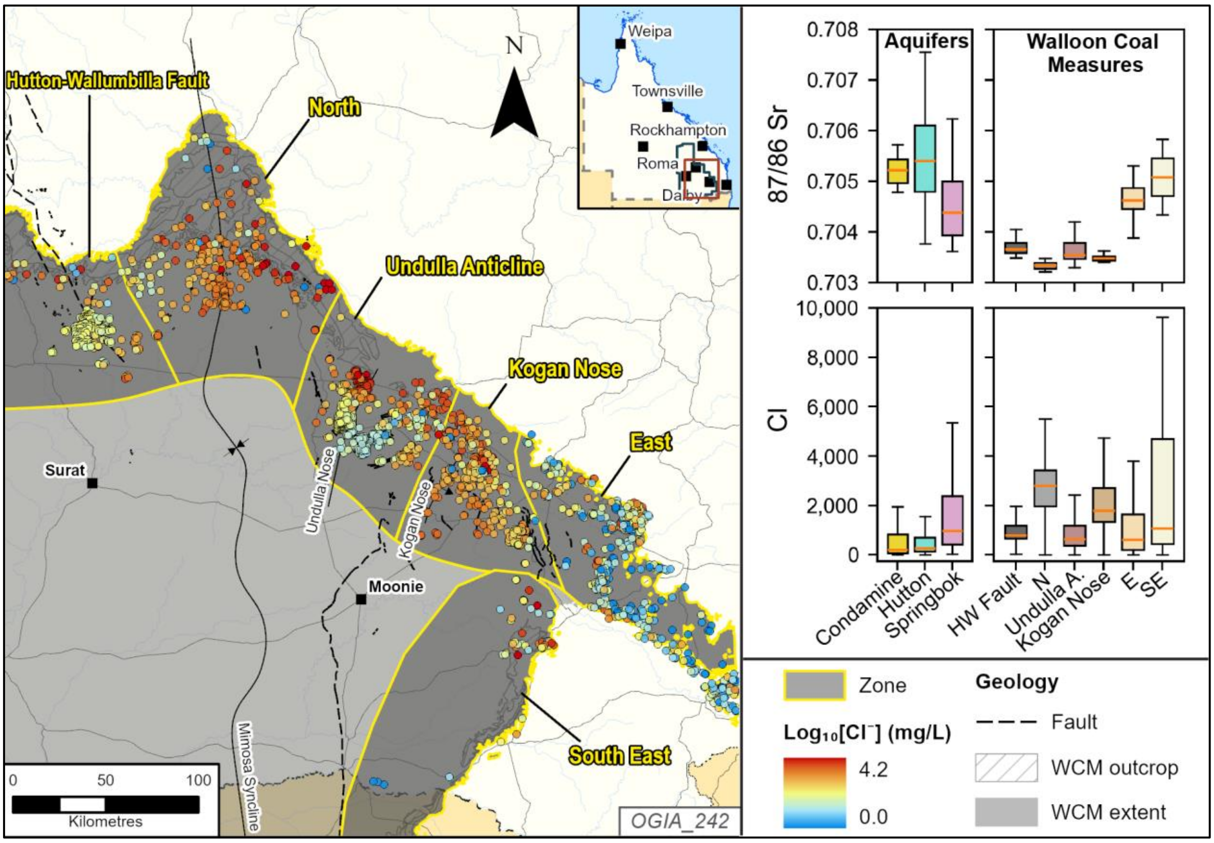

Figure 9-6: Chloride distribution, $^{87}Sr/^{86}Sr$ ratio and Cl concentration across zones and aquifers

In summary, groundwater trends in the Walloon Coal Measures continue to reflect the influence of CSG development, with deeper and more pronounced depressurisation near active gas fields. Hydrochemical trends suggest possible groundwater flow into the Walloon Coal Measures from nearby aquifers in some areas, especially near faults. This is consistent with McPherson et al. (2022), which found that folds and faults within the Surat Basin sequences are, in places, potential groundwater divides that may contribute to compartmentalisation of aquifers. Coal mining impacts remain minor and localised, with CSG being the dominant factor where overlapping footprints occur. Overall, while broad inter-aquifer connectivity is limited, localised vertical flow into the Walloon Coal Measures is reflected in structurally complex zones.

9.6.2 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 (Figure 9-7). These production areas are separated by the Taroom Trough, where the Bandanna Formation is present at significant depths (>5,000 m).

The Bandanna Formation is generally hydraulically isolated from overlying Surat Basin aquifers by the low-permeability Rewan Group, reducing the likelihood of groundwater movement from other aquifers; however, the two contact zones – where the Surat Basin sediments have eroded the Bowen units, with some Permian coal formations coming into contact with the Precipice Sandstone – present a risk of potential pathways.

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.

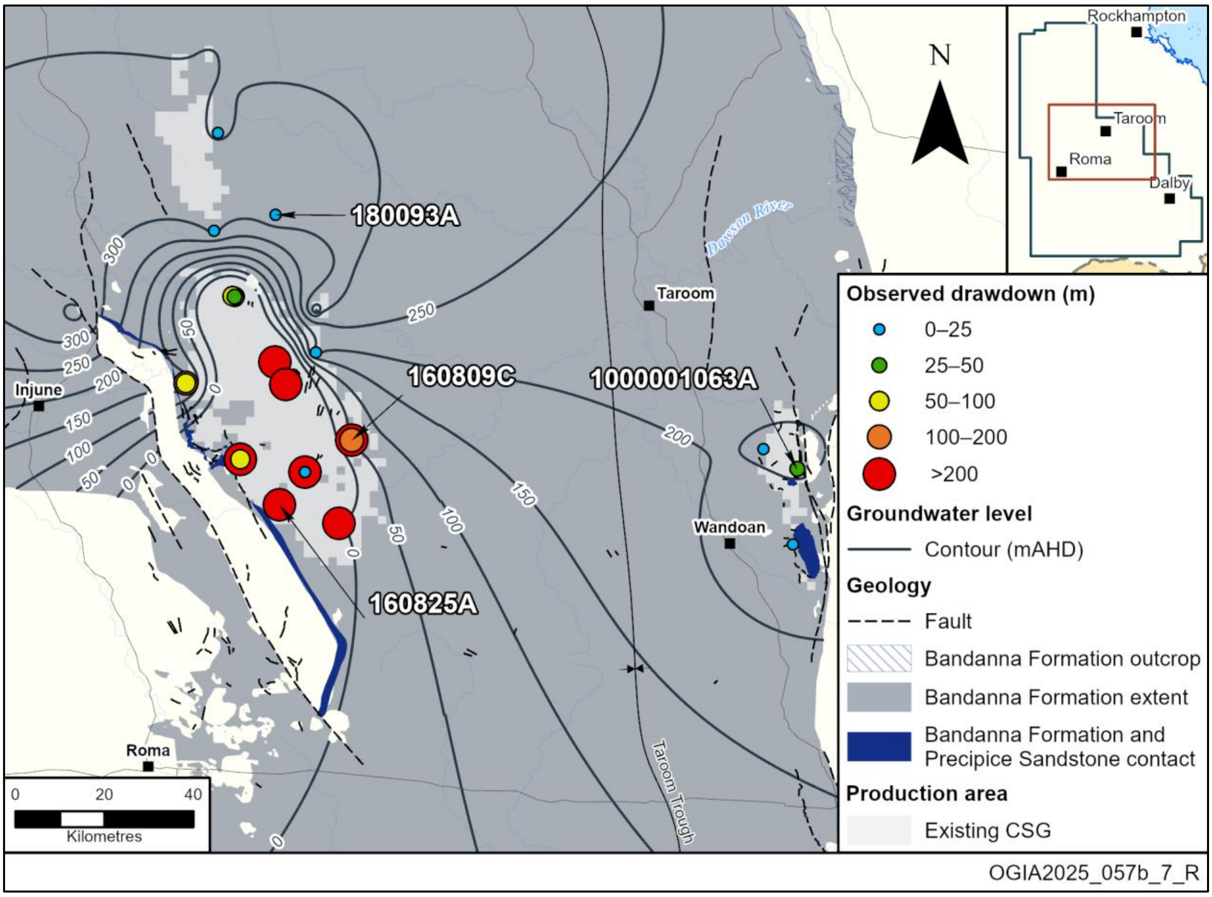

Figure 9-7: Current groundwater levels and observed drawdown in the Bandanna Formation

Similar to the Walloon Coal Measures, CSG depressurisation has caused significant drawdowns in the Bandanna Formation, especially in western fields such as Fairview and Spring Gully, with observed declines exceeding 450–550 m in some locations. Drawdowns in eastern fields are generally lower (<20 m), indicating a more confined impact footprint. Many of these locations are near the interpreted contact zones (Figure 9-7).

Examples of groundwater level response to CSG development in the Bandanna at four representative locations (Figure 9-7) are shown in Figure 9-8. In the western side of the Taroom Trough, about 13 km of the Arcadia gas field, the Hungry Creek 1 (RN180093A) monitoring site is comparatively remote from CSG production and shows around 2 m of decline since monitoring started late in 2018. The Spring Gully development area started production in 2013, where drawdowns up to 340 and 500 m are observed (RN160809C/Spring Gully MB5 and RN160825A/Spring Gully MB3). In the eastern gas fields, monitoring at RN1000001063A/Scotia 30 exhibits a sharp decline in groundwater levels, coinciding with a significant increase in local CSG production.

The **water-to-gas production ratio** (Figure 9-9) is potentially a useful indicator of whether areas near geological features – like faults or the Precipice Sandstone–Bandanna Formation contact zone – are hydraulically connected. Typical water production profiles have ratios of less than 0.1:1, accounting for 90% of the wells targeting the Bandanna Formation or equivalent formations. Wells with ratios greater than 0.1:1 either are early in the depressurisation phase or naturally produce more water.

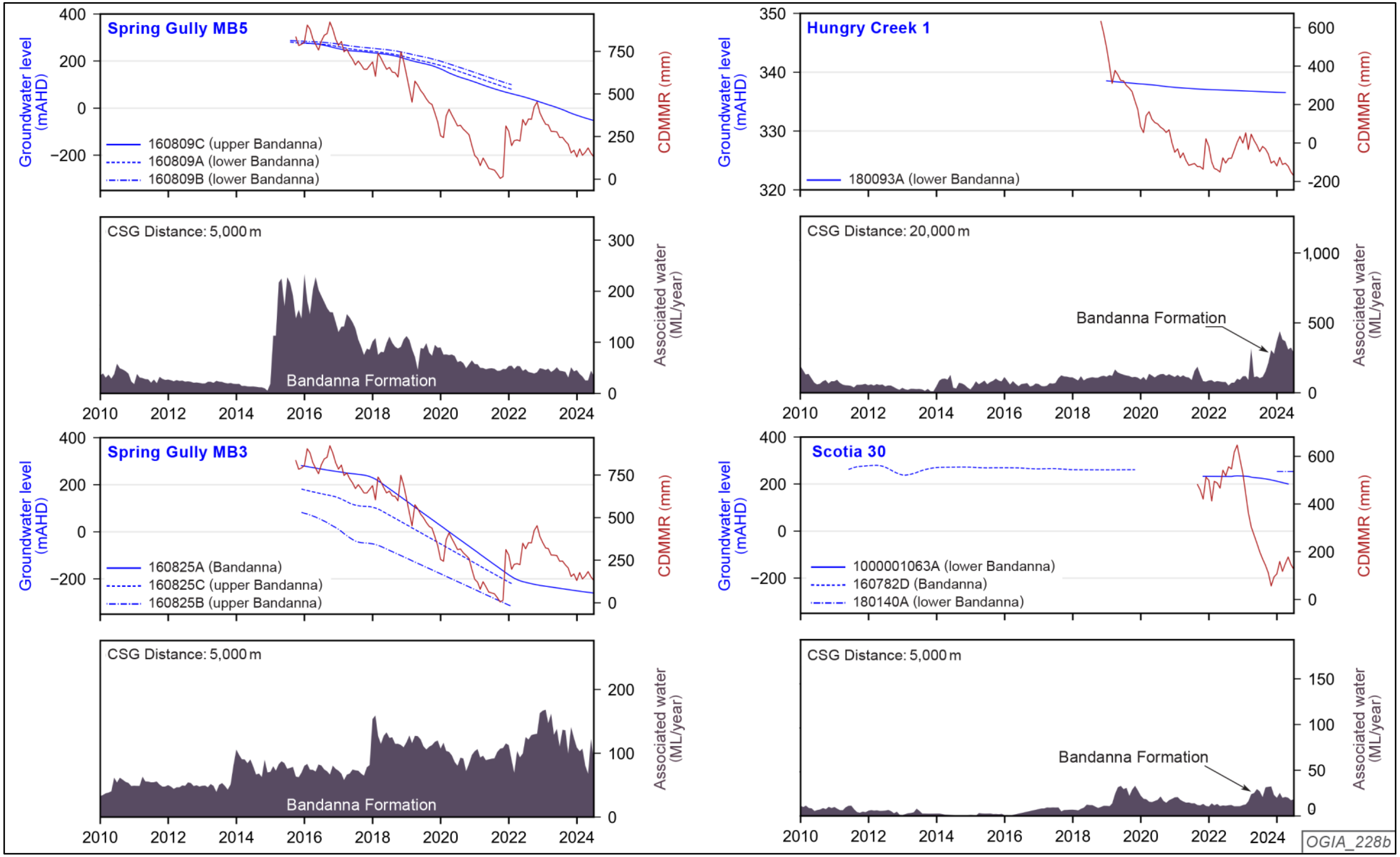

Figure 9-8: Groundwater level trends at selected sites in the Bandanna Formation

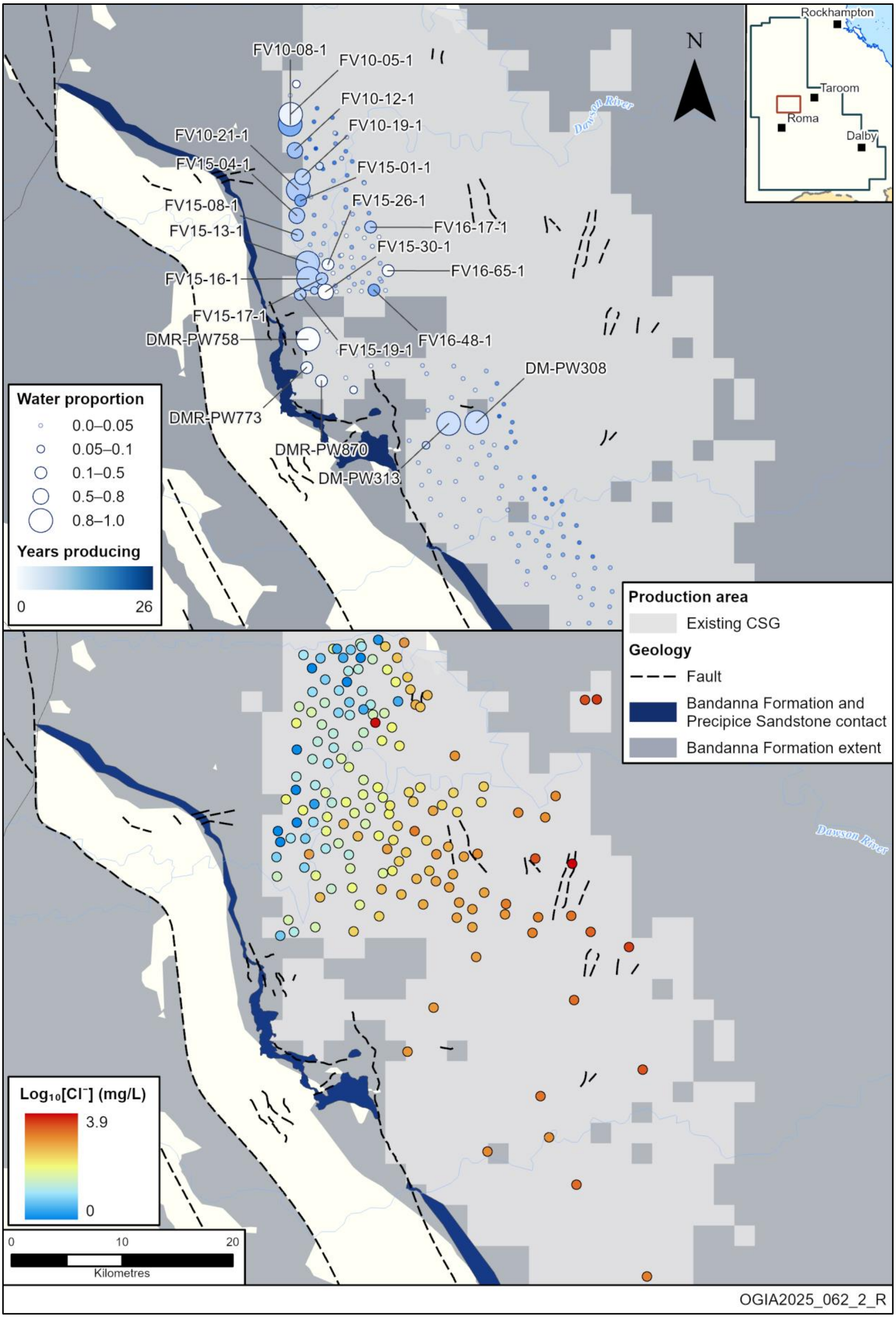

Figure 9-9: Proportion of water-to-gas production in CSG wells (top) and distribution of chloride (bottom) near the western contact zone in the Bandanna Formation

These higher ratios are mainly located along the western edge of the production field, adjacent to the western contact zone and mapped faults – suggesting flow across these structural features into the Precipice Sandstone. Consistent with this interpretation, low chloride concentrations adjacent to the western contact zone resemble the fresher Precipice Sandstone groundwater, further supporting cross-formational flux into the Bandanna Formation (Figure 9-9).

In summary, while the Bandanna Formation is mostly hydraulically confined from overlying aquifers, structural features like faults and contact zones are potentially allowing some cross-formational flow with the Precipice Formation under sustained CSG depressurisation.

9.7 Trends in adjacent aquifers

This section provides a summary of the analysis for the pre-development and post-development periods for aquifers adjacent to the resource target formations – the Precipice, Hutton and Springbok sandstones and the Condamine Alluvium. Used to support the analysis for each aquifer are representative hydrographs, local water use, rainfall trends, CSG water extraction, coal mine dewatering, estimated groundwater use from water bores, and reinjection volumes.

9.7.1 Precipice Sandstone

The Precipice Sandstone is largely isolated from the Walloon Coal Measures but there are some areas of connection in the north with the Bandanna Formation – the CSG target formation in the Bowen Basin (section 7.5.4). There is also substantial conventional oil and gas production from the Moonie oil field in the southern part of the CMA, which has produced directly from the Precipice Sandstone since 1964 (section 7.3.2).

Groundwater flow directions in the Precipice Sandstone generally follows regional patterns, flowing north of the Great Dividing Range toward the Dawson River and southward toward basin centres (Figure 9-10). Reinjection of treated water by Origin Energy since 2015 – at its Spring Gully and Reedy Creek-Combabula gas fields – has altered flow dynamics, creating localised mounding and influencing flow over large distances due to high transmissivity of the aquifer. These changes have introduced a groundwater divide between Miles and Roma.

Groundwater levels in the Precipice Sandstone showed a mix of moderately rising and declining trends prior to the start of reinjection in 2015 (Figure 9-11). These variations were largely influenced by both groundwater extraction and rainfall recharge. Rising groundwater level responses have extended 100 km from the injection sites and have risen by more than 50 m at Reedy Creek site (Figure 9-12); however, more subdued and delayed responses further away are also noted. While most responses are clearly linked to reinjection, some bores also show influence of direct water use from the aquifer.

In contrast, groundwater levels around and east of the Kumbarilla Ridge show minimal response to reinjection; groundwater levels continue to decline due to lower transmissivity in the Precipice Sandstone in that area, combined with ongoing groundwater use for town water supply, agriculture and industry. Monitoring of the Precipice Sandstone near the Moonie oil field shows large fluctuations in groundwater levels, reflecting corresponding changes in oil and gas production.

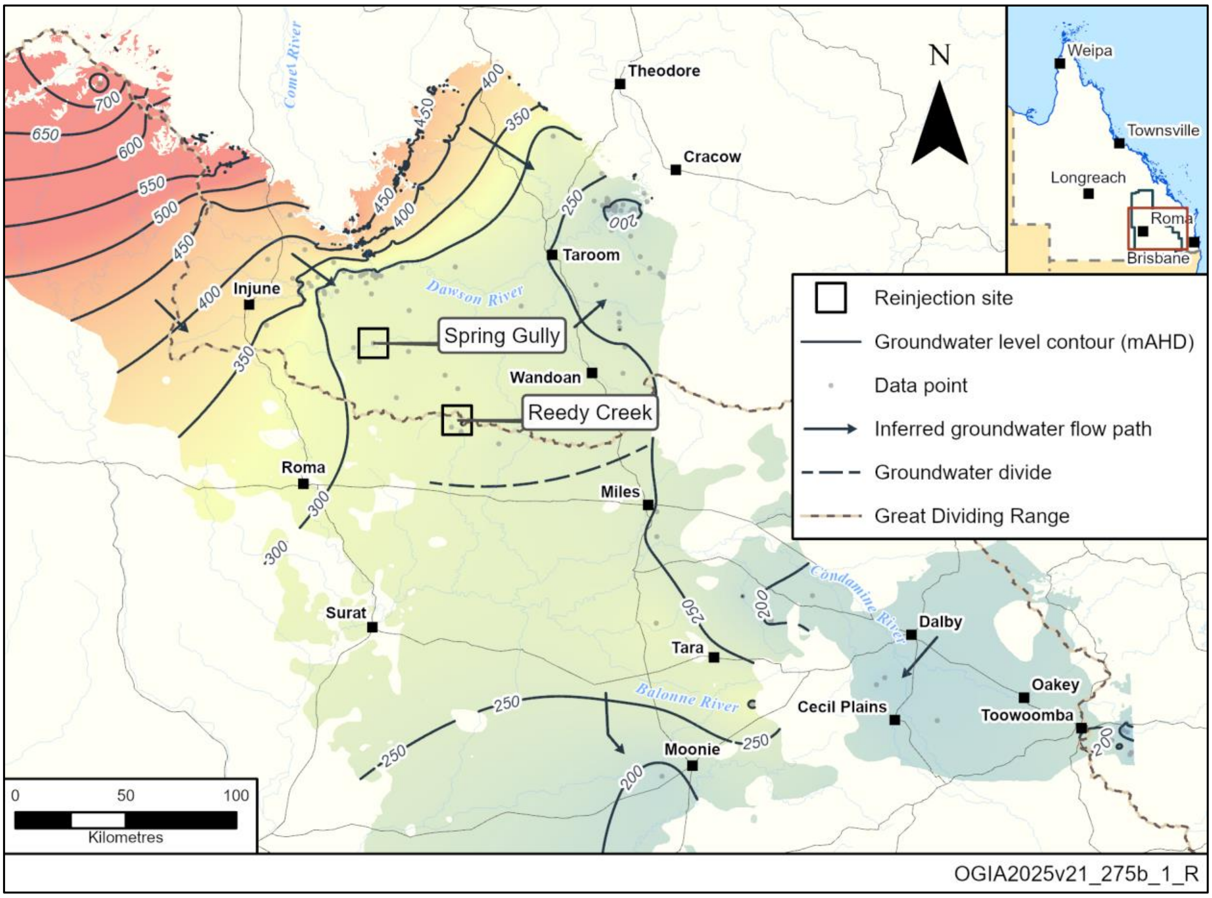

Figure 9-10: Current potentiometric surface (groundwater level) and flow directions in the Precipice Sandstone

Despite the dominant rising trend from reinjection, several areas now show a declining trend, due to a range of contributing factors. The most significant is in the western contact zone, where the Precipice Sandstone is in contact with the CSG-producing Bandanna Formation. Multiple lines of evidence suggest that these declines are likely at least partially influenced by induced leakage from the depressurisation in the nearby CSG fields.

Groundwater levels at bores RN160736A (Spring Gully PB1) and RN160925A (Figure 9-13, show a marked divergence from other bores within 10 km (RN160506A, RN123144A, RN123470A). The groundwater level in Spring Gully PB1, for example, has now fallen below its pre-reinjection reference level. The declining trend also aligns with increased water extraction from the Bandanna Formation within approximately 5 km of the contact zone, while water use in the Precipice Sandstone occurs much further (~25 km) away and does not correlate with the rainfall pattern. Overall, the evidence suggests that nearby CSG production has contributed at least partially to the observed declines in groundwater levels in the Precipice Sandstone.

Further away from the reinjection sites, south of the Great Dividing Range (near Cecil Plains), declines at monitoring bores Tipton-194 (RN160543A) and Carn Brea-20 (RN160632A) are attributed to local groundwater use, which averages approximately 1,000 ML per year within a 25-kilometre radius (Figure 9-14). Monitoring shows large groundwater level fluctuations around the Moonie oil field, with a general decline until 2021, followed by a rise. While not strongly correlated with local water production, the recent rise likely reflects reduced conventional oil and gas production.

Hydrochemistry trends and methane concentrations in the Precipice Sandstone indicate the presence of gas, though the origin is uncertain and may be attributed to a combination of in-situ production, migration from deeper parts of the aquifer and migration from the Bowen Basin. Key sites around the western and eastern contact zones, however, exhibit trends that are more likely indicative of free gas migration from the underlying Bowen Basin – further highlighting potential connectivity between the Precipice Sandstone and Bandanna Formation.

As noted in section 9.6.2 and shown in Figure 9-9, water-to-gas production ratios of wells adjacent to the western contact zone are consistent with flow from the Precipice Sandstone towards the Bandanna Formation across this zone.

In the western contact zone, although strontium isotopes ($^{87}Sr/^{86}Sr$) are less effective as groundwater tracers due to limited contrast with the Precipice Sandstone, a distinct contrast in Cl is observed between the northern and southern development areas. Water chemistry in the north resembles the Precipice Sandstone, suggesting groundwater flux across the contact. The eastern contact zone shows stronger hydrochemical differentiation with the Precipice Sandstone, with trends in Cl and $^{87}Sr/^{86}Sr$ providing clearer evidence of mixing. In particular, selected production wells show declining Cl and rising $^{87}Sr/^{86}Sr$ ratios over time, with some trends observed up to 12 km away from the contact zone, which may reflect production-related impact.

In summary, reinjection has been the main driver of upward groundwater level changes since 2015 but the trend has now started to reverse. Early indications of impacts from CSG development around the western contact zone in the northern part of the Surat CMA have likely started to emerge as expected. Further south, groundwater levels continue to decline due to local water use, including historical activities at the Moonie oil field.

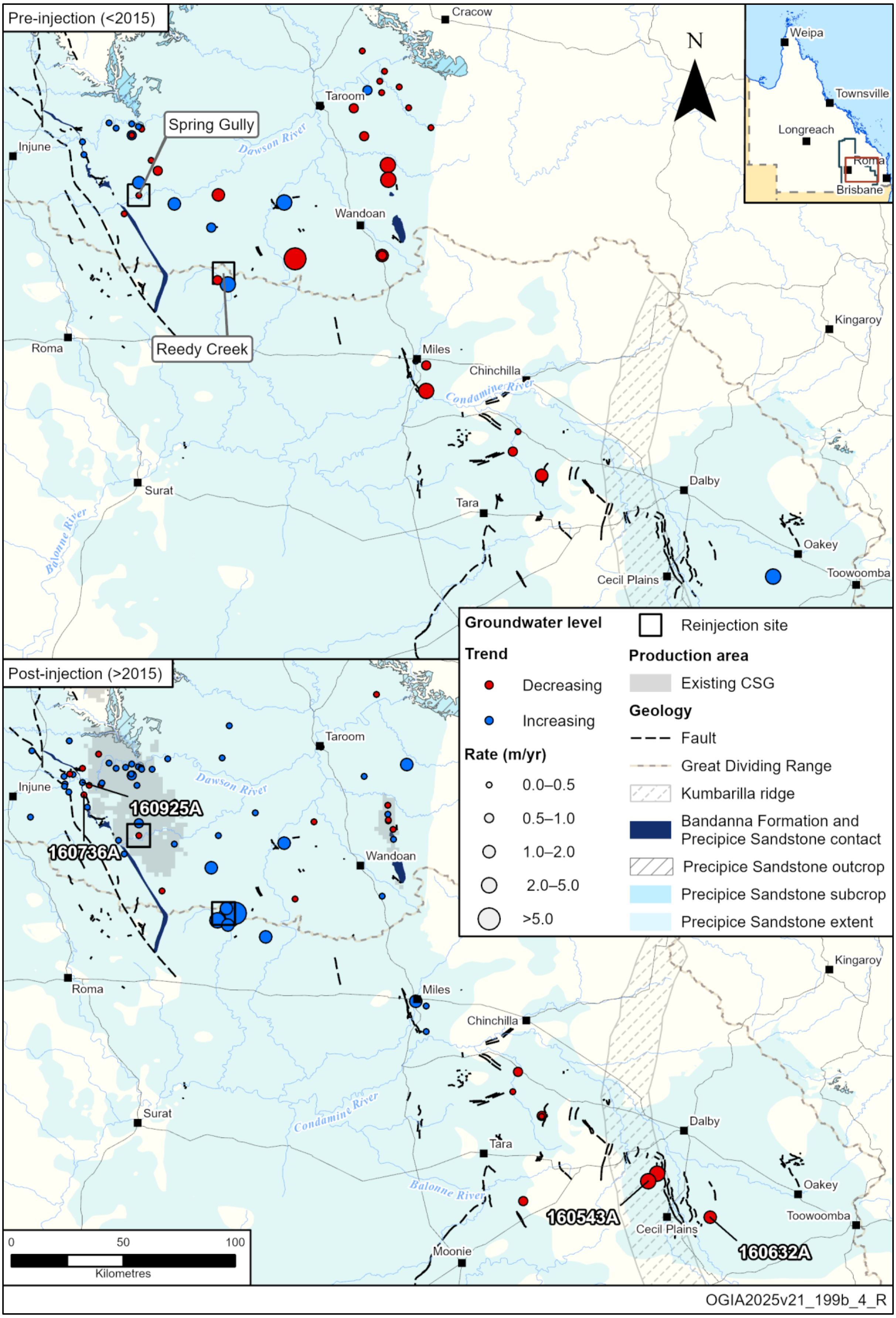

Figure 9-11: Pre-CSG and post-CSG groundwater level trends in the Precipice Sandstone

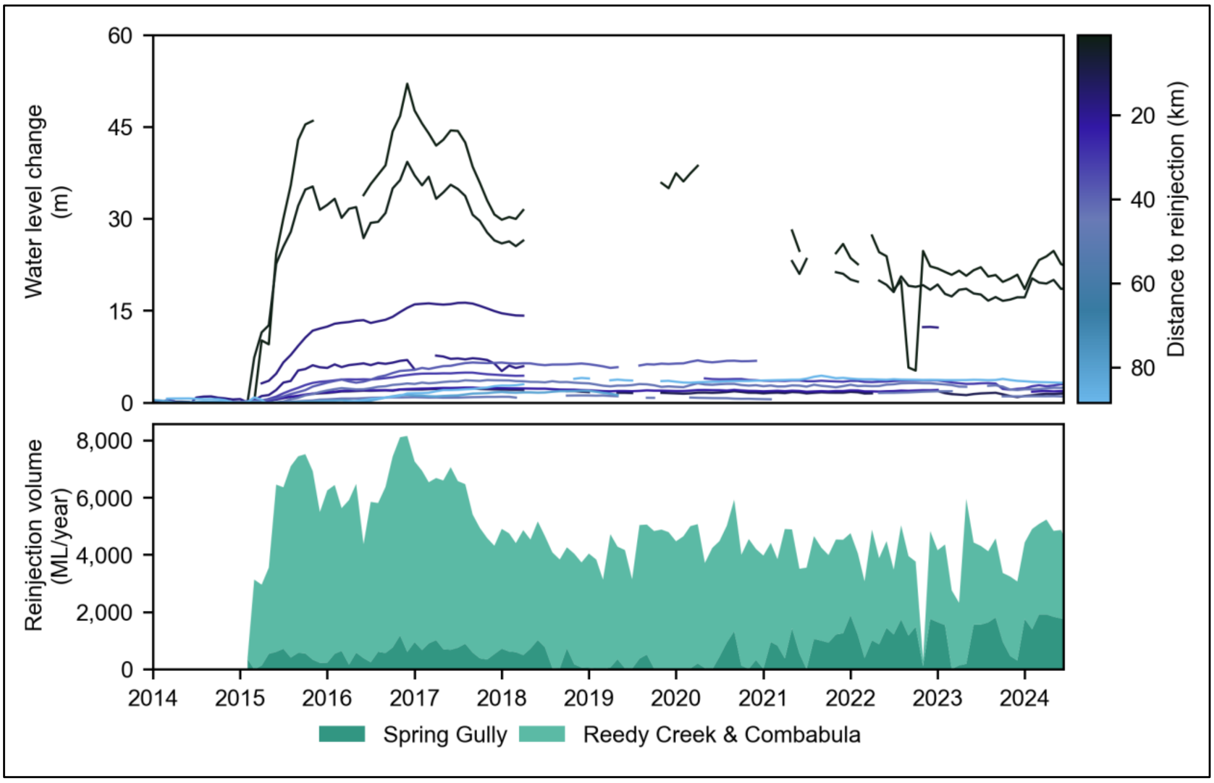

Figure 9-12: Hydrographs showing the relationship between water level responses and distance to reinjection

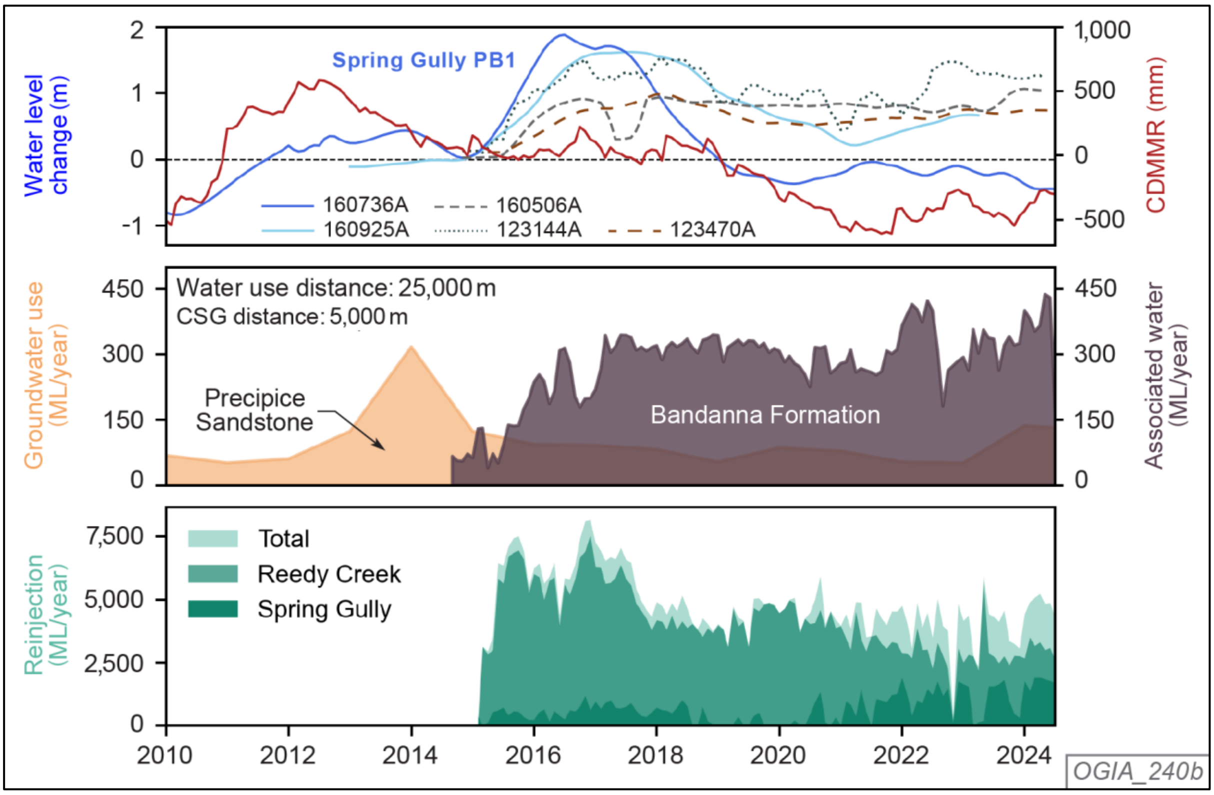

Figure 9-13: Example hydrographs showing trends in the Precipice Sandstone in the western contact zone

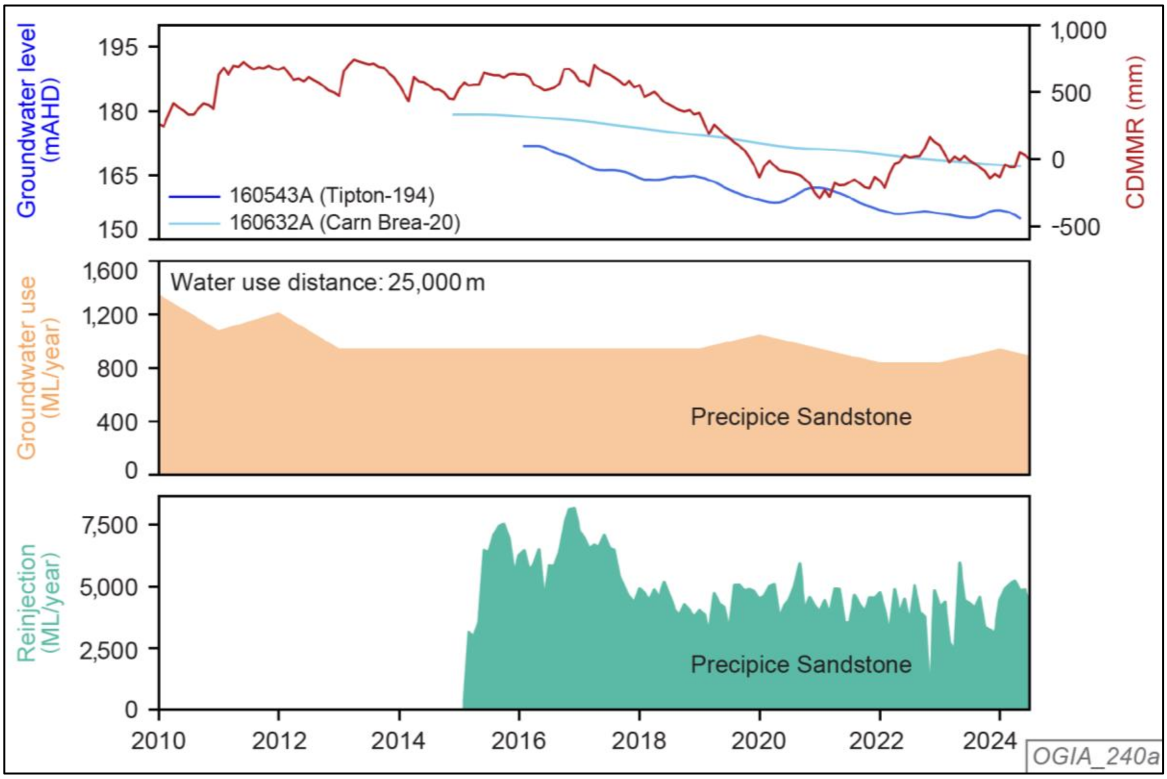

Figure 9-14: Example hydrographs showing trends in the Precipice Sandstone in the south around Cecil Plains

9.7.2 Hutton Sandstone

Connectivity between the Hutton Sandstone and the overlying Walloon Coal Measures in the Surat Basin is limited due to the intervening Durabilla Formation aquitard, as described in section 7.5.3.

Groundwater flow directions in the Hutton Sandstone (Figure 9-15) are similar to other Surat Basin formations, with a 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. 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 2016c).

Declining trends have historically been observed throughout the Hutton Sandstone aquifer, including within the CSG development areas. The Hutton Sandstone is heavily utilised for water supply, with current groundwater use estimated at around 13,000 ML/year. There are more than 3,960 bores with groundwater level data in the Hutton Sandstone in the Surat CMA but reliable trends could only be derived for 160 sites. The spatial distribution of sites and the estimated annual trend rates are presented in Figure 9-16, with representative hydrographs shown in Figure 9-17.

In the pre-CSG development period, regional groundwater level declines in the Hutton Sandstone are observed at around 80% of monitoring points. In shallow areas near the aquifer's outcrop, groundwater levels are closely linked to climate and local pumping. Near Injune (RN13030613A), groundwater levels mirror rainfall patterns, as there is little water use in the area. Around the Commodore coal mine, levels are influenced by both climate and pumping. Away from the outcrops, in the deeper, confined parts of the aquifer, there is no obvious correlation with rainfall. Sites like WaarWaar-MB3-H (RN160724A) show persistent, long-term declining trends, even with little to no local extraction. This reflects the broader, historical depletion of the aquifer system.

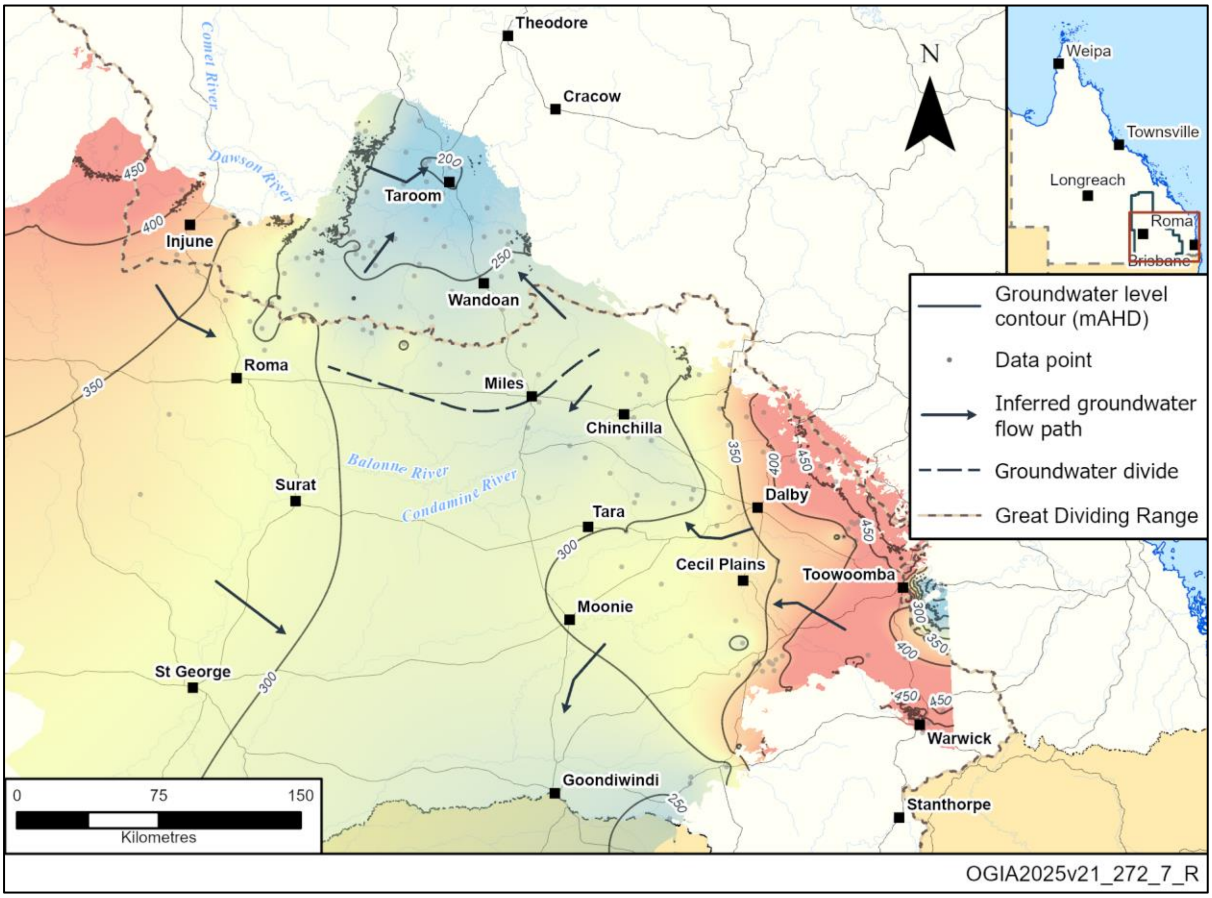

Figure 9-15: Current potentiometric surface (groundwater level) in the Hutton Sandstone

Located within a CSG field, Phillip 5M (RN160722A) exhibits a decline of around 10 metres, which is significantly greater than the 1–2-metre declines observed at nearby wells. While no direct causal link has been established, the anomalously high rate of decline suggests an influence from local geological or hydrological factors.

Against the backdrop of general decline, a few sites exhibit anomalous trends that suggest likely influence from CSG development. The strongest evidence for potential impact is at Glenora-4M (RN160989), located 40 km northeast of Roma. Multiple lines of evidence point to CSG influence, such as a declining rate that notably exceeds the expected background decline, distinct periods of increased drawdown that appear to be associated with nearby CSG production activities, and low or declining Cl concentrations coupled with high or increasing $^{87}Sr/^{86}Sr$ ratios (Figure 9-18).

The combination of anomalous pressure declines and supporting hydrochemical evidence at sites like Glenora-4M indicates that such impacts are most likely occurring where geological or structural features facilitate hydraulic connectivity between formations. In summary, while most groundwater changes in the Hutton Sandstone reflect established background declines resulting from responses to climate and water extraction, two sites now exhibit trends that suggest potential localised impacts from CSG development.

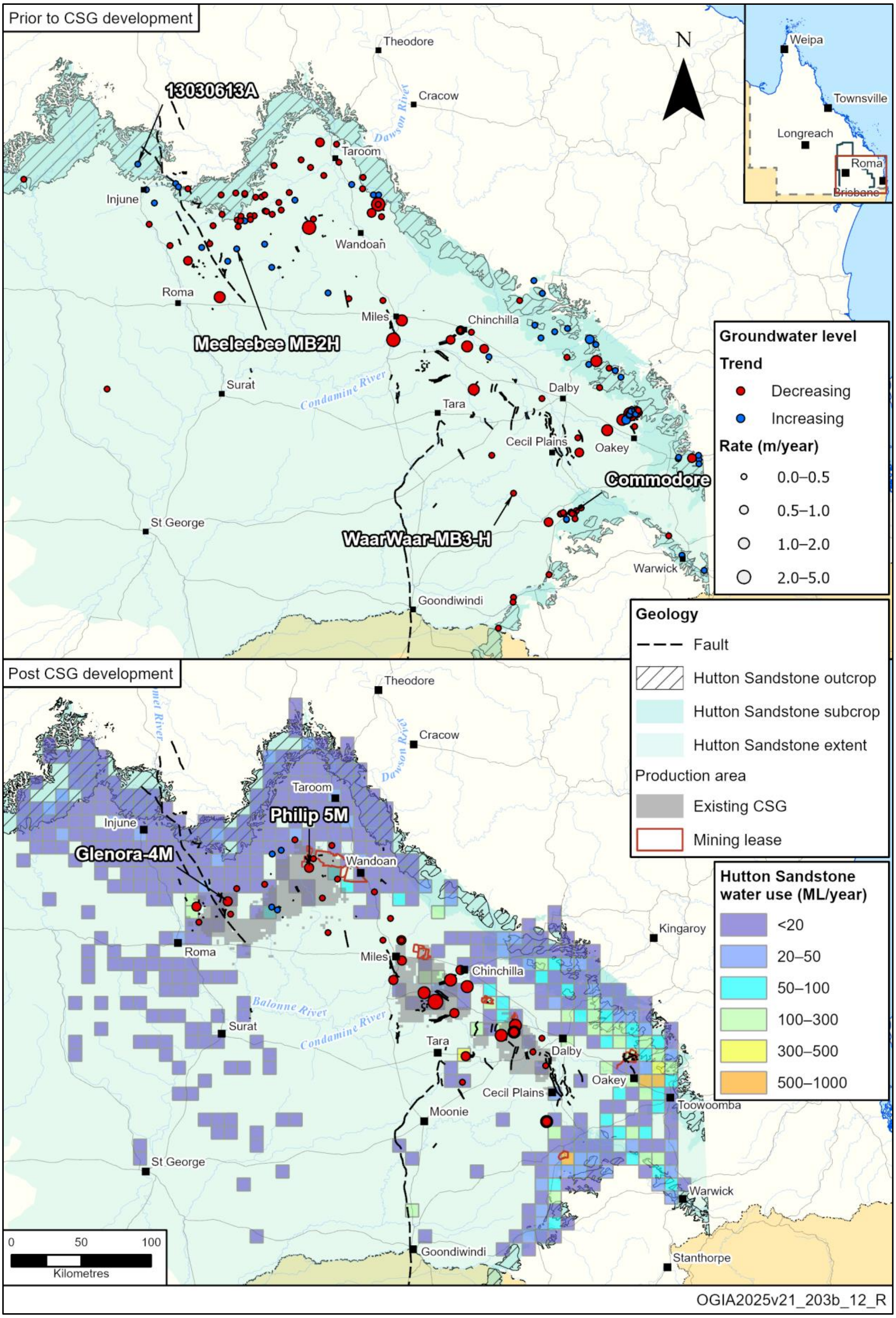

Figure 9-16: Pre-CSG and post- CSG groundwater level trends in the Hutton Sandstone

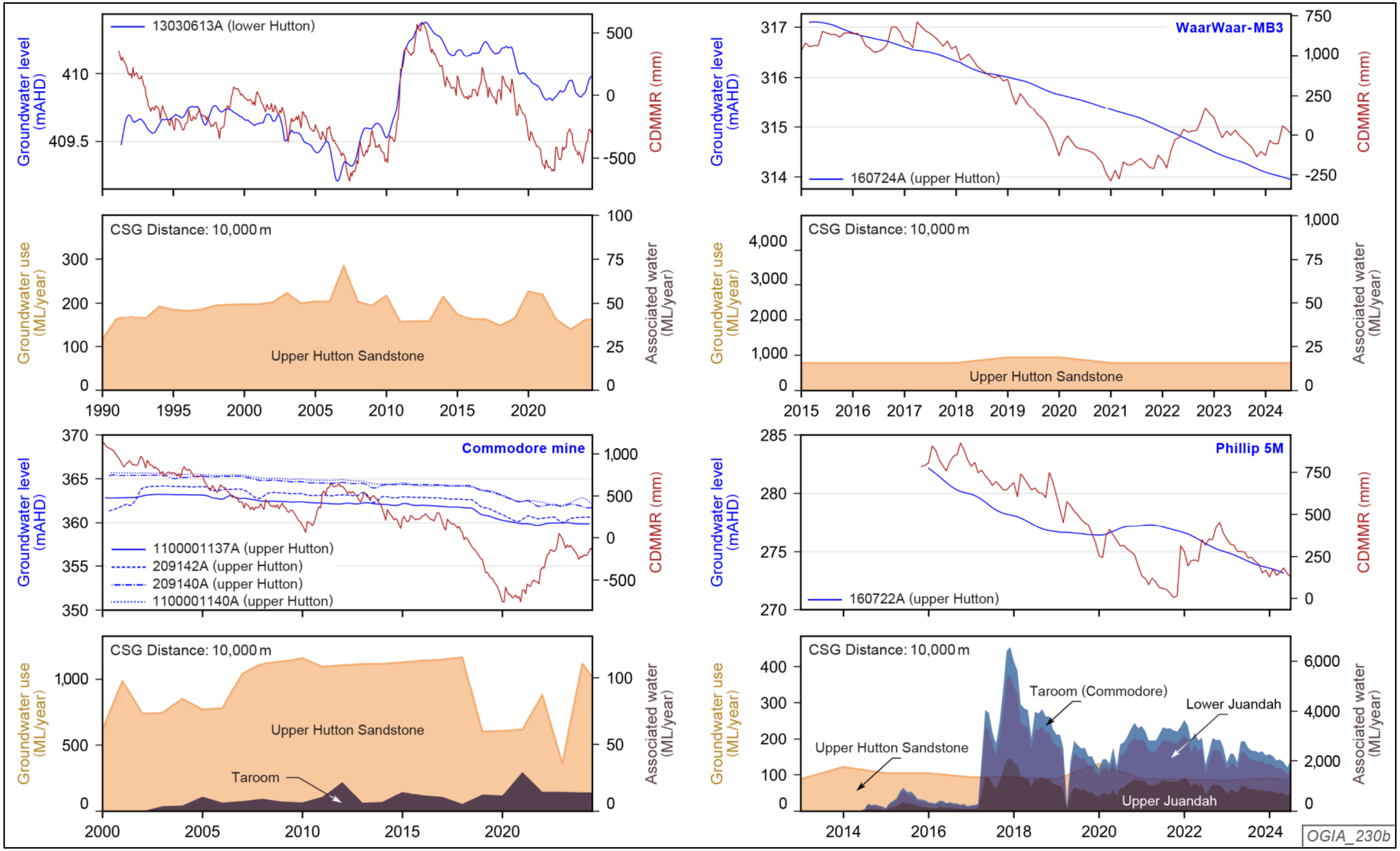

Figure 9-17: Example hydrographs showing trends in the Hutton Sandstone

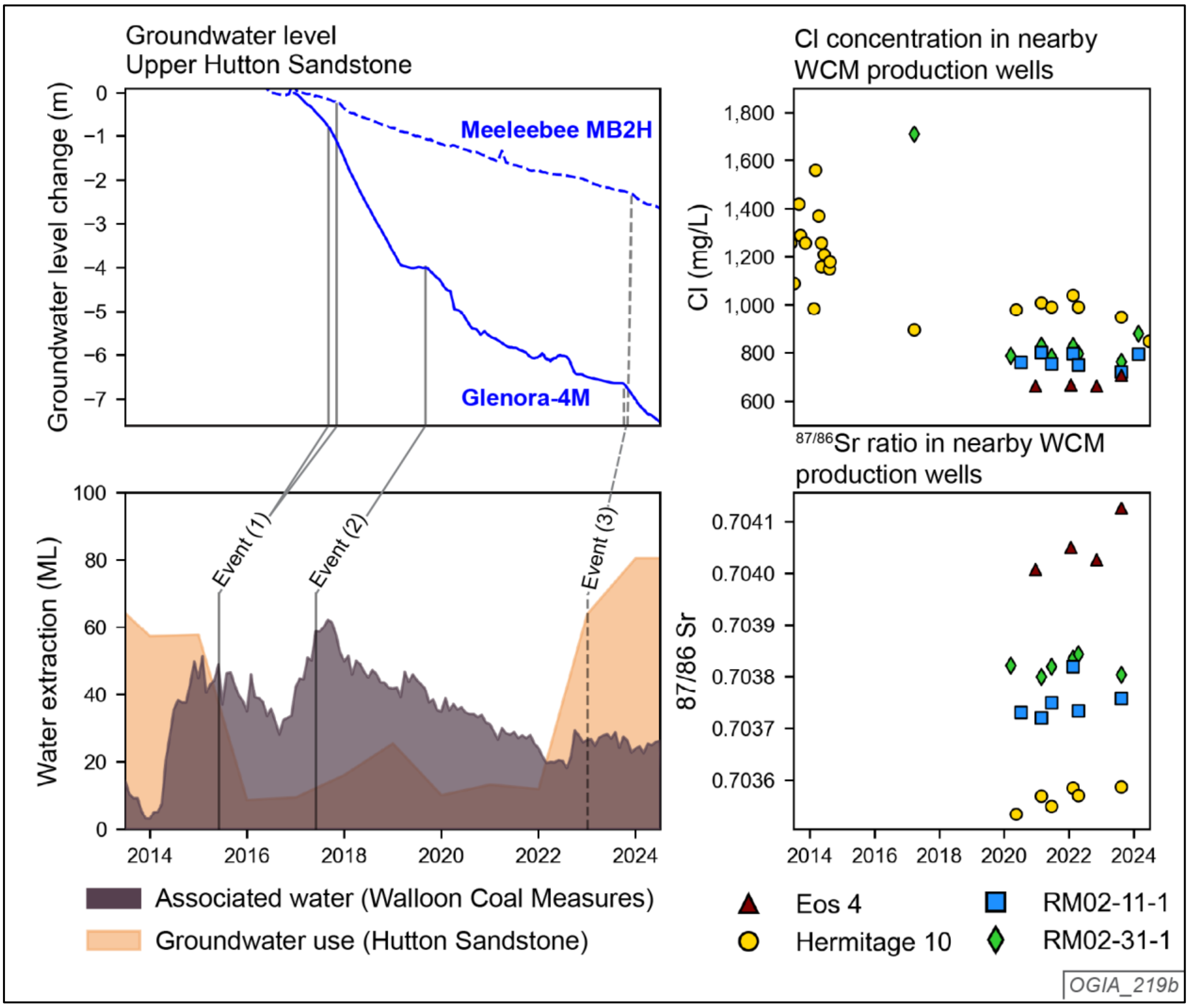

Figure 9-18: Groundwater level and nearby hydrochemistry trends at Glenora-4M

9.7.3 Springbok Sandstone

The Springbok Sandstone overlies the Walloon Coal Measures, separated by a non-coal zone. As discussed in section 7.5.2, 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 (Figure 9-19). South of the GDR, groundwater flow is generally to the south and southwest, towards the deeper areas of the Basin, consistent with the dip of the formation. North of the GDR, data is limited but suggests possible northward groundwater flow and discharge to the upper tributaries of the Dawson River and associated minor alluvium.

Due to the heterogeneous nature and low permeability of the Springbok Sandstone, monitoring responses can be variable, with some sites showing delayed recovery after drilling or being affected by sampling and pumping activities. Prior to CSG development, **groundwater levels** in the Springbok Sandstone show a combination of both rising and falling trends, influenced largely by climate variability and local water use, with overall changes generally being of low magnitude. In the post-CSG period, declining trends are observed more widely across the monitoring network, while rising trends are smaller and less common (Figure 9-20).

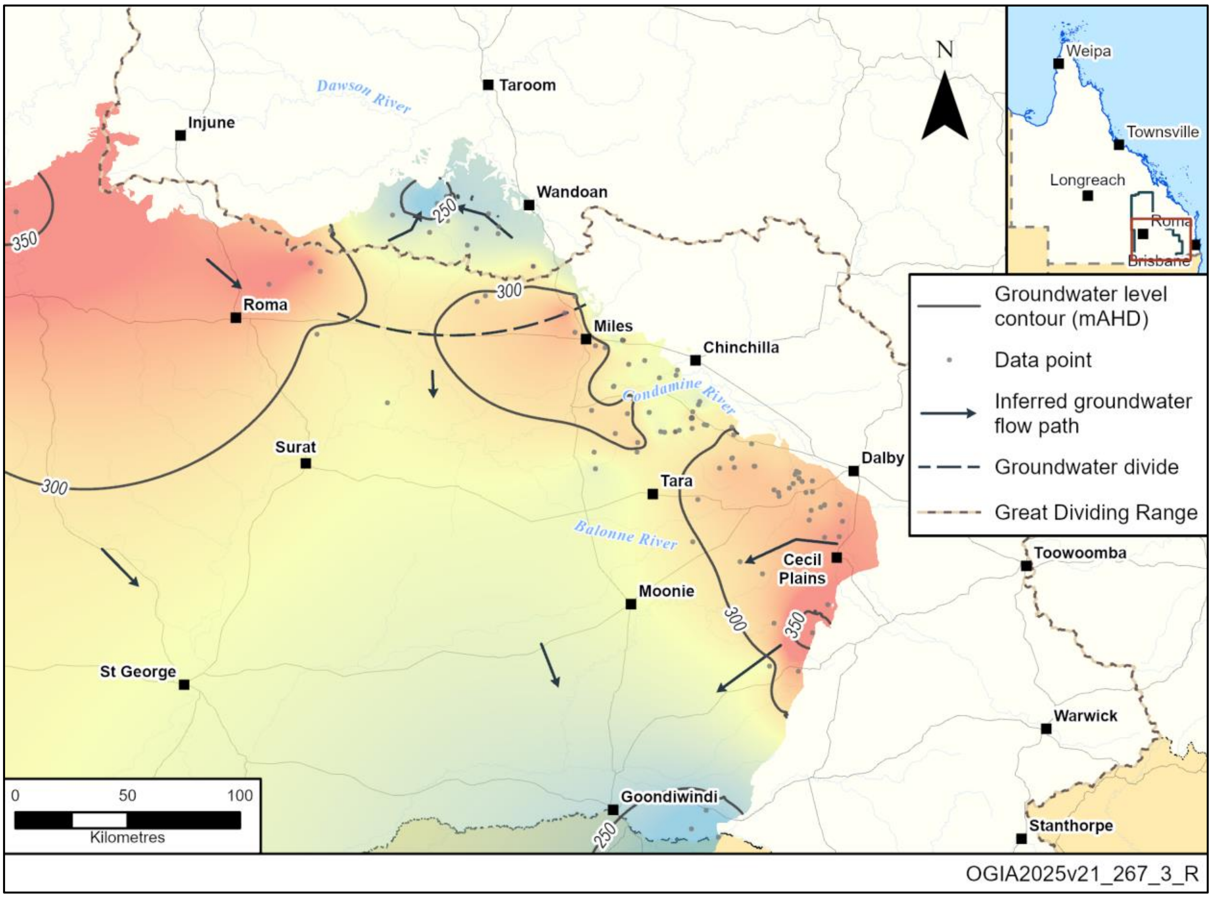

Figure 9-19: Current groundwater levels in the Springbok Sandstone

The spatial distribution of sites and the estimated annual trend rates are presented in Figure 9-20, with representative hydrographs shown in Figure 7-11. In areas remote from CSG development, groundwater levels are primarily influenced by climate and local geology. Near outcrop areas (RN41640043A) groundwater levels show a strong correlation with seasonal rainfall while away from direct recharge (GilbertGully-MB2/RN160728A) a steady declining trend is observed, reflecting the limited influence of short-term climate patterns.

Around 30 km south of Chinchilla, within CSG development, impacts from depressurisation are observed at Kenya East GW4 (RN160525A), primarily driven by a nearby fault juxtaposing the Walloon Coal Measures directly against the Springbok Sandstone, creating a zone of enhanced connectivity. Groundwater levels were stable until late 2014, when local CSG production began. A rapid fall commenced immediately after, resulting in a total decline of around 30 metres so far. This is also supported by hydrochemistry from nearby CSG production wells showing a declining chloride trends, reflective of the ingress of water from the Springbok Sandstone. At the same time, a nearby monitoring bore in the Upper Springbok Sandstone (Kenya East 2, RN160519A) shows a minimal decline – less than 0.2 metres.

Other sites show evidence of more subtle impacts, including potential gas migration. At Broadwater GW4 (RN160635A), declining groundwater levels correlate with increased local CSG development and hydrochemistry indicates some gas migration: high methane (CH_4) concentrations and a declining sulphate (SO_4) trend, coincident with rising trends in iron (Fe^{2+}) and manganese (Mn^{2+}) (Figure 9-21). Rising groundwater trends are also observed in some areas, primarily near the formation's edge, most likely due to gas migration.

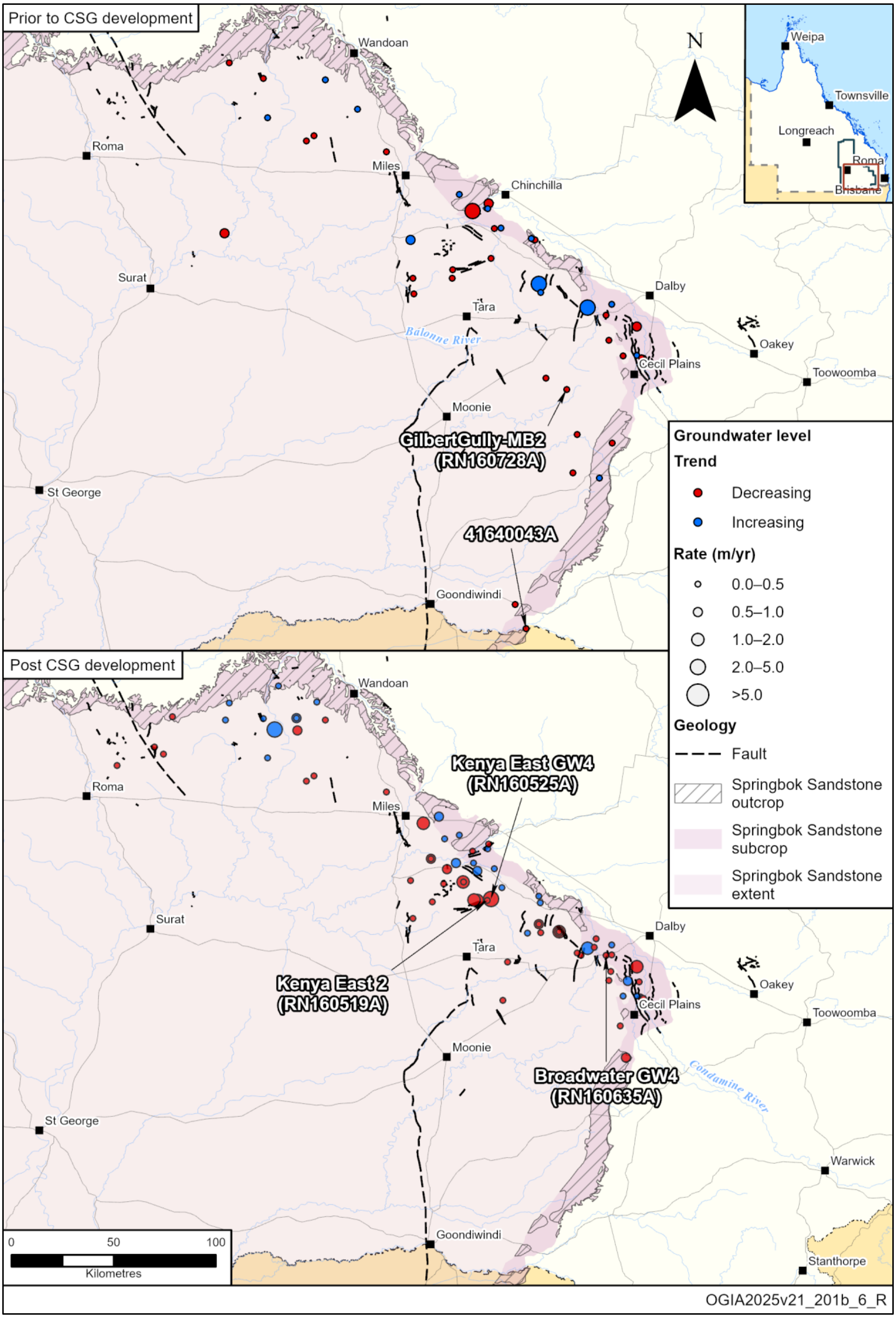

Figure 9-20: Summary of groundwater level trends in the Springbok Sandstone

In summary, there are variable trends in the Springbok Sandstone. There is evidence of CSG impact in groundwater levels and hydrochemistry trends at some locations, particularly where connectivity may be enhanced due to local geological features, such as faults. Some rising groundwater trends are generally observed near the edge of the Springbok Sandstone, likely influenced by gas migration from the Walloon Coal Measures into the Springbok Sandstone.

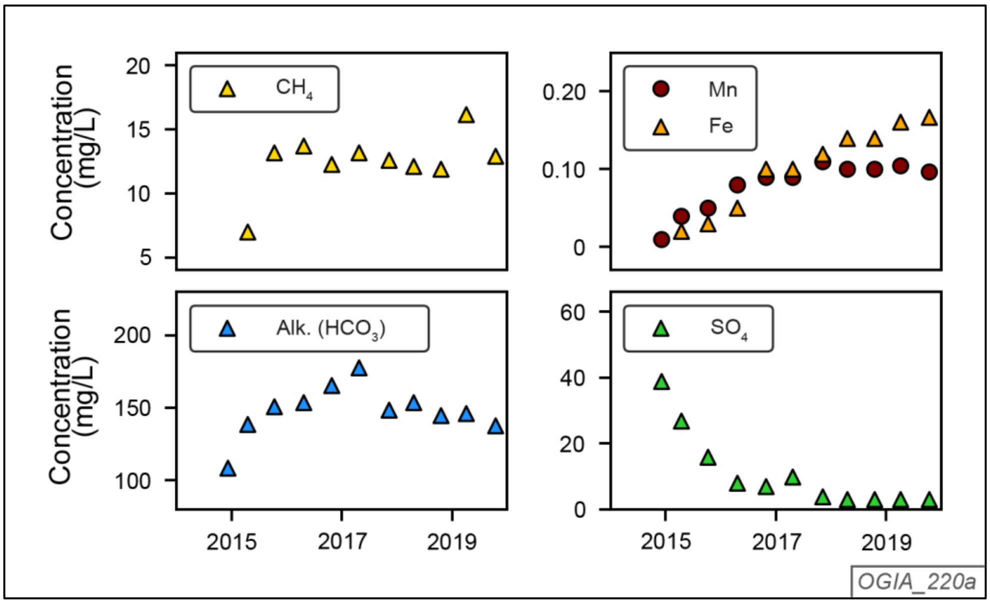

Figure 9-21: Hydrochemistry trends at Broadwater GW4

9.7.4 Condamine Alluvium

The Condamine Alluvium overlies the Walloon Coal Measures along the eastern Surat Basin and has been extensively developed for irrigation and other water supply purposes. Until recently, the majority of CSG development has occurred outside of the alluvium footprint.

The Condamine Alluvium functions primarily as an unconfined to semi-confined groundwater system, responding to direct recharge from rainfall, riverbed leakage, and groundwater discharge through groundwater use (OGIA 2016c). Long-term groundwater uses from water bores across the Condamine Alluvium, including local water use extraction within a 25-kilometre radius, is presented in Figure 9-22. Groundwater use from the alluvium itself for agriculture and S&D purposes remained relatively stable until around 1995, after which it increased and showed large annual fluctuations. CSG activity within a 10-km buffer of the alluvium also increased significantly since 2014.

Groundwater flow directions in the Condamine Alluvium have been derived from groundwater level data between 2021 and 2025 are shown in Figure 9-23 together with some representative hydrographs in Figure 9-24. There is a predominant groundwater flow direction from south to north; at the same time, elevated groundwater levels east of Cecil Plains and along the eastern boundary create a distinct localised flow pattern directed toward the west.

Historically, groundwater levels declined with the onset of groundwater pumping for agricultural use; from the 2010s, they began to stabilise or rise due to changes in water management practices. More recently, significant rainfall events in the early 2020s have contributed to further increases in groundwater levels.

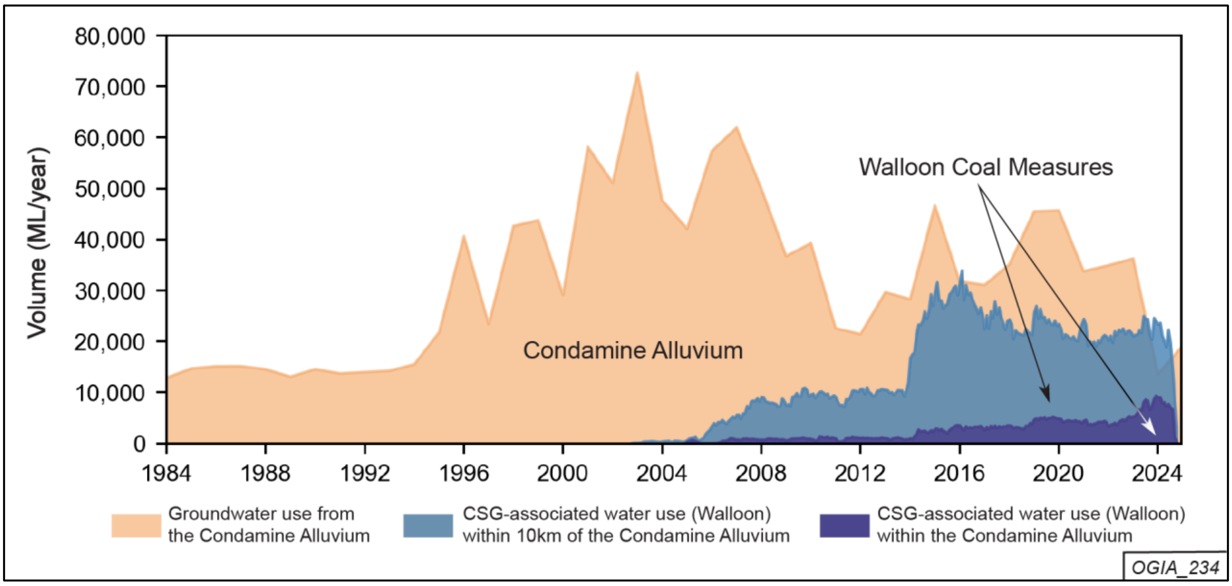

Figure 9-22: Comparative trends in groundwater use and CSG water extraction within 10km of the Condamine Alluvium footprint

Groundwater level trends near CSG fields consistently show that the alluvium's groundwater levels are decoupled from the CSG-induced drawdown in the deeper Walloon Coal Measures. North of Dalby, within three kilometres of the Daandine gas field, RN42230169A shows stable groundwater levels prior to 1990, before then declining and becoming more variable, reflecting changes in local groundwater use and climate. Although CSG production in the Walloon Coal Measures began in 2010 (as seen in Daandine-164/RN160678A), Condamine Alluvium groundwater levels continued to correlate more strongly with local extraction and climate patterns.

Walloon Coal Measures groundwater levels in nested bores at Longswamp 7 show increased drawdown after 2022 due to CSG depressurisation, compared to a general rise in groundwater levels in the Condamine Alluvium around that site. Near the Horrane Fault (RN42230155A), the Condamine Alluvium shows a steady long-term decline in groundwater levels, with no noticeable response or correlation to nearby CSG water production.

Groundwater levels at Tipton 195 (RN160717A) generally reflect climatic patterns, with a recent rise likely linked to reduced local water use and increased rainfall; however, hydrochemical trends (Figure 9-25) are likely influenced by some gas migration. Dissolved methane concentrations peaked at around 30 mg/L in 2016, then subsequently declined as nearby CSG water production increased. Similar trends in dissolved Fe, Mn and HCO_3 suggest methane biodegradation may be influencing water chemistry (Figure 9-25). This is consistent with the findings in section 7.5.4 – that the hydrochemical indicators do not provide information about the magnitude of water movement, or flux, between the units. In summary, groundwater levels in the Condamine Alluvium are primarily influenced by local groundwater use and climate and, as yet, no CSG impacts are identified from monitoring data. There are indications of free gas migration in some areas.

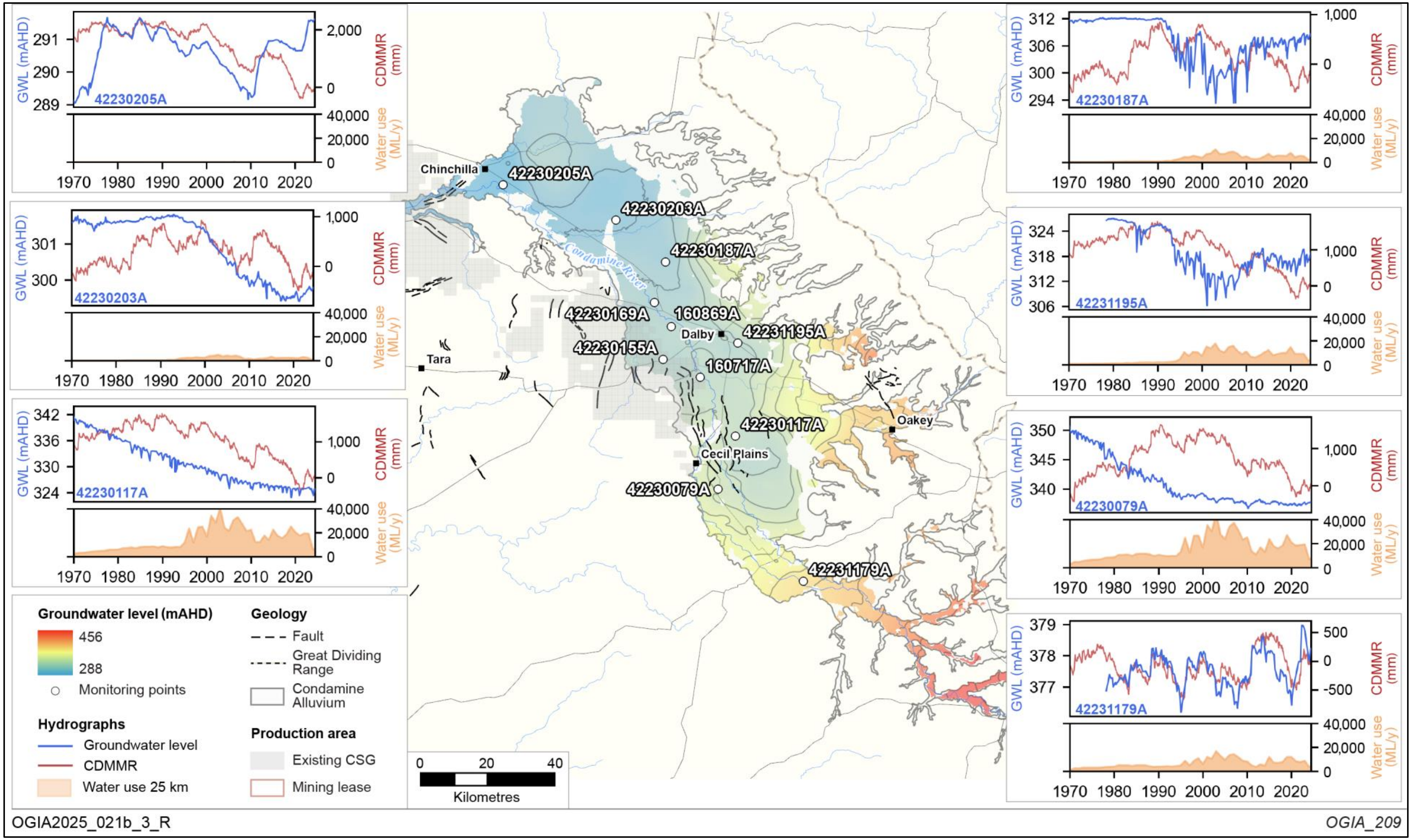

Figure 9-23: Example hydrographs showing trends and the potentiometric surface in the Condamine Alluvium

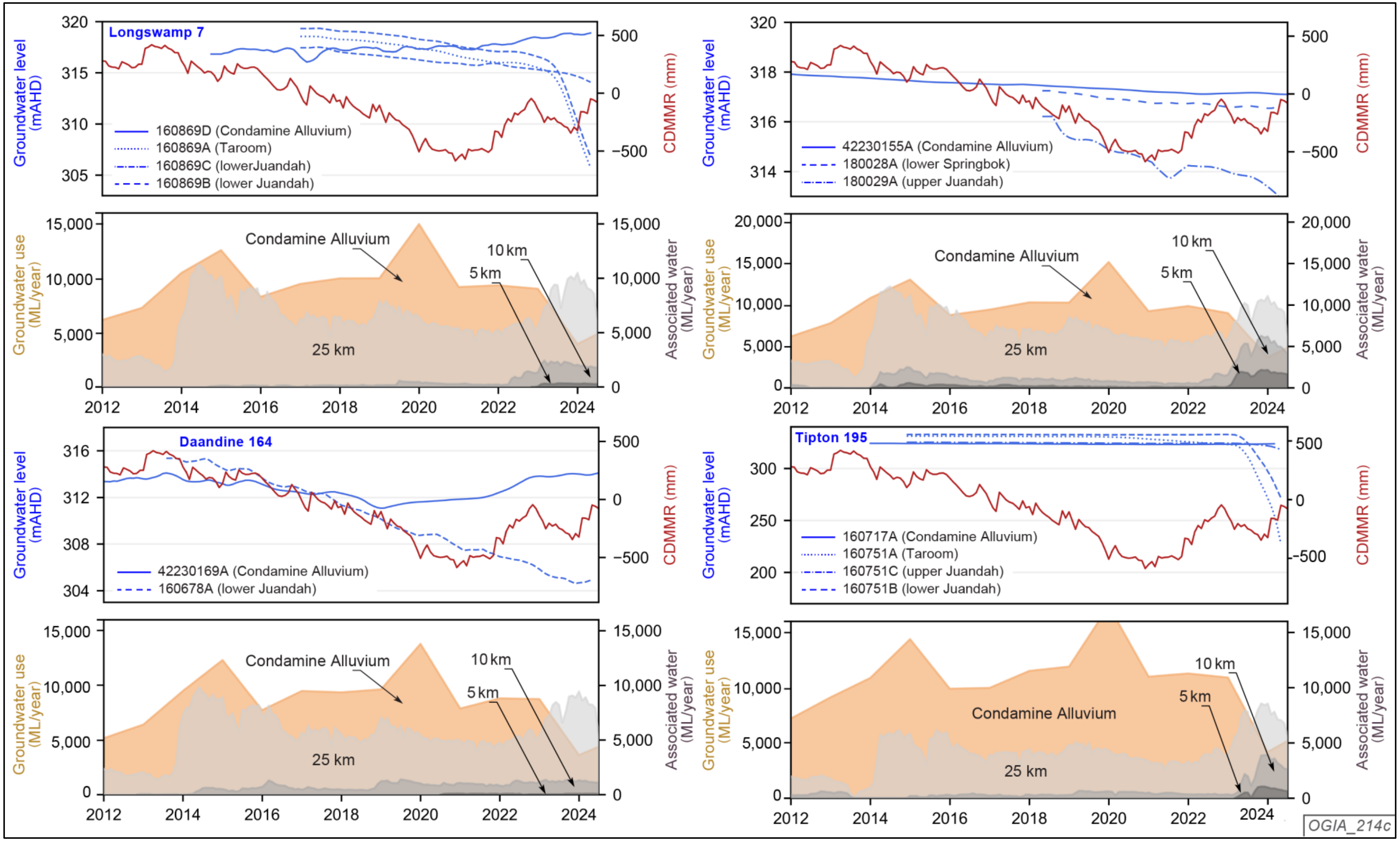

Figure 9-24: Example hydrographs showing trends in the Condamine Alluvium and the underlying Walloon Coal Measure

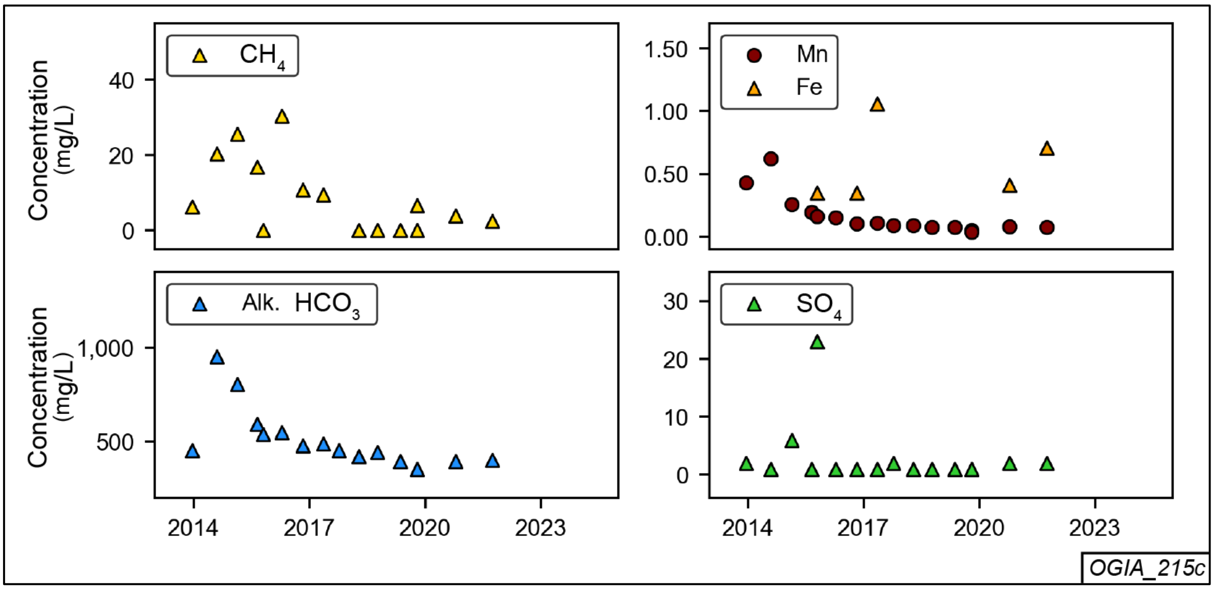

Figure 9-25: Hydrochemistry trends for Condamine Alluvium bore (Tipton 195/RN160717A)

9.8 Trends in CSG-induced subsidence

As detailed earlier, ground motion or ground movement may be caused by a range of environmental and anthropologic factors (Figure 7-4). 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. To eliminate seasonal effects, a baseline trend is established from data collected over a reasonable period. This is similar to the approach used in establishing groundwater level impacts from CSG development.

A range of methods and tools can be used to measure ground motion, the most common and efficient being a remote-sensing technique called InSAR, whereby satellite-derived radar signals are processed to determine the change in ground elevation (ground motion).

InSAR data coverage is available since 2006, corresponding with commencement of CSG operations in the Surat Basin. The data is available: from the ALOS satellite, for the period 2006–2011 at an interval of 46 days; from RADARSAT-2 for the period 2012–2017 at an interval of 24 days; and from Sentinel-1 since 2015 at intervals of 6–12 days. Sentinel-1 data is also available from points as close to one another as 20 metres, resulting in a '**point cloud**'.

The available point cloud, together with trends, is shown around the western edge of the Condamine Alluvium in Figure 9-26 and for the Surat CMA in Figure 9-27. These figures show **ground notion** as mm/year **over a period** from early 2015 to 2024, in different colours: red = greater downward ground motion; yellow = medium downward ground motion; green = neutral or upward ground motion. Also shown, as insets, are charts of ground motion over time at representative locations with respect to proximity to gas fields, selected to show the rate of change from background setting to CSG fields; red lines indicate the means of nearby InSAR points and ground motion is averaged from all data points within an area of about 250×250 m.

Within the gas fields (concentration of red points) around Chinchilla and west of Dalby, just outside of the Condamine Alluvium footprint, total ground motion of about 150 mm is noted since the record became available. The rate of ground motion (in mm/year) is higher in the early development stages. Spatially, it reduces at the margins of gas fields (yellow), changing to a nearly flat rate (green) further away from the gas fields. Closer to the Condamine Alluvium, the rate of ground motion in and around the gas fields is typically from 10 to 15 mm/year, with some instances of 20 mm/year.

By way of comparison, additional and separate studies by OGIA in assessing farm-scale impacts suggest that ground motion unrelated to CSG depressurisation and away from existing CSG development can frequently move up and down by around 25 mm due to variations in soil type, changes in moisture content and climatic factors. An important distinction is that these natural or non-CSG-related variations are fluctuations along a somewhat flat trend, compared to CSG-related ground motion, which is a unidirectional downward trend.

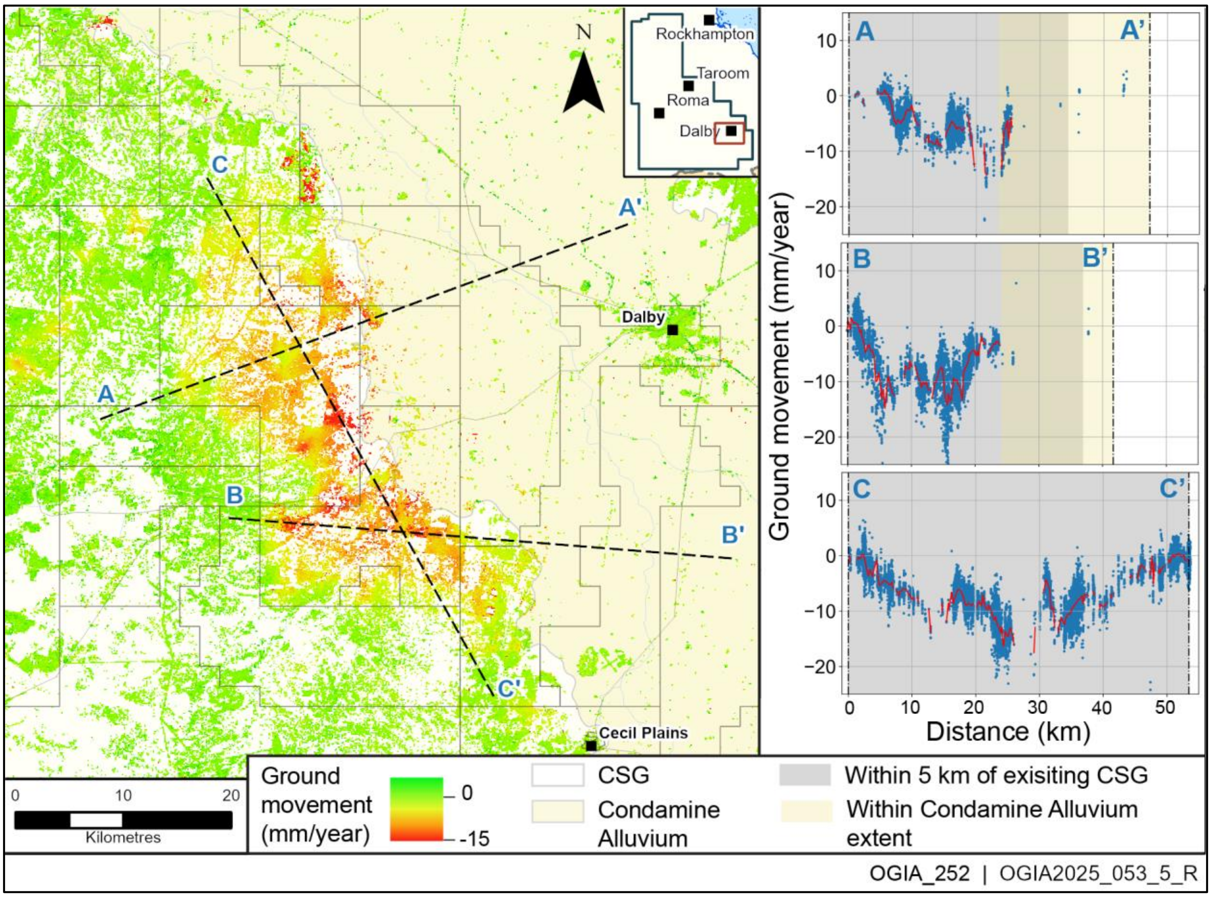

Figure 9-26: Spatial pattern of InSAR-derived ground motion around eastern gas fields near the Condamine Alluvium

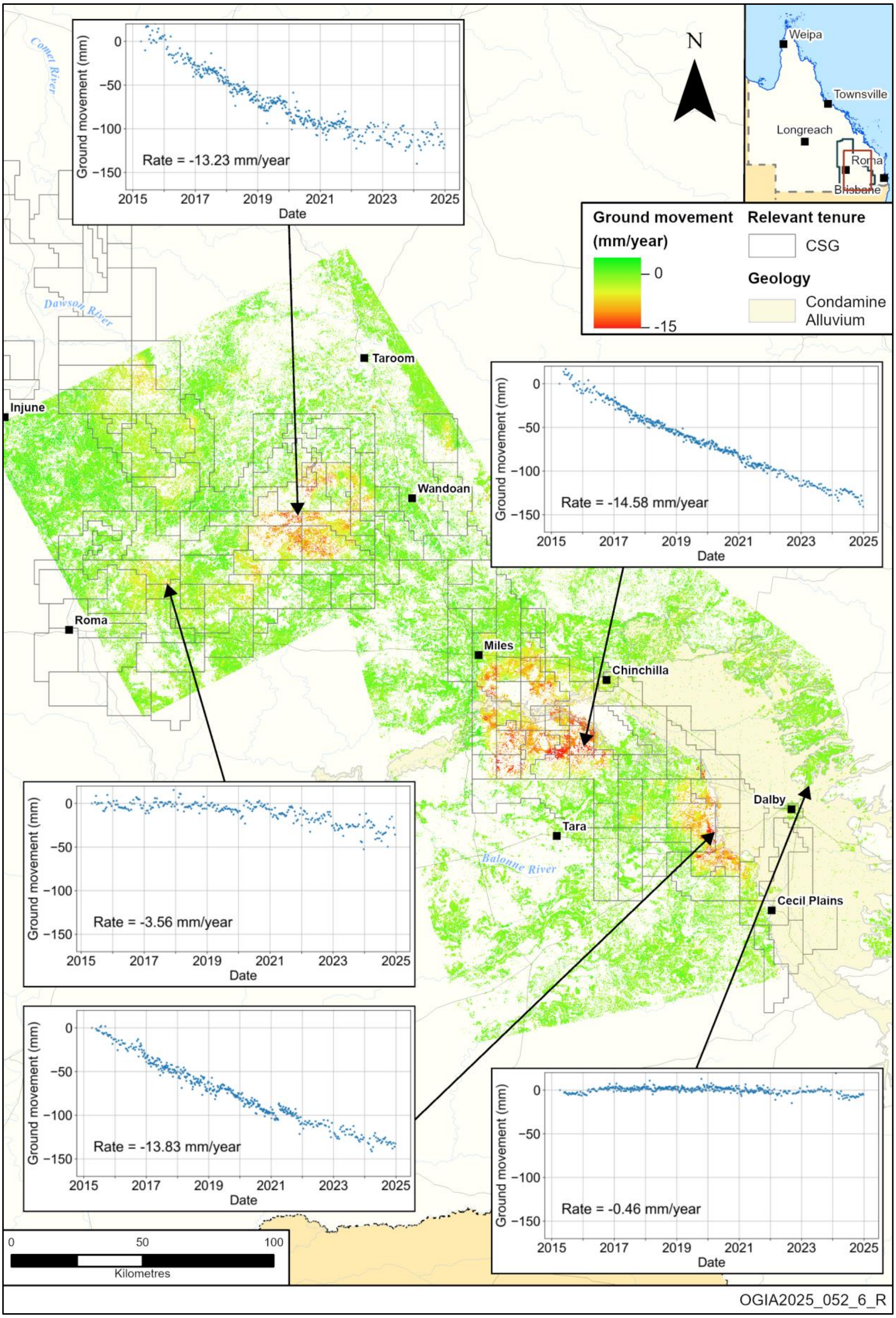

Figure 9-27: Spatial and temporal pattern of InSAR-derived ground motion around gas fields in the Surat CMA, 2015 to 2024 (Zhang, Cui & Pandey 2025)

9.9 Summary of identified impacts from monitoring data

- The observed groundwater level in an aquifer is a composite representation of multiple influences acting on the groundwater system, requiring further analysis to separate out impacts from CSG and coal mining development.
- OGIA has used groundwater level and groundwater chemistry trends from thousands of monitoring points.
- Analysis of monitoring data to isolate CSG and coal mining impacts has involved an analysis of trends before and after the CSG depressurisation period, further assisted by a multiple-lines-of-evidence framework and statistical methods.
- Maximum impacts are observed within the gas fields in the Walloon Coal Measures – the primary target for CSG in the Surat Basin – and the Bandanna Formation – the target formation in the Bowen Basin – with magnitudes of up to 280 m and 550 m, respectively.
- The Precipice Sandstone – the aquifer in direct contact with the Bandanna Formation in some parts – has likely started showing some impacts, as expected, despite the reinjection of about 4,500 ML/year.
- As reported previously, declining trends are observed throughout the Hutton Sandstone, the aquifer immediately below the Walloon Coal Measures but separated by an aquitard – mainly due to groundwater take for water supply, with some indications of localised impacts from CSG development.
- The Springbok Sandstone, which overlies the Walloon Coal Measures and is little used for water supply, continues to show evidence of CSG impact where connectivity is enhanced due to local geological features, such as faults.
- Groundwater levels in the Condamine Alluvium are primarily influenced by local groundwater use and climate, with no identifiable CSG impacts yet – also as reported in the previous UWIR.
- The ground motion influenced by CSG-induced subsidence around the western edges of the Condamine Alluvium is showing a movement rate of 10–15 mm/year, with some instances of 20 mm/year.

Chapter 10 Predictions of cumulative impacts

10.1 Preamble

Impacts are predicted changes in groundwater level (or 'drawdown') in response to cumulative groundwater extraction from CSG, coal mining and conventional oil and gas extraction. While the regional groundwater flow model does take into account groundwater extraction by other users – for consumptive purposes such as for S&D, irrigation, town water supply – as well as non-associated groundwater use and reinjection by the resources industry, the 'impacts' predicted are explicitly the impacts from the associated water extraction.

10.2 Terminology

Impact – the change in groundwater pressure ('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 impact monitoring and detection**.**

Trigger threshold – five metres of predicted groundwater level impact 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 (by the end of 2028 for this UWIR) – also informally referred to as the **short-term impacts.**

Long-term affected area (LAA) – also defined in the Water Act, an aquifer area within which groundwater levels are predicted to fall by more than the trigger threshold at any time in the future.

10.3 What causes changes to predictions

Predictions of groundwater impacts depend on:

- the **modelling tool itself**, which is customised computer-based code that mathematically represents geology, groundwater flow and resulting ground motion (detailed in Chapter 8)
- the footprint and timing of existing and proposed CSG, coal mining and conventional oil and gas development – the **industry development profile** – as detailed in section 3.3.3.

A change to either of the above will result in changes to impact predictions. More often than not, it is the development profile changes over time that, in turn, change predictions.

10.4 Impacts on aquifers and target formations

10.4.1 Immediately affected area and long-term affected area

It is a requirement of the UWIR to identify ***immediately affected areas*** (IAA) and ***long-term affected areas*** (LAA) based on statutory thresholds of timing and magnitude of impacts. ***Trigger thresholds*** are five metres for consolidated aquifers, such as sandstone, and two metres for unconsolidated aquifers, such as alluvium.

The term IAA refers to the part of an aquifer where groundwater levels are predicted to decline beyond the trigger threshold within three years of the UWIR's release (for this UWIR, by the end of 2028) – representing short-term impacts. Because there is generally greater certainty about tenure holders' development schedules over the next few years than further into the future, the IAA provides a risk-based practical basis for proactively managing impacts that are more likely to eventuate.

The LAA presents the maximum impacts – it is the area of an aquifer where groundwater levels are predicted to decline beyond the trigger threshold at any time in the future, based on the same trigger thresholds. Unlike the IAA, which is a precursor to management actions, the LAA is only for information purposes. IAAs will keep increasing with each successive UWIR, eventually merging with the LAAs, if the industry's cumulative development plans do not materially change.

There are separate IAAs and LAAs for each aquifer in the CMA – including the target CSG formations. These are shown in Figure 10-1 and Figure 10-2. The Springbok Sandstone, Hutton Sandstone and Walloon Coal Measures comprise subdivisions that are hydrogeologically distinct and often accessed separately by water bores. Separate IAAs and LAAs are therefore presented in this UWIR for the first time as below:

- Springbok Sandstone – Upper Springbok and Lower Springbok sandstones
- Walloon Coal Measures – Upper and Lower Juandah coal measures and Taroom Coal Measures, whereby any bore in the Durabilla Formation is included with Taroom and the top non-productive coal is included as part of the Upper Juandah Coal Measures.
- Hutton Sandstone – upper Hutton and lower Hutton sandstones

As stated in section 8.10, a total of 500 sets of predictions were made for each time step, to account for uncertainty and generate probabilistic distribution as P5 (5th percentile), P50 (most probable) and P95 (95th percentile). The IAA and LAA presented are based on P50 values as the most probable outcome.

10.4.2 Magnitude and temporal variability of impacts

The magnitude of groundwater level impact in a formation varies spatially, typically diminishing exponentially away from production areas. It also changes over time – expanding with time until the development peaks and then contracting during the post-development period. While some areas around the centre of the development will experience larger impacts, for most areas, the impacts are much less.

Acknowledging the complex temporal and spatial variations in impact, the magnitude and temporal variability is presented through the following non-statutory measures:

- **Magnitude of impact** (in m) – in 90% of the impact footprint, the impact will be less than this magnitude. In other words, only 10% of the impact footprint of that formation is likely to experience more than this magnitude.
- **Relative footprint** (as %) is the 5-m impact area footprint as a percentage of the collective 1-m impact area footprint from all formations. This provides an indication of the relative extent of impacts in a formation compared to overall impacts – particularly compared to the impact footprint in the CSG target formation.

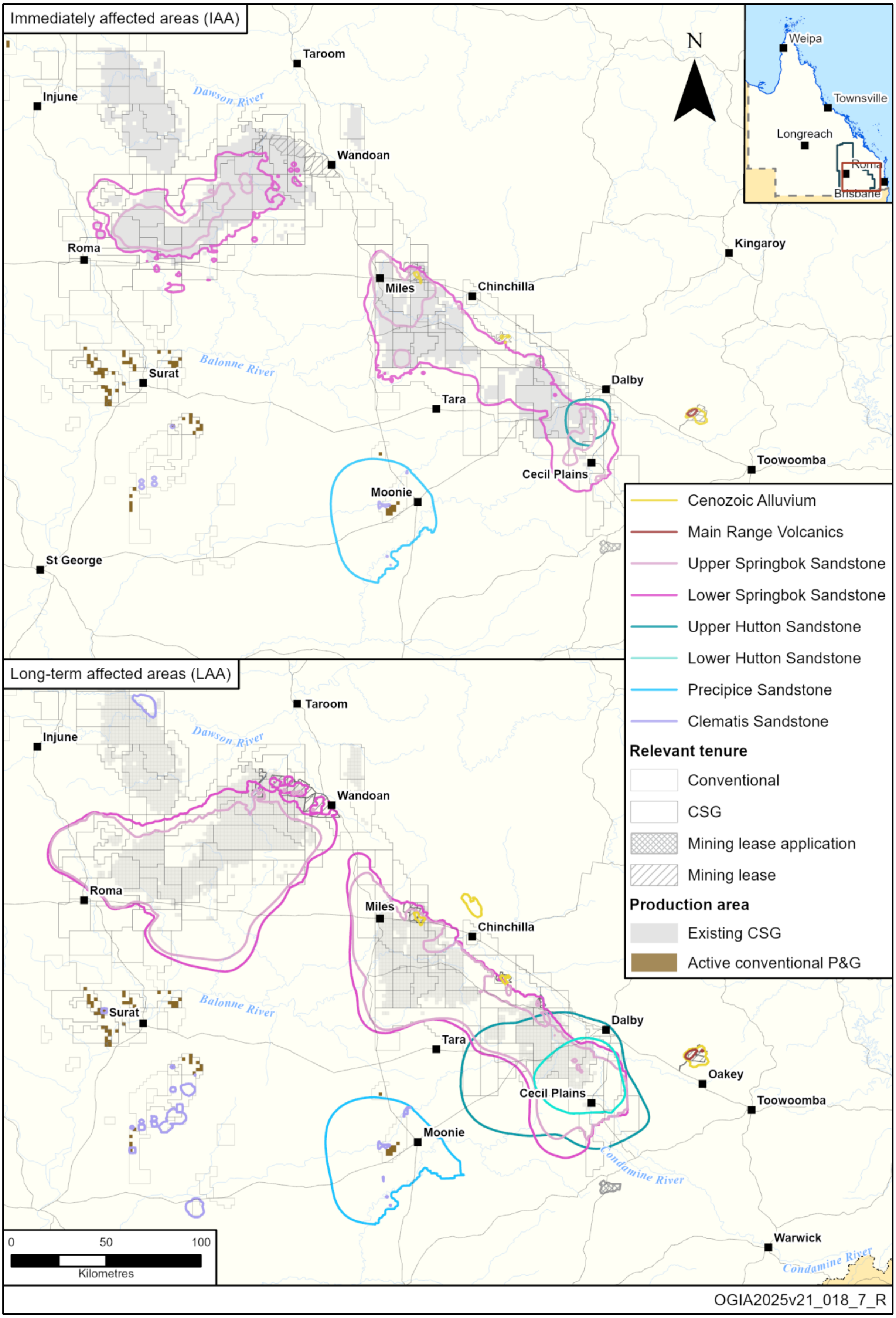

Figure 10-1: Immediately and long-term affected area (IAA and LAA) extents in the aquifers surrounding the CSG target formations

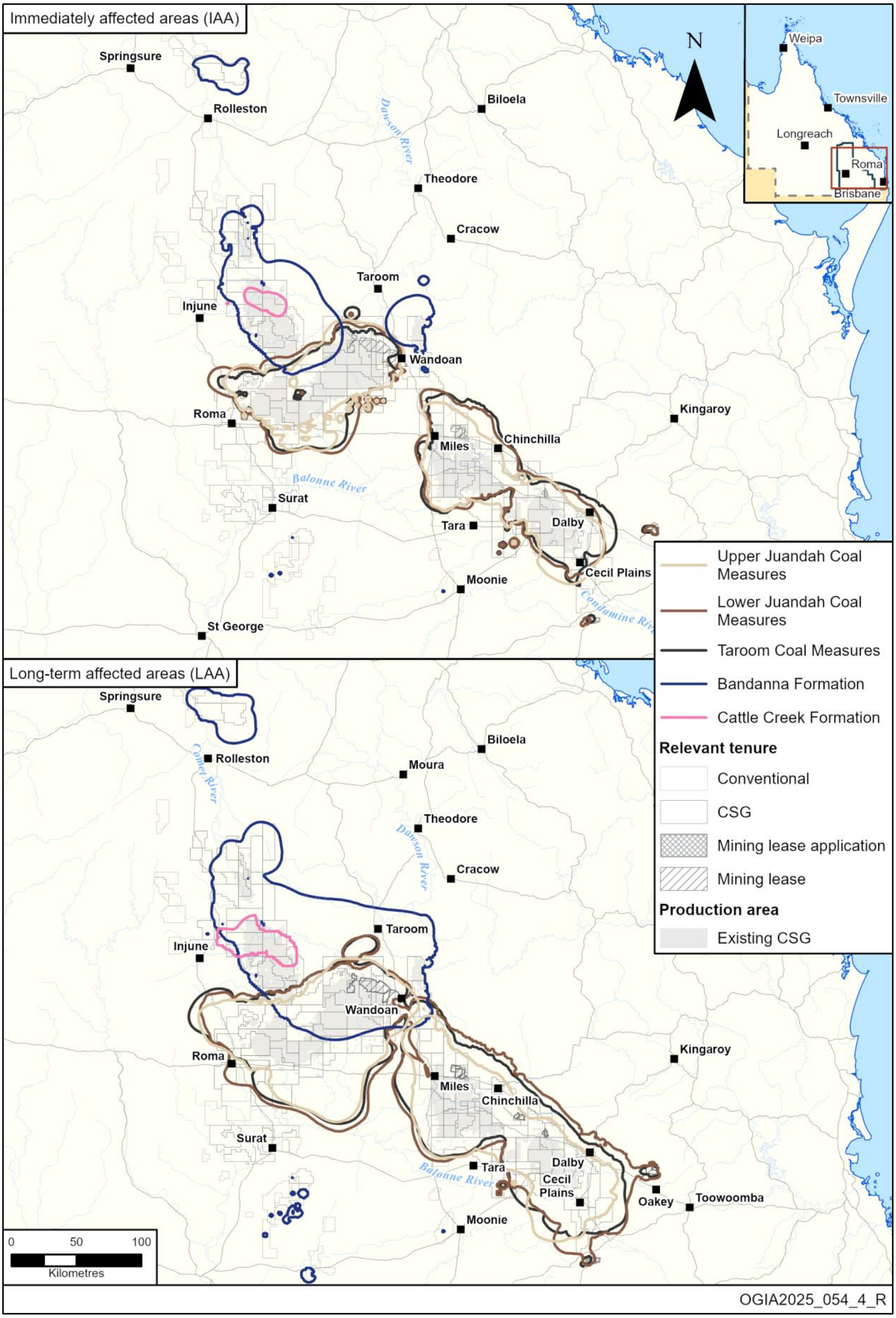

Figure 10-2: Immediately and long-term affected area (IAA and LAA) extents in the CSG target formations

- **Time series** is a plot of impact propagation over time at a specific location – including the 5th and 95th percentile bounds. This demonstrates how impacts will vary over time, when they peak and how long they may take to recover.

Magnitude of impact and relative footprints in formations are shown in Figure 10-3 and Figure 10-4, respectively. The spatial distributions of P50 impacts for the key aquifers and formations are also shown from Figure 10-5 to Figure 10-10. The upper and lower bounds (P95 and P5) are presented in a detailed modelling report (Cui, Gallagher, et al. 2025). Time series of impacts at selected locations are presented in Figure 10-11 and Figure 10-12 and the time series of predictions of net loss of water from the Condamine Alluvium to the Walloon Coal Measures is shown in Figure 10-13.

Some of the key observations from those plots for the CSG target formations and the surrounding aquifers are summarised below.

10.4.2.1 CSG target formations

- The impact footprint is comparable to that reported in the previous UWIR, with some slight expansion to shallower areas southeast of Roma and east of Moonie, and some contraction south of Cecil Plains. Most of the changes are driven by the changes in the development profile.
- The magnitude of maximum impacts in subdivisions of the Walloon Coal Measures is practically equivalent to the target pressure in those formations to achieve optimal gas production.
- The typical magnitude of impact in the lowermost part of the Walloon Coal Measures – the Taroom Coal Measures – is relatively greater, at about 420 m, compared to the middle part (Lower Juandah Coal Measures), which is about 350 m, and the uppermost part (Upper Juandah Coal Measures), which is likely to be about 200 m. Generally, the deeper the formation, the greater the impacts.
- Depressurisation is greatest in the coal measures – close to 600 m in some localised areas towards the middle of the gas fields, where the formation is also at its deepest. Conversely, in the shallower southeast and eastern margins of the target formations near the outcrop areas, the depressurisation is likely to be about 100–150 m.
- Impacts in the CSG target formations generally extend to about 10 km from the production wells but the 5-m impact extends only 5–-10 km from the gas fields.
- Impacts in the Bandanna and Cattle Creek formations, the two CSG targets in the Bowen Basin, are much higher compared to the Surat Basin because the coal seams are also much deeper.
- Since the previous UWIR, while there is significant contraction of the impacts in the Bandanna Formation due to corresponding contraction in the planned development, the magnitude in some areas has increased.
- Impacts in the Cattle Creek Formation, located several hundred metres below the Bandanna Formation, are limited due to the small development footprint around the Fairview CSG field.
- In areas close to the edge of the predicted impacts in the Walloon Coal Measures, groundwater levels are expected to recover within five years. Within CSG production areas, groundwater levels are predicted to take more than 1,000 years to fully recover.

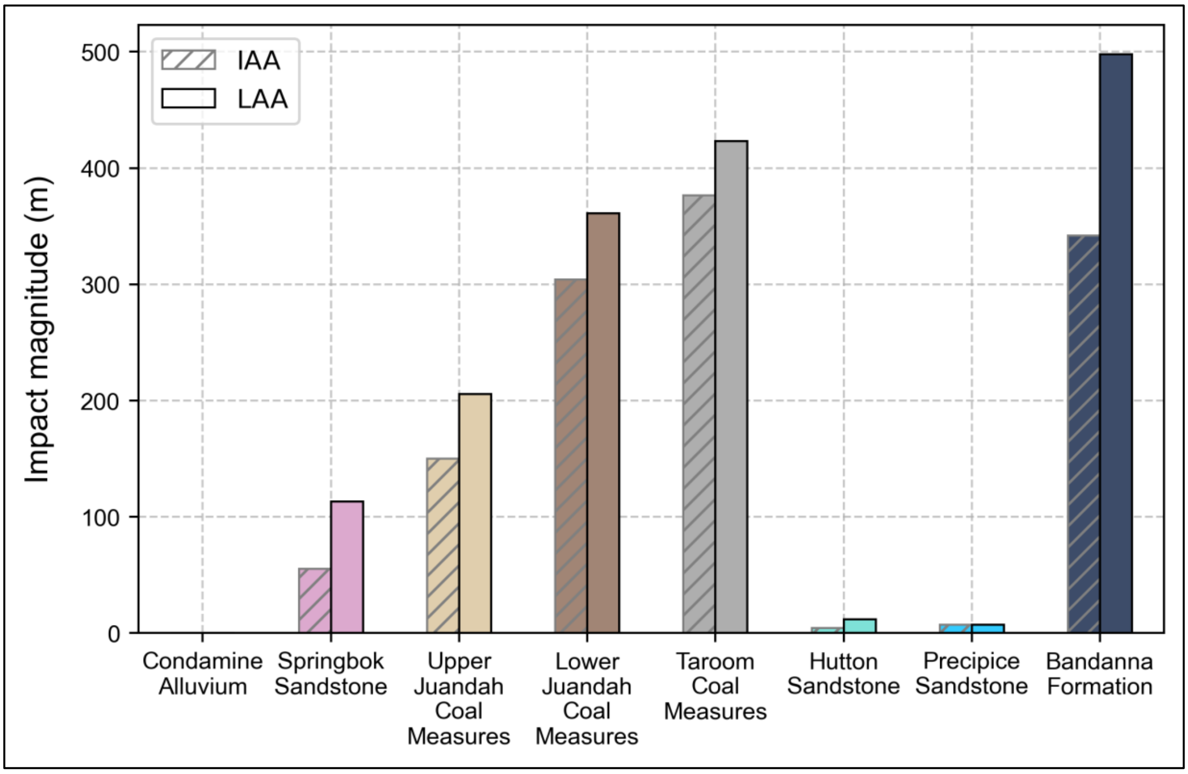

Figure 10-3: Typical magnitude of impacts in affected formations

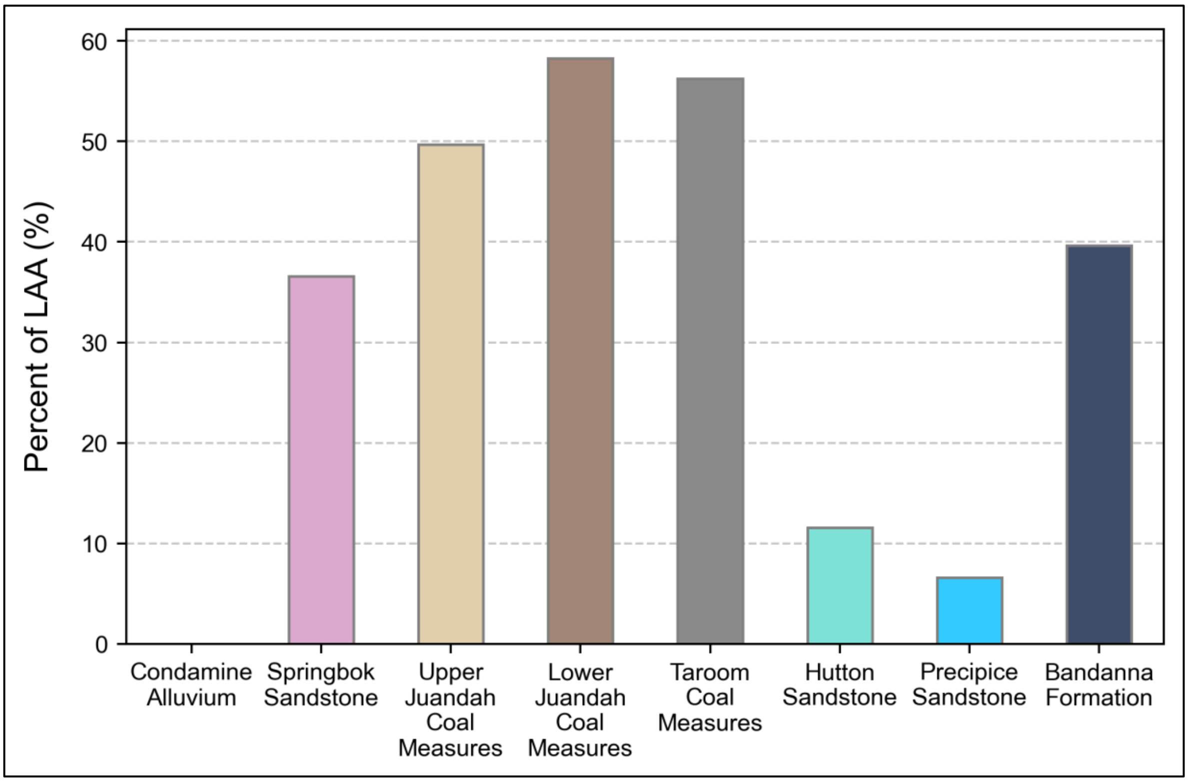

Figure 10-4: Relative footprints of impacted areas in the formations

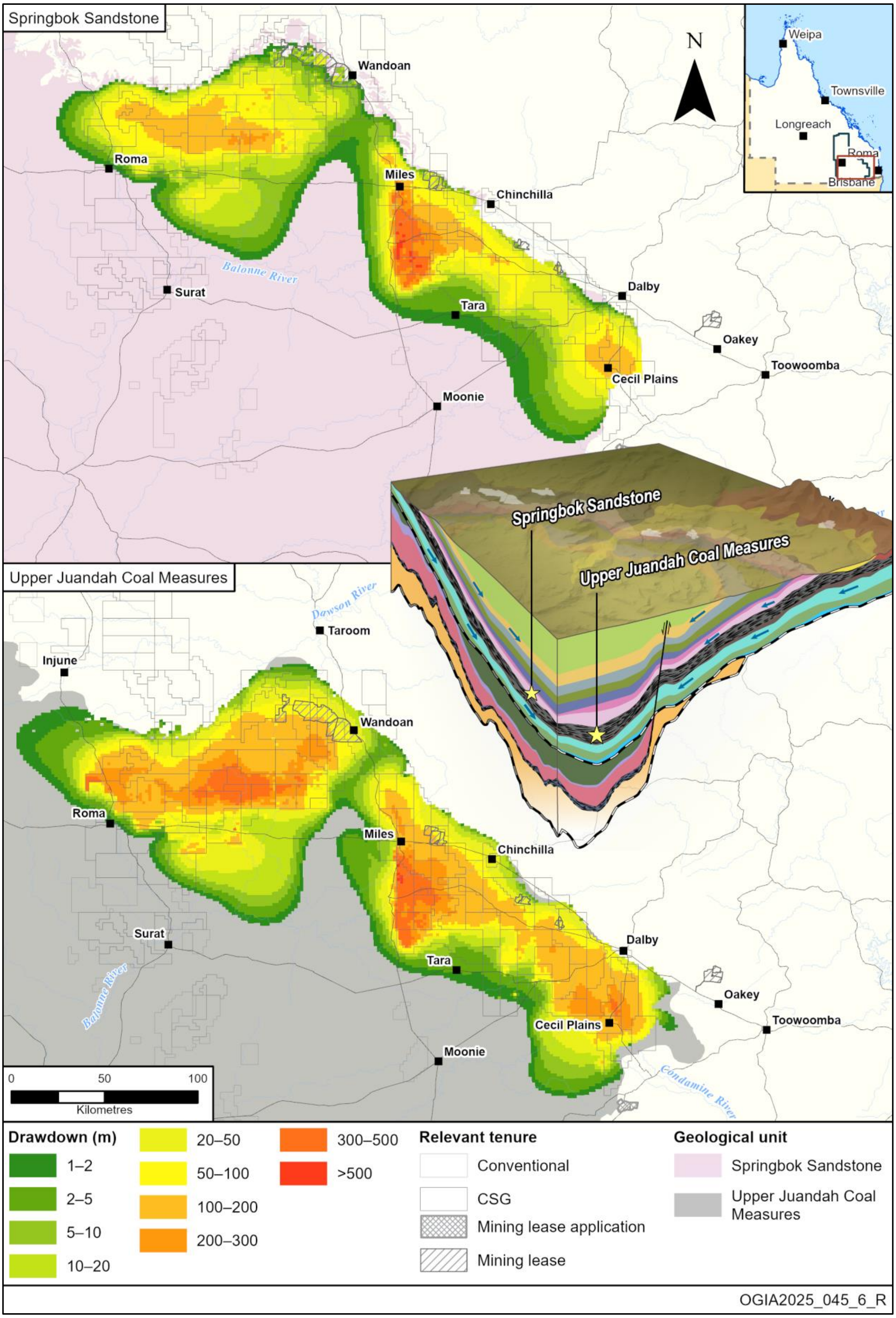

Figure 10-5: Long-term impact distribution, Springbok Sandstone and Upper Juandah Coal Measures

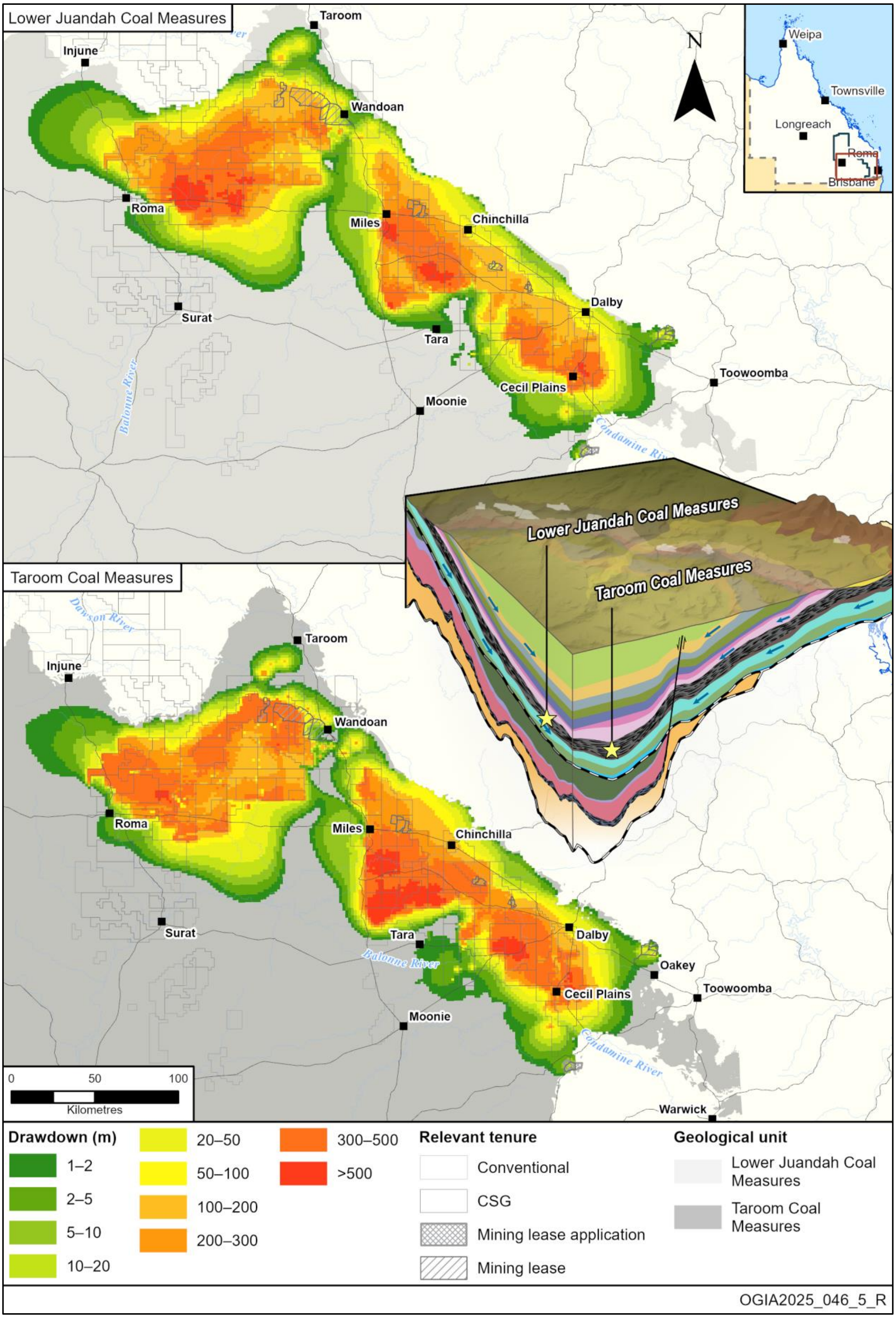

Figure 10-6: Long-term impact distribution, Lower Juandah and Taroom coal measures

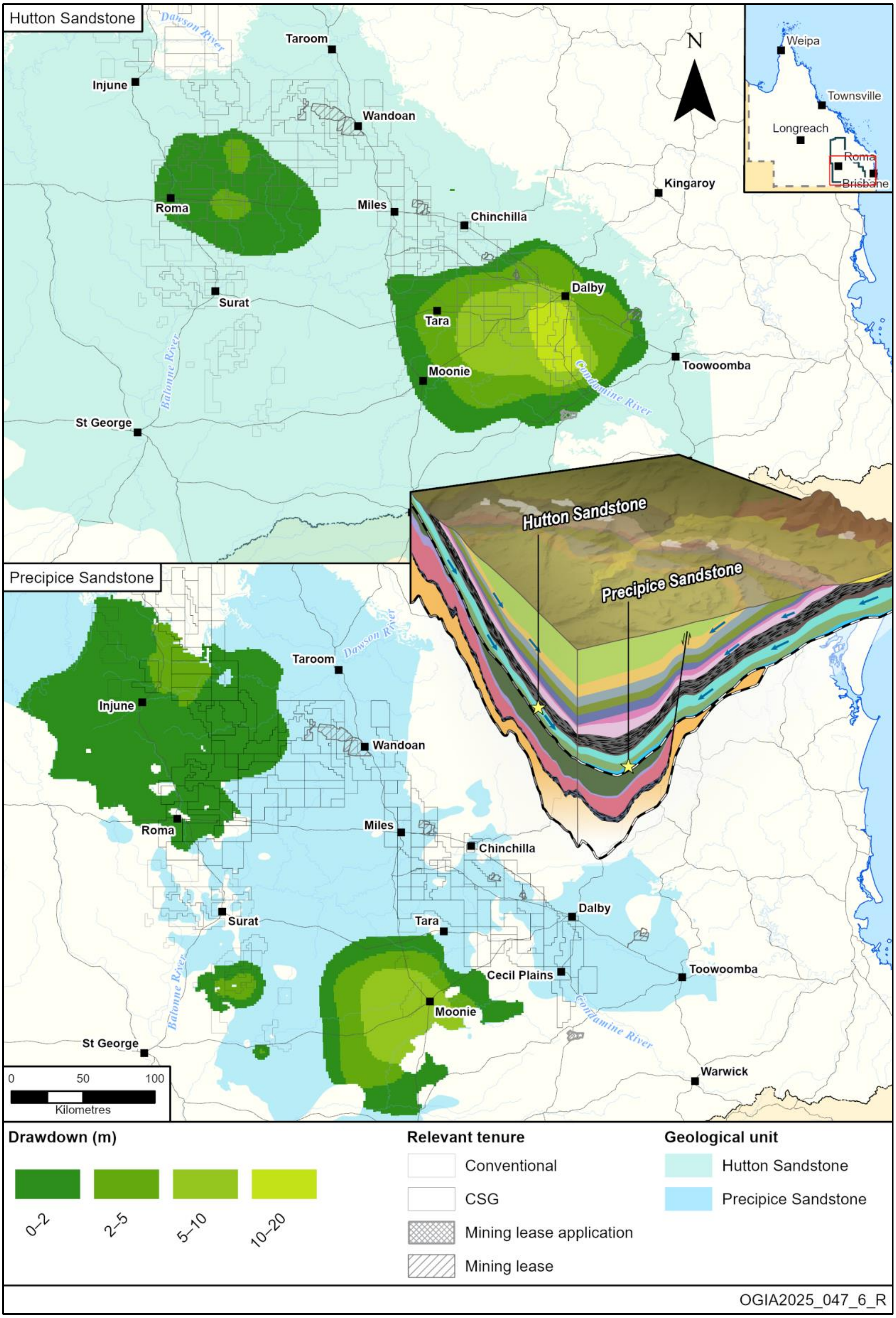

Figure 10-7: Long-term impact distribution, Hutton and Precipice sandstones

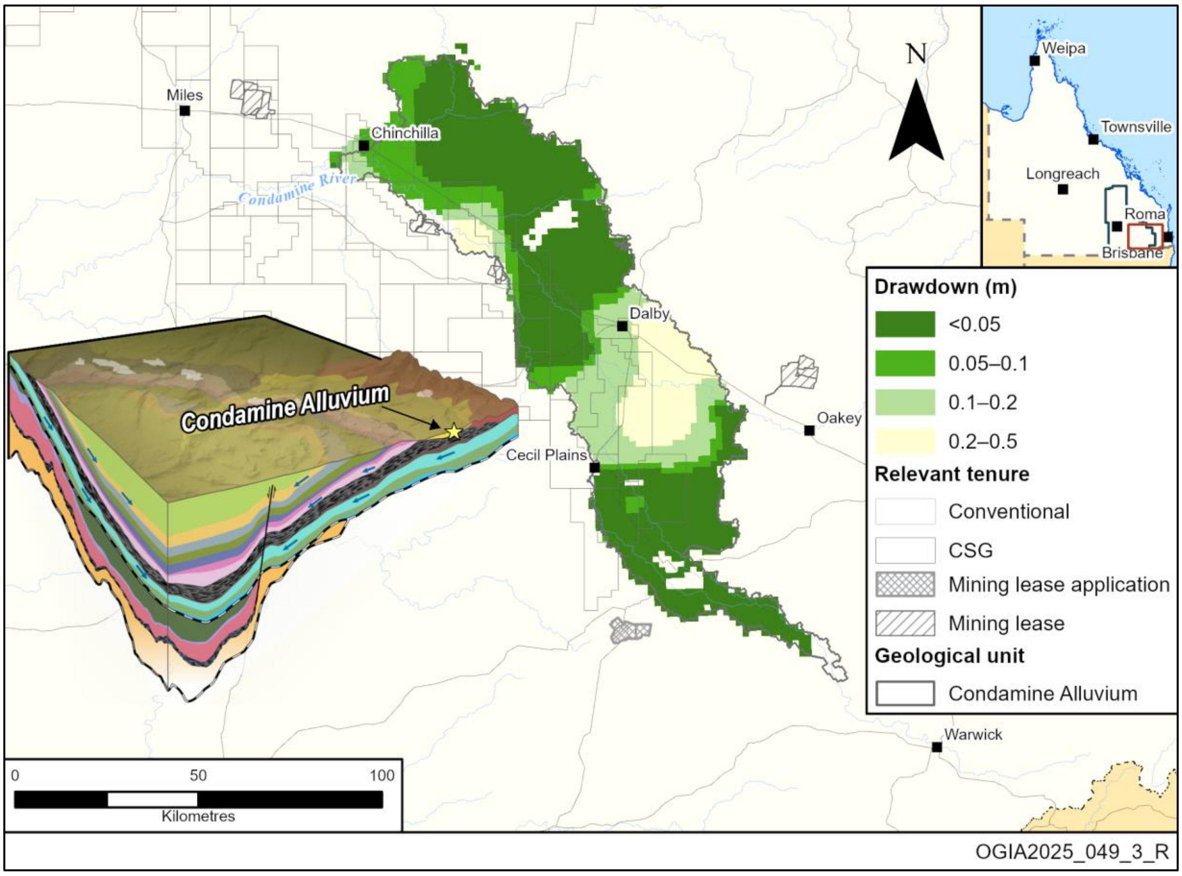

Figure 10-8: Long-term impact distribution, Condamine Alluvium

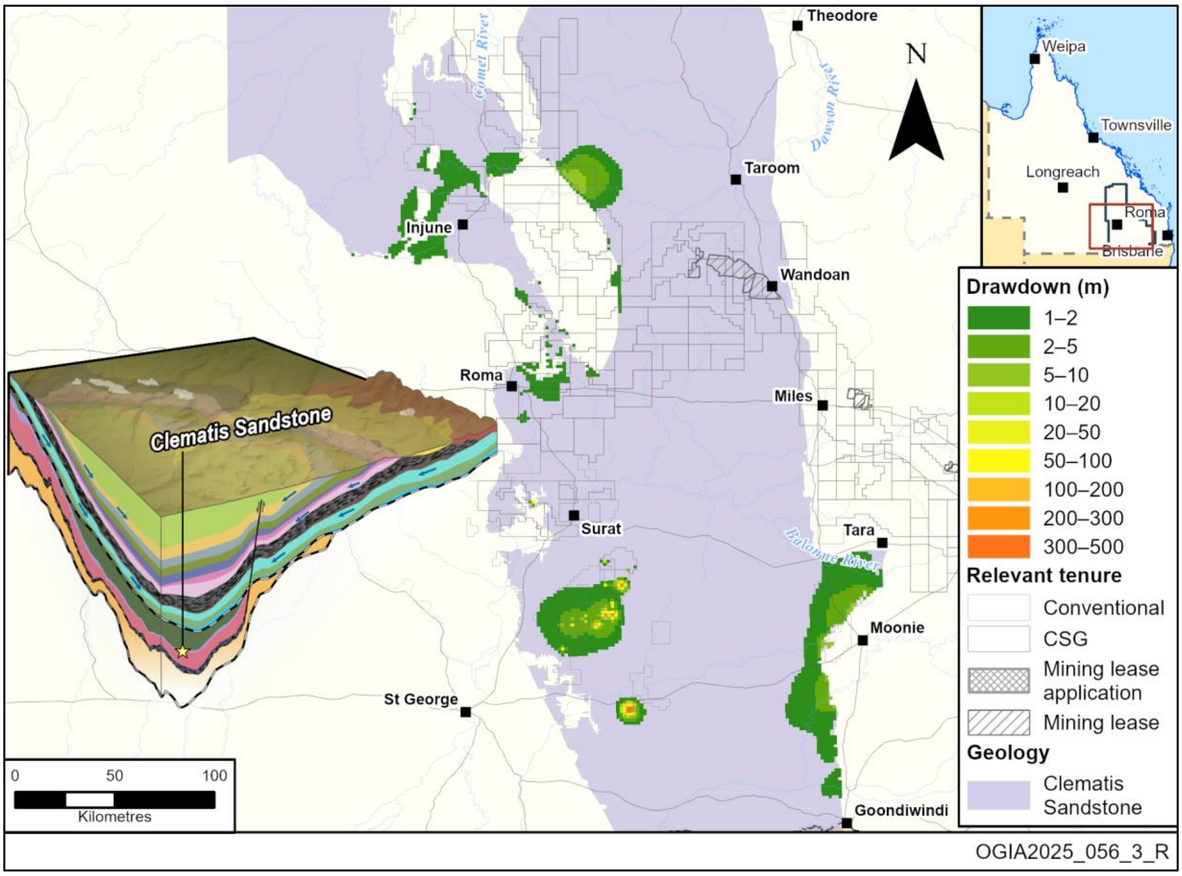

Figure 10-9: Long-term impact distribution, Clematis Sandstone

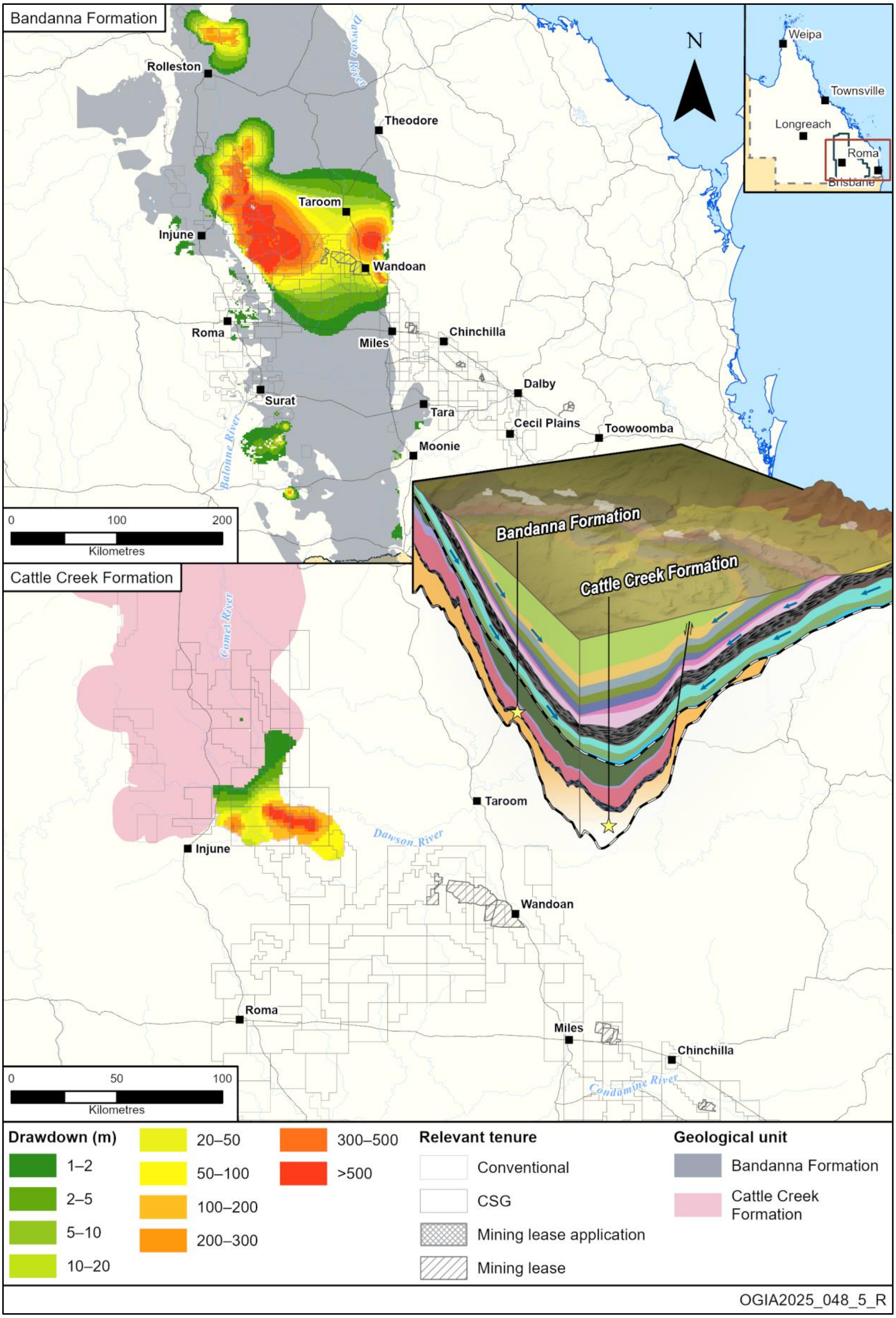

Figure 10-10: Long-term impact distribution, Bandanna and Cattle Creek formations

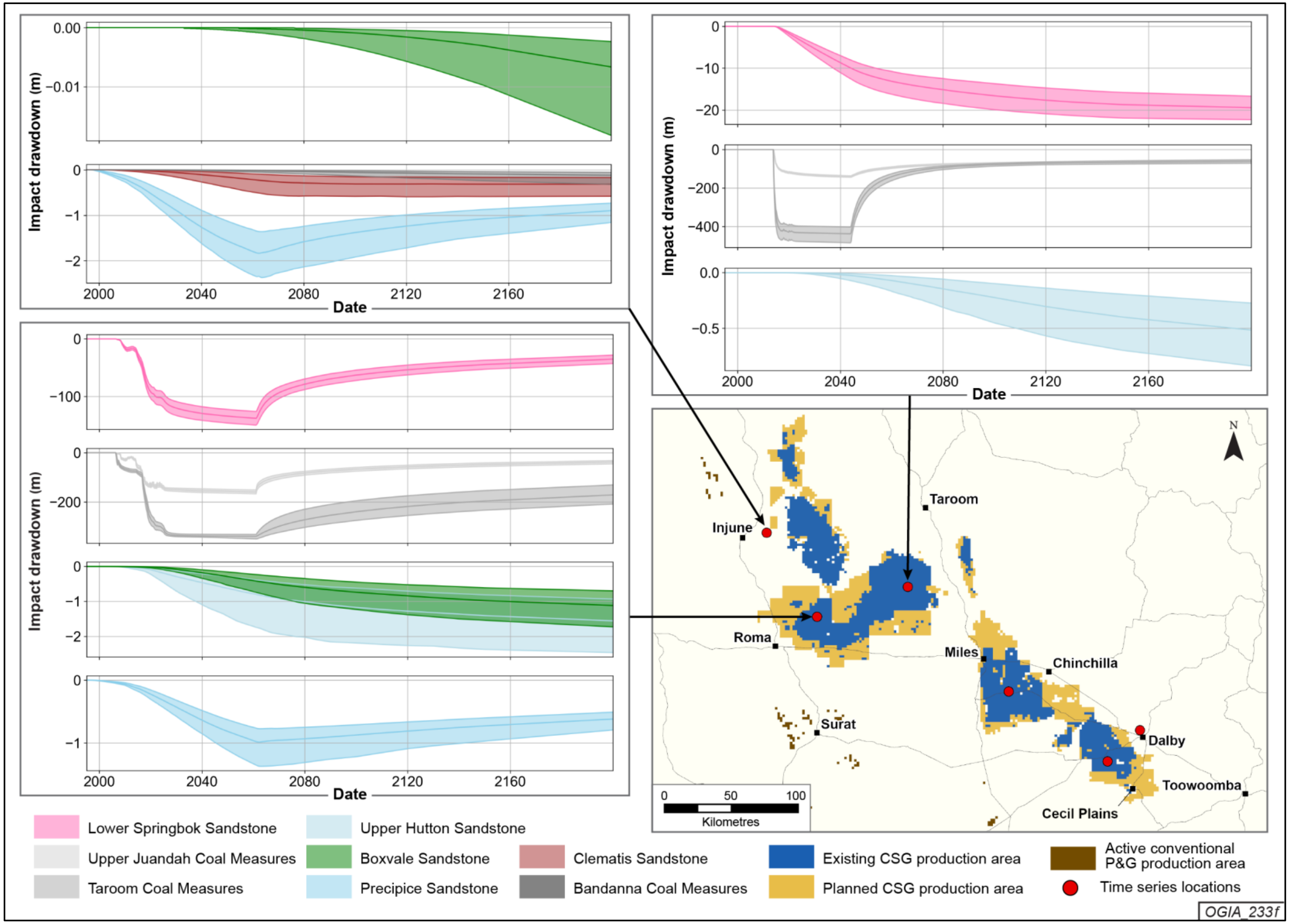

Figure 10-11: Time series of predicted impacts at some locations in the northern CMA

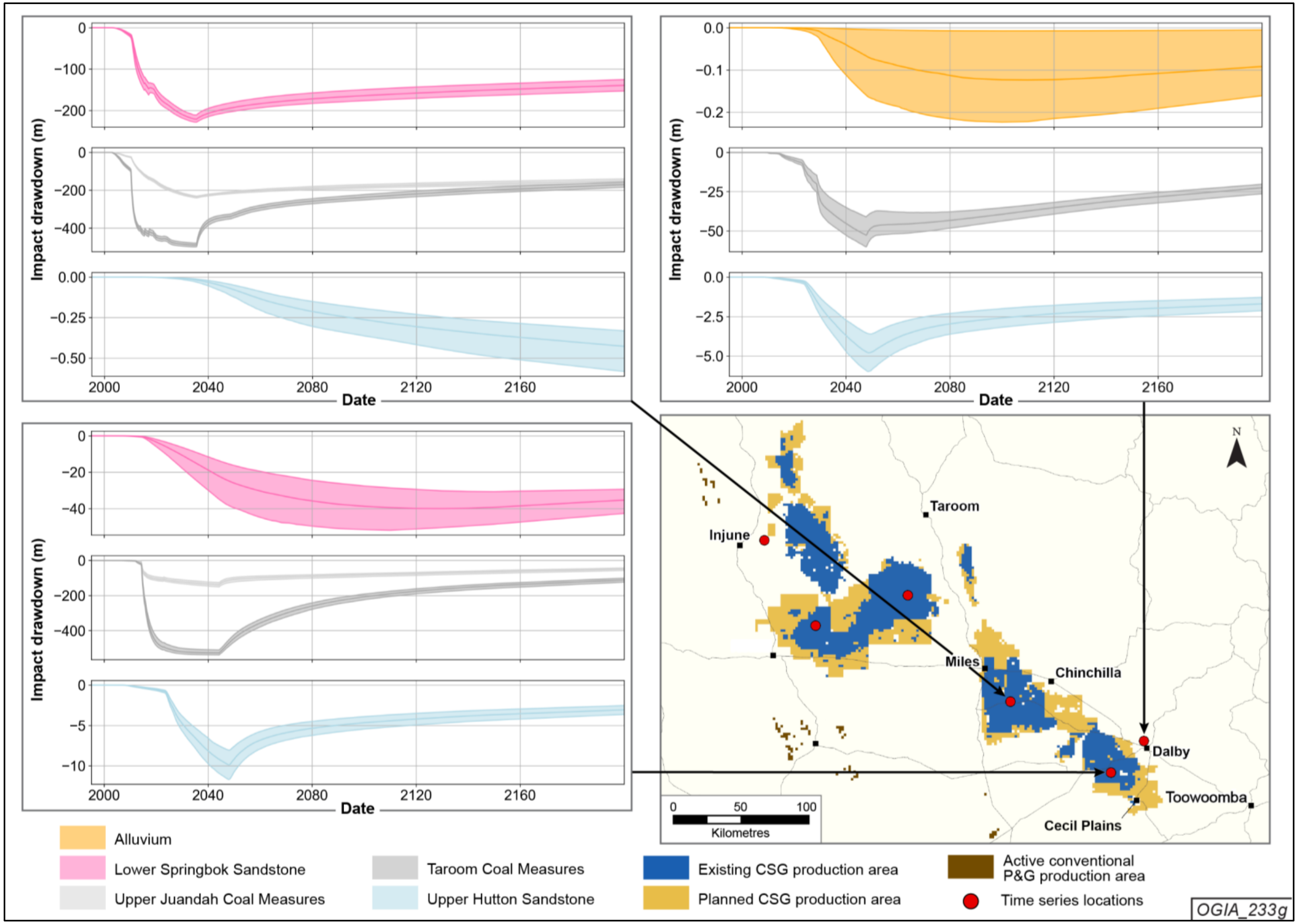

Figure 10-12: Time series of predicted impacts at some locations in the southern CMA

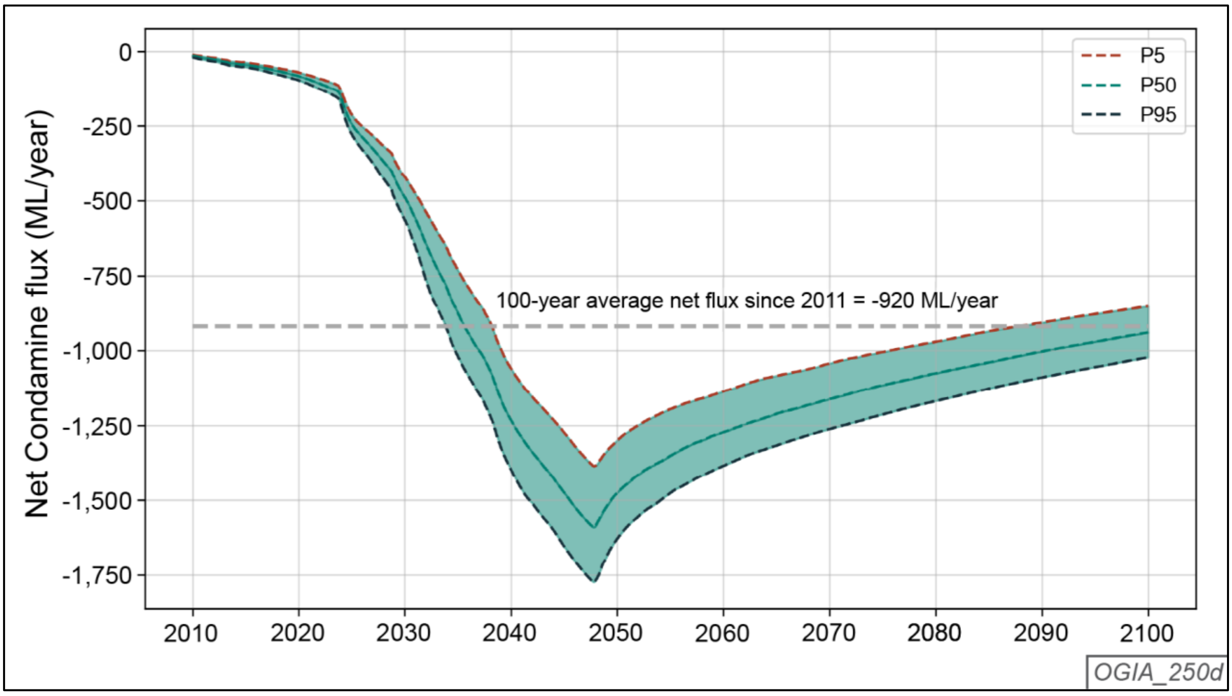

Figure 10-13: Time series of predictions of net loss of water, Condamine Alluvium to Walloon Coal Measures

10.4.2.2 Overlying aquifers and formations

- Substantial impacts are predicted in the Springbok Sandstone, which overlies the Walloon Coal Measures. This is primarily due to the partial completion of CSG wells into the Lower Springbok Sandstone (section 7.5.2). The impact footprint and pattern are very similar to those of the Walloon Coal Measures, but the magnitude is less, at around 110 m.
- Compared to the underlying 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.
- The impact pattern in the Condamine Alluvium is broadly similar to the previous UWIR and remains less than half a metre. The edge of the impact footprint, as represented by 10 cm of drawdown, is very sensitive to model recalibration.
- The average net loss of water from the Condamine Alluvium to the underlying bedrocks is predicted to be about 920 ML/year over the next 100 years, as shown in Figure 10-13. This is marginally less compared to the predictions in the last UWIR but broadly consistent with predictions in other UWIRs since 2012.

10.4.2.3 Underlying aquifers and formations

- Relatively lesser impacts are predicted in the southern parts of the Surat Basin in three underlying aquifers – the Hutton, Precipice and Clematis sandstones.
- The magnitude of impact in the Hutton Sandstone is likely to be less than 10 m and will occur decades from now.
- Impacts in the Precipice Sandstone in the north are from the CSG development in the Bowen Basin, due to connectivity along the western contact zone (section 7.5.4). The one-metre impact footprint is significantly wider compared to the previous UWIR. This is primarily due to

improved calibration of water production in the model and minor changes to the production profile and well screen placement.

- There are some uncertainties associated with representation of the localised processes driving impact predictions in the Precipice Sandstone.
- In relation to the impact predictions in the Precipice Sandstone, there has been some advancement in the conceptualisation of the system, combined with observed signals of potential impacts in the last two years. This is not fully represented in the regional model at this stage, due to interdependencies of sequencing of tasks. OGIA is committing to focus on developing and implementing a separate, problem-specific, modelling strategy for the Precipice Sandstone during the next UWIR cycle.
- Elsewhere, impacts in the Precipice and Clematis sandstones are from conventional oil and gas activities, as detailed in the next section.

10.4.3 Impacts from conventional oil and gas activities

As noted earlier, predicted long-term impacts in the Precipice and Clematis sandstones are from conventional oil and gas activities associated with the Moonie oil field, where production started in 1964 and is now in a declining phase, nearing end of life. Conventional production contributes only 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 than CSG formations and is progressively retracting. Due to the depth of impacted aquifers, they are not generally accessed for water supply in the areas of predicted impact.

10.4.4 Mining impacts

Mining impacts are integrated into the cumulative impacts, as summarised in previous sections. This section discusses mining-only impacts, for information purposes. As detailed in section 3.4.3, five of the seven 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 modelling run was carried out to assess additional impacts from coal mining, as presented in Figure 10-14. The results suggest the following:

- In northern areas, west of Wandoan, 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) could be up to 55 m in localised areas near the mine pits. For most areas, it is less than 10 m.
- In the central areas, around the Cameby Downs, Kogan Creek and Wilkie Creek mines, the long-term predicted impact is influenced by the timing of pit development. While it may reach up to 67 metres in close proximity to the mine pits, it is generally less than 20 metres and diminishes 10–15 km from the mine sites.

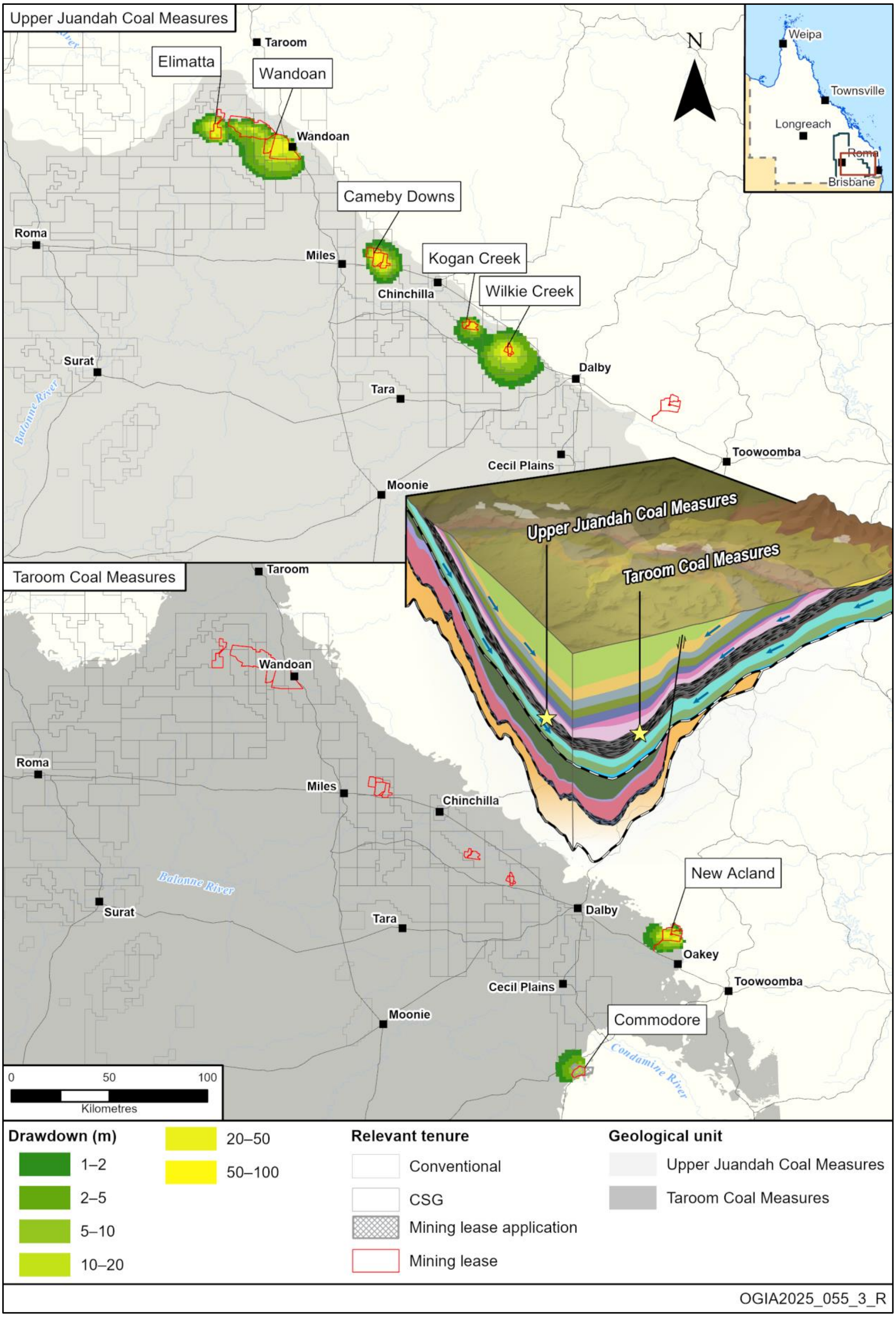

Figure 10-14: Long-term impact (LAA) distribution, Upper Juandah and Taroom coal measures, around coal mines

- In the southern areas, the New Acland and Commodore mines – targeting the Taroom Coal Measures – are located approximately 40 km from CSG development. As a result, both mines are unlikely to substantially overlap with regional CSG impacts. Mining-induced drawdowns may reach up to 30 m at New Acland and up to 15 m at Commodore, with no predicted impact beyond 10 km from the mine pits.
- The differences from the previous UWIR prediction primarily relate to the change in mining development plans and the withdrawal of The Range mine.

Impacts are predicted in the post-mining period, 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.

10.5 Associated water extraction and inter-formation flow

Regional model predictions of associated water extraction in the Bowen and Surat basins are presented in Figure 10-15. The average extraction over the life of the industry is estimated to be approximately 32,000 ML/year, with a peak of around 70,000 ML/year around 2030. Between 2014 and 2060, when most of the production is expected to occur, the average is approximately 46,000 ML/year – compared to the 54,000 ML/year predicted in the previous UWIR (2021). Predicted extraction in the next three years (2026–2028) is likely to be around 66,000 ML/year.

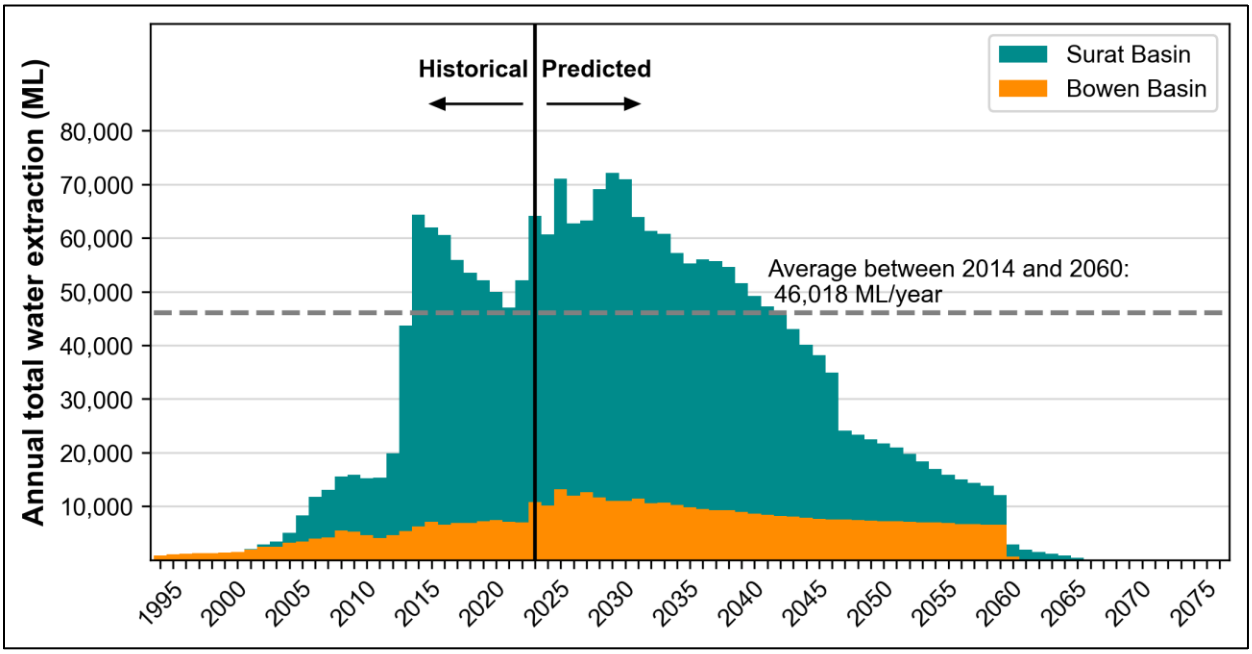

Figure 10-15: Associated (CSG) water extraction from model predictions

The timing and volume of predicted associated water extraction will continue to vary in future, due to ongoing changes in the scheduling and location of CSG production activities. Over a 100-year period from the start of the CSG production, most associated groundwater extracted will come from the Walloon Coal Measures. Around 10% of the water is predicted to be coming from surrounding aquifers through cross-formational flow, of which about 1% is 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, 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.

10.6 Impacts on water bores

A number of water supply bores accessing the aquifers and the CSG target formations (section 5.8) are likely to experience impacts in the short and long terms, as detailed in previous sections. The number of water bores within LAA and IAA areas, and corresponding make good arrangements, are described in Chapter 11. This section presents the magnitude of impacts at the locations of those water supply bores.

The magnitude of impacts likely to be experienced by water supply bores in different formations are shown in Figure 10-16. Most bores in the Walloon Coal Measures are likely to experience a drawdown of 20–60 m. This is significantly less than the magnitude of impacts throughout the extent of the formation because water supply bores tend to be located in shallower parts of the formation, where impacts are also relatively much lesser. The only surrounding aquifer where impacts in water bores exceed five metres is the Springbok Sandstone. Drawdown in water bores in all other formations, such as the Precipice Sandstone and the Hutton Sandstone, will remain less than four metres.

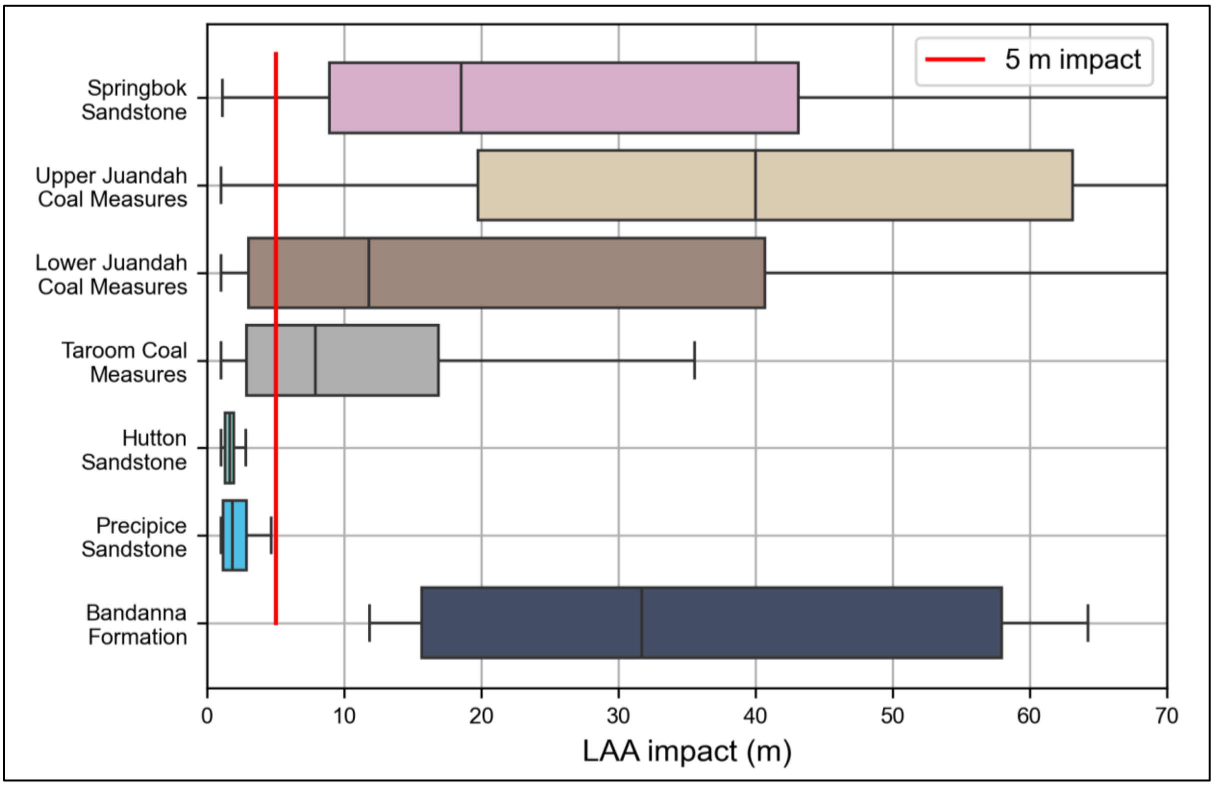

Figure 10-16: Magnitude of predicted impacts to water supply bores in different formations

10.7 Uncertainties in predictions

The subsurface geological environment is complex and the understanding of its architecture and performance under stress is limited to observations and measurements from some parts of the system. Groundwater models are simplified constructs that are continuously refined to assimilate new data, improvements to conceptualisations and inherent uncertainties, in order to improve predictions and inform management options – relating to resource development, in this instance. In this context, uncertainties in predictions can arise from three sources:

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

As detailed in Chapter 8, the regional groundwater flow model was set-up to explore parameter uncertainty, generating 3,000 sets of predictions to derive the P50 that is used in determining impacts, as discussed in earlier sections. Further scrutiny of the range of predictions indicates that impact footprints in the Walloon Coal Measures and Springbok Sandstone may vary by about 10 to 15%, possibly more for other formations. There is also greater uncertainty in the Bowen Basin, which reflects the comparatively lesser calibration data available in that basin. In addition to impact areas, the predicted average associated water extraction volumes may vary by about 12% for an individual development profile.

10.8 Predictions of subsidence

10.8.1 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 environmental values (EVs) located within areas of potential risk. 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 environmental impact statement (EIS) and environmental authority (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 motion 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 estimates a maximum subsidence of up to 280 mm around the Roma gas field and 150 mm for the Arcadia and Fairview gas fields (Santos 2013). QGC estimates 80 mm in the central gas fields, increasing to 145 mm in the south and 180 mm in the north (QGC 2012).

OGIA undertook a cumulative assessment of regional-scale CSG-induced subsidence for the UWIR 2021. The predictions were based on a combination of geomechanical and groundwater flow modelling, accounting for all existing and proposed development. The subsidence model was history-matched to ground motion data. Predictions of subsidence within the Condamine Alluvium footprint suggested that most of the cropping area was likely to experience less than 100—150 mm of subsidence by the end of 2060, with some exceptions around the heavily developed CSG fields, where the maximum subsidence could be up to 175 mm. The maximum change in ground slope from CSG-induced subsidence in most areas was expected to be less than 0.001% (10 mm over 1 km) but could be up to 0.004% (40 mm over 1 km) in some areas.

10.8.2 Current predictions of regional-scale cumulative subsidence

Predictions of CSG-induced subsidence for this UWIR are made using the much-improved and peer-reviewed coupled groundwater and geomechanical modelling approach described in Chapter 8 (Cui, Schoning, et al. 2025). Predictions are presented in this report as regional slope change around the Condamine Alluvium (Figure 10-17), the P50 magnitude of subsidence in the Surat Basin (Figure 10-18) and probabilities of various magnitudes of subsidence as derived from stochastic analysis, across the Walloon Coal Measures footprint (Figure 10-19).

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. For most parts, the CSG-induced subsidence is likely to remain 100-150 mm or less. Only in some very limited and localised areas west of Chinchilla and around Cecil Plains is the probability of CSG-induced subsidence greater than 200 mm. Echoing the findings from 2021, the maximum change in regional ground slope from CSG-induced subsidence in most areas is still predicted to be less than 0.001% (10 mm over 1 km), reaching up to 0.004% (40 mm over 1 km) in some areas around the Horrane Fault within the Condamine Alluvium footprint.

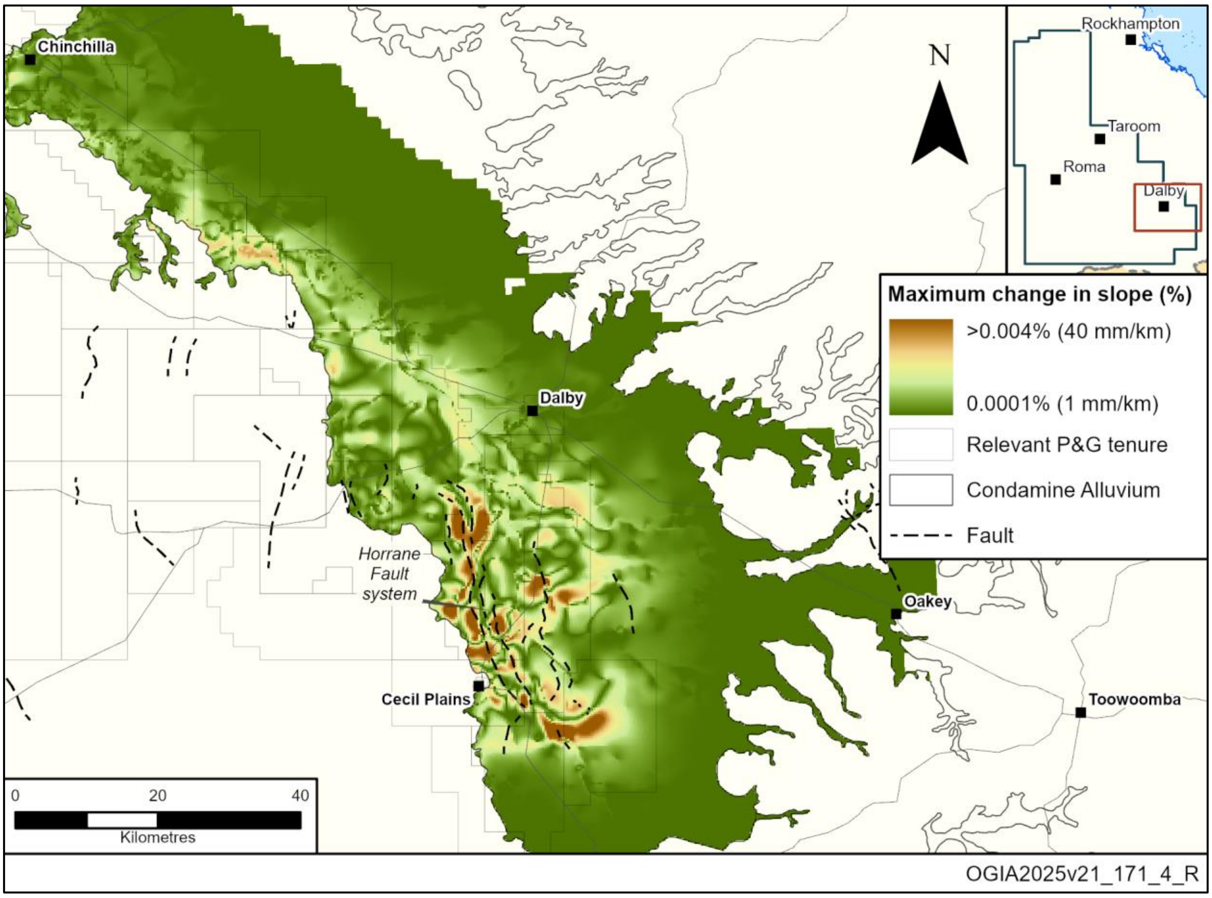

Figure 10-17: Predicted maximum change in ground slope from CSG-induced subsidence within the Condamine Alluvium footprint by 2060 (P50)

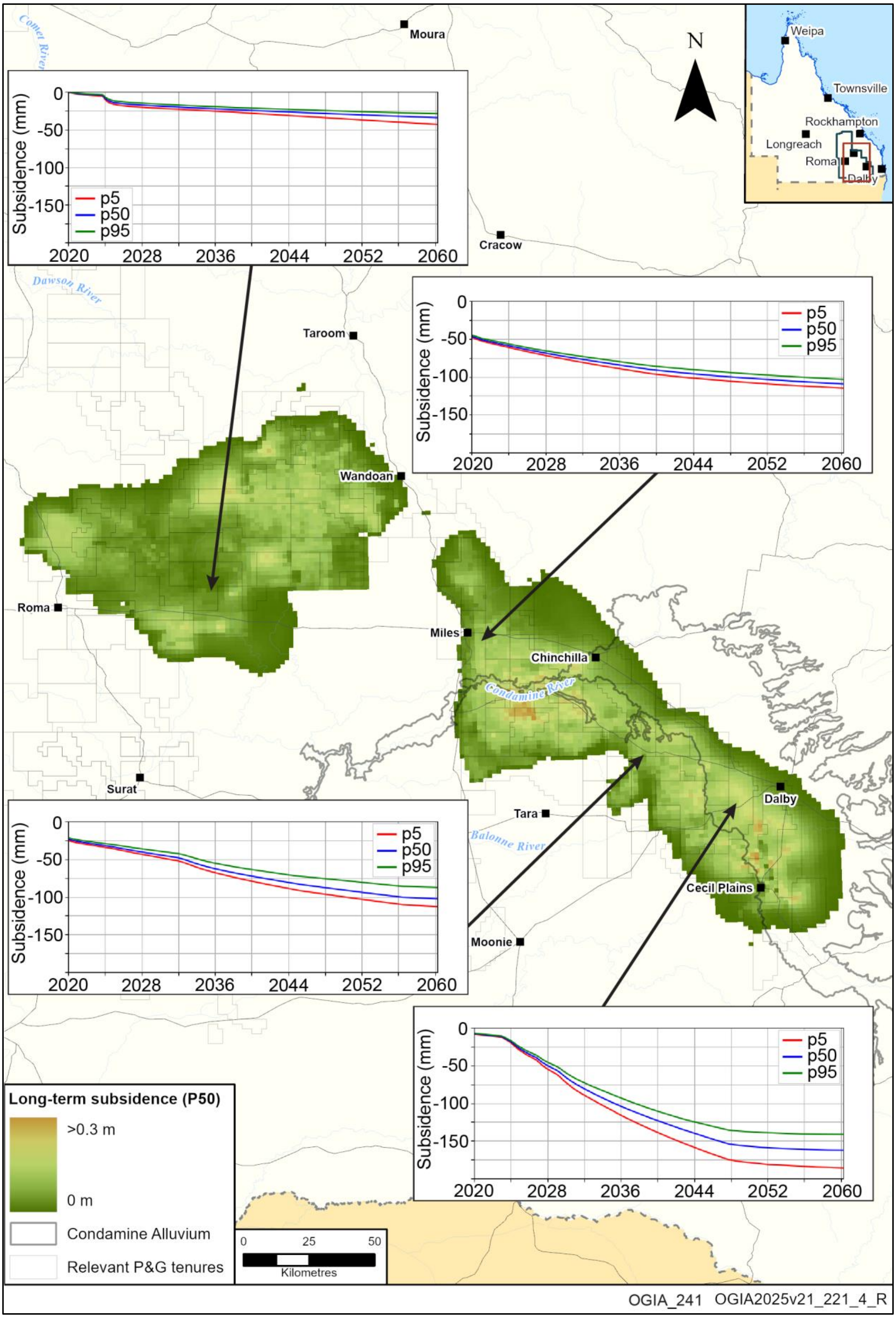

Figure 10-18: Predicted CSG-induced subsidence (P50) in the Surat Basin

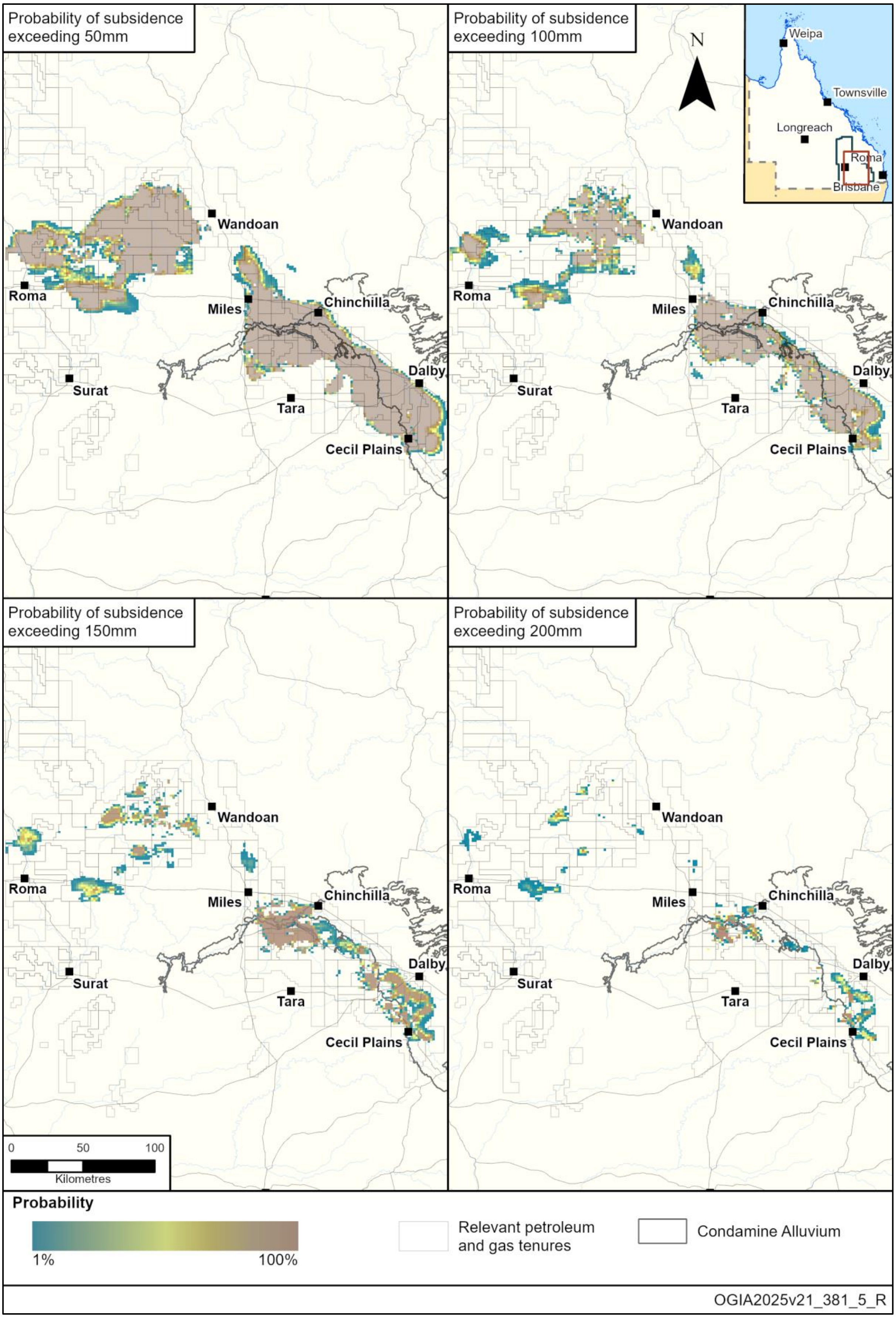

Figure 10-19: Probabilities of predicted subsidence across the Walloon Coal Measures footprint exceeding 50, 100, 150 and 200 mm by 2060

10.9 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 specifically, the predictions are used as below:

- IAAs to determine the water bores that are likely to be impacted in the short term and require follow-up make good arrangements (Chapter 11)
- LAAs to flag water bores that may potentially require make good arrangements in the future (Chapter 11)
- the magnitude and timing of impacts on springs for determining the risk to those environmental assets, developing a strategy for impact mitigation and monitoring, and scoping further assessments where required (Chapter 13)
- the magnitude and timing of impacts on terrestrial groundwater-dependent ecosystems (TGDEs) to determine risk (Chapter 14)
- a strategy for ongoing monitoring to verify the predictions of impacts and the effectiveness of management strategies, and for ongoing improvements in assessing impacts (Chapter 12)
- assessment of impacts on EVs to support the regulator’s ongoing evaluation of EAs (Chapter 14).

10.10 Summary of predicted impacts

- Typical depressurisation in the lowermost part of the Walloon Coal Measures is relatively greater (about 420 m) compared to the middle and the upper parts, which will experience 350 and 200 m respectively, although more than 500 m of depressurisation is expected towards the centre of some gas fields.
- Predicted impacts in the CSG target formations generally extend to about 10 km from the production wells but the 5-m impact extends only 5–10 km from the gas fields.
- Since the previous UWIR, there is significant contraction of the impacts predicted in the Bandanna Formation due to corresponding contraction in the planned development, despite the predicted magnitude in some areas having increased.
- Groundwater levels within CSG production areas are predicted to take hundreds of years to fully recover.
- Substantially greater impacts are predicted in the Springbok Sandstone, which overlies the Walloon Coal Measures, compared to the underlying Hutton Sandstone.
- The predicted impact pattern in the Condamine Alluvium is broadly similar to the previous UWIR and remains less than half a metre, with an average net loss of water of about 920 ML/year over the next 100 years – marginally less compared to the predictions in the last UWIR.
- In the Precipice Sandstone, the one-metre impact footprint is significantly wider compared to the previous UWIR due to revised calibration and minor changes to production profile, although the latest conceptualisation is not fully reflected in the model.

- The average annual volume of associated water extraction by resource development is predicted to be about 46,000 ML/year – compared to the 54,000 ML/year predicted in the previous UWIR.
- For most parts, the CSG-induced subsidence is likely to remain less than 100-150 mm but in some very localised areas, it could greater than 250 mm.
- The maximum change in regional ground slope from CSG-induced subsidence in most areas is predicted to be less than 0.001% (10 mm over 1 km), reaching up to 0.004% (40 mm over 1 km) in some areas around the Horrane Fault within the Condamine Alluvium footprint.

Part IV Impact management and monitoring strategies

Chapter 11 Management of impacts on water bores

11.1 Preamble

A core part of the underground water management framework in Queensland 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 – that is, by the extraction of groundwater as associated water. Chapter 10 presents impacts on groundwater levels in aquifers and Chapter 5 provides a profile of water bores in the Surat CMA and their source aquifers. This chapter presents water bores that are predicted to be impacted in the short and long terms, and how that prediction underpins the ***make good of water bores***.

11.2 Water bore authorisation for the purpose of make good

One of the core purposes of the underground water management framework (under Chapter 3 of the Water Act) is to provide for proactively making good a water supply bore that may be impacted by the extraction of associated water by a resource tenure holder. The legislative definition of a water bore is very broad, effectively covering a range of construction means to tap an aquifer, that could take or interfere with groundwater. The definition is for the purpose of wider water resource management and is not limited by a water bore's operational condition or its capacity to supply water – both of which characteristics do inform the eligibility and application of make good arrangements.

Chapter 3 of the Water Act effectively considers a water supply bore to be an 'asset' for landholders and there are therefore some inherent ambiguities in using the generic definition for make good purposes. Consequently, until further clarity is available, the following criteria are applied in constraining a water bore for make good purposes, using precautionary principles:

- The Water Act implies 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 bore is therefore considered a water bore unless there is sufficient information to demonstrate that either it was not authorised for construction, it was dry when constructed, or it has insufficient yield for at least domestic use (this being the purpose with the lowest yield demand).
- Water bores inherently degrade and enter a state of disrepair over time. Regardless, this is not a defining factor in respect to whether the water bore is eligible for make good arrangements. It is, however, a factor that may be considered in a bore assessment, in relation to the potential yield of a water bore.
- Construction of a water bore must be authorised according to the requirement at the time of its construction. 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 5.8.1. Broadly, all artesian bores require development permits regardless of their location. The permit requirements for sub-artesian bores can be an assessable development, accepted development (self-assessable) where a water bore must be constructed in accordance with a self-assessment code, or not assessable development (exempt).
- In the Condamine Alluvium, a sub-artesian water bore for S&D purposes is exempt development, 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, except those for domestic use only, those for S&D use in the Eastern Downs management area, and those that are 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 came into effect in 2000 – including a requirement to provide data for recording in the GWDB.
- 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 an 'unregistered' bore) may still be a legally constructed water bore.
- In some cases, water bores were screened across multiple aquifers to achieve a desired yield and quality, prior to the introduction of the minimum construction standards in the 1990s – and hence the bores constructed to tap multiple aquifers prior to that period are still valid.

11.3 Framework for make good arrangements

11.3.1 General

The term 'make good arrangements' is an informal term that encompasses the 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 DETSI 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** – for a water bore that is predicted to be impacted, a make good agreement is to be in place for that water bore prior to any impairment of water supply from that bore.
- **Adaptive and flexible** – the actual make good measures are to be 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 or 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.

11.3.2 Process and key components

Details on the legislative processes relating to make good arrangements are provided in the DETSI guidelines (Department of Environment and Science 2017). Key elements in terms of steps that occur pre-UWIR, post-UWIR and their interlinkages, are presented in Figure 11-1 and summarised in the following subsections.

11.3.2.1 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. Currently, for a water bore located on tenure, a baseline assessment plan is submitted by the tenure holder to DETSI. For off-tenure water bores, it is the UWIR that identifies baseline assessment requirements. The Queensland Government is now considering better aligning those requirements[8].

Information typically collected in a baseline assessment includes the bore’s location, groundwater level and quality, construction, and pumping infrastructure, but does not include investigations of pumping capacity, bore yields or removal of pumping infrastructure for collecting data. Those steps are typically part of a bore assessment if the bore is identified as an IAA bore[9]. Baseline 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.

11.3.2.2 Compilation of water bore data and aquifer attribution

Establishing the source aquifer for a water bore and its physical status, as detailed in section 5.6, involves a desktop assessment for verifying and synthesising water bore information, supplemented with aerial photos and scrutiny of site-specific information in priority areas. This information is the basis for identifying the aquifer, or aquifers, that supply water to the water bore. The compilation also determines whether the water bore is considered an existing water bore for the purpose of make good arrangements.

11.3.2.3 Prediction of impact

The outcome of model predictions for each aquifer (section 10.4) is used to identify the IAA, 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 – by the end of 2028 for this UWIR. The IAA provides a risk-based practical basis for proactively managing impacts that are the most likely to eventuate.

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[8] www.detsi.qld.gov.au/our-department/public-notices/efficiencies-streamlining-ep-act-other-portfolio-amendments
[9] DETSI bore assessment guideline: www.des.qld.gov.au/policies?a=272936:policy_registry/rs-gl-bore-assessment.pdf

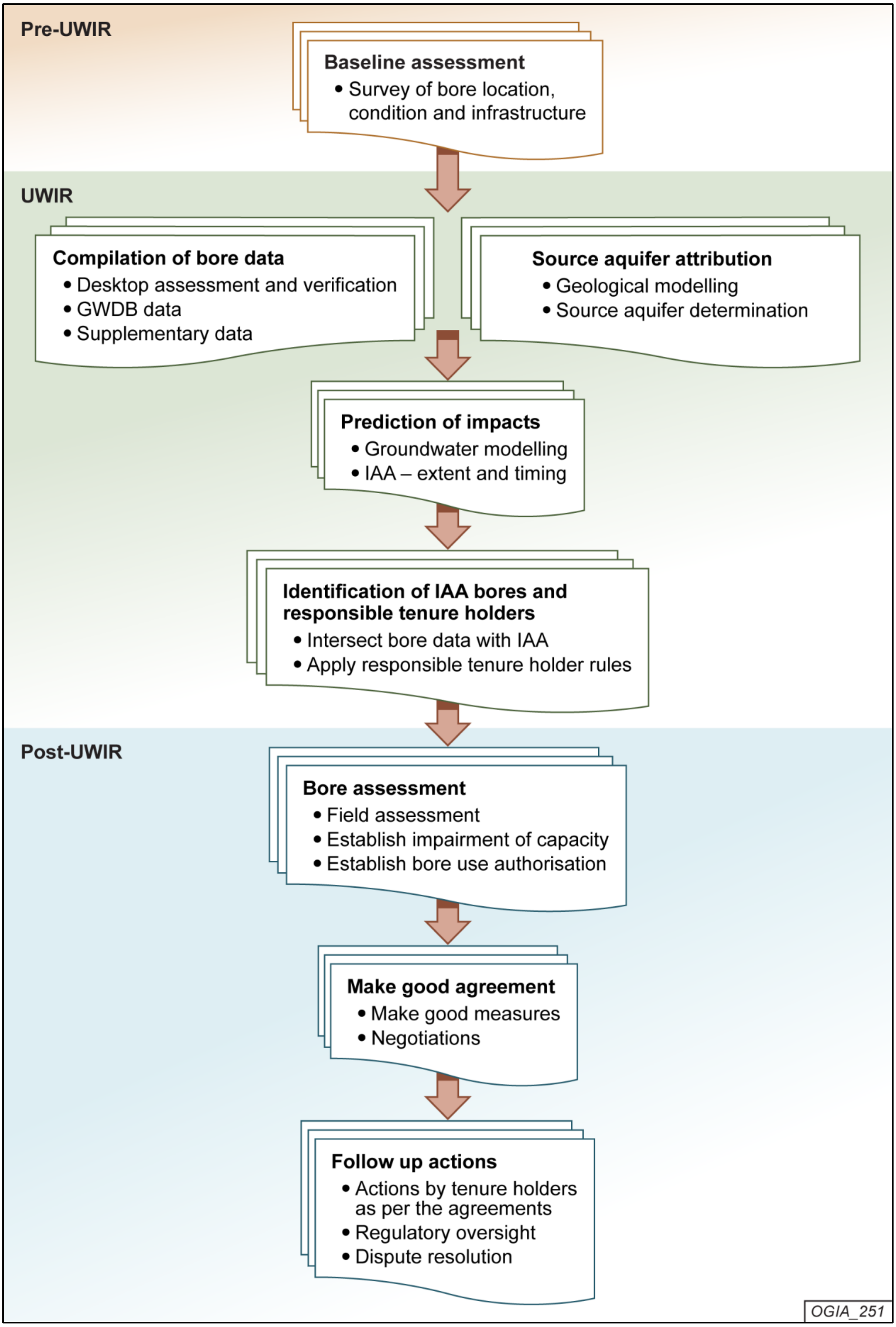

Figure 11-1: Simplified flow diagram of key steps in make good arrangements for water bores

11.3.2.4 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 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 as provided in Schedule 4. 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.

11.3.2.5 Bore assessment

After a UWIR is approved, the first step for IAA bores is for the RTH to undertake a bore assessment of each identified IAA bore. 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 by the RTH (such as hydrogeological measurements or pump tests) 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.

11.3.2.6 Establishment of water bore impairment

The main purpose of bore assessment is to establish whether the water supply from a water bore could potentially be impaired because of the predicted impacts. The assessment is undertaken by the RTH to assess if 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**'. The statutory term 'existing bore' refers to a water bore that was in existence before the first UWIR took effect (1 December 2012). Conversely, a 'new bore' – also defined in the legislation – is a bore that was constructed in the Surat CMA after the first UWIR took effect. A non-statutory term, 'replacement bore' refers to a water bore that replaces another water bore, for which all obligations relating to make good are deemed to be transferred from the original water bore to the replacement water bore.

11.3.2.7 Make good agreement

A make good agreement is a legally binding agreement between an RTH and a 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 for future review, additional local-scale assessment, rework or 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.

11.3.2.8 Implementation of make good measures

Implementation 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 DETSI, as the responsible regulator, and facilitated by government agencies responsible for managing and coordinating natural resources, such as the Engagement and Compliance Unit within DNRMMRRD and Coexistence Queensland.

If a water bore is not located within an IAA but is experiencing impairment, including as a result of free gas released due to a resource tenure holder's activity, the chief executive of DETSI 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.

11.3.3 Responsibilities of various parties

- **Bore owners** provide access to the water bore, and information about the water bore, to the RTHs and OGIA when requested.
- **RTHs** undertake baseline assessments 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** compiles and verifies water bore information and status; develops and maintains geological and groundwater flow models; makes predictions of IAAs; updates and reports predictions and IAA bores in the UWIR every three years; reviews predictions and IAA bores every year, reported through an annual review; receives and maintains baseline and bore assessment information from the RTHs; and supports implementation of make good arrangements.
- **DETSI** provides overall regulation of make good arrangements; develops and provides guidelines or forms in relation to make good arrangements and obligations; maintains relevant data; and oversees compliance.
- **DLGWV and DNRMMRRD** support engagement, support compliance and maintain the GWDB.
- **Coexistence Queensland** supports engagement and facilitates coexistence.

11.4 IAA bores

11.4.1 Process for determining IAA bores in the UWIRs

As summarised in the previous sections, three sets of information are required in order to determine whether 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 that establish the **IAA footprint** for each aquifer, as presented in section 10.4.1.

In the Surat CMA, OGIA compiles and verifies water bore location and status information for the purpose of the UWIR (section 5.4). 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 5.5 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. Water bores with following characteristics are excluded for further consideration:

- water bores that are reported as abandoned and/or destroyed
- water bores that are reported in the bore baseline assessment as 'could not be found or located' – further verified by OGIA through other available information and discussions with water bore owners, where possible
- water bores that are recorded in the GWDB as decommissioned
- 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 (section 11.2)
- water bores where multiple aquifers are accessed and for which the impacted aquifer is contributing less than 10 per cent of the accessed water
- water bores owned by tenure holders.

Previous UWIRs also excluded water bores for which make good agreements had already been voluntarily settled between the tenure holders and the water bore owners. In this UWIR, those bores are now included for transparency and follow-up actions as necessary to ensure that the make good obligations and agreements are in accordance with the legislative requirements.

The filtered dataset from the above process is intersected with the IAA for the corresponding aquifer to determine which of the water bores tapping the aquifer are IAA bores. In each successive UWIR, IAA bores are determined on a rolling basis for the next three years.

11.4.2 IAA bores in this UWIR

Applying the process described in the previous section, there are 76 water bores that are identified in this UWIR for the first time as IAA bores – that is, they are predicted to be impacted by more than five metres in next three years (2026–2028). These are in addition to the 350 IAA bores from the previous UWIRs (from 2011 to 2025), which are detailed in a later section (11.4.4). Table 11-1 provides a summary of these IAA bores, Schedule 4 provides a full list of water bores and Figure 11-2 shows the location of IAA and LAA bores.

Of the 76 IAA bores, 56 are in the Walloon Coal Measures, which is the primary target for CSG production in the Surat CMA. The IAA bores are mainly concentrated in two areas where the Walloon Coal Measures is accessible at relatively shallower depths – along the Warrego Highway, between Miles and Chinchilla, and between Wandoan and Roma, at the northern edge of the Surat Basin (Figure 11-2). There are 20 water bores identified in the Springbok Sandstone, located south of the Warrego Highway, spanning from Cecil Plains to south of Chinchilla.

Table 11-1: Summary of identified IAA bores for the period 2026–2028*

Formation	Subdivision	Water bore purpose			
		Agriculture	S&D	TWS	Total
Springbok Sandstone	Upper Springbok Sandstone	-	3	-	3
	Lower Springbok Sandstone	3	13	1	17
Walloon Coal Measures	Upper Juandah Coal Measures	4	25	-	29
	Lower Juandah Coal Measures	-	14	-	14
	Taroom Coal Measures	1	12	-	13
Total		**8**	**67**	**1**	**76**

Note:
TWS = town water supply, S&D = stock and domestic

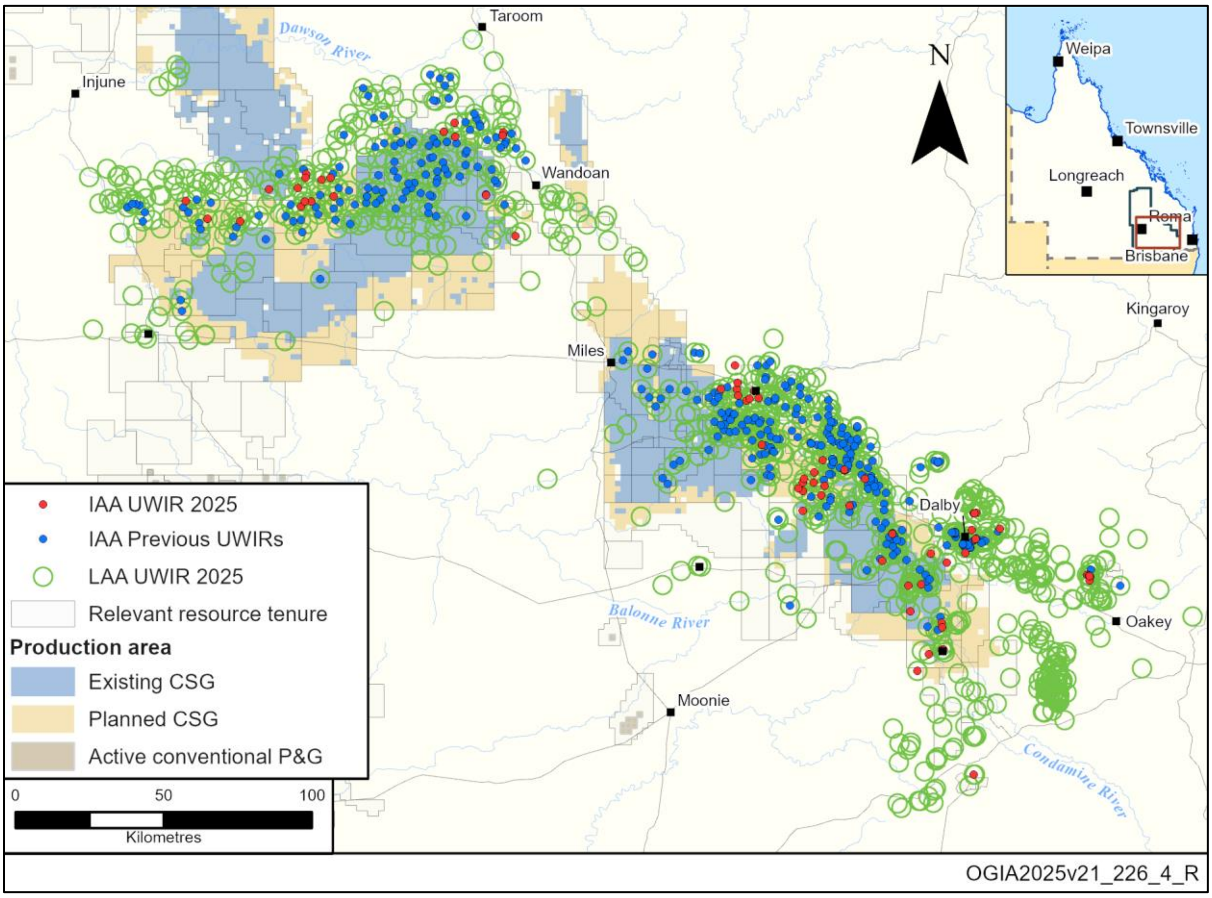

Figure 11-2: Location of IAA and LAA bores

As stated earlier, this UWIR now includes IAA bores for which make good agreements have already been voluntarily settled between the tenure holders and the water bore owners. Of the 76 IAA bores, 20 fit this description and are listed separately in Schedule 4 (Table S4-2) for the first time.

11.4.3 Changes in IAA bores since the last UWIR in 2021

The UWIR 2021 listed IAA bores based on the impact threshold being reached by the end of 2024. Extension of the UWIR timeframe by 12 months (section 2.2) implied that no IAA bores would be identified from the end of the current UWIR cycle (the end of 2024) until the next UWIR, towards the

 **This table has been corrected since 23 October.*

end of 2025. To fill this gap, the annual review 2024[10] specifically identified 14 additional water bores that could potentially be impacted during the year 2025. The requirement for bore assessments and make good of the 14 bores was affected through an amendment to the UWIR 2021 in the form of an addendum[11].

11.4.4 Net IAA bores since the first UWIR in 2012

As described in section 11.4.1, IAA bores are determined in each successive UWIR, on a rolling basis for the next three years. Every iteration of the UWIR extends the short-term period by three years to identify additional IAA bores for progressive implementation of make good arrangements. The total number of effective IAA bores therefore increases with each UWIR and will eventually equal the number of LAA bores.

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. In some instances, an IAA bore listed in a previous UWIR may no longer be an IAA bore in this UWIR because of changes to bore information, attributed source aquifer, or predictions resulting from a combination of revised production scheduling and model calibration.

For tracking IAA bores, the informal term '**net IAA bores**' is used by OGIA to refer to bores that have become IAA bores as a result of being identified and listed in a UWIR (previous and current), or post-UWIR changes. A summary of those net IAA bores from successive UWIRs and changes within the UWIR cycles is presented in Table 11-2, below.

Table 11-2: Summary of net IAA bores

Period	Added	Removed	Net IAA bores (running total)
UWIR 2012	85	-	85
Post-UWIR, 2012–2015	*10*	*25*	*70*
UWIR 2016	57	-	127
Post-UWIR, 2016–2019	*1*	*6*	*122*
UWIR 2019	100	-	222
Post-UWIR, 2020–2021	*13*	*2*	*233*
UWIR 2021	108	-	341
Post-UWIR, 2022–2025	*14*	*5*	*350*
UWIR 2025	76	-	426

As of the last UWIR in 2021, there were 341 net IAA bores. Since then, 14 additional IAA bores had been included through an amendment process and five have been removed. Adding the 76 IAA bores identified in this UWIR makes a total of 426 water bores that have been effectively determined as IAA bores since 2012. Of the 426 net IAA bores, about 75% are within relevant tenure area boundaries

[10] www.ogia.water.qld.gov.au/__data/assets/pdf_file/0010/1983538/surat-uwir-annual-review-2024.pdf
[11] www.ogia.water.qld.gov.au/__data/assets/pdf_file/0004/2046793/addendum-report-2025-surat-uwir-2021.pdf

while the remainder are outside, and only about 25% of the IAA bores are within the existing production footprint where CSG wells are already operating. The majority – more than 70% – are in the Walloon Coal Measures and are for S&D purposes.

The 350 net IAA bores prior to this UWIR are listed in Schedule 4 (Table S4-3), along with the impacted formation, purpose, RTH, the year the bore was first identified as an IAA bore and the current status of the make good process. Of those 350 bores:

- bore assessments have been completed for 272, as the first step towards make good agreements
- tenure holders have advised that bore assessments were unable to be undertaken on 29 due to the bores being abandoned, unable to be found, having preexisting damage or access issues that precluded assessment being done in the field
- 23 have gone directly into make good agreements without bore assessments
- 26 bores remain outstanding – half of those came into effect with the UWIR 2021 addendum, the other half having uncertain authorisation
- Make good has so far been executed for 212[12] – in some instances, make good arrangements were reached without bore assessments
- there are 82 for which make good is currently under negotiation
- a total of 166 have been decommissioned, or agreed to be decommissioned, primarily as a result of make good agreements.

In some instances, tenure holders have also been progressively entering into proactive make good agreements with bore owners ahead of those bores being identified as IAA bores in previous UWIRs. There are 42 such bores in addition to 350 previously identified IAA bores. For greater clarity and to ensure that make good obligations are properly applied to those bores, additional information regarding make good agreements is provided in Schedule 4 (Table S4-3) and Schedule 5 (Table S5-1). As stated previously, IAA bores include those with proactive make good agreements, for the same reason.

Confidential compensation arrangements of make good agreements are not available to OGIA and as such, OGIA does not receive information about water bores that may be drilled as a result of make good agreements. The available information from DLGWV and tenure holders does suggest, however, that about 34 alternate water bores may have been completed as a result of make good arrangements – eight into the Precipice Sandstone and 26 into the Hutton Sandstone.

11.4.5 Follow-up actions for identified IAA bores

11.4.5.1 Bore assessment and make good obligations

Once the UWIR is approved and takes effect, the RTH listed against each IAA bore in Schedule 4 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 (section 11.3.2). This will include, among other things, establishing the

[12] This potentially includes some in-principle agreements.

water bore's authorised use and purpose, and whether it is an existing water bore (sections 11.3.2.6 and 11.3.2.7).

OGIA has verified all available information about the bores that are identified as IAA bores, including physical verification subject to access. In some instances, however, if a water bore cannot be found during the bore assessment process, then it is not eligible for make good measures and notice of this outcome should be lodged to close out the make good obligation process.

11.4.5.2 Reporting

RTHs are obliged to provide the outcome of a baseline assessment and bore assessment to OGIA. There is also a requirement for tenure holders to advise the chief executive of DETSI when a make good agreement is entered into. To provide improved transparency and tracking of make good obligations, from this UWIR onwards, tenure holders are required to report the status of bore assessments and make good agreements every six months (1 April and 1 October of every year), as specified in Table 11-3. Categories of status are indicative only. To be clear, no confidential, financial or contractual information is required. The purpose of the reporting is to keep track of a water bore throughout its make good lifecycle.

Table 11-3: Reporting requirement for the status of make good obligations

Make good obligation	Information to be reported
Bore assessment	• Current status of bore assessment – such as underway, field visit completed, access issues, impairment established, impairment not established, completed, or not required • Date of assessment commencement • Outcome of assessment – impaired or not impaired
Make good agreement	• Status of make good agreement – such as agreement required, agreement not required, negotiations underway, in-principle agreement reached, agreement completed, required, or not required • Date of the agreement being entered into • Make good measure – such as required, not required, monitoring only, financial compensation, alternate water supply, or replacement bore
Decommissioning	• If a water bore is decommissioned as part of a make good agreement, OGIA requires the tenure holder to advise the status and date of the decommissioning

11.5 LAA bores

LAA bores are 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 water bore information and source aquifer is intersected with LAAs (section 10.4.1) rather than IAAs. LAA bores will change over time for various reasons, including:

- changes in development profile
- change in construction details or updated aquifer information
- change to bore status (new drills, abandoned, and so on).

A summary of LAA bores is provided in Table 11-4. The total number of LAA bores identified in this UWIR stands at 747 (compared to 701 in the last UWIR), which includes 350 previously identified IAA bores (net), 76 newly identified IAA bores, 206 LAA bores carried over from previous UWIRs, and an additional 115 LAA bores identified this UWIR.

Of the 747 LAA bores, 302 are recorded in the GWDB as decommissioned, unable to be found or proactively entered into make good agreements. As many of the decommissioned bores are likely be decommissioned proactively, they are included for accounting purposes – to keep track of all water bores that are likely to be impacted. LAA bores are listed in Schedule 5.

About 92% of the LAA bores are for S&D purposes and 96% are in the CSG and coal mining target formations, or the Springbok Sandstone. LAA bores do not trigger any further actions for tenure holders. These water bores are identified for information purposes only, unless identified as IAA bores in this UWIR or 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.

Table 11-4: Water bores in LAA*

Formation	Subdivision	Purpose				Total (number of bores)
		Agriculture	Industrial	S&D	TWS	
Alluvium	Main Range Volcanics	-	-	1	-	1
Westbourne	Westbourne	-	-	9	-	9
Gubberamunda Sandstone	Gubberamunda Sandstone	-	-	2	-	2
Springbok Sandstone	Upper Springbok Sandstone	2	-	66	-	68
	Lower Springbok Sandstone	3	-	31	1	35
Walloon Coal Measures	Upper Juandah Coal Measures	6	-	55	-	61
	Lower Juandah Coal Measures	18	-	157	2	177
	Taroom Coal Measures	3	1	78	1	83
Hutton Sandstone	Upper Hutton Sandstone	2	-	4	2	8
Bandanna Formation	Upper Bandanna Formation	-	-	1	-	1
Subtotal – physically existing bores		**34**	**1**	**404**	**6**	**445**
Bores with make good agreements, decommissioned or uncertain status						*302*
Total LAA bores						**747**

This table has been corrected since 23 October.

11.6 Baseline assessment program for off-tenure bores

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 11.3.2.3). 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 DETSI and in accordance with guidelines prepared by DETSI.

The Water Act includes baseline assessment exemptions for 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 December 2016 inclusion of coal mining under Chapter 3 of the Water Act. These exemptions are 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 DETSI 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 legalisation (ss. 397 and 402 of the Water Act). In relation to the third criterion, 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, as a consequence of resource development, is expected within three years (2026–2028) as shown in Figure 11-3. This is because baseline assessments are most effective when they are undertaken immediately before impacts are expected to occur.
- RTHs must carry out baseline assessment for water bores that tap aquifers within the baseline assessment areas for those aquifers.
- Assessments are to be carried out in accordance with the current DETSI guidelines for baseline assessments.
- Assessments must be completed, and the results reported to OGIA, within 12 months of the UWIR being approved.

A list of off-tenure water bores that require baseline assessment is provided in Schedule 6.

Information and data collected during baseline assessments are of variable quality. The information reported by a tenure holder at the time of visiting a water bore is often heavily reliant on existing information available on the GWDB. OGIA has undertaken a project since 2017, in collaboration with DLGWV, to verify the RNs assigned during baseline assessments completed by tenure holders. The verification project involves a desktop check to validate the RN assigned at the time of the baseline assessment. The desktop check process includes a cross-check of data, photos and other information provided by tenure holders with data held in various DLGWV databases (GWDB, DLGWV Water Management System, GSQ Open Data Portal and MyMinesOnline). Where available, field reports and photos are matched with aerial imagery.

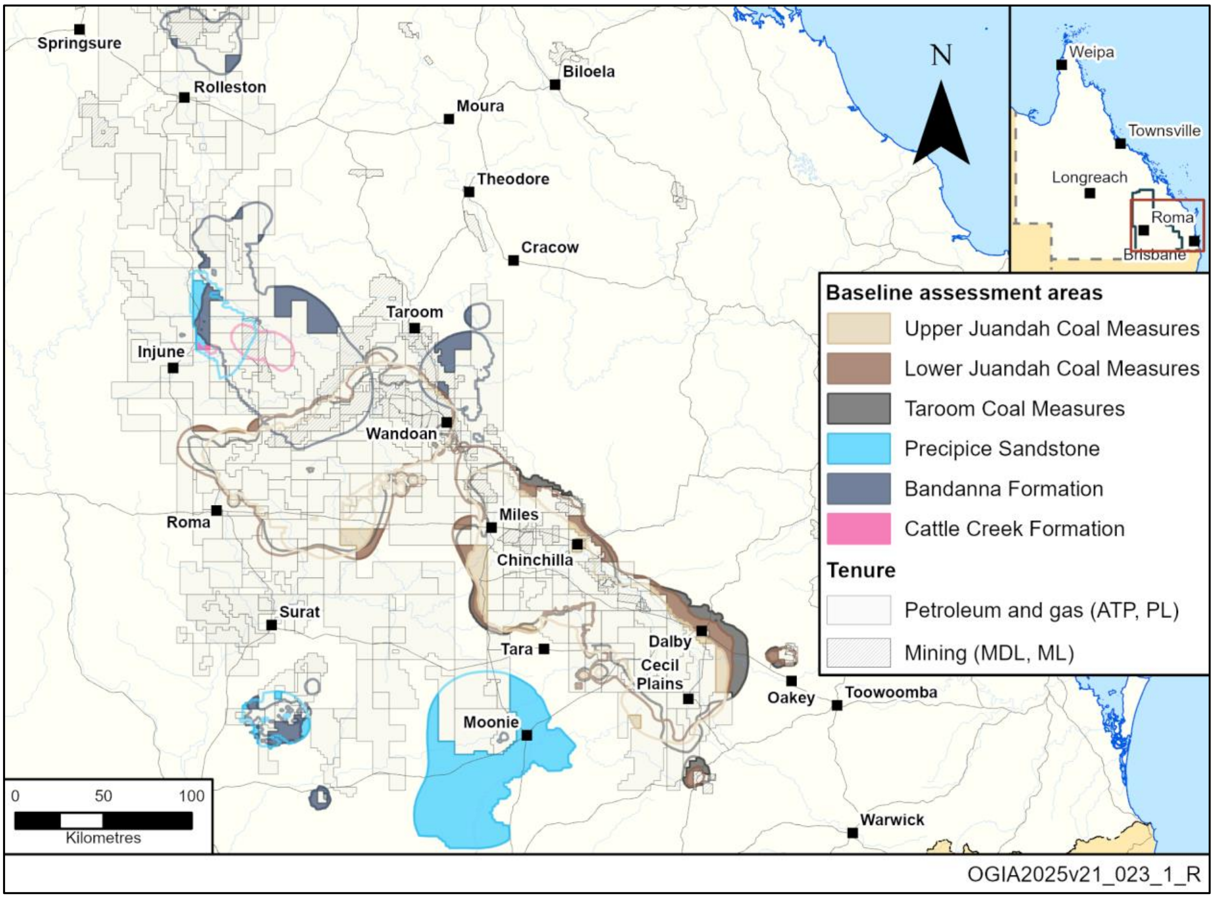

Figure 11-3: Baseline assessment areas

To date, OGIA has completed verification of about 85% of the baseline database, identifying that 7% of baseline assessments have incorrectly assigned RNs and 11% were unable to have RNs assigned during baseline assessment. Some of those water bores have subsequently been linked to existing RNs by OGIA; the water bores that remain without RNs are processed by DLGWV and allocated new RNs. Once water bores are verified, the associated non-confidential information from the baseline assessment is included in the datasets made available through the GSQ Open Data Portal.

11.7 Accessing water bore information

OGIA is the custodian of various bore related datasets in the Surat CMA that are of interest to various stakeholders. This information can be accessed from a number of platforms:

- 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 the magnitude and timing of impacts – are provided through OGIA's revised 'Bore Search Tool', which is part of OGIA's online StoryMap[13].
- OGIA-verified water bore location, physical status and source aquifer information 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. The database currently holds more than 5,500 completed

[13] www.ogia.water.qld.gov.au/products-tools

baseline assessments, of which about 4,700 are in the Surat CMA. Due to confidentiality reasons, this data is only made available on a case-by-case basis, when requested. Relevant information from this database is extracted by OGIA for verification purposes and progressively incorporated into the GWDB.

- Groundwater level and water quality data obtained from baseline assessments and bore assessments is made available through the GSQ Open Data Portal.
- Information about the status of IAA bores that have been identified so far, and progress on implementation of make good agreements, is provided in Schedule 4. Upon implementation of the new 'make good obligation reporting', OGIA will report on the updated status of make good obligations through an appropriate mechanism.
- Detailed data about water bores, in terms of water bore location, construction details, and so on, is maintained in the GWDB and accessible through the Queensland Globe[14].

11.8 Summary of impacted water bores

- A total of 747 water bores – about seven per cent greater than last time – 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 in the long term are for S&D purposes. The majority are in the CSG target formations or the Springbok Sandstone. Fewer than one percent of bores predicted to be impacted are in recognised aquifers of the GAB – none are in the Condamine Alluvium.
- IAA bores are based on short-term impacts, identified in each UWIR on a rolling basis for the next three years. They require further proactive bore assessment and make good to provide for a proactive and risk-based approach to managing impacted water bores.
- Of the 747 LAA bores, 350 had been identified as IAA bores in the previous four UWIRs on a rolling basis and make good is completed for 212.
- Added in this UWIR are a further 76 IAA bores that are likely to be impacted within the next three years (2026–2028). The total number of IAA bores to date is now 426.
- IAA bores without make good agreements 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.
- 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 the web-based 'Bore Search Tool'

[14] https://qldglobe.information.qld.gov.au

Chapter 12 Water Monitoring Strategy

12.1 Preamble

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

- identify past groundwater impacts from CSG, conventional oil and gas, and coal mining in the Surat Basin
- improve knowledge about the groundwater flow system, which in turn improves ability to predict future impacts
- support the evaluation of 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 for an ongoing assessment. The monitoring network from the previous UWIRs is progressively reviewed to incorporate recent findings and emerging data. In this UWIR, the review has particularly considered the outcomes of the AEM survey in the Condamine Alluvium (Chapter 7) and the regional groundwater and water chemistry trends analysis (Chapter 9).

12.2 Terminology

Monitoring point – a groundwater piezometer or bore constructed to monitor the groundwater level or groundwater chemistry, as shown in Figure 12-1.

Monitoring network – a collection of groundwater monitoring points.

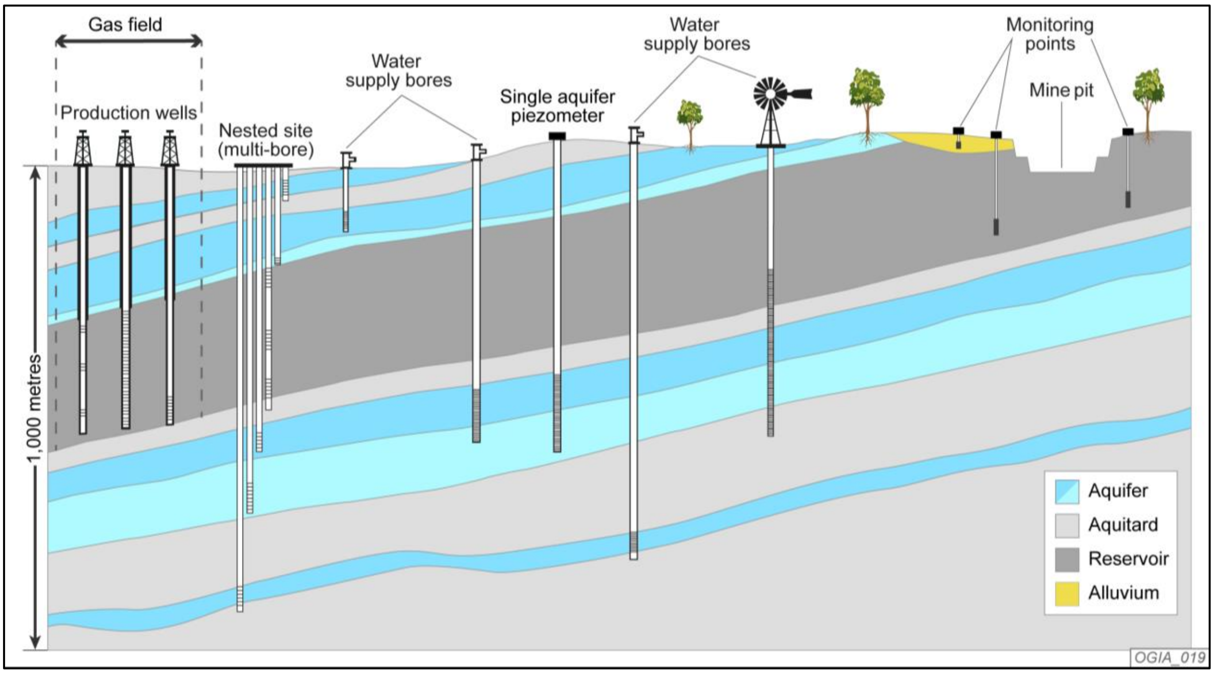

Figure 12-1: Schematic of monitoring installation types in the Surat CMA

12.3 Components of the monitoring strategy

There are three core components of the WMS, detailed in the subsequent sections of this chapter:

- design, installation and maintenance of a **monitoring network** including:

  - a groundwater **level** network
  - a groundwater **chemistry** network
  - a groundwater **quantity** network (groundwater extraction volumes)
- tenure holder **reporting** of the data and of activities relating to the above components.

Individual tenure holders are responsible for specific monitoring obligations, which are assigned in accordance with the rules outlined in section 15.3. Sections 12.5, 0 and 12.7 below provide the details of each component of the WMS and additional information is available in Schedules 1,2 and 3.

12.4 Groundwater monitoring network

12.4.1 Network objectives and rationale

Consistent with the purpose of the WMS, the design of the network is informed by the following objectives:

- **establish background trends** attributable to climatic variability and groundwater use, allowing separation of resource development impacts from other contributing factors and understanding of how the groundwater systems function
- **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 to overlying and underlying formations
- **understand groundwater flow and connectivity pathways near connectivity features** in areas where there is high potential for connectivity between coal formations and other aquifers, such as where regional faults and associated fracture zones have been identified and where formations separating reservoirs from other aquifers are either thin or absent
- **understand groundwater flow and connectivity pathways near high-value assets** such as springs and water bores where impacts are predicted, enabling understanding of groundwater level conditions and effectiveness of management strategies
- **improve conceptual understanding and future groundwater flow modelling** by collecting and securing data for model calibration and validation
- **assess groundwater conditions around coal mining pits** to improve understanding of impact pathways and saturation level at the mine pits**.**

12.4.2 Guiding design principles

Consistent with the objectives, the review and design of the monitoring network is guided by the following principles.

- Incomplete components of the monitoring network from the previous UWIR have been reassessed and the revised network specification replaces the previous network specification.
- In general, a higher density of monitoring points is required inside and near existing and planned CSG development areas compared to more distant areas, where background monitoring is the primary focus (for example, Tipton 206 (RN 160789)).

- Where practicable, multiple monitoring points for multiple formations are located in close proximity to each other, providing information on groundwater level differences between formations – following the concept of nested monitoring points (Figure 12-1).
- In some formations, such as the Springbok and Hutton sandstones, separate monitoring is required for the lower and upper parts, respectively, that immediately overlie and underlie the CSG target formations (for example, Glenburnie-18 (RN 160941)).
- Lead time is necessary to allow collection of sufficient data ahead of resource development in areas where future impacts are predicted, 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 ongoing changes to the development profile. There are, however, certain monitoring points (such as Dione 12M) that are designed for ambient background conditions and will therefore continue to be required, regardless of any changes to development profile.
- The use of suitable existing tenure holder monitoring points – such as 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 – monitoring points that are not also used for water extraction or installed with pumping equipment (other than sampling equipment) – except where there is sufficient contextual data to interpret monitoring data for the specific purpose.
- The monitoring network maximises the use of existing monitoring points and requirements are commensurate with the level of relative impact from (and development by) CSG, conventional oil and gas, and coal mining tenure holders.
- Where possible and as far as practicable, OGIA looks to take into consideration monitoring networks established under other State and Commonwealth approval conditions, where the monitoring data may assist in meeting UWIR monitoring objectives.
- The water chemistry network has included points where ongoing monitoring was not required because previous measurements were sufficient to establish background trends. The need for further measurements is, however, reviewed in each UWIR and may result in additional measurement requirements at a later stage.

12.4.3 Tracking status of the monitoring network

From this UWIR onward, for clarity and transparency, the obligations for tenure holders to install and maintain monitoring points, as well as the monitoring points' installation status and monitoring status, will be characterised and tracked using the following attributes:

- **Obligation status** – whether the monitoring point is 'required' to be installed and maintained by the tenure holder as part of the WMS network. Monitoring points removed at a later stage due to review or logistical reasons will be classified as 'not required'.
- **Installation status** – whether the installation of the monitoring point is completed as per the requirement of the UWIR. This status could be 'installed' or 'not installed', noting that in some

instances the equipment and construction may fail after installation and require replacement or repair.

- **Monitoring status** – whether the monitoring point is actively collecting data and reporting in accordance with the prescribed frequency and currency, and whether the monitoring data is representative of the monitored formation. 'Active' indicates OGIA is receiving monitoring data and 'not active' means that data is temporarily not collected due to logistical issues, such as equipment failure.

The WMS status as presented in the UWIR is relative to the time the WMS is reviewed and is therefore a snapshot in time.

12.4.4 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 2012 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. As stated earlier, the network is reviewed at the time of preparing each UWIR, taking into consideration emerging logistical issues, updated conceptualisation, trends and data.

The initial monitoring network specified in the UWIR 2012 incorporated 130 existing monitoring points. The network has since grown to about 807 installed groundwater level and chemistry monitoring points, with an additional 81 to be installed under this UWIR, as shown in Figure 12-2 – increasing to a network of 888 dedicated monitoring points, up 10% compared to the last UWIR. An additional 175 points are to monitor the chemistry of the water extracted from CSG wells. This growth has provided important continuity of historical monitoring data.

As the groundwater monitoring network has evolved, additional challenges have emerged in relation to new hydrogeological understanding and the performance of monitoring infrastructure, including variability in groundwater systems, changes to development plans, new techniques for the analysis of data, upkeep of existing installations, and keeping pace with technological advances. As stated previously, the water chemistry network has included points where ongoing monitoring needs are reviewed with each UWIR. An example is in the Condamine Alluvium, where AEM survey data and subsequent re-evaluation of the connectivity has resulted in seven new groundwater level monitoring points being specified in this UWIR.

While the WMS network provides high-quality monitoring data from key representative locations, monitoring is not limited to this network alone. Several other formal and informal monitoring networks have important complementary datasets that are available for OGIA to use, including landholder bore monitoring (Groundwater Online, Groundwater Net), departmental groundwater monitoring held on the groundwater database, and non-WMS monitoring by P&G and mining tenure holders, among others. This is described further in section 12.8. OGIA combines all of these datasets into an integrated groundwater level dataset totalling more than 7,200 monitoring points, which may contribute to OGIA's impact assessment. OGIA has additionally equipped 14 departmental bores for ongoing monitoring.

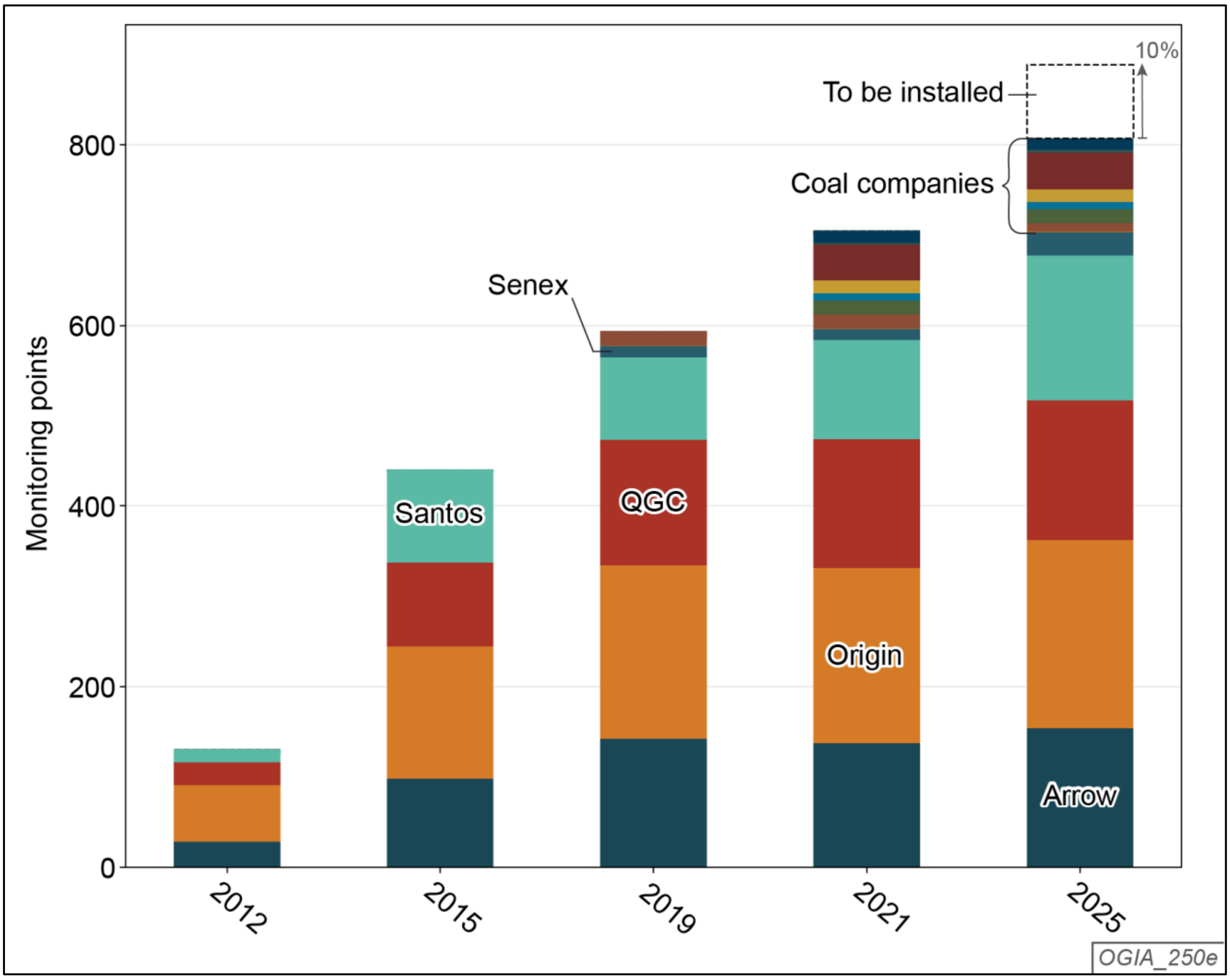

Figure 12-2: Cumulative growth of WMS monitoring points

12.5 Groundwater level network

A summary of groundwater level monitoring points is provided in Table 12-1. This network consists of 762 groundwater level monitoring points, 705 of which are already installed or pre-existing as part of the previous and current UWIR obligations, with an additional 57 new monitoring points to be installed in the next three years.

During the last UWIR cycle, eight monitoring points were removed from the WMS groundwater level monitoring network. Since then, the network has expanded, commensurate with the expanding CSG footprint and to improve conceptual understanding of connectivity in the Condamine Alluvium; the Horrane Fault; and impact on springs. The design specifications of the groundwater level network are summarised in Table 12-2.

Table 12-1: Summary of WMS groundwater level monitoring points (P&G and mining)

Group	Formation	Installed	To be installed	Total
Alluvium, basalt and mine spoil	Mine spoil	1	-	1
	Condamine Alluvium	29	7	36
	Other Cenozoic formations	26	3	29

Group	Formation	Installed	To be installed	Total
Surat Basin (GAB)	Springbok Sandstone	87	10	97
	Upper Juandah Coal Measures	91	10	101
	Lower Juandah Coal Measures	81	4	85
	Taroom Coal Measures	110	4	114
	Walloon Coal Measures	15	1	16
	Hutton Sandstone	86	7	93
	Other Surat Basin formations	146	5	151
Bowen Basin	Bandanna Formation	25	5	30
	Other Bowen Basin formations	8	1	9
Total		**705**	**57**	**762**

Table 12-2: Design, maintenance and reporting specification of the groundwater level network

Design element	Specification
Location	• Coordinates for individual monitoring points are provided in Schedule 2
Parameter	• Groundwater level
Frequency	• Daily – for CSG installations • Monthly – for coal mining installations at operational coal mines
Installation type	• To suit the formation types
Installation guidelines	• As detailed in Schedule 1
Installation timing	• For new points, generally within three years or less, as specified in Schedule 2 • For replacement points, within 12 months • OGIA will review the timing in each annual review and inform DETSI and tenure holders for follow-up actions
Maintenance and replacement	• RTHs must maintain each monitoring point and if a point fails to provide data representative of the target formation, notify OGIA within 1 month of becoming aware of the failure • Monitoring points must be repaired or replaced within the timeframe outlined under '*Installation, maintenance, data collection and provision*' or agreed with OGIA
Contextual information	• For all new constructions, RTHs must provide to OGIA, for endorsement, summaries of the planned design of monitoring points prior to construction • A monitoring bore completion diagram must be provided to OGIA within six months of completion
Measurement type	• Data loggers – where daily measurements are required • Manual – where monthly measurements (at minimum) are required

Design element	Specification
Installation, maintenance, data collection and provision	• The RTH is as specified in Schedule 2 • Data provision by the RTH to OGIA via the POD, on 1 April and 1 October every year (the 'submission date') • A monitoring point will be considered active where there is a monitoring record within six months of the latest submission date • Where an RTH becomes aware that a monitoring point has failed and needs repair, within two months of the failure, the RTH must advise OGIA of the failure and whether the monitoring point will be repaired or replaced • If a monitoring point is to be repaired, the repair must be completed within six months of advising OGIA • If a monitoring point is to be replaced, the replacement must be completed within 12 months of advising OGIA • If a monitoring point is not providing data representative of the formation, the point will be considered as failed and needing repair or replacement

A list of the individual monitoring points – with corresponding obligations, monitoring status and the required timeframes – is available from the OGIA website and in Schedule 2. The locations of the monitoring points for key formations are shown for the Condamine Alluvium (Figure 12-3), Springbok Sandstone and Walloon Coal Measures (Figure 12-4) and Hutton and Precipice sandstones (Figure 12-5).

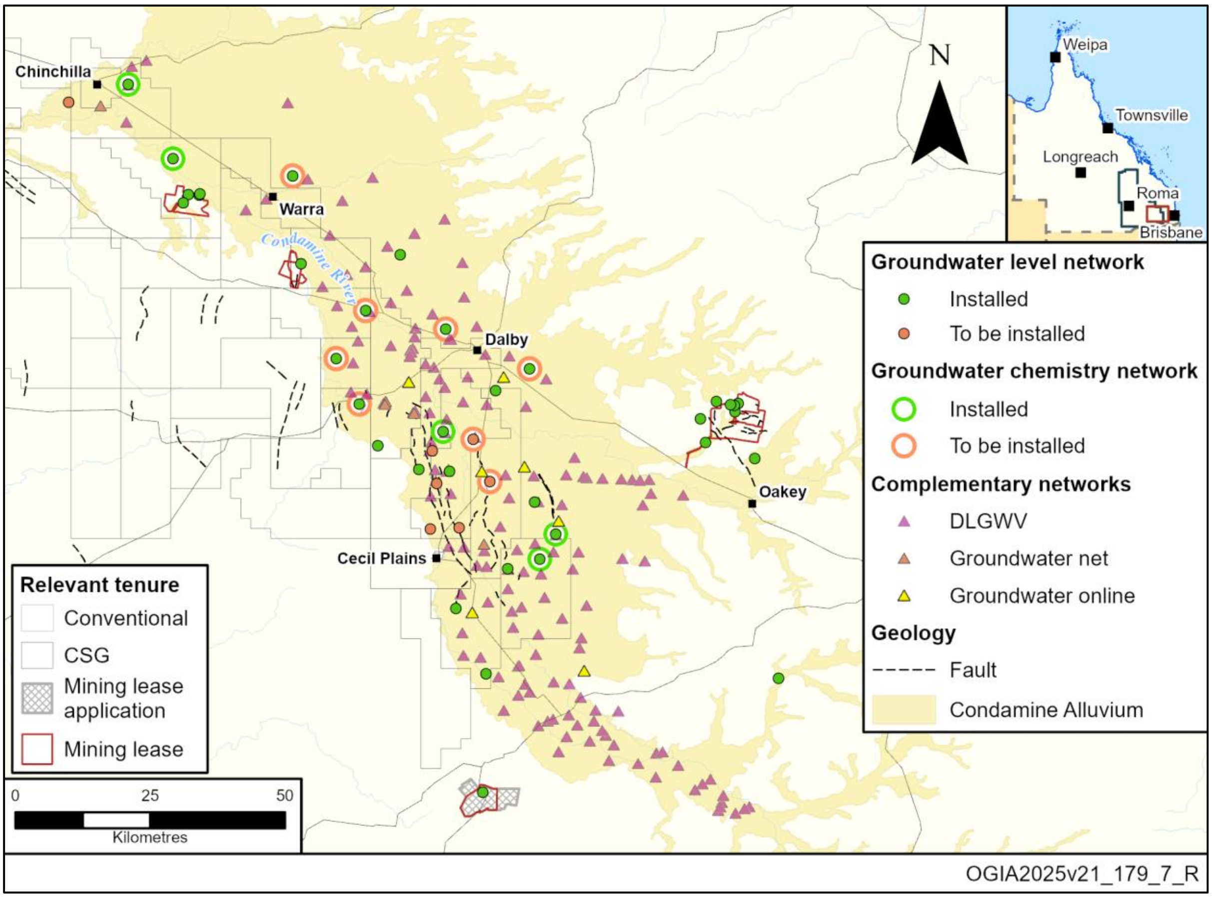

Figure 12-3: Groundwater monitoring networks – Condamine Alluvium

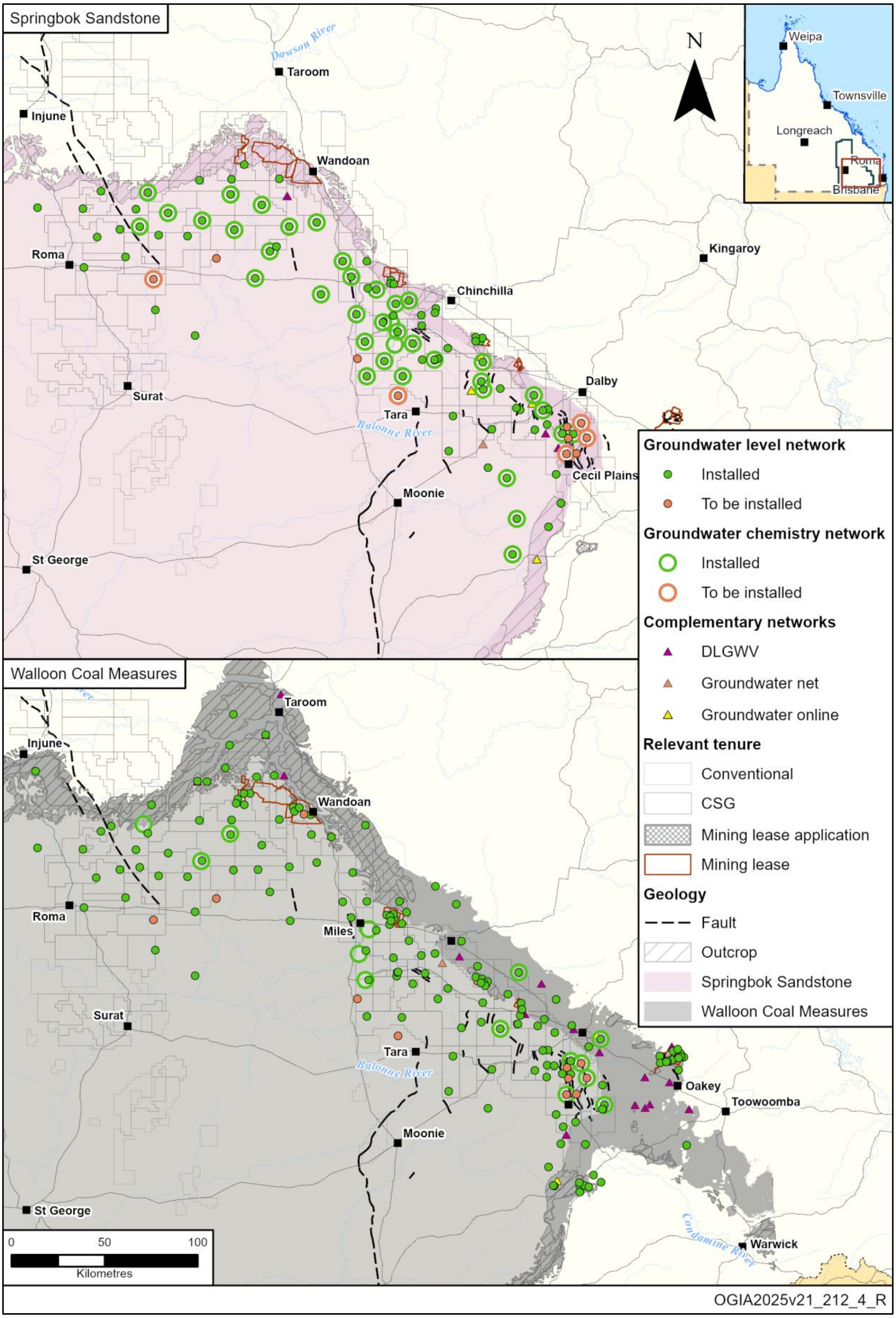

Figure 12-4: Groundwater monitoring networks – Springbok Sandstone and Walloon Coal Measures

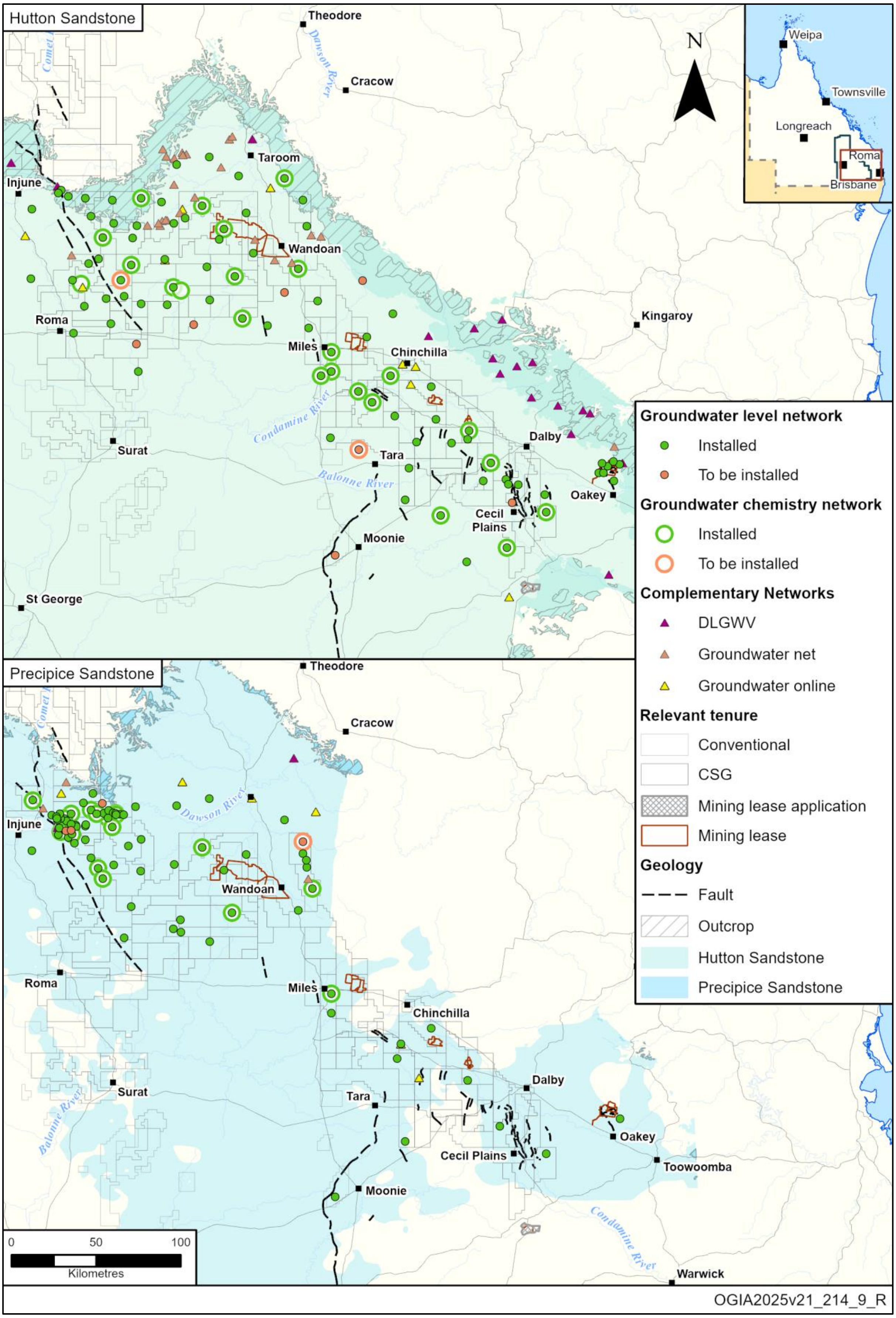

Figure 12-5: Groundwater monitoring networks – Hutton and Precipice sandstones

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

- There are 705 existing monitoring points, of which 648 (92%) are actively monitoring and the remaining 57 (8%) are not actively monitoring.
- The network has been growing steadily since the first UWIR in 2012; 57 new points are proposed in this UWIR, expanding the network to 762.
- About 42% of points are in the Walloon Coal Measures in the Surat Basin, 4% are in the coal formations of the Bowen Basin and 54% are in surrounding formations.
- There are 198 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.

12.6 Groundwater chemistry network

As with the groundwater level monitoring network, the groundwater chemistry network has evolved since its initial specification in the UWIR 2012. The initial objective of the groundwater chemistry network was to include strategic locations to acquire a suite of samples to better characterise aquifers. The use of groundwater chemistry time-series data to identify potential groundwater connectivity and potential resource industry impacts is becoming more prevalent in OGIA’s work; as such, OGIA is looking to broaden the coverage of the groundwater chemistry time-series data. To achieve this, the frequency of samples in the design specification for the groundwater chemistry network has been updated. OGIA will identify a monitoring frequency for each groundwater chemistry network monitoring point; this will be utilised in a dynamic fashion in successive UWIRs, allowing OGIA to review and adapt the groundwater chemistry monitoring as needed.

A summary of WMS groundwater chemistry monitoring points is provided in Table 12-3. The network includes 126 monitoring points, of which 102 are existing and 24 are proposed. About 19% of the points monitor the CSG target formations, with additional groundwater chemistry monitoring from production wells specified in section 12.7. The design specification of the groundwater chemistry network is summarised in Table 12-4.

The suites for groundwater chemistry include both major ions and isotopes, to support aquifer characterisation and identifying of potential connectivity and impacts from resource development. The water chemistry network also requires monitoring of groundwater chemistry from 175 production wells (Schedule 3, Table S3-3), 27 of which are not yet in production and will only require monitoring once production commences. A list of these wells is provided in the WMS supporting document. The density of these sites is generally one per production block, with higher density specified in areas where there is higher potential for connectivity.

Table 12-3: WMS groundwater chemistry network monitoring points

Group	Formation	Installed	Not installed	Total
Alluvium	Condamine Alluvium	5	8	13
Surat Basin (GAB)	Springbok Sandstone	38	5	43
	Upper Juandah Coal Measures	2	2	4
	Lower Juandah Coal Measures	2	-	2
	Taroom Coal Measures	-	1	1
	Walloon Coal Measures	4	2	6
	Hutton Sandstone	23	2	25
	Other Surat Basin formations	20	1	21
Bowen Basin	Bandanna Formation	8	3	11
Total		**102**	**24**	**126**

Table 12-4: WMS groundwater chemistry network design specification

Design element	Specification
Location	• Coordinates for individual monitoring points are provided in Schedule 3
Parameter	• Field parameters, laboratory analysis (Suite A) and isotope samples (Suite B) • Specific requirements for each monitoring point are specified in Schedule 3
Frequency	• Suite A – where specified, sampled every six months • Suite B – where specified, a strontium isotope sample is required every 12 months in the CSG production wells, and once only in Springbok Sandstone, Hutton Sandstone and Precipice Sandstone • Dormant – where no samples or data submission are required for this UWIR cycle, but the monitoring point is maintained
Installation type	• To suit the formation and conditions
Installation guidelines	• As detailed in Schedule 1
Installation timing	• Generally, new monitoring points are required within 2 years and replacement points required within 12 months as specified in Schedule 3 • OGIA to review the timing each year in the annual review and inform DETSI and tenure holders for follow-up actions
Maintenance and replacement	• RTHs must maintain each monitoring point and if a point fails to provide data representative of the target formation, must notify OGIA within one month of becoming aware of the failure • Monitoring points must be repaired or replaced within the timeframe outlined under '*Installation, maintenance, data collection and provision*' or agreed with OGIA
Measurement type	• Sampling in accordance with Schedule 3

Design element	Specification
Installation, maintenance, data collection and provision	• The RTH is as specified in Schedule 3 • Data provision by the RTH to OGIA via the POD, on 1 April and 1 October every year (the 'submission date') • A monitoring point will be considered active where there is a monitoring record within 12 months of the latest submission date • Where an RTH becomes aware that a monitoring point has failed and needs repair, within two months of the failure, the RTH must advise OGIA of the failure and whether the monitoring point will be repaired or replaced • If the monitoring point is to be repaired, the repair must be completed within six months of advising OGIA • If the monitoring point is to be replaced, the replacement must be completed within 12 months of advising OGIA • If a point is not providing data representative of the formation, the monitoring point will be considered as failed and needing repair or replacement

12.7 Monitoring of associated water extraction

As detailed in sections 3.3.5 and 3.4.4, associated water is extracted by tenure holders during the production of P&G and to enable the safe operation of coal mines. This water extraction is subject to statutory reporting requirements, including the following:

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

There are guidelines from DNRMMRRD for reporting and processing of associated water extraction data in situations where direct measurements are not available (Department of Natural Resources Mines and Energy 2020).

Monitoring of associated water extraction volumes is critical to the 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 and while annual and six-monthly measurements provide useful information, more frequent measurement and recording is necessary for this purpose – for example, monthly extraction volumes are required by OGIA. Similarly complementary monitoring is also required for water chemistry from production wells.

Table 12-5 provides the specification for the associated water extraction network and the locations of groundwater chemistry monitoring points for CSG production wells are shown in Figure 12-6.

Table 12-5: Associated water extraction monitoring specifications

Element	Legislative reporting requirements	Additional and complementary monitoring under the UWIR WMS
Location	• All P&G wells that are extracting associated water • All coal mines extracting more than 2 ML/year	• None
Frequency	• Six-monthly volumes for individual CSG wells • Permit scale for conventional wells • Annual frequency for mines	• Monthly volumes for P&G wells
Measurement method	• P&G – not specified • Coal mines – methods specified in guidelines (Department of Natural Resources Mines and Energy 2020)	• Individual metering of P&G wells as far as practicable
Contextual information	• Perforation, stratigraphy, lithological, remarks	• Measurement methods
Responsibilities	• RTH for data collection	• RTH for data collection
Data provision	• Annual submission for coal and six-monthly for P&G tenure holders • Data provided via the GSQ Open Data Portal	• P&G RTHs to provide data to OGIA via the POD, on 1 April and 1 October • OGIA to maintain data, perform QA/QC for on-going analysis and make data available to stakeholders

12.8 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 (GWAN), from community-based monitoring and from other monitoring undertaken by tenure holders. A subset of this data is selected for use in various projects, based on project-specific criteria. The complementary networks include the following:

- **Other state government or dedicated monitoring** – within the Surat CMA, there are about 3,100 monitoring points that are generally located in shallower parts of the formations, where groundwater use is more concentrated. Of these, about 328 GWAN bores are currently actively monitoring and data is available to OGIA. OGIA has additionally equipped 14 GWAN bores for ongoing monitoring.
- **Groundwater Online and Groundwater Net** – since 2014, DLGWV 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 60 landholder water bores monitored through this program.

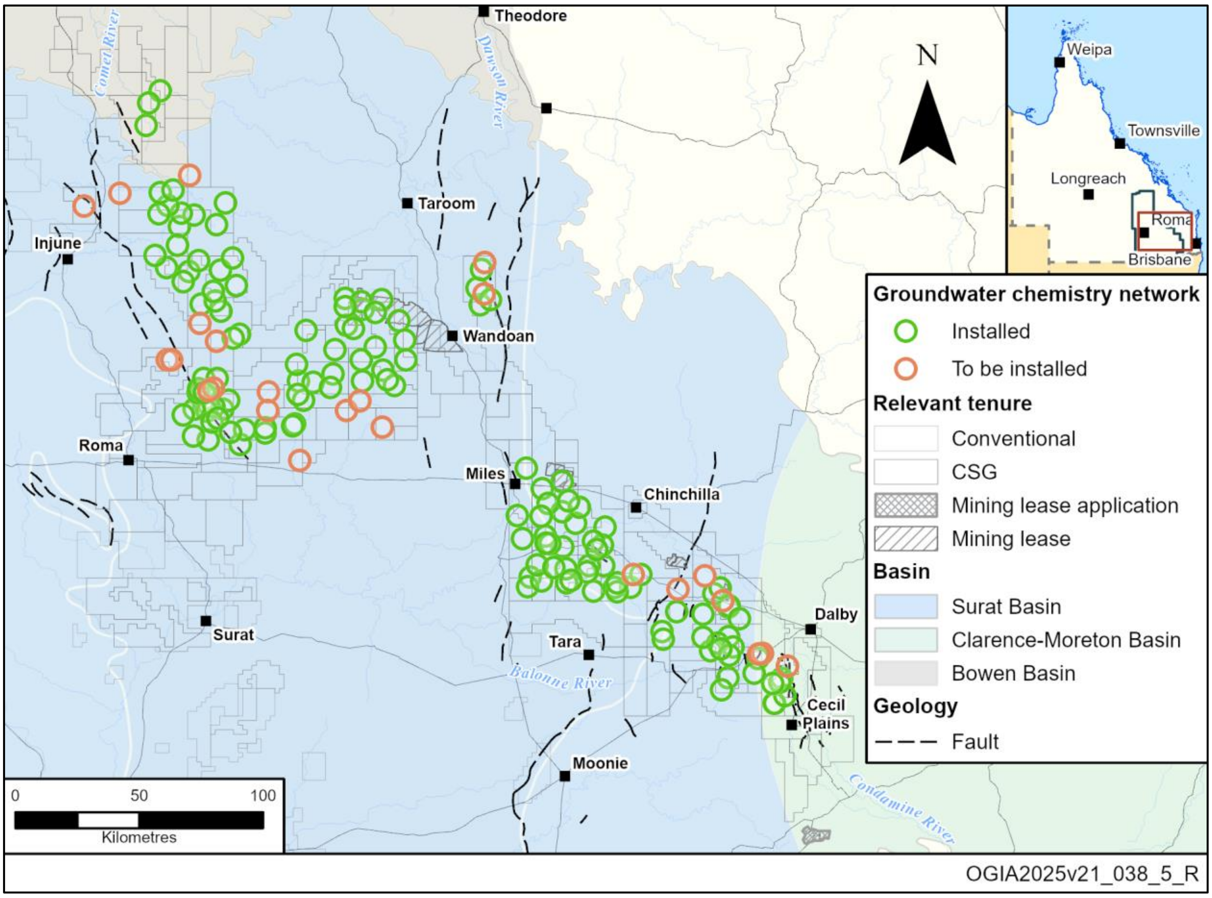

Figure 12-6: Groundwater chemistry monitoring points for CSG production wells

  - ‘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 90 monitoring points within the Surat CMA.

- **Other tenure holder monitoring** – in the Surat CMA, resource tenure holders have provided data for around 3,600 additional 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.

Data from the above sources is combined into integrated groundwater level and chemistry datasets, totalling more than 6,400 monitoring points. The integration of the above datasets provides OGIA access to an additional 4,480 CMA groundwater chemistry monitoring points, of which about 70% have five or more records.

12.9 Timeframe for implementation

The WMS identifies RTHs for the installation and maintenance of monitoring infrastructure including the networks for groundwater level, groundwater chemistry and groundwater quantity (groundwater extraction and reinjection volumes). The timeframes for implementation are summarised in sections 12.5, 0 and 12.7 and specific timing details for the installation of each individual monitoring point are provided in Schedule 2 and Schedule 3. A program for baseline assessment is specified in Schedule 6; this must be completed within 12 months of the UWIR being approved.

12.10 Summary of tenure holder WMS obligations

Rules for assigning RTH obligations are specified in 15.3. 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 Schedules 1, 2 and 3
- repair and replacement of monitoring points in accordance with those specified in this chapter and Schedules 1, 2 and 3
- submission of the following to OGIA on 1 April and 1 October of each year via the POD, which will include functionality to update WMS network implementation details online:
    - a WMS network implementation report for OGIA endorsement, including the current status of groundwater monitoring points, planned installation of monitoring points, any emerging implementation issues and any proposed changes to the location or timing of installations
    - a WMS water monitoring report that includes details about the monitoring point or production well construction and an explanation of any monitoring record gaps or changes 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 – formatted 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 QA processes, a data correction report providing an explanation of the corrections
- where a new monitoring point is required under the WMS, provision of the following, for endorsement by OGIA, is to be made via the POD:
    - the planned design of monitoring points, provided prior to construction
    - a monitoring bore completion diagram, provided upon completion.

12.11 Availability of monitoring data

Implementation of the WMS since the UWIR 2012 has progressively built a substantial groundwater monitoring network across the Surat CMA. OGIA has a statutory obligation to maintain a database of relevant information, including monitoring data in the Surat CMA. Data from the WMS has improved knowledge about the groundwater flow system and has helped to identify where further improvements are required.

OGIA makes data available through a variety of sources;

- **Groundwater level** monitoring data acquired under the UWIR can be accessed through the Queensland Globe. A more comprehensive groundwater level dataset, including additional data from baseline assessments, is also made available through the GSQ Open Data Portal.
- **Groundwater chemistry** monitoring data acquired under the UWIR is made available through the GSQ Open Data Portal. This dataset also includes additional data from baseline assessments.

- **Associated water** production volumes acquired under the UWIR are made available through the GSQ Open Data Portal.
- **LiDAR** acquired under the UWIR can be accessed through OGIA's LiDAR tool, with the data made available through the LiDAR repository website, Elvis[15].

12.12 Monitoring strategy for CSG-induced subsidence

Regional monitoring of ground motion is required in order to establish baseline and background trends in ground motion and identify CSG-induced subsidence that may have already occurred. This monitoring is now also providing data to improve the groundwater flow model.

The strategy presented here is for regional-scale monitoring. While this will provide data at the sub-metre scale, it may not be suitable for farm-scale assessment in all cases. This is currently a matter for separate consideration, which OGIA has been supporting through a pilot project. Further details are available in Quici et al. (2025) and Zhang et al. (2025).

While it is not possible to measure CSG-induced subsidence directly, ground motion that affects slopes and drainage can be measured and monitored over time. Complex data processing and modelling techniques are then employed to unpack CSG-induced subsidence from the observed ground motion. There is no single method that can reliably and efficiently measure changes in ground elevation across an entire landscape over time, particularly in floodplain areas, so a combination of techniques is employed, primarily comprising:

- monitoring of ground motion **trends** over time at various locations through InSAR
- monitoring of **landform changes** in slopes and drainage through LiDAR.

12.12.1 InSAR

InSAR is a remote-sensing method employed for the measurement of ground motion. OGIA undertook a detailed review of the InSAR method and available data to assess its suitability for the purpose of monitoring ground motion in the Surat Basin and the Condamine Alluvium (Zhang et al. 2025). InSAR's ability to detect millimetre-scale changes over wide areas makes it an efficient tool for monitoring ground motion.

Despite InSAR's limitations associated with coverage of data in agricultural areas, the coverage is sufficient to establish a spatial and temporal pattern of ground motion in the Surat CMA. InSAR interprets radar signals and does not directly measure the ground motion; future improvements or changes in InSAR data processing techniques may therefore change the interpreted ground motion, to some extent, without affecting overall patterns of ground motion.

OGIA will continue to use the InSAR data provided by SkyGeo's processing of the Sentinel-1 satellite, which has provided a measurement every 6–8 days since 2015. It has an accuracy of about 9 mm, which is comparable to available GPS data, while the precision of individual displacement estimates and the displacement rate are 6–8 mm and 1–2 mm/year, respectively.

[15] https://elevation.fsdf.org.au

12.12.2 LiDAR

OGIA has also reviewed LiDAR as a tool for monitoring landform changes (Quici et al. 2025), which found that airborne LiDAR scanning (ALS) is the most cost-effective and time-effective technique both for frequent surveys and for monitoring large regional areas, including floodplains. Alternate techniques may provide more accurate data but may not be practical for ongoing monitoring.

Point cloud data acquired from ALS surveys, with a typical point density of 4 to 16 points/m^2 in the current datasets, is considered suitable for producing digital elevation models (DEM) at resolutions of up to 1 m, for mapping landform changes. ALS data should not be used to quantify subtle ground motion over time; instead, terrain derivatives such as slope should be used to monitor changes in landscape over time. Climatic and land use factors, including vegetation coverage and water ponding, may potentially affect the LiDAR survey but can be addressed through the consideration of complementary datasets, such as aerial imagery or satellite observations.

As part of the strategy for monitoring CSG-induced subsidence, Arrow will continue to undertake at least one airborne LiDAR survey (or an alternate method that can provide similar or higher accuracy) each year in the Condamine Alluvium within 5 km of CSG production areas, preferably during the dry season when leaf coverage is minimal and there is no ponding of water. Arrow will provide the data to OGIA within three months of each survey and, following a QA/QC process, OGIA will make the data available on its website.

12.13 Summary of the monitoring strategy

- 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 strategy includes a groundwater monitoring network and tenure holder obligations for implementation of the network and reporting. The network comprises monitoring of groundwater level, groundwater chemistry and associated water extraction.
- So far 705 groundwater level monitoring points are established as part of the WMS, which is proposed to increase by 57 points to a total 762 in this UWIR.
- Similarly, the groundwater chemistry network is proposed to increase from the current 102 points to 126 points.
- The total network of dedicated groundwater level and groundwater chemistry monitoring points in the WMS will increase by 10%, from 807 points that are currently installed, to 888.
- About 42% of all groundwater level monitoring network points are in the Walloon Coal Measures in the Surat Basin, 4% are in the coal formations of the Bowen Basin and 54% are in surrounding formations.
- Monitoring of CSG associated water extraction includes monthly volumes reported to OGIA every six months.
- Several other formal and informal monitoring networks have important complementary datasets that are available for OGIA to use.
- Monitoring of CSG-induced subsidence comprises ground motion trends over time at various locations, through InSAR, and monitoring of landform changes in slopes and drainage, through airborne LiDAR.

Chapter 13 Spring Impact Management Strategy

13.1 Preamble

The Spring Impact Management Strategy (SIMS) is developed for managing impacts on springs and watercourses that are supported by groundwater. It includes an assessment of risks to springs and actions to be taken for preventing or mitigating those risks, as well as how ongoing improvements are to be made in understanding those risks.

This chapter summarises the risk assessment workflow and provides an overview of locations where mitigation actions are required following the risk assessment, as well as an update on progress where actions have been taken or are planned.

13.2 Terminology

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

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

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

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.

Mitigation group – a group of springs in close proximity that may share the same impact pathway and mechanism, where actions to mitigate impacts may also be similar, and 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.

13.3 Components of the strategy

The SIMS includes the following components:

- identification of the **springs of interest** (section 13.4)
- **assessment of risks** to springs from current and planned resource development in the Surat Basin impacting the source aquifers of the springs of interest, incorporating predictions of impact in the source aquifer, spring condition and ecological value (section 13.5)
- a **spring impact mitigation strategy** for preventing or mitigating impacts on springs where predicted impacts on source aquifers are more than 0.2 metres (section 13.6)
- a **spring monitoring program** identifying monitoring sites, appropriate techniques and frequency (section 13.7).

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

13.4 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 any aquifer with a predicted impact of more than 0.2 metres drawdown at any time at the location of the spring, regardless of whether the impacted aquifer is the likely source aquifer for the spring. Predictions are derived from the regional groundwater flow model (Chapter 8).

Table 13-1 summarises the number of sites in the Surat CMA recognised for their conservation significance under the EPBC Act or NC Act, the number of springs currently identified as springs of interest in the Surat CMA, and the total number of springs in the Surat CMA.

Table 13-1: Springs in the Surat CMA

Spring type	Springs associated with the EPBC/NC Act listings	Springs of interest	Springs in the Surat CMA
Spring complexes (spring vents)	18 (134#)	51 (245#)	86 (391)
Watercourse springs	-	84	94
Spring groups	12	38	59

Note:
Total number of spring vents within the identified complexes.

Compared to the UWIR 2021, the number of spring complexes and watercourse springs of interest has decreased, although the number of vents within the complexes is higher.

13.5 Risk assessment

The methodology used for the current assessment of risk to springs is consistent with the previous UWIRs and is derived from the intersection of likelihood of impacts 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 the source aquifer for the spring 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. The risk assessment also considers residual risk in consideration of the proposed mitigation actions, as outlined in section 13.6. The complete risk assessment workflow is available in Appendix D and OGIA (2016d).

Locations of the springs identified, through the springs risk assessment workflow, as currently or previously at-risk, are shown in Figure 13-1, with the categories detailed in section 13.6.1. Additional information on risk assessment outcomes from all UWIRs is provided in Schedule 7 (Table S7-1).

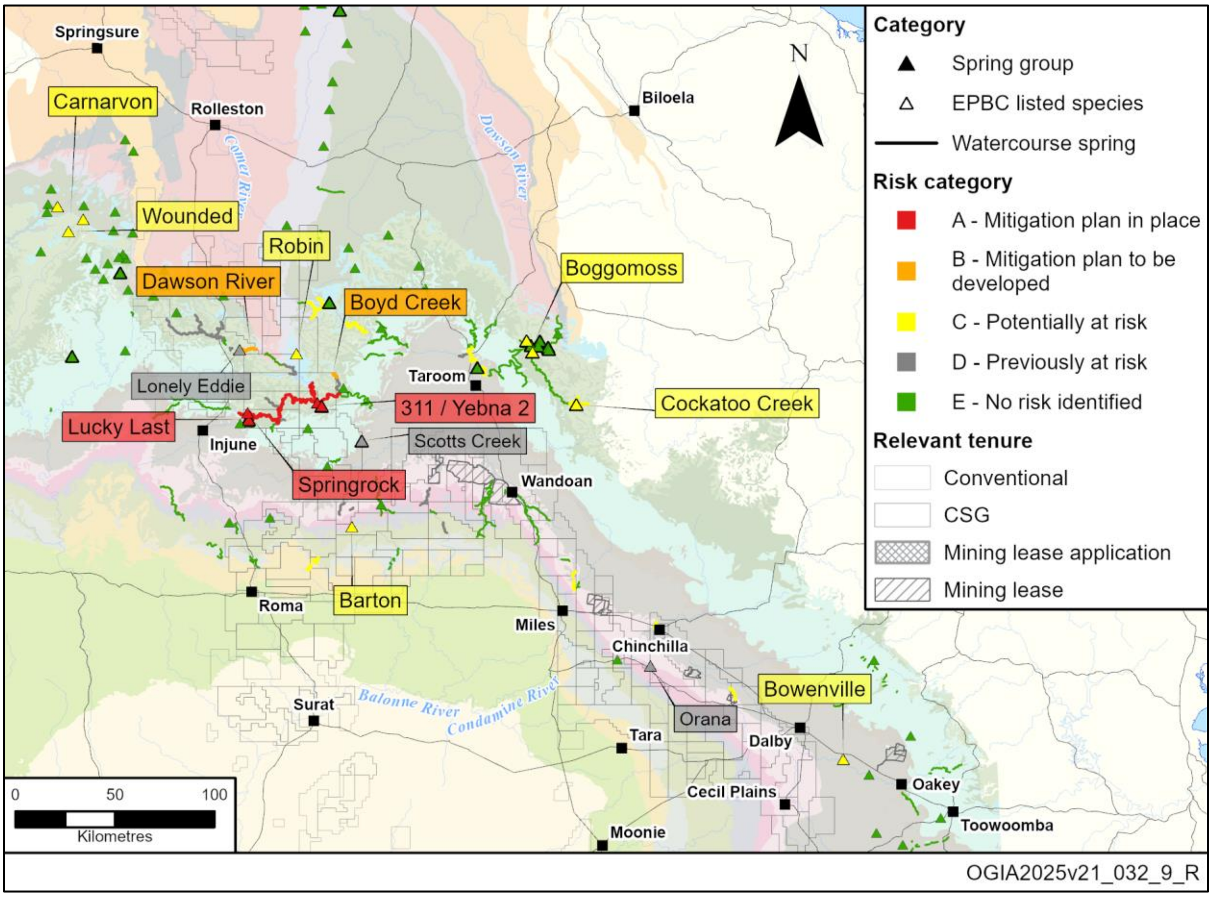

Figure 13-1: Locations of at-risk springs within the Surat Basin

13.6 Spring impact mitigation strategy

13.6.1 Mitigation categories

There are a large number of springs in the Surat CMA. The general approach to spring impact management and monitoring is to focus on springs based on the risk assessment outcomes. The springs of interest are first narrowed down to springs that are dependent on the aquifers where impact is predicted, followed by a detailed risk assessment and then prioritisation of mitigation and monitoring actions commensurate to the risk. Since predictions of impact and knowledge about source aquifers are continuously evolving, the risk profile and follow-up actions may also change over time.

Spring groups are categorised A to E, based on the mitigation actions and prioritisation:

- **Category A (at risk, with a mitigation plan)**: springs at high risk and where mitigation action plans are already in place.
- **Category B (at risk, with a mitigation plan to be developed)**: springs at risk, based on the predictions in this or the previous UWIRs, for which mitigation action plans have not previously been required.
- **Category C (potentially at risk, pending further investigations):** springs identified as being potentially at risk, where additional conceptualisation and verification by OGIA is required before mitigation plans may be required.

- **Category D (previously at risk):** springs identified as being at risk in past UWIRs but where subsequent assessment and predictions have reduced or eliminated the risk.
- **Category E (no risk identified at any time):** springs never identified as being at risk through the risk assessment process.

Predicted impacts in this UWIR are more than 1 m for Category A and B springs, typically less than 1 m for Category C springs and less than 0.2 m for Category D and Category E springs. A map showing the location of the springs in the above categories is presented in Figure 13-1 with a summary of risks and mitigations presented in Table 13-2.

Table 13-2: Spring risk assessment summary

Spring group	Number of sites in group		Source aquifer	Unmitigated risk, 2025	UWIR 2025 action
	Complexes	Water-courses			
Springrock	1	2	Precipice Sandstone	Very high	Mitigation plan to be reviewed (Category A) – tenure holder
311/Yebna 2	2	4*		Very high	
Lucky Last	1	1	Boxvale Sandstone	High	
Dawson River	0	1	Precipice Sandstone	Very high	Mitigation plan to be developed (Category B) – tenure holder
Bowenville	1	0	Basalt	Moderate	Verification required (Category C) – OGIA
Carnarvon	2	0	Quaternary basalts	Low	
Carnassier	1	0	Precipice Sandstone	High	
Robin	1	0		Moderate	
Wounded	1	0		Moderate	
Robinson Creek	0	3		Very high	
Blyth Creek	0	1	Orallo/Mooga	High	
Palm Tree Creek	0	1	Taroom Coal Measures	Moderate	
Dogwood Creek	0	1	Alluvium	Moderate	
Rocky Creek	0	1		Moderate	
Wilkie Creek	0	1	Alluvium	Very high	Verification required (Category C) – tenure holder

Spring group	Number of sites in group		Source aquifer	Unmitigated risk, 2025	UWIR 2025 action
	Complexes	Water-courses			
Barton	1	0	Gubberamunda Sandstone	Moderate	Review conceptualisation (Category C) – OGIA
Boggomoss	2	0	Precipice Sandstone	Moderate	
Cockatoo	1	2		High	

* Includes Boyd Creek (Category B)

13.6.2 Mitigation actions required in previous UWIRs

In the UWIR 2021, seven groups of springs were identified as being of moderate to very high risk. The three groups with very high risk (Springrock, Lucky Last, and 311/Yebna 2) have mitigation plans in place through Santos's approved Spring Impact Mitigation Plan (SIMP). Based on the UWIR 2019 risk assessment, impact modelling, and evaluation by OGIA, the SIMP was approved by DETSI in June 2021 and took effect through an amendment to the UWIR in August 2021 (CDM Smith 2021). The SIMP requires certain mitigation actions to bring the residual risk to low. The actions are triggered by OGIA notifying the tenure holder and DETSI, based on biannual analysis of monitoring data at specific sites, if CSG impacts have commenced at those sites. To date, there have been no CSG impacts reported for the nominated trigger bores (Schedule 7, Table S7-3).

Mitigation plans were not required for the four other spring groups – Cockatoo Creek, Carnassier, Barton and Bowenville – as some conceptual uncertainties remained. Additional work completed by OGIA during 2024 has improved the conceptual understanding of the Cockatoo Creek spring group and refined the extents and likely source aquifer of the watercourse.

Three other spring groups – Lonely Eddie, Horse Creek and Scotts Creek – were identified in previous UWIRs as having some risk, but subsequent revisions to the conceptual understanding or impact predictions have reduced or eliminated the risk.

The UWIR 2021 also identified three unverified reaches of watercourses that required field verification by tenure holders to assess whether the reaches received groundwater discharge and, if so, to identify the source aquifers. Field surveys of the Dawson River (W42) and Boyd Creek (W179) watercourse springs were carried out during the 2023 dry season. The surveys identified potential or likely groundwater inflows along some sub-reaches and ruled out groundwater inflows along others. Verification of the Wilkie Creek (W278) watercourse spring has been delayed due to a change of tenure holder (ownership) at Wilkie Creek mine. The Wilkie Creek survey is expected to occur in the 2025 dry season.

13.6.3 Updated mitigation strategy

The updated strategy is summarised in terms of the mitigation categories described earlier. In summary, the updated assessment of propagation of impacts in the Precipice Sandstone now necessitates a review of the current mitigation plans for Springrock, Lucky Last, and 311/Yebna 2 to ensure that they remain fit for purpose. Santos is required to submit this review to OGIA for endorsement within six months of the UWIR 2025 taking effect. Updated conceptual understanding of Cockatoo Creek is yet to be fully reflected in the impact modelling. Given that impacts to the 'potentially at risk' springs are anticipated sometime in the future – not in the immediate term –

mitigation action plans are deferred until additional conceptualisation and modelling is completed in the next UWIR cycle. Four other spring groups – Lonely Eddie, Horse Creek, Scotts Creek and Orana – were identified in previous UWIRs as having some risk, but subsequent revisions to the conceptual understanding or impact predictions have reduced or eliminated the risk.

13.6.3.1 Category A springs – three groups

Springrock (Precipice Sandstone)

This group was assigned a high risk score in previous UWIRs and the unmitigated risk remains high in UWIR 2025. Outcomes from the OGIA watercourse inflow assessment (section 6.3.3) showed that Hutton Creek is vulnerable to changes in both the short-term hydrological cycle and also depressurisation of the regional confined aquifer from activities such as CSG development.

Santos has committed to implementing a flow augmentation scheme, extracting water from bores in the Precipice Sandstone, some distance away from the spring, and providing flow directly into the spring wetland. Once triggered, the mitigation action will commence between one and two years from when the trigger is activated, depending on the early warning monitoring location where CSG impacts are confirmed by OGIA. In the current assessment, there is an increase in maximum impact but the residual risk profile remains as low because of the proposed actions.

Lucky Last (Boxvale Sandstone Member)

Compared to the previous assessment, there is a slight decrease in the predicted source aquifer impact for this mitigation group – maximum impact of about 0.3 m (P50) – however, the risk profile remains high. There is some ongoing ambiguity around the impact pathway for this mitigation group, which OGIA will continue to investigate in the next UWIR cycle.

Santos's currently approved mitigation actions for the Lucky Last spring group include offsetting drawdown in the source aquifer by retiring a landholder's groundwater license in that aquifer and introducing stock-control measures to improve wetland condition and resilience against any potential impacts on the wetland. These options are no longer viable (pers comm. Santos, September 2025) and Santos is therefore required to develop alternative mitigation options and resubmit the SIMP for this spring group.

311/Yebna 2 (Precipice Sandstone)

This group was assigned risk scores ranging from high (complexes) to moderate (watercourses) in previous UWIRs. For the UWIR 2025, the predicted impact in the source aquifer has increased and the unmitigated risk for this mitigation group is now high in all components. Outcomes from the OGIA watercourse inflow assessments (section 6.3.3) have confirmed that the 311/Yebna 2 watercourses would be at risk from changes in groundwater pressure within the regional aquifer, caused by activities such as CSG depressurisation.

In accordance with the current SIMP, Santos will undertake two mutually exclusive mitigation actions: offset of the predicted drawdown through 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 against the predicted impact.

13.6.3.2 Category B springs – two watercourses

This category comprises two watercourse springs verified as being potentially or likely sourced from the Precipice Sandstone, as verified through field surveys in 2023. **Dawson River (reach W42d)** was identified as likely to be receiving water from the Precipice Sandstone. The watercourse lies to the north of the Springrock mitigation group and has a high unmitigated risk in the UWIR 2025 risk assessment. The tenure holder is required to develop a monitoring and mitigation plan for this site.

The upper reaches of **Boyd Creek (W179)** were identified as potentially sourcing water from the Precipice Sandstone. Given the uncertainty with the initial survey, the tenure holder is required to conduct an additional round of sampling to confirm the initial findings, prior to a monitoring and mitigation plan being developed if a likely connection is confirmed.

The monitoring and mitigation plan for each site should include identification of suitable locations along the creeks to conduct flow gauging and surface water chemistry sampling, plus the measurement of groundwater levels and water chemistry in nearby water bores with screens in the same source aquifer. Options for mitigation of CSG-derived impacts should also be identified. Once endorsed by OGIA, the monitoring and mitigation plans will be integrated into a revised SIMP.

13.6.3.3 Category C springs – 14 spring groups and potential watercourses

This section details springs where, although some risk is identified, improvements to model predictions and some conceptual understandings (section 10.4.2.3) are necessary before firming up on the risk assessment and developing actions plans (if needed). Several of these sites are located around the margins of the Precipice Sandstone. OGIA plans to field verify those sites that have not yet been assessed, and develop a dedicated Precipice Sandstone groundwater model within the next UWIR cycle.

Cockatoo Creek (Precipice Sandstone)

A moderate risk score was assigned to this spring group in the UWIR 2021 and the potential risks remain similar in the UWIR 2025, although the time to reach the 0.2-m impact threshold has increased slightly. Outcomes from the spring vent conceptualisation (OGIA 2015b) and watercourse inflow assessment (section 6.3.3) suggest that the springs are at least partly supported by groundwater from the Precipice Sandstone. Analysis of methane gas collected from nearby bores and the creek suggest that there may also be a historically active gas migration pathway from the Bowen Basin coal measures into the Surat Basin sediments in the Cockatoo Creek area, either via displacement of strata along the Cockatoo Fault or via the Surat–Bowen basin contact zone near Wandoan.

Boggomoss (Precipice Sandstone)

Two complexes within this spring group – Boggomoss and Dawson River 6 – are predicted to be at risk for the first time in the UWIR 2025. The calculated risks are moderate, with drawdown of approximately 0.2 m (P50) predicted to occur more than 35 years into the future. These complexes were conceptualised (OGIA 2015c) and assessed as being supported by groundwater from the Precipice Sandstone.

Additional Precipice Sandstone springs

A small number of likely Precipice Sandstone-sourcing spring groups, along the fringe of the mapped outcrop, are predicted to potentially be at risk in the UWIR 2025. These include the **Carnassier** spring group, the spring vent at **Robin,** vents within the **Wounded** spring group, and a group of three watercourses at **Robinson Creek**. Timeframes for impacts are mostly decades into the future, allowing further investigations to better understand impact pathways and risk profiles.

Barton (Gubberamunda Sandstone)

The Barton spring is conceptualised to be fed by local groundwater flow from the Gubberamunda Sandstone. This spring has been predicted to be impacted since the UWIR 2016 and has been included in the UWIR field monitoring program since that time. Predictions in UWIR 2025 are slightly lower than in the UWIR 2021, with a predicted impact of up to 0.6 m leading to a moderate risk score.

Bowenville (Main Range Volcanics)

The Bowenville spring complex, fed by the Main Range Volcanics, was identified as potentially impacted for the first time in the UWIR 2021. Predicted impacts in the UWIR 2025 are similar and remain small – approximately 0.2 m (P50), more than 35 years in the future – giving the site a moderate risk score.

Carnarvon Gorge (Quaternary basalts)

Two complexes within the Carnarvon Gorge spring group – both attributed to basalt source aquifers – were identified as being at risk for the first time in the UWIR 2025. Groundwater in these basalts is conceptualised, however, to be recharged via local flow paths, which would not be affected by regional depressurisation. Consequently, the risks for these sites have been revised down to low, pending further verification of the source aquifers by OGIA.

Additional non-Precipice Sandstone watercourses

There are also five potential watercourse springs sourced from aquifers other than the Precipice Sandstone that require verification before any additional actions are specified.

13.6.3.4 Category D springs – four spring groups plus several watercourses

This category comprises springs where some risk was identified in the past but subsequent revisions in conceptual understanding or impact predictions have reduced or eliminated the risk. The springs include both spring groups – **Lonely Eddie**, fed by the Precipice Sandstone, **Horse Creek** (**Springbok Sandstone**), **Scotts Creek** (**Hutton Sandstone**), **Orana (Cenozoic sediments)** – and a number of potential watercourse springs initially identified through desktop assessment by AGE (2005) and OGIA (2017b) but subsequently found to be disconnected from groundwater.

13.7 Spring monitoring and investigations

Spring monitoring is needed to understand the natural variability in spring discharge. Similar to understanding influences on observed groundwater levels (Chapter 9), this information provides the basis for establishing the background conditions and correlation with seasonal conditions, groundwater use and potential impacts from resource development.

This section specifies the monitoring required at springs to assess groundwater discharge changes that may relate to changes in groundwater pressures in the aquifers that feed the springs. Collectively, monitoring at springs and in their source aquifers supports identification of any future impacts from associated groundwater extraction. At many locations, groundwater monitoring in the springs' source aquifers is also included in the WMS (Chapter 12).

13.7.1 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 for the monitoring network. Each RTH is to carry out monitoring at the sites to which it is assigned, according to the requirements specified in Table 13-3.

Table 13-3: Spring vent monitoring network design specification

Design element	Specification
Location	• Spring monitoring sites as provided in Schedule 8 (Table S8-1)
Frequency	• Six-monthly (April and November)[1]
Wetland discharge	• Required at sites specified in Schedule 8 (Table S8-1) • Details of the method as specified in Schedule 8 (Table S8-3)
Water chemistry	• Required at sites specified in Schedule 8 (Table S8-1) • Monitoring suite as per Schedule 8 (Table S8-3)
Flora	• Required at sites specified in Schedule 8 (Table S8-1) • Presence or absence of species listed in Schedule 8 (Table S8-5)
Wetland condition	• Photographs and descriptions of the wetland from all aspects; additional details of this requirement and prompts for monitoring are provided in Schedule 8 (Table S8-3)
RTH	• The tenure holder responsible for the monitoring obligation
Data collection and provision	• Collected by the RTH and provided to OGIA on 1 April and 1 October each year

Note:
1. Preferred months. Surveys can be completed in adjacent months if climatic or site access conditions are more favourable.

13.7.2 Watercourse spring monitoring network

Based on the outcomes of the risk assessment and 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 13-4.

Table 13-4: Watercourse spring network design specification

Design element	Specification
Location	• Watercourse spring monitoring sites as listed in Schedule 8 (Table S8-2)
Frequency	• Annual, with a subset of locations surveyed every six months as specified in Schedule 8 (Table S8-2)
Discharge	• Low-flow sampling at sites specified in Schedule 8 (Table S8-2)
Water chemistry	• Field water chemistry at sites specified in Schedule 8 (Table S8-2)
RTH	• The tenure holder responsible for the monitoring obligation
Data collection and provision	• Collected by the RTH and provided to OGIA on 1 April and 1 October each year

13.7.3 Watercourse spring verification

There are eight potentially at-risk unverified reaches of watercourses, which require field verification. One of these was initially flagged in the UWIR 2021 and remains a tenure holder commitment. The other sites are additions to the verification listings and will be assessed by OGIA. The reaches to be verified are identified in Schedule 7 (Table S7-1). The verification process will include a dry season longitudinal survey of the reaches to assess whether groundwater is discharging to surface water, surface water chemistry sampling to identify the likely source aquifer, and the measurement of groundwater levels and chemistry in nearby shallow water bores. Where a reach is verified as a watercourse spring, OGIA will identify the RTH and specify monitoring and mitigation actions where appropriate in a future UWIR. The annual review will provide an update on the progress and outcomes from these activities.

13.8 Timeframe for implementation and reporting

The SIMS identifies RTHs for monitoring, investigations, mitigation actions and reporting at spring complexes and watercourse springs. The timeframes for implementation are summarised in sections 13.6 and 13.7, with additional detail provided in Schedule 7 (Table S7-2).

13.9 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 86 spring groups and 94 watercourse springs in the Surat CMA, generally located around the edges of the Surat Basin and primarily fed by the Precipice, Hutton and Gubberamunda sandstones.
- Impacts of more than 0.2 m are predicted in one or more of the underlying aquifers at 51 spring groups and 84 watercourses locations but only 22 of those source water from impacted aquifers.
- A risk assessment based on the intersection of impact likelihood and consequences has identified 18 spring groups and watercourses with moderate or high risks, where mitigation actions may be required at some stage.
- Three sites at very high risk, with mitigation plans in place through an approved SIMP under previous UWIRs, now require updates based on the assessment in this UWIR.
- An additional two sites now require mitigation plans under this UWIR, while all other potentially at-risk sites need further investigations and assessment before firming up the risk assessment and subsequent action plans.
- OGIA will undertake investigations for those springs where some level of risk has been identified, before assessing potential mitigation actions, if necessary.
- Monitoring is specified at 34 spring vents and 7 watercourses on the basis of the risk assessment. The data collected, in combination with groundwater level monitoring data, will provide a basis for understanding background trends and potential impacts on springs.

Chapter 14 Environmental values and TGDEs

14.1 Preamble

Environmental values (EVs) and TGDEs are grouped together in this chapter because, unlike water bores and springs, the management strategies for EVs and TGDEs are provided through separate instruments, outside the UWIR. The UWIR scope only requires a description of impacts on EVs from the exercise of underground water rights, so that environmental authorities can be reviewed in response to changes that may occur during the operational phase of resource projects.

For most of the EVs supported by groundwater in the Surat CMA – such as aquifers, springs and water bores – their characterisation and assessment are explicitly included in other parts of the UWIR (Chapters 4 to 7 and Chapter 9).

14.2 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 extent.

Terrestrial GDE (TGDE) – vegetation which requires access to the subsurface presence of groundwater, either intermittently or permanently, to maintain ecological composition and function.

14.3 Definitions and the concept of 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. EVs could be further classified based on their uses: those that are for natural use (such as aquatic ecosystems) and those that are for human use (such as farm supply, recreation, industrial, or cultural and spiritual use).

The concept of EVs acknowledges that a single water body may have multiple relevant values. For instance, a particular aquifer might simultaneously support drinking water supply, agricultural irrigation, ecosystem health, and cultural or recreational uses. EV determination is fundamentally a community-driven process, reflecting the aspirations of local communities to protect and enjoy their environmental assets, both now and into the future.

The Environmental Protection (Water and Wetland Biodiversity) Policy 2019 (EPP) mandates that the EVs of groundwater must be enhanced or protected. For numerous regions across Queensland, the specific range of EVs and their water quality objectives (WQOs) for natural surface water and groundwater have been pre-determined and scheduled in the relevant EPP, providing targets for environmental management. Most EVs have associated WQOs, with some established irrespective of the local water quality and some derived based on local conditions. For example, the WQOs for drinking water depend on the minimum acceptable water quality for consumption, while the WQOs for aquatic ecosystems depend on the local quality of the water, which varies by basin, catchment or aquifer.

14.4 Scope

Aquatic ecosystems and **human use of groundwater** are dependent on three primary attributes of groundwater – quality, quantity and groundwater level. Those 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.

In a UWIR, the scope of assessment of impacts to EVs is limited to those impacts that result from the exercise of underground water rights by P&G and coal mining tenure holders. Groundwater or EV impacts related to other activities are not assessed as part of the UWIR and 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 EVs relating to:

- groundwater level and quantity – which could affect the integrity of aquatic ecosystems and the cultural, spiritual and ceremonial values of water
- groundwater quality – which could affect the suitability of water for water supply (S&D and town water supply), the suitability of water for irrigation, farms supply and aquaculture and the suitability of water for industrial use
- formation integrity – which could affect aquifer characteristics.

14.5 Approach to the characterisation of EVs

Within the Surat CMA, specific EVs and WQOs have been established for the Fitzroy Basin (Department of Environment and Heritage Protection 2011a, 2011b, 2011c, 2011d, 2011e, 2011f, 2011g) and the Murray-Darling and Bulloo River Basins (Department of Environment and Science 2020). The basins were subdivided – into zones and depths, in the case of the Fitzroy Basin; and into aquifers and zones, in the case of the Murray-Darling and Bulloo River Basins. Individual WQOs based on local data were assigned to each of these groups for the aquatic ecosystems' water use, while national guidelines were referenced to set WQOs for other uses.

In the Fitzroy Basin, for each groundwater management area or catchment, two groundwater management zones were defined, based on a vertical subdivision – above and below 30 metres of depth. By contrast, in the Murray Darling and Bulloo River Basins, there are many groundwater management areas or catchments and aquifer groups within each zone. In some cases, multiple hydrogeological units are amalgamated within each aquifer group for the purposes of the EPP.

For **aquatic ecosystems**, the available groundwater quality data was compiled to determine the 20th, 50th and 80th percentiles for each parameter within each groundwater management zone. This range is then provided as a baseline range that can be used to establish trigger values, noting that more detailed analysis of site data, if carried out for a particular site, could supplant this baseline. The WQOs based on local percentiles provide a suggested reference for assessing change since the commencement of resource development.

If local water quality data is to be used for a detailed assessment based on available site data, the supporting guidance material recommends a minimum of eight samples at each site should be used in the comparison of water quality (Department of Environment and Science 2021). As there are limited locations where there is sufficient data for this type of analysis, to process the data efficiently and using a similar approach to that applied in Chapter 9, the data has been partitioned into pre-CSG and post-CSG, based on the timing and distance (within 10 km) to the nearest CSG well.

In other sections of this report, assessment of impacts on EVs has been made for changes in groundwater pressure (level) and subsidence, including a discussion of the implications for the groundwater uses listed in the EPP. In some cases, data can be measured and evaluated; in others, there are data limitations or knowledge gaps and it is not always possible to quantify impacts that have occurred or are likely to occur in the future. In those circumstances, a conceptual understanding of potential impacts is provided. As an example, a comparison of available pH data (pre-CSG and post-CSG) to WQOs provides a general overview of the relationship. In Figure 14-1 and Figure 14-2, coloured bars represent the aquatic ecosystems WQOs for each zone as P20, P50 and P80. Pre-CSG and post-CSG data (blue and red lines) are also provided as P20, P50 and P80, while dashed lines represent WQOs for EVs other than aquatic ecosystems. A good match between the available data and WQOs is evident for some zones, while there are discrepancies in others, even in pre-CSG data.

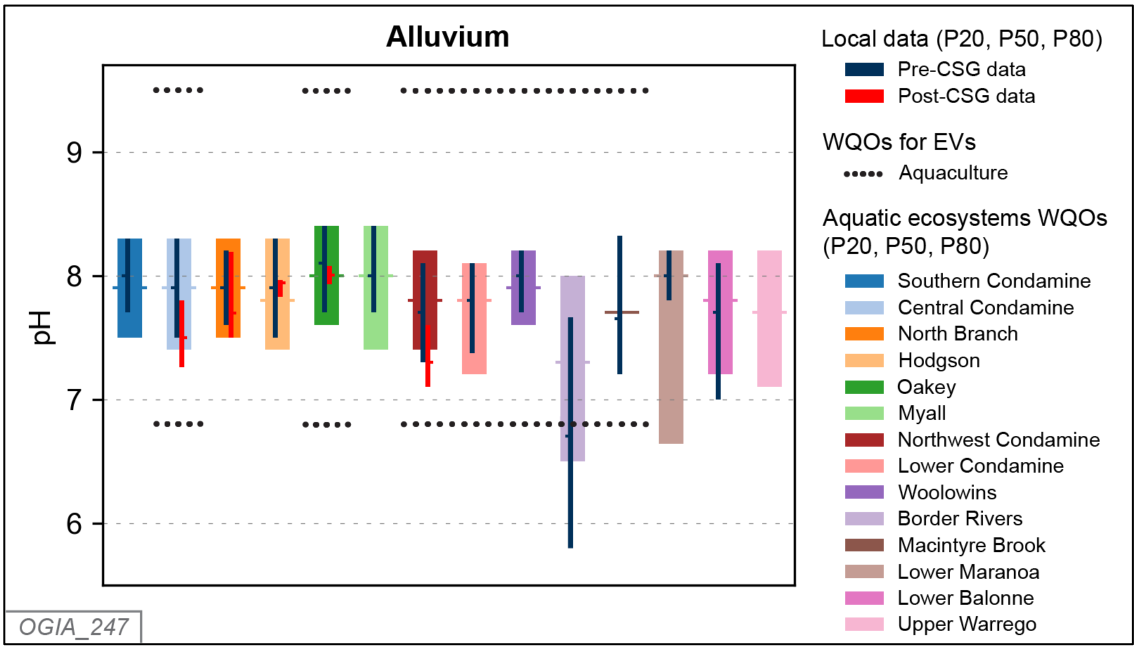

Figure 14-1: Available pH data, pre-CSG and post-CSG, compared to WQOs – alluvial zones in the Murray-Darling and Bulloo River Basins

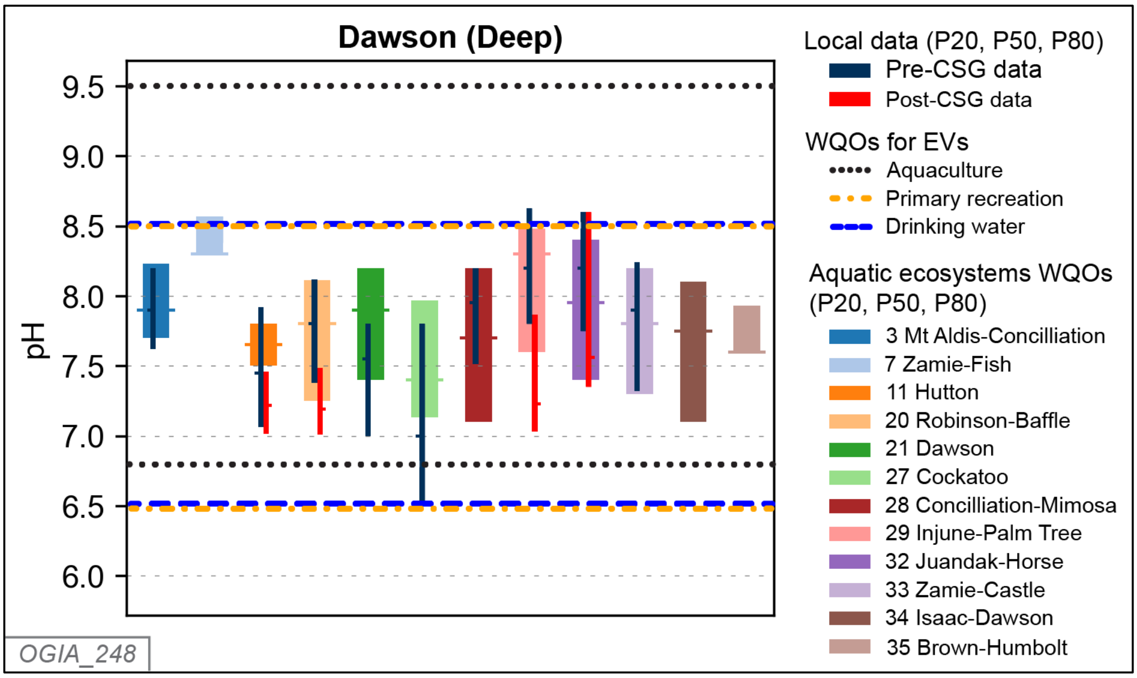

Figure 14-2: Available pH data, pre-CSG and post-CSG, compared to WQOs – Dawson catchment (deep) in the Fitzroy Basin

14.6 Synthesis of impacts on EVs

The following sections provide a summary of the impacts to EVs in the Surat CMA, with linkages to previous sections of the UWIR to minimise duplication.

14.6.1 An overview

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.

In some instances, there is pre-CSG data outside the prescribed 20th and 80th percentiles. This could be due to either non-CSG influences or an increase in data availability since the EPP was established, as a substantial amount of new data has become available since 2012.

Hydraulic gradients induced by the CSG depressurisation induce flow of water (or leakage) from adjacent aquifers towards the CSG reservoir. Material change (or impact) in water quality of the adjacent aquifer is therefore conceptually unlikely; however, free gas migration may have some potential change to groundwater quality. This is an area of ongoing consideration for OGIA (OGIA 2023c).

14.6.2 Stock and domestic (S&D) water supply

Groundwater is accessed directly by users in the Surat CMA with little to no post-extraction treatment. As detailed in Chapter 5, S&D use accounts for about 25% of groundwater use, more than half of which is from GAB formations and the remainder is from the alluvium and basalts.

There are 691 S&D and seven town water supply bores predicted to be affected by the exercise of underground water rights over the life of the industry (section 10.6). Of those bores, 2% access the shallow aquifers above the Springbok Sandstone, 96% access the Springbok Sandstone, Walloon Coal Measures or Bandanna Formation; and the remainder access the Hutton Sandstone. In the short term (the next three years), one town water supply bore and 67 S&D water bores – tapping the Springbok Sandstone and Walloon Coal Measures – are predicted to be impacted.

Due to the movement of water into the CSG 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.

14.6.3 Irrigation, farm 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 5). Occurring across all three groundwater systems – alluvium and basalts, Surat Basin and Bowen Basin – stock-intensive use accounts for around 11% (about 6,600 ML/year) of groundwater use.

In contrast, irrigation development is primarily from the Condamine Alluvium and Main Range Volcanics (about 8,000 to 9,000 ML/year), accounting for around 17% of water use in the area of interest. In addition to these irrigation licences, many water licences are issued for ‘agricultural purposes’, a high proportion of which are likely to include irrigation use. Irrigation and agricultural use, combined, account for around 46% of the groundwater use in the area of interest. Water quality requirements for cropping mean that the majority of take for irrigation and agriculture is from the Alluvium and the Main Range Volcanics.

Over the life of the industry, the groundwater levels in 46 agricultural use water bores – 25 stock-intensive and 21 other agricultural bores – will be affected by more than the trigger threshold (Chapter 11). These water bores access the Walloon Coal Measures, Springbok Sandstone, Hutton Sandstone and Condamine Alluvium. In the short term, three agricultural water bores tapping the Springbok Sandstone, and five water bores tapping the Walloon Coal Measures are predicted to be impacted.

Due to the movement of water into the CSG target formations from adjacent aquifers, there is unlikely to be any impact on the quality of water used for agricultural purposes in the short and long terms.

14.6.4 Industrial use

Around five per cent (about 2,200 ML/year) of groundwater use is for industrial purposes, including power stations and mining operations (Chapter 4). This use is predominantly from the Precipice and Hutton sandstones – about 84% of industrial take in the area of interest.

Over the life of the industry, there are three industrial water bores predicted to be affected by more than the trigger threshold. These water bores access the Springbok Sandstone and Walloon Coal Measures. There are no industrial water bores affected in the short-term. Due to the movement of water into the CSG reservoirs from adjacent aquifers, there is unlikely to be any significant impact on water quality that could have implications on industrial use in the short and long terms.

14.6.5 Cultural and spiritual values

Aboriginal Australians have a holistic and interconnected relationship with water – one connected system with spiritual, cultural, environmental, social and economic values. While springs are commonly areas of significance, water more broadly is vital for many aspects of Aboriginal life (Department of Natural Resources Mines and Energy 2019). This interconnected relationship is integral to hunting, fishing, ceremonies and storytelling. Groundwater-dependent cultural sites are important for the intergenerational transfer of knowledge, for upholding ceremonial practices, and for sustaining culturally significant species (Moggridge, Bourke & Wallis 2023).

Indigenous worldviews often recognise non-human elements, including rivers, as having agency; this forms a sacred connection (Watts 2013; Leonard et al. 2023) and embeds responsibility to care for the land, which provides for the community physically, culturally and spiritually – forming an ongoing cycle of reciprocity (Hemming et al. 2017).

Springs and groundwater-fed streams can hold profound cultural importance; in arid to semi-arid landscapes, they may be the only permanent sources of water and are often considered creation or dreaming sites (Moggridge 2020). For the purposes of the SIMS risk assessment (Chapter 13), it is considered that all springs are culturally significant and that groundwater discharge is necessary to maintain that significance. The location, magnitude and timing of predicted impacts are also described in Chapter 13.

The general area of predicted impact in the north is within the custodial lands of the Iman people. The maintenance of flow and the health of the Dawson River (‘Wardingarri’) is of profound cultural significance. Given the cultural importance of groundwater discharge to the Dawson River, increased collaboration and engagement with indigenous groups in this area is planned to increase in the post-UWIR period. This will ensure that indigenous scientific approaches, perspectives and knowledge systems are incorporated to provide a more holistic approach to understanding potential impacts.

14.6.6 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 6). The aquifers that feed springs in the Surat CMA are primarily the Clematis, Precipice, Hutton and Gubberamunda sandstones, and basalts. Details of groundwater pressure impacts in the short and long terms are provided in Chapter 9 and Chapter 10.

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 2023d). The significance of any change will depend upon the initial conditions and the magnitude of change.

14.6.7 Formation integrity

The process of CSG production has the potential to alter the porosity and permeability of rocks, through compaction. In the Walloon Coal Measures, compaction occurs within coal seams as well as the interburden and a corresponding reduction in permeability will occur within the formation. In surrounding aquifers, this effect is likely to be inconsequential, as these rocks are less prone to compaction and the pressure declines are much lower, compared to the CSG target formation.

Accordingly, subsidence modelling (section 10.8) 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 by settlement, rather than by compaction (Aghighi, Cui, Schöning, Espinoza, et al. 2024). This uniform settlement is unlikely to affect the physical characteristics of aquifers and confining layers.

14.6.8 Subsidence implications for EVs

Aquatic ecosystems and aquifer integrity are generally the main EVs that could potentially be affected by subsidence, through changes to landform and surface water flow that support those features. Some aquatic ecosystems in the Surat Basin rely on surface watercourses and CSG-induced subsidence, depending upon its magnitude, may change the slope of tributaries, resulting in changes in flow and direction that would affect aquatic systems. As detailed in previous sections, the magnitude of CSG-induced subsidence is relatively low compared to the topography of the landforms in the Surat Basin – except the Condamine Alluvium floodplains. OGIA has undertaken a separate pilot project to develop and test methods for the farm-scale assessment of CSG-induced subsidence impacts, including catchment-scale modelling to support mapping changes to inundation areas from CSG-induced subsidence. 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; however, this is outside the scope of the UWIR assessment, as detailed in section 2.3.

14.7 Assessment of risk to TGDEs

TGDEs occur where vegetation requires access to the subsurface presence of groundwater, either intermittently or permanently, to maintain ecological composition and function. Characterisation of TGDEs and the conceptual understanding of their responses to changes in groundwater regime are described earlier (section 6.4). The following subsections detail the risks to TGDEs resulting from predicted impacts on groundwater levels in aquifers that supports those TGDEs.

14.7.1 Previous assessment

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. These investigations have informed tenure holders' 'groundwater monitoring and management plans', which include the development of early warning indicators and trigger thresholds for TDGEs. 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.

In the UWIRs 2019 and 2021, OGIA completed regional-scale desktop assessments over the three timeframes, as required in the legislation – the past, within the next three years, and over the life of the industry. In the UWIR 2021, historical changes to groundwater levels in the Walloon Coal Measures were generally less than 10 metres at the location of potential TGDEs, while in the longer term, the majority of impacts were less than 15 metres. The UWIR 2021 was also the first to assess impacts to TGDEs from coal mines and the risk assessment was adjusted to assess TGDEs reliant on perched aquifers within the coal mining leases. These TGDEs are not included in the regional risk assessment as CSG depressurisation is unlikely to affect perched aquifers.

14.7.2 Approach to risk assessment for the UWIR 2025

The overall approach to the risk assessment is consistent with the previous assessments, as shown in a flow diagram in Appendix E. The risk assessment includes first identifying TGDEs of interest – those in selected land zones within the footprint of predicted drawdown greater than 0.2 m within the outcrop of affected aquifers – and then assessing risk to the TGDE as a function of the likelihood and consequence of drawdown in the outcropping formation. This considers biodiversity status and the magnitude and timing of impacts, to assess the consequence of any change in the groundwater regime.

Three risk categories were used to assess the spatial distribution of risk to TGDEs:

- areas of low risk, where predicted impacts on regional ecosystems (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 of '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 risk assessment is considered conservative because it is applied to vegetation communities and extents that have been classified, mostly through desktop study by the Queensland Herbarium, as potential TGDEs – this could include vegetation that is not dependent on groundwater. For a TGDE spatial polygon containing multiple REs, the risk assessment determines the biodiversity status of the polygon by assigning the RE with the highest level of concern, rather than the RE that covers the greatest area.

14.7.3 Outcomes from the risk assessment

The risks derived from the assessment are summarised for the three timeframes during which the TGDEs are predicted to be affected: prior to 2025 ('past'), in the next three years ('2026–2028') and over the life of the industry ('long term'). The outcome is summarised in Table 14-1 and presented in Figure 14-3. The risk assessment for TGDEs predicted to be affected prior to 2025 and in the short term are presented in Appendix F.

Table 14-1: Summary of risk assessment for TGDEs (area of interest)

Risk category	Area of TGDEs predicted to be affected		
	Past	2026–2028	Long term
Low	1.4% (6,981 ha)	1.5% (7,244 ha)	5.7% (27,696 ha)
Medium	0.2% (1,187 ha)	0.3% (1,357 ha)	0.7% (3,366 ha)
High	0.7% (3,180 ha)	0.6% (3,116 ha)	2.2% (10,724 ha)

Note:
Area percentages were calculated by dividing each resulting area in any period by the total extent of the long-term area of interest, defined as the total area of outcrops where drawdown is predicted to exceed 0.2 m any time during the long-term period (533,901 ha).

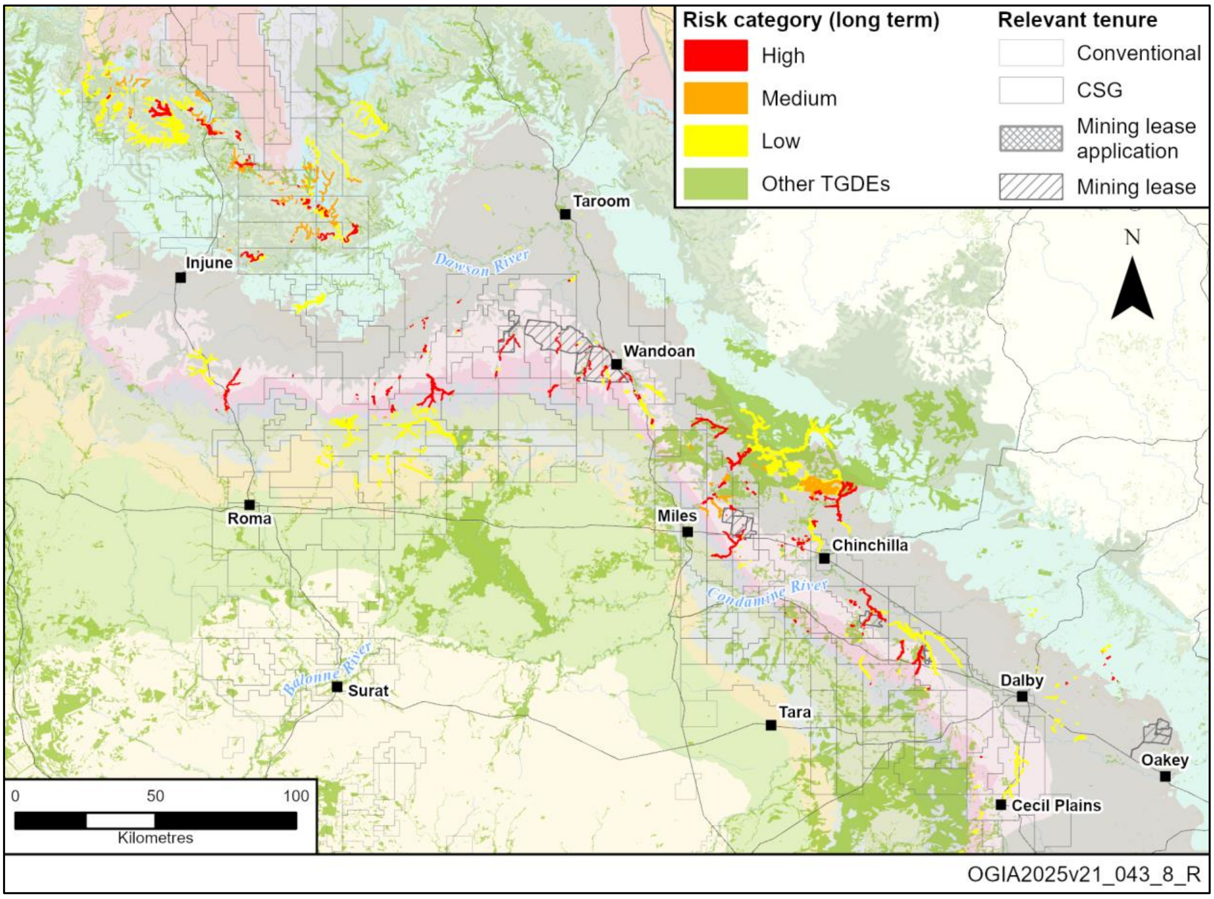

Figure 14-3: Locations of potentially long-term at-risk TGDEs

14.7.4 Validation using remote-sensing images

The initial TGDE risk assessment identifies those sites that could potentially be impacted by P&G or coal mine developments. As it is impractical to regularly field-monitor each site to verify changes in vegetation condition, OGIA has been developing a workflow to detect changes in vegetation condition using remote-sensing data in conjunction with available hydrological datasets.

The workflow utilises data from Sentinel-2 satellites to generate a monthly normalised difference vegetation index (NDVI) time series for the TDGEs in the selected land zones across the CMA. This time series is then compared to those at a reference site that has a similar RE composition, is not identified as at-risk, and is located within 5 km of the impacted site, where possible.

Modified Mann-Kendall analysis is used to look for statistical changes in the difference in NDVI between the two sites. Differences with statistically significant downward trends indicate that vegetation on the at-risk site is becoming less healthy than the reference site over time. In many cases, there is more than one reference site associated with each at-risk site. If the majority of Mann-Kendall analyses show the same significant falling trend, there is higher confidence that the identified difference is accurate. The workflow has revealed that in areas with falling groundwater levels, the NDVI difference remains small and driven by non-CSG factors, such as bushfire and climatic variability.

14.7.5 Potential uncertainties and monitoring

Queensland TGDE mapping has been developed by the Queensland Herbarium using available datasets and engagement with subject matter experts (Glanville et al. 2016). As mentioned above, however, some uncertainty remains regarding the scale and the level of confidence of TGDE mapping, and the identification of source aquifers. Of the potential TGDEs identified, only a small number 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.

Additional to mapping, large error terms are associated with the 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 also associated with high uncertainty.

14.8 Summary

- An EV is a quality or physical characteristic of the environment that is conducive to ecological health, public amenity or safety and may relate to natural use (such as aquatic ecosystems) or human use (such as recreation, industrial or cultural and spiritual).
- Various water quality parameters and limits of their values are prescribed in relevant EPPs.
- The analysis suggests that water quality parameter values have not changed significantly since the commencement of CSG operations.
- In some instances, there is pre-CSG data outside the prescribed limits that could be due to either non-CSG influences or an increase in data availability since the limits were established.
- TGDEs occur where vegetation requires access to groundwater, either intermittently or permanently, to maintain ecological composition and function.
- The total area of TGDEs predicted to be affected by more than 0.2 m drawdown in their source aquifers is approximately 8.6% of the long-term area of interest.

Chapter 15 Responsible tenure holder obligations

15.1 Preamble

As detailed in section 1.5, resource tenure holders' right to take associated water is subject to several obligations relating to the management of impacts caused by the exercise of the right, including to make good the impairment of supply from water bores.

To ensure there is clarity on impact management actions (s. 369 of the Water Act), where impacts from multiple tenure holders may overlap in a CMA, the responsibilities of individual tenure holders for specific obligations are assigned in the UWIR. This chapter provides rules for determining individual RTHs for obligations arising from the impact management strategies detailed in previous chapters. There is no change to the rules compared to the previous UWIR.

15.2 Underground water obligations for RTHs

Underground water obligations can be grouped into two categories:

- ***Make good obligations*** for management of impairment of a bore's water supply – such as baseline assessment, bore assessment and make good agreement (section 11.3).
- ***Report obligations*** that are much broader and primarily relate to water monitoring obligations, spring impact management obligations (Chapter 12 and Chapter 13) and any other obligations specified in the previous chapters of this report.

In the following sections, 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, which is advised by DETSI, with the notice of approval of the report made available on its website.

15.3 Assignment of underground water obligations

15.3.1 General

The locations of current and planned P&G production tenures and coal mining tenures are shown in Figure 3-3. For the tenures identified in section 3.3.2, details about the current authorised tenure holders based on the information as at January 2025, are provided 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.

15.3.2 Changes compared to previous rules

There are no changes affecting the rules compared to the previous UWIR.

15.3.3 Assignment rules

15.3.3.1 '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 associated water licence (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. 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.

15.3.3.2 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, tenure holders are required, under the Water Act, 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 section 1.1 and the rules for assignment are prescribed in this section.

> Rule 5: The RTH for a water bore requiring baseline assessment under Chapter 11 is the authorised tenure holder of a relevant P&G tenure or relevant existing mining tenure that is closest to the water bore.

15.3.3.3 Reporting obligations – WMS, SIMS and others

Obligations relating to the WMS, SIMS and subsidence – specified in Chapter 12 and Chapter 13 are primarily for implementing a monitoring network, 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 where those actions are required.

The above rules imply that, in some instances, reporting obligations may be assigned to P&G tenure holders within mining tenure. This is intended because of the regionally extensive nature of impacts caused by the P&G (primarily CSG) operations. In the instances where a reporting obligation or action – such as installation of a monitoring point or management of an impacted watercourse – is required primarily due to mining operations, 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 where those actions are required.

15.3.3.4 Transfer of obligations

There are instances where, through mutual agreement with the RTH, a tenure holder other than the one identified as the RTH has taken responsibility, or intends to take responsibility, for some underground water obligations. 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.

OGIA will notify DETSI and the affected tenure holders within 30 days of transfer approvals. For transparency, OGIA will also provide the outcome of any approved transfers in the annual review.

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 UWIRs in effect at the time. To provide certainty, RTHs and underground water obligations from previous UWIRs will therefore continue to be maintained, based on the following rule.

> Rule 11: Irrespective of Rules 1 to 10, an 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.

15.4 Determination of RTHs 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 schedules:

- follow-up bore assessment and make good arrangements for each of the IAA bores – column 'RTH', Table S4-1 in Schedule 4
- bore baseline assessment – section 1.1; column 'RTH', Table S6-1 in Schedule 6

- installation and maintenance of monitoring points and implementation of monitoring strategy – various parts of Chapter 12; 'RTH' columns, Tables S2-2 and S3-3 in Schedule 2 and S3-4 in Schedule 3
- monitoring and mitigation of relevant spring groups – sections 13.6 and 13.7; 'RTH' columns, Table S8-1 and Table S8-2 in Schedule 8
- monitoring of subsidence – section 12.12.

A summary of each RTH's obligations is also provided in Table S9-1, Schedule 9.

15.5 Linkages between an AWL and UWIR obligations

AWL requirements for mining tenure holders came into force following an 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. 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.

15.6 Summary of RTH obligations

- In a CMA, where impacts from multiple tenure holders 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.
- Primarily, the rules assign tenure holders responsibility for the UWIR-identified obligations within their own tenures and for those obligations 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 operation, 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 schedules.

Chapter 16 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.

16.1 Annual reporting

OGIA prepares annual reviews to provide updates 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 reviews to DETSI for the UWIR 2024. These reviews 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 Schedule 4 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 Schedule 8

16.2 Other reporting and publications

OGIA's strategy on reporting its research and technical findings continues to evolve. OGIA is gradually publishing findings between the UWIR cycles, as they become available and this practice will continue in the coming cycle. 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 also intends to continue the practice, following the publication of the UWIR.

16.3 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 12) 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 12 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 DLGWV 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'[16] on the OGIA website. OGIA is currently also progressing a project to develop a web-based portal for making available online the additional data and outputs presented in the UWIR.

16.4 Communication videos

OGIA has produced communication videos to support understanding of some fundamental elements of the impact assessment. These are available on the OGIA website[17].

- *Introduction to the Surat CMA* (www.youtube.com/watch?v=KzejrE1OOn4) introduces the Surat CMA and some of the key groundwater assets in the CMA.
- *Geology of the Surat CMA* (www.youtube.com/watch?v=v2Jf0lvdWJI) 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=rNOpMZEr3uE) 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=-gBw2EgqJKk) explains how groundwater impacts may occur in aquifers surrounding the coal mines in the Surat Basin.

16.5 Revising the UWIR and future research directions

Queensland's regulatory framework requires revision of the UWIR every three years unless the chief executive of DETSI 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 shift focus from regional-scale assessment to more localised assessments in areas of particular interest, where groundwater assets are either at risk, or likely to be at risk. At this stage, the focus areas are:

- specific purpose-built tools for improving predictions in the Precipice Sandstone in the northern area, where there are number of GDEs dependent on this aquifer
- a numerical model and related tools to improve the resolution of predictions in the Condamine Alluvium, particularly around the Horrane Fault, and to accommodate recent improvements in geological modelling and conceptualisation of connectivity
- investigations and verification of springs that are flagged as potentially at risk and may require mitigation actions in the future.

[16] www.ogia.water.qld.gov.au/products-tools
[17] www.ogia.water.qld.gov.au

Appendices

Appendix A Key datasets and scientific assessments underpinning the UWIR

Datasets

Key raw datasets used in the assessment in the UWIR are as follows:

- downhole geophysical logs (gamma, density, resistivity, calliper, etc.) and well construction details (casing type and intervals, plugs and screens) from 11,663 petroleum wells
- over 18,000 coal exploration holes have been drilled in the Surat CMA, most with stratigraphic picks from mining companies. Approximately 9,000 include geophysical logs, of which 4,500 had suitable datasets.
- four AEM surveys have been conducted across the Surat CMA, including a 2,200 km survey commissioned by OGIA over the western Condamine area in May 2023 (114 flight lines), and three additional surveys undertaken by Geoscience Australia in the northern Surat Basin (Ray et al. 2021).
- more than 300 2D seismic surveys and 12 3D surveys
- from the GWDB, data for about 72,070 bores with locations, of which approximately 66,690 have recorded depths and 46,480 contain construction details
- around 12,000 permeability measurements from core and drill stem tests, sourced from tenure holders
- bore baseline, bore assessment and bore census information collected by tenure holders
- groundwater level and hydrochemical information from the GWDB, WMS and bore and baseline assessments
- WMS database (pressure, water chemistry and associated water volumes)
- non-consumptive groundwater use by P&G tenure holders from the GSQ Open Data Portal
- coal tenure holder associated water estimates from the GSQ Open Data Portal
- gas production data (up to October 2022) from a selection of CSG wells – between Chinchilla and Cecil Plains and within 10 km of Bandana contact zone
- LiDAR data from the tenure holders to assist with Groundwater Dependent Ecosystem assessments, field investigations, and geological mapping
- InSAR data of observed ground motion over time, from SkyGeo.

Primary data analysis

The following is a list of key primary data analysis, by OGIA or others, used in supporting the assessment and management strategies in the UWIR:

- **stratigraphic interpretations** for 11,663 petroleum wells (including 5% deviated), 4,483 coal bores, and 48 water bores with relevant geophysical log data; for the previous UWIR, lithological classifications were created from geophysical logs to include six units: clean sandstone, sandstone-dominated heterolith (dirty sandstone), mudstone-dominated heterolith (siltstone), mudstone, carbonaceous shale, and coal

- **geological unit extents** (outcrop and subcrop) derived from GSQ and Cranfield (2017) mapping, refined using higher-confidence data like borehole records, using the detailed surface geology (1:100,000 scale) and solid geology datasets
- **seismic interpretation** of 2D and 3D surveys from tenure holders to consolidate and revised faults and contact zone mapping
- geophysical inversion and geological interpretation of the **AEM survey** commissioned by OGIA (Schöning et al. 2025)
- desktop **verification of about 4,600 bore baseline** and bore census records, with some field verification, resulting in an update to approximately 2,000 bore locations, and the addition of almost 500 water bores to the GWDB – by OGIA
- **interpretation of bore construction** data in relation to casing and intercepted geology to determine the source aquifer from which a bore is likely to be accessing water – by OGIA
- compilation of **resource development profiles** – provided by the industry and compiled by OGIA
- compilation and **QA/QC of groundwater level** data from the GWDB, WMS, bore and baseline assessments and OGIA field-based projects
- compilation and **QA/QC of water chemistry** data from the GWDB, WMS, baseline assessments and OGIA projects, as well as supplementary datasets from CSIRO, GA and relevant open-source data
- automated generation of **potentiometric surfaces** from available data (Erasmus et al. 2025; OGIA 2023c)
- identification of CSG wells and **coal holes** screened across multiple formations and assessment of implications for connectivity (OGIA 2023e).

Development of methods and techniques by OGIA

The following key methods and techniques were primarily developed by OGIA in supporting the assessment and management strategies in the UWIR:

- determination of **source aquifers** for bores and wells (OGIA 2021d)
- a method for estimating **unmetered water use** (S&D and non-S&D) – developed in 2012 and modified in 2016, 2020 (Singh et al. 2020) and 2024 (Smallacombe et al. 2024)
- a method to perform **fault juxtaposition** and seal analysis (OGIA 2020)
- a **spring typology** to classify springs in the Surat CMA (OGIA 2016b)
- refined chloride mass balance techniques for estimating **groundwater recharge** (OGIA 2016e)
- **numerical permeameters** for obtaining regionally upscaled hydraulic conductivity from detailed lithology and permeability data (OGIA 2016f, 2019c)
- a method to **approximate two-phase flow** in MODFLOW-USG (Herckenrath, Doherty & Panday 2015)
- estimation of **permeability enhancement** due to placement of CSG wells (OGIA 2016f)

- a method to **represent geological faults in groundwater models**
- advanced **signal processing** techniques to determine the influence of stressors on groundwater levels (OGIA 2023c)
- a subsidence package for MODFLOW-USG to model CSG-induced subsidence accounting for poroelastic compaction and coal shrinkage (Aghighi, Cui, Schöning, Espinoza, et al. 2024)
- a method for assessing the potential for **formation bridging** in CSG fields (Aghighi, Cui, Schöning & Pandey 2024)
- an integrated **hydro-mechanical modelling framework** to concurrently simulate CSG-Induced subsidence and groundwater impacts (Cui, Schoning, et al. 2025)
- analytical estimates of drawdown and **radius of influence** in formations adjacent to the Walloon Coal Measures at coal exploration holes and selected production wells (OGIA 2023e).
- a QA/QC workflow for processing **LiDAR data.**
- a **probabilistic inversion** code using ensemble-based methods (randomised maximum likelihood) to estimate and quantify the uncertainty associated with the inversion of the Condamine Alluvium AEM survey (Schöning et al. 2025)
- a workflow to assign **pre-development and post-development periods**, based on improved determination of active CSG well dates and proximity to monitoring sites (Erasmus et al. 2025)
- **integrated groundwater level and hydrochemistry databases** consolidate groundwater level and hydrochemistry data, with density-corrected groundwater levels and automated QA/QC processes (Erasmus et al. 2025)
- a framework for **identifying groundwater mixing trends** and **detecting impacts** through improved understanding of the variability in selected hydrochemical parameters (Erasmus et al. 2025).

Models

The following various models were developed by OGIA in supporting the assessment in the UWIR:

- a regional-scale geological model of the Surat and southern Bowen basins, covering an area of approximately 450×650 km, including 21 layers (all majors units) and 32 major faults, at 250-m grid resolution (OGIA 2019b, 2021b)
- a high-resolution 3D sub-regional geological model for the Condamine Alluvium footprint was developed. Integrating recent AEM data with a comprehensive reinterpretation of existing seismic, petroleum well, coal bore and water bore datasets, this geological model serves as the architecture for a sub-regional groundwater impact model for the Condamine Alluvium (Bui Xuan Hy et al. 2025)
- a two-phase flow model in Eclipse designed to test pseudo-dual phase approximation (OGIA 2016f)
- a dual steady-state and transient calibrated regional groundwater flow model comprising 35 layers with a 1.5×1.5-km grid resolution, covering an area of approximately 450×650 km and

supported by 3,000 calibrated parameter sets obtained using PEST++IES (OGIA 2021f, 2019c)

- a history-matched analytical subsidence model, coupled to OGIA's regional groundwater model and calibrated to InSAR observations in the Condamine Alluvium (OGIA 2023f)
- an integrated groundwater flow and geomechanical model simultaneously calibrated to groundwater and ground motion data was developed and implemented – allowing concurrent predictions of groundwater impacts and subsidence, as well as maximising the value of calibration datasets.

Appendix B Water use tables

Table B-1: Estimated groundwater use in the area of interest in 2024

<table>
<tr><th rowspan="2" colspan="2">Formation</th><th colspan="4">Number of water bores</th><th colspan="4">Water use (ML/year)</th></tr>
<tr><th>S&D</th><th>Non-S&D</th><th>Non-assoc.</th><th>Total</th><th>S&D</th><th>Non-S&D</th><th>Non-assoc.</th><th>Total</th></tr>
<tr><td colspan="10">Alluvium and basalt</td></tr>
<tr><td colspan="2">Cenozoic Sediments</td><td>138</td><td>2</td><td>-</td><td>140</td><td>179</td><td>42</td><td>-</td><td>221</td></tr>
<tr><td colspan="2">Condamine Alluvium</td><td>1,969</td><td>488</td><td>-</td><td>2,457</td><td>1,075</td><td>13,976</td><td>-</td><td>15,051</td></tr>
<tr><td colspan="2">Main Range Volcanics</td><td>372</td><td>71</td><td>-</td><td>443</td><td>320</td><td>2,010</td><td>-</td><td>2,331</td></tr>
<tr><td colspan="2">Other Alluvium</td><td>587</td><td>41</td><td>-</td><td>628</td><td>1,989</td><td>1,231</td><td>-</td><td>3,220</td></tr>
<tr><td colspan="2">Other Basalts</td><td>132</td><td>2</td><td>-</td><td>134</td><td>115</td><td>181</td><td>-</td><td>296</td></tr>
<tr><td colspan="2">Alluvium and basalt subtotal</td><td>3,198</td><td>604</td><td>-</td><td>3,802</td><td>3,679</td><td>17,441</td><td>-</td><td>21,120</td></tr>
<tr><td colspan="10">Great Artesian Basin (GAB)</td></tr>
<tr><td colspan="2">Upper Cretaceous formations</td><td>103</td><td>3</td><td>-</td><td>106</td><td>194</td><td>159</td><td>-</td><td>353</td></tr>
<tr><td colspan="2">Wallumbilla Formation</td><td>69</td><td>1</td><td>-</td><td>70</td><td>105</td><td>3</td><td>-</td><td>109</td></tr>
<tr><td colspan="2">Bungil Formation</td><td>159</td><td>1</td><td>-</td><td>160</td><td>307</td><td>7</td><td>-</td><td>313</td></tr>
<tr><td colspan="2">Mooga Sandstone</td><td>451</td><td>9</td><td>2</td><td>462</td><td>834</td><td>268</td><td>51</td><td>1,153</td></tr>
<tr><td colspan="2">Orallo Formation</td><td>582</td><td>20</td><td>-</td><td>602</td><td>723</td><td>794</td><td>-</td><td>1,517</td></tr>
<tr><td colspan="2">Gubberamunda Sandstone</td><td>624</td><td>65</td><td>18</td><td>707</td><td>840</td><td>2,282</td><td>156</td><td>3,277</td></tr>
<tr><td colspan="2">Westbourne Formation</td><td>68</td><td>2</td><td>-</td><td>70</td><td>94</td><td>15</td><td>-</td><td>109</td></tr>
<tr><td colspan="2">Springbok Sandstone</td><td>204</td><td>14</td><td>3</td><td>221</td><td>223</td><td>220</td><td>25</td><td>468</td></tr>
<tr><td rowspan="3">Walloon Coal Measures</td><td>Upper Juandah Coal Measures</td><td>159</td><td>7</td><td>-</td><td>166</td><td>173</td><td>209</td><td>-</td><td>382</td></tr>
<tr><td>Lower Juandah Coal Measures</td><td>353</td><td>35</td><td>-</td><td>388</td><td>295</td><td>885</td><td>-</td><td>1,180</td></tr>
<tr><td>Taroom Coal Measures</td><td>268</td><td>32</td><td>-</td><td>300</td><td>136</td><td>300</td><td>-</td><td>437</td></tr>
<tr><td colspan="2">Durabilla Formation</td><td>107</td><td>12</td><td>-</td><td>119</td><td>109</td><td>130</td><td>-</td><td>239</td></tr>
<tr><td colspan="2">Hutton Sandstone</td><td>1,169</td><td>130</td><td>-</td><td>1,299</td><td>1,480</td><td>4,343</td><td>-</td><td>5,823</td></tr>
<tr><td colspan="2">Evergreen Formation</td><td>130</td><td>5</td><td>-</td><td>135</td><td>419</td><td>111</td><td>-</td><td>530</td></tr>
<tr><td colspan="2">Precipice Sandstone</td><td>278</td><td>39</td><td>15</td><td>332</td><td>617</td><td>4,045</td><td>173</td><td>4,835</td></tr>
<tr><td colspan="2">GAB subtotal</td><td>4,724</td><td>375</td><td>38</td><td>5,137</td><td>6,549</td><td>13,770</td><td>405</td><td>20,723</td></tr>
<tr><td colspan="10">Bowen Basin</td></tr>
<tr><td colspan="2">Moolayember Formation</td><td>16</td><td>-</td><td>-</td><td>16</td><td>54</td><td>1</td><td>-</td><td>55</td></tr>
<tr><td colspan="2">Clematis Group</td><td>43</td><td>-</td><td>1</td><td>44</td><td>146</td><td>-</td><td>-</td><td>146</td></tr>
<tr><td colspan="2">Rewan Group</td><td>136</td><td>-</td><td>-</td><td>136</td><td>187</td><td>-</td><td>-</td><td>187</td></tr>
<tr><td colspan="2">Bandanna Formation</td><td>45</td><td>1</td><td>-</td><td>46</td><td>85</td><td>2</td><td>-</td><td>87</td></tr>
<tr><td colspan="2">Cattle Creek Formation</td><td>3</td><td>-</td><td>-</td><td>3</td><td>3</td><td>-</td><td>-</td><td>3</td></tr>
<tr><td colspan="2">Upper & Lower Permian</td><td>64</td><td>5</td><td>-</td><td>69</td><td>87</td><td>60</td><td>-</td><td>147</td></tr>
<tr><td colspan="2">Bowen Basin subtotal</td><td>307</td><td>6</td><td>1</td><td>314</td><td>562</td><td>64</td><td>-</td><td>626</td></tr>
<tr><td colspan="2">Metamorphic/ igneous/old basement rocks</td><td>15</td><td>16</td><td></td><td>31</td><td>17</td><td>-</td><td>-</td><td>17</td></tr>
<tr><td colspan="2">TOTAL</td><td>8,244</td><td>1,001</td><td>39</td><td>9,284</td><td>10,806</td><td>31,275</td><td>405</td><td>42,485</td></tr>
</table>

Table B-2: Estimated groundwater use in the area of interest (averaged 2004-2024)

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
Alluvium and basalt									
Cenozoic Sediments		106	2	-	108	168	48	-	216
Condamine Alluvium		1,908	509	-	2,417	6,468	23,193	-	29,661
Main Range Volcanics		375	70	-	445	208	1,897	-	2,105
Other Alluvium		563	46	-	609	1,197	1,390	-	2,587
Other Basalts		96	2	-	98	113	165	-	278
Alluvium and basalt subtotal		3,048	629	-	3,677	8,154	26,693	-	34,847
Great Artesian Basin (GAB)									
Upper Cretaceous formations		283	109	-	392	235	159	-	394
Wallumbilla Formation		171	3	-	174	123	4	-	127
Bungil Formation		372	11	-	383	311	27	-	338
Mooga Sandstone		644	20	2	666	830	184	11	1,025
Orallo Formation		834	36	-	870	713	708	-	1,421
Gubberamunda Sandstone		759	95	18	872	949	3,049	161	4,159
Westbourne Formation		273	22	-	295	92	6	-	98
Springbok Sandstone		317	36	3	356	222	253	25	500
Walloon Coal Measures	Upper Juandah Coal Measures	341	45	-	386	246	414	-	660
	Lower Juandah Coal Measures	517	59	-	576	313	634	-	947
	Taroom Coal Measures	516	50	-	566	133	271	-	404
Durabilla Formation		344	37	-	381	108	181	-	289
Hutton Sandstone		1,250	159	-	1,409	1,555	4,141	-	5,696
Evergreen Formation		349	52	-	401	408	141	-	549
Precipice Sandstone		334	41	16	391	984	4,009	238	5,231
GAB subtotal		7,304	775	39	8,118	7,221	14,181	435	21,837
Bowen Basin									
Moolayember Formation		77	2	-	79	66	246	-	312
Clematis Group		76	-	1	77	160	-	0	160
Rewan Group		163	2	-	165	195	0	-	195
Bandanna Formation		90	2	-	92	94	2	-	96
Cattle Creek Formation		4	-	-	4	2	-	-	2
Upper & Lower Permian		89	5	-	94	98	74	-	172
Bowen Basin subtotal		499	11	1	511	615	323	0	938
Metamorphic/ igneous/old basement rocks		11	-	-	***11***	26	-	-	***26***
TOTAL		10,862	1,415	40	**12,317**	16,016	41,196	**435**	**57,647**

Table B-3: Median values for key water quality parameters in the target formations and adjacent aquifers in the Surat CMA (between 2004 and 2024)

Formation		Samples	Concentration (mg/L)								pH	SAR
			Calcium	Magnesium	Sodium	Potassium	Chloride	Sulphate	Bicarbonate	TDS		
Condamine Alluvium		4038	40	32	212	2	200	30	472	1,015	7.8	7
Springbok Sandstone		494	14	2	682	4	964	2	427	2,116	8.2	56
Walloon Coal Measures	Undivided	4166	6	1	1,100	7	865	1	1305	3,556	8.5	106
	UJCM	268	59	28	1,320	10	2,055	10	451	3,994	8.0	31
	LJCM	299	22	11	540	4	559	8	528	1,867	8.2	25
	TCM	781	86	49	650	6	985	82	521	2,613	7.9	13
Hutton Sandstone		2,172	21	9	340	3	310	13	464	1,416	8.1	18
Precipice Sandstone		901	11	4	63	3	33	1	156	268	7.5	8
Bandanna Formation		543	3	1	843	6	646	1	1151	2732	8.5	96

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

Appendix C Make good process flow diagram for impacted bores

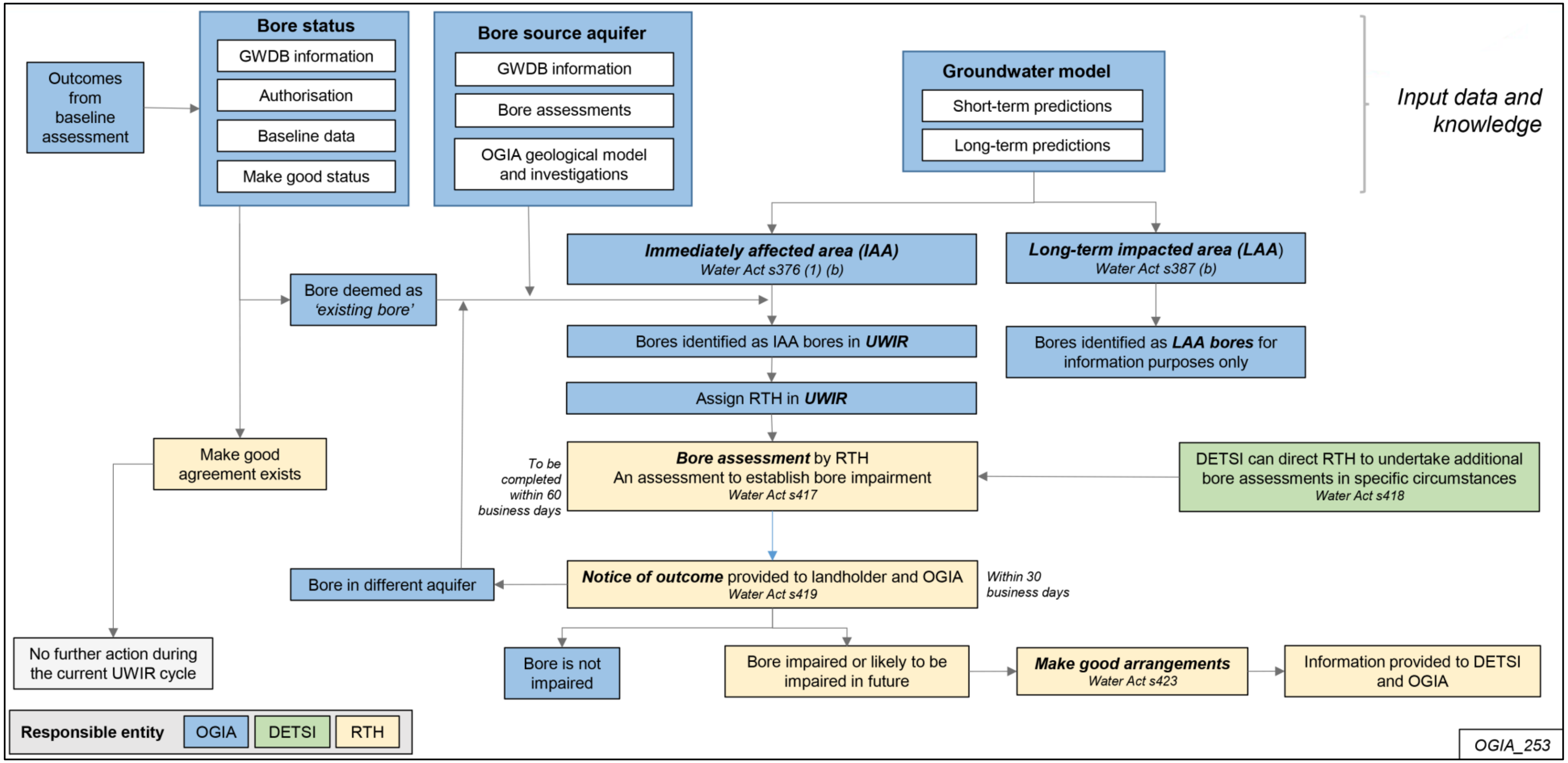

Figure C-1: Make good process flow diagram for impacted bores

Appendix D Spring impact assessment and management process flow diagram

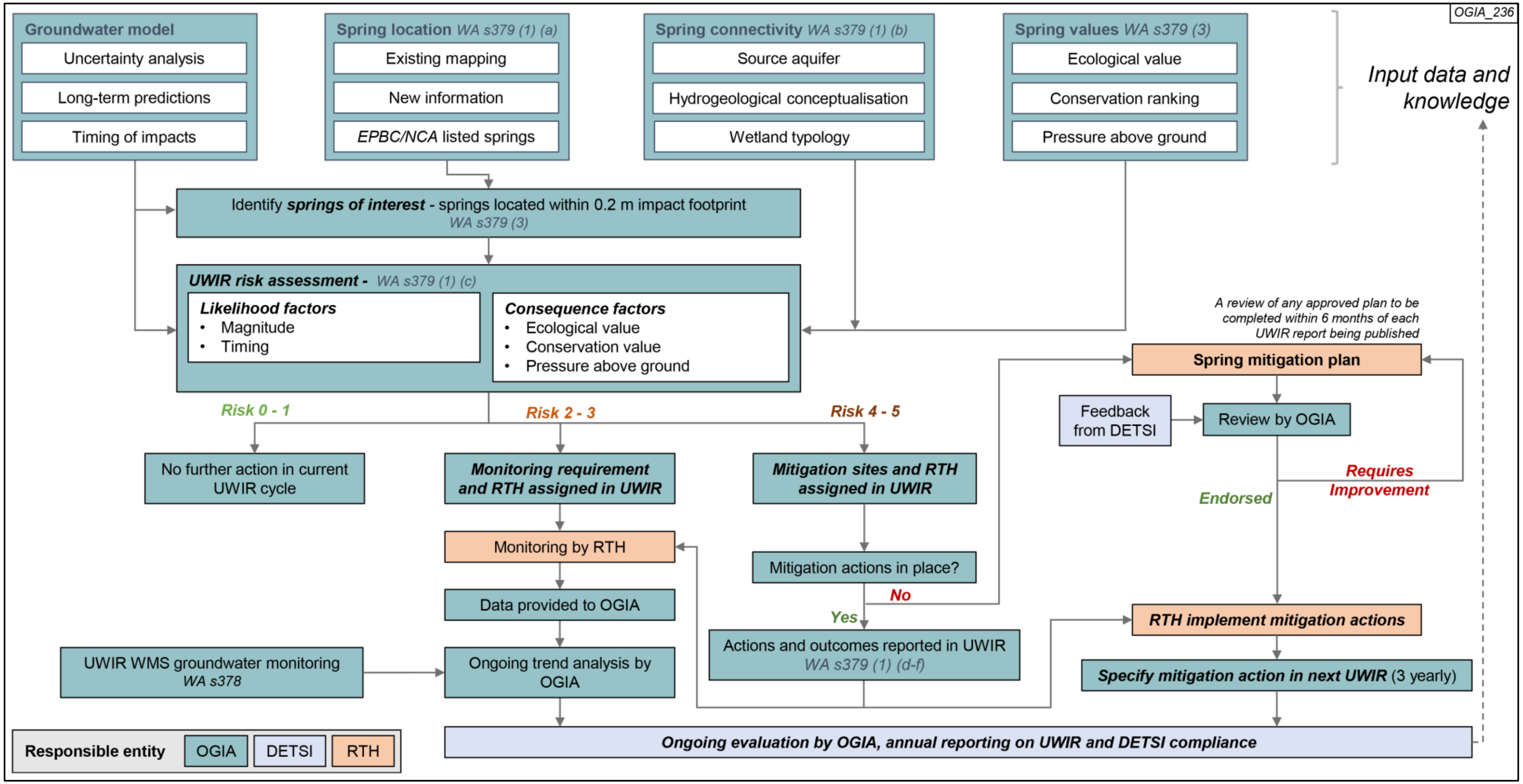

Figure D-1: Spring impact assessment and management process flow diagram

Appendix E Terrestrial groundwater-dependent ecosystem process flow diagram

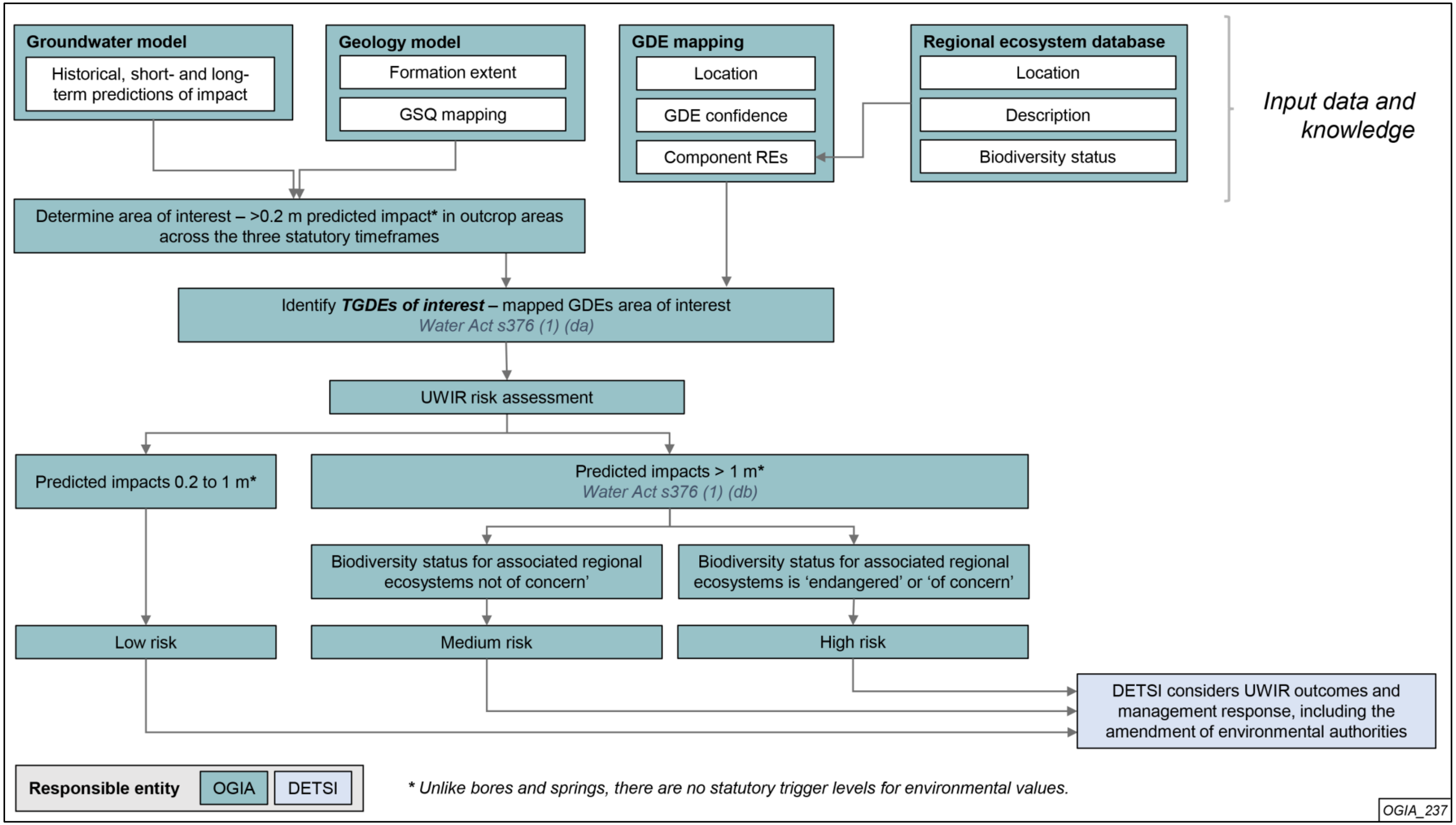

Figure E-1: Terrestrial groundwater-dependent ecosystem (TGDE) assessment flow diagram

Appendix F TGDE risk assessment – pre-2025 and short term

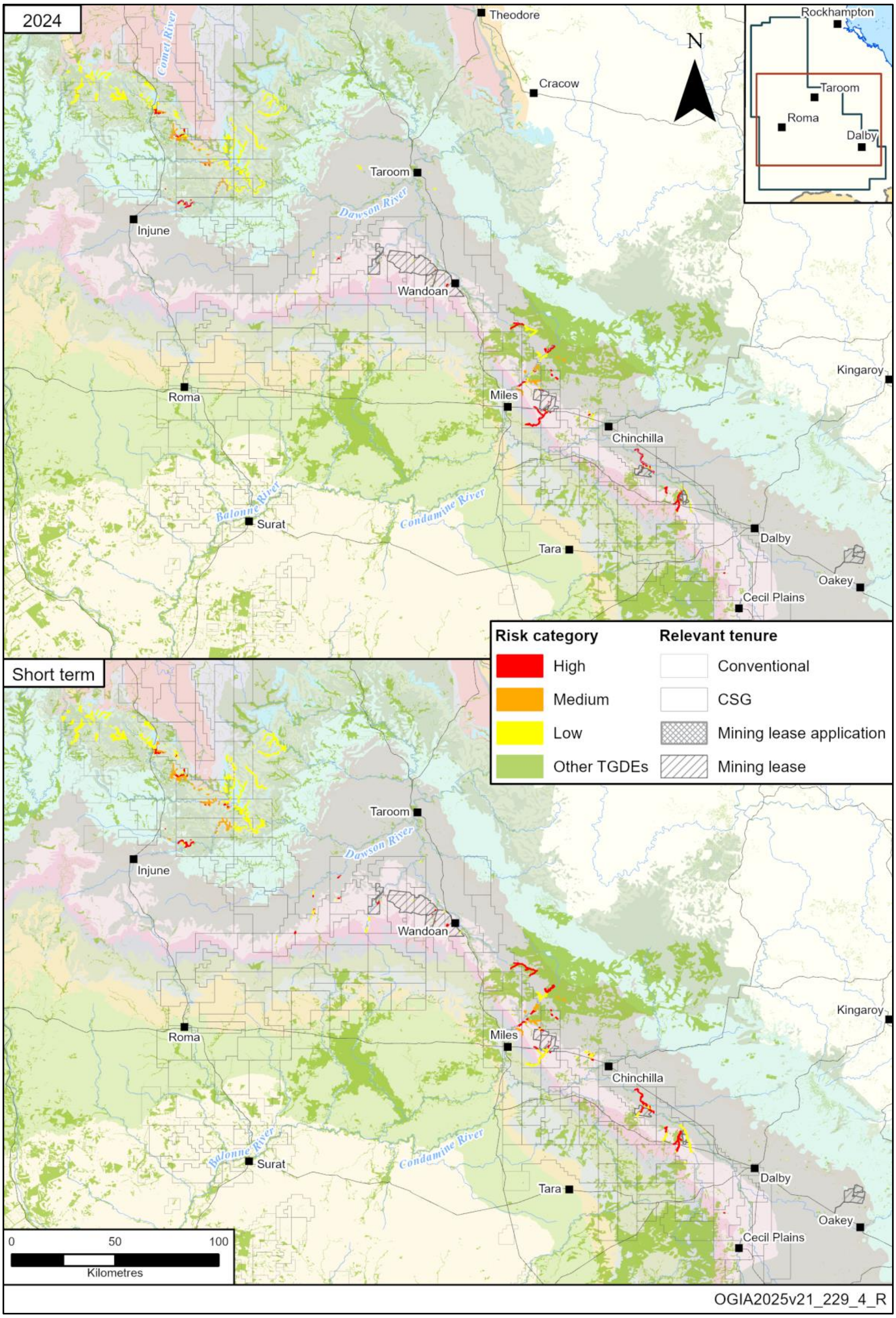

Figure F-1: TGDE location and risk assessment (pre-2025 and short-term)

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