Department of Natural Resources and Mines

Office of Groundwater Impact Assessment

Underground Water Impact Report for the Surat Cumulative Management Area

2016

Queensland
Government

This publication has been compiled by The Office of Groundwater Impact Assessment, Department of Natural Resources and Mines.

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Abbreviations

˚C	degrees Celsius
3D	three-dimensional
AETG	Aquatic Ecosystems Task Group
AGL	AGL Energy Ltd (including subsidiaries and joint venture partners)
Arrow	Arrow Energy Ltd (including subsidiaries and joint venture partners)
ATP	authority to prospect
CMA	cumulative management area
CSG	coal seam gas
DERM	Department of Environment and Resource Management (Queensland)
DNRM	Department of Natural Resources and Mines (Queensland)
EA	environmental authority
EHA	Environmental Hydrology Associates
EHP	Department of Environment and Heritage Protection (Queensland)
EIS	environmental impact statement
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
GAB	Great Artesian Basin
GWDB	DNRM’s groundwater database
IAA	Immediately Affected Area
KCB	Klohn Crippen Berger
km	kilometres
L	litres
L/s	litres per second
LAA	Long-term Affected Area
LNG	liquefied natural gas
m	metres

MERLIN	Mineral and Energy Resources Location and Information Network
mg/L	milligrams per litre
ML	megalitres
ML/year	megalitres per year
mm	millimetres
MNES	matters of national environmental significance
OGIA	Office of Groundwater Impact Assessment
Origin	Origin Energy Ltd (including subsidiaries and joint venture partners)
P&G	petroleum and gas
P&G Acts	*Petroleum and Gas (Production and Safety) Act 2004* and *Petroleum Act 1923*
PEST	Model-Independent Parameter Estimation and Uncertainty Analysis software
PL	petroleum lease
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)
the Range	the Great Dividing Range
S&D	stock and domestic
Santos	Santos Ltd (including subsidiaries and joint venture partners)
Senex	Senex Energy Ltd (including subsidiaries and joint venture partners)
SIMS	Spring Impact Management Strategy
USGS	United States Geological Survey
UWIR	underground water impact report
Water Act	*Water Act 2000*
WMA	water monitoring authority
WMS	Water Monitoring Strategy

Summary

Context for this report

The *Petroleum and Gas (Production and Safety) Act 2004* and *Petroleum Act 1923* authorises tenure holders to undertake activities related to the exploration for, and production of, petroleum and gas, including the right to take or interfere with groundwater. Those groundwater rights exist because water is found in association with petroleum and gas and it is not practicable to manage the water separately.

The *Water Act 2000* establishes responsibilities for petroleum tenure holders to monitor and manage the impacts caused by the exercise of these groundwater rights, including a responsibility to ‘make good’ impairment of private bore water supplies.

When water is extracted from a gas well, groundwater pressure declines in the area surrounding the well. If there are multiple gas fields adjacent to each other, the impacts of water extraction on groundwater pressures can overlap. In these situations, a cumulative approach is needed for the effective assessment and management of groundwater pressure impacts. In Queensland, where this situation exists, a Cumulative Management Area (CMA) can be established. Within a CMA the Office of Groundwater Impact Assessment (OGIA) is responsible for assessing impacts and establishing integrated management arrangements in an Underground Water Impact Report (UWIR).

- Petroleum and gas operators have the right to extract groundwater in the process of producing petroleum and gas because the water and the gas are intimately connected.
- The Surat Underground Water Impact Report forms part of the regulatory framework for managing the impacts of this groundwater extraction.

In the Surat and southern Bowen basins, a coal seam gas (CSG) industry is being developed which involves multiple adjacent projects. As a consequence, the Surat CMA was established in 2011 and the Surat UWIR 2012 was prepared. That report is now being updated to incorporate new knowledge.

Accordingly, the draft Surat UWIR 2016 was released for public consultation on 22 March 2016. The consultation draft was adjusted in response to issues raised during consultation before being submitted to the Chief Executive of the Department of Environment and Heritage Protection for approval. On approval, a UWIR becomes a statutory instrument under the Water Act 2000.

Current groundwater extraction

CSG production involves pumping water from coal formations to reduce the water pressure in the coal seams, releasing the gas that is attached to the coal. Gas is produced from the Walloon Coal Measures of the Surat Basin, and from the Bandanna Formation and Cattle Creek Formation of the southern Bowen Basin. These coal-bearing formations consist of many thin coal seams separated by low-permeability rock. The coal seams collectively make up a small proportion of the total thickness of the coal-bearing formations.

The Walloon Coal Measures is a geological layer of the Great Artesian Basin which comprises layers of lower-permeability rocks alternating with aquifers of high economic importance which also feed springs of high ecological and cultural importance.

The coal-bearing formations have variable potential for CSG production. Since 2012, the area of planned CSG development has contracted significantly as tenure holders improve their understanding of the resource.

- The area of planned CSG development has contracted significantly since 2012.

  (Figure 2-9)

Conventional gas production involves pumping gas from traps in porous rock such as sandstones. These operations are in a declining stage and there are no plans for expansion. Water extraction has decreased to about 1,000 megalitres per year.

Much more water is produced during CSG production in comparison to conventional operations. CSG water extraction has increased to about 65,000 megalitres per year.

Groundwater in the CMA is primarily used for consumptive purposes such as agriculture, industry, town supply, stock and domestic supply. The total amount extracted for these purposes is about 203,000 megalitres per year: 53,000 megalitres from the Great Artesian Basin, 144,000 megalitres from overlying alluvial and volcanic aquifers, and 6,000 megalitres from deeper Bowen Basin formations.

- Water extraction for coal seam production CSG production has increased to about 65,000 megalitres per year.

  (Figure 5-3)

Predicted water level impacts

Predictions of groundwater pressure reductions contained in the Surat UWIR 2012 have been revised using a new regional groundwater flow model which has been constructed using the latest data and modelling techniques.

When water is extracted from coal formations, the water from surrounding aquifers will tend to flow into the coal formations. The degree of connectivity between coal-bearing formations and surrounding aquifers determines the extent to which water extraction from the coal seams will affect groundwater pressure in surrounding aquifers.

Queensland’s regulatory framework requires that predicted water pressure impacts in aquifers be shown as ‘Immediately Affected Areas’ and ‘Long-term Affected Areas’. The model has been used to update the extent of those areas.

- The Long-term Affected Area for an aquifer is the area within which the impacts are predicted to exceed the trigger threshold at any time in the future.
- The Immediately Affected Area for an aquifer is the area within which water level impacts are predicted to exceed the trigger threshold within three years.
- The trigger thresholds are five metres for consolidated aquifers (such as sandstones) and two metres for unconsolidated aquifers (such as sand aquifers). A water level decline in a bore of more than the trigger threshold increases the risk of impairment of water supply from the bore.

Long–term Affected Areas

The extents of the Long-term Affected Areas have changed. For the Walloon Coal Measures, there is an overall contraction, although there is some expansion to the north-east. The change is due to the contraction of planned CSG development, improved knowledge about variations in the permeability of the coal seams and improved modelling methods. The affected area for the overlying Springbok Formation has contracted because vertical permeability is now understood to be lower than the estimates used in the 2012 assessment. The affected area of the underlying Hutton Formation has increased slightly as a result of the improved simulation of water pressures in the overlying coal formation. There are minor changes to other formations.

A Long-term Affected Area is not predicted for the Condamine Alluvium. The net loss of water from the alluvium is predicted to be 1,160 megalitres per year on average over a 100 year period; a slight increase over the 1,100 megalitres per year predicted in 2012.

- There have been changes to Long-term Affected Areas for aquifers because of contraction of planned CSG development and because of improved modelling. Overall there has been a reduction since 2012.
- For the Condamine Alluvium there is no significant change since 2012. A net loss of 1,160 megalitres per year out of the alluvium is predicted, but that will not cause water levels to fall by more than the trigger threshold.

(Figure 7-5)

In 2012 it was predicted that 528 bores would be affected and 59 of these have subsequently been decommissioned. The number of bores now predicted to be affected in the long term has changed. The change reflects not only the changes to the Long-term Affected Areas but also new information about water bores. Bore records have been reviewed and the source aquifers for many water bores better identified.

- 459 bores are now predicted to be affected by CSG water extraction in the long term. In addition, 59 bores have already been decommissioned.

(Table 7-2)

Immediately Affected Areas

The Immediately Affected Areas and the number of bores predicted to be affected in those areas has changed. The area and number will increase over time as the CSG industry progressively develops. There were 85 bores identified in 2012. Tenure holders were required to carry out bore assessments for these bores and, if necessary, enter into agreements with bore owners about measures to avoid impairment of bore water supply. Currently, 34 of those bores remain at some stage of that process, with the balance having been resolved to completion.

57 additional bores are now identified through updated modelling of current industry development plans.

- The extents of the predicted Immediately Affected Areas have increased in response to progressive industry development.
- 91 bores of the 459 bores are predicted to be affected by more than the trigger threshold of five metres within three years. This comprises 34 bores yet to be resolved from earlier assessments and 57 newly identified bores.

(Figure 7-4 and Table 7-1)

The amount of water extracted in the process of producing CSG depends on the permeability of the coal seams. Industry experience to date shows the coal seams being developed are producing less water than was expected when the industry commenced. The total water extraction over the life of the industry (1995 to 2070) is now estimated to be 3,570 gigalitres, the majority of which will be extracted over the period of peak production from 2014 to 2060.

Water Monitoring Strategy

The Surat UWIR 2012 specified a monitoring network of 618 monitoring points to be installed progressively by the end of 2016. This timing provided opportunity to review the design before the UWIR was updated. Of these 618, 491 are installed or under construction. The monitoring network requirements in UWIR 2016 are now being updated. The unfinished part of the earlier specification has been adjusted based on improved understanding of the groundwater flow system. Additional existing bores have also been incorporated into the network. When fully installed, the monitoring network will comprise 675 monitoring points. Petroleum tenure holders operate the monitoring network and report data to OGIA.

Water pressures are declining in the coal formations in areas of development. However, at this time, there is no significant departure from background trends in other formations; this is in line with expectations at this early stage of industry development.

- Although water pressures are declining in the coal formations, there is no significant departure from background trends in other formations at this early stage of development.

  (Chapter 6)

Spring Impact Management Strategy

Springs with significant cultural and ecological values, fed by Great Artesian Basin aquifers, exist in the Surat CMA. The UWIR includes a Spring Impact Management Strategy.

Recent OGIA research has improved understanding of the connection of springs to source aquifers. Current modelling provides updated predictions of water pressure declines in source aquifers. There are four sites that could potentially experience impact in the source aquifer for the spring in the long term. Investigations will continue at those sites.

Natural spring dynamics are complex. Monitoring at representative sites will continue to ensure that any future impact from CSG water extraction is correctly identified.

- Investigations will continue at four sites where pressure reduction in the source aquifer could occur in the long term. Spring monitoring will continue.

  (Section 9.6)

Responsible tenure holders

The *Water Act 2000* establishes obligations for petroleum tenure holders to ‘make good’ impairment of private bore supplies that result from CSG water extraction. This action might be achieved by making alterations to the bore, by establishing a replacement water supply or by some other measure. However, within the CMA, operations by multiple tenure holders can contribute to the impairment. The UWIR 2012 established arrangements for identification of an individual petroleum tenure holder as the responsible tenure holder for these obligations. Responsibilities are also assigned to individual petroleum tenure holders to carry out parts of the integrated water monitoring strategy. The arrangements established in UWIR 2012 will continue.

- Arrangements established in 2012 for the assignment of responsibilities to individual petroleum tenure holders will continue.

Reporting and review

In accordance with Queensland's regulatory framework, OGIA will prepare annual reports on the implementation of the UWIR 2016. These reports will summarise monitoring results and assess if there is any new information that would indicate a significant change to predicted impacts.

OGIA will continue to undertake research to build new knowledge to support future revision of the UWIR 2016. Collaboration will continue with research bodies, universities and petroleum tenure holders to achieve the best outcomes in an efficient manner.

- OGIA will report annually, continue to undertake and promote research to improve knowledge, and update the model and UWIR 2016 to incorporate new knowledge.

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1 Introduction

1.1 Water rights of petroleum tenure holders

Petroleum is a legislative term that includes oil, conventional gas and coal seam gas (CSG). However, the general term ‘petroleum and gas’ is often used to refer to both liquid petroleum and gaseous petroleum.

The *Petroleum and Gas (Production and Safety) Act 2004* and the *Petroleum Act 1923* (collectively referred to here as the P&G Acts) authorise petroleum tenure holders to undertake activities related to petroleum exploration and production. This authorisation also affords them the right to take or interfere with groundwater. However, the *Water Act 2000* (Water Act) establishes responsibilities for petroleum tenure holders to monitor and manage the impacts caused by exercising of their water rights, including a responsibility to ‘make good’ any impairment of private bore water supplies. These provisions exist because it is not practicable to produce petroleum without also extracting groundwater.

1.2 Managing the cumulative impacts of adjacent CSG wells

When water is extracted from a CSG well, groundwater pressure falls in the area surrounding the well. Where a well field has been established, the fall in pressure extends laterally, beyond the extent of the well field. If there are multiple adjacent well fields, the fall in pressure caused by extracting water from the individual fields overlaps, resulting in an even greater cumulative fall in pressure. In this situation, assessing and managing water levels requires an approach that looks at the cumulative impacts.

Under the Queensland regulatory framework, an area of concentrated development, where impacts on water pressure in aquifers are likely to be overlapping from multiple petroleum operations, can be declared a cumulative management area (CMA). In these areas, the Office of Groundwater Impact Assessment (OGIA) is responsible for:

- predicting the regional impacts on water pressures in aquifers
- developing water monitoring and spring management strategies
- assigning responsibility to individual petroleum tenure holders for implementing specific parts of these strategies.

The regulatory framework provides that OGIA set out these predictions, strategies and responsibilities in an underground water impact report (UWIR).

Established in 2011, the Surat CMA covers the area of current and planned CSG development in the Surat Basin and the southern Bowen Basin. The extent of the Surat CMA is shown in Figure 1-1. The first Surat UWIR was prepared in 2012. This report, the Surat UWIR 2016, is an update of the UWIR 2012.

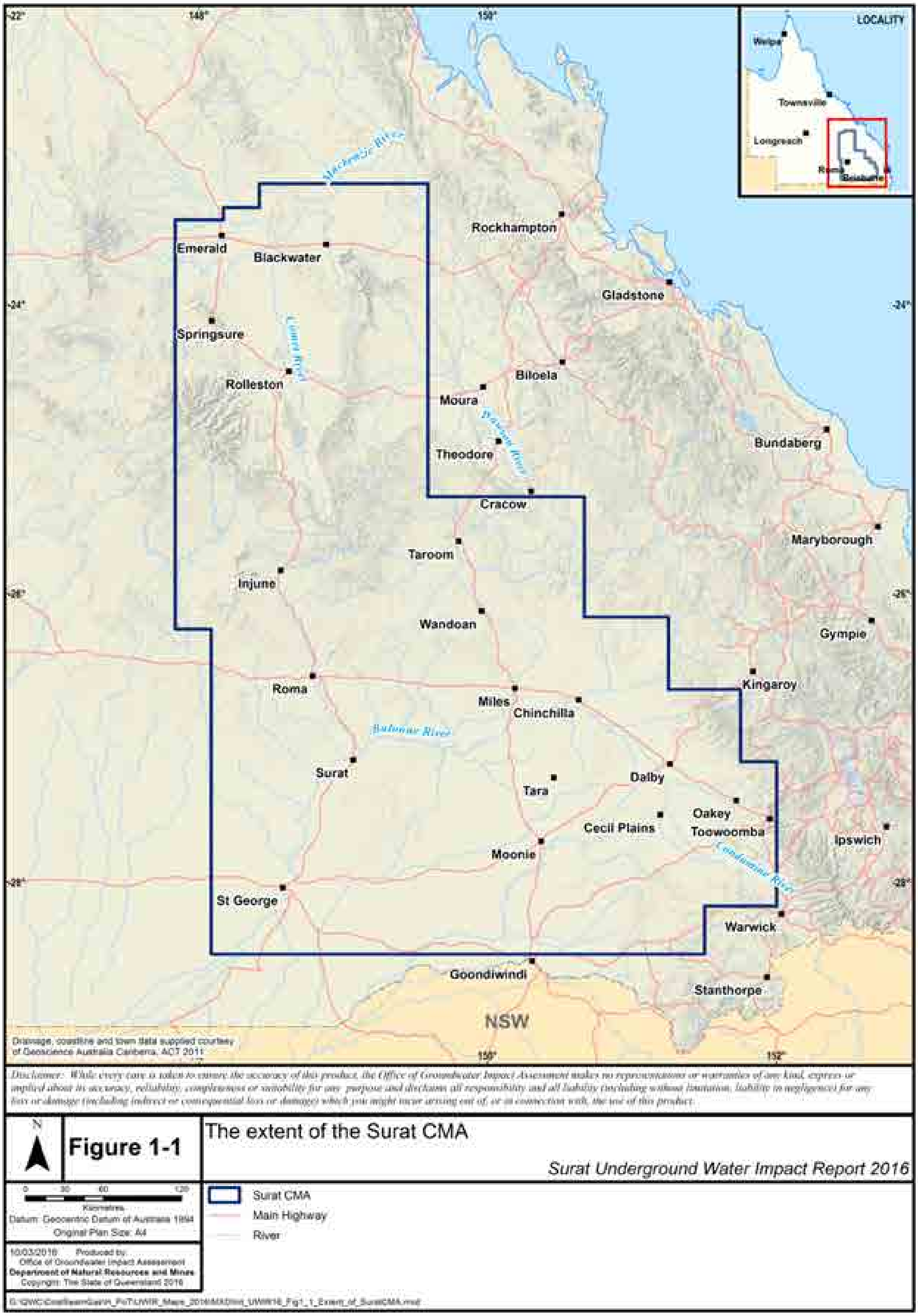

Figure 1-1 The extent of the Surat CMA

1.3 The Surat Underground Water Impact Report

Since the UWIR 2012 was prepared, OGIA has carried out technical studies of the nature of the groundwater flow system. Existing geological, geophysical and hydrogeological records have been reviewed in detail and new data has become available. Connectivity between formations has been assessed. New groundwater flow modelling techniques have been developed to better represent groundwater movement in coal formations that exist within a multilayered regional groundwater system. Water bore records have been reviewed to learn more about the aquifers from which the bores source water. A new groundwater flow model has been developed and has been used to prepare this report.

Chapters 2–6 provide the contextual background for this report. Chapter 2 provides an overview of petroleum and gas tenures and associated activities in the Surat CMA. Chapters 3 and 4 summarise the landscape, climate, land use, geology and hydrogeology of the area. Chapter 5 summarises historical and current groundwater extraction. Chapter 6 summarises water pressure trends in the area.

Chapter 7 describes the techniques and methods used for predicting groundwater impacts, and important aspects of the construction of the new regional groundwater flow model. Maps show the areas where impacts on water pressures are predicted to exceed statutory trigger thresholds in both the short and long term.

Chapter 8 specifies the water monitoring strategy, which is the regional network of monitoring points used for assessing water pressure trends. It describes the adjustments to the original specifications and sets out the requirements for reporting data to OGIA.

Chapter 9 specifies the strategy for managing impacts on springs in the area. It explains the work done to better understand the risk to springs and it specifies spring management actions to be implemented by petroleum tenure holders.

Chapter 10 assigns responsibilities to individual petroleum tenure holders. The Water Act specifies the circumstances under which petroleum tenure holders need to investigate impairment of private bore supplies and develop ‘make good’ agreements with bore owners about the impairment. The chapter specifies how the petroleum tenure holder responsible for fulfilling those obligations is identified. It also specifies the petroleum tenure holders responsible for specified parts of the water monitoring and spring impact management strategies.

Chapter 11 describes the reporting of the actions required under the UWIR.

2 Petroleum and gas production

- The area of planned CSG development has contracted since 2012 as productive areas become more clearly defined.

This chapter provides an overview of how petroleum and gas is produced. It also shows the areas where development exists or is planned within the Surat CMA. This information has been used to develop an industry development scenario, for input to the regional groundwater flow model to assess the long-term and short-term impacts of CSG development on groundwater.

In this report, the term ‘petroleum and gas’ is used to collectively refer to conventional petroleum and gas, as well as CSG.

2.1 Petroleum and gas production and methods

Historically, petroleum and gas have been extracted from reservoirs in highly porous rock formations, such as sandstone, using conventional production methods. More recently, new (or unconventional) production methods have been developed to extract gas from other reservoirs, including coal seams and low porosity rock formations, such as shale. Gas produced by conventional methods is referred to as ‘conventional gas’, while gas produced from coal seams and shale is collectively referred to as ‘unconventional gas’. In the Surat CMA, both conventional and unconventional gas is produced, the unconventional gas being CSG. There is no emerging plan for the development of shale gas in the Surat CMA.

The volume of water extracted during the development of conventional gas reserves is much less than the volume of water extracted during production of CSG. In CSG development areas, the gas resource is distributed over a relatively large area and to enable the gas to flow towards the production well, water pressure in the coal seam has to be significantly reduced ('depressurisation' of the coal seam). Water extraction peaks early in the life of a CSG production well. The amount of water extracted can vary substantially between gas fields. These differences are discussed in more detail in the following sections.

2.1.1 Conventional petroleum and gas

Conventional petroleum and gas is found in porous rock formations such as sandstone. Gas and other petroleum products that form over a long geological timeframe move through porous rock, in a generally upward direction, until a trap stops the movement and concentrates the hydrocarbons. The trap could be dome-shaped at the boundary between the permeable formation and the overlying impermeable formation, or it could be a faulted structure in the rock, which has the same effect. As the gas concentrates, the porous rock becomes a gas reservoir. Gas is produced by drilling a well into the reservoir. As there tends to be water in the reservoir, under the gas, the production well usually also returns a quantity of water.

Extracting petroleum and gas from conventional reservoirs requires a relatively small number of production wells, compared to CSG reservoirs, because the gas tends to be localised and can move relatively easily though the porous rock towards the well. Although water is extracted along with the gas, there is no need to lower water pressure over large areas to produce the gas. The volume of water extracted varies, but it is generally much less than for CSG. As the petroleum and gas reserves are depleted, the ratio of water extracted to the petroleum gas produced increases, as shown in Figure 2-1.

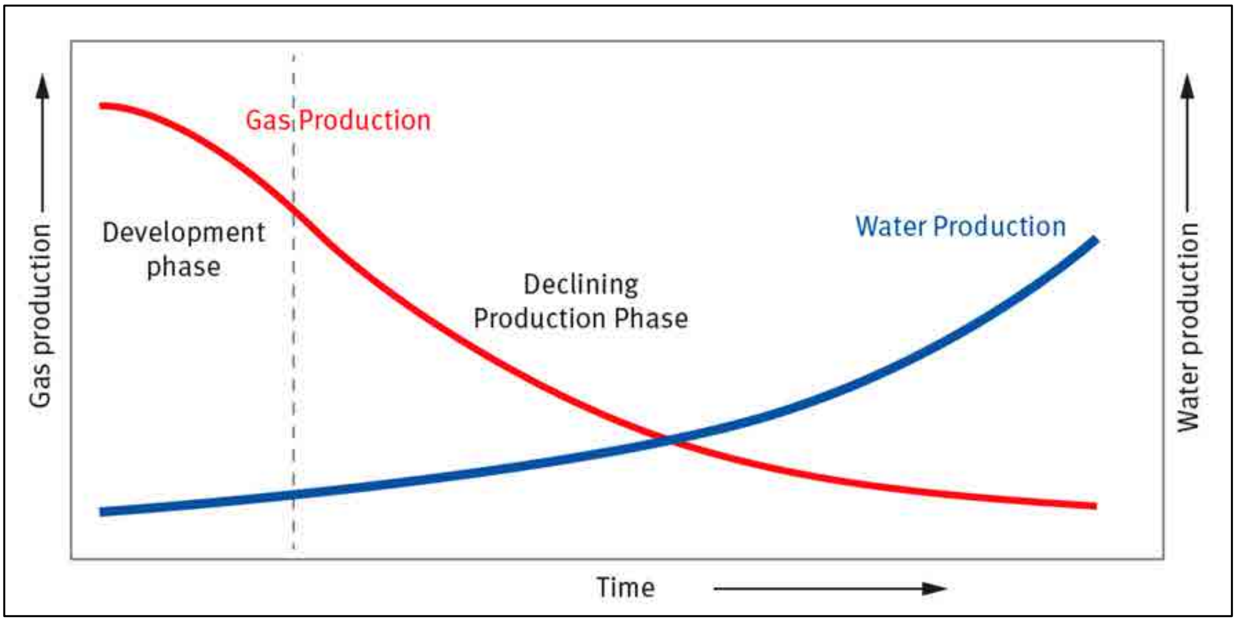

Figure 2-1 Typical gas and water flow in conventional petroleum and gas production

2.1.2 Coal seam gas

CSG which is comprised mostly of methane, is attached to the surface of coal particles, along fractures and cleats, and is held in place by water pressure. The coal is then both the source and the reservoir for the gas.

The gas is extracted by drilling a well into the coal formation and pumping water from the well to depressurise the formation. Initially, just water is extracted, but as the pressure drops, the ratio of gas to water slowly increases.

Figure 2-2 shows a diagram of a typical CSG well. When water and gas flow together toward a gas well, this is known as 'dual phase flow' (Morad et al. 2008). To produce gas, the water pressure in the well is reduced to between 35 and 120 psi, which is equivalent to 25–80 metres head of water. The volume of water that needs to be pumped to achieve the pressure reduction varies from well to well, and is highly dependent on the geology intersected by the well. Once the desired pressure has been reached, pumping continues at the rate necessary to maintain the pressure until gas production becomes uneconomical. The relationship between gas production and water extraction over time is shown in Figure 2-3.

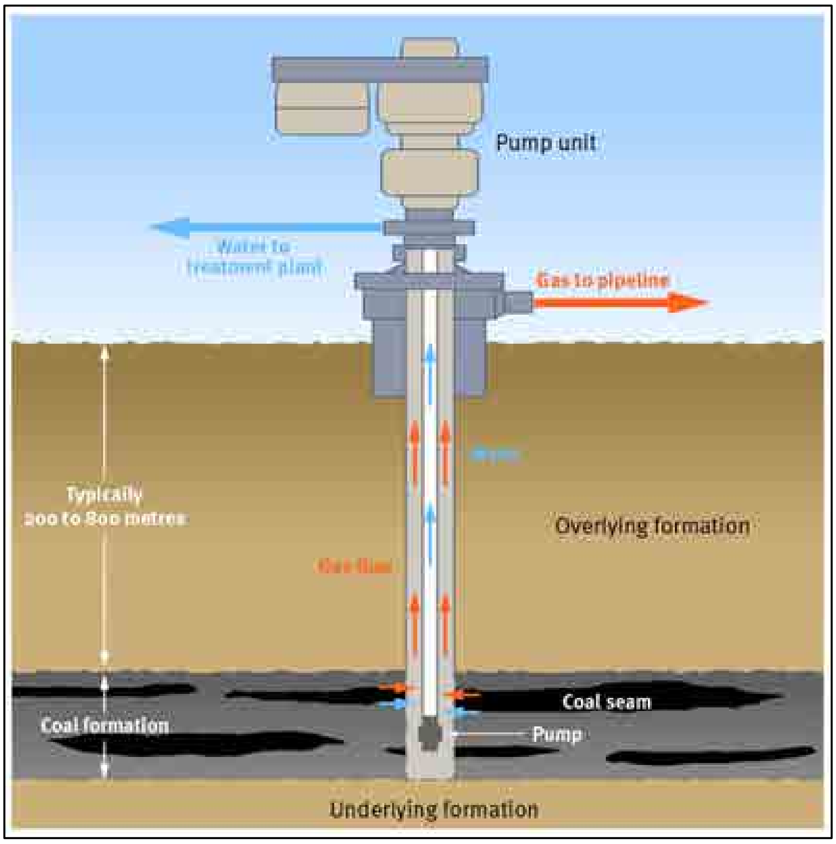

Figure 2-2 A typical coal seam gas well

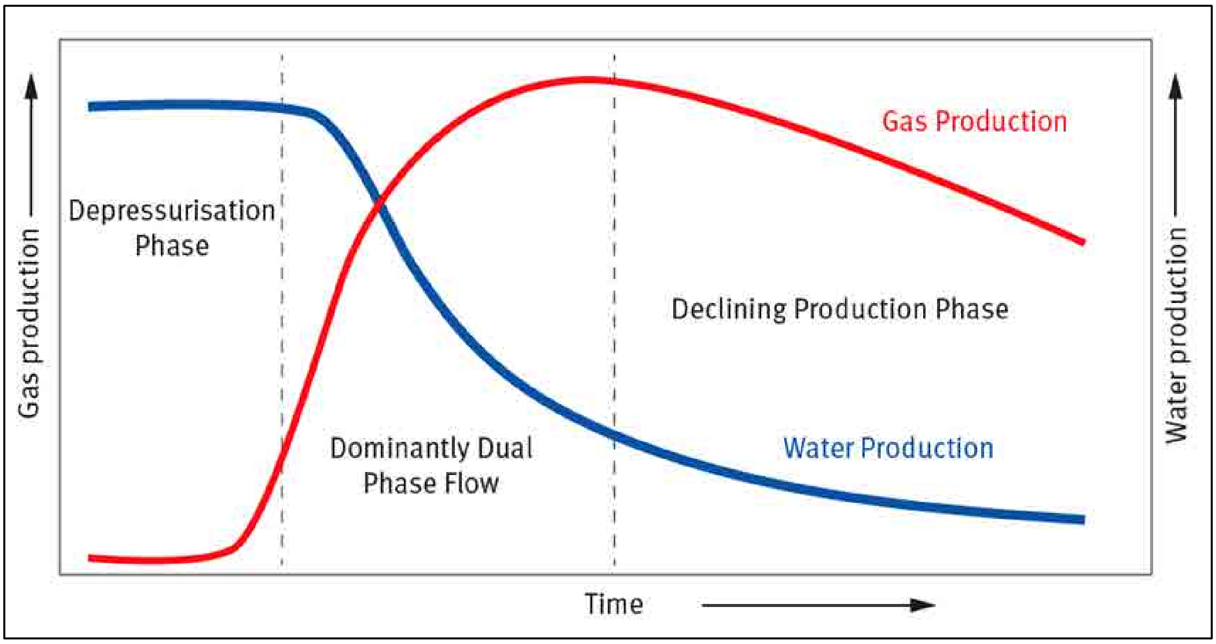

Figure 2-3 Typical gas and water flow in coal seam gas production

2.2 Types of tenures and authorities

2.2.1 Petroleum tenures

The P&G Acts specify authorities that can be granted for activities related to petroleum and gas exploration and production. The two authorities of relevance to this report are those that provide the holders with the right to take or interfere with groundwater during the course of carrying out authorised activities which are:

- an authority to prospect (ATP)
- an authority to operate a petroleum lease (PL).

The P&G Acts refer to ATPs and PLs collectively as petroleum tenures. There is no distinction between a petroleum tenure that supports conventional petroleum and gas production and a petroleum tenure that supports CSG exploration and development. However, the use of the tenure is usually constrained by the environmental authorities granted under Queensland's *Environmental Protection Act 1994* or the development plans for the tenure approved under the P&G Acts. Petroleum tenures relate to specific areas of land which are generally described in terms of blocks and sub-blocks. Each block is about 75 square kilometres and each sub-block is about three square kilometres.

An ATP gives the holder the right to explore (or prospect) for petroleum resources. That right includes:

- drilling test wells to evaluate or test natural underground reservoirs for petroleum resources
- carrying out test production
- taking groundwater in the course of carrying out these activities.

The holder of an ATP may apply for a PL if a commercially viable petroleum resource is discovered. The application must be accompanied by an initial development plan that details the nature and extent of the proposed activities.

A PL authorises the holder to:

- carry out production testing
- produce petroleum within the tenure area
- take groundwater in the course of carrying out these activities.

A PL can be granted for up to 30 years, with potential for renewal. Water extraction must be reported to the Department of Natural Resources and Mines (DNRM). Tenure holders may relinquish all or a part of a tenure at any time.

The entity or entities that hold petroleum tenures are referred to as petroleum tenure holders. An entity may be an individual person, an entity under the *Corporations (Queensland) Act 1990*, or a government-owned corporation. As tenures are often held as joint ventures, DNRM assigns a single entity as the 'authorised holder' when it grants an ATP or PL. The term ‘authorised holder’ replaces the earlier term ‘principal holder’. The authorised holder is the primary contact for the petroleum tenure and is legally responsible for dealing with served notices and other documents. All obligations established for a petroleum tenure holder under this report are obligations of the authorised holder.

DNRM records all mining and petroleum tenure information in the MyMinesOnline system. General petroleum tenure holder information stored in this database is publicly accessible. Information about petroleum wells (test and production) and water production is recorded in the Queensland Digital Exploration

Reports System (QDEX Reports) managed by the Geological Survey of Queensland. Most of this information is publicly available.

2.2.2 Environmental authorities

The P&G Acts provide that a petroleum tenure cannot be granted unless an environmental authority (EA) has been issued under the *Environmental Protection Act 1994* (Queensland). An EA can apply to multiple petroleum tenures. In relation to water, the EA primarily deals with the management of surface water and contamination issues relating to surface and groundwater. Specifics of tenure holders' obligations to manage groundwater impacts associated with exercising their underground water rights are established in the Water Act, as discussed in Chapter 1.

A prospective PL holder is required to develop an environmental management plan to support an application for an EA. An environmental management plan identifies the environmental values, potential impacts and actions to protect environmental values. Depending on the proposed scale of operations, major projects are also required to prepare environmental impact statements (EIS) in support of their environmental management plans. To improve certainty, a proponent may elect to prepare an EIS even though the scale of the project is not large enough to mandate this requirement.

The *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act) identifies matters of national environmental significance (MNES), which are protected. Included are a number of springs in the Surat CMA. If a project is likely to have a significant impact on any of these springs, a federal environmental approval under the EPBC Act is also required.

In mid-2013, the EPBC Act was amended to include potential impacts to water resources by CSG and large coal mining developments as an MNES. A bilateral agreement between the Queensland Government and the Australian Government has been implemented to coordinate the approval processes. This agreement provides for the state and federal approval agencies to seek advice from an independent expert scientific committee established by the Australian Government.

2.2.3 Water monitoring authorities

Petroleum tenure holders can have obligations to carry out activities such as monitoring on lands other than those over which they hold tenure. For example, the Water Monitoring Strategy (Chapter 8) specifies monitoring activities for individual tenure holders in areas outside the tenure areas.

To deal with these situations, the P&G Acts provide that a petroleum tenure holder can apply for a water monitoring authority (WMA). A WMA allows the holder to carry out water monitoring activities in the area to which the WMA relates, which can be land outside the tenure. A WMA ends when the petroleum tenure to which it relates becomes non-current.

2.3 Petroleum tenures in the Surat CMA

The locations of relevant petroleum and gas tenures in the Surat CMA are shown in Figure 2-4. For the purpose of this report, the term 'relevant petroleum and gas tenures' comprises the following CSG tenures and conventional petroleum and gas tenures:

- **CSG tenures** include PLs and ATPs on which CSG production infrastructure exists or is proposed. These CSG tenures have been identified from DNRM datasets, current development plans provided by CSG companies, and current and completed EISs. Excluded are tenures that were originally identified in EISs but which have subsequently been relinquished.

- **Conventional petroleum and gas tenures** are tenures on which conventional petroleum and gas operations exist. No new conventional operations are planned.

As shown in Figure 2-4, most of the relevant tenure in the Surat CMA is held by the following six entities:

- Santos, its subsidiaries and joint venture partners (collectively referred to as 'Santos' in this report).
- Origin Energy, its subsidiaries and joint venture partners, including Australia Pacific LNG (collectively referred to as 'Origin' in this report).
- Queensland Gas Company, its subsidiaries and joint venture partners (collectively referred to as 'QGC' in this report).
- Arrow Energy, its subsidiaries and joint venture partners (collectively referred to as ‘Arrow’ in this report).
- Senex Energy Limited, its subsidiaries and joint venture partners (collectively referred to as ‘Senex’ in this report).
- AGL Energy Limited, its subsidiaries and joint venture partners (collectively referred to as AGL in this report).

Major changes to tenure holdings since the UWIR 2012 include an increase in tenure held by Santos in the area south of Blackwater and around Roma and Taroom. The majority of this additional area forms part of the Santos GLNG Gas Field Development Project. The Coordinator General’s evaluation report for the GLNG Gas Field Development Project EIS was signed on 3 December 2015, concluding the EIS process. Also, Senex Energy has acquired tenure to the north-east of Roma which will form part of its Western Surat Gas Project. The necessary approvals are being progressed with production from this area planned from 2018. Arrow has also added tenure towards the northern boundary of the CMA around Blackwater. This area forms part of the Bowen Gas Project, the major part of which exists outside the CMA in the northern Bowen Basin. The EIS for this project was approved in September 2014. Elsewhere within the CMA, Arrow has recently relinquished tenure, resulting in a contraction of its holdings in the area around Chinchilla, Dalby and Cecil Plains.

2.4 Production areas in the Surat CMA

Not all of the CSG tenure area shown in Figure 2-4 will necessarily be developed. Much of the area for which an ATP has been granted may never progress to a PL. Even where a PL is granted, production wells may only be established on a portion of the tenure area. The area from which CSG will eventually be produced is therefore expected to be significantly smaller than the area of tenure shown in Figure 2-4. To clarify the outlook for development, OGIA has used information obtained from DNRM about existing petroleum and gas production, and information from petroleum tenure holders about current plans for the growth and sequencing of future production, to divide the area of CSG tenures shown in Figure 2-4 into five categories as follows:

- Current CSG production area – land on which CSG production was occurring at the beginning of 2015.
- Planned CSG production area – land on which petroleum tenure holders have advised they plan to develop.

- Potential CSG production area – land on which petroleum tenure holders have advised they are not expecting to develop but which they may develop in the future depending on a range of economic and technical factors.
- Active conventional petroleum and gas production area – land on which conventional petroleum and gas operations are extracting water from the geological formations of the GAB.
- Inactive conventional petroleum and gas production area – land on which conventional petroleum and gas is no longer active.

Figure 2-5 shows the extent of these areas and the location of gas fields within current or planned development areas. Figure 2-6 shows tenures which will be at least partly developed. Further detail is provided in the sections below.

A comprehensive list of the petroleum tenures that support the current, planned and potential CSG production areas, and the holders of those tenures, is provided in Appendix A-1.

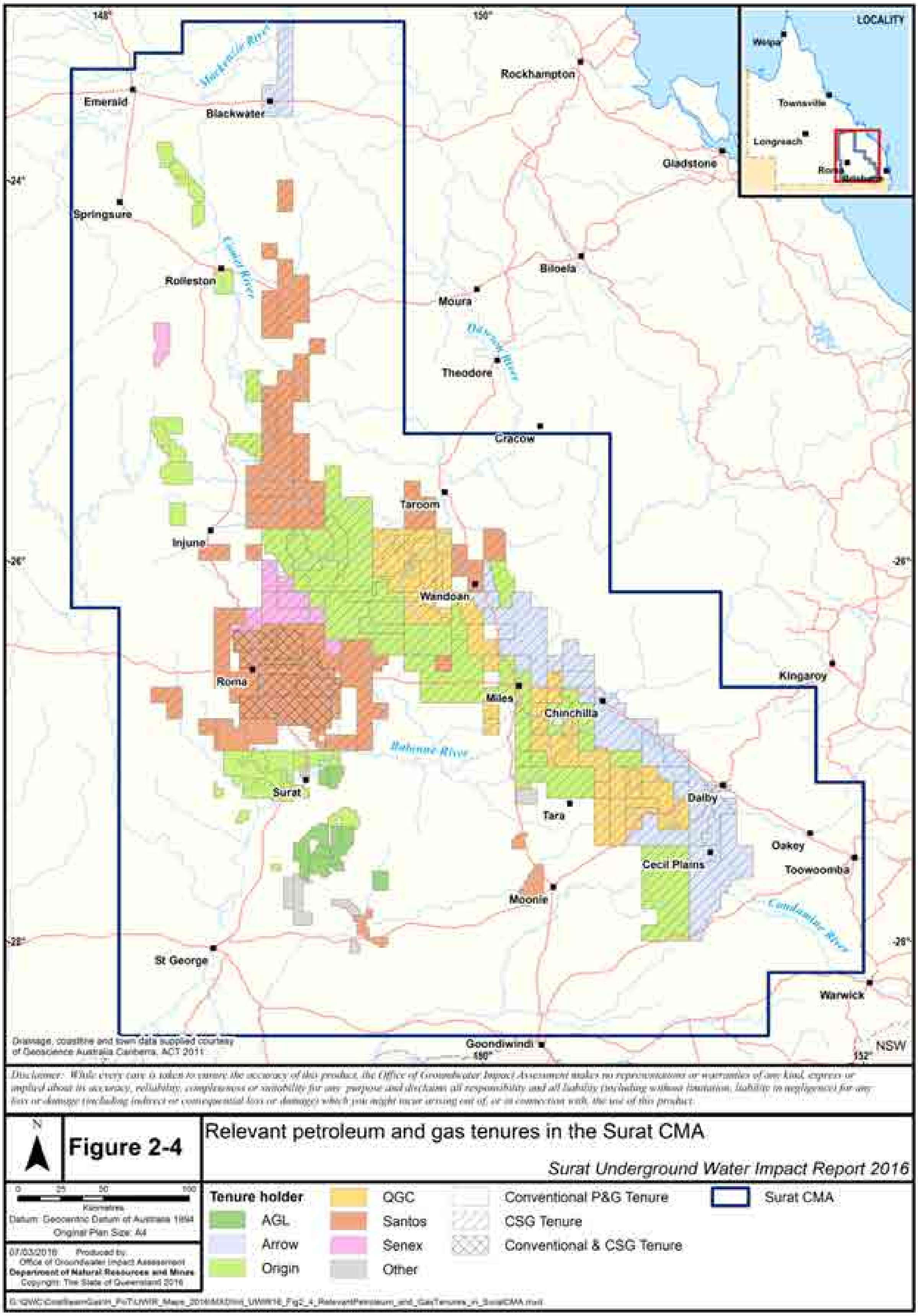

Figure 2-4 Relevant petroleum and gas tenures in the Surat CMA

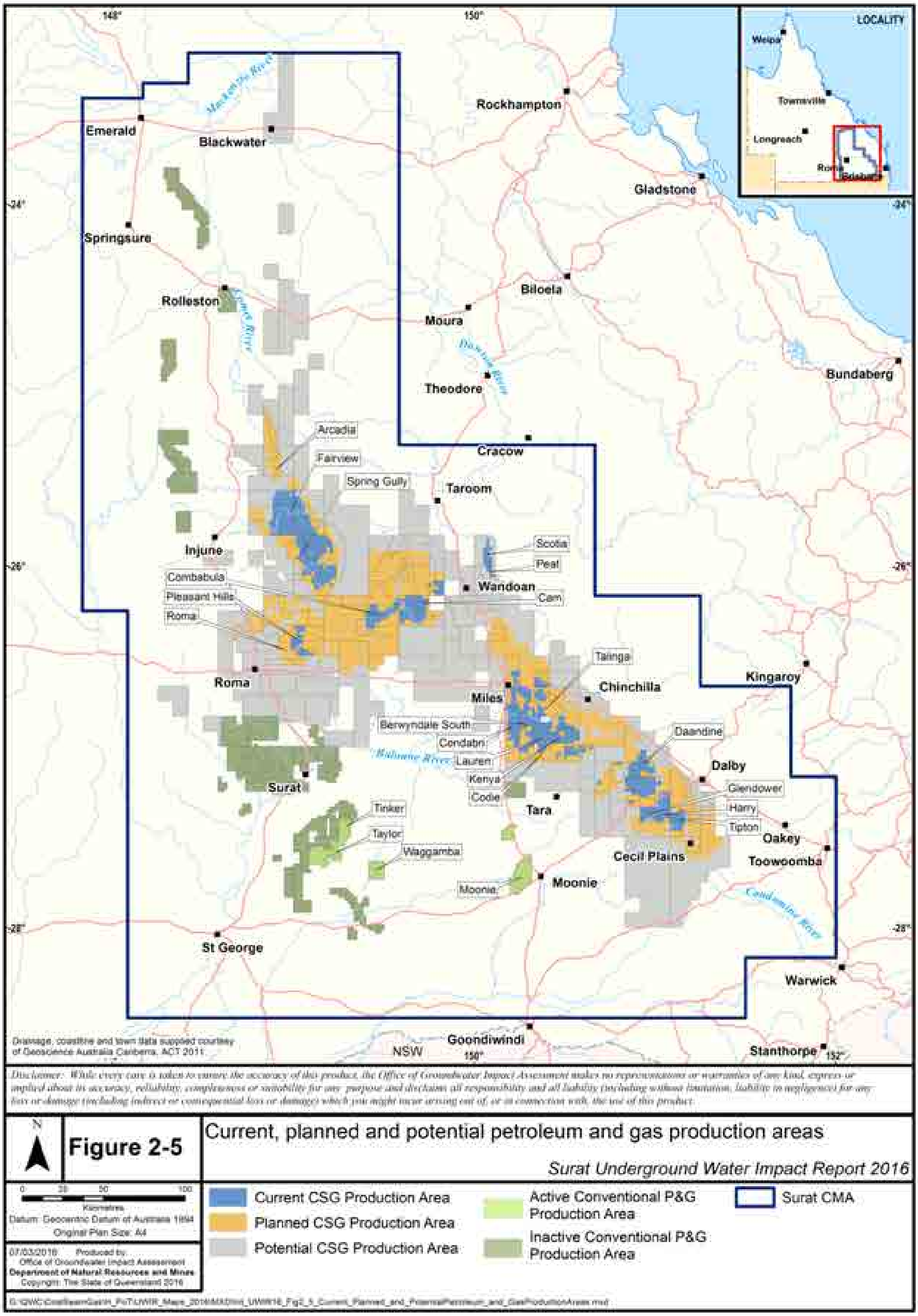

Figure 2-5 Current, planned and potential petroleum and gas production areas

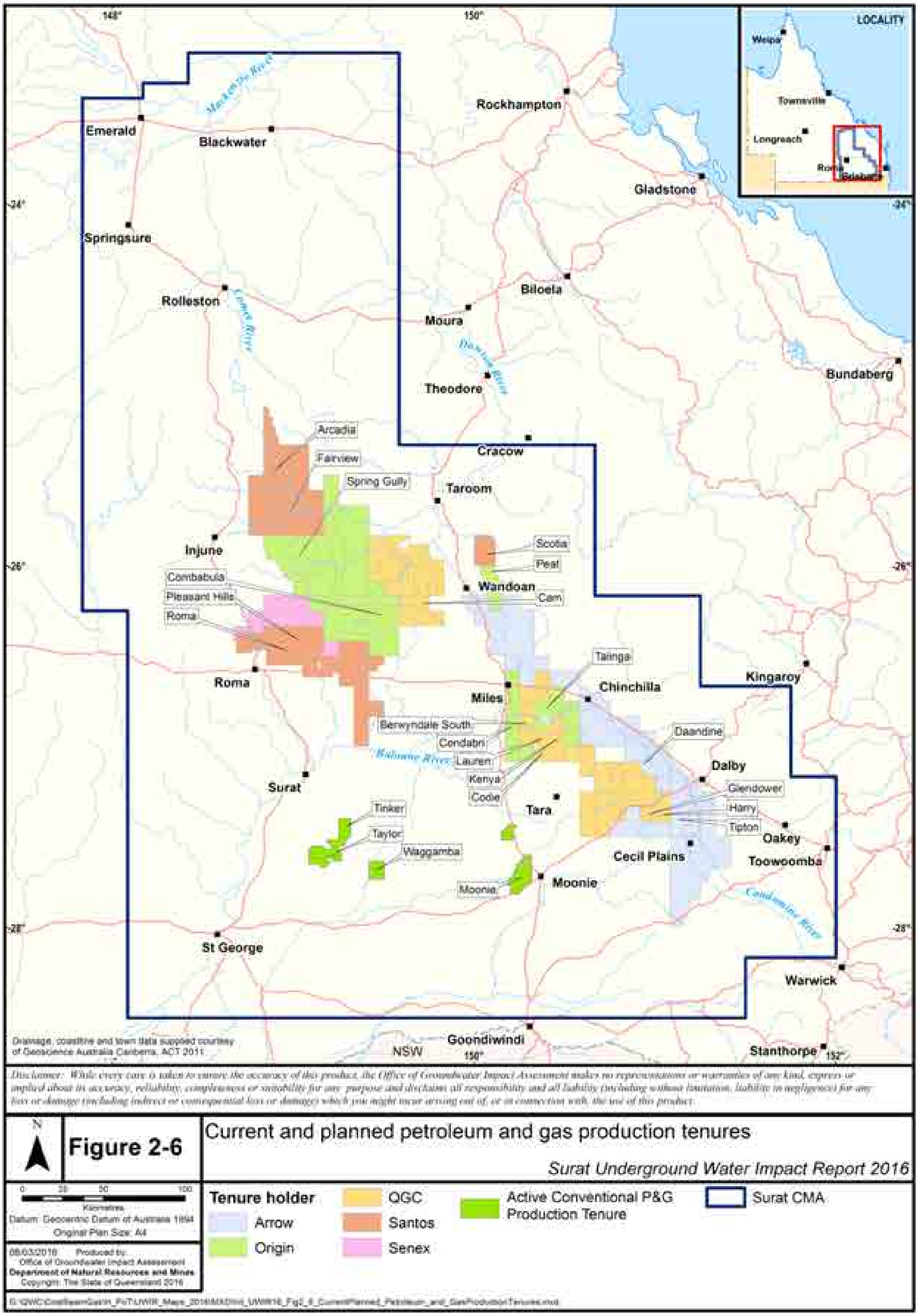

Figure 2-6 Current and planned petroleum and gas tenures

2.4.1 Existing coal seam gas production areas

The current CSG production area in the Surat CMA is shown in Figure 2-5. The recent growth in CSG wells and gas production in the area is shown in Figure 2-7 and Figure 2-8. As at January 2016, approximately 6,500 CSG wells had been constructed in the Surat CMA (Queensland Spatial Catalogue, QSpatial). However, in addition to production wells, this total includes exploration and test wells both inside and outside of the current or planned production areas.

Detailed information provided to OGIA by tenure holders shows that about 5,600 CSG production wells had been constructed in the Surat CMA as at January 2015 (4,600 in the Surat Basin and 1,000 in the southern Bowen Basin). This is a significant increase on the 2,100 wells (1,500 in the Surat Basin and 600 in the southern Bowen Basin) which existed when the UWIR 2012 was prepared. The increase reflects the build-up to the commissioning of the liquefied natural gas (LNG) plants in Gladstone in late 2014. Growth has been greater in the Surat Basin than in the southern Bowen Basin.

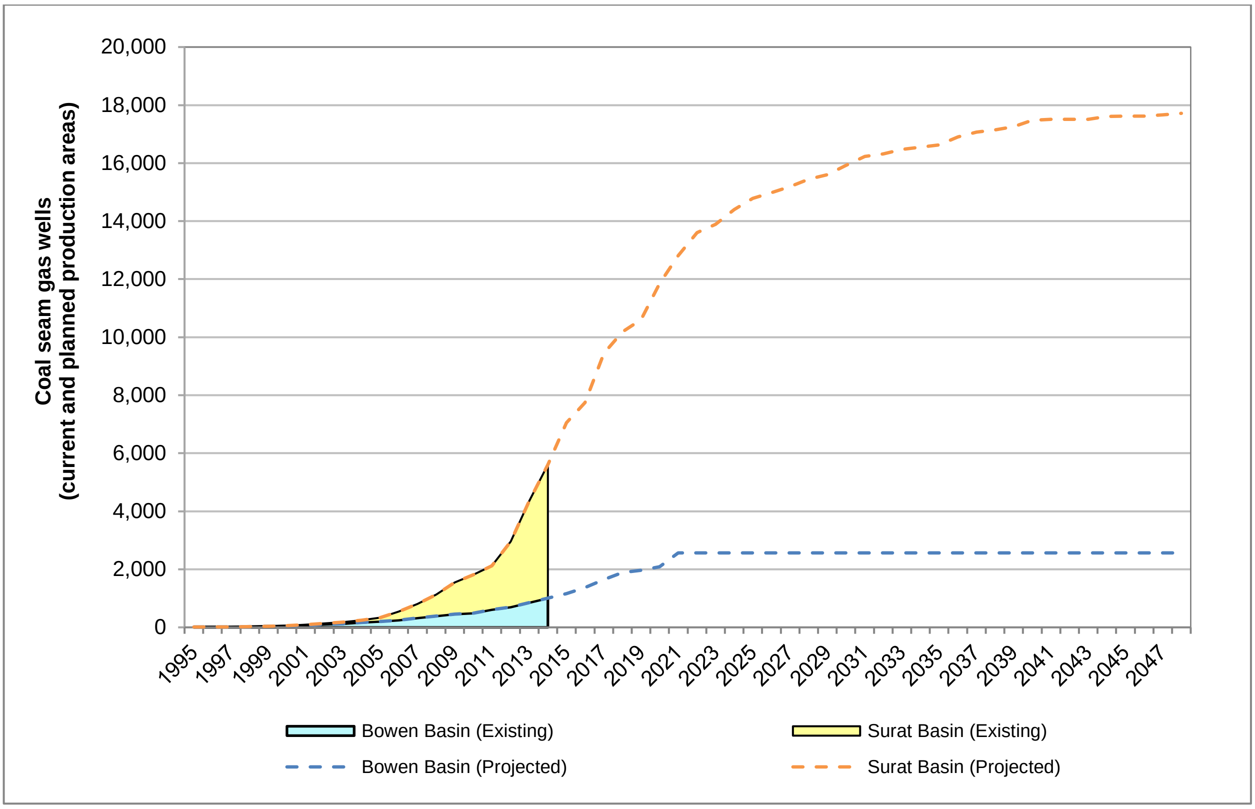

Figure 2-7 Existing and projected future CSG wells in current and planned production areas

Since the UWIR 2012 was prepared, additional gas fields have been established. These include Origin's Combabula and Condabri fields and QGC's Cam, Ross, Woleebee Creek, Glendower, Harry, Isabella and David fields. Total gas production in the Surat Basin has increased, as shown in Figure 2-8. As mentioned above, other than some additional wells in the Fairview and Spring Gully fields, there has been little to no expansion in the southern Bowen Basin and this is reflected in the gas production data shown in Figure 2-8.

Detailed information on current CSG production areas, including a breakdown of the number of CSG wells proposed in each CSG gas field area and proposed cessation dates, is provided in Table A-1 of Appendix A-1.

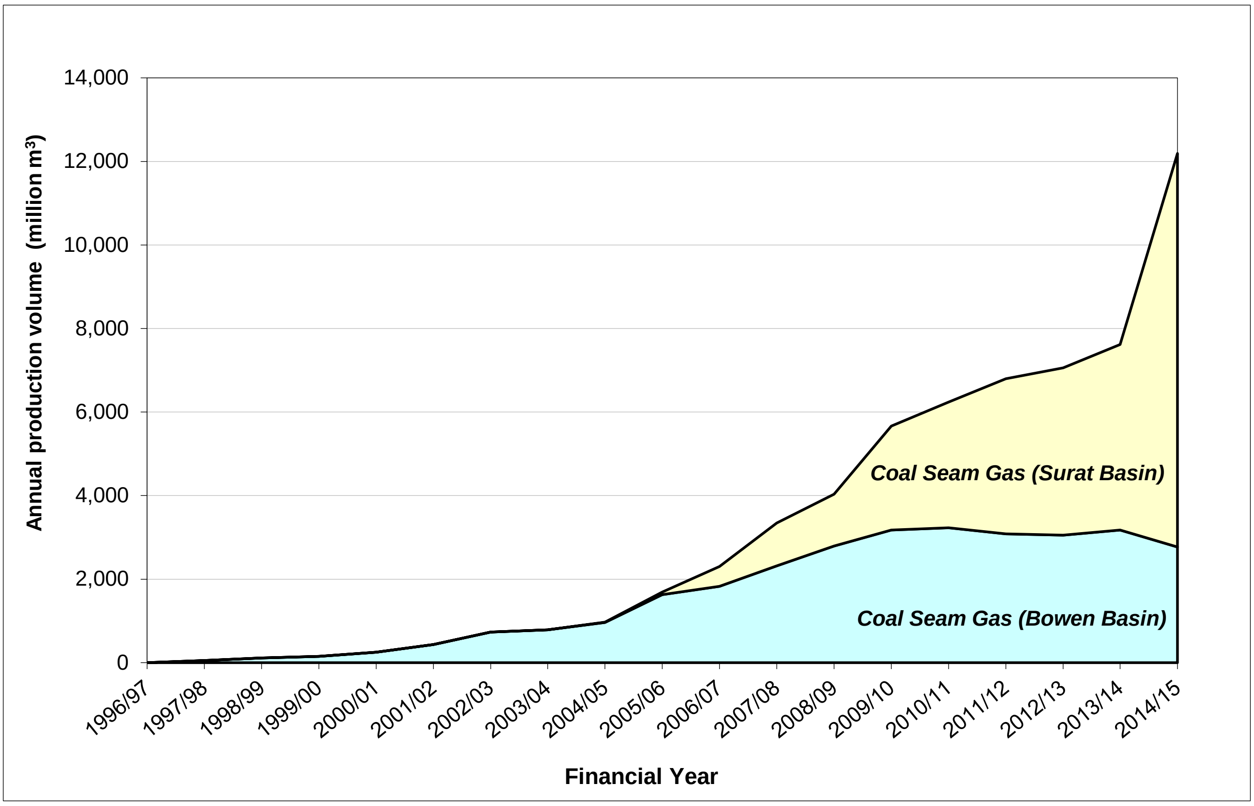

Figure 2-8 Queensland coal seam gas production (Source: DNRM, 2015)

2.4.2 Planned coal seam gas production areas

Since the UWIR 2012 was prepared, the area identified by tenure holders as being planned for CSG production has been substantially reduced. Much of the area previously planned for production is now regarded as only ‘potential production area’ with no clear plan for development. A comparison of current and planned CSG development areas in 2012 and 2015 is provided in Figure 2-9. The total area over which production is either taking place or is planned in the future has reduced by around 45% from about 21,000 km^2 in 2012 to 12,000 km^2 in 2015. The change reflects a change in market conditions, lower-than-expected coal permeability and, therefore, lower gas yields in some areas. The industry development scenario used in predicting future impacts on water resources, as set out in Chapter 7, is based on the current and planned development areas shown in Figure 2-5. The CSG companies estimate that development of these areas will require the installation of about 17,900 CSG wells as shown in Figure 2-7. Detailed information on planned CSG production areas, including a breakdown of the number of CSG wells proposed in each CSG gas field area and proposed commencement and cessation dates, is provided in Table A-2 of Appendix A-1.

Most of the future development is planned for implementation over the next five to 10 years which will result in a decrease in the rate of CSG well installation in the Surat Basin in around 2025 and little, if any, new drilling in the Bowen Basin after 2021 (Figure 2-7). Since the typical life of a gas field is about 25 years, substantial production is expected to cease around 2060.

The following is a broad overview of the planned future development shown in Figure 2-5.

Santos’s development plans in the southern Bowen Basin include expansion of its Fairview field and development of the Arcadia field. There are currently no plans to develop areas north of Arcadia or to further expand the Scotia field and these areas are only potential CSG production areas. In the Surat Basin, Santos intends to expand its current operations in the Roma field to the east and west, although the planned development footprint in this area is smaller than previously envisaged.

Origin's development plans in the Surat Basin include expansion of the existing Condabri field south of Miles, and expansion of the Combabula field west of Wandoan. The large areas of Origin tenure to the south of Wandoan and south-west of Cecil Plains are unlikely to be developed. Currently, only the Spring Gully field in the Bowen Basin has development plans. The existing Peat field north-east of Wandoan will continue to produce gas; however, there are no plans to expand this field.

QGC plans to develop most of the remaining tenure within its Northern Development Area located north and west of Wandoan, and its Central Development Area located east and south of Miles. QGC also proposes limited further expansion of its existing operations in its Southern Development Area west of Dalby, although there are no current plans to develop most of the western half of this area.

Arrow's development plans include significant expansion of the existing Tipton and Daandine fields and the development of a third area south-east of Wandoan. There remains a band of planned development to the south of the Warrego Highway between Dalby and Chinchilla. However, there is little planned development north-east of the Warrego Highway between Dalby and Chinchilla as much of the tenure in this area has been relinquished. The Arrow tenure area south of Cecil Plains has also seen some relinquishments and a contraction in development plans. Arrow has no plans to produce CSG from the southern Bowen Basin within the Surat CMA, although it does hold tenure over an area to the north of Blackwater which forms part of the Bowen Gas Project.

Senex's future development plans are currently limited to development of a relatively small area in the Surat Basin to the north of the existing Santos Roma field.

Figure 2-5 shows substantial areas of tenure which are identified as 'potential' CSG production areas. These are areas over which environmental approvals have been granted and which could be developed but for which the CSG companies currently have no development plans. Since 2012 the total area over which CSG development has been approved (i.e. the total current, planned and potential production areas shown in Figure 2-5) has increased from around 32,000 km^2 to 37,000 km^2 as a result of the tenure changes described in Section 2.3. However, as discussed above CSG production is only currently planned from around 12,000 km^2 of this area.

In order to assess the impacts of actual CSG development exceeding the currently planned development, OGIA has developed a 'high development' scenario which involves the installation of about 31,000 CSG wells. This is considered to be the maximum that could practicably be installed under current approvals. Detail on how this high development scenario was prepared is provided in Appendix A-2. Compared to the predictions presented in Chapter 7, under this high development scenario the number of water supply bores affected in the long term would be approximately 17 percent higher, and the total volume of water extracted over the lifetime of the industry would be approximately 43 percent higher.

2.4.3 Conventional petroleum and gas production areas

The conventional petroleum and gas fields in the Surat CMA are mature and most are in decline or nearing depletion. Most of the exploration and development of conventional resources occurred from the 1960s through to the 1990s. There are no current plans for expansion. The main focus for existing conventional operations is the efficient extraction of the remaining oil and gas reserves. About 20 conventional petroleum and gas production wells remain in operation and these are spread across the Tinker, Taylor and Waggamba fields operated by AGL and the Moonie field currently held by Santos. At the time of preparing this report, Santos advised that the Moonie field was in the process of being sold. A small amount of water is also extracted from the three wells at the Pleasant Hills field operated by Santos, although this field is mainly now used for storing CSG.

The location of active conventional petroleum and gas fields is shown in Figure 2-5. Conventional petroleum and gas production in the Surat and southern Bowen basins accounts for less than five per cent of current gas production and less than two per cent of current water extraction. These proportions will continue to fall as the CSG industry develops.

The Evergreen Formation and the Precipice Sandstone are the main reservoirs in the Surat Basin for conventional production, but nearly 75 per cent of the conventional production in the Surat CMA is from deeper Permian Bowen Basin formations that are well isolated from the overlying Surat Basin formations.

The conventional fields north of Roma are primarily gas fields while further south there is a mix of oil and gas fields, and the Moonie field is entirely an oil field. Moonie accounts for nearly half the oil production in the Surat CMA and nearly 90 per cent of all the water produced from conventional activities in the Surat CMA.

Further information on active and inactive conventional petroleum and gas production areas is provided in Table A-3 of Appendix A-1.

2.5 Non-petroleum and gas resource activities in the Surat CMA

Coal mining along the eastern and northern margins of the Surat Basin targets the Walloon Coal Measures, which is the formation targeted for CSG development. However, coal mining is mostly confined to areas where the coal is no more than about 150 metres below the ground. Economic quantities of CSG are found below these depths, so there is expected to be little or no overlap between the predicted impacts associated with CSG and coal mining developments in the area. The potential impacts of future coal mining on groundwater resources were recently assessed as part of the Australian Government’s Bioregional Assessment Program.

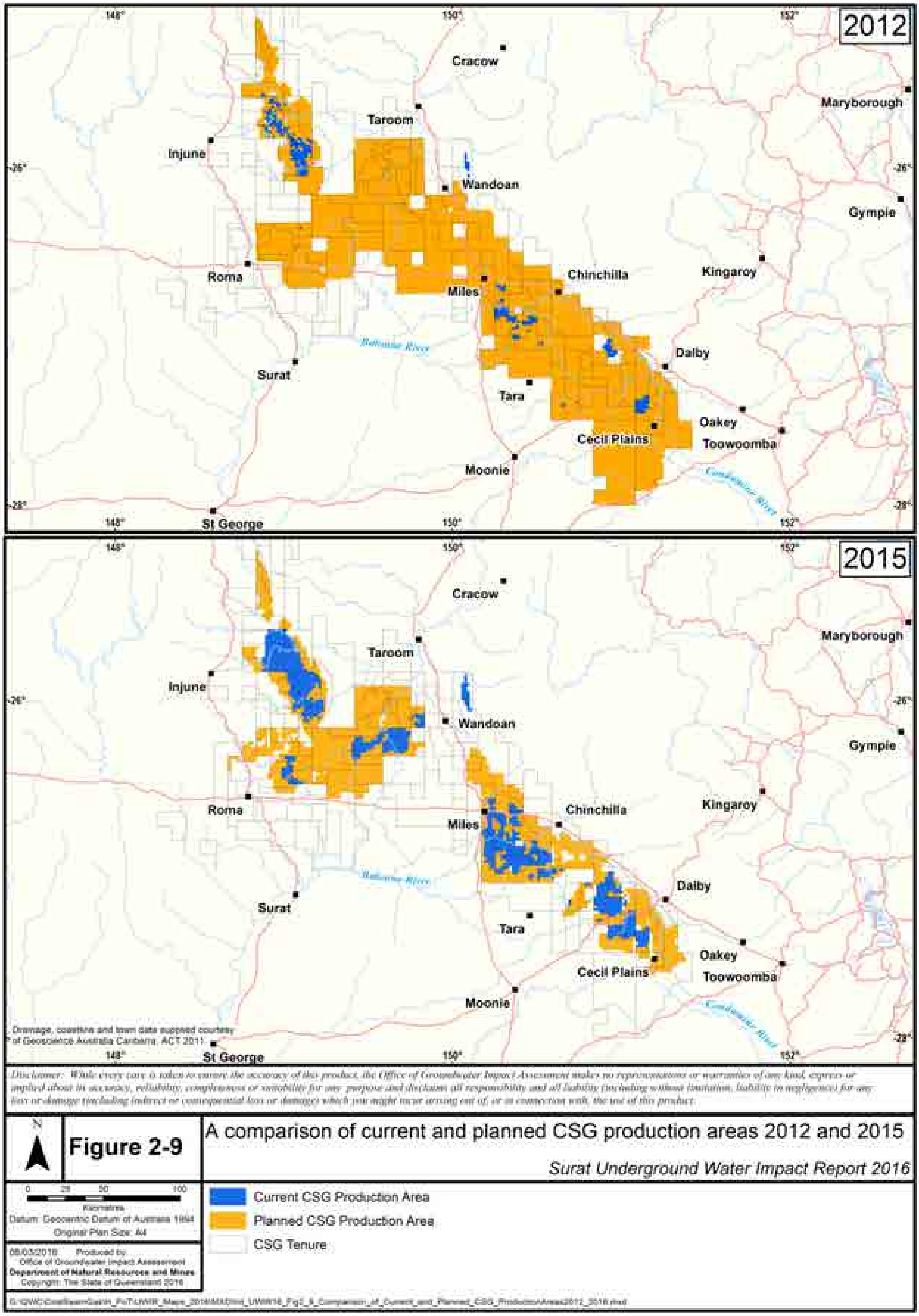

Figure 2-9 A comparison of current and planned CSG production areas in 2012 and 2015

3 Regional landscape and geology

- A new regional geological model has been developed incorporating information from more than 4,800 CSG wells and from a review of existing water bore data.
- The regional geological model will continue to be revised as new data becomes available to support future UWIR updates and water resource management activities in the area.

This chapter describes the physical setting and geology of the region in and around the Surat CMA, which form the basis for assessing the hydrogeology of the area (Chapter 4) and for developing the new regional groundwater flow model. Understanding the geology also supported the spring investigations that OGIA carried out to develop the spring impact management strategy (Chapter 9).

3.1 Landscape

The Surat CMA straddles the Great Dividing Range (‘the Range’) and falls within a region covering various catchments of both the southern Fitzroy River Basin and the northern Murray-Darling Basin (Figure 3-1).

3.1.1 Topography

The Range rises to about 1,100 metres in the Carnarvon National Park where sandstone outcrops form plateaus and steep escarpments which are often capped with basalt. The Range becomes subdued between Miles and Inglewood where it appears as rolling hills with elevations of less than 300 metres. It then rises again to more than 1,100 metres on the Queensland – New South Wales border in the area south of Warwick, where basalts and granites are exposed at ground level. The topography slopes gently down from the Range towards the south-west.

3.1.2 Surface drainage

The Range divides the Murray-Darling Basin river systems, which are dominated by the Condamine and Balonne rivers, from the northerly and easterly flowing Nogoa, Comet, Dawson and Boyne river systems. Figure 3-1 shows the extent of the river basins and the location of the major watercourses.

The Condamine-Balonne river system is the dominant surface drainage system in the south of the region. The Condamine River originates in elevated areas south of Warwick and flows north-west towards Chinchilla where it then turns westward towards Roma. There are extensive floodplains associated with the upper and central areas of the Condamine River. South of Roma and downstream of the confluence with the Dogwood Creek, the Condamine River is known as the Balonne River and drains towards the south-west across the border into the Darling River system.

A local plateau, reaching about 400 metres above sea level, divides the Moonie and Balonne river catchments, with the tributaries of the Balonne River flowing north and those of the Moonie River flowing south. The Maranoa River lies to the west of the region and flows to the south. In the south of the region, the McIntyre River forms the Queensland – New South Wales border. In the north of the region, surface drainage is to the north and east, into the river systems of the Fitzroy Basin which drain to the sea at Rockhampton.

Rainfall and runoff are highly variable and evaporation rates are high. Consequently, many of the rivers and streams in the area are ephemeral and are characterised by large variations in the duration and volume of flows. Intermittency is an important feature of the natural hydrology and, under natural conditions, prolonged base flows occur only in wetter years in most watercourses. There are some spring-fed stream sections in the region. For example, the Dawson River is fed in part from the Hutton Sandstones; the Nogoa River in part from the Precipice Sandstone.

3.1.3 Climate

The climate of the area is sub-tropical with most rainfall occurring in summer. Much of the area is categorised as semi-arid. The average annual temperature is about 20 °C with temperatures ranging from 0 °C in winter to 35 °C in summer.

The highest rainfall generally occurs between November and February and the lowest between April and September, but it is highly variable. Intense cold fronts and low-pressure systems originating in the Southern Ocean can result in high rainfall during winter and spring in some years.

Average annual potential evapotranspiration ranges between 1,800 mm/year and 2,500 mm/year; this exceeds rainfall, with the annual rainfall deficit increasing towards the west. Rainfall records show that for the 10 years before the major rainfall events of the summers of 2010–11 and 2011–12, monthly rainfall had been below average. Since that time, rainfall has generally continued to be below average with some summer months between 2013 and 2015 having some of the lowest rainfalls on record for that time of year.

3.1.4 Land use

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 petroleum and gas extraction, mining (mainly coal) and conservation.

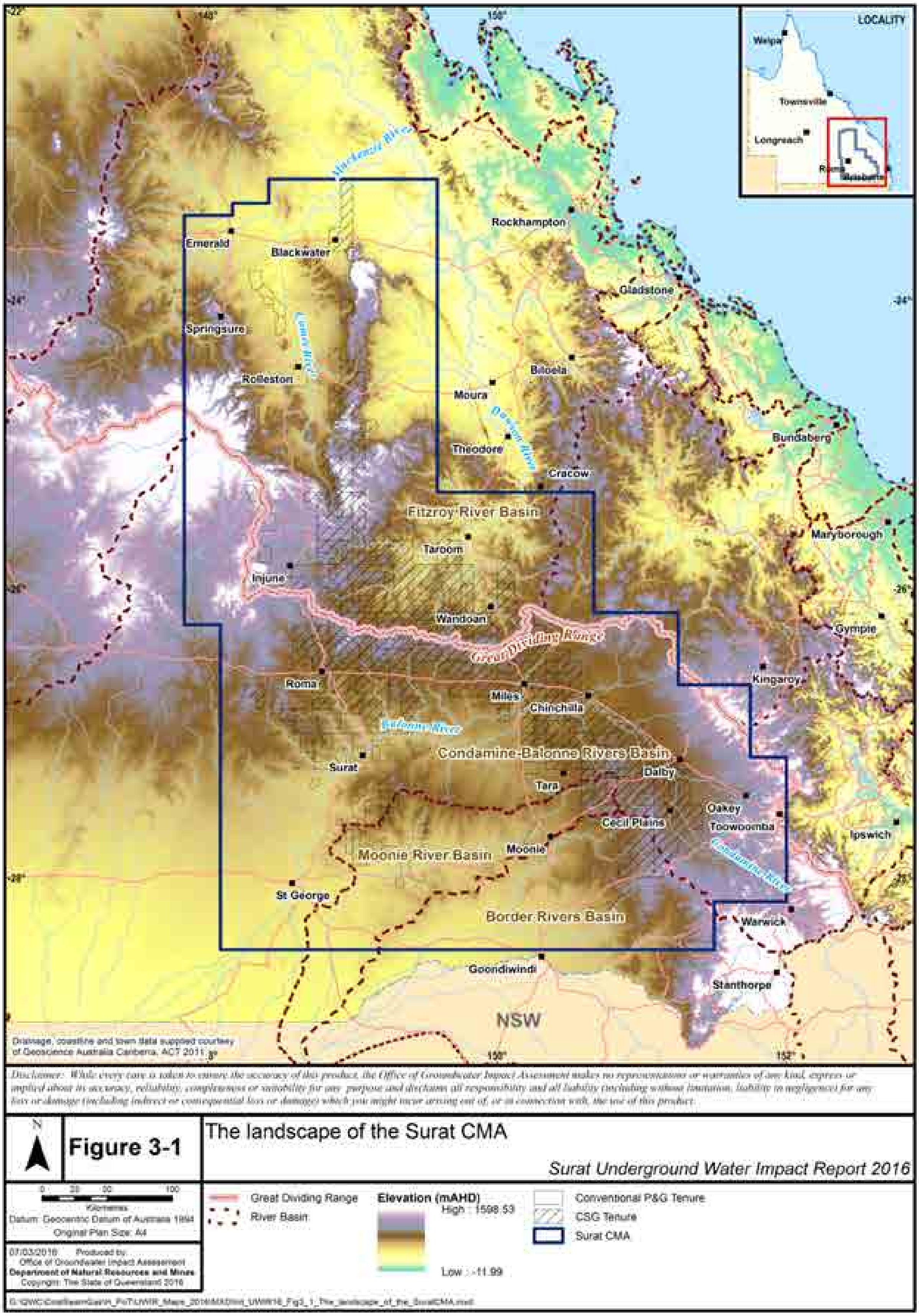

Figure 3-1 The landscape of the Surat CMA

3.2 Geology

The Surat CMA covers part of three geologic basins:

1. the southern Bowen Basin
2. the northern Surat Basin
3. the western Clarence-Moreton Basin.

Geologic formations within the three basins are mainly comprised of various layers of sandstone, siltstone and mudstone.

The Bowen Basin is the deepest and oldest of the three basins, and runs north-south through the centre of the region. Overlying this is the Surat Basin, which covers most of the central and southern parts of the Surat CMA. The sediments of the Clarence-Moreton Basin interfinger with those of the Surat Basin across the Kumbarilla Ridge to the east. Overlying these basins are extensive areas of unconsolidated younger alluvial sediments and volcanics. Figure 3-2 shows the distribution of the basins. Figure 3-3 shows more detail on the structures that define the basins. Figure 3-4 is a simplified geological cross-section across the basins. The stratigraphy of the geologic sequences of relevance within the Surat CMA is presented in Appendix B.

The GAB is not a geologic basin; it is a hydrogeological, or groundwater, basin comprising parts of other geologic basins. Within the Surat CMA, the GAB includes the Surat Basin and equivalent formations in the western part of the Clarence-Moreton Basin (which is now considered to be an eastern hydrogeological extension to the Surat Basin (Ransley & Smerdon 2012)). Chapter 4 describes the hydrogeology of the GAB in more detail.

3.2.1 The Bowen Basin

The Bowen Basin is elongated, trending north-south, and extends from central Queensland, south beneath the Surat Basin, into New South Wales where it eventually connects with the Gunnedah and Sydney basins.

It contains Permian to Triassic age sediments with a maximum thickness of about 9,000 metres (Cadman et al. 1998). In the Surat CMA, the basin has two main centres of sedimentary deposition—the Taroom Trough to the east and the Denison Trough to the west (Figure 3-3).

In the east, the Bowen Basin is bound by the Gogango Thrust Zone, the Auburn Arch and a series of north-south oriented faults comprising the Goondiwindi, Moonie and Leichardt–Burunga fault zones which extend south from the Auburn Arch. Although remnants of the Permian sequence are found to the east of these faults, erosion during the Triassic period has largely restricted the occurrence of the sediments to the west (Cadman et al. 1998).

To the west, the Bowen Basin is bounded by the Anakie Inlier and the Collinsville, Springsure and Roma shelves (Totterdell 1990). The margins of the basin in the south-west are less well defined. Formations thin towards the west across the Nebine Ridge and gently dip towards the Taroom Trough.

The depositional history of the Bowen Basin is complex and individual formations are not always laterally extensive or easy to correlate across the basin (Draper 2013). Deposition in the basin began during the Early Permian, with river and lake sediments and volcanics being deposited in the east, and a thick succession of coals and non-marine sedimentary rocks in the west (Geoscience Australia 2015). These sediments were then overlain by mostly fine-grained sediments such as mudstone and siltstone of marine origin. These sediments include the Cattle Creek Formation which is the most recent target for CSG exploration in the Denison Trough area.

In the Late Permian, a thick succession of marine and fluvial sediments, including extensive coal seams, was deposited. This sequence includes the uppermost CSG-producing coal seams in the Bowen Basin—the Bandanna Formation. The Bandanna Formation comprises mostly mudstone and siltstone with some clayey sandstone to a thickness of up to 370 metres. The average thickness of the coal in the Bandanna Formation is about 10 metres.

The Rewan Formation, a thick sequence of mudstone, siltstone and clayey sandstone, was deposited from rivers and lakes over the Bandanna Formation. This was followed by deposition of the Clematis Group sandstones and, finally, more mudstones and siltstones of the Moolayember Formation. Widespread erosion then followed before the deposition of the Surat Basin sediments (Cadman et al. 1998).

3.2.2 The Surat Basin

The Surat Basin is one of the major basins forming the GAB and occupies an area of 440,000 square kilometres (180,000 square kilometres of which is in Queensland). The basin extends from north of Taroom in south-east Queensland to the Coonamble Embayment near Dubbo in New South Wales (Figure 3-2).

The sediments of the Surat Basin interfinger with those of the Eromanga Basin in the west, across the Nebine and Eulo ridges and the Cunnamulla Shelf. The boundary between the Surat Basin and the Clarence-Moreton Basin to the east was historically considered to be the Kumbarilla Ridge (Draper 2013). However, Day et al. (2008) consider the eastern boundary of the Surat Basin to be the Toowoomba Strait, which is equivalent to the present-day line of the Main Range through Toowoomba. They argue that the sedimentary sequences in the most westerly sub-basin of the Clarence-Moreton Basin (the Cecil Plains Sub-Basin) are more similar to the sediments in the Surat Basin than to the remainder of the Clarence-Moreton Basin east of the Toowoomba Strait. Ransley and Smerdon (2012) show a clear lithostratigraphic correlation between the sediments of the Surat Basin and the Cecil Plains Sub-Basin and this correlation was also evident in preparing the new regional geological model for the Surat CMA.

The Surat Basin is bounded to the north-east by the Auburn Arch and to the south-east by the Texas Block. The northern margin of the basin has been exposed and extensively eroded, and the sediments generally dip in a south-westerly direction.

The basin comprises a mainly Jurassic to Cretaceous age sequence of alternating layers of sandstones, siltstones and mudstones. This sequence is more than 2,500 metres thick in the Mimosa Syncline which overlies the Taroom Trough, but is much broader and shallower. The basal Jurassic sequence comprises mainly sandstones, siltstones and mudstones deposited from lakes and rivers. In the middle Jurassic, over much of the basin, swamps deposited coal measures. Conditions then returned to mainly river deposition until the early Cretaceous, when up to 1,200 metres of shallow marine mudstones, siltstones and some sandstones were deposited. Finally, as the oceans retreated once more during the Cretaceous, further siltstone- and sandstone-dominated units were laid down and this completed deposition in the basin (DNRM 2005). Appendix B outlines the stratigraphy of the Surat Basin.

The deepest sediments throughout most of the Surat Basin are the sandstones and siltstones of the Precipice Sandstone. Overlying this formation is the Evergreen Formation, a thick sequence of mainly siltstone and mudstone, which is overlain by the Hutton Sandstone, comprising mainly sandstone, with some siltstone and mudstone.

Overlying the Hutton Sandstone is the Walloon Coal Measures—a thick sequence of siltstone, mudstone and fine-to-medium-grained clayey sandstone—which contains the main CSG-producing coals in the Surat

Basin. While the total thickness of the Walloon Coal Measures can be up to 650 metres, the average thickness is about 300 metres. However, the total coal thickness is generally less than 30 metres.

The fine-to-medium and often clayey sandstones, siltstones and mudstones of the Springbok Sandstone were deposited over the Walloon Coal Measures following a period of erosion. The Springbok Sandstone is overlain by the Westbourne Formation—which mainly comprises layered, or ‘interbedded’, siltstone and mudstone—and the Gubberamunda Sandstone, which consists of fine-to-coarse-grained sandstone. The thinly bedded sandstone, siltstone, mudstone and fossil wood of the Orallo Formation was deposited over the Gubberamunda Sandstone. The Mooga Sandstone was deposited over the Orallo Formation and grades upwards into the interbedded lithic and quartzose sandstone, siltstone and mudstone of the Bungil Formation.

Sedimentation in the Surat Basin ended in the Cretaceous with the interbedded muddy siltstone, fine-grained sandstone and mudstone of the Wallumbilla Formation; the Surat Siltstone; and the Griman Creek Formation of the Rolling Downs Group.

3.2.3 The Clarence-Moreton Basin

The Clarence-Moreton Basin covers an area of about 10,000 square kilometres in south-east Queensland and also extends into north-eastern New South Wales (Figure 3-2). The basin contains sediments of Late Triassic to Late Jurassic age, up to 1,500 metres thick.

The basin consists of three main centres of sedimentary deposition, or sub-basins—the Cecil Plains, Laidley and Logan sub-basins (O’Brien & Wells 1994). Only the most westerly sub-basin, the Cecil Plains Sub-basin, falls within the Surat CMA.

As discussed in the previous section, the boundary between the Surat Basin and the Clarence-Moreton Basin is contentious. Recent publications and investigations consider the Cecil Plains Sub-basin to be an easterly extension of the Surat Basin because the sedimentary sequences correlate much more closely with those of the Surat Basin than those of the remainder of the Clarence-Moreton Basin (Day et al. 2008; Ransley & Smerdon 2012).

While the younger Cretaceous Surat Basin sequences are eroded over the Kumbarilla Ridge, there is a clear lithostratigraphic correlation between the Jurassic sequences in the Surat and Clarence-Moreton basins. Even the deepest formation, the Precipice Sandstone, interconnects around the northern end of the Kumbarilla Ridge (Ransley & Smerdon 2012). The upper unit of the Woogaroo Subgroup—the Ripley Road Sandstone (previously termed the Helidon Sandstone)—is the equivalent of the Precipice Sandstone, while the upper part of the Marburg Subgroup, or Marburg Sandstone, is the equivalent of the Hutton Sandstone.

The Walloon Coal Measures is continuous between the Surat and Clarence-Moreton basins, representing a widespread (> 500 km) episode of deposition of river, lake, swamp and marsh sediments. The formation has been either partly eroded or exposed over much of the eastern part of the Clarence-Moreton Basin (Goscombe & Coxhead 1995).

Throughout the remainder of this report, the Surat Basin stratigraphic sequence naming convention is used (Appendix B).

3.2.4 Cenozoic formations

The Cenozoic Era began about 65 million years ago and continues to the present day.

Thin accumulations of Cenozoic-aged unconsolidated alluvial sediments cover much of the Surat CMA. These sediments typically comprise sand, silt and clay deposited along pre-existing streams and drainage lines.

The Condamine Alluvium is one of the more significant accumulations of alluvial sediments in the region. The thickness of alluvium ranges from less than 10 metres—in headwater areas and along the floodplain margins—to 130 metres in the central floodplain near Dalby. The sediments in the central Condamine area are dominated by fine-to-coarse-grained gravels and channel sands interbedded with clays. A thick clayey sequence of sheetwash (fan) deposits overlies the floodplain deposits in the east (Huxley 1982; KCB 2010a).

The Condamine River has eroded its valley along the strike of the Walloon Coal Measures, so the coal measures mainly form the basement over most of the alluvial area (Huxley 1982). The basement, therefore, generally comprises siltstones, sandstones, shales, coals and, occasionally, basalts (associated with the Great Dividing Range) on the eastern margin.

The Main Range Volcanics are comprised mostly of basalt and overlie the eroded surface of the Clarence-Moreton Basin and some older basement rocks. Most of the volcanics are extensively eroded and covered in part with alluvium, including the Condamine Alluvium.

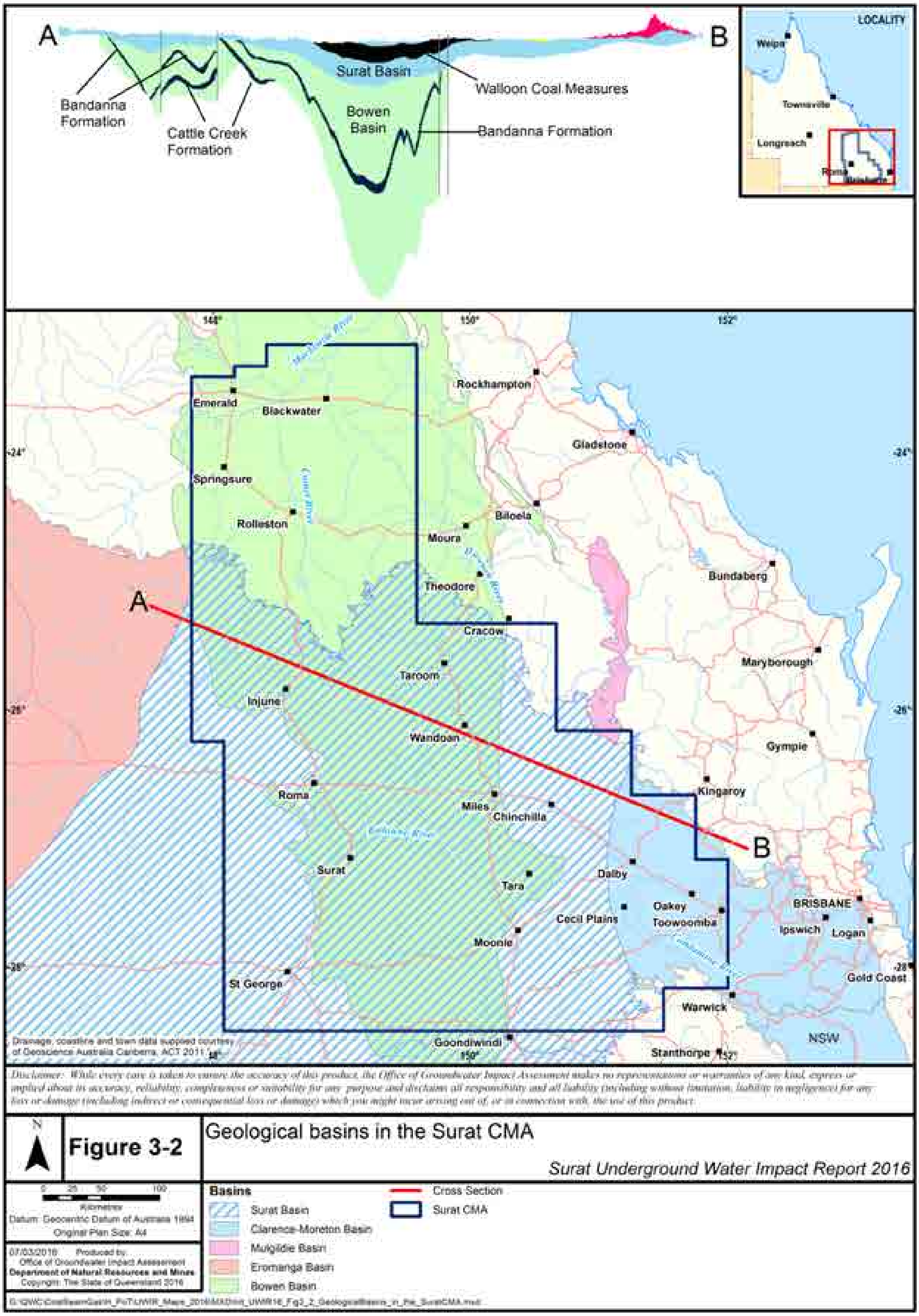

Figure 3-2 Geological basins in the Surat CMA

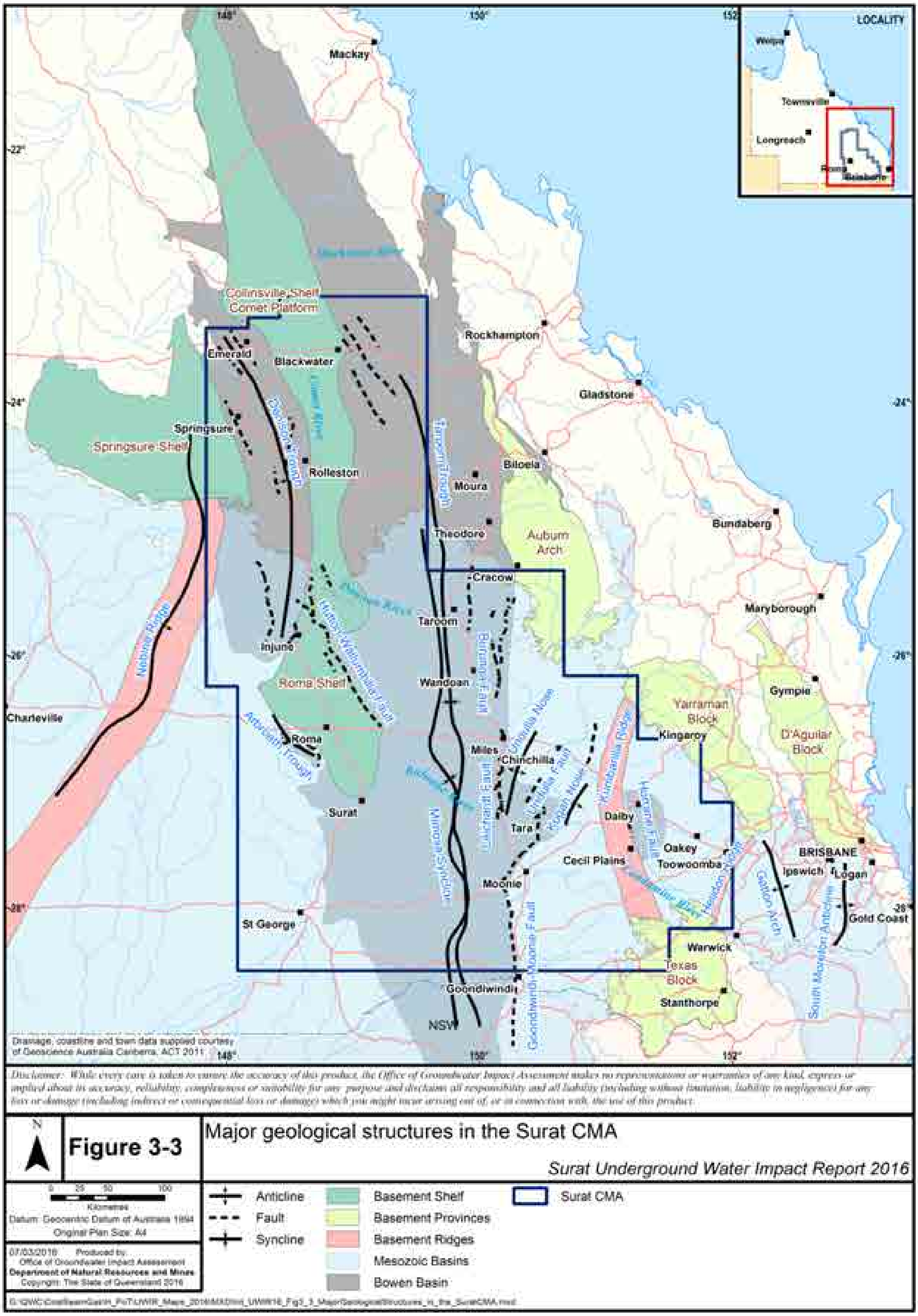

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Figure 3-3 Major geological structures in the Surat CMA

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Figure 3-3 Major geological structures in the Surat CMA

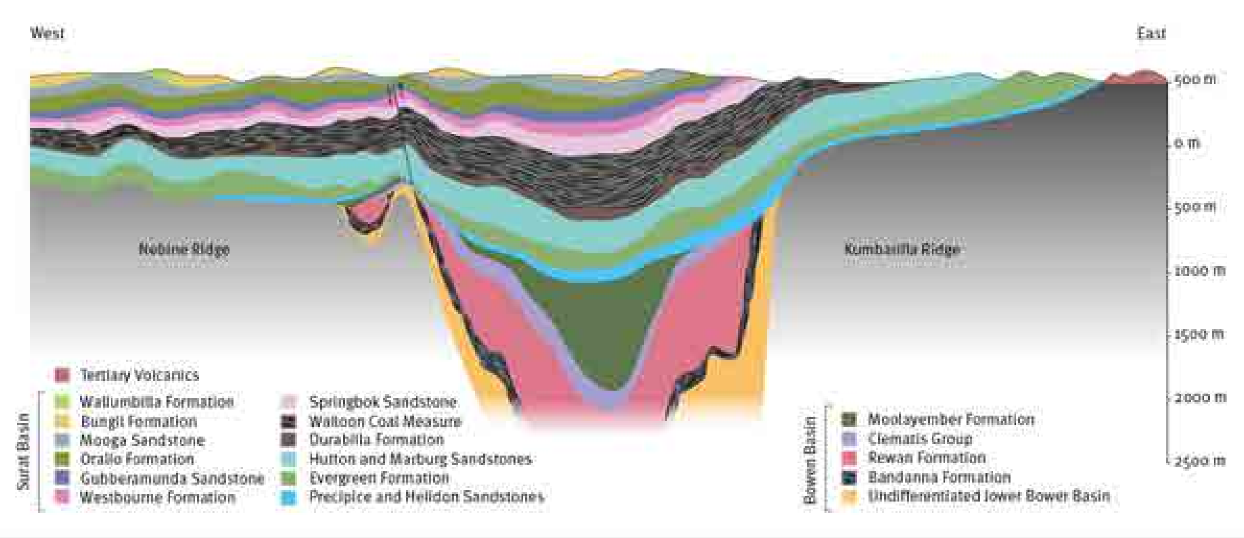


Figure 3-4 A geological cross-section through the Surat and Bowen basins

3.3 Developing the geological model

A geological model is a digital 3D spatial representation of the various rocks and sediments below the ground surface. It defines the extent and thickness of each geological unit, including aquifers and aquitards, which can then be assigned hydraulic properties in a groundwater flow model. A representative geological model is, therefore, an important component of any groundwater flow model.

As part of reconceptualising and redeveloping the regional groundwater flow model for the Surat CMA, a new regional geological model was developed. Significant improvements incorporated into the new geological model include:

- more accurate representation of surficial sediments, including the Condamine Alluvium and the Main Range Volcanics
- interpretation by OGIA of substantial additional primary data. The revised modelled surfaces are based primarily on the identification of the top and bottom of each geologic formation present in more than 4,800 bores
- the inclusion of a number of the major geologic faults.

The extent, or domain, of the revised geological model and the primary input datasets are shown in Figure 3-5. A visualisation of the modelled geology is shown in Figure 3-6. The model includes all of the main stratigraphic units, from the basement underlying the Bowen and Surat basins through to the surface Cenozoic sediments, alluvium and basaltic cover. The model was developed in Petrel (version 2013.2), a geological modelling package developed by Schlumberger.

3.3.1 Modelling the Condamine Alluvium

Within the model domain, the Cenozoic sediments of the Condamine Alluvium are the most important surface formation. The Condamine Alluvium comprises alluvial and sheetwash (fan) sediments of the Condamine River which have been deposited into valleys eroded into the Main Range Volcanics and the formations of the Surat and Clarence-Moreton basins (KCB 2010a).

OGIA has revised the geological model of the Condamine as part of a study into the connectivity between the Condamine and the underlying Walloon Coal Measures (Section 4.4.1). This revised model of the Condamine was also incorporated into the new regional geological model. Lithological descriptions from more than 3,500 water bores in the Condamine Alluvium area were used. The Condamine model delineates broad units of the alluvium and the first contact with the underlying Surat Basin sediments.

3.3.2 Modelling the Main Range Volcanics

The Main Range Volcanics are deposited on the eroded surface of the Surat Basin sediments and basement rocks (Huxley 1982). Most of the volcanics have themselves been extensively eroded and are covered in part with alluvium, including that of the Condamine Alluvium (Exon 1976). The average thickness of the basalt is about 70 metres; however, many drill holes have extended beyond a depth of 150 metres into basalt without reaching underlying formations.

To define the base of the Main Range Volcanics, drillers' logs were reviewed from about 4,200 water bores that intersect basalt. Although the majority of these bores do not fully penetrate the basalt—only 665 fully penetrate—they define the minimum basalt thickness at the locations of those bores. These data were used to model the base of the Main Range Volcanics for inclusion in the regional geological model.

3.3.3 Modelling the Surat and Bowen Basin units

A lithostratigraphic approach was adopted for modelling the consolidated Surat and Bowen basin units. This involves defining the boundaries between geological units or formations based on their lithological properties and stratigraphic relationships, which effectively results in the strata being divided based on major changes in the environment of deposition. For example, lithostratigraphic sub-divisions would be expected in each of the following scenarios:

- where mainly sandy river-deposited sediments change to fine-grained swamp or marine sediments
- where periods of uplift and erosion cause a hiatus in deposition, such as at the contact between the Walloon Coal Measures and the Springbok Sandstone.

The lithostratigraphic divisions of the Bowen and Surat basins are defined well in the literature. The most comprehensive summary is provided by Green et al. (1997); they reviewed the definition of stratigraphic units in the Surat and Bowen basins and also identified characteristic geophysical wireline log signatures for each unit. These signatures were used by OGIA to generate about 38,000 'stratigraphic picks' (interpreted formation tops) from geophysical logs for more than 4,800 petroleum and gas wells and water bores. This methodology was adopted on the basis of its objectivity, repeatability and ability to generate a regionally consistent set of stratigraphic picks for input to Petrel, the software used to develop the regional geological model.

In the new geological model, the Surat Basin has 12 stratigraphic layers, from the basal Precipice Sandstone through to the undifferentiated Cretaceous units above the Wallumbilla Formation. The Bowen Basin has five stratigraphic layers, which are, in ascending stratigraphic order:

- undifferentiated lower Bowen Basin sediments
- the Bandanna Formation
- the Rewan Formation
- the Clematis Formation

- the Moolayember Formation.

In addition to the 38,000 stratigraphic picks derived from wireline log correlation, about 10,000 control markers were used to provide stratigraphic control in areas of the model with limited well data, and to replace missing formation data in borehole logs and at outcrop boundaries.

Seventeen faults were incorporated into the regional geological model (Figure 3-5). Displacements along each of these faults were calculated within the model, based on the available well markers on both sides of the faults.

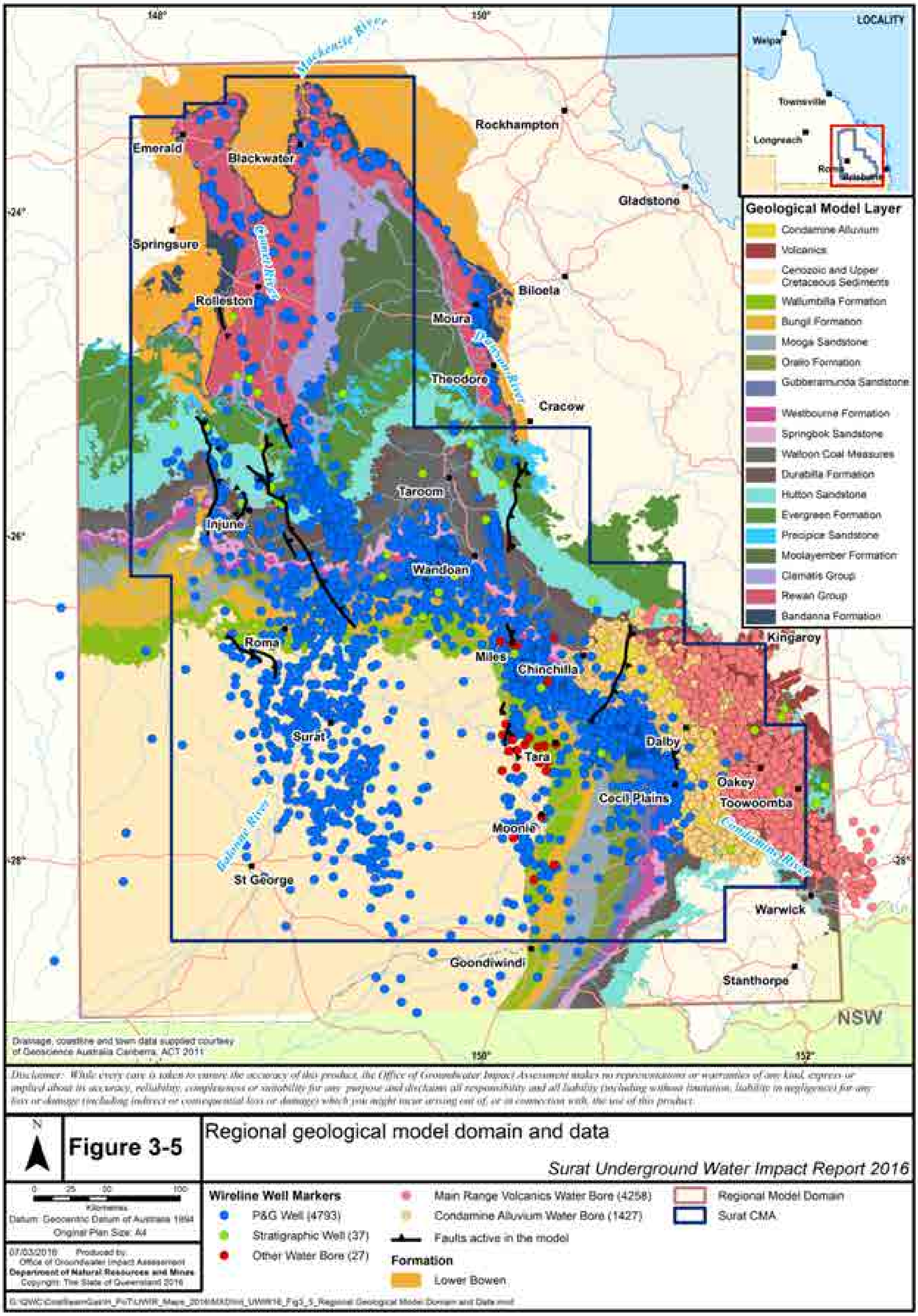


Figure 3-5 Regional geological model domain and data

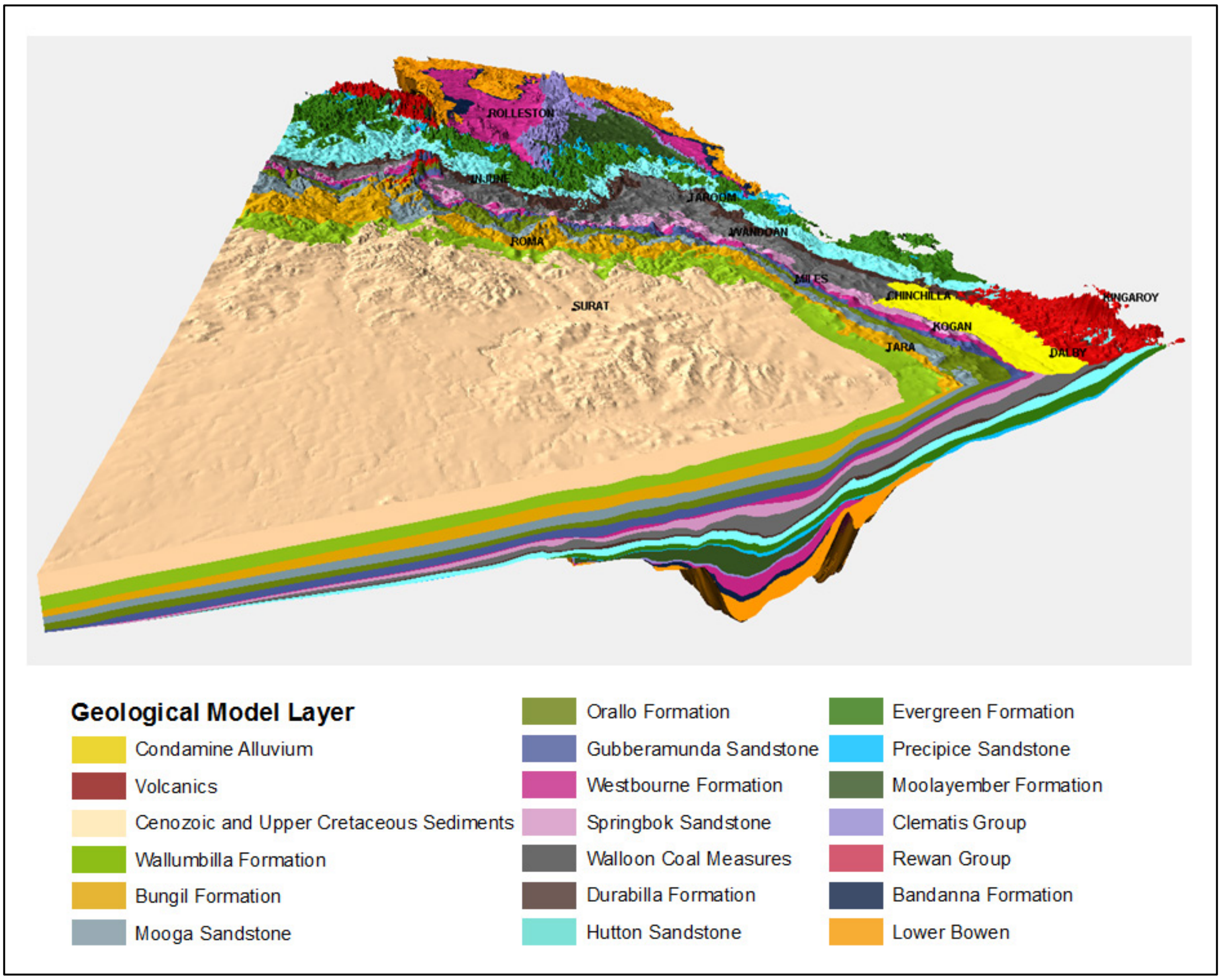


Figure 3-6 Geological model visualisation

4 The hydrogeology of the Surat CMA

- New information about the water balance components of the regional groundwater flow system and the way water moves within the system has supported the construction of the regional groundwater flow model.
- More than 40,000 permeability data elements from CSG wells are now available, comprising data from laboratory tests, drill stem tests and pumping tests.
- Water level data for more than 12,000 water bores have been extracted from the state groundwater database.
- The connectivity between coal formations and other formations has been investigated.

This chapter builds on the basic understanding of the region's geology to develop an understanding of the region's hydrogeology. It provides an understanding of the way groundwater moves through and between geologic formations and provides information that formed the basis for developing the regional groundwater flow model.

A substantial amount of new information has become available since the UWIR 2012 was prepared, which has improved our understanding of the hydrogeology of the Surat CMA.

4.1 The basic concept of groundwater flow

Groundwater in geologic formations flows from areas where the water level—or water pressure—is higher, to areas where it is lower, in much the same way that surface water flows from areas of higher elevation to areas of lower elevation. The difference in water levels is generally referred to as the 'hydraulic gradient'. However, unlike surface water, groundwater flows slowly, through pores and fractures in formations.

The flow of groundwater in confined or pressurised units, such as the Walloon Coal Measures, is controlled by two primary hydraulic parameters of the material through which it flows: the permeability and the storativity. Permeability is a measure of the ease with which water can flow through the material. Storativity is a measure of the capacity of the material to store or release water in response to a pressure change. Highly permeable materials, such as sand, let the water flow relatively easily, resulting in a gentle hydraulic gradient in response to groundwater extraction. In contrast, lower-permeability materials such as clay, although yielding relatively small amounts of water, result in much steeper hydraulic gradients. Geologic formations with higher permeability are known as aquifers and formations with lower permeability are known as aquitards.

Within a geologic formation, water typically flows more easily along bedding planes (the surfaces that separate different layers) than vertically through them. As a result, horizontal permeability is substantially higher than vertical permeability.

In addition to extraction from bores groundwater also flows naturally to surrounding formations, springs and watercourses. At any given time, water pressure in a geologic formation reflects a balance—or in the case of falling water levels, an imbalance—between the volume of water entering the system (recharge) and the volume of water flowing out of the system (discharge).

4.2 Groundwater systems in the Surat CMA

CSG exists in the Walloon Coal Measures of the Surat and Clarence-Moreton basins, and in the Bandanna and Cattle Creek formations of the underlying Bowen Basin. A number of regional aquifers within these basins are used for water supplies. Overlying the basins are also extensive areas of unconsolidated younger alluvial sediments and volcanics, which contain significant aquifers in localised areas such as the Condamine Alluvium.

4.2.1 The Great Artesian Basin

The GAB is not a geologic basin. It is a hydrogeological basin comprising various geologic sequences of several geologic basins. In the Surat CMA, the GAB consists of the Surat and Clarence-Moreton basins.

Historically, the GAB has often been described as comprising a sequence of alternating layers of permeable sandstone aquifers and lower-permeability siltstone and mudstone aquitards (Figure 4-1), which generally dip in a south-westerly direction. However, information provided by detailed geophysical logging of petroleum and gas wells in the Surat CMA and elsewhere confirms that this is a simplified description. Even those units typically considered to be the main aquifers of the GAB contain significant proportions of siltstone and mudstone; this is reflected in the relatively low bore yields in some parts of recognised aquifers. Similarly, the GAB's aquitards can contain some permeable sandstones and siltstone horizons that can yield reasonable quantities of water.

The thickness of the sedimentary sequence is almost 2,500 metres in the centre of the Mimosa Syncline. The thickness of individual formations typically ranges between 100 metres and 600 metres.

The main aquifers within the GAB, from the deepest to the shallowest, are the Precipice Sandstone, Hutton Sandstone, Springbok Sandstone, Gubberamunda Sandstone, Mooga Sandstone, Bungil Formation, and their equivalents. These aquifers are typically laterally continuous, have significant water storage, are permeable and are extensively developed for water supply. However, in some areas, they have more of the character of aquitards than aquifers.

The Springbok Sandstone and the Walloon Coal Measures show a particularly high degree of variability. At many locations, the Springbok Sandstone has a very high content of mudstone and siltstone with very low permeability. This tends to locally isolate groundwater contained in the formation. Similarly, the Walloon Coal Measures has thin permeable coal seams and sandstones that can yield usable quantities of water, particularly where the formation is at shallow depth, where it is more readily recharged and water is of better quality.

Minor aquifers occur within the Boxvale Sandstone Member, and the Doncaster and Coreena members of the Wallumbilla Formation. These aquifers are not typically high-yielding or laterally continuous, and water quality is often poor.

The major aquitards are the Evergreen, Birkhead, Westbourne, Orallo, Wallumbilla and Griman Creek formations, and their equivalents. The Westbourne Formation, with its thickness ranging from 100 metres to 200 metres, separates the Gubberamunda Sandstone from the underlying Springbok Sandstone. The Evergreen Formation is a thick aquitard (averaging 300 metres) lying between the overlying Hutton Sandstone and underlying Precipice Sandstone aquifers.

Most recharge occurs to the outcrop areas in the north, north-west, north-east and east along the Great Dividing Range. Recharge is mainly by rainfall, which either directly infiltrates the outcrop areas, or indirectly leaks from streams or overlying aquifers. Previous work in the area (Kellett et al. 2003) suggests that direct rainfall or diffuse recharge rates are low, generally less than 2.5 millimetres per year. However, recharge rates through preferred pathway flow during high-intensity rainfall events, and localised recharge from stream or aquifer leakage, can provide up to 30 millimetres per year. Recent work by OGIA has extended the work of Kellett et al. (2003) to other areas, finding similar values but also a rainfall-related trend of higher recharge towards the north and east of the basin. These recharge values were used as starting values for developing the regional groundwater flow model.

Recharge water flows primarily along bedding planes and fractures from the recharge areas towards the south, south-west and west. Although previous studies have noted an apparent northward flow component in some aquifers (Hodgkinson et al. 2009), recent work carried out by OGIA—based on a much larger dataset than has been previously available—suggests topographically driven groundwater flow towards the north and north-east in the Hutton and Precipice Sandstone units in the area to the north of the Range. This suggests that recharge to these units in the area close to the northern margin may not contribute significantly to the overall GAB water balance. Groundwater moves very slowly and flow velocities in the GAB have been estimated at 1–5 metres per year (Habermehl 1980). Figure 4-2 shows the location of the recharge areas and the dominant flow directions.

Groundwater movement within the GAB is dominated by subhorizontal flow in the aquifers, with vertical leakage from the aquifers through the intervening low-permeability aquitards occurring throughout the basin at a much slower rate where pressure differences exist.

Natural discharge occurs via springs, rivers, vertical leakage and subsurface flow into adjoining areas.

Water extraction varies across the basin. Aquifers that are relatively shallow and contain good-quality water are more heavily used. Further information on historical groundwater extraction within the Surat CMA is provided in Chapter 5.

Water quality in most aquifers is generally fresh to brackish and suitable for stock, with salinity averaging 1,900 milligrams per litre (mg/L). However, the Walloon Coal Measures generally has higher salinity, averaging 3,000 mg/L and ranging from about 150 mg/L to more than 18,000 mg/L. Water 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 water has resided in the formation.

4.2.2 The Bowen Basin

The Triassic age sandstone aquifers of the Clematis Group and equivalent formations of the Bowen Basin were historically recognised as aquifers of the GAB due to their artesian pressure and potential for input into the GAB. However, recent studies have recognised the potential fluxes between many underlying basins and the GAB and have excluded these sandstones from the GAB (Ransley & Smerdon, 2012; Ransley et al, 2015). The potential interaction between the Clematis Group and other aquifers of the Bowen Basin and the GAB are dealt with through the concept of basement connectivity.

The Clematis Group sandstones and equivalent formations are the main aquifers used for water supply purposes in the Bowen Basin. The Moolayember Formation is primarily a fine-grained siltstone and mudstone confining bed for the Clematis Sandstone, generally separating it from Surat Basin sediments above. Although minor aquifers occur within the Moolayember Formation; these are generally poor in quality and yield and are not laterally continuous.

Across most of the Bowen Basin, the Clematis Sandstone aquifers are separated from the Bandanna Formation (from which CSG is produced in the Bowen Basin) by a thick sequence of fine-grained, low-permeability siltstones and mudstones of the Rewan Group.

Limited data is available on the groundwater conditions within the deeper Permian sediments underlying the Bandanna Formation. However, in general, these formations are fine-grained, cemented, and have little permeability. These deeper Permian sediments include the coal-bearing Cattle Creek Formation which has been the target of recent CSG exploration activities.

Because sedimentation was not continuous across the Bowen Basin, the formations are not as laterally extensive as those in the GAB. The formations have complex geology and display laterally variable hydraulic properties. Water quality is poor, generally, with very high salinity in some places.

4.2.3 Alluvial systems

Within the Surat CMA, various river systems have associated alluvial systems. The groundwater in these systems has been developed for irrigation, for stock and domestic use, and for town water supplies. The most significant and highly developed system is the alluvium associated with the Condamine River—the Condamine Alluvium.

The Condamine Alluvium is a broad term used to describe the alluvial and sheetwash deposits of the Condamine River and its tributaries. The Condamine alluvial aquifer is comprised of gravels and fine-to-coarse-grained channel sands interbedded with clays. The proportion of clay within the sand and gravel beds increases downstream. The aquifer is generally 30–60 metres thick, although it reaches a maximum thickness of 130 metres in the central floodplain near Dalby. The individual channel sand and gravel aquifers are less than 20 metres thick. Permeability is higher in the central part of the aquifer and ranges from 0.5 to 40 metres per day.

A thick, clayey sequence of sheetwash deposits overlies the productive granular alluvium in the east, causing the aquifer to be semi-confined in nature. The sheetwash is composed of low-permeability fine-grained material (Huxley 1982; KCB 2010a).

Groundwater levels within the Condamine Alluvium show almost no difference in water levels with depth. This implies that although the system is made up of many discrete beds, they are extensively inter-connected, with the result that Condamine Alluvium acts for the most part as a single aquifer system (KCB 2010a).

Recharge is primarily infiltration from the Condamine River, with some contribution directly from rainfall and laterally from the surrounding bedrock and alluvium of the tributaries of the Condamine River. The consistent layer of low-permeability black soil (up to 10 metres thick) over most of the Condamine Alluvium restricts rainfall recharge.

Groundwater quality within the Condamine Alluvium is generally good; however, salinity is higher on the alluvial margins which are more distant from the river and in the down-valley direction where permeability is lower. In these areas, the groundwater has resided in the aquifer for longer and there is more potential for the alluvium to interact with the basement (KCB 2010a). The salinity in the aquifer ranges from about 40 mg/L to more than 16,000 mg/L, with an average of about 1,500 mg/L.

The Condamine Alluvium is heavily used for water supply purposes. The groundwater is mainly used for irrigation and town water supply, with minor consumption for domestic, stock watering, industry, stock-intensive and commercial supplies. Bore yields range up to 60 litres a second (L/s), though most are less than 10 L/s (DERM 2009; KCB 2010b).

Groundwater extraction from the Condamine Alluvium has caused a considerable fall in groundwater levels. Water levels vary from less than 10 metres below ground level on the edges of the alluvium to more than 40 metres below ground level in the main extraction area in the centre of the alluvium, to the east of Cecil Plains. Water levels have been steadily falling since the 1960s (KCB 2010a). On average, water levels have fallen by about six metres, but in areas further away from the Condamine River, levels have fallen by up to 26 metres.

4.2.4 Basalts

The Tertiary age Main Range Volcanics contains significant aquifers that are used for irrigation, stock and domestic and town supplies. The aquifers occur at depths ranging from two metres to 155 metres below ground surface, with thickness generally varying from 10 to 30 metres. Bore yields are highly variable, ranging from 5 L/s to 50 L/s, with an average of about 20 L/s. Water quality is generally good, with salinity averaging 900 mg/L and ranging from 50 mg/L to 4,000 mg/L. The water tends to be high-quality because the aquifers respond quickly to recharge from direct infiltration of rainfall, particularly in the elevated areas, and contribute recharge to connected aquifers. Tertiary basalts also occur in the north of the area overlying the Bowen Basin sediments. In general, the aquifers in these basalts are not as high-yielding as those of the Main Range Volcanics.

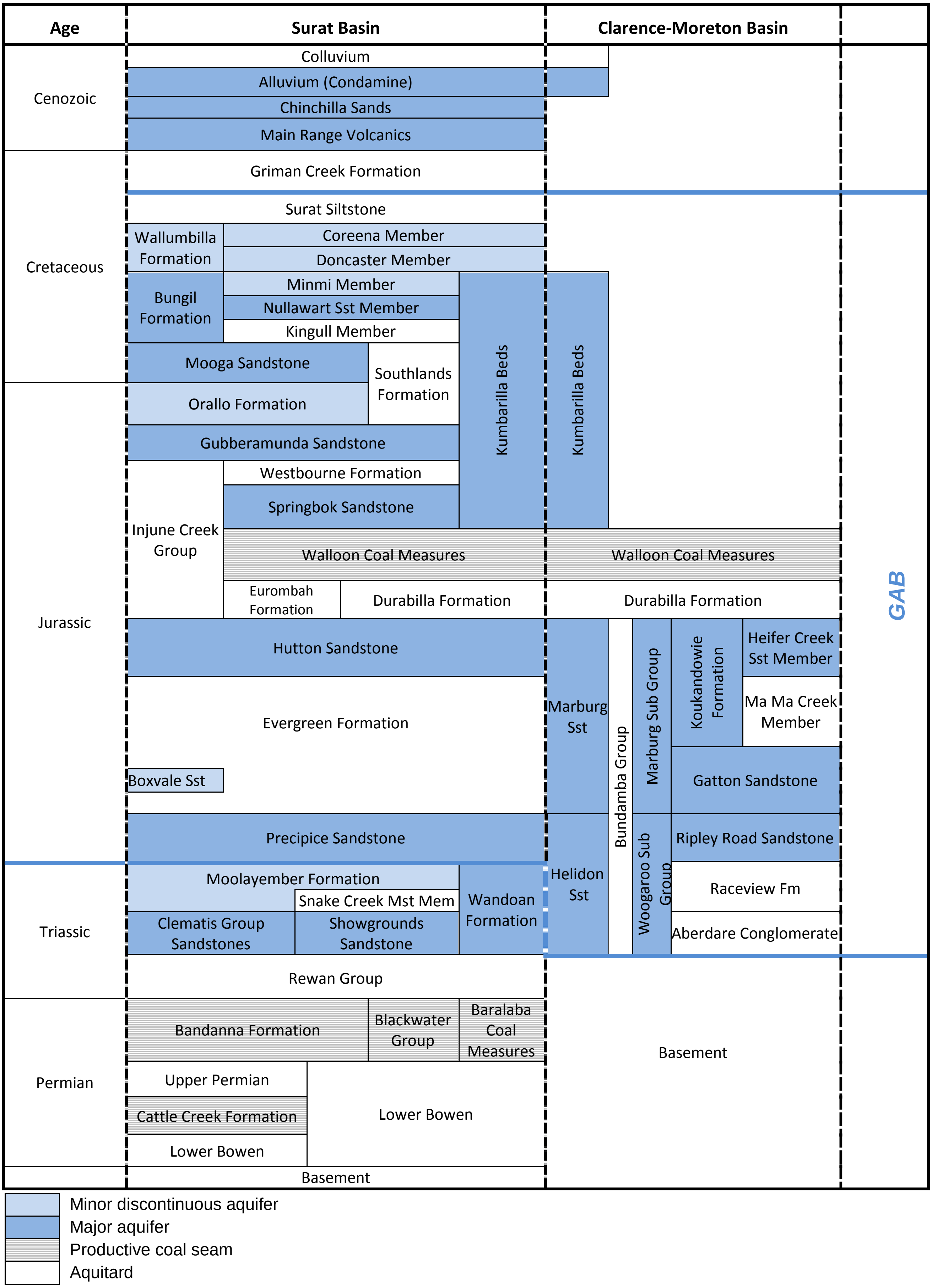


Figure 4-1 Regional hydrostratigraphy

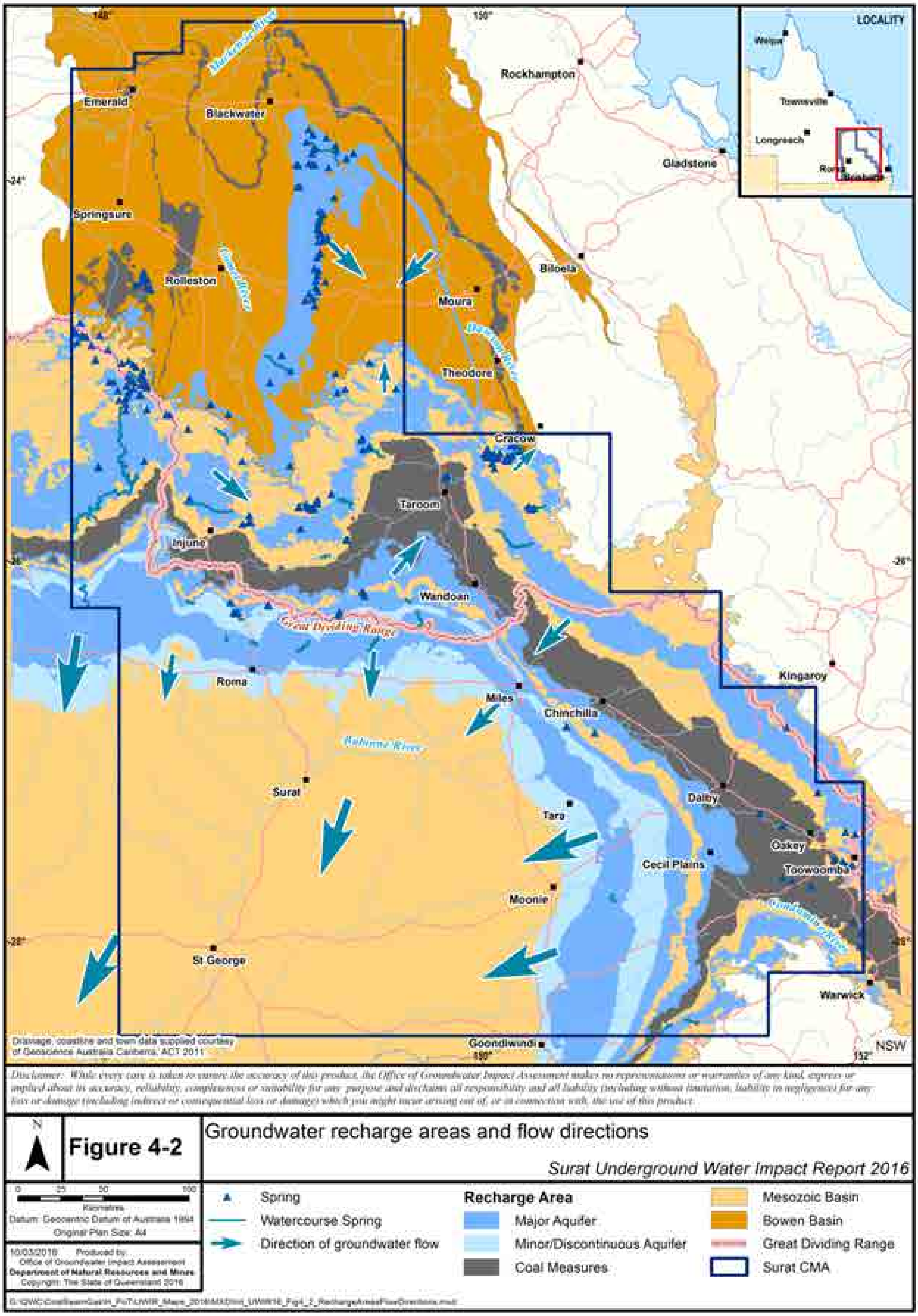


Figure 4-2 Groundwater recharge areas and flow directions

4.3 Hydrogeology of the coal sequences

4.3.1 The Walloon Coal Measures

The Walloon Coal Measures comprise siltstone, mudstone, fine-to-medium-grained lithic sandstone, and coal deposited over geologic time from rivers and in lakes and swamps across the Surat and Clarence-Moreton basins (Scott et al. 2004). Within the Walloon Coal Measures, the Durabilla Formation, the Taroom Coal Measures, the Tangalooma Sandstone and the Juandah Coal Measures have some lateral continuity.

Figure 4-3 shows the recognised stratigraphy of the Walloon Coal Measures; however, the geology is much more complex, comprising mostly thin, discontinuous layers (Scott et al. 2004). Figure 4-4 presents a visualisation of the Walloon Coal Measures, developed by OGIA from detailed geophysical log data for the Talinga area. It shows the complexity of the geology.

At the basin scale, the Walloon Coal Measures is considered to be an aquitard, although in places it functions as an aquifer. The coal seams are generally the more-permeable units and sit within a sequence of mainly low-permeability mudstones, siltstones or fine-grained sandstones. As shown in Figure 4-4, most of the coal seams comprise numerous thin, non-continuous stringers, or lenses (up to 45 individual coal seams can be recognised in places) separated by bands of low-permeability sediments. The coal thickness makes up less than 10 per cent of the total thickness of the Walloon Coal Measures.

Permeability reduces with depth in the Walloon Coal Measures, as the cleats and fractures within the coal seams—which provide most of the permeability in the formation—close up due to the weight of the overlying material. In general, the porosity and permeability of sandstones within the formation is limited, but some sandstones have high porosity and permeability, particularly within the Clarence-Moreton Basin (Bradshaw et al. 2009).

Even though the water quality is generally poor (averaging 3,000 mg/L of total dissolved salt) and bore yields are low (0.2 L/s to 3 L/s), the Walloon Coal Measures is developed for stock and domestic, stock-intensive, industrial and urban purposes, where aquifers can be accessed at shallow depths near the outcrop areas (DNRM 2005). Groundwater is encountered from 20 metres below the ground, with most supplies being deeper than 30 metres (Huxley 1982). Groundwater generally flows from higher elevations in the north and east toward the west and south-west.

The coal seams within the Walloon Coal Measures do not continue across to the western margin of the basin. The Walloon Coal Measures grades into the siltstones and sandstones of the Birkhead Formation. The Birkhead Formation acts primarily as a confining bed in the Surat Basin, supplying only small amounts of poor-quality water mainly associated with fine-grained sandstones; although in the far west, outside the Surat CMA, the formation characteristics are more similar to an aquifer than a confining bed.

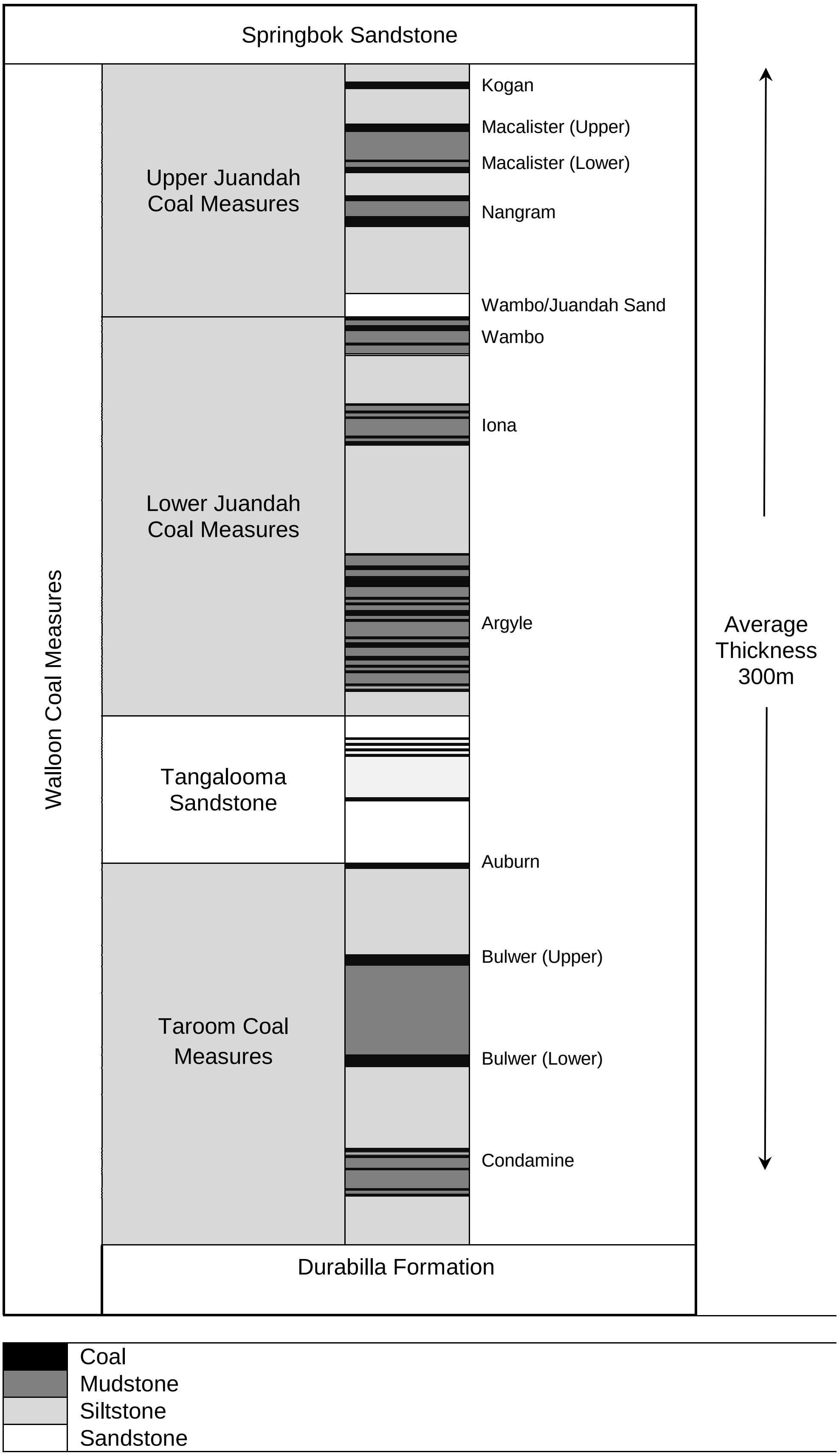


Figure adapted from Scott et al. 2004, Ryan et al. 2012 and Hamilton et al. 2014

Figure 4-3 Stratigraphy of the Walloon Coal Measures

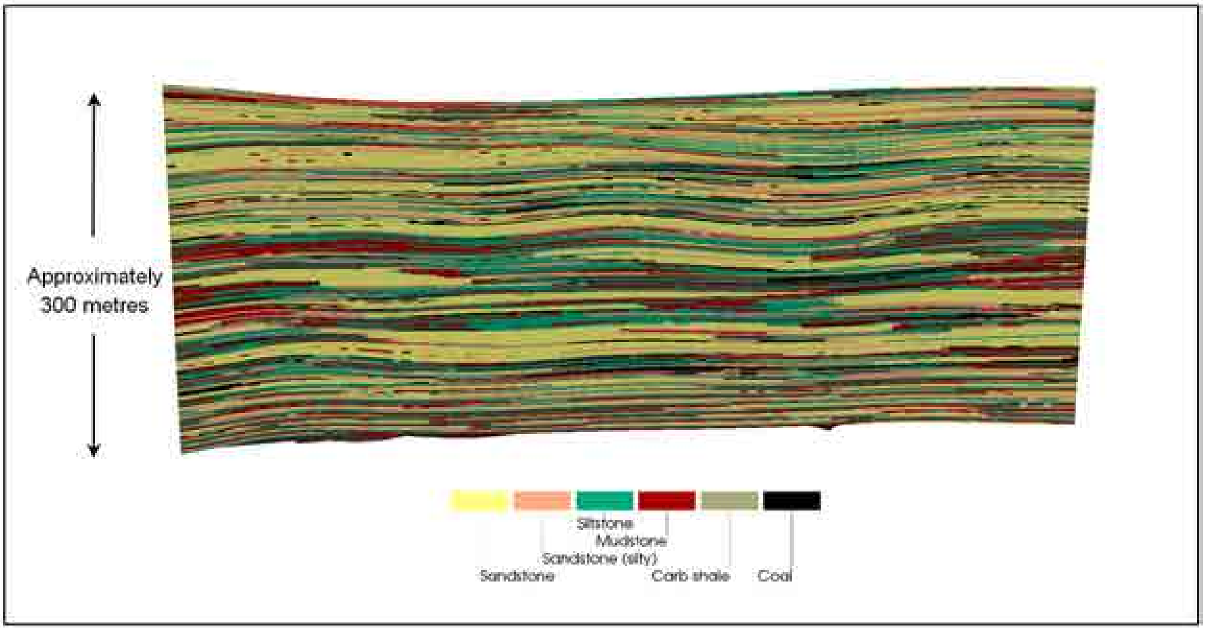


Figure 4-4 Walloon Coal Measures visualisation showing the complexity of the geology

4.3.2 The Bandanna Formation

The Bandanna Formation comprises interbedded coal, mudstone, siltstone and minor clayey sandstone. The thickness of the Bandanna Formation varies from 70 metres to 250 metres. The formation outcrops on the northern boundary of the Surat CMA. The outcrop area constitutes the primary recharge zone for the formation.

The coal seams of the Bandanna Formation are the only sediments with any appreciable permeability within mainly low-permeability sandstones and siltstones. Groundwater flow within the Bandanna Formation is dependent on the permeability of individual coal seams and their vertical and lateral interconnection. Ten individual coal seams can be identified; they tend to be slightly thicker (typically less than two metres) and therefore more continuous than the coal seams in the Walloon Coal Measures. Coal seams typically comprise less than 15 per cent of the total thickness of the Bandanna Formation.

The permeability of the coals of the Bandanna Formation within the deepest areas of the Bowen Basin, in the Taroom Trough, is likely to be so low that there is very limited groundwater flow.

Very little groundwater is being extracted for agricultural or other purposes from this formation. Water quality is variable, with salinity ranging from about 200 mg/L to 9,000 mg/L.

4.3.3 The Cattle Creek Formation

Recent CSG exploration in the Bowen Basin has identified potential economic gas reserves within the coals of the Cattle Creek Formation. Development of this formation is planned as part of the Fairview gas field (Appendix A). In this area, the formation is present at depths of up to 1,800 metres below ground surface and about 500 metres below the base of the Bandanna Formation

4.4 Connectivity

In terms of groundwater movement, the connectivity between two geologic formations is the ease of, or resistance to, groundwater flow between the formations. Where no discernible material separates the formations, the connectivity depends on the weighted average of the vertical permeability of the two formations. Where material separates the two formations, the connectivity depends on the thickness and vertical permeability of the intervening material. As an example, weathered clay and silt provides more resistance to flow than a gravel bed. Similarly, a thick layer of silt provides more resistance to flow than a thin layer of the same material.

All geologic materials are permeable to some extent. Therefore, all adjacent geologic formations are connected to each other to some extent. It is the degree of connectivity that varies.

A good hydraulic connection is not in itself sufficient to induce groundwater to flow between two formations. A hydraulic gradient must also exist, which is a relative difference in water pressure between the formations. While there will be no flow between well connected formations if there is no hydraulic gradient between them, there will be some flow between even poorly connected formations if there is a large hydraulic gradient between them.

4.4.1 The Walloon Coal Measures and the Condamine Alluvium

The Condamine Alluvium is an important groundwater resource that overlies the Walloon Coal Measures. Since 2012, OGIA has led research into the connectivity between the two formations using the following lines of investigation:

- reinterpreting and modelling the geology of the area to map the interface between the formations
- surveying and mapping groundwater levels in the Condamine Alluvium and the Walloon Coal Measures to establish historical and current differences in groundwater levels between the formations
- assessing the chemistry of the groundwater to identify hydrochemical indicators of any past mixing of groundwater between the formations
- conducting aquifer pumping tests and associated drilling at selected sites to establish the physical characteristics of the contact zone between the two formations and to measure vertical hydraulic conductivity.

Details of the research activities and outcomes are reported separately (OGIA 2016a) and are summarised in this section.

The Walloon Coal Measures is the basement unit beneath most of the central area of the Condamine Alluvium. The alluvium is incised into the Walloon Coal Measures by up to 120 metres (Figure 4-5). Across much of the area, the contact between the formations is dominated by an undifferentiated clay, comprising basal alluvial clays of the Condamine Alluvium and/or the weathered upper part of the Walloon Coal Measures. The two are often indistinguishable from each other but have similar hydraulic properties. This clay-rich horizon is termed the transition zone. The extent and thickness of the transition zone was mapped through the review of about 3,500 private water bores and geological modelling of the overlying and underlying formations. Although the transition zone is not present over all of the Condamine area (Figure 4-6), the transition zone—together with the upper mudstones and siltstones of the Walloon Coal Measures above the level of potential for commercial CSG resources—provides a resistance to vertical flow.

Groundwater level data for the area provides further insight into the connectivity between the formations. Water extraction for irrigation has lowered the groundwater level in the more developed parts of the Condamine Alluvium by up to 26 metres over the past 60 years, significantly altering the flow pattern in the formation. Groundwater levels in the Walloon Coal Measures have not materially changed, resulting in a difference of 5–20 metres between the formations across much of the central part of the Condamine Alluvium (Figure 4-7). This difference in groundwater levels suggests that there is a significant impediment to flow between the two formations.

An assessment of the hydrochemistry data supports this conclusion. The study of about 3,000 groundwater chemical analyses found that the underlying hydrochemical signatures in the two formations are different and are more likely to be the result of chemical evolution of water within the formations rather than the movement of water between the formations, even in areas where significant groundwater level differences have existed for a long time.

Aquifer pumping tests were run and observation bores were installed in collaboration with industry and landholders to establish the physical characteristics of the transition zone and to measure the effective vertical hydraulic conductivity at two representative locations. Continuous core samples were collected to observe geological material during drilling, together with geophysical logging of drill holes and lab testing of the core material. The pump tests involved pumping large volumes of groundwater from the Condamine Alluvium and measuring changes to pressure at a range of depths within the Condamine Alluvium and the Walloon Coal Measures. Numerical analysis of the data provided estimates of vertical hydraulic conductivities of about 10^{-6} metres/day, which is typical of a highly effective aquitard.

In summary, detailed mapping shows that low-permeability material exists between the Condamine Alluvium and the parts of the Walloon Coal Measures that could contain commercially viable CSG. Aquifer pumping tests provided estimates of vertical hydraulic conductivities for the material and these estimates are consistent with a highly effective aquitard. Groundwater level data and hydrochemistry data show that, even though groundwater differences between the formations have existed for a long period, there is no evidence of significant movement of water between the formations. All of this suggests that the level of hydraulic connectivity between the Condamine Alluvium and the Walloon Coal Measures is low.

4.4.2 The Walloon Coal Measures and the aquifers of the GAB

As noted in Section 4.3.1, the coal seams within the Walloon Coal Measures are separated by lower-permeability mudstone, siltstone and fine-grained sandstone. For the most part, low-permeability siltstones and mudstones are found at the top of the formation, above the uppermost productive coal seams, and also at the bottom of the formation, below the lowermost productive coal seams. These relatively low-permeability layers act as aquitards, generally separating the productive coal seams from the Springbok Sandstone aquifer above and the Hutton and Marburg Sandstone aquifers below, except in areas where the upper aquitard has been eroded away.

The thickness of the aquitard layer between the upper productive coal seams of the Walloon Coal Measures and the Springbok Sandstone is typically about 15 metres, although in some places it is absent, and it generally has low permeability. Figure 4-8 shows the thickness distribution of this layer.

The Springbok Sandstone is highly variable in nature. At some locations it is an important aquifer but in other places it is highly compacted and has very low permeability. The formation was deposited on the eroded surface of the Walloon Coal Measures. In parts of the north-eastern Surat Basin, the upper aquitard of the Walloon Coal Measures was completely eroded before the deposition of the Springbok Sandstone, and the formation is in contact with the productive coal seams (Scott et al. 2007). A higher degree of interconnectivity is expected in these areas. However, while there are some similarities between the hydrochemistry of water samples taken from the two formations, there are distinct differences in the concentrations of calcium, magnesium and sulphate, suggesting limited interconnectivity (OGIA 2016b). At this early stage of CSG development, the available monitoring data shows little or no evidence of CSG-related pressure impacts in the Springbok Sandstone and, therefore, also suggests limited connectivity (Section 6.3.2).

The aquitard layer of the Walloon Coal Measures separating the lowermost productive coal seams (typically the Taroom Coal Measures) from the underlying Hutton Sandstone is about 45 metres thick, on average (Figure 4-8). This lower aquitard, often referred to as the Durabilla or Eurombah Formation, is mainly siltstone, mudstone and fine-to-medium-grained poorly sorted sandstones with almost no coal and, consequently, little permeability. The Durabilla Formation is present at thicknesses in excess of 30 metres throughout the proposed area of CSG development; connectivity between the Walloon Coal Measures and the underlying GAB units, including the Hutton Sandstone, is therefore considered to be low. This is reflected in the hydrochemistry data which suggests that groundwater quality in the Walloon Coal Measures is distinctly different from that encountered in the underlying Hutton Sandstone. This difference in hydrochemistry becomes more pronounced with distance from the recharge areas and with increasing confinement. Therefore, in areas of CSG production, these formations show significant hydrochemical differences (OGIA 2016b). Connectivity between the formations is expected to be low (Section 6.3.3).

4.4.3 Permian coal measures and surrounding aquifers

The Bandanna Formation is the main productive CSG formation within the Bowen Basin. It is laterally isolated from its equivalent to the north, the Rangal Coal Measures, by erosion. It is isolated from its equivalent to the east, the Baralaba Coal Measures, by significant faulting. Therefore, depressurisation of the Bandanna Formation is unlikely to affect aquifers to the north around Clermont and to the east around Biloela.

The deeper Permian formations underlying the Bandanna Formation have extremely low permeability. Therefore, it is unlikely that depressurisation of the Bandanna Formation will affect the underlying formations.

The Bandanna Formation is generally isolated from the overlying major aquifers by the thick, very low-permeability mudstones of the Rewan Group. Therefore, for the most part, depressurisation of the Bandanna Formation will not affect overlying aquifers. However, there is a narrow, north-south trending zone lying to the east of Injune, close to the existing CSG production fields of Fairview and Spring Gully (Figure 4-9). In this zone, the geological strata to the east of the Hutton-Wallumbilla Fault were uplifted and subsequently eroded away before deposition of the Precipice Sandstone, bringing the Precipice Sandstone into direct contact with the Bandanna and Cattle Creek formations in this area. This leads to a potentially higher degree of interaction between both of these coal-bearing strata and the Precipice Sandstone in this area. Recent geological mapping and modelling work carried out by OGIA suggests that the contact zone between the Bandanna Formation and the Precipice Sandstone in this location is somewhat narrower than previously mapped in UWIR 2012.

The presence of coal within the Bandanna Formation is variable. The more permeable and productive coal-bearing horizons are located in the more easterly part of the contact area with the Precipice Sandstone. Within this area, there is relatively high potential for groundwater flow between the productive coal measures of the Bowen Basin and the Precipice Sandstone.

The Precipice Sandstone is separated from the next major aquifer above it, the Hutton Sandstone, by the Evergreen Formation, which is a thick formation of very low permeability. The Evergreen Formation is known to be an effective seal because it forms a cap, trapping gas for conventional petroleum and gas production. It is unlikely that any pressure reduction in the Precipice Sandstone resulting from depressurisation of the Bandanna Formation will affect the Hutton Sandstone.

Some of the earliest CSG fields have been developed in the Bandanna Formation. Fairview was developed in 1996 and Spring Gully in 2005. Monitoring data around the developed area supports the above understanding about connectivity. Water pressures have fallen in the Bandanna Formation by more than 200 metres due to depressurisation for CSG production, with no discernible effect on water levels within the Precipice Sandstone to date (Section 6.3.5).

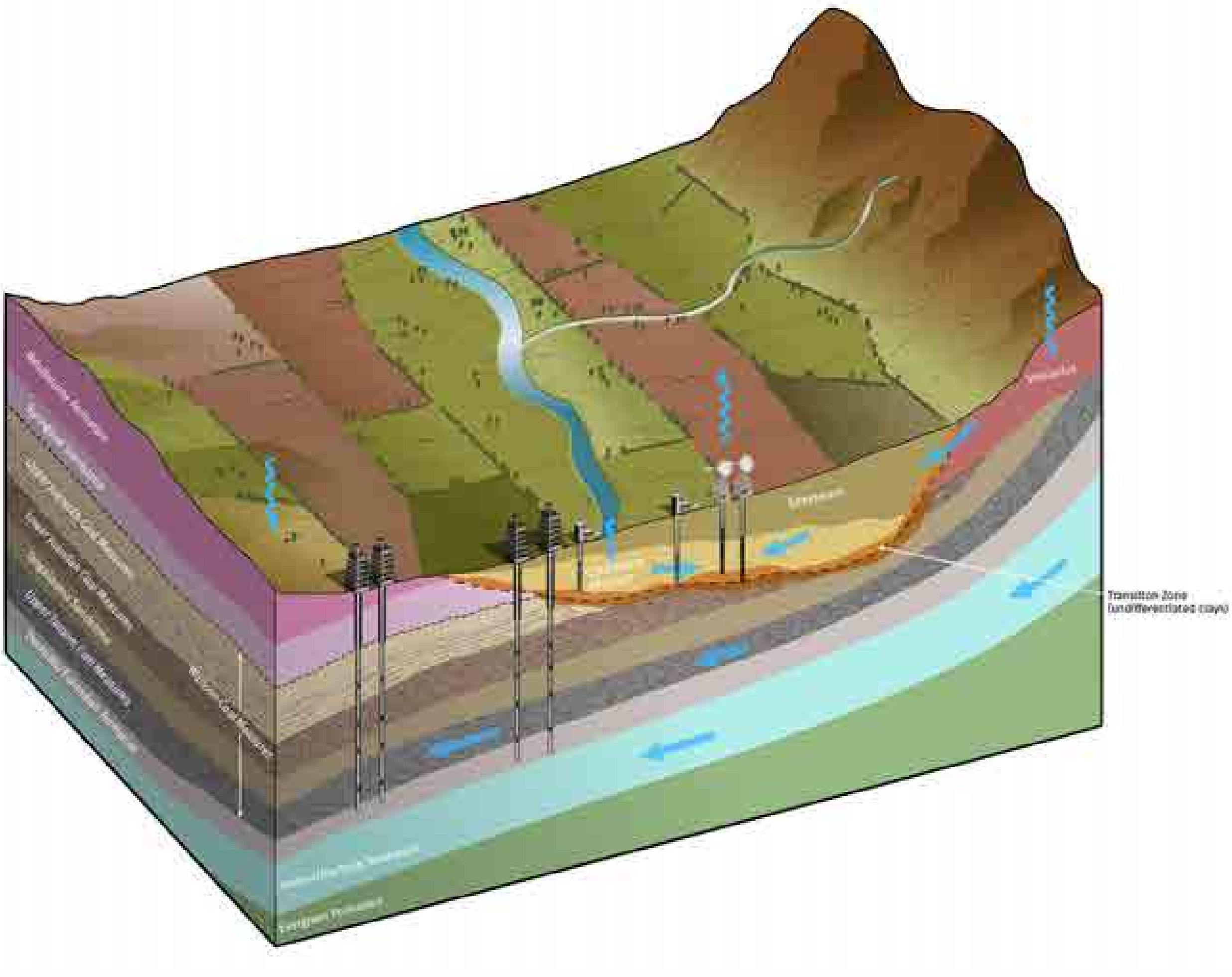


Figure 4-5 Schematic of the regional hydrogeological setting around the Condamine Alluvium

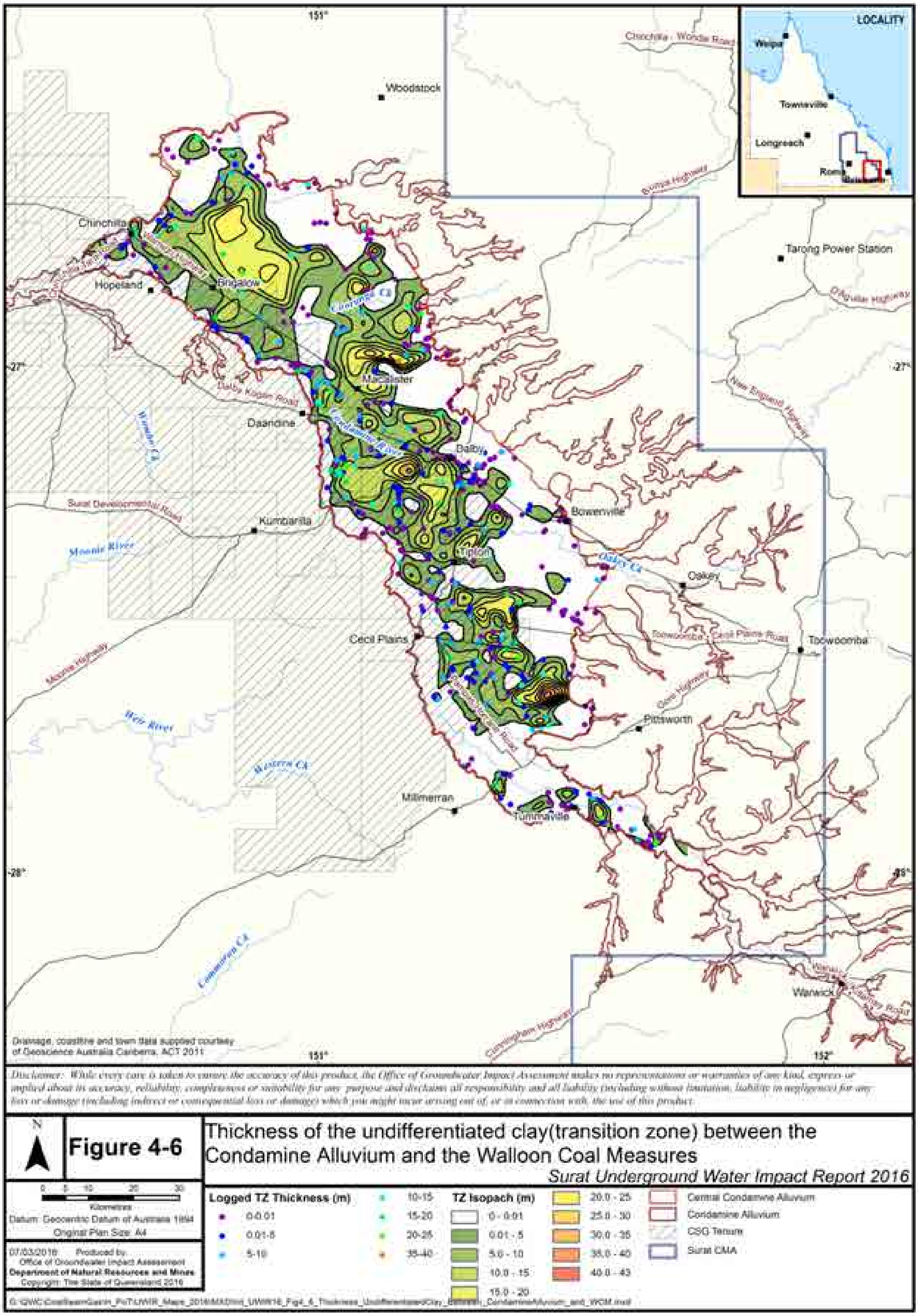


Figure 4-6 Thickness of the undifferentiated clay (transition zone) between the Condamine Alluvium and the Walloon Coal Measures

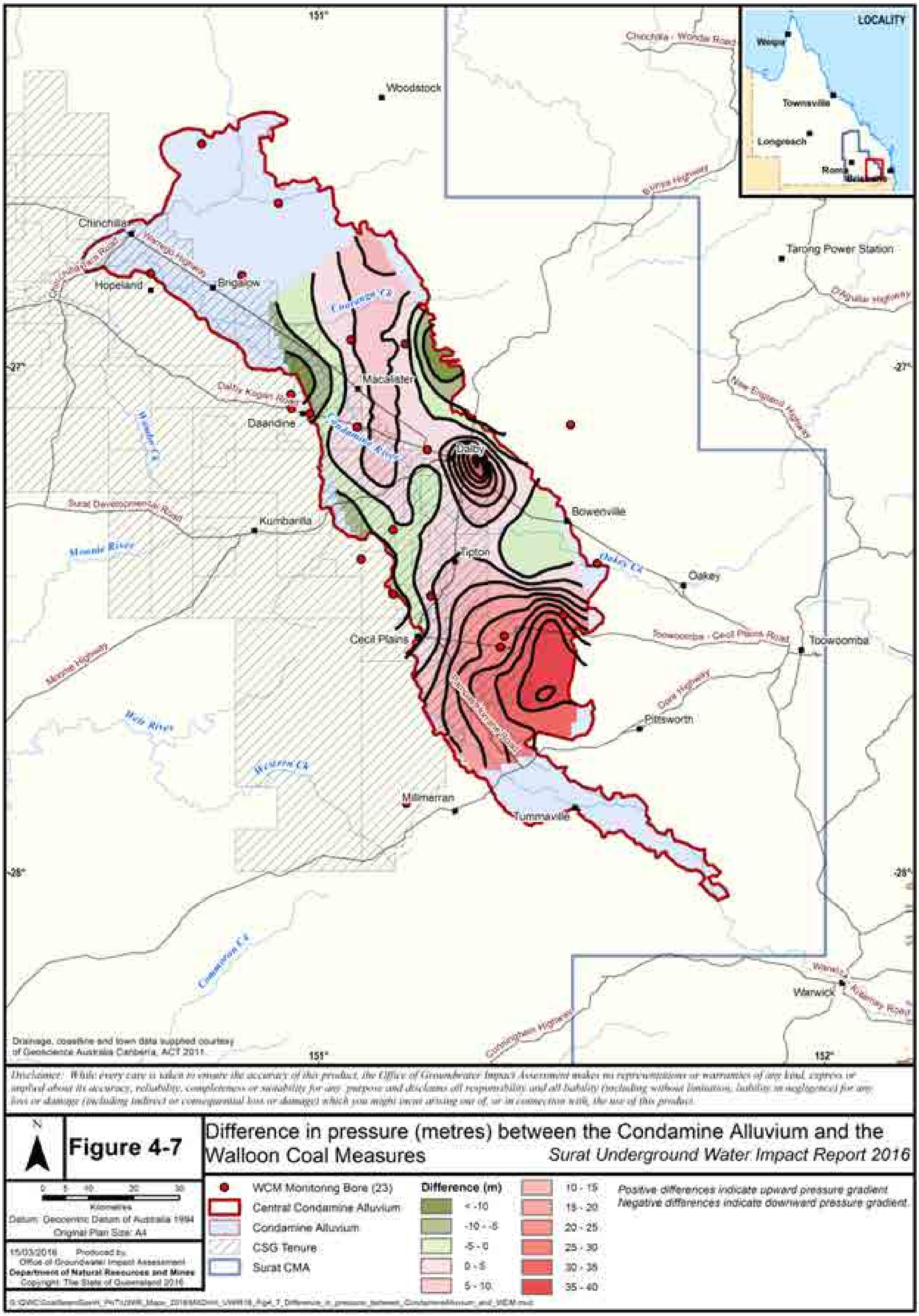


Figure 4-7 Differences in pressure (metres) between the Condamine Alluvium and the Walloon Coal Measures

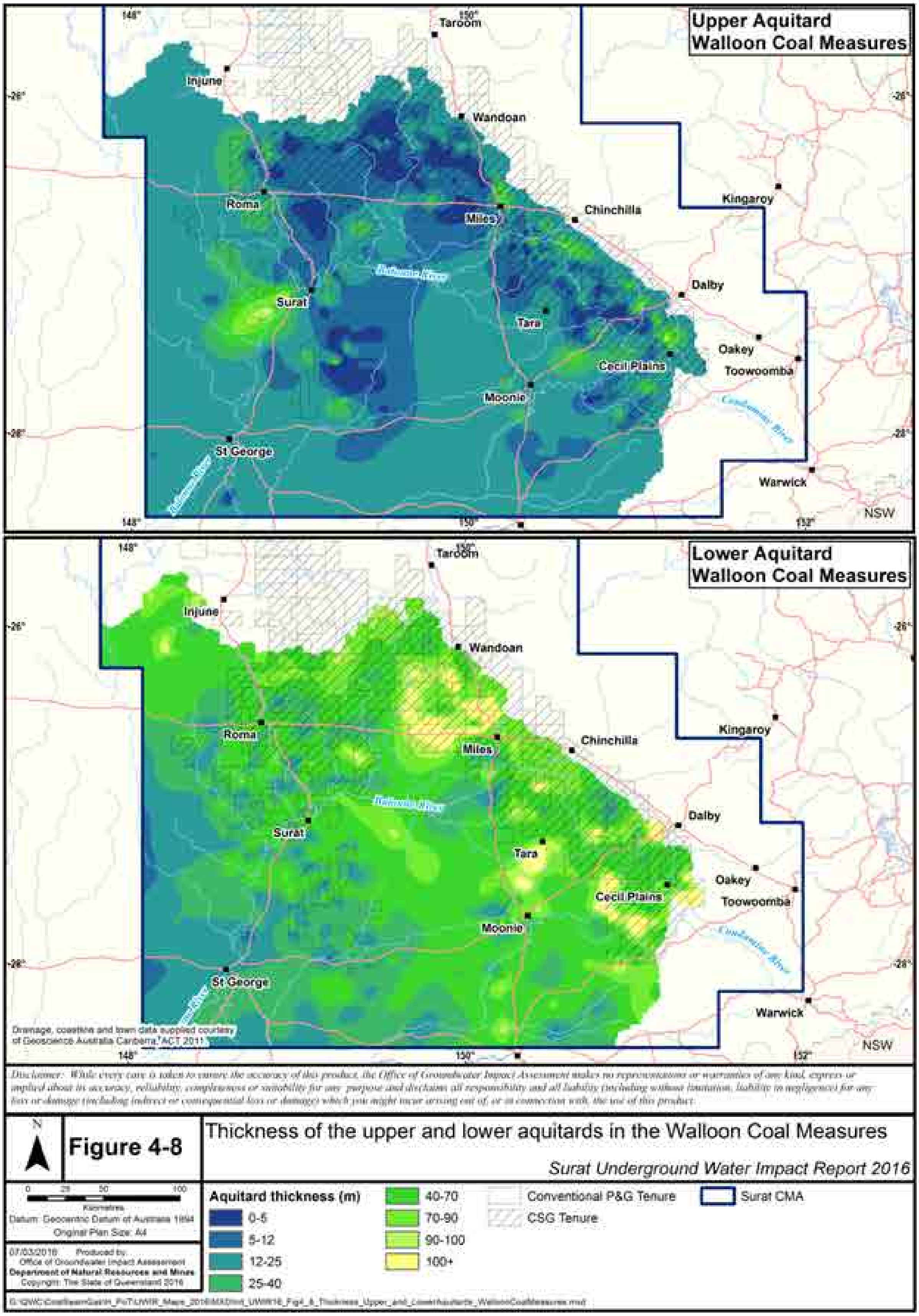


Figure 4-8 Thickness of the upper and lower aquitards in the Walloon Coal Measures

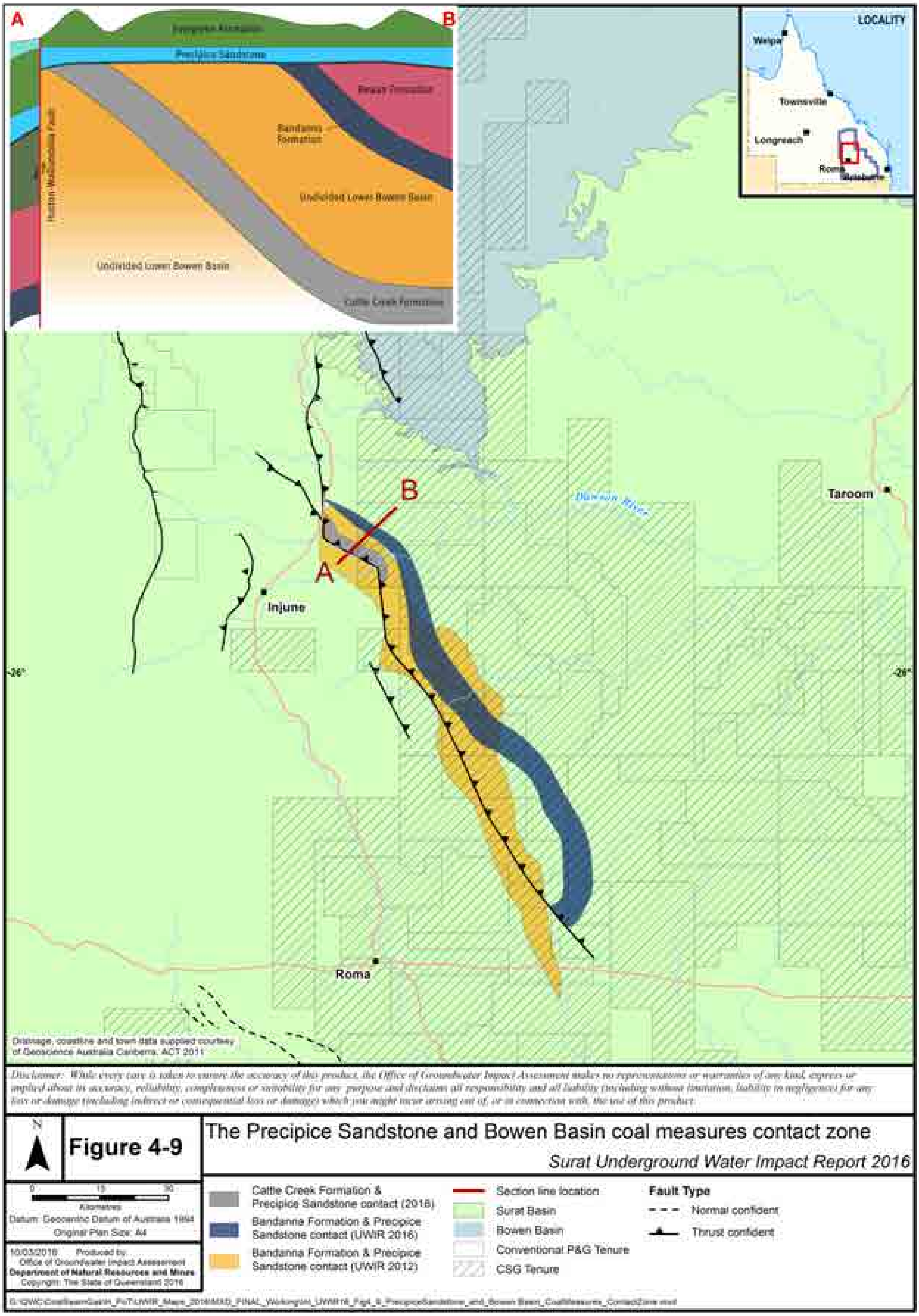


Figure 4-9 The Precipice Sandstone and Bowen Basin coal measures contact zone

4.5 The influence of geological structures

The sedimentary rocks in the Surat Basin were deformed after being deposited, resulting in a variety of geological structures related to systems of faults, fractures and folds. From a regional groundwater impact assessment point of view, faults are of significance because they can bring coal reservoirs into direct contact with GAB aquifers in some areas. For instance, as discussed previously (Section 4.4.3) and shown in Figure 4-9, geological strata to the east of the Hutton-Wallumbilla Fault have been uplifted and eroded, bringing the Precipice Sandstone into direct contact with the Bandanna and Cattle Creek formations in this area. This leads to a potentially higher degree of interaction between both of these coal-bearing strata and the Precipice Sandstone in this area.

The Hutton-Wallumbilla Fault is one of 37 regional-scale fault systems within the Surat CMA, the locations of which are shown in Figure 3-3. Displacements associated with these fault systems in the Bowen Basin strata can be in excess of 1,000 metres. Since they typically extend for hundreds of kilometres, they are relatively easy to trace across multiple seismic survey lines and, therefore, have been mapped. However, these displacements do not typically extend up into the overlying Surat Basin formations. For 17 of these regional fault systems, there is sufficient data for them to be modelled as individual features in both the revised geological model (Section 3.3) and the associated groundwater flow model (Section 7.2). The potential impacts of the remaining 20 fault systems, for which there is less information, will continue to be assessed using uncertainty analysis techniques.

The most common structures present within the Surat Basin are steeply dipping (60–80 degrees) normal faults. These faults are relatively minor features that cannot easily be correlated across seismic survey lines, which are typically about two kilometres apart and, therefore, cannot easily be mapped other than in areas where 3D seismic surveys have been carried out. Estimated throws on normal faults identified in the eastern Surat Basin range from less than 10 metres to about 90 metres, with 77 per cent of the faults having throws of less than 20 metres (Sliwa 2013). There appears to be little or no spatial relationship between the location of the major fault systems in the underlying Bowen Basin and those of the normal fault populations, although there is an apparent tendency for the larger normal faults to occur towards the margins of the Surat Basin where the basin sediments directly overlie basement bedrock (Sliwa 2013). Since the location of these faults is not well defined, they are not explicitly modelled in either the revised geological model or the regional groundwater flow model. Their potential influence on groundwater flow will continue to be assessed using uncertainty analysis techniques.

From a hydrogeological perspective, faults may act as either barriers or conduits to groundwater flow and, since fault hydraulic properties are typically highly variable, individual faults may switch from barriers to conduits over relatively short distances. Furthermore, faults can have relatively low permeability in the horizontal direction, thereby restricting flow within units, but can also have relatively high permeability in the vertical direction, thereby supporting flow between units.

Over time, processes such as mineralisation and precipitation tend to effectively seal fractures created at the time of faulting. In areas that are tectonically relatively stable, such as the Surat CMA, fault permeability decreases over time, unless the fault is reactivated by an earthquake or other tectonic event. Flow across fault planes can also be restricted by processes such as clay smearing (Yielding et al. 1997).

Fault properties, therefore, tend to be spatially highly variable but they also vary with time and it is generally not possible to predict the hydrogeological behaviour of individual faults without detailed field investigations, which would typically comprise targeted drilling, geophysical survey and hydrogeological monitoring. OGIA has undertaken one such investigation of the Hutton-Wallumbilla Fault in the vicinity of the Lucky Last spring complex (Section 9.2.2), which has significantly improved our understanding of the likely hydrogeological behaviour of this particular fault at this location. However, it is not practicable to repeat this type of investigation for all faults within the Surat CMA. Representing faults, therefore, is a significant challenge to any regional-scale modelling study. Nevertheless, from the information available it is possible to make some general statements about the likely hydrogeological behaviour of faults within the area. This information has been used to inform parameterisation of faults in the regional groundwater flow model (Section 7.2).

In general, most of the faults in the Surat CMA are likely to restrict flow, especially in the horizontal direction, thereby generally reducing the propagation of CSG impacts laterally, compared to un-faulted areas. The coal seams within the major CSG reservoirs in the area are generally relatively thin and comprise only a small proportion of the overall thickness of these units (typically less than 10 per cent). Any displacement of these seams will, therefore, tend to introduce a barrier to groundwater flow since there is a high probability that a permeable coal seam will be juxtaposed with a less-permeable siltstone, claystone or mudstone on the other side of the fault. Even in situations where the coal seams are juxtaposed against other permeable sandstone or coal units, the generally high clay content of most of the other strata means that the potential for clay smearing across the fault plane is likely to be significant at most locations within the CMA. There are numerous examples of the importance of clay content in affecting the hydrogeological behaviour of faults within petroleum and gas fields. For instance, experience from operation of the Hibernia field in Newfoundland, Canada, suggests that even relatively minor clay content of less than 15 per cent in faulted rocks was enough to reduce the fault permeability by about five orders of magnitude compared to the host-rock permeability (Cerveny et al. 2004). Anecdotal information provided by the CSG companies operating in the Surat CMA suggests that about 90 per cent of faults identified within the Walloon Coal Measures behave as barriers to flow. This is considered to be consistent with experience of mining these same coals, which also suggests that the coal units in the Bowen and Surat basins are typically highly compartmentalised.

Due to a range of site-specific factors, including the elapsed time since the faulting event occurred and the presence or absence of clay within the host rock, it is nevertheless possible that individual faults act as conduits to flow in both horizontal and vertical directions. Where this occurs, it is possible that the presence of faults could propagate CSG impacts laterally within the coal reservoirs and/or vertically into adjacent aquifers such as the Springbok and Hutton sandstones, compared to un-faulted areas. As a result, the potential influence of faulting on groundwater flow will continue to be assessed using uncertainty analysis techniques (Section 11.5.2).

4.6 Abandoned or poorly constructed bores

There are about 22,500 water supply bores in the Surat CMA. In recent decades, construction standards have required that bores be constructed in such a way that they access only one aquifer, and that bores be properly abandoned when they are no longer in service. However, some older bores may be open to more than one formation.

About 1,700 conventional petroleum and gas bores have been drilled in the CMA. In recent decades these bores have been required to be properly abandoned when they are no longer in service, or converted for use as water supply bores. However, older abandoned wells may be allowing water to flow between formations.

A similar situation applies to bores drilled for coal exploration or coal mine development. In recent decades, coal exploration bores have been properly abandoned but in earlier decades abandonment practices were poor. In the Surat CMA, coal bores are rarely drilled to a depth of more than 200 metres and, therefore, are located in or near the outcrop areas of the Walloon Coal Measures on the margin of the basin. Coal bores in the outcrop areas have no effect on groundwater connectivity. Coal bores near the outcrop areas could increase connectivity locally; however, these bores are likely to be uncased and to have collapsed over time, thereby reducing the potential for cross-formational flow.

Given that the majority of the 6,500 CSG wells installed in the CMA are of relatively recent construction, the risks associated with these bores are considered to be relatively low. However, since formations other than target coal formations can contain minor coal seams, some CSG may have been screened into those formations and contribute to cross-formational flow.

Overall, although there may be local effects resulting from poor construction or abandonment of bores and wells, these effects are unlikely to be significant at a regional scale. Nevertheless, the potential effects of abandoned or poorly constructed water supply, conventional petroleum and gas and CSG wells will be assessed using uncertainty analysis techniques (Section 11.5.2).

4.7 Understanding how springs function

Since the preparation of UWIR 2012, monitoring and research at springs has provided a significant body of new knowledge that has improved our understanding of how springs function and about their source aquifers. This in turn has allowed a better assessment of the risk associated with CSG water extraction in the Surat CMA, and to update the spring monitoring strategy as set out in Chapter 9. Monitoring and research activities in the CMA have focused on springs located in areas where impacts on groundwater pressures were predicted in the UWIR 2012, and on springs known to host a listed species or a listed ecological community under the EPBC Act.

The following monitoring and research activities have been completed:

- Tenure holders monitored spring vents and watercourse springs in accordance with the UWIR 2012 and Australian Government CSG project approval conditions under the EPBC Act.
- Tenure holders evaluated and assessed options for preventing or mitigating impacts at spring sites identified in the UWIR 2012.
- OGIA and tenure holders conducted field investigations, including surface geological mapping, ground geophysics, and installing investigation bores and piezometers at higher risk sites.

The new data generated through these activities has led to an improved understanding of groundwater flow, at both regional and local scales, for 17 representative spring complexes. The activities carried out and the results are set out in a detailed report (OGIA, 2016c) and are summarised in this section. The following general conclusions were reached:

- Groundwater flow along subsurface geological structures or at the contact between geological units is the dominant control on groundwater flow to spring wetlands.
- Erosion and dissection of the landscape by surface water flows are the main surface processes that control where groundwater naturally discharges in the landscape (Figure 4-10).
- Many spring wetlands receive groundwater inflows from both regional and local groundwater systems. The regional aquifers providing flow to the spring wetlands are the Precipice Sandstone, the Boxvale Sandstone Member of the Evergreen Formation, the Hutton Sandstone, the Gubberamunda Sandstone and the Clematis Sandstone. However, at many wetlands, local groundwater is a significant contributor. For a number of wetlands, previous source aquifer attributions have been revised.

- The geometry (shape) of the spring wetlands is controlled by the presence or absence of a low permeability regolith and the local topography. The extent of the regolith and the thickness of the organic, clay-rich wetland soils significantly influence wetland flora. Surface-water flows significantly influence the geometry and flora assemblages in springs located within watercourses.
- Seasonal changes in evapotranspiration appear to have a significant influence on the extent of the wetlands. Seasonal changes to wetland area and discharge are superimposed onto subtler longer-term changes driven by land use, climate and changes in groundwater pressures.

4.7.1 How springs occur in the Surat CMA

There are three basic hydrogeological mechanisms by which springs occur in the Surat CMA. The mechanisms are described below and shown in Figure 4-10.

a) **Change in permeability:** A spring can form where there is a change in the hydraulic properties of the geology within the landscape. This type of spring is often referred to as a ‘contact spring’. Where a higher-permeability layer overlies a lower-permeability layer, water is restricted from flowing across the boundary. As a result, the water tends to flow laterally and may reach the surface as a spring. This can occur where there is change in permeability within a geologic formation or at the boundary of a geologic formation.

b) **Presence of a geological structure:** A geological structure, such as a fault, can provide a path to the surface along which water can flow. If an underlying aquifer is confined by material with low permeability, and the water pressure in the aquifer is high enough, water can flow to the surface to form a spring.

c) **Erosion of the surface geology:** Erosion and dissection of the landscape by surface water flows can provide opportunities for groundwater to reach the surface. This can occur where an outcropping aquifer is eroded, creating a depression that is deep enough to reach the water table. This situation is generally associated with creeks and streams. In other areas, a confining unit may be dissected, resulting in a reduction in the thickness of the confining unit, and providing an opportunity for groundwater to flow to the surface.

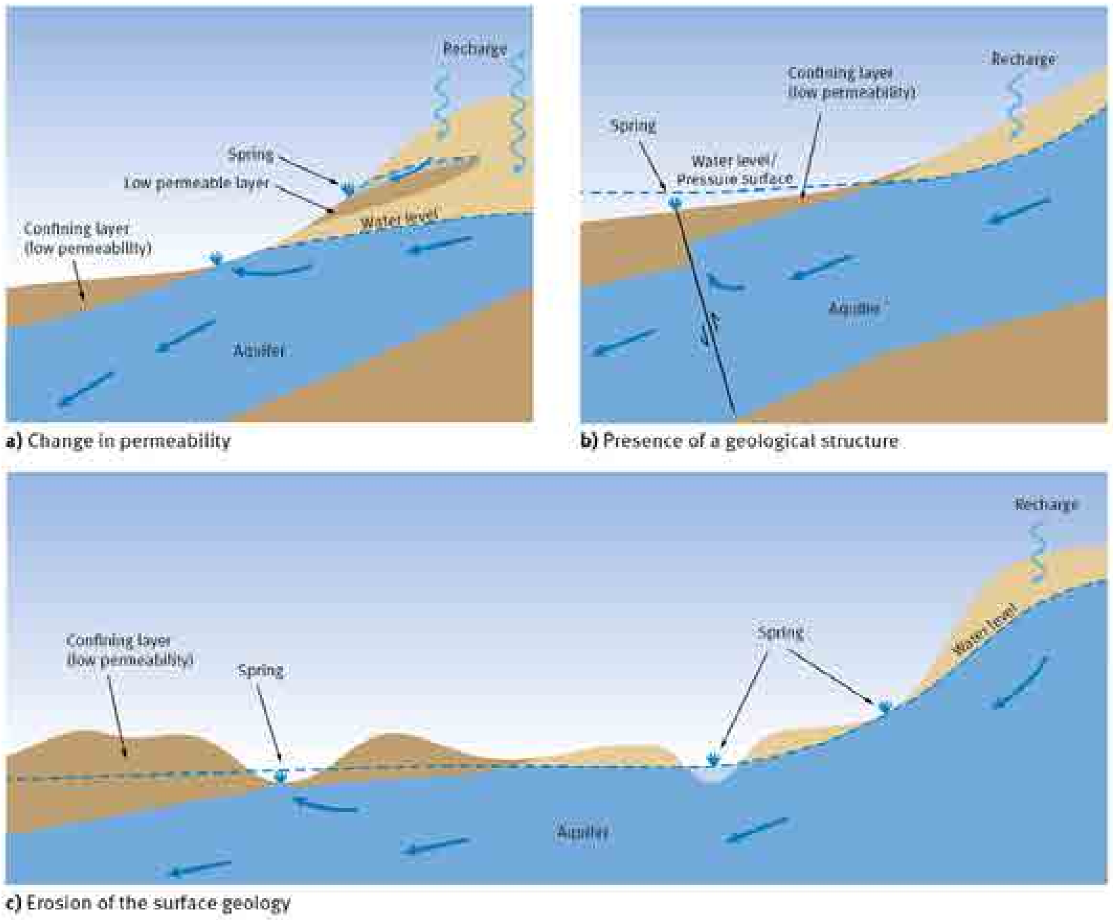


Figure 4-10 Hydrogeological mechanisms for groundwater discharge

4.7.2 Spring wetland typology

A wetland typology was developed to support the preparation of the spring impact management strategy for the Surat CMA, as set out in Chapter 9. The wetland types are based on how and where the wetland occurs within the landscape. The landscape setting and the main hydrological processes for each wetland type are shown in Figure 4-11.

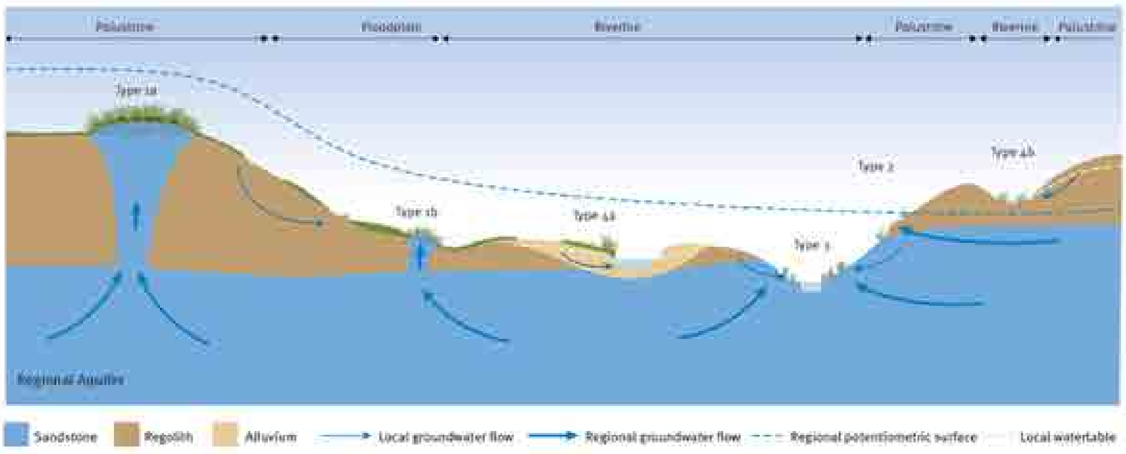


Figure 4-11 Wetland types in the Surat CMA

The wetland attributes incorporated into the typology are landscape setting, geomorphology, groundwater flow system, regolith, water regime and floristic assemblages, as described in Table 4-1.

Table 4-1 Wetland types

Wetland type	Description
Type 1	Permanent fresh-to-brackish wetlands located outside drainage lines with well-developed peat wetland soils and dense vegetation cover. These wetlands are mainly fed by regional groundwater systems with some local groundwater system contributions. There are two subtypes: • Type 1a is located on the floodplain or within a palustrine landscape setting. • Type 1b is located at the interface between the floodplain and riverine environments and is influenced by surface-water flows. This wetland type is associated with artesian conditions and hydraulic mechanisms (Figure 4-10b or Figure 4-10c).
Type 2	Semi-permanent brackish wetlands located outside drainage lines with minor wetland soils and minor vegetation cover. These wetlands are mainly fed by regional groundwater systems and are associated with hydraulic mechanism (Figure 4-10c).
Type 3	Permanent to semi-permanent riverine wetlands, with minor wetland soil development and moderate vegetation cover. These wetlands are mainly fed by local and regional groundwater systems with significant influence of surface-water flows. These wetlands are associated with hydraulic mechanism (Figure 4-10c).
Type 4	Semi-permanent fresh riverine to palustrine wetlands, with minor wetland soil development and moderate vegetation cover. These wetlands are mainly fed by local groundwater systems. There are two subtypes: • Type 4a is located within a riverine environment with deep, sandy alluvial deposits (non-GAB). • Type 4b is located within a riverine-to-palustrine environment with shallow or no consolidated material. These wetlands can form in areas of significant topography in the northern Surat Basin. These wetlands are associated with hydraulic mechanism (Figure 4-10a).

Each spring wetland in the Surat CMA has been assigned a wetland type and these are listed in Appendix H-1. The typology has been used to specify monitoring approaches and for assessing risk to springs from a change in the groundwater regime caused by P&G water extraction (Section 9.4).

5 Current groundwater extraction

- The rate of CSG water extraction in the Surat CMA has increased from 18,000 megalitres per year in 2012 to about 65,000 megalitres per year.
- The 22,500 water bores in the Surat CMA are extracting about 203,000 megalitres per year for non-CSG purposes.
- Recorded details of the water bores and the new geological model have been used to check which aquifers the water bores are accessing.
- New methods have improved the estimation of the volume used for stock watering, which is a major component of the water balance.

Groundwater is used extensively in the Surat region. Grazing is the biggest use of groundwater from the GAB aquifers, while irrigation for agriculture is the biggest use of groundwater from shallow aquifer systems such as the Condamine Alluvium. Groundwater extraction associated with P&G development has increased with the expansion of the CSG industry.

This chapter summarises current estimated water use related to P&G and non-P&G activities to show the relative significance of the two water-use sectors and to inform construction and calibration of the regional groundwater flow model.

5.1 Non-petroleum and gas groundwater extraction

Non-P&G uses of groundwater in the Surat region are agriculture, industrial use, town water supply, and stock and domestic (S&D) use. Under the Water Act, an authorisation is required for extraction of groundwater, other than for P&G activities. The type of authorisation varies depending upon the aquifer system and the risk to the resource. The following types of authorisation exist in the Surat CMA:

- For GAB aquifers, a water licence is required for taking groundwater for all non-P&G activities, including S&D use in most areas. Water licences for uses other than S&D have annual volumetric limits as a condition of the licences.
- For the Condamine Alluvium and Main Range Volcanics, a water licence with a volumetric limit is required for taking groundwater for all uses other than S&D. A statutory authorisation exists for S&D use and a water licence is not required.
- Other groundwater systems in the area are not heavily used. A statutory authorisation exists for taking groundwater from these systems.

DNRM administers the licensing provisions of the Water Act. Information about water licences, authorised volumetric limits and uses is recorded in DNRM's Water Management System, and information about the bores that take water is recorded in DNRM's Groundwater Database (GWDB). The GWDB may not contain records of all water bores that take water under a statutory authorisation. Many bores with volumetric limits are metered, but S&D bores are not metered.

The spatial distribution of the water bores in the Surat CMA is shown in Figure 5-1. The historical growth in water bore construction is shown in Figure 5-2.

Table 5-1 is a summary of all non-P&G water bores and the estimated current water extraction per aquifer. The estimated extraction for volumetric entitlement bores is the maximum currently authorised under the respective water licence; actual water use may be less than this.

Since preparing the UWIR 2012, OGIA has refined the method used to estimate water extraction from S&D bores (OGIA 2016b). The new method takes into account the property size, the livestock-carrying capacity and the availability of other water supplies to estimate the groundwater demand. The method also differentiates between rural and urban or peri-urban properties. Because S&D use is a major component of many water resource assessments, OGIA will continue to promote to water resource managers the use and further development of the new method to estimate S&D water use.

The method by which bores are attributed to aquifers has also been improved since the UWIR 2012 was prepared and is now based on the new regional geological model (Section 3.3). In most cases, the attribution was clear. However, in cases where bore construction information was limited, aquifer attribution was made on the basis of the information available.

These changes—to the method of estimating the volume of water extracted from S&D bores and to the attribution of bores to aquifers—are reflected in some significant changes to Table 5-1, compared to the equivalent table in the UWIR 2012. In particular, the volume of extraction from S&D bores has decreased substantially.

Also, a significant number of bores previously thought to be extracting water from GAB formations are now assessed to be accessing water from shallow alluvial and Upper Cretaceous formations. Some bores have now been attributed to low permeability layers that are more generally considered to be aquitards, such as the Durabilla Formation, although these bores tend to be restricted to outcrop areas.

In the Condamine Alluvium, the total number of bores has reduced slightly, but the estimated total volume of water extraction has risen since 2012. This reflects some aquifer reassignment by OGIA and the granting of new entitlements in areas away from the central Condamine Alluvium.

As summarised in Table 5-1, there are about 22,500 water bores within the CMA. Less than seven per cent of these are artesian. Total water extraction is about 203,000 ML/year, of which about 53,000 ML/year is from the GAB formations and 150,000 ML/year is from other aquifers. Most of the non-GAB extraction is from shallow alluvial strata, including the Condamine Alluvium and the Main Range Volcanics.

The water use types listed in Table 5-1 are defined as follows:

- **Agriculture** includes irrigation, aquaculture, dairy farming and intensive stock watering. It excludes non-intensive stock and domestic use.
- **Industrial** includes industrial, commercial and mining use.
- **S&D** includes rural stock and domestic use, and urban/peri-urban domestic use.
- **Town water supply** includes supplies for schools and similar institutions; reticulated domestic supply systems operated by groups of individuals; and some commercial and industrial use where the water is delivered through town water reticulation systems.

Table 5-1 Non-petroleum and gas groundwater extraction in the Surat CMA

Formation	**Number of bores**			**Estimated groundwater extraction (ML/year)**				**Total**
	Non-S&D	S&D	Total	Agriculture	Industrial	Town water supply	S&D	**(ML/year)**
Non-GAB upper formations								
Condamine Alluvium	1,144	2,709	3,853	64,251	1,476	4,227	2,070	**72,024**
Other alluvium	322	1,201	1,523	16,130	555	1,311	1,447	**19,443**
Main Range Volcanics & Tertiary Volcanics	1,293	5,924	7,217	39,200	2,659	4,459	4,726	**51,044**
Other Cenozoic age units	11	165	176	706	4	11	378	**1,099**
Upper Cretaceous formations	7	210	217	120	-	-	663	**783**
Sub-total	2,777	10,209	12,986	120,407	4,694	10,008	9,284	**144,393**
GAB formations								
Wallumbilla Formation	3	90	93	518	-	-	221	**739**
Bungil Formation	3	232	235	20	-	68	671	**759**
Mooga Sandstone	8	543	551	103	-	75	1,259	**1,437**
Orallo Formation	31	620	651	359	2	177	1,209	**1,747**
Gubberamunda Sandstone	62	499	561	1,777	810	585	1,450	**4,622**
Westbourne Formation	-	229	229	-	-	-	376	**376**
Springbok Sandstone	32	233	265	2,393	742	199	1,003	**4,337**
Walloon Coal Measures	253	1,394	1,647	8,995	370	425	1,628	**11,418**
Durabilla Formation	5	276	281	101	-	21	443	**565**
Hutton and Marburg Sandstones	342	2,303	2,645	8,810	777	2,141	3,255	**14,983**
Evergreen Formation	45	559	604	1,483	1,874	218	1,287	**4,862**
Precipice and Helidon Sandstones	29	293	322	1,970	2,092	1,704	672	**6,438**
Moolayember Formation	-	151	151	-	-	-	352	**352**
Sub-total	813	7,422	8,235	26,529	6,667	5,613	13,826	**52,635**
Non-GAB lower formations								
Clematis Sandstone	7	145	152	-	-	326	981	**1,307**
Rewan Group	-	111	111	-	-	-	309	**309**
Bandanna Formation	10	93	103	437	59	406	167	**1,069**
Bowen Permian	27	716	743	1,541	67	144	1,229	**2,981**
Basement Rocks	12	88	100	231	37	-	130	**398**
Sub-total	56	1,153	1,209	2,209	163	876	2,816	**6,064**
Total	**3,646**	**18,784**	**22,430**	**149,145**	**11,524**	**16,497**	**25,926**	**203,092**

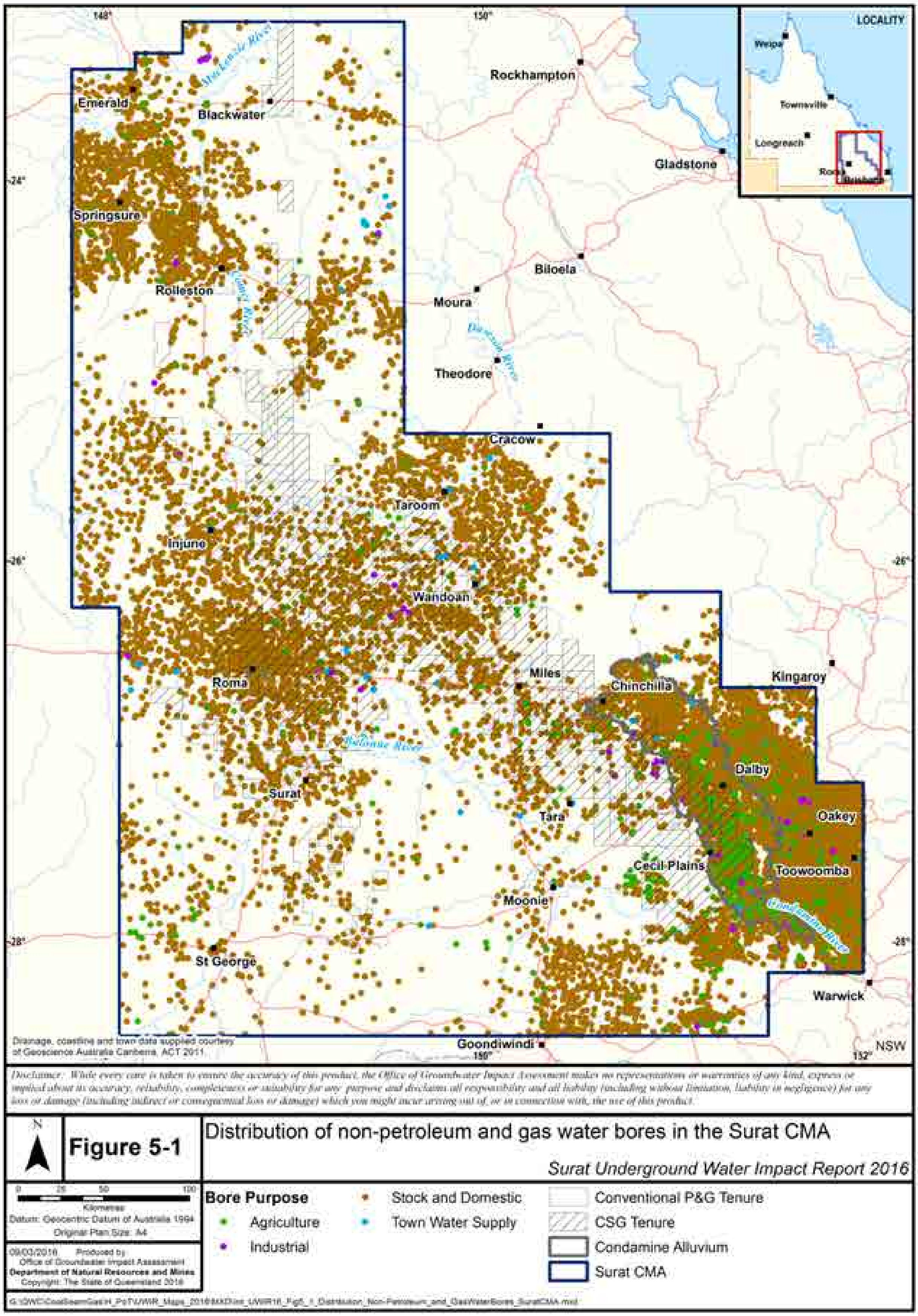


Figure 5-1 Distribution of non-petroleum and gas water bores in the Surat CMA

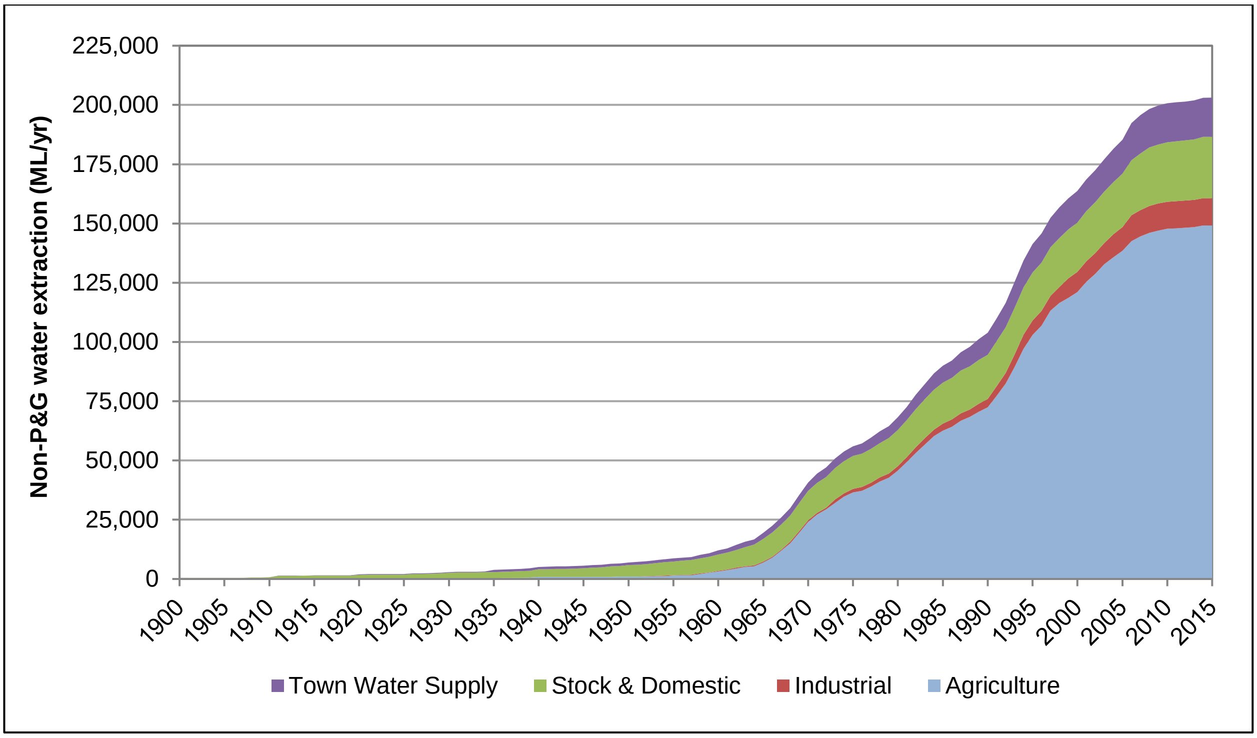


Figure 5-2 Historical groundwater extraction (ML/year) from non-petroleum and gas water bores

5.2 Petroleum and gas groundwater extraction

Petroleum tenure holders have a right to take groundwater under the P&G Acts, as described in Chapter 2. There are two types of petroleum and gas production:

- conventional oil and gas production from mainly sandstone formations
- CSG production from coal formations.

The two types of activities are discussed separately in this section as they have very different water extraction characteristics.

5.2.1 Conventional petroleum and gas groundwater extraction

Conventional petroleum and gas production is operating in the Bowen and Surat basins. Historically, the most significant extraction has been from the Triassic age Showgrounds Sandstone of the Bowen Basin and the Jurassic age Precipice Sandstone and Evergreen Formation of the Surat Basin.

Only about 20 conventional petroleum and gas production wells remain in operation across the Tinker, Taylor and Waggamba fields operated by AGL, and the Moonie field operated by Santos (Figure 2-5). There is also minor production from the three wells at the Pleasant Hills field operated by Santos, although this field is now mainly used for storing CSG. As shown in Figure 5-3, the volume of water extracted by conventional operations has decreased from about 1,800 ML/year at the time of the UWIR 2012 to only 1,000 ML/year in late 2014. Most of the water is extracted from the Precipice Sandstone at Moonie.

5.2.2 Coal seam gas groundwater extraction

CSG production relies on large-scale depressurisation of coal seams, as described in Chapter 2. This process involves extracting large amounts of water in comparison to conventional operations. While conventional petroleum and gas production has reached a mature stage of development, the CSG industry is at a relatively early stage and water extraction will increase. Current and planned CSG production areas are shown in Figure 2-5.

At the time the UWIR 2012 was prepared, CSG extraction from the southern Bowen Basin was from four major gas fields known as Fairview, Peat, Scotia and Spring Gully. Since that time, other than some additional wells in the Fairview and Spring Gully fields, there has been little to no expansion in the southern Bowen Basin. Figure 5-3 shows that extraction from the southern Bowen Basin has been steady at a rate of about 5,000 ML/year.

CSG expansion has continued in the Surat Basin. Since the UWIR 2012 was prepared, more gas fields have been brought into production—Origin's Combabula and Condabri fields and QGC's Cam, Ross, Woleebee Creek, Glendower, Harry, Isabella and David fields. The result is a recent significant increase in the rate of water extraction, from about 12,000 ML/year in July 2013 to 59,000 ML/year in July 2015 (Figure 5-3).

As of July 2015, the total combined rate of water extraction from all P&G activities in the Surat CMA was about 65,000 megalitres per year.

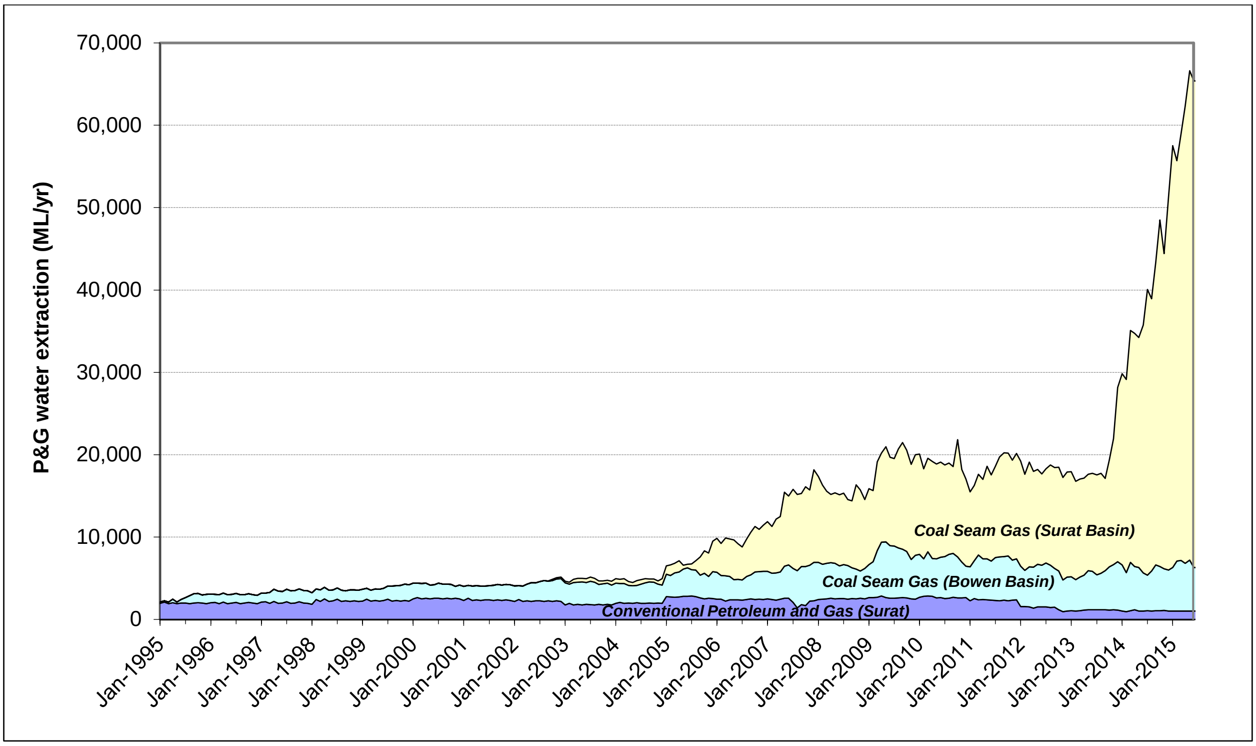


Figure 5-3 Historical water extraction (ML/year) from petroleum and gas wells

Tenure holders treat the extracted water to a high standard and then use it or supply it directly to water users for beneficial purposes such as irrigation. One beneficial use is the injection of treated water into aquifers to improve the overall condition of the groundwater resource that supports water supply bores in the area. There are technical difficulties to overcome in order to safely inject the water. However, Origin Energy has recently established injection facilities at the Spring Gully and Reedy Creek gas fields, where it is injecting 27 ML/day (equivalent to about 9,900 ML/year) into the Precipice Sandstone. Injection is done in accordance with strict environmental conditions established under an environmental authority issued by the Department of Environment and Heritage Protection. Understanding gained from monitoring the aquifer response to injection in this area will be incorporated into the regional groundwater flow model.

6 Trends in groundwater pressure

- Water pressures are falling in the coal formations in areas of CSG development.
- Water pressures in aquifers above and below the coal formations continue to follow background trends with no clear impact from CSG water extraction at this early stage of industry development.

This chapter provides an overview of trends in water pressure over time in the GAB aquifers. In an undisturbed groundwater system, water pressure represents a balance between recharge and discharge attained over long time scales. Therefore, all other factors being equal, if average rainfall was to occur every month there would be little or no variation in pressure. However, during extended periods of above or below-average rainfall, the pressure rises or falls accordingly. Water pressure can also rise or fall in response to groundwater extraction, whether for water supply purposes or for CSG depressurisation purposes.

For the aquifers in the Surat CMA, there are background trends that are independent of any impacts from CSG water extraction. These trends may reflect seasonal or longer-term variations in recharge or in water extraction for agriculture or other non-CSG purposes. To estimate the impact of CSG water extraction on observed water pressure, an understanding of background trends is required.

Monitoring to date shows significant declines in water pressure in the target coal formations, which are clearly the result of CSG water extraction. However, at this early stage of CSG development there is little impact predicted for the formations above and below the coal formations. For these formations, the current focus for monitoring is on understanding background trends so that CSG impacts can be more clearly identified as they progressively emerge.

This chapter discusses background trends in water pressure and any changes to those trends since CSG development began.

6.1 Data availability

While many bores in the Condamine Alluvium and the Main Range Volcanics have water pressure records, these aquifers are generally not underlain by current CSG production areas and are not expected to show detectable changes in water pressure as a result of CSG development. The relatively high density of time-series monitoring data available for these aquifers was collected in response to the extraction of large volumes of groundwater for non-CSG purposes.

The availability of data for the GAB formations within the Surat CMA is more limited. There are about 133 bores in the GAB formations with enough time-series water pressure data to provide information about trends in water pressure before CSG development began. More pressure monitoring points have been established in recent years and more will be installed under the requirements of UWIR 2016. These points will become progressively more useful over time, but currently only provide a relatively short period of record. Figure 6-1 shows representative groundwater pressure monitoring points in the Surat CMA to support the following discussion about trends.

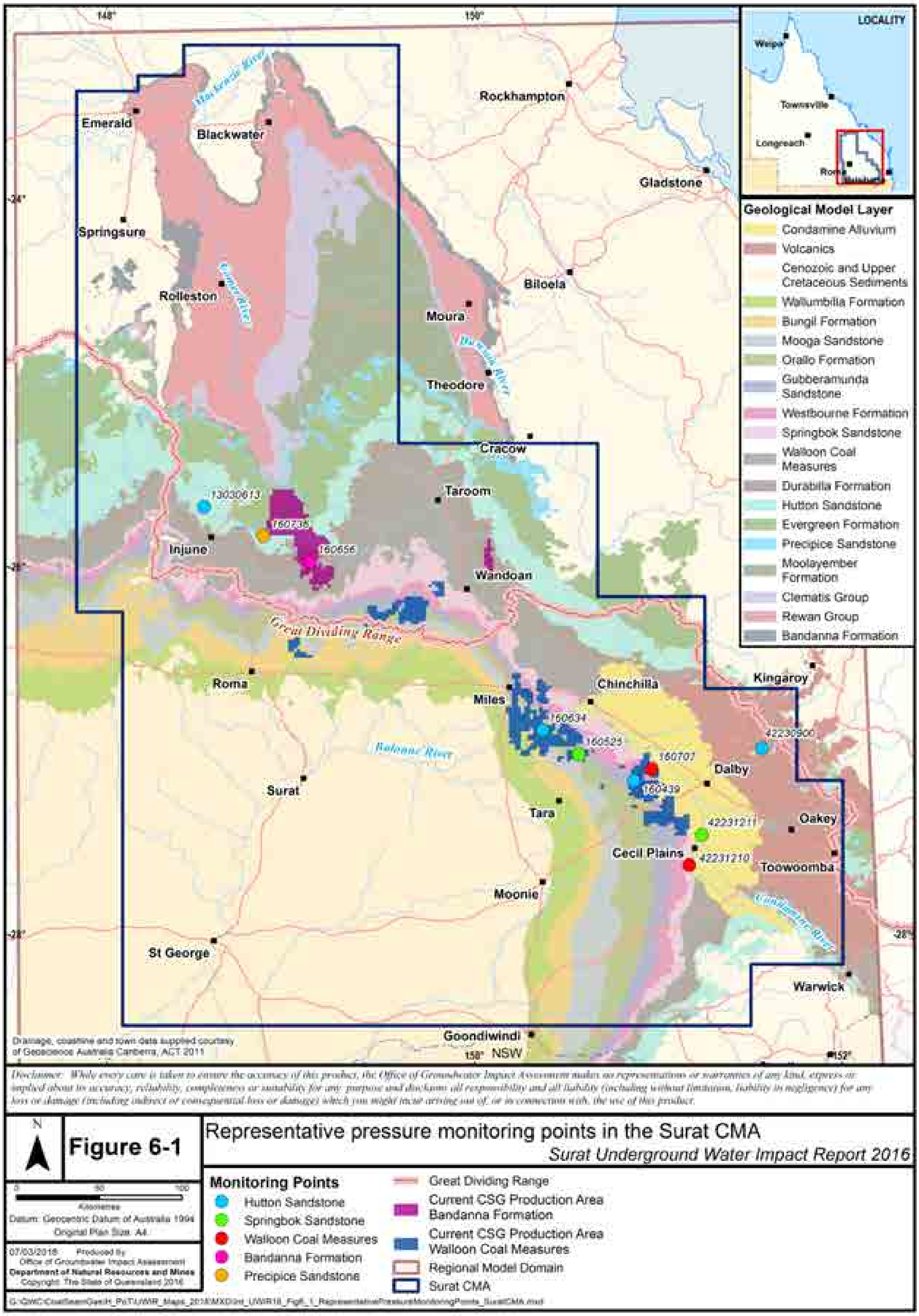


Figure 6-1 Representative pressure monitoring points in the Surat CMA

6.2 Background trends

About two thirds of the 133 GAB bores with long-term records show declining trends before CSG development began. These trends are thought to be related to natural seasonal or longer-term variations in rainfall and/or groundwater extraction for agricultural or other non-CSG purposes, as discussed below.

6.2.1 Recharge variation

Under natural conditions, groundwater pressure represents a balance between recharge and discharge in the groundwater system. An aquifer typically receives recharge in areas where the aquifer is exposed at the ground surface. In these areas, recharge mainly occurs during periods of high-intensity rainfall and associated high stream flow.

Following recharge, groundwater moves down-gradient from outcrop areas into confined parts of the system, where the aquifer is overlain by other formations. The length of time it takes for the recharge to be observable in the water pressure record in a monitoring bore depends on the distance between the monitoring bore and the recharge area and the nature of the aquifer material. Bores closer to recharge areas typically show more immediate and clearer responses to variations in rainfall. Bores farther away from recharge areas typically show weaker responses, but water pressures can be seen to rise or fall in response to longer periods of above or below-average recharge.

Rainfall records are a useful tool for understanding water pressure response to recharge variation, for areas both near to and more distant from outcrop recharge areas. For instance the record of cumulative deviation from mean monthly rainfall highlights persistent periods of higher or lower rainfall and hence recharge. Records for Roma, Dalby and Injune are shown in Figure 6-2.

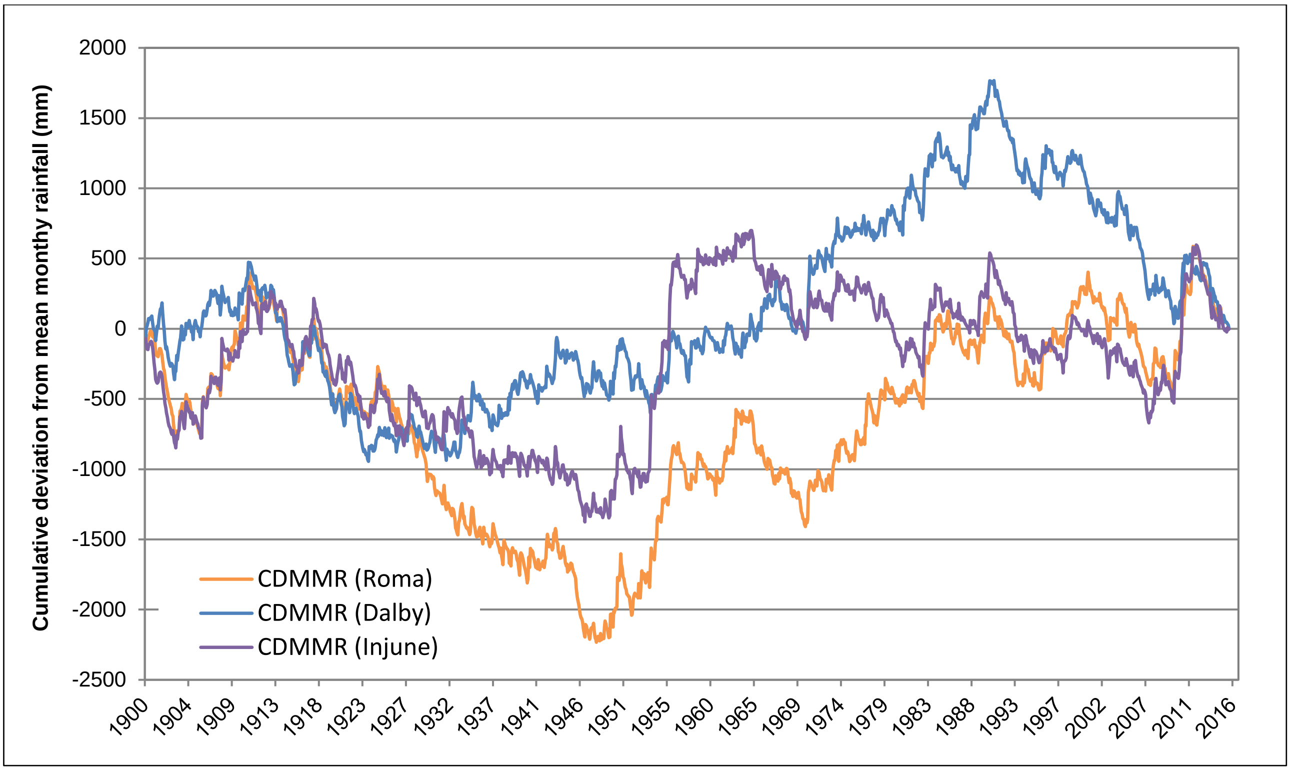
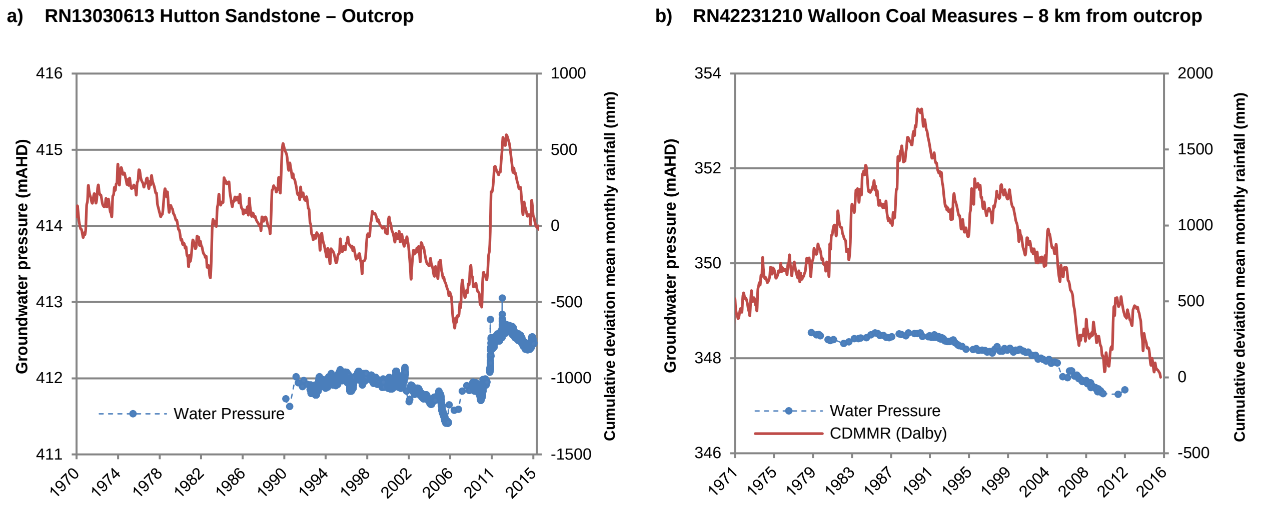


Figure 6-2 Cumulative deviation (mm) from mean monthly rainfall for Roma, Dalby and Injune

The relationship between fluctuations in groundwater pressure and rainfall or recharge is most evident in areas close to or within an aquifer outcrop. For example, bore RN13030613 (Figure 6-3a) is located in the recharge area of the Hutton Sandstone, and the water pressure is strongly correlated with long-term rainfall trends. In contrast, bore RN42231210 (Figure 6-3b) is located in the Walloon Coal Measures about eight kilometres from the recharge area, and the correlation is less pronounced.

It is important to note that long wetting or drying cycles can influence background trends. As an example, Figure 6-2 shows that in the Dalby area, a strong drying period has existed since 1990.


a) RN13030613 Hutton Sandstone – Outcrop

b) RN42231210 Walloon Coal Measures – 8 km from outcrop

Figure 6-3 Hydrographs showing trends related to variation in aquifer recharge

6.2.2 Non-CSG groundwater extraction

Changes in water extraction will change the water balance in an aquifer, leading to a rise or fall in water pressure. Within the Surat CMA, water extraction from the GAB aquifers has been increasing for a long time, primarily for stock and domestic use, and for intensive stock purposes. This expansion is likely to be the most common cause of declining trends in water pressure in the CMA.

For example, bore number RN42231211 (Figure 6-4a) is located in the Springbok Sandstone about eight kilometres from the recharge area. It shows a steady declining trend between 1979 and 2011, despite an extended period of above-average rainfall from 1979 to 1990. Although lower recharge rates during the period of 1990–2011 may have contributed, the declining trend is likely to be the result of water extraction for agricultural or other non-CSG uses. A more complex example is provided by bore number RN42230900 (Figure 6-4b) which is located in the Hutton Sandstone in an area of moderately intense groundwater development. It shows a long-term declining trend in water pressure due to water extraction, but also appears to be influenced by seasonal variation in rainfall and/or local pumping.

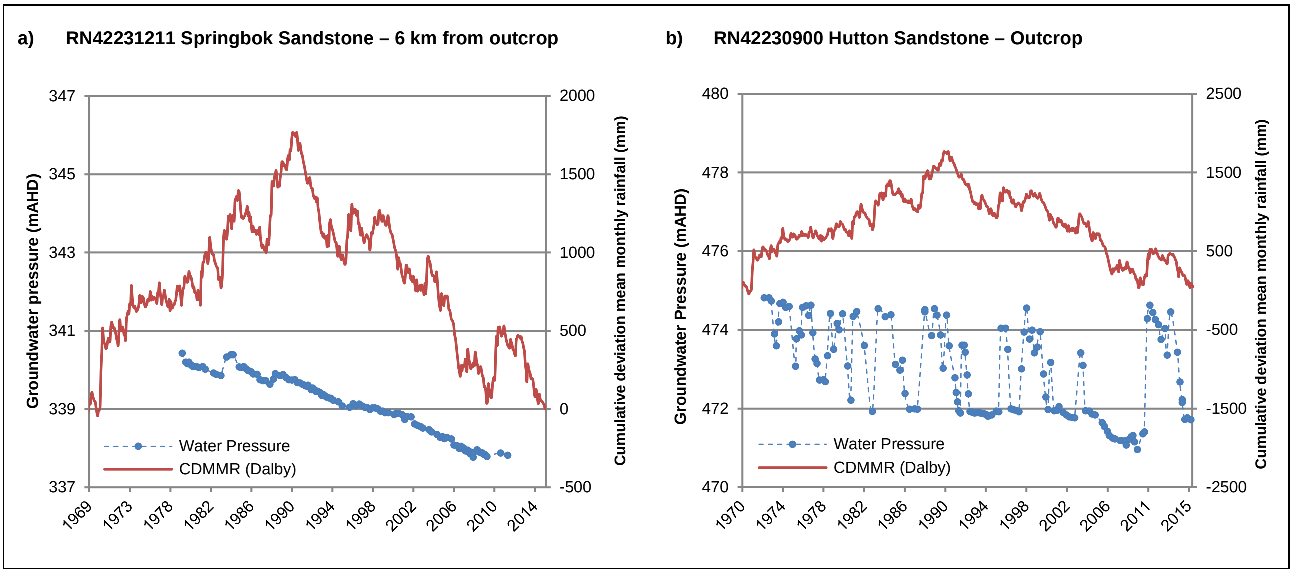


Figure 6-4 Hydrographs showing trends related to non-CSG groundwater extraction

6.3 Recent changes in background trends

Water extraction associated with CSG development began in the Bowen Basin in 1995 and in the Surat Basin in 2005 (Section 2.4.1). The regional groundwater flow model predicts the impacts on groundwater pressure from these activities (Chapter 7). These impacts will superimposed on background trends caused by seasonal or longer-term variation in rainfall/recharge and by extraction for agriculture and other non-CSG purposes. This section discusses recent pressure trends in the Walloon Coal Measures and in the overlying and underlying aquifers.

6.3.1 Walloon Coal Measures

In areas of CSG development, groundwater pressures began to fall in the Walloon Coal Measures when development began. However, the coal formations are complex with relatively high-permeability coal seams existing in a relatively low-permeability matrix of mainly mudstones and siltstones. The individual coal seams do not extend over large distances and are not well-interconnected until a CSG well is constructed through them.

As a result, the pressure response to CSG water extraction within the formation is complex. Pressure falls quickly in coal seams at the start of development but falls more slowly in the matrix material and coal seams that remain disconnected. At this stage, pressure reductions of up to 200 metres have been observed at some monitoring locations within the Walloon Coal Measures (Figure 6-5a). However, other monitoring points—some of them close to CSG production areas—show little or no pressure reduction.

Pressure impacts in the Walloon Coal Measures tend to be limited to the immediate vicinity of CSG production areas. For instance, in the areas to the south and west of Chinchilla and Dalby where CSG extraction has been ongoing since 2005, of 37 observation points located more than five kilometres from active CSG areas, only two show more than five metres of drawdown.

6.3.2 Springbok Sandstone

As the target CSG reservoir is depressurised, the impacts on overlying and underlying aquifers are predicted to occur over a significant area. The regional groundwater model predicts that the Springbok Sandstone, which overlies the Walloon Coal Measures, will be the first aquifer to be affected. At this early stage of CSG development, water pressure changes that are clear departures from background trends are expected to be minimal but will become more apparent with time.

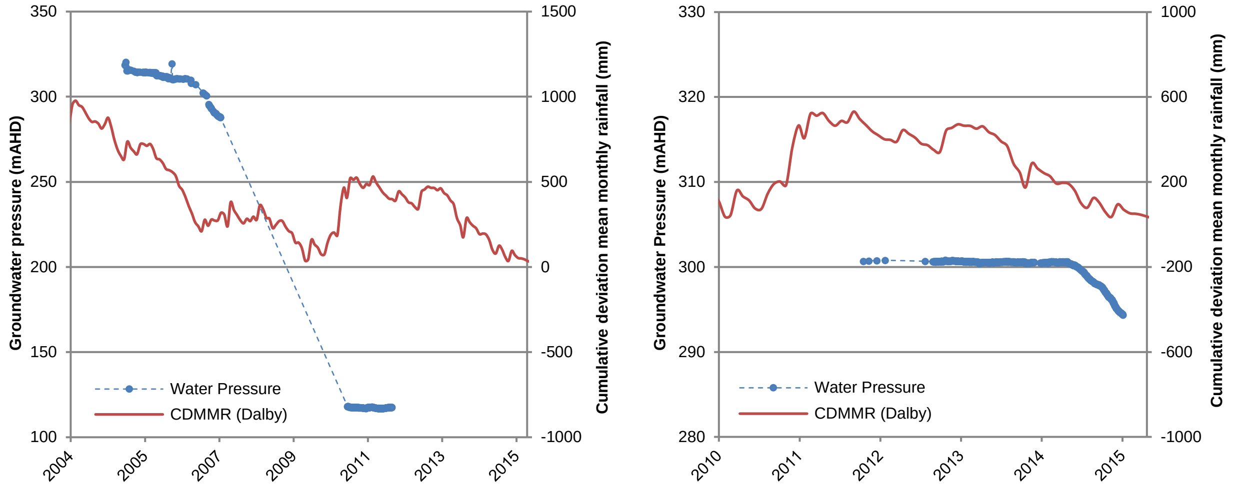
It is possible that bore RN160525 (Figure 6-5b) is starting to show a fall in water pressure caused by CSG water extraction from the underlying Walloon Coal Measures, although other factors could be operating. The bore is located within the Kenya East CSG production area. Background water pressure was stable, but a declining trend began in the first half of 2014 and, by early 2015, had led to a pressure reduction of about five metres. This bore is the only bore showing a clear change from the background trend; however, the long-term trend data is limited.

6.3.3 Hutton Sandstone

The Hutton Sandstone underlies the Walloon Coal Measures. Modelling predicts that there will be no impact on the Hutton Sandstone at this early stage of CSG development.

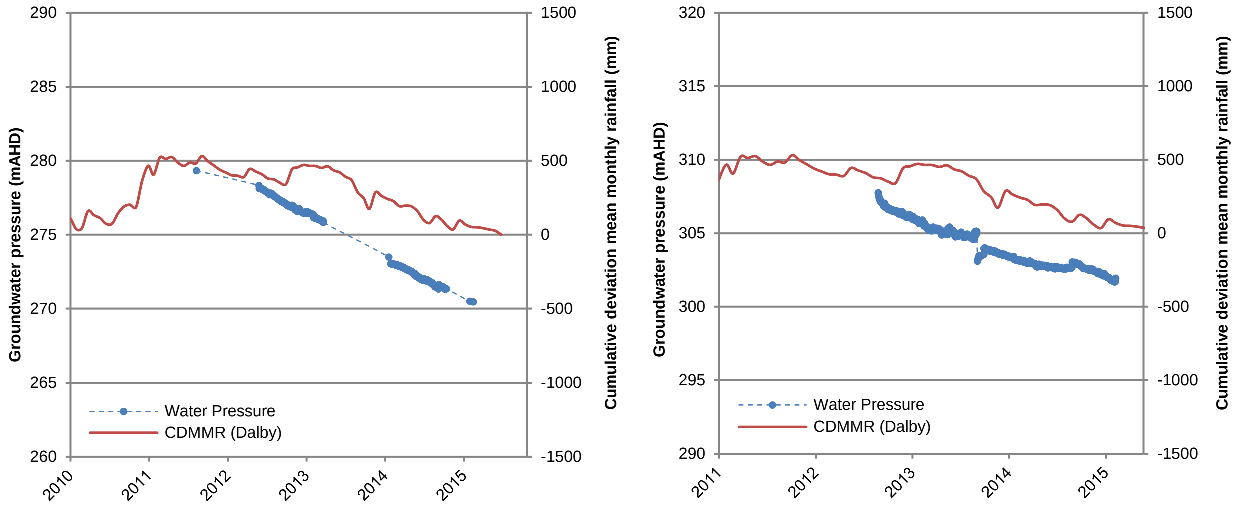
Although there are declining background trends in the Hutton Sandstone, some records show recent relatively large declines of up to two metres per year (Figure 6-5c and Figure 6-5d). At this stage, it is considered likely that this is a response to progressive increases in water extraction from the Hutton Sandstone for non-CSG purposes. However, in the absence of a long-term record at this location, it is not possible to determine if the rate of decline has increased since CSG development began.

OGIA will investigate local conditions at sites where significant falls in water pressure have been recorded. All possible contributing causes will be investigated, including possible local connections to the overlying Walloon Coal Measures.



a) **RN160707 Walloon Coal Measures – Daandine**

b) **RN160525 Springbok Sandstone – Kenya East**



c) **RN160634 Hutton Sandstone - Talinga**

d) **RN160439 Hutton Sandstone – Ruby Jo**

Figure 6-5 Hydrographs showing trends near CSG production areas in the Surat Basin

6.3.4 Bandanna Formation

CSG extraction from the Bandanna Formation in the Bowen Basin began in 1995 and groundwater pressure reductions of more than 250 metres have been observed in some locations (Figure 6-6a).

6.3.5 Precipice Sandstone

As mentioned in Section 4.4.3, the Bandanna Formation is generally isolated from the overlying major aquifers by the Rewan Group aquitard. Therefore, for the most part, depressurisation of the Bandanna Formation will not affect overlying aquifers. However, there is a narrow, north-south trending zone, close to the existing CSG production fields of Fairview and Spring Gully, where the Precipice Sandstone is in direct contact with the Bandanna and Cattle Creek formations in this area. Ongoing monitoring in this area (Figure 6-6b) suggests that groundwater pressures in the Precipice Sandstone are stable, despite the significant pressure decreases in the Bandanna Formation.

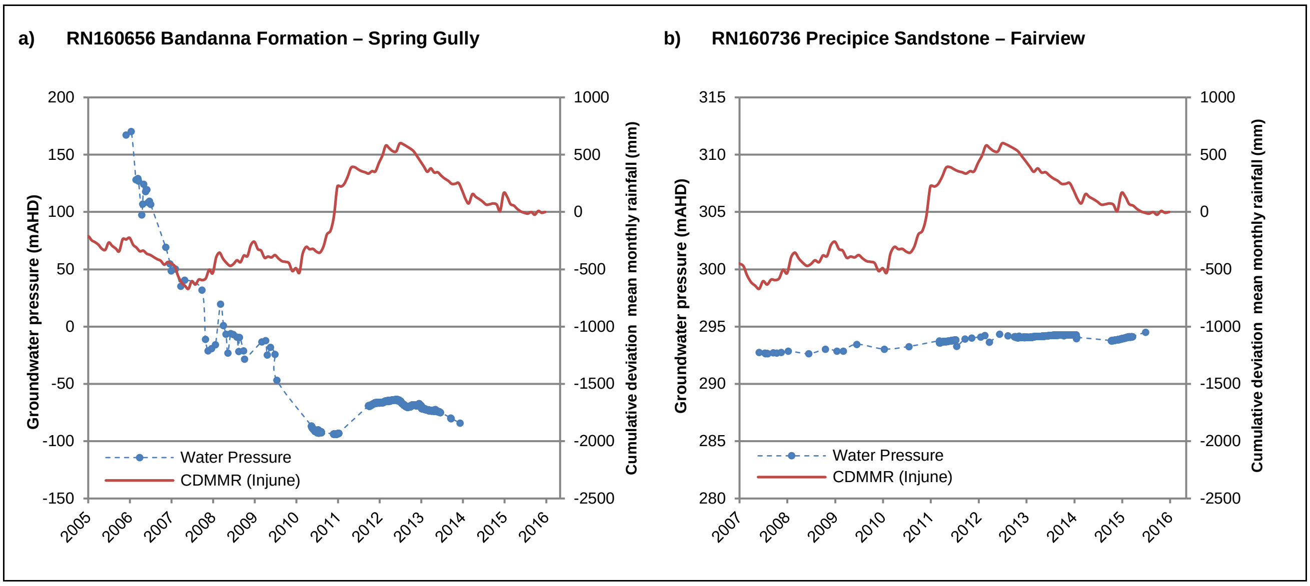


Figure 6-6 Hydrographs showing trends near CSG production areas in the Bowen Basin

6.4 Conclusions

An extensive network of monitoring bores has recently been established and more bores are still being added. However, the number of long-term records showing background trends in the GAB formations in the area of CSG development is limited and, therefore, the opportunity to identify changes to background trends since CSG development began is also limited. Nevertheless, enough information is available to support the following conclusions.

In most of the long-term water pressure records, we see long-term declining trends which pre-date CSG development. This reflects below-average rainfall over much of the recharge area over the period of 1990–2011 and increased water extraction for agriculture and other non-CSG purposes.

The effect of lower rainfall on water pressure is clear in recharge areas. However, in areas more remote from recharge, subdued effects are also apparent. Water extraction from the major aquifers, for agriculture and other non-CSG purposes, has progressively increased over a long period. In areas close to significant CSG development, this has contributed to the declining trend.

At this time, there is little evidence of a departure from background trends other than in the coal formations.

7 Predictions of groundwater impacts

- The extent of the long-term affected area in the Walloon Coal Measures has decreased because of reductions to planned CSG development and improved groundwater flow modelling. There are changes in the extent of the long-term affected areas in other formations.
- 459 existing bores are predicted to be affected by CSG water extraction in the long term. This is in addition to the 59 bores that have been recorded as decommissioned since 2012.
- 91 of the 459 bores are predicted to be affected within three years. This comprises 34 bores which were previously identified as IAA bores but have not yet been decommissioned and 57 newly identified bores. Of the previously identified bores, 36 have been decommissioned since 2012.
- The net loss of water from the Condamine Alluvium to the underlying coal measures is predicted to be 1,160 megalitres per year, which is in line with the 2012 predictions.

This chapter provides an overview of the regional groundwater flow model that OGIA has developed to make predictions about groundwater pressure impacts. It provides predictions made using this revised model. The Immediately Affected Areas (IAA) and the Long-term Affected Areas (LAA) are identified for aquifers in which water level or water pressure impacts are predicted to exceed trigger thresholds. This chapter also provides details about the bores in the IAA and LAA.

7.1 Methods and techniques for predicting groundwater impact

7.1.1 Numerical modelling approaches

There are established mathematical relationships that can be used to predict water pressure changes in simple homogeneous formations in response to relatively uniform and localised water extraction. Techniques based on these relationships are referred to as analytical techniques. However, in situations where there are spatial variations in hydraulic properties, complex interactions with surrounding formations and spatially distributed and variable groundwater extraction—as is the case in the Surat CMA—analytical techniques are of limited use. In these instances, a numerical groundwater flow model is a more appropriate tool for predicting water pressure changes.

A groundwater flow model is a computer-based mathematical representation of a groundwater system using the laws of physics. A modelling code is used to construct a groundwater flow model of a groundwater system in a similar way to that in which a spreadsheet program (such as Microsoft Excel) can be used to carry out relatively simple calculations. However, in the case of a groundwater flow model, the designs are complex, consisting of numerous input and output files and millions of calculations that can only be carried out by using modern high-performance computers. A model is generally developed for all or part of a groundwater system, with the modelled area referred to as the model domain. A model domain exists in three dimensions. It is divided into a number of building blocks to represent the ground surface and the geologic formations present within the area.

There are three basic steps involved in constructing a groundwater flow model:

- **Conceptualisation.** This involves using available information to translate a complex three-dimensional geological system, and knowledge of groundwater flow processes in that system, into a simple idealised representation. Numerous assumptions are involved in this process.

- **Model construction.** The simplified conceptual representation of the system is then converted into a three-dimensional mathematical representation of the physical system and flow processes, which is the groundwater flow model. A model is a series of large computer files representing hydraulic parameters, boundary conditions, groundwater extraction, groundwater recharge, elevation of geologic layers, model grid, and other elements.
- **Model calibration.** Once constructed, a model is then calibrated based on actual observed groundwater pressures, extraction rates and other available information including expert knowledge. This calibration process typically involves adjusting the hydraulic parameters of each model layer until the best possible match between predicted and observed data is achieved. Calibration of complex models is carried out using specialised computer programs.

Once constructed and calibrated, a model can then be used to predict changes in water pressure or flow in response to various development scenarios.

Any prediction of the future will be subject to a degree of uncertainty and predictions made using a numerical model are no exception. Some uncertainties are associated with model construction; other uncertainties can arise from the assumptions contained in the development scenario used to make predictions.

Uncertainties are associated with model construction because:

- A groundwater system can be simplified in more than one way depending upon the knowledge available about the system at the time and the accuracy of field measurements of data (conceptualisation uncertainty).
- A model can potentially be calibrated to replicate the same observed data using quite different sets of hydraulic parameters (calibration uncertainty).

The effect of calibration uncertainty on predictions made using the numerical model can be assessed using a technique known as predictive uncertainty analysis. Application of this technique requires specialised skills, significant computer capacity and time; it involves using multiple sets of parameters, all of which are physically realistic and all of which calibrate the model, to make a large number of alternative predictions. These are then statistically analysed to provide a measure of uncertainty in model predictions.

It is not practicable to use this type of technique to comprehensively assess conceptualisation uncertainty in large models. Alternative realisations of the geology have been considered as part of the initial model parameterisation (Section 7.1.2). However, for other components of the conceptualisation, the only practicable approach is to periodically review the conceptualisation as new information about the system becomes available.

Predictive uncertainty associated with assumptions about future groundwater development is not a modelling issue. Any prediction of the impact of CSG development will be dependent upon the assumptions about how, when and where the development will progress in the future. This component of uncertainty is managed by re-running the model on an annual basis using the current development assumptions as discussed in Chapter 11.

Groundwater systems such as the GAB are complex and our understanding about these systems improves over time, as more information becomes available. A number of research programs, overseen by OGIA and other organisations, have provided additional understanding during the current reporting cycle; OGIA also receives additional input data and feedback on model performance on an almost-continual basis. This additional information has led to the development of a substantially revised regional groundwater flow model which has been used along with the latest industry development plan to produce a revised set of cumulative impact predictions.

7.1.2 Initial model parameterisation approach

Initial estimates of hydraulic conductivity for regional modelling purposes are typically derived from statistics calculated from the available hydraulic parameter data. For instance, initial hydraulic conductivity estimates for each formation in the previous model were based on the median of all of the available hydraulic parameter data. For shallow formations where there was no evidence of a relationship between depth and hydraulic conductivity this median value was then applied to the full extent of each formation and hence prior to model calibration it was assumed that a number of layers were homogenous. Spatial variability was then introduced into these model layers, by allowing the initial hydraulic conductivity to vary as required during calibration, until the best possible match between predicted and observed water pressures was achieved. Whilst this approach works well in areas where there is good coverage of calibration data, it works less well in areas where there is poor coverage.

A substantially improved initial parameterisation and calibration approach was adopted during development of the new regional groundwater flow model. The aim was to develop a set of initial parameters that reflects, as much as possible, the current state of geological knowledge throughout the CMA. The uncertainties associated with these estimates were also characterized. These initial estimates were then revised during model calibration. This revised approach sought to extract full value from the substantially expanded geological and hydraulic parameter data set now available for the CMA—in particular, detailed lithological data derived from processing geophysical logs for over 3,500 petroleum and gas wells and some 12,800 high quality hydraulic parameter estimates, often for the same wells. The main components of this approach can be summarised as follows:

- Initial values of hydraulic conductivity for each of six lithology types (clean sand, dirty sand, siltstone, mudstone, carbonaceous shale and coal) identified in geophysical logs were derived from expert knowledge, literature and permeability analyses based on petrophysical log data.
- These initial values were then input to a stochastic permeability model and calibrated (or ‘conditioned’) through comparison with the available hydraulic parameter data at three different scales. This conditioning procedure provided estimates of all parameters used in the permeability models, as well as estimates of the uncertainties associated with these parameters.
- Once calibrated, these values were then used to populate numerical permeameters—detailed 21 km by 21 km numerical models of each stratigraphic unit and covering the full extent of the 12 stratigraphic units modelled—to derive spatially variable formation-scale horizontal and vertical hydraulic conductivity based on 20 different possible realisations of the highly heterogenous lithology observed in each area. In total, over 138,000 MODFLOW model runs were carried out during this part of the process.

The output from this process provided an extremely robust set of initial hydraulic conductivity parameters. Furthermore, through consideration of 20 alternative lithological realisations of each stratigraphic unit present within each permeameter area, this process also provided a range of possible alternative parameter estimates for use in model calibration and uncertainty analyses.

7.2 The regional groundwater flow model

OGIA has retained use of the MODFLOW platform for the revised regional groundwater flow model, although the latest version, MODFLOW-USG, is now used rather than MODFLOW 2005. MODFLOW was originally developed by the United States Geological Survey in 1988 and has been progressively updated. It has become an industry standard for groundwater flow modelling. Other modelling packages including FEFLOW and ECLIPSE were considered but ultimately MODFLOW was retained due to its proven capabilities for regional groundwater impact assessment and public accessibility of the software including the source code.

The regional groundwater model domain overlays the entire Surat CMA area and includes coal seam formations and potentially connected aquifers within the Surat, southern Bowen and Clarence-Moreton basins. Figure 7-1 shows the model domain. The model includes 32 layers to represent the full GAB sequence and alluvial formations within the Surat CMA and the CSG-producing Bandanna and Cattle Creek formations in the Bowen Basin.

Figure 7-1 also shows the extent of two sector models or sub-models of the Talinga CSG wellfield area and part of the Condamine Alluvium. These are highly detailed models which were developed for the specific purpose of better understanding the response of the Walloon Coal Measures and other adjacent aquifers to CSG pumping. The Talinga Sector Model was developed using the ECLIPSE reservoir modelling platform, which is also used by CSG operators to estimate gas production from proposed CSG wellfields. The Condamine Sector Model was developed using MODFLOW-USG. Understanding gained through the development of these models led directly to a number of improvements in the revised regional groundwater flow model, including a number of revisions to the MODFLOW-USG code to allow more accurate simulation of CSG water extraction. These revisions included the development of additional functionality to allow simulation of water desaturation due to gas production in coal seams in and around CSG wells using MODFLOW-USG. This work was undertaken by OGIA in collaboration with one of the primary developers of the MODFLOW code and was also the subject of a peer reviewed academic paper which has been published in the Journal of Hydrology (Herckenrath et al, 2015).

The regional groundwater model is used to predict regional water pressure or water level changes in aquifers within the Surat CMA in response to extraction of CSG water. More specifically, the model is used to:

- define the IAA of consolidated aquifers – that is the area where water pressures are predicted to decline by more than five metres within the next three years
- define the LAA of consolidated aquifers – that is the area where water pressures are predicted to decline by more than five metres at any time in the future
- identify potentially affected springs – springs where the water pressure in aquifers underlying the spring sites is predicted to decline by more than 0.2 metres at any time in the future
- predict the rate and volume of water movement between formations
- estimate the quantity of CSG water that is expected to be produced.

It should be noted that the model is designed for regional water pressure impact assessment and is not designed to be used to directly predict water pressure or water level variations at a local scale. Although output from the model would be a relevant consideration when assessing impacts at a specific location, local factors should also be taken into consideration.

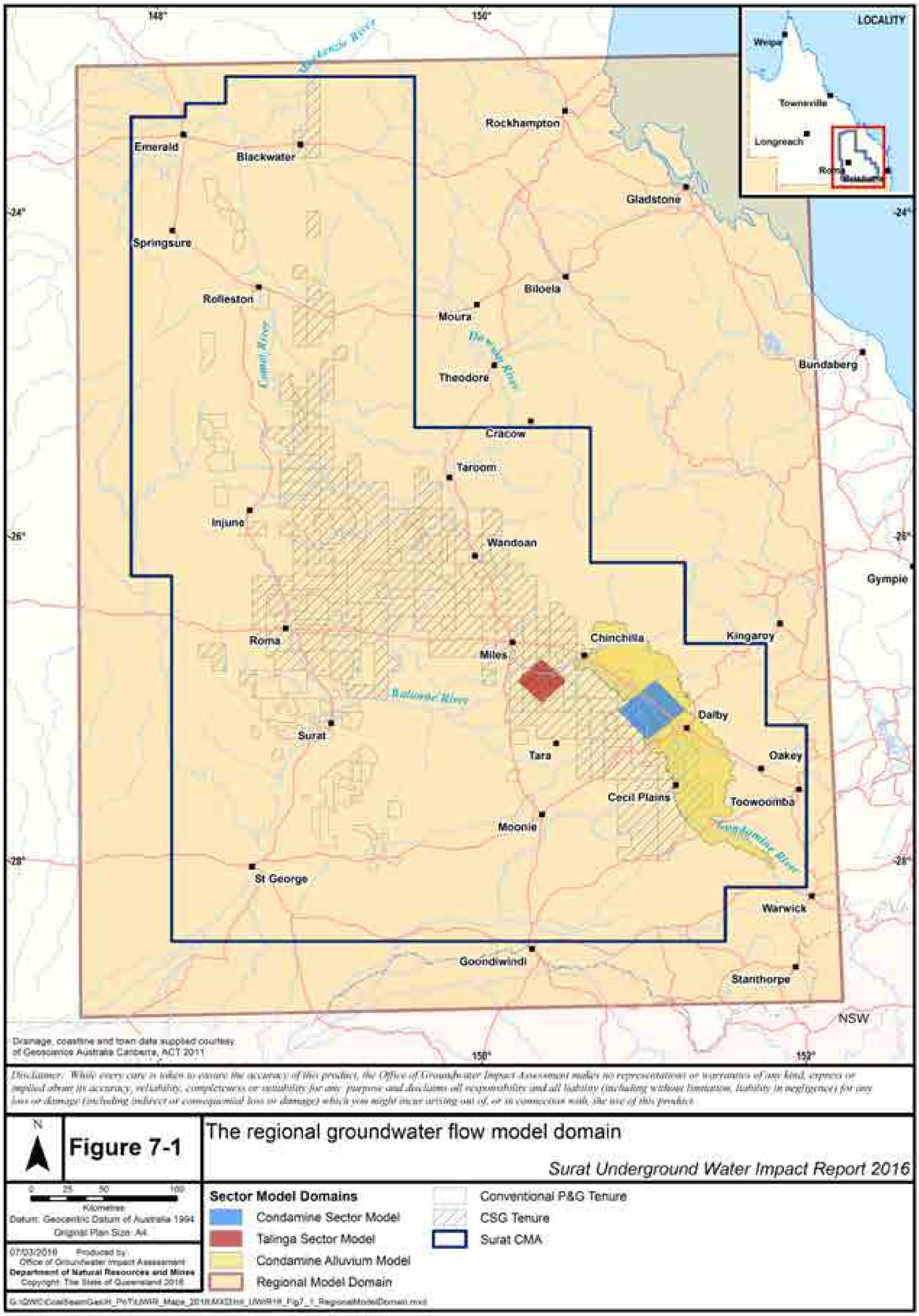


Figure 7-1 The regional groundwater flow model domain

7.2.1 Conceptual framework for the model

The geology and hydrogeology summarised in Chapters 3 and 4 was the basis for developing an updated and revised conceptual framework for model construction. Information and data used to develop the revised numerical model include:

- revised modelling of the Condamine Alluvium and Main Range Volcanics based on re-interpreted geological logs for over 7,700 water bores
- interpreted geologic formation contacts for the consolidated geologic formation were developed by OGIA from geophysical logs for over 4,800 petroleum and gas wells and water bores
- estimated displacements associated with 17 major fault systems as extracted from the regional geological model
- initial parameter distributions derived from detailed lithological data and an extensive database of hydraulic parameter estimates at a variety of scales
- revised estimates of the rate of natural groundwater recharge for all modelled units based on an extension of the work of Kellett et al (2003).

The hydrostratigraphy shown in Figure 4-1 has been represented numerically using the 32-layer system shown in Figure 7-2. This represents an increase on the 19 layers included in the earlier regional groundwater flow model. By increasing the number of layers represented in the model, there is less need to group stratigraphic units into single model layers. Accordingly, individual model layers are now used to represent the Bungil Formation and the Mooga Sandstone. A number of stratigraphic units are now also represented using multiple model layers. In particular, the main target coal reservoirs (the Walloon Coal Measures, Bandanna Formation and Cattle Creek Formation) are now represented using a minimum of three layers to allow a more accurate representation of aquifer geometry in key areas such as the Condamine Alluvium where coal seams subcrop beneath other aquifer layers. The Springbok Sandstone and Hutton Sandstone have also been subdivided into multiple layers, based on geophysical log interpretations which show distinct differences in lithology and hydraulic parameters in the upper and lower parts of these formations.

The regional groundwater flow direction is dominantly from the outcrop or recharge areas in the north, northwest and northeast to the south, south-west and west. Recharge occurs predominantly by direct infiltration of rainfall in the outcrop areas, or indirectly by leakage from streams and/or overlying aquifers. A diagrammatic representation of the groundwater conceptualisation is presented in Figure 7-3.

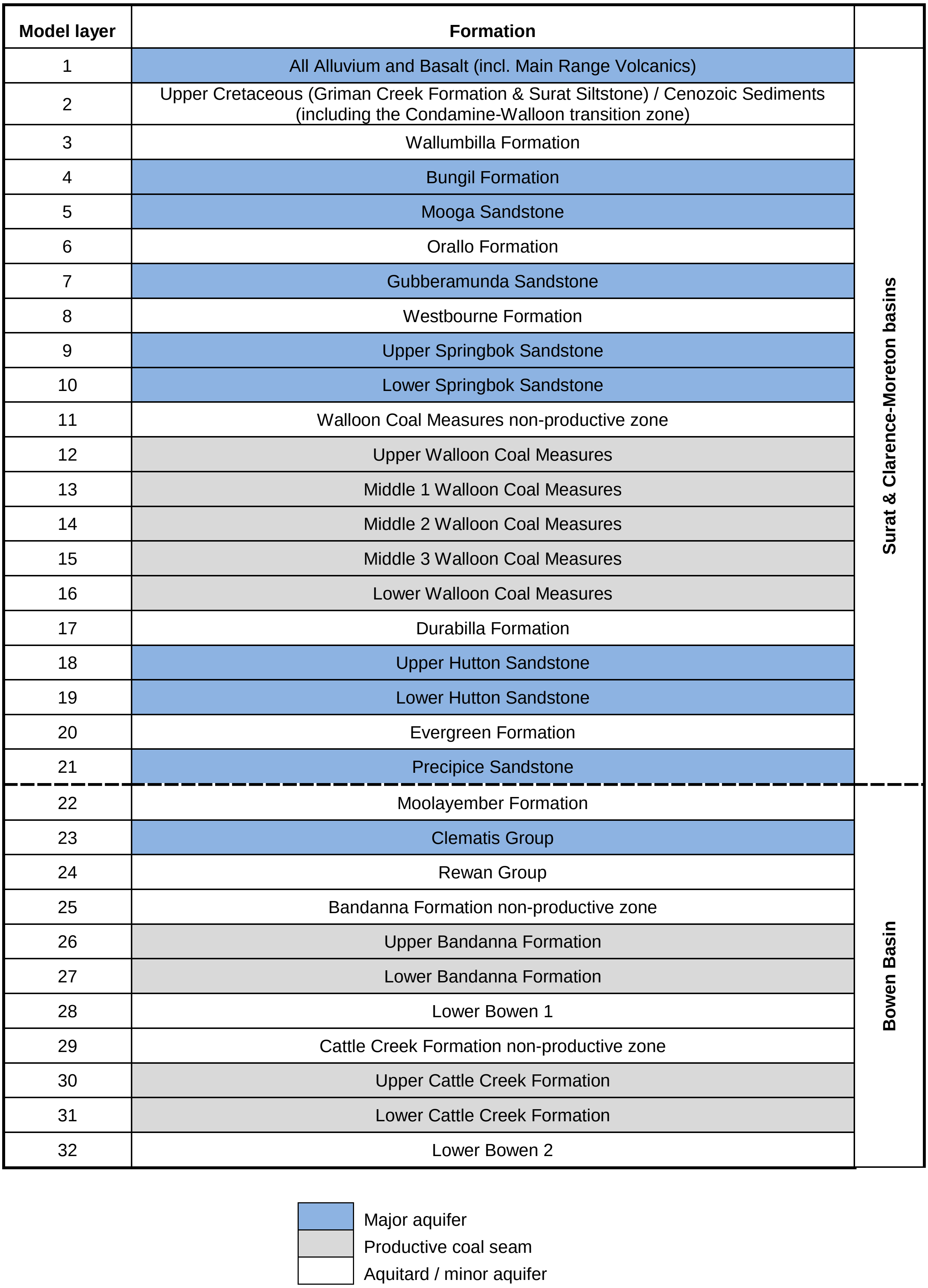
The hydrogeology of the coal formations is complex in that they comprise highly varied sequences of sediments which contain material of high and low permeability. The coal seams are often the main water-bearing layers within a sequence of dominantly low-permeability mudstones, siltstones or fine-grained sandstones (see Chapter 4).

It is not practical to represent the individual coal seams within these coal formations in the regional groundwater flow model as separate layers. This is in part because it is often not possible to correlate the coal seams across the area. However, detailed modelling undertaken by OGIA shows that CSG production leads to the development of pressure gradients within the reservoirs. In order to represent the gradients in a groundwater flow model, multiple layers are required. Hence a minimum of three layers have been used to represent each of the coal formations. A total of six layers have been used to model the Walloon Coal Measures; this allows a more accurate representation of the geometry of the contact zone with the Condamine Alluvium. The layers included in the model are as follows:

- an upper ‘non-productive’ layer representing a generally low-permeability mudstone which sits above the upper-most screens in CSG wells and therefore does not produce any CSG (model layer 11)
- the remainder of the thickness of the Walloon Coal Measures above the underlying Durabilla Formation aquitard is then split into five further layers (model layers 12 to 16).

All of the six layers used to represent the Walloon Coal Measures therefore represent composite layers which include a number of relatively high-permeability thin coal seams, separated by thicker predominantly low-permeability mudstone, siltstone and sandstone units. To best accommodate the dispersed nature of predominantly vertical flow of water through low-permeability interburden to thin, discontinuous permeable coal layers when the latter are undergoing depressurisation during CSG production, all coal measure layers were represented using so-called “dual porosity” functionality available through MODFLOW-USG.

Three layers have been used to represent the Bowen Basin coal formations (the Bandanna Formation and Cattle Creek Formation) two of which are simulated using dual porosity functionality. As with the Walloon Coal Measures, an upper ‘non-productive’ layer has been defined, based on CSG well screen information, and the remaining thickness of each formation is then divided into upper and lower sections.



Model layer	Formation	
1	🟦 All Alluvium and Basalt (incl. Main Range Volcanics)	Surat & Clarence-Moreton basins
2	☐ Upper Cretaceous (Griman Creek Formation & Surat Siltstone) / Cenozoic Sediments (including the Condamine-Walloon transition zone)	
3	☐ Wallumbilla Formation	
4	🟦 Bungil Formation	
5	🟦 Mooga Sandstone	
6	☐ Orallo Formation	
7	🟦 Gubberamunda Sandstone	
8	☐ Westbourne Formation	
9	🟦 Upper Springbok Sandstone	
10	🟦 Lower Springbok Sandstone	
11	☐ Walloon Coal Measures non-productive zone	
12	▩ Upper Walloon Coal Measures	
13	▩ Middle 1 Walloon Coal Measures	
14	▩ Middle 2 Walloon Coal Measures	
15	▩ Middle 3 Walloon Coal Measures	
16	▩ Lower Walloon Coal Measures	
17	☐ Durabilla Formation	
18	🟦 Upper Hutton Sandstone	
19	🟦 Lower Hutton Sandstone	
20	☐ Evergreen Formation	
21	🟦 Precipice Sandstone	
22	☐ Moolayember Formation	Bowen Basin
23	🟦 Clematis Group	
24	☐ Rewan Group	
25	☐ Bandanna Formation non-productive zone	
26	▩ Upper Bandanna Formation	
27	▩ Lower Bandanna Formation	
28	☐ Lower Bowen 1	
29	☐ Cattle Creek Formation non-productive zone	
30	▩ Upper Cattle Creek Formation	
31	▩ Lower Cattle Creek Formation	
32	☐ Lower Bowen 2	

🟦 Major aquifer
▩ Productive coal seam
☐ Aquitard / minor aquifer

Figure 7-2 Layers and corresponding formations represented in the regional groundwater flow model

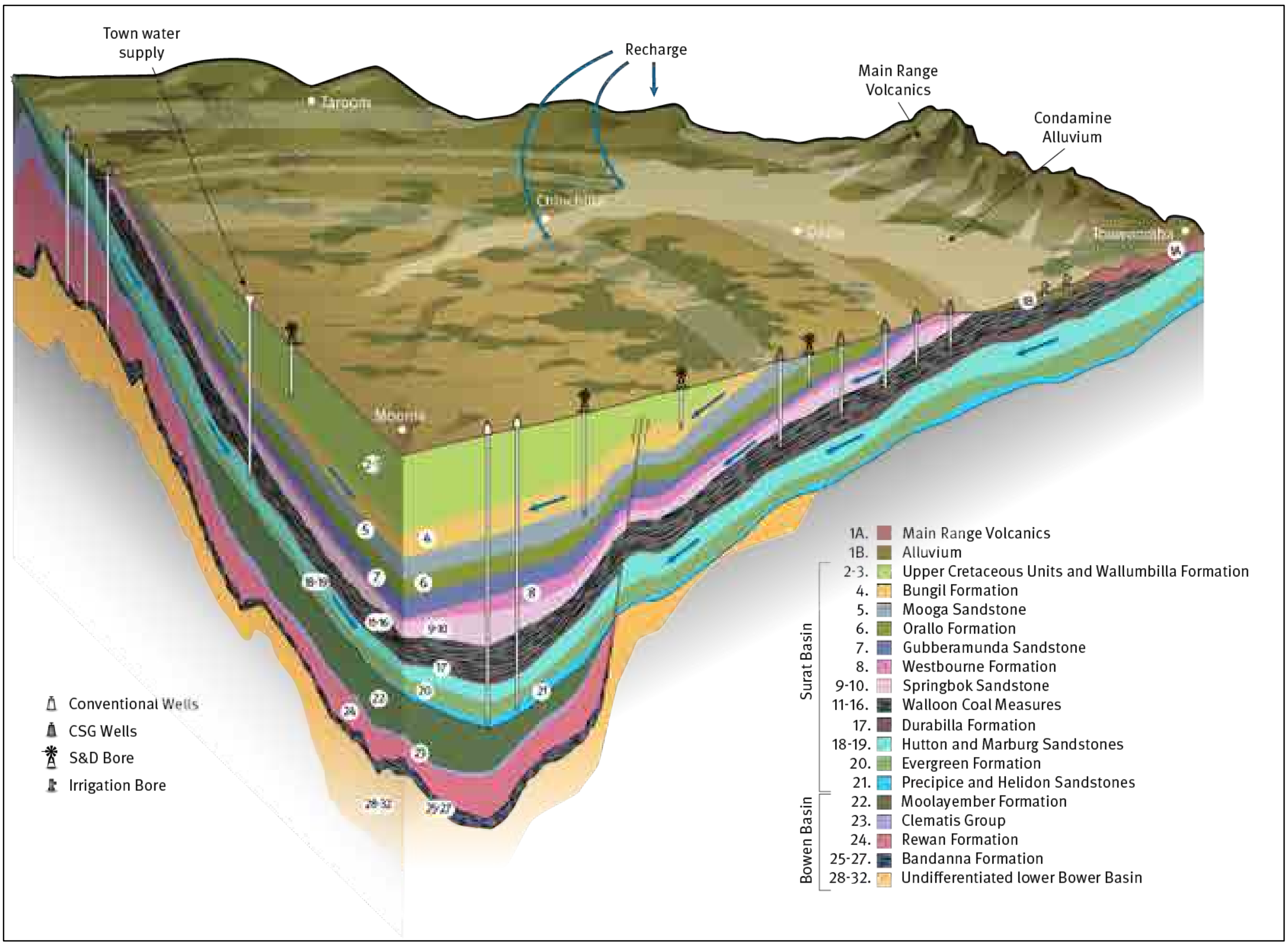


Figure 7-3 Conceptual model of the groundwater systems in the Surat CMA

7.2.2 Groundwater model construction and calibration

The model has been constructed using the MODFLOW-USG finite volume code (Panday et al., 2013) distributed by the United States Geological Survey. This software is the most recent version of the MODFLOW family of groundwater modelling software. The new version supports the development of a wide variety of structured and unstructured grid types. This enables erosional features such as the contact between Walloon Coal Measures and the overlying Condamine Alluvium to be better represented. In consultation with its principal author (Sorab Panday), OGIA made a number of enhancements to MODFLOW-USG to improve its performance in the CSG impact assessment context.

7.2.2.1 Model grid and parameterisation

The revised model domain covers an area of around 460 km by 650 km across the southern Bowen Basin and Surat Basin, capturing all CSG development areas within the Surat CMA. Overall the revised domain is similar in size to the previous regional groundwater flow model; it has been expanded slightly to the east, to better simulate interaction with the Clarence-Moreton Basin, and contracted slightly from the west, due to geological data being extremely limited in this area and the previous modelling finding no impact from CSG development. The revised model now incorporates 32 layers to represent all major aquifers and aquitards present in the area. Several units, including each of the main coal formations and the GAB aquifers immediately above and below the Walloon Coal Measures, are represented using multiple model layers. Each layer is divided into 1.5 km by 1.5 km model cells. The thickness of each model layer within any column of model cells represents the cumulative thickness of all lithologies represented by the layer, averaged over the area of the column.

For units where detailed permeameter calculations were carried out as described in Section 7.1.2, outputs from that process were used as the initial parameter values. For other units, initial values were taken from previous model calibration results.

7.2.2.2 Simulation of CSG and other groundwater extractions

As mentioned in Section 2.1.2, optimal conditions for the flow of CSG are typically achieved when water pressures in the production well are between 35 and 120 psi, which is equivalent to 25–80 metres head of water. The volume of water that needs to be pumped to achieve this pressure reduction varies from well to well, and is dependent on the permeability of the coal seams. In the initial stage, water is extracted from a well until the necessary pressure reduction has been reached; extraction then continues at the rate necessary to maintain the pressure in the well. During the initial phase, the pressure in the surrounding formation is substantially higher than in the well. This pressure difference gradually dissipates until the pressure in the formation is close to or the same as the pressure in the well, at which point gas production declines to uneconomic levels. In areas where CSG extraction is taking place, a vertical hydraulic gradient is induced within the coal formations. Smaller reductions in the head of water are experienced near the top of the formation while greater reductions in the head of water are experienced near its base. As far as water is concerned, each CSG extraction well acts as a kind of ‘seepage face’ towards which water flows in accordance with the reduced pressure regime which is operative within the well. This is simulated using the MODFLOW-USG ‘drain’ boundary condition. Multiple MODFLOW-USG drains are assigned to each well; these descend over time as pressures in the CSG extraction well are reduced.

Other non-P&G related groundwater extractions summarised in Section 5.1 have also been included in the numerical model. Extractions from the Condamine Alluvium and Main Range Volcanics have been simulated indirectly using a MODFLOW-USG ‘drain’ boundary condition. Extractions from the remaining formations included in the model have been simulated directly using the MODFLOW-USG ‘well’ boundary condition.

7.2.2.3 Model calibration

Once constructed, the groundwater flow model was calibrated in steady state to replicate pre-CSG extraction conditions to 1995, based on the assumption that a reasonable dynamic balance between recharge and discharge existed at that time. Although the GAB is recognised as a dynamic system, the majority of boreholes show relatively minor trends over the period of 1960 to 1995 in the Surat area. Therefore, the assumption of steady state conditions in 1995 is considered a reasonable approximation for regional modelling purposes. To test this assumption further, a second parallel calibration was carried out to groundwater pressure data for the period prior to 1947, when only a few water bores were in existence.

Additional calibration of the model was carried out by matching model-generated monthly water production figures with water production data supplied by gas companies. Total modelled CSG water production over the period of 1995 to 2014 is around 176,500 ML—a value which is within one per cent of the actual total over this time period. Matching of vertical pressure gradients within coal measures calculated by the MODFLOW-USG regional model with those calculated by gas company reservoir models (using the ECLIPSE simulator) provided a basis for further parameter refinement through the calibration process.

As in the previous modelling studies, rather than attempt to represent the detail of the Condamine Alluvium in the regional groundwater flow model, groundwater levels were instead imported from a separate sub-model which has a finer resolution of 500 metres by 500 metres. This sub-model for the Condamine Alluvium was developed for water resource planning purposes.

A water level dataset from about 12,000 bores was available for calibration of the revised model—a substantial increase on the dataset from about 1,500 bores available for calibration of the previous model. The increase is a result of the OGIA review of old water bore records to attribute the source aquifers for all bores, so that water level data from these bores could be used for calibration. Previously, a lack of knowledge of the source aquifer prevented this water level data from being used.

Calibration of the model was carried out using specialist automated calibration software PEST. Consistent with the current Australian Groundwater Modelling Guidelines (Barnett et al. 2012), a range of quantitative and qualitative measures was used to assess each calibration iteration. The overall aim of these iterations was to gradually improve the calibration performance while at the same time avoiding calibration outcomes that were inconsistent with expert knowledge of groundwater flow in the basin.

7.2.2.4 Simulation of the Condamine Alluvium

Over the past 15–20 years, a number of local-scale models have been developed for the Condamine Alluvium. These models have been developed to assess the response of the Condamine alluvial groundwater system to agricultural extraction, in order to determine a sustainable level of allocation from the system. DNRM has an established model that it has used to support water resource management for the Condamine aquifer (the Condamine Model). As in the previous UWIR modelling study, rather than seeking to duplicate the detailed Condamine Model within the regional model, the following integrated approach was adopted:

- Calibrated data from the Condamine Model was used to define the hydraulic parameters of the relevant layer within the Condamine footprint in the regional model.
- Time-variant water level conditions from the Condamine Model were imported into the regional model.
- The regional model was used to predict the change in flow from the Condamine Alluvium to the Walloon Coal Measures and the resulting impact on groundwater levels in the Condamine.

The Condamine Model used in 2012 was used again for this UWIR update. DNRM is in the process of revising the model.

7.2.3 Model set-up for making predictions

The groundwater model was set up to make predictions starting from 1995. For predictive runs, starting water levels were obtained from the steady state run which accounted for the water extraction existing in 1995.

The model was set up to run in predictive mode from 1995. Two separate predictive runs were made: a Base Run and a CSG Production Run. The Base Run involved running the model without CSG-related water extraction. In the CSG Production Run, water extraction from current and proposed CSG extraction was added to the Base Run water extraction. In a change from the previous UWIR, conventional P&G extraction has been included in the Base Run. The difference in predicted water levels between the CSG Production Run and the Base Run therefore provides the water pressure impacts predicted to result from current and planned CSG water extraction. Predicted water level impacts due to ongoing conventional P&G extraction are excluded because conventional P&G production is in decline; water extraction is now less than two per cent of total P&G water extraction and falling. Conventional P&G extraction commenced in the 1960s and impacts will have occurred before introduction of the statutory framework in 2011.

Simulated CSG wells were switched on and off in the model in accordance with information provided by the tenure holders about the sequencing of development for each 1.8 km by 1.8 km sub-block of the production tenures. As described in Section 2.4, there have been recent major changes to the proposed sequencing of planned development. Generally there has been a reduction in the planned production area.

Figures A-1 to A-6 in Appendix A present information about the timing of production commencement and cessation in each of the target coal formations for various parts of production tenures. This information was used in the regional model.

7.3 Results of groundwater impact predictions

As described in Sections 7.1 and 7.2, a number of important revisions have been made since the previous UWIR, to both the modelling approach and the resulting numerical model. There have also been some significant changes to both the timing and footprint of planned CSG development within the area (Section 2.4). This has resulted in a revised set of impact predictions which are described below.

The predicted impacts are for the calibrated model which is based on robust parameterisation as described in Section 7.2.2. New approaches to uncertainty analysis are being developed and will be applied; results will be provided in the first annual report on implementation of the Surat UWIR 2016.

Predictions of impacts have been made for the coal formations from which CSG is produced, and for the following aquifers: Bungil Formation, Mooga Sandstone, Gubberamunda Sandstone, Springbok Sandstone, Hutton Sandstone, Precipice Sandstone, Clematis Sandstone and the Condamine Alluvium.

A generic description of depressurisation of aquifers in a multilayered aquifer system such as the GAB, and how this depressurisation can cause a decline in pressure in bores tapping the different layers, is presented in Appendix D for information purposes.

7.3.1 Immediately Affected Areas

The IAA of an aquifer is the area within which water levels are predicted to fall, due to water extraction by petroleum tenure holders, by more than the trigger threshold within three years. The trigger thresholds are specified in the Water Act. They are five metres for consolidated aquifers (such as sandstone) and two metres for unconsolidated aquifers (such as sands). Figure 7-4 shows the extent of the IAAs.

As discussed in Section 7.2.2, CSG extraction leads to the development of a significant vertical hydraulic gradient within the coal reservoirs, such that the pressure reduction at the top of the reservoir is less than that at the bottom. As a result, multiple layers have been modelled within the coal formations. The IAA extents are the maximum predicted impacts in all the layers used to represent each formation.

The predicted water level impact in completed water supply bores within the coal formations will vary depending on the depth to which the bores penetrate the coal formations. Bores that penetrate a short distance into the coal formation will experience less pressure reduction than bores that penetrate to greater depth. As a result, some water bores—although completed within the IAA for a coal formation—are not predicted to be affected within the next three years because significant pressure reductions are not expected at the depth of the water bores. Details of those bores are provided in Table E-4 of Appendix E.

Table 7-1 provides a summary of water supply bores that are now or in the past have been identified as being affected bores in an IAA. There are 91 bores which are either identified for the first time (57 bores) or which have been previously identified and for which ‘make good’ obligations are ongoing (34 bores). The 57 newly identified bores includes bores that are currently authorised (Table E-1 of Appendix E) and bores that are currently not authorised (Table E-2 of Appendix E). The previously identified bores are listed in Table E-3 of Appendix E). In addition, there are 36 bores which have been recorded as decommissioned since 2012.

Table 7-1 Affected water bores in Immediately Affected Areas

Category	Agriculture	Industrial	Town Water Supply	S&D	Total
Newly identified bores	0	1	0	56	57
Previously identified bores	2	1	0	31	34
Existing bores	**2**	**2**	**0**	**87**	**91**
Previously identified bores now decommissioned					36
Total					**127**

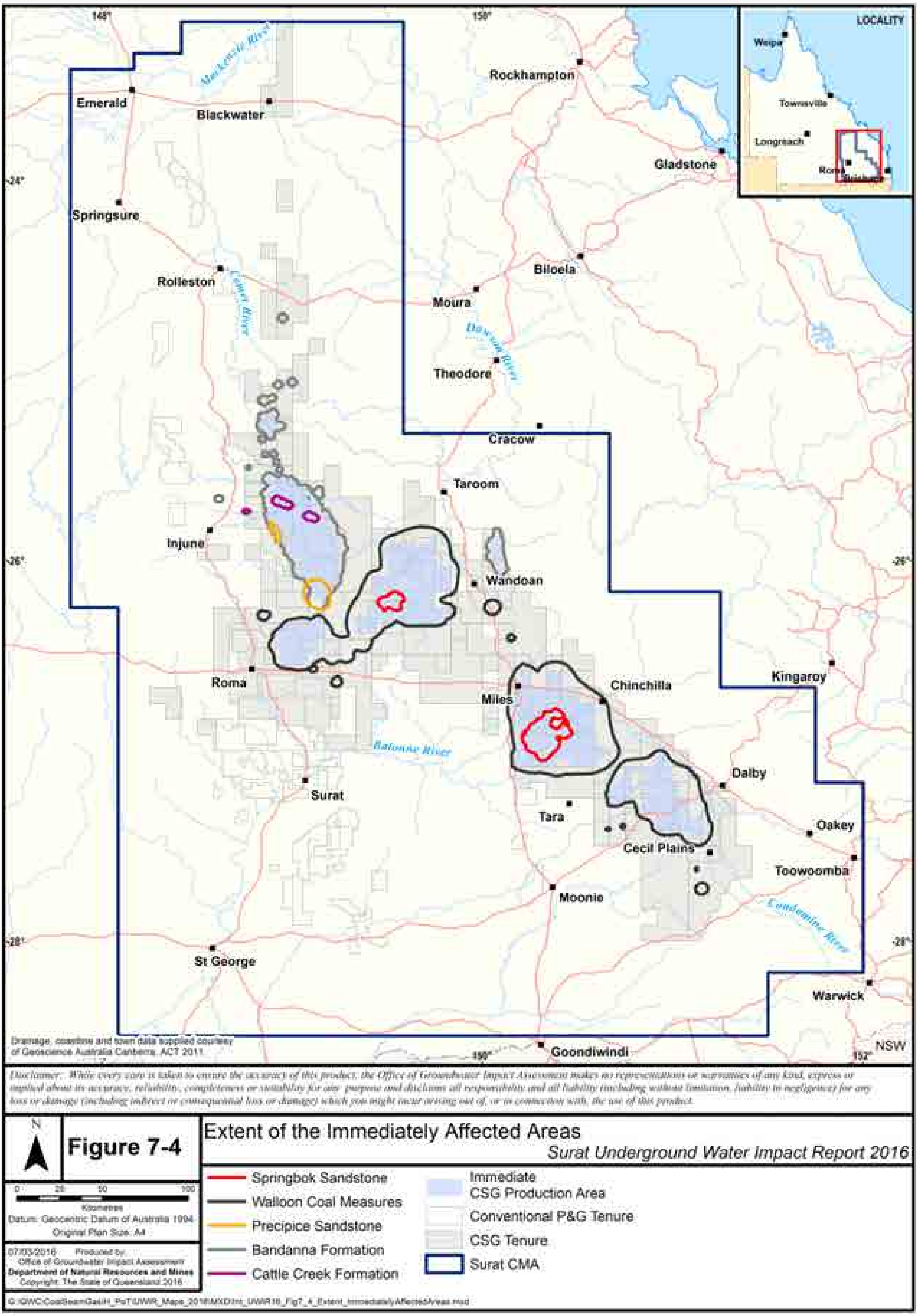


Figure 7-4 Extent of the Immediately Affected Areas

7.3.2 Long-term Affected Areas

The Long-term Affected Area (LAA) of an aquifer is the area within which water levels are predicted to fall, due to water extraction by petroleum tenure holders, by more than the trigger threshold at any time in the future. The trigger thresholds are specified in the Water Act. They are five metres for consolidated aquifers (such as sandstone) and two metres for unconsolidated aquifers (such as sands).

Figure 7-5 shows the extent of the LAAs. The LAAs are significant for the Walloon Coal Measures, the Bandanna Formation, the Springbok Formation, and the Hutton Sandstone. Small LAAs are identified for the Cattle Creek Formation, Precipice Sandstone, Clematis Sandstone and Gubberamunda Sandstone.

Table 7-2 provides a summary of the number of current water supply bores that are predicted to be affected in the long term. There may be other private bores that are located within the geographic extent of the LAA for an aquifer, but which extract water from another aquifer. They are not included in this summary. In addition to the 459 currently existing bores predicted to be impacted in the long term, a further 59 bores identified as long-term affected bores in UWIR 2012 have been decommissioned. Not all of these bores will have been decommissioned because of CSG development. Some result from database corrections to reflect abandonment that took place prior to the commencement of CSG development.

Table 7-2 Water bores in Long-term Affected Areas

Aquifer or Sub Aquifer	Agriculture	Industrial	Town Water Supply	S&D	Total
Gubberamunda Sandstone					0
Westbourne Formation				17	17
Springbok Sandstone	2			45	47
Walloon Coal Measures	30	3	1	304	338
Durabilla Formation		2		8	10
Hutton & Marburg Sandstones	4	1	2	28	35
Evergreen Formation		1		1	2
Precipice & Helidon Sandstones				9	9
Clematis Sandstone					0
Rewan Group				1	1
Bandanna Formation					0
Cattle Creek Formation					0
Existing bores	**36**	**7**	**3**	**413**	**459**
Previously identified bores now decommissioned					59
Total					**518**

The LAAs identified in Figure 7-5 show only the extent of areas which are predicted to experience more than five metres of impact in the long-term. Further details about the distribution of long-term impacts are shown on maps provided in Appendix F-1 to F-9. A summary of the long-term impact distribution is provided below.

- **Walloon Coal Measures**: This is the CSG target formation in the Surat Basin. There are 338 existing water bores that source water from the formation in the affected area. Most of these are located to the north and east of active CSG development areas where the formation is shallow and where predicted impacts also tend to be smaller. Half of the affected bores are likely to experience an impact of less than 17 metres.

- **Bandanna Formation**: This is the main CSG target formation in the Bowen Basin. There are no water bores within this formation in the affected area.
- **Cattle Creek Formation**: This is a new CSG target formation in the Bowen Basin that is present several hundred metres below the Bandanna Formation. There are no water bores within this formation in the affected area.
- **Springbok Sandstone**: This aquifer overlies the Walloon Coal Measures. It is separated from the productive coal seams by the upper aquitard of Walloon Coal Measures (Section 4.4.2). There are 47 existing bores that source water from the formation in the affected area. Half of the bores are likely to experience an impact of less than 10 metres.
- **Hutton Sandstone**: This aquifer underlies the Walloon Coal Measures. It is separated from the productive coal seams by the Durabilla Formation, which is an aquitard. There are 35 water bores that source water from the formation in the affected area. Most of the bores are likely to experience an impact of less than 10 metres.
- **Precipice Sandstone**: Over most of the affected area, the maximum impact is expected to be less than two metres. However, west of CSG fields of the Bowen Basin near Injune, the aquifer is in direct contact with the Bandanna Formation and the Cattle Creek Formation which is also now proposed to be developed. Injection of treated CSG water into the formation has also recently commenced nearby (Section 5.2.2). The potential positive impact on regional pressures is substantial, but has yet to be fully assessed. Impact predictions in the vicinity of the contact are therefore preliminary and a more detailed sub-regional assessment of the area will be carried out. There are nine bores that source water from the formation in the affected area.
- **Gubberamunda Sandstone**: This aquifer is not well-connected to the coal formations. There are no water bores that source water from the formation in the affected area.
- **Clematis Sandstone**: This is the upper aquifer of the Bowen Basin. There are no water bores within the affected area.
- **Non-aquifer formations**: There are 30 water bores with predicted long term impacts of more than 5 metres that are currently assessed as accessing formations that are not typically considered to be aquifers, including the Westbourne, Durabilla and Evergreen Formations and the Rewan Group. Although details about these bores will need to be clarified to confirm that they are in fact accessing these units, they are included as bores that are likely to be impacted.
- **Condamine Alluvium**: There is no LAA for the Condamine Alluvium. It is predicted that there will be net loss of water from the Condamine Alluvium to the Walloon Coal Measures of about 1,160 ML/year over the next 100 years, which is very close to predictions made in 2012. However, this loss of water will not be enough to significantly affect water bores accessing the Condamine Alluvium. The maximum reduction in water level is expected to be 1.6 metres in the north-west but less than 0.25 metres across the majority of the area.

The following are general comments about the difference between the current assessment of the LAAs and the assessment made in 2012.

The LAA for the Walloon Coal Measures extends further in the north-east and has contracted in the south-west. The extension towards the north-east reflects an improved understanding of the spatial variation in horizontal permeability within the Walloon Coal Measures. Horizontal permeability tends to be relatively high in the north-east where the coal is close to the surface and then gradually reduce with depth towards the south-west. The reduction in the area of planned CSG development is also a significant factor. The number of water bores likely to be affected in the long term has decreased from 400 to 338. The decrease is due to the reduction in the planned development area, the changes to the LAA, bore decommissioning, and improved information about which aquifers the bores access.

The LAA for the Springbok Sandstone which overlies the Walloon Coal Measures is smaller than assessed in 2012. This reflects the generally lower vertical permeability resulting from parameterisation and calibration of the new groundwater flow model as discussed in Sections 7.1 and 7.2. The number of water bores likely to be affected in the long term has reduced from 104 to 47.

The LAA for the Hutton Sandstone is larger than assessed in 2012. The formation is separated from the overlying Walloon Coal Measures by the Durabilla Formation, which is an aquitard. While the Durabilla Formation is now considered to be less permeable than previously believed, pressure reductions at the base of the Walloon Coal Measures are predicted to be higher. The net effect of these two factors is that the LAA is larger than previously predicted. This has resulted in an increase in the number of impacted bores, from 23 to 35, although improved information about water bores is also a contributing factor.

The LAA for the Precipice Sandstone is larger than assessed in 2012. The affected area of the formation is in the vicinity of its contact with the underlying coal formations east of Injune (Figure 4-9). The increase reflects newly planned CSG extraction from the Cattle Creek Formation and increased predicted impacts at the base of the coal formations as a result of improved simulation of CSG extraction.

There is little significant change with regard to the timing of impacts. Maximum impacts in any aquifer will occur at different times at different geographic locations. Maximum impacts in the coal formations will occur towards the end of the current major CSG project 30-40 year lifecycle, generally between 2030 and 2060. Maximum impacts in the Precipice Sandstone close to the contact zone with the Bandanna Formation and the Cattle Creek Formation to the east of Injune are predicted to occur between 2040 and 2060. Maximum impacts in the Springbok Sandstone are expected to occur between 2040 and beyond the end of the life of the industry. In indirectly connected aquifers, such as the Hutton and Gubberamunda sandstones, there will be a significant time lag before maximum impacts occur and before pressures start to recover.

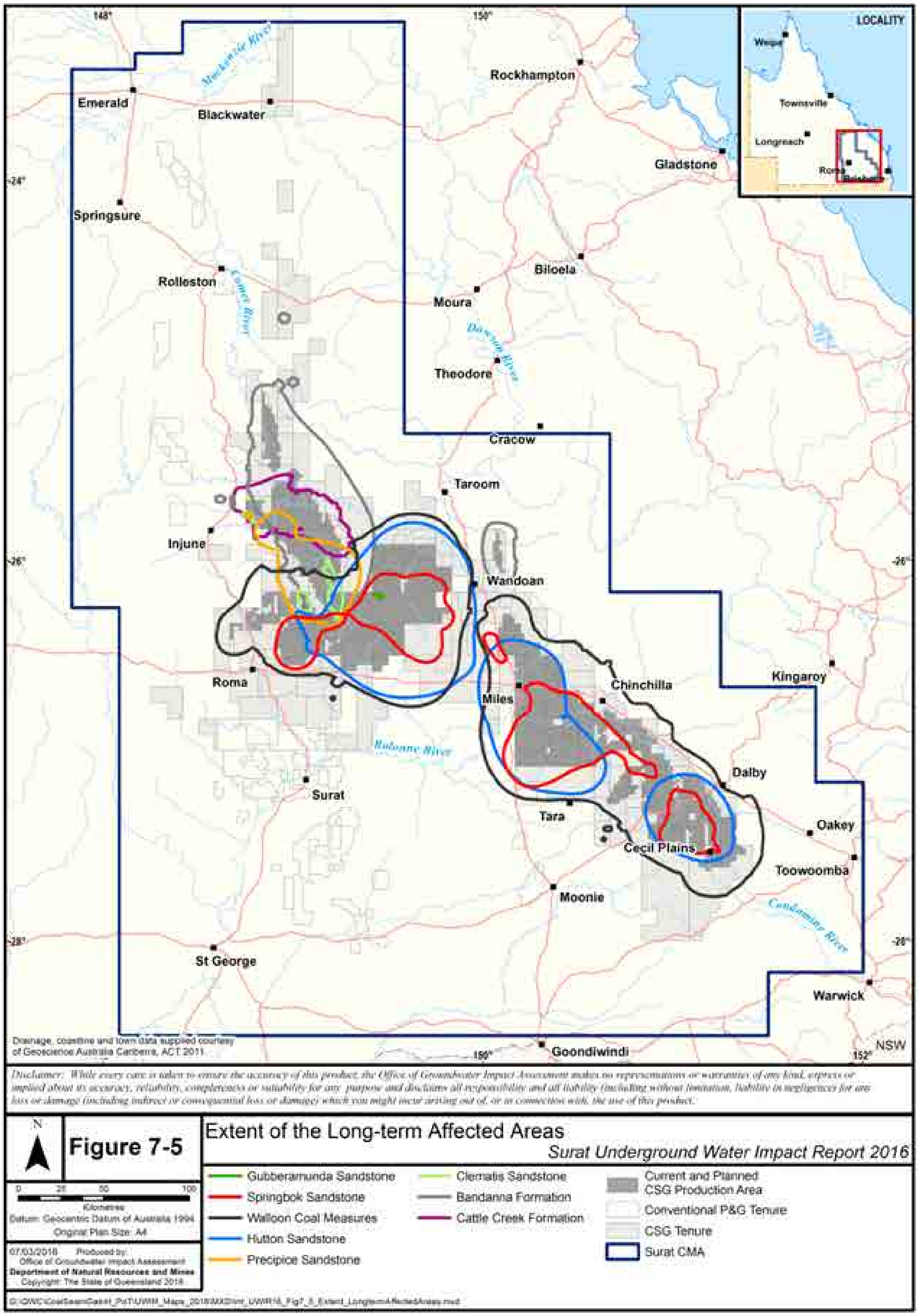


Figure 7-5 Extent of the Long-term Affected Areas

7.3.3 Water extraction forecast

The volume of water extracted in the process of producing CSG in the Surat CMA is not as high as was estimated in 2012. Estimates of future extraction have been progressively revised down on the basis of industry experience and since the planned CSG development area has reduced. The permeability of coals seams varies and this affects the volume of water that needs to be removed in order to reduce enough pressure to produce gas. More of the less-permeable coals seams are being encountered than was expected in 2012.

Current CSG water extraction is about 65,000 ML per year and rising. It is estimated that, over the next three years, water extraction will be about 110,000 ML per year. Current projections, based on the installation of 17,900 CSG wells over the current and planned development areas shown in Figure 2-5, are that about 3,570 gigalitres of water will be extracted over the lifetime of the CSG industry. Around 90 percent of this total will be extracted over the period of peak production from 2014 to 2060 during which an average annual extraction rate of about 70,000 ML per year is forecast.

8 The Water Monitoring Strategy

8.1 Overview

- Of the 618 monitoring points scheduled to be completed by the end 2016, a total of 491 are complete or under construction. Monitoring data is being received for 369 of these monitoring points.
- The monitoring network requirements have been revised on the basis of new knowledge about the system and to maximise the use of suitable existing bores.

The Water Monitoring Strategy (WMS) for the Surat CMA was initially specified in the UWIR 2012 and has since been progressively implemented. This chapter sets out amendments to the WMS to meet emerging needs. The implementation of the WMS is progressively building knowledge about the way the groundwater flow system is responding to water extraction by petroleum tenure holders and other water users. This knowledge will continue to support ongoing improvements in regional groundwater flow modelling, thereby improving predictions of the impact of planned CSG water extraction on groundwater pressures. The WMS is not directed at issues related to storing and handling chemicals involved in CSG operations or at assessing the impacts of hydraulic fracturing operations.

In this report, the term ‘monitoring point’ refers to monitoring works installed to monitor water pressure and/or water chemistry in specific geologic layers, at specific geographic locations. Technologies are available that allow multiple monitoring points to be installed in a single borehole to monitor conditions in multiple geologic layers.

Figure 8-1 shows various types of monitoring installations.

The term ‘monitoring network’ is used in this report to refer to all the monitoring points of the WMS. The WMS includes specifications for installing and operating the monitoring network, and specifications for monitoring the volume of water extracted from petroleum and gas wells.

The WMS is being implemented by petroleum tenure holders in accordance with their individual obligations, as assigned in Chapter 10. Implementation includes constructing and operating the monitoring points and reporting data and implementation progress to OGIA every six months. Once the data collected from the monitoring points has been checked, it is entered into the GWDB, which is publicly accessible online via the Queensland CSG Globe. The water production data at the wellfield scale is publicly available on the QDEX Reports system.

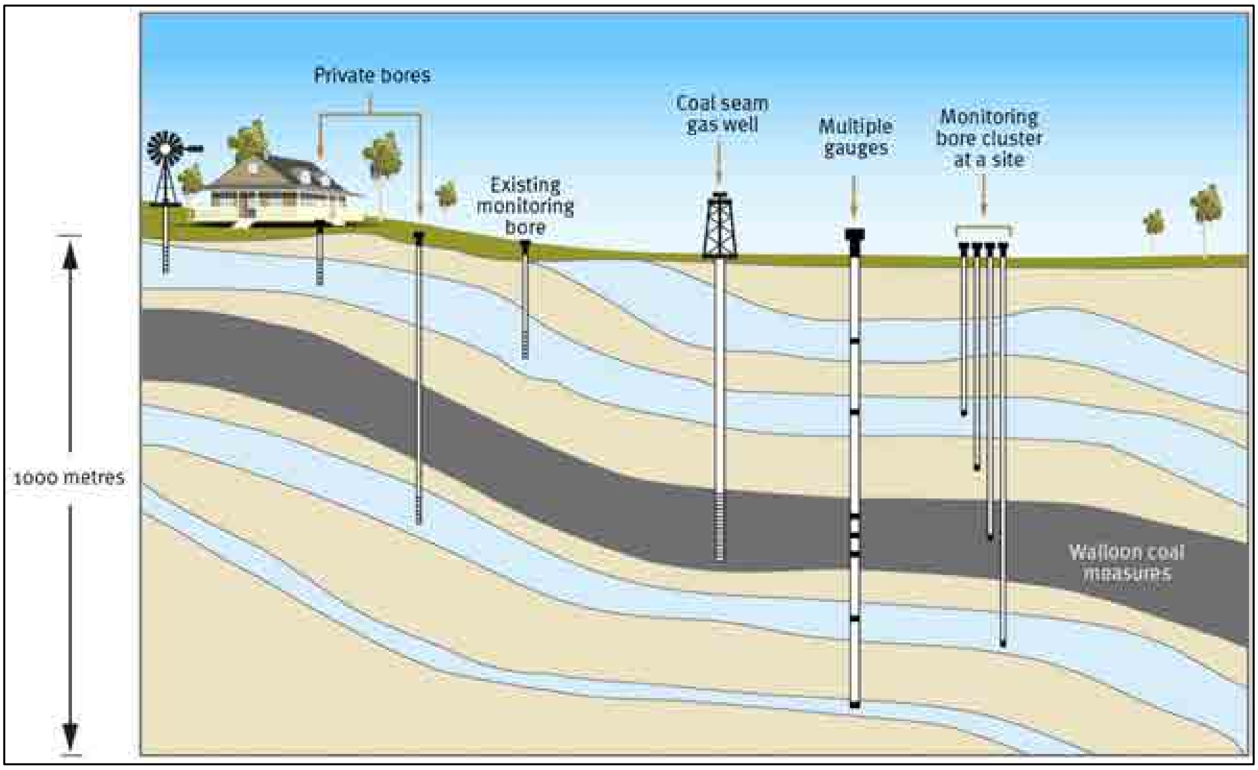


Figure 8-1 Types of groundwater monitoring installations

8.2 Rationale for the WMS

The WMS is designed to complement existing monitoring activity to achieve specific monitoring objectives. The rationale for the WMS is discussed in the following sections.

8.2.1 Monitoring objectives

The WMS is designed to achieve the following objectives:

- **Establish background trends:** Monitoring is needed to establish background trends in groundwater pressure caused by climate variability and by extraction of groundwater for other uses, in advance of any water extraction by petroleum tenure holders. Identifying these background trends allows separation of the impacts of CSG development from other contributing factors. Background trends also provide useful insight into the functioning of groundwater systems by enabling the development of regional water level or pressure contours.
- **Identify changes within and near areas of petroleum development:** Monitoring is needed in and around existing and developing gas fields to identify, at an early stage, the impacts of CSG water extraction.
- **Identify changes near specific locations of interest:** In some locations, groundwater use is concentrated or of critical importance, such as for town supply or in areas of regionally significant agricultural development. There are also locations where water pressure data is needed to improve knowledge about the risk to springs from CSG development. Background trends and CSG water extraction impacts are of particular interest at these locations.
- **Improve future groundwater flow modelling:** The regional groundwater flow model is based on a conceptualisation of the hydrogeology of the groundwater flow system. Water pressure and water

quality monitoring data is required to improve understanding of how the groundwater flow system works, including how connectivity between aquifers works. Understanding the system allows us to progressively improve the groundwater flow model used to predict how aquifers will respond to CSG development.

8.2.2 Evolution of the monitoring network

The UWIR 2012 identified a network of 396 new pressure monitoring points to be constructed by the end of 2016 to complement the 102 existing points, giving a total network of 498 points. Of these, 120 were identified for water chemistry monitoring as well as water pressure monitoring, bringing the total number of points to 618. By late 2015, 491 of the total 618 points were either operational or under construction. During that time, new information about geology at some of the planned monitoring locations became available and, based on this information, OGIA decided to defer installation at some of the proposed monitoring points until the network requirements were reviewed in the process of developing UWIR 2016.

Changes with regard to complementary monitoring network activity have influenced the review of the WMS. Over recent years, the CSG Compliance and Engagement Unit of DNRM has developed ‘CSG Online’. This program is identifying private water bores that are suitable for monitoring in the area and, with the support of the bore owners, is installing monitoring equipment in the bores. The data provides bore owners with useful information about the condition of their bores as well as trends in water levels. The data is entered into the GWDB. By late 2015, there were 25 monitoring points in the CSG Online network with an additional 17 points soon to be added. CGS Online is a source of useful data that OGIA will continue to use to complement data from the WMS network.

The WMS network proposed in the UWIR 2012 built on existing monitoring points established by petroleum tenure holders. Over and above these points, tenure holders have also provided data to OGIA from other existing monitoring points, which have been instrumented by tenure holders for a variety of monitoring purposes. These points are providing useful data now and may continue do so in the long term. OGIA will maximise use of these points as part of the monitoring network; should they become unavailable for monitoring at some future time, OGIA will reassess the monitoring needs as part of the subsequent update of the UWIR.

8.2.3 Design principles of the monitoring network

The WMS has been reviewed against the following principles:

- The part of the monitoring network specified in the UWIR 2012 that was not started by September 2015 has been re-assessed as part of the current review of the WMS. The revised network specification replaces the unimplemented part of the UWIR 2012 network specification.
- In accordance with industry best practice (European Commission 2004), the primary focus area for monitoring is the footprint of planned CSG development because the biggest impacts are expected to be near the CSG production areas. In 2012, the WMS provided for a monitoring density within the LAAs (Section 7.3.2) of about 0.3 monitoring points per 100 square kilometres, which is comparable to that achieved in other similar basin-scale aquifer monitoring networks.
- Beyond the footprint of planned CSG development, monitoring requirements relate more to background monitoring, and supporting further development of the regional groundwater flow model. In these areas, the monitoring density is lower, in keeping with the relatively minor impacts predicted in these areas.

- The network design, which is based primarily on achieving desired coverage, is adjusted to achieve the objective of monitoring locations of specific interest.
- Where practicable, the monitoring points for multiple target formations in an area are located in close proximity to provide focussed information on pressure differences between formations.
- The network design is based on the planned CSG development as set out in Chapter 2. If further development was planned, the lead time to implement that development would allow enough time for the monitoring network specification to be reviewed as part of a UWIR update.
- The use of existing tenure holder works capable of providing monitoring data is maximised so that the drilling of new dedicated monitoring bores can be focussed on the areas of greatest need.
- The network is designed having regard to the availability of complementary data from the expanding CSG Online network operated by the CSG Compliance and Engagement Unit of DNRM.
- A major part of the monitoring network is already in place. New drilling required under the WMS has been scheduled to give tenure holders enough time for planning.

8.3 Components of the WMS

The WMS is comprised of the following components:

- Installation of the water monitoring network by tenure holders.
- Ongoing collection and reporting of water pressure and water chemistry data by tenure holders.
- Ongoing collection and reporting of water extraction data from petroleum and gas wells by tenure holders.
- Regular assessment by OGIA of the data provided by tenure holders, with annual reporting of those assessments, as set out in Chapter 10.

8.3.1 Specifications of the monitoring network

The monitoring points of the monitoring network are listed in Table G-1 of Appendix G. Where a monitoring point is yet to be installed, the date for completion is specified. The locations of existing and proposed water pressure and water quality monitoring points are shown in Figure 8-2 and Figure 8-3 respectively. Table 8-1 provides a summary of the regional monitoring network.

The locations of monitoring points in each of the main aquifers are shown in Figures G-1 to G-9 in Appendix G.

Table G-2 lists the monitoring points that will provide data to complement the water monitoring network; it includes existing CSG Online bores that are particularly useful in complementing the network, and bores that are intended to become CSG Online bores.

The main features of the WMS monitoring network are as follows:

- Of the 675 proposed monitoring points, 491 are already operational or under construction, 56 exist but are not yet part of the WMS monitoring network, 111 are completely new points and 17 are complementary to the WMS network. Monitoring data is being received for 369 of these monitoring points.

- About 70 per cent of the monitoring points are in formations and at locations where CSG impacts on groundwater pressure of more than five metres are predicted. The other 30 per cent are located outside the areas of significant impact, in more remote aquifers or aquitards.

Table 8-1 Summary of the monitoring network

Target unit	Number of monitoring points				
	Existing WMS network	Existing points for inclusion	Proposed new WMS	Complementary network	Total
Condamine Alluvium	21	0	3	0	24
Main Range Volcanics	4	0	0	0	4
Mooga Sandstone	10	0	0	0	10
Orallo Formation	5	0	0	0	5
Gubberamunda Sandstone	49	4	6	2	61
Westbourne Formation	7	2	0	0	9
Springbok Sandstone	81	4	15	0	100
Walloon Coal Measures	213	8	56	0	277
Hutton Sandstone	39	18	21	8	86
Evergreen Formation	2	1	0	2	5
Precipice Sandstone	29	19	4	3	55
Clematis Sandstone	7	0	2	2	11
Bandanna Formation	24	0	2	0	26
Cattle Creek Formation	0	0	2	0	2
Total	**491**	**56**	**111**	**17**	**675**

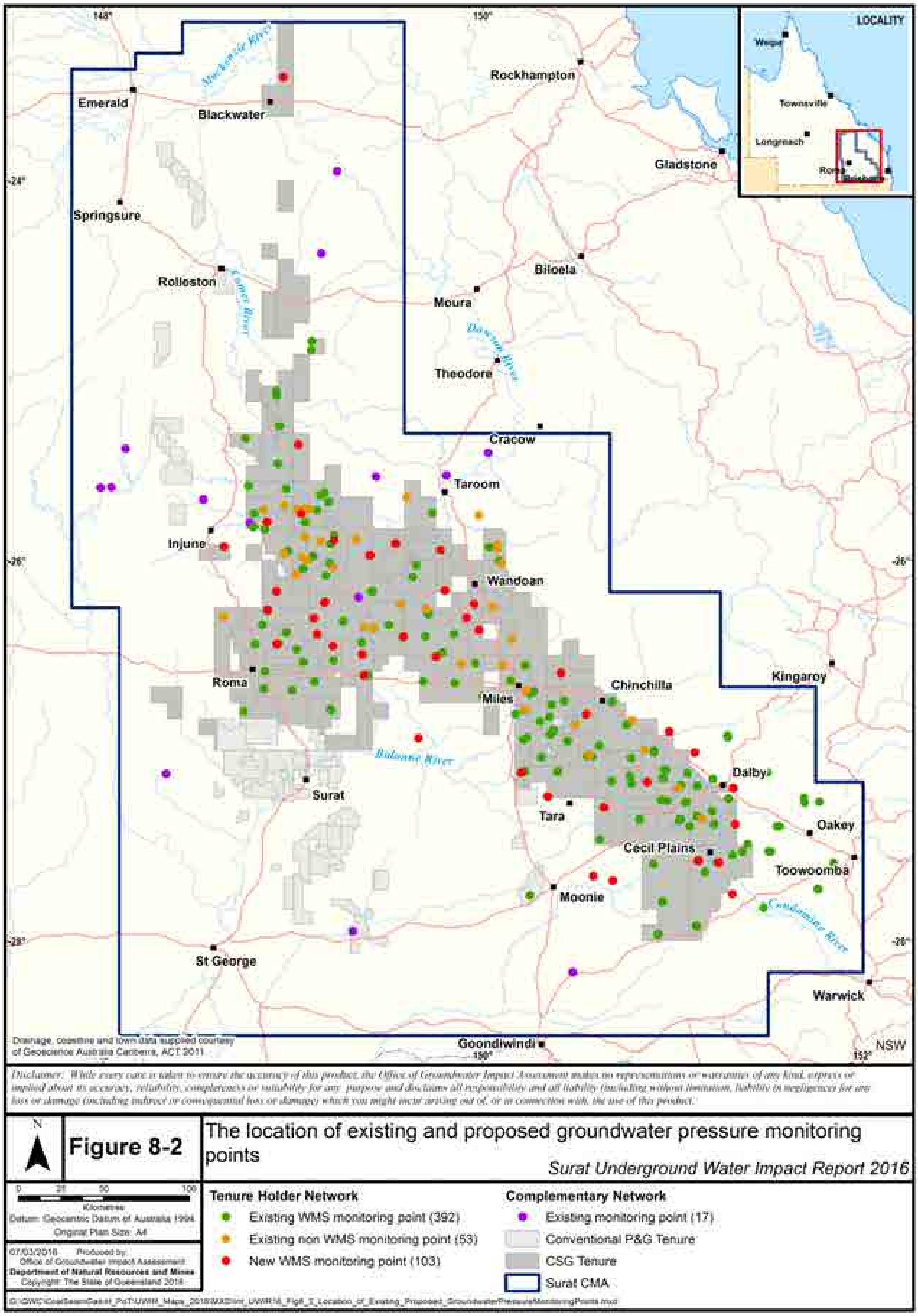


Figure 8-2 The location of existing and proposed groundwater pressure monitoring points

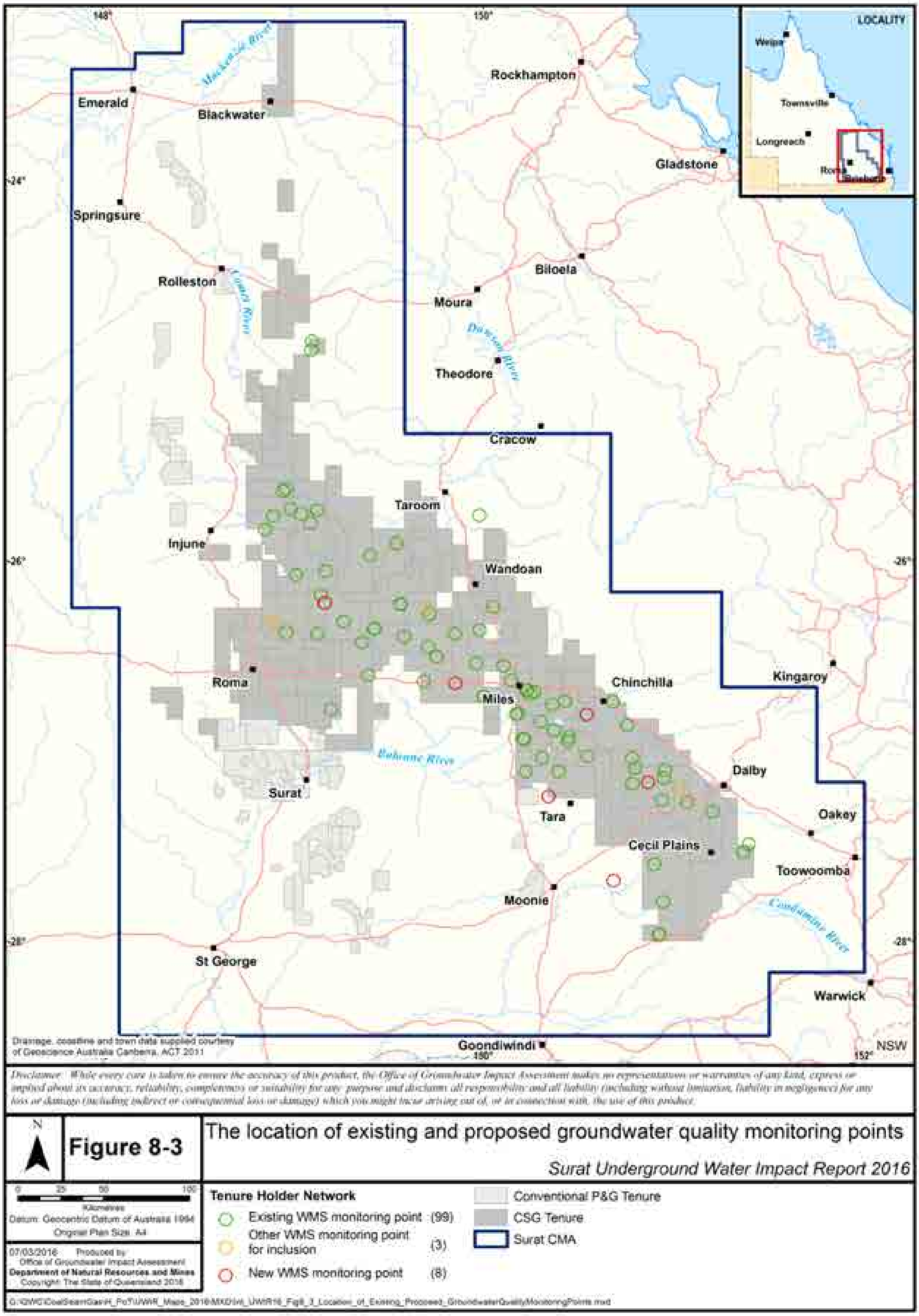


Figure 8-3 The location of existing and proposed groundwater quality monitoring points

8.3.2 Installing and maintaining the monitoring network

The WMS is being implemented by responsible petroleum tenure holders. Table G-1 of Appendix G specifies:

- The responsible tenure holder for each monitoring point.
- The location of each monitoring point. For new monitoring points, it may be impracticable to site works at the specified locations. Details of proposed changes to specified locations must be submitted to OGIA for approval before construction, as specified in Section 8.3.4.
- The timing requirement for installation. Details of difficulties in meeting the required timing must be notified to OGIA for approval, as specified in Section 8.3.4.

The field parameters and chemical components to be collected and analysed every six months are specified in Table G-3 of Appendix G.

A guideline for constructing new monitoring points is provided in Appendix G-2. Monitoring points must be constructed in accordance with the guideline or in a way that achieves the same outcomes.

The responsible tenure holder must maintain each monitoring point. If a monitoring point fails and it is not practicable to repair it, the tenure holder must notify OGIA, as specified in Section 8.3.4. The need for monitoring at the location will then be considered at the next update of the UWIR.

8.3.3 Monitoring of CSG wells

The P&G Acts and associated regulations require that petroleum tenure holders monitor water extraction from petroleum and gas wells. For OGIA assessment purposes, the water extraction data is required at monthly intervals.

8.3.4 Reporting to OGIA on the network implementation

Responsible tenure holders must submit to OGIA a **network implementation report** at the end of March and September each year, in the format specified by OGIA. The report should provide details about the installed monitoring points, the planned installation of monitoring points and any emerging implementation issues. If a report proposes a change to the location or timing of the installation of a monitoring point, or other changes to the planned network as a result of emerging geological knowledge or other matters, the proposed change needs to be endorsed by OGIA.

Responsible tenure holders must submit to OGIA a **water monitoring report** at the end March and September each year, in the format specified by OGIA. The report should provide details of the monitoring data collected under the WMS and must explain any gaps in the monitoring record associated with maintenance issues or failure of a monitoring point.

If, as a result of tenure holder quality assurance processes, a tenure holder needs to amend monitoring data previously submitted in a water monitoring report, the tenure holder must submit to OGIA a **data correction report** explaining the corrections.

8.3.5 Baseline assessment program

A baseline assessment is an assessment of a private bore by a petroleum tenure holder to obtain information about bore construction, water levels and water quality. The information provides a baseline of bore condition and performance. This information supports the development of agreements between bore owners and petroleum tenure holders about ‘making good’ any impairment of bore supply caused by the extraction of groundwater by petroleum tenure holders. The water level and water quality information can also assist OGIA in its ongoing assessment of the groundwater system.

The Water Act requires that petroleum tenure holders carry out baseline assessments of water bores on tenures before production begins on the tenures. Assessments are carried out in accordance with baseline assessment plans approved by EHP and in accordance with guidelines issued by EHP.

The Water Act also provides that the WMS contain a program for baseline assessments for the LAAs. This program includes land outside the tenures on which production is occurring. In many parts of the LAAs, impacts on water level or water pressure will not occur for a long time. Baseline assessments are best done immediately before the impacts are expected to occur. If they are done too early, the information collected would be out of date and not useful for assessing changes.

For this reason, the program for carrying out baseline assessments for the LAAs supports the progressive expansion of the area assessed, so that assessments are completed close to the time that the impact is predicted to occur. A predicted impact of one metre within three years has been adopted as the trigger for carrying out a baseline assessment. Each time a new UWIR is prepared, a new one-metre impact area will be established.

The baseline assessment program is as follows:

- The baseline assessment area for an aquifer is an area where a water pressure fall of more than one metre is expected within three years, as shown in Figure 8-4.
- Responsible tenure holders must carry out baseline assessments for bores that tap an aquifer within the baseline assessment area for the aquifer.
- If a baseline assessment has already been carried out in accordance with other obligations arising under the Water Act, no further assessment is required.
- Assessments are to be carried out in accordance with the guidelines for baseline assessments issued by EHP.
- Assessments must be completed, and the results reported to OGIA, within 12 months of the UWIR being approved.
- Each time the UWIR is reviewed, new baseline assessment areas will be established until the baseline assessment areas for an aquifer coincide with the entire LAA for the aquifer.

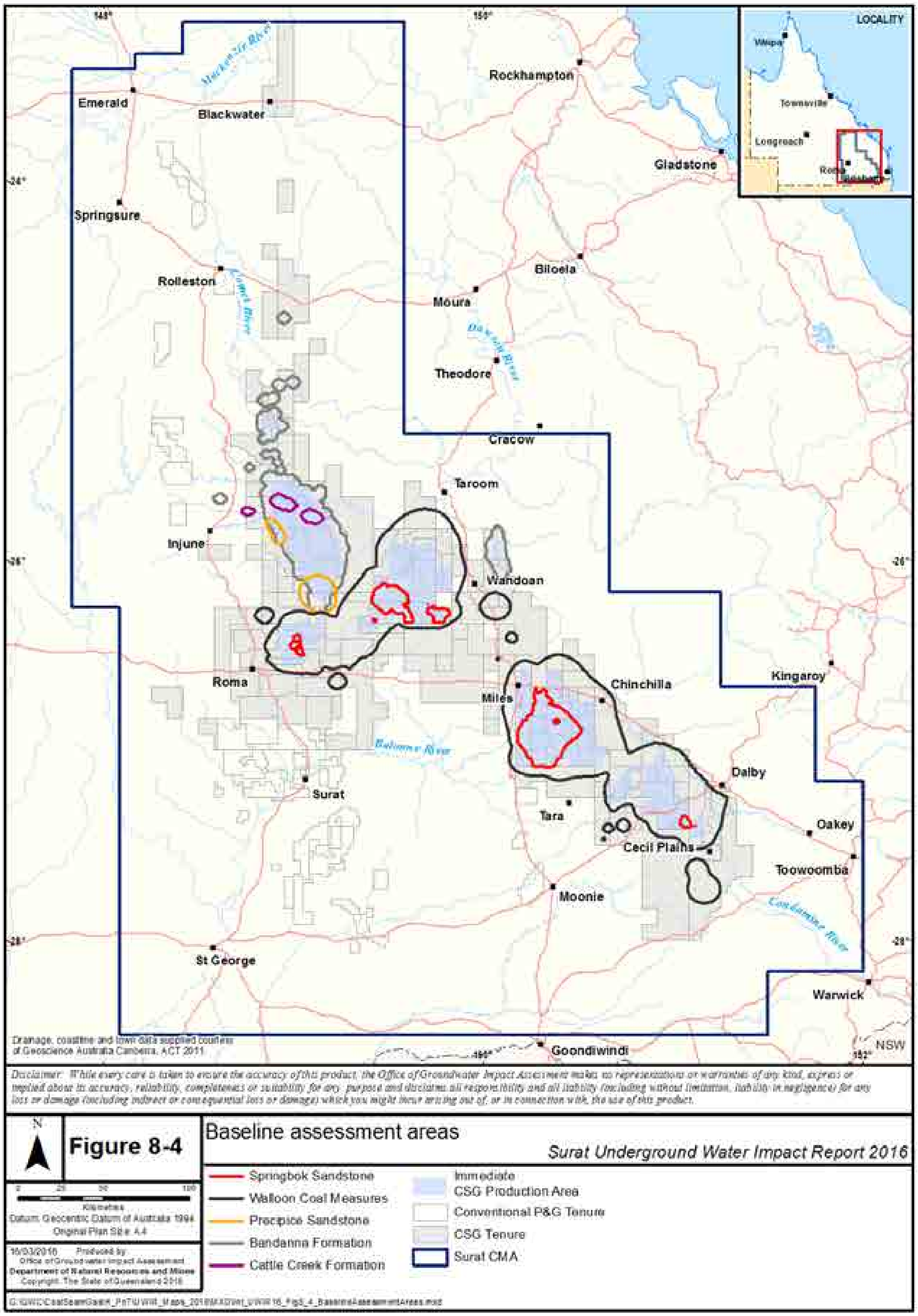


Figure 8-4 Baseline assessment areas

9 Spring Impact Management Strategy

- An improved system for assessing the risk to springs has been developed.
- The spring monitoring requirements have been revised on the basis of the risk assessment.
- Four spring sites require further investigation to clarify risk and assess mitigation options.

9.1 Introduction

The Spring Impact Management Strategy (SIMS) for the Surat CMA was first specified in the UWIR 2012 and has been implemented from that time. This chapter updates the strategy in response to the revised predictions of impacts and the new understanding about the way springs respond to seasonal conditions, non-groundwater related stresses, and water extraction from aquifers by petroleum tenure holders and other water users.

Springs are fed by aquifers and are often associated with significant cultural heritage and ecological values. If the pressure in an aquifer feeding a spring is lowered by water extraction, then the flow of water to the spring will be reduced, potentially affecting the spring’s cultural and/or ecological values.

The Water Act requires that the spring impact management strategy include the following components:

- **A list of potentially affected springs:** Springs that overly aquifers with a predicted impact of more than 0.2 metres drawdown are identified.
- **An assessment of connectivity to underlying aquifers:** For potentially affected springs, the aquifers that provide flow to the spring are identified.
- **An assessment of risks to springs:** The risk of current and planned P&G development impacting on the source aquifers of potentially affected springs is assessed.
- **A spring monitoring program:** The program identifies monitoring sites, appropriate techniques and frequency.
- **A spring impact mitigation strategy:** A strategy is developed for avoiding or mitigating impacts where the fall in water level in the source aquifer for a spring is predicted to be more than 0.2 metres.

The monitoring and mitigation strategies identified in the spring impact management strategy are implemented by petroleum tenure holders in accordance with individual responsibilities, as assigned in Chapter 10. Responsibilities include collecting the required monitoring data, and reporting to OGIA on implementation on a six-monthly basis that aligns with reporting on the WMS implementation.

9.1.1 Terminology

GAB springs are commonly described as either ‘spring vents’ or ‘watercourse springs’. The term ‘spring complex’ is also commonly used to group spring vents. The meanings of those terms are set out in Table 9-1.

Table 9-1 Spring terminology

Term	Description
Spring vent	A single point in the landscape where groundwater is discharged at the surface. A spring vent can be mounded or flat and can also present as wetland vegetation, with no visible water at the location of the spring.
Spring complex	A group of spring vents located close to each other. The spring vents are located in the same surface geology, and share the same source aquifer and landscape position. No adjacent pair of spring vents in the complex is more than 10 km apart.
Watercourse spring	A section of a watercourse where groundwater from a GAB aquifer enters the stream through the streambed. This includes waterholes and flowing sections of streams dependent on groundwater. This type of spring is also referred to as a baseflow-fed section of a watercourse.

Springs in the GAB are often further classified by features such as size, location in the landscape and regional hydrogeological setting (for example, whether they are located in a recharge area or a discharge area).

The emerging nomenclature that encompasses features traditionally referred to as springs is based on the concept of ‘groundwater-dependent ecosystems’. These ecosystems need permanent or intermittent access to groundwater to meet at least some of their water needs to maintain communities of plants and animals, ecological processes and ecosystem services (Richardson et al. 2011). Three types of groundwater-dependent ecosystems are recognised:

- ecosystems dependent on the surface expression of groundwater
- ecosystems dependent on the subsurface expression of groundwater
- cave and aquifer ecosystems.

In this report, a feature identified as a spring vent or watercourse spring aligns with the definition ‘ecosystem reliant on the surface expression of groundwater’ in the groundwater-dependent ecosystems framework.

9.2 Springs in the Surat CMA

The inventory of springs in the area has been established over a long period. More recently, research by OGIA and petroleum tenure holders has identified previously unknown springs. In addition, Queensland Parks and Wildlife Services and other researchers have better identified springs in areas of limited access, such as the Carnarvon Gorge. All new data on spring locations is included in the spring dataset held by the Queensland Herbarium, which forms the basis of this spring impact management strategy.

In the Surat CMA, springs are not known to be fed by the formations targeted for CSG development. They mostly receive groundwater flow from: the Clematis Sandstone; the Precipice Sandstone; the Boxvale Sandstone Member of the Evergreen Formation; the Hutton Sandstone; the Gubberamunda Sandstone; and the Bungil Formation. Some springs are associated with the Tertiary Volcanics and the Cenozoic sediments.

The occurrence and distribution of springs are primarily driven by regional and local geology, topography and the nature of the supporting groundwater flow system. Most springs are located along or near the northern and central outcrop areas of the Surat and Bowen basins. The main hydrogeological and morphological processes that form springs in the region are summarised in Section 4.7.1.

The locations of all potentially affected springs in the Surat CMA are shown in Figure 9-1.

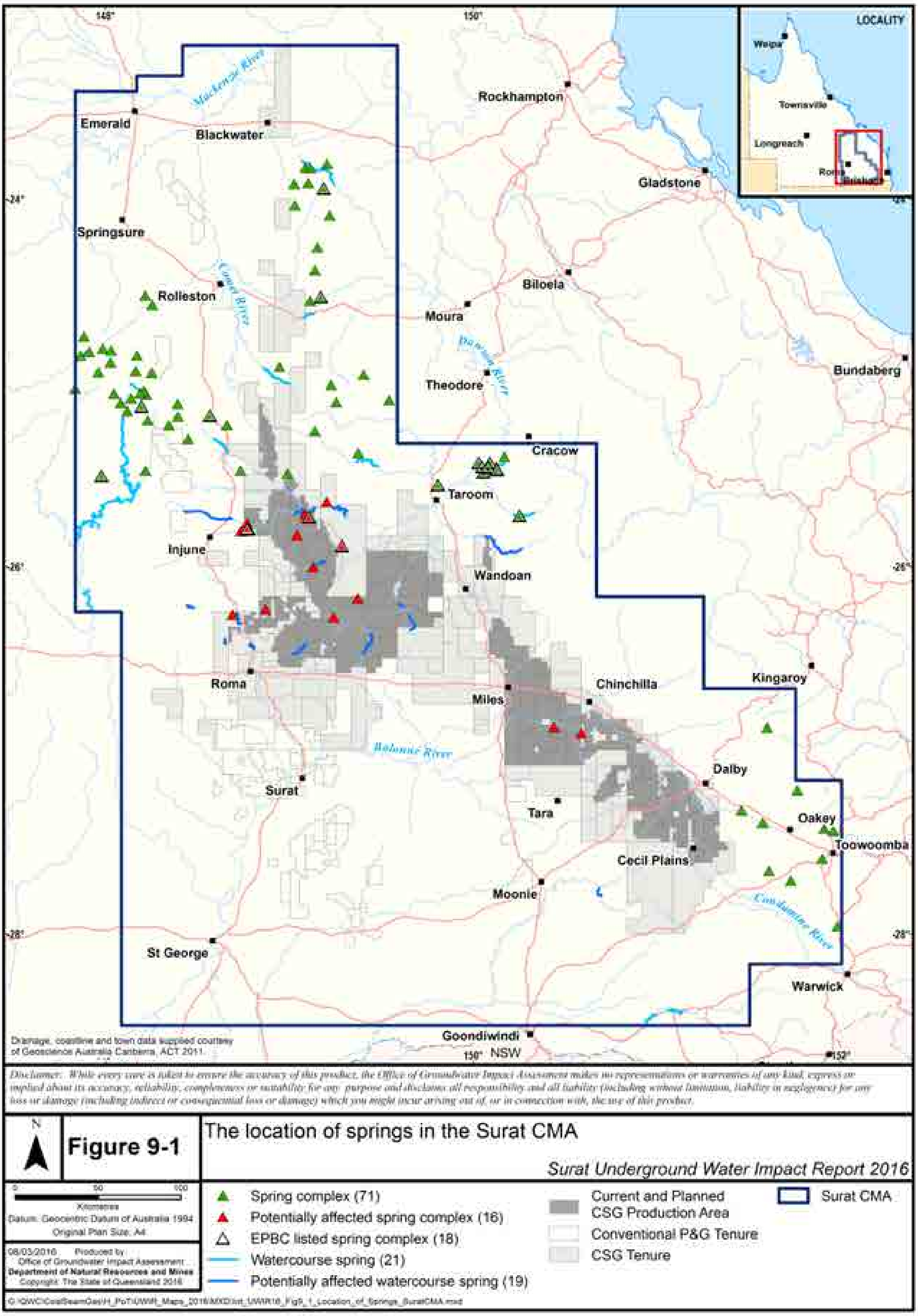


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Figure 9-1 The location of springs in the Surat CMA

9.2.1 Ecological and cultural values of springs

Ecological value is the perceived importance of an ecosystem, which is underpinned by the living and/or non-living components and processes that characterise the ecosystem (AETG 2012). A number of springs in the Surat CMA are known to provide unique ecological habitats and contain rare and threatened species. In addition, groundwater discharge can sustain waterholes and watercourses where the discharge plays an important role in maintaining stream ecosystem functions and processes.

Information on the ecological value of the springs in the CMA was collated in 2011 by the Queensland Herbarium to support the preparation of the UWIR 2012. This work included determining the presence of listed ecological communities under the EPBC Act and their conservation ranking. This information has been used in assessing the risks to springs, as described in Section 9.4. Table 9-2 shows the numbers of springs in the Surat CMA recognised for their conservation significance under the EPBC Act and Queensland's *Nature Conservation Act 1992* (NC Act).

Table 9-2 Ecological values associated with springs in the Surat CMA

Listed species / ecological community	**Conservation status**		**Number of springs associated with the listing in the Surat CMA**
	EPBC Act	**NC Act**	**Spring complexes (Spring vents)***
The community of native species dependent on natural discharge of groundwater from the GAB	Endangered	-	14 (112)
Eriocaulon carsonii	Endangered	Endangered	5 (18)
Myriophyllum artesium	-	Endangered	1 (5)
Arthraxon hispidus	Vulnerable	Vulnerable	1 (18)
Phaius australis	Endangered	Endangered	2 (2)
Thelypteris confluens	-	Vulnerable	1 (2)
Livistona nitida	-	Near Threatened	3 (7)

* The number in brackets is the total number of spring vents within the complexes.

Ecological values can be affected by impacts other than reduction in flow from source aquifers. For example, spring vents can be degraded by impoundment and excavation. As a result, for a spring wetland in good physical condition and known to host endemic species, the consequence of a reduction in flow from the source aquifer would be greater than for a spring that has been extensively modified through excavation or impoundment. These factors are incorporated into the risk assessment (Section 9.4).

Springs are associated with cultural heritage values. Unlike ecological values, cultural heritage values are not often documented. Over the past decade, a number of studies have provided data on the cultural heritage values of springs in the Surat Basin. The studies have varied in their purpose and spatial extent. However, descriptions of the cultural heritage values generally align with the categories identified by Central Queensland Cultural Heritage Management (2005) as follows:

- **Mythological associations:** The linkage between a spring and its water, and mythological events and/or creator beings or other beings.
- **Ritual and ceremonial associations:** The role that a spring and its water play in the conduct of ceremonies. This may also be linked to the mythological associations.

- **Economic and subsistence associations:** The role that a spring, or group of springs, and the water available from them, play in the patterns of seasonal, economic and subsistence activities of particular Aboriginal groups.
- **Major or personal historical events:** Events such as births, massacres, and long-term camping and habitation.

In addition to these studies, specific investigations and EISs have identified cultural heritage values as part of project approval requirements. Where values are identified, they are recorded in the Aboriginal and Torres Strait Island Cultural Heritage Register. The register has been searched to identify cultural heritage sites that are close to springs (Table 9-3).

Table 9-3 Cultural heritage records associated with springs in the Surat CMA

Type of record	Number of records		
	Within 500 metres of springs	Within 1.5 km of springs	Within 3 km of springs
Artefact scatter	246	845	1242
Burial site	18	34	54
Contact site	-	1	2
Cultural site	-	5	14
Dwelling	-	1	4
Earthen arrangement	-	2	2
Engraving	11	34	62
Grinding groove	9	33	53
Hearth/oven	4	8	11
Historical place	1	1	1
Isolated find	7	48	122
Landscape feature	7	19	30
Painting	62	178	322
Pathway	-	8	14
Quarry	11	17	23
Resource area	7	11	19
Scarred/Carved Tree	26	73	118
Shell midden	11	22	23
Stone arrangement	-	2	4
Story place	-	4	4
Well	-	1	3
Total	**420**	**1,347**	**2,127**

9.2.2 Recent research

Since the UWIR 2012 was prepared, a range of monitoring and research activities have been undertaken by OGIA and petroleum tenure holders to learn more about springs. This new knowledge, together with output from the new regional groundwater flow model, has enabled an improved assessment of risk. The activities are summarised in this section.

The UWIR 2012 specified requirements for tenure holders to carry out quarterly monitoring at spring vents. At the same time, the Australian Government also set monitoring and other requirements on tenure holders as conditions of approval under the EPBC Act. In addition to spring monitoring, petroleum tenure holders and OGIA carried out field investigations at representative sites to learn more about the local hydrogeological settings.

For example, the Lucky Last and Abyss spring complexes overlie the Hutton-Wallumbilla Fault, north-east of Injune. OGIA led field activities at this location including geology mapping, ground geophysics and the construction of nested investigation bores. The information collected provides a detailed understanding of local groundwater flow directions and characterisation of the Hutton-Wallumbilla Fault at this location.

The springs in the area include watercourse springs and spring vents. However, watercourse springs are more difficult to identify than spring vents. The UWIR 2012 identified potential watercourse springs based on a desktop method and identified the need to better define the existence of watercourse springs. Methods used in the Lake Eyre Basin by other researchers have been now been applied in the northern Surat CMA to better identify the existence of watercourse springs. While these methods are designed to map terrestrial groundwater-dependent ecosystems, such mapping is a good indicator of potential watercourse springs in nearby streams. Work will continue to better identify watercourse springs and thereby improve the assessment of risk.

Spring monitoring is challenging for a variety of reasons and new monitoring techniques continue to emerge in response to those challenges. OGIA has reviewed the literature on spring monitoring techniques and held a workshop to collate expert views. Knowledge gained from those activities has been incorporated in the monitoring techniques required in the monitoring program (Section 9.5). This knowledge has also led to the design of a field pilot that will be implemented to test the usefulness of other emerging methods.

As detailed in Section 4.7.2, work on the hydrogeological setting of individual springs has enabled the development of a system that groups wetlands by type, using characteristics relating to how a wetland has formed and how it is likely to respond to a change in the groundwater regime (OGIA 2016c). This typology supported the design of the spring monitoring requirements specified in the monitoring program (Section 9.5) and has also been incorporated into the system for assessing risk to springs.

9.2.3 Potentially affected springs

The Water Act requires that the UWIR assess the potential groundwater impacts of P&G activities on all ‘potentially affected springs’. A spring is defined as the land to which water rises naturally from below the ground and the land over which water then flows. The Water Act defines a potentially affected spring as a spring overlying a GAB aquifer in which the modelled long-term predicted reduction in water pressure in any underlying aquifer resulting from P&G water extraction exceeds 0.2 metres. Output from the regional groundwater flow model has been used to identify the potentially affected springs in the Surat CMA.

The details of the potentially affected springs are provided in Appendix H-1. The locations of these springs are shown in Figure 9-1 and the number of springs is shown in Table 9-4. Springs associated with the Main Range Volcanics to the north, south and west of Toowoomba are associated with local flow systems and are disconnected from the regional flow regimes in the underlying GAB formations.

The number of spring complexes and spring vents in the Surat CMA has increased due to changes to the Queensland Herbarium system of classification and the identification of new spring vents identified through research activities.

Table 9-4 Springs in the Surat CMA

Spring type	Total	Number of springs associated with an EPBC Act listing (Table 9-2)	Potentially affected springs		
			EPBC Act listed	Not listed	Total
Spring complexes (Spring vents)*	87 (387)	18 (134)	4 (23)	12 (38)	16 (61)
Watercourse springs	40	-	-	19	19

* The number in brackets is the total number of spring vents within the complexes.

9.3 Connectivity between springs and aquifers

To assess the risk to a spring associated with a pressure reduction in underlying aquifers, it is necessary to identify the source aquifer providing water to the spring. The source aquifer to a spring depends upon the local hydrogeological setting and the mechanism through which groundwater flows to the surface. 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 through fractures or faults to the spring.

The source aquifer for each spring has been reassessed based on secondary information about the springs, local and regional scale geology, hydrogeology, hydrochemistry and monitoring data. The wetland typology described in Section 4.7.2 resulting from recent research has also been used. An updated attribution of source aquifers to springs is provided in Appendix H-1.

The Lucky Last spring complex, a high-value spring listed under the EPBC Act and in the UWIR 2012, is of particular interest with regard to connectivity. The source aquifer was predicted to be impacted by P&G water extraction; however, recent investigation has shown that the source aquifer for the spring is the Boxvale Sandstone Member of the Evergreen Formation, not the deeper Precipice Sandstone as previously understood (OGIA 2016c). As a result, the Lucky Last spring complex is no longer at risk of impact from P&G water extraction.

Another important outcome is a clearer understanding that some springs are supported by local flow systems. For these springs, the distance between recharge and discharge is typically less than five kilometres, so these springs respond rapidly to seasonal variation in recharge. Local flow systems that are disconnected from the regional groundwater flow system are not affected by water pressure reduction in regional aquifers resulting from P&G water extraction.

Similarly, there is now a clearer understanding that some springs are supported by both local and regional groundwater flow systems. In these cases, a more constant background rate of groundwater flow to the spring from a regional aquifer is overlain by seasonally fluctuating flow from a local flow system.

The improved attribution of source aquifers is important for assessing the risk to springs, as set out in in Section 9.4. Together with the new spring wetland typology (Section 4.7.2) arising from studies into the hydrogeological setting, it has been used in updating the design of the spring monitoring program (Section 9.5).

9.4 Assessing the risk to springs

An assessment of risk has been carried out for all springs to ensure management strategies align with risk associated with P&G water extraction.

The risk assessment criteria relate to:

- the likelihood of a drop in pressure in a source aquifer due to P&G water extraction
- the consequence for the spring should the pressure drop.

The likelihood is assessed using the regional groundwater flow model. The consequence is evaluated using a combination of factors, including the estimated magnitude of pressure in the spring's source aquifer and the known ecological values.

Details of the risk assessment methodology are provided in Appendix H-2. The results of the risk assessment are provided in Appendix H-3. The results have been used to select monitoring sites and in the design of pressure monitoring requirements.

9.5 The spring monitoring program

The objectives of spring monitoring are to understand the natural variability in spring discharge and to better understand the source aquifers that feed the springs at some locations. This understanding will ensure that any future impacts from P&G water extraction are correctly identified.

The monitoring data collected to date indicates that many springs show significant variability related to seasonality in rainfall, evapotranspiration and local groundwater contributions. At this stage, no impacts from P&G water extraction have been observed.

During the implementation of the spring monitoring program as defined in the UWIR 2012, the methods for monitoring evolved in response to improvements in knowledge and seasonal conditions. To prepare for the review of the monitoring program, emerging techniques reported in the literature were identified and reviewed at an expert workshop. An important outcome from the study was the knowledge that, to understand if changes in spring discharge are related to changes in the groundwater regime, all spring water balance components need to be identified and monitored, where possible. The wetland typology described in Section 4.7.2 has been used to determine the spring water balance components to be monitored under the UWIR.

A pilot project will be implemented by OGIA over the next three years to evaluate new monitoring methods. If the pilot project overlaps with tenure holder monitoring obligations under the UWIR, the pilot project activities will displace the tenure holder's obligations under the UWIR. Outcomes from the pilot project will be used in the next update of the UWIR.

9.5.1 Selecting the spring monitoring sites

Spring sites vary considerably in their ecological values and their physical condition. For this reason, the spring risk assessment (Section 9.4 and Appendix H2) has been used to inform the selection of monitoring sites. Representative springs from spring complexes classified as 'high risk' or 'moderate risk' have been considered for monitoring. Typically, these classifications result from a lack of data, so the data collected is likely to lower the risk rating when the risk assessment is next updated.

Eleven spring complexes, comprising 50 spring vents and three watercourse springs, will be monitored under the program. These sites are in spring complexes other than those identified as ‘low risk’. The locations are shown in Figure 9-2 and individually listed in Appendix H-3.

There are many ways of measuring spring attributes such as spring discharge. For each spring location and monitoring attribute, the required measurement method is specified in Table H-7 of Appendix H-4. The responsible tenure holder for each monitoring site is listed in Table H-5 (spring vents) and Table H-6 (watercourse springs).

The water management strategy (Chapter 8) specifies pressure monitoring at locations near some springs. Data from those sites will be used in conjunction with spring monitoring data for future assessment.

9.5.2 Spring discharge

The flow of groundwater to some springs is sufficient for water to continuously flow away from the springs and drain into watercourses or other landscape features. However, at springs where the flow of groundwater to the springs is relatively small, the spring discharge can be completely consumed by evaporation and by transpiration by plants, leaving no flow away from the springs. As a result, a range of approaches to monitoring are required, as detailed below.

At sites where flow is concentrated into a single channel (Wetland type 3, Section 4.7.2), flow is to be measured by a standard technique. At sites where there are many small flow lines (Wetland types 1 and 2, Section 4.7.2) and measuring the flow without potentially damaging spring values would be impractical, a visual estimate is required.

At sites where no flow is visible, wetland attributes are to be monitored as indicators of change in the spring water balance. The area of wetland vegetation is the area of permanent saturation sufficient for colonisation by wetland species. Beyond that boundary, there is often a seasonally moist zone of increased discharge from the spring in response to seasonal rainfall, evaporation and transpiration by the vegetation. For these sites, the boundary of the wetland vegetation and the extent of the seasonally moist zone are to be monitored. A list of terrestrial and aquatic species is provided in Table H-9 in Appendix H-4 to assist in delineating the boundaries.

Measuring these attributes provides a basis for estimating groundwater flux and related changes observed in the wetland, along with other monitored attributes such as groundwater pressure, physical condition, climate, rainfall and evapotranspiration.

Depending on the characteristics of the spring (Section 4.7.2), either the extent of wetland vegetation or the extent of groundwater discharge—or both—need to be monitored. Table H-5 and Table H-6 in Appendix H-3 specify the monitoring methods required at each monitoring site.

9.5.3 Water chemistry

The water chemistry of a spring can be influenced by the aquifer feeding the spring, surface water flows, evapotranspiration and land use. Water chemistry contributes to improving the identification of a spring’s source aquifer and for identifying seasonal spring ecological processes and dynamics.

Table H-8 in Appendix H-3 lists the chemical parameters to be measured.

9.5.4 Physical condition

Monitoring a spring’s physical condition can provide information about changes in the groundwater regime which are not apparent from other monitoring data. For example, the extent of salt scalding and iron staining around the periphery of a spring indicates recent changes in the groundwater regime.

Also, springs can be influenced by a range of non-groundwater-related stressors, such as animal disturbance. Depending on the extent of disturbance, these factors may alter the accuracy of the monitoring data about the wetland vegetation boundary, the moist zone and the water chemistry.

A guide to observing the physical condition of springs is specified in Table H-7 in Appendix H-3.

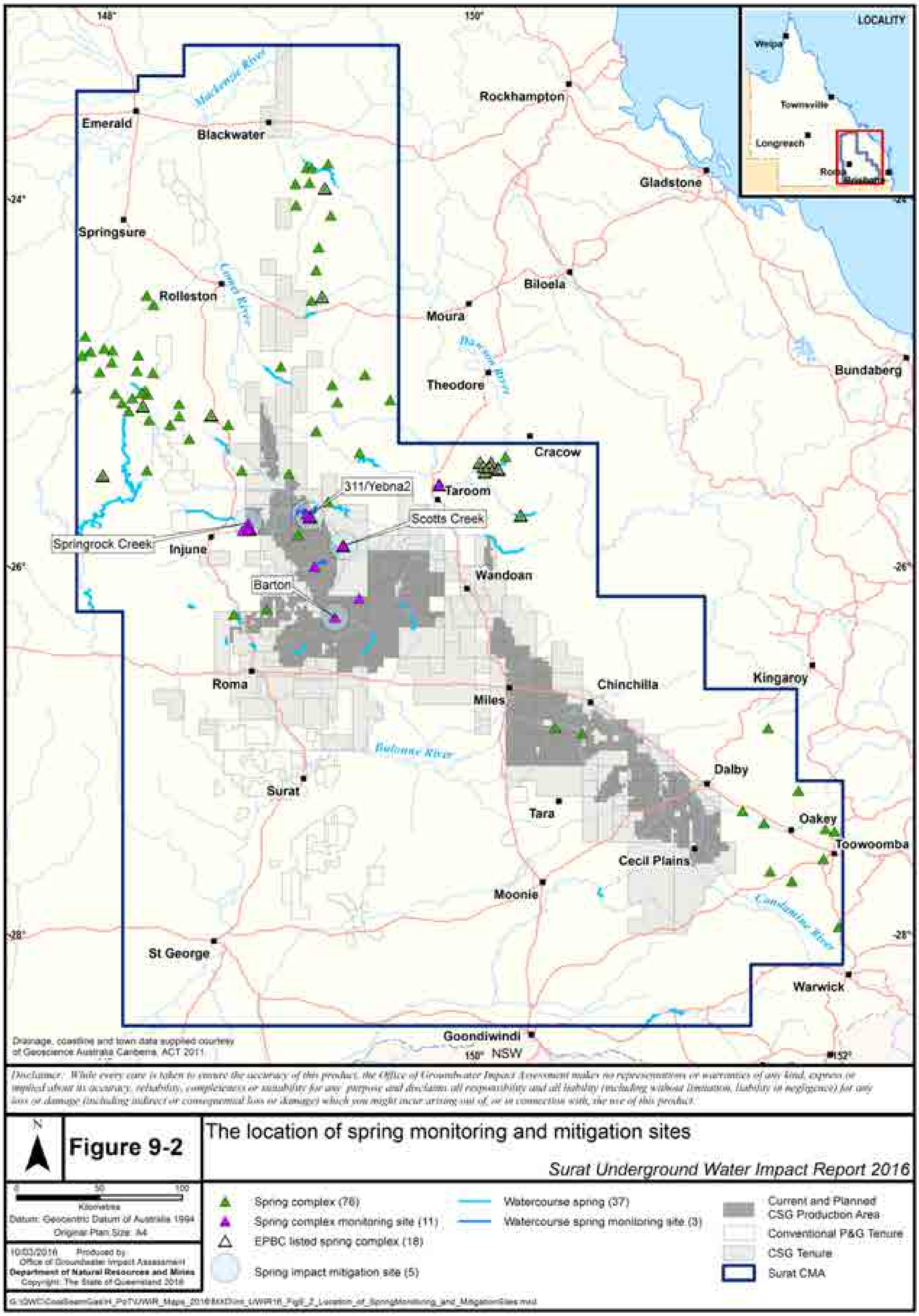

Figure 9-2 The location of spring monitoring and mitigation sites

9.6 Spring impact mitigation strategy

The Water Act requires that the UWIR include a strategy to prevent or mitigate the impact of P&G water extraction on springs. The UWIR 2012 identified five spring complexes where pressure impacts in the source aquifers were predicted to be greater than 0.2 metres at some time in the future. It required tenure holders to evaluate the options available to mitigate the predicted pressure impacts.

At two sites (Barton and Scotts Creek), tenure holders established that the predicted impact could be balanced out by relocating stock water supply bores that are already impacting the springs.

At the other three sites (Lucky Last, Springrock Creek and 311/Yebna), it became clear from the initial assessment that a more detailed understanding of the local hydrogeological setting was needed before appropriate mitigation actions could be developed. That work has been carried out and incorporated into the new risk assessment strategy.

9.6.1 Mitigation sites

A mitigation site is a site where, on the basis of current knowledge, actions are likely to be required at a future date to prepare to avoid, mitigate or offset future spring impacts.

An important outcome of the spring research activities that have been carried out is that the Lucky Last spring complex is no longer considered to be at risk. It has been established that the spring complex is fed from the Boxvale Sandstone Member of the Evergreen Formation, which is not predicted to be affected by P&G water extraction.

Currently, there are four mitigation sites. At two of the four mitigation sites—‘Barton (283)’ and ‘Scotts Creek (260)’—plans have already been developed by the responsible tenure holder, Origin Energy. The plans are to relocate existing stock water supply bores that are currently impacting on the spring’s source aquifer to balance out the predicted impact of CSG water extraction. These plans are being progressed with bore owners so they are ready to be activated in advance of any impact. No action beyond the monitoring scheduled in the spring monitoring program is required for these sites at this time.

For the other two mitigation sites, Santos is the responsible tenure holder. Santos has established that it is not technically possible to balance out impacts by relocating existing water bores that currently impact the source aquifer pressures at the spring. The first of these two sites is known as ‘Springrock Creek (561)’. The second site is the ‘Yebna group’ of spring complexes and watercourse springs at essentially the same location as Springrock Creek site. The group comprises the springs ‘Yebna 2 (591)’, ‘Yebna 2 (311)’, ‘Hutton Creek (W81)’ and ‘Dawson River (W40)’.

At the location of Springrock Creek and the Yebna group, the risk to the springs resulting from a fall in pressure in the source aquifer has been better defined by research and monitoring activities. However, the risk should be further clarified by the tenure holder through the collection of additional field data. Details about the two spring groups, and comments about knowledge requirements, are provided in Table 9-5. Options to offset future impacts should also be further assessed.

The long-term impact at the Springrock Creek site is currently predicted to be 5.7 metres, with the earliest impact occurring in 2022. The maximum impact at the other mitigation sites is predicted to be two metres, with the earliest impacts occurring decades into the future. The predicted impact at the Springrock Creek site is related to newly planned CSG development from the Cattle Creek Formation of the Bowen Basin, which has introduced new complexities to the prediction of impacts in the Precipice Sandstone. Due to the limited development and exploration of the Cattle Creek Formation to date, there is uncertainty with regard to its extent, thickness and hydraulic properties. In parallel with work to be undertaken by the responsible tenure holder OGIA will carry out a subregional assessment of the contact between the Bandanna and Cattle Creek formations with the Surat Basin to improve the prediction of impacts.

Table 9-5 Sites for mitigation actions

Site name	Source aquifer	Responsible tenure holder	Site knowledge requirements (Appendix H-2)
Springrock Creek	Precipice Sandstone	Santos	• Improve understanding of the height of groundwater pressure above ground level at the spring. • Improve understanding of aquatic values at the spring.
Yebna group	Precipice Sandstone	Santos	• Improve understanding of the height of groundwater pressure above ground level at the spring. • Improve understanding of the volume of groundwater discharge to the Hutton Creek and Dawson River.

Additional sites could become mitigation sites as knowledge about the local hydrological setting of springs is improved through the spring monitoring program or through confirmation of the existence of watercourse springs at locations where long-term pressure impacts are predicted. However any pressure impacts in the spring source aquifers are predicted to occur well into the future. At this stage, the information from the monitoring program, field validation program and further assessment by OGIA of source aquifer impacts will provide a basis for improving the risk assessment. The need for more targeted action by tenure holders will be reassessed in the next update of the UWIR.

9.6.2 Mitigation actions

The responsible tenure holder is to further investigate the mitigation sites listed in Table 9-5 to:

- collect data to address the knowledge requirements identified in Table 9-5
- assess potential offset options that are not related to the groundwater regime—for example, supporting landholders to reduce spring degradation caused by animals accessing the springs.

A plan for addressing these items must be prepared within three months of the approval of the UWIR 2016.

10 Responsible tenure holder obligations

- No changes have been made to the assignment of tenure holder responsibilities.

10.1 Meaning of responsible tenure holder

Under Queensland's regulatory framework, petroleum tenure holders have the right to take groundwater in the process of producing petroleum and gas. A number of obligations are associated with this right. Petroleum tenure holders have an obligation to make good impairment to the adequacy of water supply from bores resulting from their water extraction. They also have an obligation to monitor water pressure and assess the future impacts.

The impacts of water extraction by a petroleum tenure holder on water pressure in an aquifer may extend beyond the tenure. In areas where a number of petroleum tenure holders operate, there may be overlapping impacts on water pressure in an aquifer from the separate operations. In such areas, supply from a water bore may be impaired because of the cumulative impacts from water extraction by multiple tenure holders. Under Queensland's regulatory framework, the Queensland Government can establish an area of overlapping impact as a cumulative management area (CMA).

Within a CMA, individual petroleum tenure holders are identified as the tenure holders responsible for specific activities, even though any individual tenure holder may not be the only entity creating the need for the activity to be carried out. These arrangements ensure that there is clear legal responsibility for actions in areas where integrated approaches are needed to manage cumulative impacts.

This chapter assigns responsibilities for specific obligations in the Surat CMA to individual petroleum tenure holders.

10.2 Underground water obligations for responsible tenure holders

The Queensland regulatory framework provides that the underground water obligations comprise 'make good' obligations and reporting obligations. These are summarised in the following sections.

10.2.1 'Make good' obligations

Make good obligations are specified in the Water Act. The Act provides that the Immediately Affected Area (IAA) for an aquifer is the area within which water pressures are predicted to fall by more than the trigger threshold within three years. The trigger thresholds are set in the Water Act as five metres for consolidated aquifers (such as sandstone) and two metres for unconsolidated aquifers (such as sand). Within the IAA for a formation, there is significant risk that the supply of water from a bore tapping the formation will be impaired within three years. For the Surat CMA, these areas are identified in Chapter 7.

The Water Act provides that, on approval of a UWIR, the responsible petroleum tenure holder is to carry out a bore assessment and enter into a make good agreement with the owners of bores that source water from an aquifer within the IAA for the aquifer. Water supply bores within the IAA which are expected to experience pressure reductions of more that the trigger threshold within three years are listed in Appendix E.

The supply from bores other than those identified in Appendix E could potentially become impaired. This could be because a bore supply is susceptible to reductions in water pressure that are smaller than the trigger threshold, or because local conditions could cause water pressure impacts to be greater than predicted by the regional groundwater flow model. The Water Act provides that in such cases EHP can direct a tenure holder to carry out a bore assessment and, if necessary, enter into a make good agreement with the bore owner. DNRM operates a CSG Compliance and Engagement Unit which carries out a range of activities for both DNRM and EHP. A bore owner with a concern in relation to make good arrangements should contact the CSG Compliance Unit in the first instance.

10.2.2 Report obligations

The report obligations arise from the UWIR itself. The Water Act provides that a report obligation is a requirement with which a responsible tenure holder must comply as specified in a UWIR. OGIA undertakes activities that need to be carried out centrally, such as regional groundwater flow modelling. However, activities that relate more directly to individual tenures are established as report obligations and are assigned to specific tenure holders who then become the responsible tenure holders for the activities. The report obligations are of two types:

- Water monitoring activities: These obligations involve constructing monitoring installations, carrying out baseline assessments and reporting data on an ongoing basis. The activities are specified in Chapter 8.
- Spring impact management activities: These obligations involve implementing a program for monitoring springs and a program to assess options for mitigating the impact of water extraction on springs. The activities are set out in Chapter 9.

10.3 Assigning underground water obligations

The tenures for current and planned petroleum and gas production are shown in Figure 2-6. Details about the tenures and the current authorised holders of the tenures are listed in Appendix A.

10.3.1 Assignment rules for ‘make good’ obligations

The bores most likely to be affected by water extraction by petroleum and gas tenure holders are on lands on tenures shown in Figure 2-6. The following rule assigns responsibility for make good obligations for these bores.

> Rule 1: The authorised holder from time to time of a petroleum tenure over land identified in Figure 2-6 is the responsible tenure holder for make good obligations in relation to a bore on the land.

Because water pressure impacts can extend laterally, impact on bore supply could occur in bores outside the lands covered by Rule 1. The following rule assigns responsibility for make good obligations in relation to those bores.

> Rule 2: For a bore on land in the CMA, other than the land to which Rule 1 applies, the authorised holder from time to time of a petroleum tenure over the land identified in Figure 2-6 that is closest to the bore is the responsible tenure holder for make good obligations in relation to the bore.

Under these rules, the responsible tenure holder will change if the ownership of a tenure changes. The responsible tenure holder for a bore can be established at any time by referring to the public access area of the DNRM tenure database.

10.3.2 Assignment rules for reporting obligations

The individual activities identified within the water management strategy and the spring impact management strategy, specified in Chapters 8 and 9 respectively, are report obligations. The following rules assign responsibility for these activities. The responsibilities are assigned to tenure holders having regard to the relative contribution of water extraction by tenure holders to the need for the assigned activity.

Baseline assessments

Baseline assessments relate to potential future make good obligations. Therefore, the same principles apply as for the assigning of responsibilities for make good obligations.

> Rule 3: The authorised holder from time to time of a petroleum tenure over land identified in Figure 2-6 is the responsible tenure holder for carrying out the baseline assessment program identified in Chapter 8 in relation to a bore on the land.
>
> Rule 4: For a bore on land in the CMA, other than the land to which Rule 3 applies, the authorised holder from time to time of a petroleum tenure over the land identified in Figure 2-6 that is closest to the bore is the responsible tenure holder for carrying out the baseline assessment program identified in Chapter 8 in relation to the bore.

Other report obligations

Activities at sites within the tenures shown on Figure 2-6 are to be carried out by the authorised holders of the tenures on which the activities are to be carried out. Since the ownership of tenures can change over time, in Chapters 8 and 9 the activities at those sites are noted as being the responsibility of the ‘current tenure holder’ which is the authorised tenure holder at a given point in time.

The following rule deals with these activities.

> Rule 5: The authorised holder from time to time of a petroleum tenure over land identified in Figure 2-6 is the responsible tenure holder for the activities identified in Chapters 8 and 9 required to be carried out on the land.

Some of the activities identified in Chapters 8 and 9 are to be carried out outside the areas shown on Figure 2-6. However, the need for the activities arises because of water extraction within the areas. Therefore, responsibility for an activity is assigned to a tenure holder from within the area. The following rule assigns responsibility in relation to these activities other than the requirement for carrying out baseline assessments.

> Rule 6: For activities other than baseline assessment, to be carried out outside the area to which Rule 5 applies, the tenure holder identified in Chapter 8 or 9 as the responsible tenure holder for the activity is the responsible tenure holder for the activity.

Under these rules, the holder at any time of a tenure shown on Figure 2-6 will always be the entity responsible for water and spring monitoring on the tenure. If there is a change of tenure ownership, responsibility will fall to the new owner.

Outside the tenure area shown on Figure 2-6 a designated tenure holder will be responsible for activities other than the carrying out of baseline assessments, irrespective of ownership changes. Only extensive changes to tenure ownership would create a need to change these responsibilities.

11 Periodic reporting and review

- Annual reports will be provided by OGIA during the implementation of the underground water impact report.
- Research will continue to improve the assessment of groundwater impacts in preparation for further revisions of the underground water impact report.

This chapter describes the arrangements for reporting on matters relating to the UWIR 2016 and the subsequent revision of the UWIR.

11.1 Introduction

The first regional groundwater flow model was developed as the basis for preparing the UWIR 2012. Since then, a new regional groundwater flow model has been developed to support the preparation of this report. The new model is highly sophisticated and OGIA will continue to develop it.

The planned CSG industry development, which is assessed using the model, is subject to change. These changes will affect the model's predictions of impacts on water pressures. Therefore, each year, changes to planned industry development will be collated and changes to predictions of impact will be reassessed.

A major part of the monitoring network has been established and data from the network will be progressively added to the DNRM Groundwater Database. As well as routine reporting of data, any significant departures from expected behaviour will be reported each year.

Queensland's regulatory framework requires that the UWIR be revised every three years, unless EHP approves a more frequent or less frequent revision.

11.2 Annual reporting

OGIA will continue to report annually to EHP and these reports will be published on the OGIA website. Over the implementation period of UWIR 2016, the annual reports will include:

- reports on further development of the regional groundwater flow model
- reports on changes to the planned CSG industry development and the effect of any changes on predictions of impacts on groundwater pressures, particularly any changes to the extent of Immediately Affected Areas for aquifers
- a summary of any unexpected changes to regional water pressure trends
- a summary of progress on research activities.

11.3 Revising the underground water impact report

Queensland's regulatory framework requires that a new UWIR be prepared every three years, unless EHP approves a more frequent or less frequent revision. A revision should incorporate the most recent drilling data, monitoring data, spring data and should use the latest development of the regional groundwater flow model. It could provide updated monitoring requirements in response to any change in circumstances.

Matters that could be expected to trigger an early revision of the UWIR are:

- unexpected changes in planned CSG development that could be expected to cause a significant increase in predicted water pressure impacts in the short term
- new knowledge about the way the groundwater system is responding to CSG development which warrants early updating of predicted impacts.

11.4 Access to information

The monitoring data reported to OGIA under the water monitoring strategy is entered onto the DNRM Groundwater Database along with monitoring data from other networks. The data is accessible through the Queensland CSG Globe. Information about using the Globe is available from the DNRM website.

Tenure holder reports, including data about the construction of CSG bores and water extraction, are available from the QDEX Reports system which can be accessed through the DNRM website.

11.5 Research

11.5.1 Approach to building knowledge

Knowledge about the groundwater flow system will continue to improve as monitoring data accumulates under the water management strategy and the spring impact management strategy. The data will show how the groundwater flow system is responding to stresses and will be used to further improve the groundwater flow model. The monitoring programs are set out in Chapters 8 and 9.

Knowledge about the groundwater flow system will also improve through targeted research. In addition to research carried out by OGIA, other research groups carry out research that is relevant to the assessment of impacts of CSG water extraction on water pressures in aquifers. OGIA collaborates with other groups on relevant research.

OGIA makes its regional geological model and output from the regional groundwater flow model available to researchers, and seeks to incorporate the outcomes of all relevant research into these models.

11.5.2 Research directions

Current or planned research activity is as follows:

- Progressively update the regional geological model to incorporate data from new CSG wells as a foundational resource for groundwater managers and researchers and future groundwater flow modelling.
- Develop and apply new methods for analysis of uncertainty in regional groundwater flow model output. This would include an assessment of the potential contribution of faults and abandoned or poorly constructed bores.
- Investigate groundwater flow in sensitive areas through sub-regional assessments.
- Investigate background trends in water level behaviour.
- In collaboration with the Queensland Herbarium and CSIRO, test new spring monitoring methodologies and better identify watercourse springs.
- In collaboration with CSG companies and the Geological Survey of Queensland, improve surface geological mapping.

- In collaboration with Geoscience Australia, the Geological Survey of Queensland and CSG companies, improve the identification and characterisation of fault systems.
- In collaboration with the University of Queensland's Centre for Coal Seam Gas, improve understanding of recharge rates and water use volumes.
- In collaboration with Queensland University of Technology, improve understanding of groundwater flow systems through hydrochemical studies.

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13 Glossary

Alluvium: Deposits of clay, silt, sand, gravel, or other particulate material that has been deposited by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at the base of a mountain.

Analytical technique: Mathematical relationships that can be used to forecast water pressure changes in a simple homogenous formation in response to relatively uniform and localised extraction.

Aquifer: A saturated underground geological formation or group of formations, that can store water and yield it to a bore or spring. A saturated formation that will not yield water in usable quantities is not considered an aquifer.

Aquitard: A geological formation that prevents significant flow of water due to its low permeability (e.g., clay layers or tight deposits of shale).

Artesian water: Water that occurs naturally in, or is introduced artificially into, an aquifer, and which if tapped by a bore, would flow naturally to the surface.

Basement (geological): Generally low permeability hard rock strata of igneous or metamorphic origin which lie below sedimentary rocks or sedimentary basins. In the same way the sediments or sedimentary rocks on top of the basement can be called a "cover" or "sedimentary cover".

Basin (geological): An area in which the rock strata dip from the margins toward a common centre; the site of accumulation of a large thickness of sediments.

Basin (groundwater or hydrogeological): A groundwater system made up of multiple aquifers, may be equivalent to a geological basin.

Confined aquifer: A saturated aquifer bounded between low permeability materials such as clay or dense rock.

Conglomerate (geological): Rock consisting of pebbles or gravel embedded in a finer cemented material; consolidated gravel.

Consolidated aquifer: A water bearing aquifer made of consolidated rock such as sandstone, coal, limestone or granite.

Conventional petroleum and gas: Petroleum and gas that is generally found in permeable formations such as sandstone trapped in reservoirs by an overlying low permeability rock formation, or within geological structures that allow the petroleum and gas to concentrate or pool.

Current tenure holder: The authorised petroleum tenure holder at a given point in time.

Deposition: The laying down/settling of material (clay, sand, rock) carried by wind, water, or ice.

Depressurisation: The extraction of groundwater by pumping to decrease pressure in the groundwater system or reduce groundwater head.

Drawdown (noun): The difference between the groundwater pressure before and after pumping or depressurisation.

Draw down (verb): To lower the water pressure as a result of extracting water.

Drill stem test: A procedure used to test the surrounding geological formation through the drill stem when a petroleum well is drilled. It is used to estimate the productive capacity, pressure, porosity or permeability of a petroleum producing formation.

Dual phase flow: The simultaneous flow of two substances through porous material; for example when gas and water are flowing through a geological formation to a well.

Elevation: Height above a set point usually in relation to a standardised sea level or datum.

Erosion: The wearing down or washing away of the soil and land surface by the action of water, wind, or ice.

Fault (geological): A break in a geological formation along which some measurable movement, or displacement, has occurred typically due to tectonic movement and uplift of the earth's crust (see also 'Fracture').

Fluvial material: Material that is eroded, transported and deposited by rivers or streams.

Fold (geological): When a stack of originally flat sedimentary strata are bent or curved typically due to tectonic movement and uplift of the earth's crust.

Formation (geological): A sediment or rock, or group of sediments or rocks. Geologists often group rocks of similar types and ages into named formations, for example the Hooray Sandstone of the Great Artesian Basin.

Fracture (geological): A minor break in a geological formation with no measurable movement, or displacement (see also 'Fault').

Geological formations: See 'Formation'.

Groundwater: Also known as underground water. Water found in the cracks, voids, pores or other spaces between particles of clay, silt, sand, gravel or rock within the saturated zone of a geological formation.

Groundwater database: A database maintained by DNRM that stores information relating to registered groundwater bores drilled within the state of Queensland.

Groundwater flow model: A set of equations, which, subject to certain assumptions, quantify the physical processes active in a groundwater system. While a model cannot simulate the detailed reality of the groundwater system, its behaviour approximates that of the actual system and is used to simulate that behaviour.

Head (groundwater): Groundwater level or pressure.

Homogenous formation: A geological formation that has identical material properties throughout its entire extent.

Horizon (geological): A bedding surface where there is marked change in the lithology within a sequence of sedimentary or volcanic rocks, or a distinctive layer or thin bed with a characteristic lithology or fossil content within a sequence.

Hydraulic gradient: The difference in water pressure or water level across one or more formations over a unit distance. The hydraulic gradient indicates which direction groundwater will flow, and how rapidly.

Hydraulic parameters: The parameters that describe the material properties that control the flow and storage of water within an aquifer, such as permeability and storavitity.

Hydrogeology: The study of how groundwater moves, how it is distributed and how it interacts with rock.

Hydrostratigraphy: The identification of units on the basis of hydraulic properties.

Immediately Affected Area: The area of an aquifer within which water levels are predicted to fall, due to water extraction by petroleum tenure holders, by more than the trigger threshold within three years. The trigger thresholds are specified in the Water Act as five metres for consolidated aquifers (such as sandstone) and two metres for unconsolidated aquifers (such as sand). Within the Immediately Affected Area, there is significant risk that the supply of water from a bore tapping the formation will be impaired within three years.

Intake bed: An area where sandstone aquifers are exposed, or where they outcrop at the surface or shallowly beneath alluvium, and where water can enter the aquifer.

Interbedded: Where beds, or layers, of geological material of different lithology or properties are layered together.

Interfinger: In relation to sedimentary rocks, to change laterally or vertically from one type to another, where the two types gradually merge, or overlap, to form interpenetrating wedges.

Lacustrine: Formed in lakes or ponds. Lacustrine deposits are stratified materials deposited in lake waters which later become exposed either by the lowering of the water level or by the elevation of the land.

Licensed entitlement: A water allocation or authority granted under the *Water Act 2000* to access and use groundwater.

Lithic: Geological deposits or sedimentary rocks that contain abundant fragments of previously-formed rocks.

Lithology: The physical characteristics of rock, with reference to qualities such as colour, composition and texture.

Long-term Affected Area: The area of an aquifer within which water levels are predicted to fall, due to water extraction by petroleum tenure holders, by more than the trigger thresholds at any time in the future. The trigger thresholds are specified in the Water Act as five metres for consolidated aquifers (such as sandstone) and two metres for unconsolidated aquifers (such as sand).

‘Make good’ agreement: The Water Act specifies the circumstances under which petroleum tenure holders need to investigate impairment of private bore supplies and develop ‘make good’ agreements with bore owners about the impairment.

Measures (geological): A series of coal-bearing rocks, such as the Walloon Coal Measures.

Member (geological): A named lithologic subdivision of a formation; for example, the Boxvale Sandstone Member.

Model domain: The areal extent of the regional groundwater flow or associated geological model.

Monitoring installation: An individual borehole equipped to monitor water quality and/or water pressure, potentially at multiple vertical levels.

Mudstone: An extremely fine-grained sedimentary rock consisting of a mixture of clay and silt-sized particles.

Numerical permeameter: Local-scale block models of the subsurface developed to derive effective formation scale hydraulic properties from detailed lithological data.

Outcrop (noun): A geological formation or rock strata exposed at the ground surface.

Outcrop (verb): To be exposed at the ground surface.

Permeable: Capable of transmitting water through porous rock, sediment or soil.

Permeability: A property of a soil, sediment or rock indicating how easily water will be transmitted through it under a hydraulic gradient.

Permeameter: See ‘numerical permeameter’.

Petroleum tenure holder: An entity that holds an authority to prospect and/or a petroleum lease under the *Petroleum and Gas (Production and Safety) Act 2004*.

Platform (geological): An area of geological material, generally igneous or metamorphic basement, which is slightly tilted to relatively flat and overlain by sedimentary material.

Potentially affected spring: A spring where the water level in the underlying aquifer is predicted to fall by more than 0.2 metres at any time in the future.

Predictive analysis: Using a groundwater flow model to forecast impacts on a groundwater system in response to an imposed stress.

Production area: The area from which petroleum and gas is planned to be produced.

Quartzose: Made of quartz.

Queensland CSG Globe: A Google Earth based online tool which provides access to information on petroleum and gas development activities, water bores and groundwater monitoring.

Recharge: The process of water flowing into an aquifer.

Regional monitoring network: The network of monitoring points specified in the water monitoring strategy for the Surat CMA.

Responsible tenure holder: The petroleum tenure holder identified as being responsible for specific activities such as monitoring and mitigating the impact of water extraction on springs.

Sediment: Material suspended in water or deposited from suspension. The plural form, sediments, is applied to all kinds of deposits from the waters of streams, lakes and seas.

Sedimentary basin: A geological basin containing a sequence of mainly sedimentary rocks.

Sequence (geological): A sequence of geological events, processes, or rocks, arranged in chronological order.

Sheetwash: Fluvial material, mainly fine-grained, deposited by extensive overland flow, typically fan-shaped.

Shelf (geological): A narrow surface of basement rock shaped like a shelf.

Siltstone: Fine-grained sedimentary rock consisting of consolidated silt.

Simulation period: The timeframe over which the groundwater predictions are made using the groundwater flow model.

Spring complex: A group of spring vents located close to each other. The vents are located in a similar geology and are fed by the same aquifer. No adjacent pair of spring vents in the complex is more than 10 km apart.

Spring vent: A single point in the landscape where groundwater is discharged at the surface. A spring vent can be mounded or flat and can also present as wetland vegetation, with no visible water at the location of the spring.

Steady state conditions: Conditions representing the long-term average hydrological balance of the groundwater system.

Storativity: Also known as storage coefficient. The capacity of the material through which groundwater flows to store or release water in response to a pressure change. Measured as the volume of water that a column of aquifer releases from storage or takes into storage per unit surface area of the aquifer per unit change in head.

Strata: A series of layers of rock in the ground (singular: stratum).

Stratigraphic Unit: a volume of rock of identifiable origin and relative age range that is defined by the distinctive and dominant, easily mapped and recognizable petrographic, lithologic or paleontologic features (facies) that characterize it.

Stratigraphy: The arrangement or layering of rock strata (stratification).

Sub-basin (geology): A smaller depression or accumulation of sediments within a larger basin; for example, the Surat Basin is a sub-basin of the Great Artesian Basin.

Syncline: A downward fold in geological strata/material.

Target unit: The geological formation, level or unit targeted for monitoring.

Trough (geological): An elongated, linear structural depression or narrow basin that is not steep-walled.

Uncertainty analysis: A technique for assessing the effect of uncertainty on prediction, using multiple realistic parameter sets to generate a large number of predictions which can then be statistically analysed to provide a measure of uncertainty in model prediction.

Unconfined aquifer: An aquifer with no overlying low permeability layers that restrict water movement into the aquifer. The water level in an unconfined aquifer is known as the water table.

Unconsolidated aquifer: An aquifer comprised of material that has not been turned into rock, such as sand.

Unit (geological): See ‘stratigraphic unit’.

Vertical permeability: The property of a formation indicating how easily or rapidly water is transmitted vertically.

Water monitoring authority: An authority under the P&G Acts that allows a petroleum tenure holder to carry out water monitoring activities in the area to which the water monitoring authority relates, which could be outside the actual tenure.

Watercourse spring: A section of a watercourse where groundwater enters the stream from an aquifer. Also referred to as a baseflow-fed watercourse.

Well field: An area within a petroleum lease with multiple wells used for P&G extraction.

Appendices

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Appendix A. Details of tenures for current and planned production areas

Appendix A-1 Current and planned CSG and conventional production areas

The current and planned production areas are discussed in Chapter 2 of the UWIR. Tables A-1 and A-2 provide details about tenures supporting current and planned CSG development, when that development started or is scheduled to start, and when it is scheduled to finish. Active and inactive conventional petroleum and gas areas are listed in Table A-3.

Major Tenure Holder:.................. The relevant tenure holder representing its subsidiaries and joint venture partners for that particular Development Area.

Development Area: .... Names used by the Major Tenure Holders to identify a geographical project area.

Some Major Tenure Holders have used local area names e.g. Fairview and Spring Gully, whilst others have used the location of the project area in relation to the project as a whole, e.g. Northern, Central and Southern Development Area.

Gas Field Name:.......................... A sub class of Development Area. Gas field names are also assigned by the Major Tenure Holder.

Generally a number of gas fields make up a Development Area.

Tenure Number: .... The tenure reference as assigned by DNRM

All tenure reference numbers associates with each gas field are listed. In some cases gas fields may include areas over which a petroleum lease (PL) has been granted and other areas where only an authority to prospect (ATP) exists at the current time.

Target Formation: .... The geological formation where extraction is occurring or will be targeted.

Commencement Date:................ The year in which production begun from the gas field or when the Major Tenure Holder has scheduled production to begin

Cessation Date:........................... The period in which the Major Tenure Holder anticipates production from the respective gas field to cease.

Total Projected Wells: .... The total number of wells planned to be installed in each gas field. For projects which have yet to receive environmental approvals total projected wells are provided for development areas rather than individual gas fields or tenure since detailed planning of well locations etc is typically not available at this relatively early development stage.

Table A-1 Current CSG production areas

Major Tenure Holder	Development Area	Gas Field Name	Tenure Number	Target Formation	Commencement Date	Cessation Date	Total Projected Wells
Arrow	Drainage Area 7	Daandine	PL194, PL230, PL252	Walloon Coal Measures	2005	2045 - 2050	218
		Drainage Area 7	ATP676, PL194, PL198, PL230, PL252, PL260	Walloon Coal Measures	2005	2045 - 2050	290
	Drainage Area 8	Tipton	PL198	Walloon Coal Measures	2005	2050 - 2055	141
		Drainage Area 8	ATP683, ATP746, PL198, PL238, PL258, PL260	Walloon Coal Measures	2007	2060 - 2065	1930
Origin	Combabula	Combabula	PL297	Walloon Coal Measures	2014	2050 - 2055	375
		Combabula North	PL408	Walloon Coal Measures	2014	2045 - 2050	350
		Reedy Creek	PL404	Walloon Coal Measures	2014	2050 - 2055	250
	Condabri	Condabri	PL265	Walloon Coal Measures	2013	2040 - 2045	325
		Condabri North	PL267	Walloon Coal Measures	2013	2040 - 2045	300
		Condabri South	PL266	Walloon Coal Measures	2014	2040 - 2045	125
	Peat	Peat	PL101	Bandanna Formation	1997	2035 - 2040	35
	Spring Gully	Durham Ranch	PL200, PL203	Bandanna Formation	2013	2040 - 2045	425
		Spring Gully	ATP592, PL195	Bandanna Formation	1999	2040 - 2045	395
		Strathblane	PL204	Bandanna Formation	2005	2035 - 2040	355
	Talinga / Orana	Orana	PL215	Walloon Coal Measures	2014	2040 - 2045	140
		Orana North	PL272	Walloon Coal Measures	2014	2040 - 2045	350
		Talinga	PL226	Walloon Coal Measures	1999	2040 - 2045	330
QGC	Central Development Area	Argyle	PL179, PL229	Walloon Coal Measures	2003	2055 - 2060	125
		Avon Downs	PL461, PL472	Walloon Coal Measures	2014	2040 - 2045	125
		Bellevue	PL247	Walloon Coal Measures	2006	2055 - 2060	125
		Berwyndale	PL201, PL211	Walloon Coal Measures	2006	2050 - 2055	125
		Berwyndale South	PL201, PL212	Walloon Coal Measures	2002	2035 - 2040	131
		Codie	PL180, PL228	Walloon Coal Measures	2007	2045 - 2050	120

Major Tenure Holder	Development Area	Gas Field Name	Tenure Number	Target Formation	Commencement Date	Cessation Date	Total Projected Wells
QGC	Central Development Area	Jammat	PL257, PL278	Walloon Coal Measures	2008	2055 - 2060	70
		Kate	PL228	Walloon Coal Measures	2011	2050 - 2055	125
		Kenya	PL180, PL228	Walloon Coal Measures	2006	2055 - 2060	125
		Kenya East	PL278	Walloon Coal Measures	2006	2055 - 2060	125
		Lauren	PL180, PL263	Walloon Coal Measures	2005	2045 - 2050	133
		Matilda-John	PL263	Walloon Coal Measures	2014	2030 - 2035	125
		McNulty	PL458, PL459	Walloon Coal Measures	2014	2055 - 2060	125
	Northern Development Area	Cam	PL276, PL277	Walloon Coal Measures	2009	2055 - 2060	129
		Kathleen	PL276, PL277	Walloon Coal Measures	2011	2055 - 2060	126
		Polaris	PL398, PL399	Walloon Coal Measures	2014	2055 - 2060	125
		Ross	PL276	Walloon Coal Measures	2008	2050 - 2055	127
		Woleebee Creek	PL276, PL277	Walloon Coal Measures	2010	2055 - 2060	127
	Southern Development Area	Broadwater	PL279	Walloon Coal Measures	2011	2055 - 2060	100
		Celeste	PL442	Walloon Coal Measures	2011	2055 - 2060	105
		Clunie	PL466, PL474	Walloon Coal Measures	2009	2055 - 2060	25
		David	PL273	Walloon Coal Measures	2010	2055 - 2060	105
		Glendower	PL274, PL279	Walloon Coal Measures	2014	2055 - 2060	110
		Harry	PL274, PL279	Walloon Coal Measures	2014	2055 - 2060	115
		Isabella	PL275	Walloon Coal Measures	2011	2055 - 2060	125
		Jen	PL275	Walloon Coal Measures	2011	2055 - 2060	40
		Ruby Jo	PL275	Walloon Coal Measures	2011	2055 - 2060	125
		Sean	ATP648, PL273	Walloon Coal Measures	2008	2055 - 2060	80
Santos	Fairview Gas Field	Fairview	PL91, PL92, PL99, PL100, PL232	Bandanna Formation	1995	2040 - 2045	525
	Roma Gas Field	Roma - West Phase 1	PL309, PL314, PL315	Walloon Coal Measures	2014	2040 - 2045	140
	Scotia Gas Field	Scotia	PL176	Bandanna Formation	2002	2040 - 2045	114

Table A-2 Planned CSG production areas

Major Tenure Holder	Development Area	Gas Field Name	Tenure Number	Target Formation	Commencement Date	Cessation Date	Total Projected Wells
Arrow	Drainage Area 2	Drainage Area 2	ATP676, ATP747, ATP810	Walloon Coal Measures	2015 - 2020	2055 - 2060	805
	Drainage Area 5	Drainage Area 5	ATP676, PL194	Walloon Coal Measures	2015 - 2020	2055 - 2060	799
Origin	Combabula	Clifford East	ATP606	Walloon Coal Measures	2015 - 2020	2040 - 2045	60
		Lucky Gully	ATP606	Walloon Coal Measures	2025 - 2030	2055 - 2060	245
		Meeleebee	ATP606	Walloon Coal Measures	2020 - 2025	2045 - 2050	155
		Muggleton	ATP606	Walloon Coal Measures	2015 - 2020	2050 - 2055	320
		Pine Hills	ATP606	Walloon Coal Measures	2015 - 2020	2050 - 2055	340
		Reedy Creek South	ATP606	Walloon Coal Measures	2015 - 2020	2050 - 2055	155
	Condabri	ATP1178	ATP1178	Walloon Coal Measures	2015 - 2020	2040 - 2045	125
	Spring Gully	Clifford	ATP592	Bandanna Formation	2015 - 2020	2040 - 2045	5
		Durham West	ATP592	Bandanna Formation	2015 - 2020	2040 - 2045	10
		Expedition Creek	ATP592	Bandanna Formation	2015 - 2020	2040 - 2045	85
		Scott Creek	PL415	Bandanna Formation	2015 - 2020	2040 - 2045	10
		Spring Creek	PL416	Bandanna Formation	2015 - 2020	2040 - 2045	10
		Spring Gully East	PL417	Bandanna Formation	2015 - 2020	2040 - 2045	175
QGC	Central Development Area	Owen	PL443	Walloon Coal Measures	2015 - 2020	2030 - 2035	24
	Northern Development Area	Acrux	PL398, PL399	Walloon Coal Measures	2015 - 2020	2055 - 2060	75
		Arthur	PL498	Walloon Coal Measures	2015 - 2020	2050 - 2055	105
		Bloodworth	PL506	Walloon Coal Measures	2015 - 2020	2055 - 2060	125
		Borrowdale	PL505, PL507	Walloon Coal Measures	2015 - 2020	2055 - 2060	125
		Cameron	PL401, PL467, PL498	Walloon Coal Measures	2015 - 2020	2055 - 2060	125
		Charlie	PL299, PL498	Walloon Coal Measures	2015 - 2020	2045 - 2050	125

Major Tenure Holder	Development Area	Gas Field Name	Tenure Number	Target Formation	Commencement Date	Cessation Date	Total Projected Wells
QGC	Northern Development Area	Fishburn	PL505, PL507	Walloon Coal Measures	2020 - 2025	2050 - 2055	125
		Golden Grove	PL397, PL464, PL505, PL506	Walloon Coal Measures	2015 - 2020	2055 - 2060	125
		Mamdal	PL276, PL277	Walloon Coal Measures	2015 - 2020	2055 - 2060	80
		Penrhyn	PL498, PL505	Walloon Coal Measures	2015 - 2020	2045 - 2050	125
		Philip	PL498	Walloon Coal Measures	2015 - 2020	2050 - 2055	115
		Portsmouth	PL401	Walloon Coal Measures	2015 - 2020	2050 - 2055	125
		Thackery	PL505, PL507	Walloon Coal Measures	2020 - 2025	2045 - 2050	125
	Southern Development Area	Anya	ATP1188	Walloon Coal Measures	2015 - 2020	2035 - 2040	20
		Jordan	PL442	Walloon Coal Measures	2015 - 2020	2050 - 2055	25
		Poppy	ATP648, PL273	Walloon Coal Measures	2015 - 2020	2055 - 2060	65
		Ridgewood	PL1010	Walloon Coal Measures	2015 - 2020	2045 - 2050	35
		Will	PL1009	Walloon Coal Measures	2015 - 2020	2055 - 2060	10
Santos	Arcadia Gas Field	Arcadia - ACP	PL421	Bandanna Formation	2015 - 2020	2040 - 2045	16
		Arcadia - Arcadia Valley Phase 1	PL420, PL421	Bandanna Formation	2015 - 2020	2040 - 2045	72
		Arcadia - Arcadia Valley Phase 2	PL420, PL421	Bandanna Formation	2015 - 2020	2040 - 2045	112
		Arcadia - North & South	PL90, PL234, PL420, PL421	Bandanna Formation	2020 - 2025	2040 - 2045	172
	Fairview Gas Field	Fairview - Early Permian East Phase 1	PL92	Cattle Creek Formation	2015 - 2020	2040 - 2045	30
		Fairview - Early Permian East Phase 2	PL92, PL100	Cattle Creek Formation	2015 - 2020	2040 - 2045	18
		Fairview - Early Permian East Phase 3	PL91, PL92, PL100, PL232	Cattle Creek Formation	2020 - 2025	2040 - 2045	201
		Fairview - Early Permian West	PL92, PL99	Cattle Creek Formation	2020 - 2025	2040 - 2045	132

Major Tenure Holder	Development Area	Gas Field Name	Tenure Number	Target Formation	Commencement Date	Cessation Date	Total Projected Wells
Santos	Fairview Gas Field	Fairview - Eastern Flank Phase 1	PL100, PL232	Bandanna Formation	2015 - 2020	2040 - 2045	81
		Fairview - Precipice Creek	PL90, PL233	Bandanna Formation	2015 - 2020	2040 - 2045	45
		Fairview - Resource Reserve	PL100, PL232	Bandanna Formation	2015 - 2020	2040 - 2045	33
	Roma Gas Field	Roma - ATP1187	ATP1187	Walloon Coal Measures	2020 - 2025	2040 - 2045	84
		Roma - East Phase 1	ATP631	Walloon Coal Measures	2015 - 2020	2040 - 2045	120
		Roma - East Phase 2	ATP631	Walloon Coal Measures	2020 - 2025	2040 - 2045	108
		Roma - East Phase 3	ATP631	Walloon Coal Measures	2020 - 2025	2040 - 2045	132
		Roma - West Phase 2A	PL309, PL310, PL314, PL315	Walloon Coal Measures	2015 - 2020	2040 - 2045	88
		Roma - West Phase 2B	PL309, PL310, PL314	Walloon Coal Measures	2015 - 2020	2040 - 2045	156
		Roma - West Remainder (2C)	PL309, PL310, PL315	Walloon Coal Measures	2015 - 2020	2040 - 2045	64
		Roma - West Remainder (3A, 3B, 3C)	PL309, PL314, PL315, PL322	Walloon Coal Measures	2015 - 2020	2040 - 2045	228
Senex	Western Surat	Daedalus	ATP795	Walloon Coal Measures	2015 - 2020	2050 - 2055	760
		Dione	ATP767	Walloon Coal Measures	2035 - 2040	2065 - 2070	
		Glenora	ATP889	Walloon Coal Measures	2015 - 2020	2045 - 2050	
		Maisey	ATP889	Walloon Coal Measures	2015 - 2020	2050 - 2055	
		Mimas	ATP795	Walloon Coal Measures	2020 - 2025	2055 - 2060	
		Pandora	ATP767	Walloon Coal Measures	2025 - 2030	2060 - 2065	
		Phoebe	ATP767	Walloon Coal Measures	2025 - 2030	2060 - 2065	
		Rhea	ATP795	Walloon Coal Measures	2035 - 2040	2065 - 2070	
		Tethys	ATP795	Walloon Coal Measures	2015 - 2020	2055 - 2060	
		Titan	ATP767	Walloon Coal Measures	2030 - 2035	2065 - 2070	

Table A-3 Conventional petroleum and gas tenures

Major Tenure Holder	Conventional Field Name	Tenure Number	Field Status
AGL	Boggo Creek	PL446	Inactive
	Boxleigh	PL15	Inactive
	Churchie	PL192, PL213	Inactive
	East Glen	PL446	Active
	Link	PL446	Active
	Roswin	PL66	Inactive
	Silver Springs	PL446	Inactive
	Sirrah	PL446	Inactive
	Taylor	PL48, PL49, PL446	Active
	Tinker	PL446	Inactive
	Waggamba	PL202	Active
Ausam Resources Pty Ltd	Downlands	PL119	Inactive
Brisbane Petroleum Ltd	Beardmore	PL280	Inactive
	Louise	PL40	Inactive
	McWhirter	PL18, PL280	Inactive
	Narrows	PL40	Inactive
	Thomby Creek	PL18	Inactive
	Yellowbank Creek	PL18	Inactive
Origin	Glentulloch	PL45	Inactive
	Kildare	PL45	Inactive
	Kincora Fields	PL14, PL21, PL22, PL27, PL30, PL53, PL70, PL71, PL264, PL227, PL511, PL512	Inactive
	Rolleston	PL42	Inactive
	Springton / Arcturus	PL41, PL54, PL67, PL173	Inactive
	Yellowbank	PL43, PL44, PL183, PL218	Inactive
Ranger Energy Pty Limited	Fairymount	PL46	Inactive
Santos	Alton	PL2	Inactive
	Avondale	PL28	Inactive
	Bloodwood	PL89	Inactive
	Deepwater	PL69	Inactive
	Moonie	PL1	Active
	Oberina	PL12	Inactive
Senex	Reids Dome	PL231	Inactive
Southern Cross Petroleum & Exploration Pty Ltd	Bennett	PL17	Inactive
	Leichhardt	PL17	Inactive

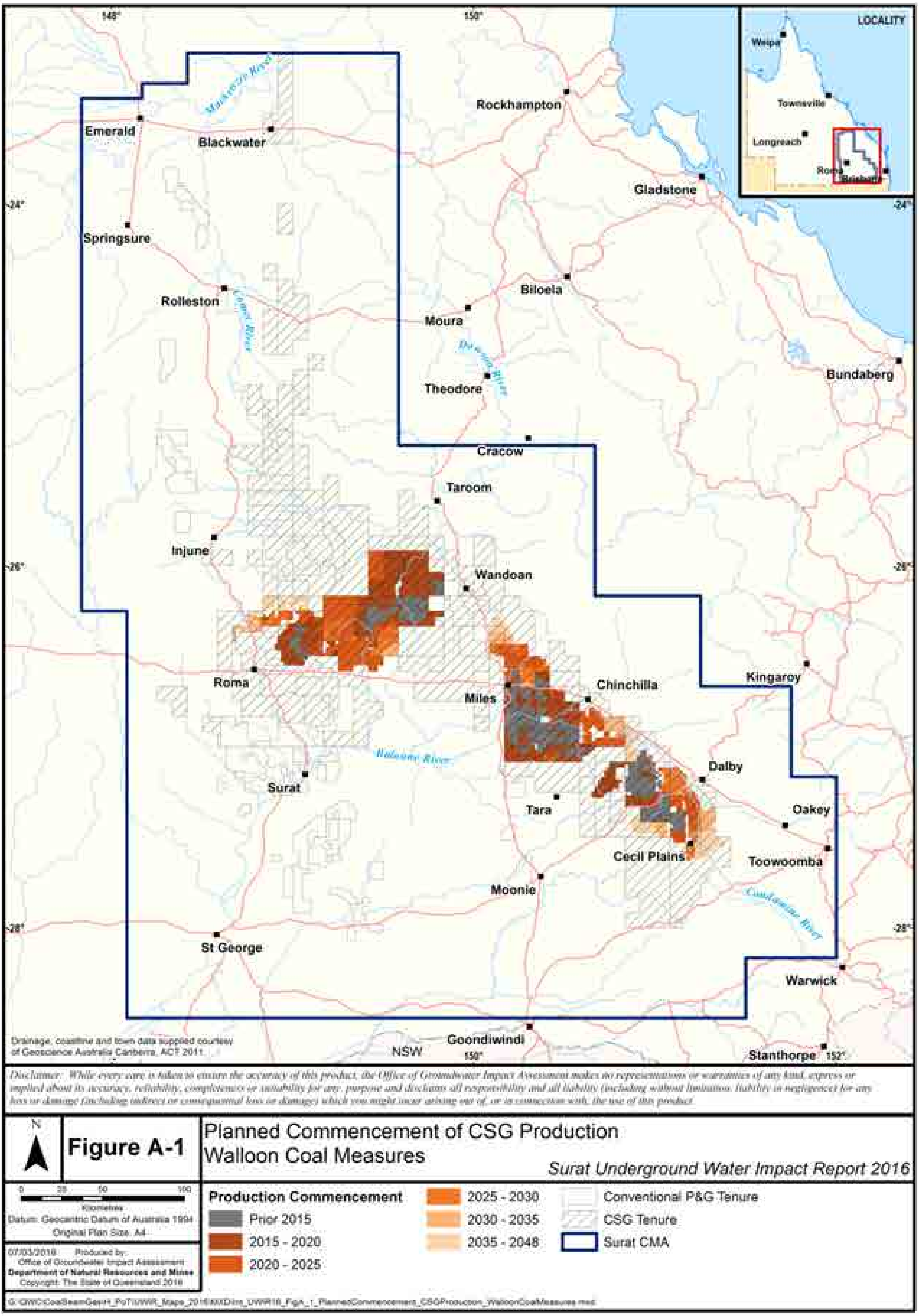

Figure A-1 Planned commencement of CSG production – Walloon Coal Measures

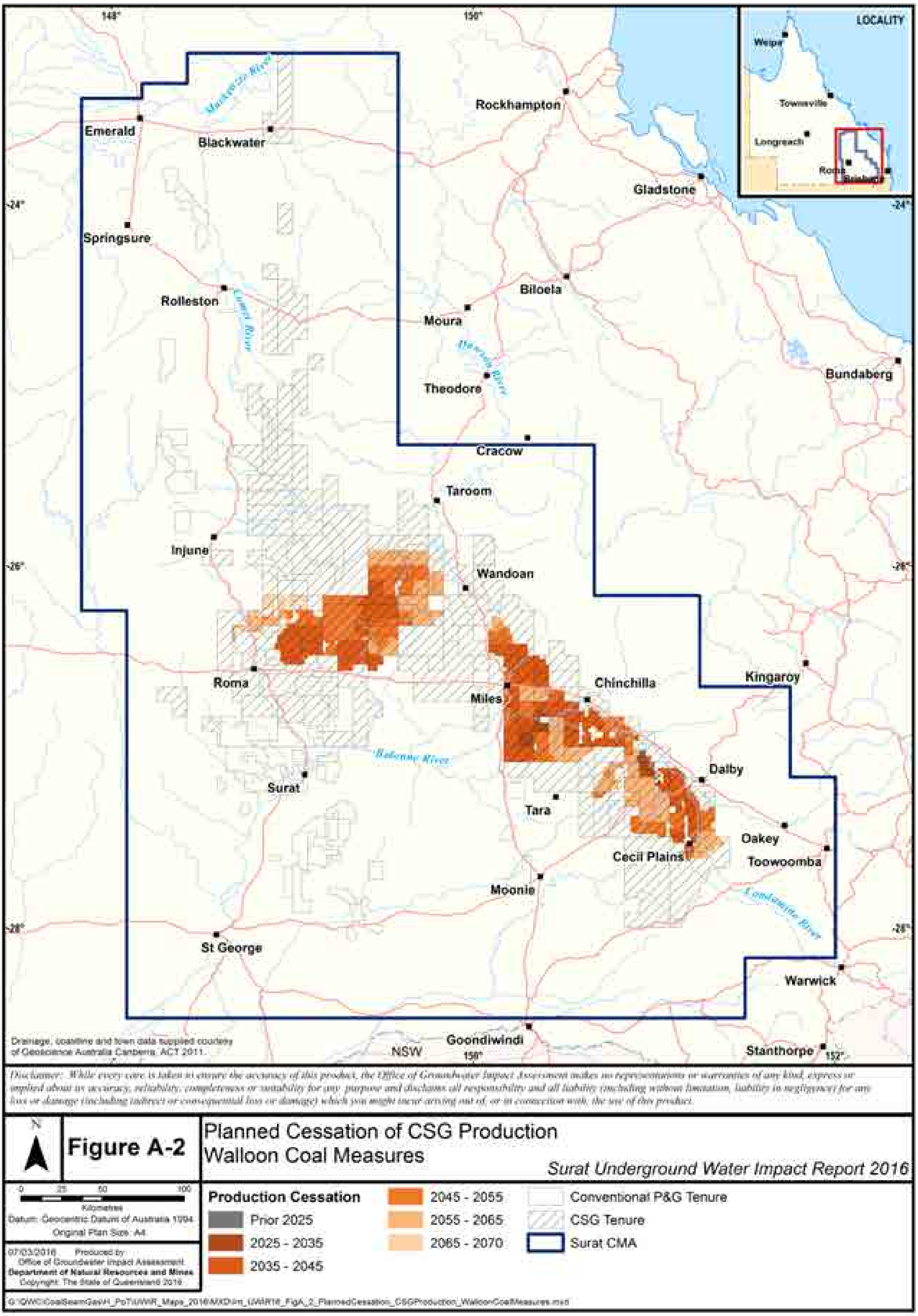

Figure A-2 Planned cessation of CSG production – Walloon Coal Measures

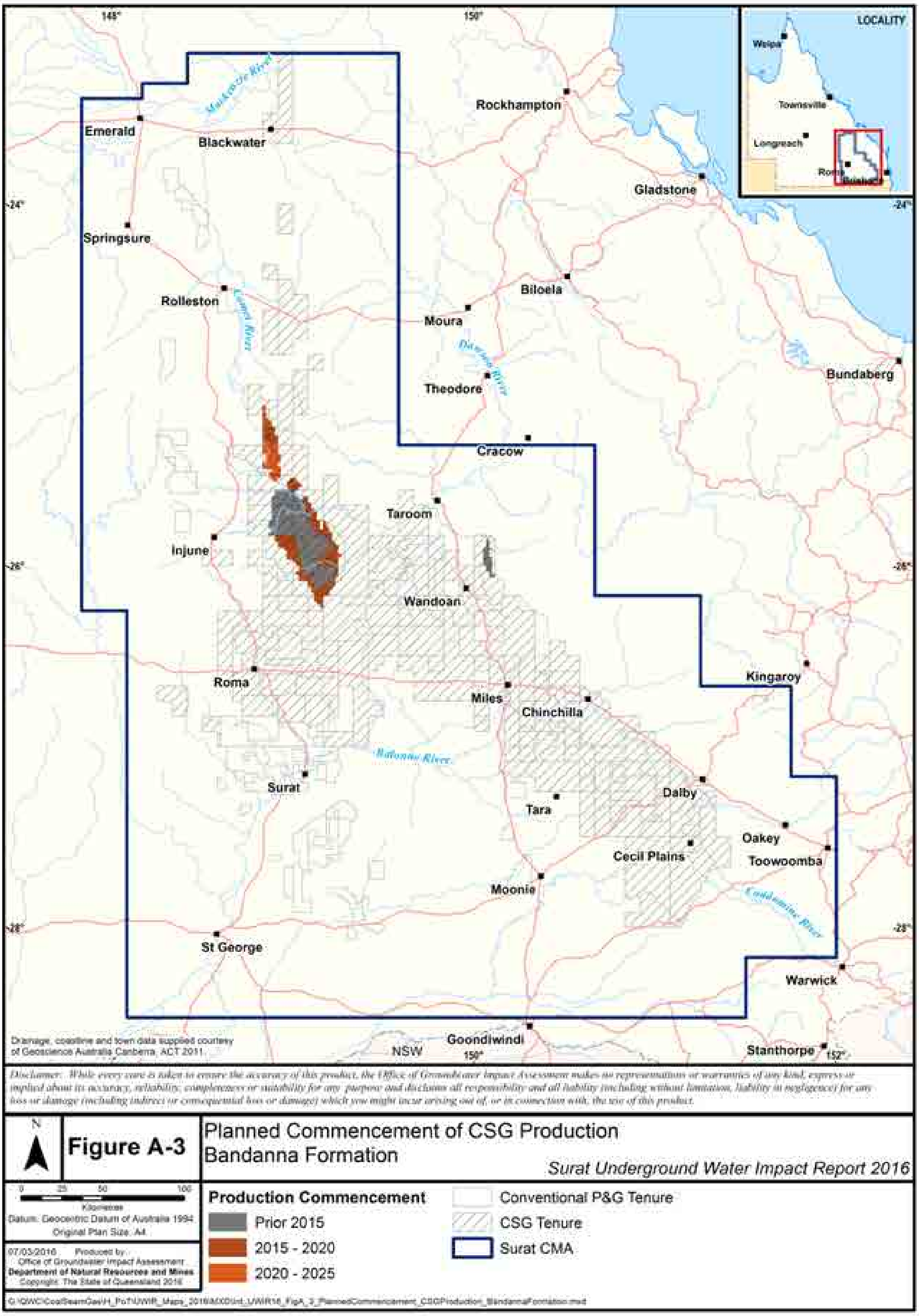

Figure A-3 Planned commencement of CSG production – Bandanna Formation

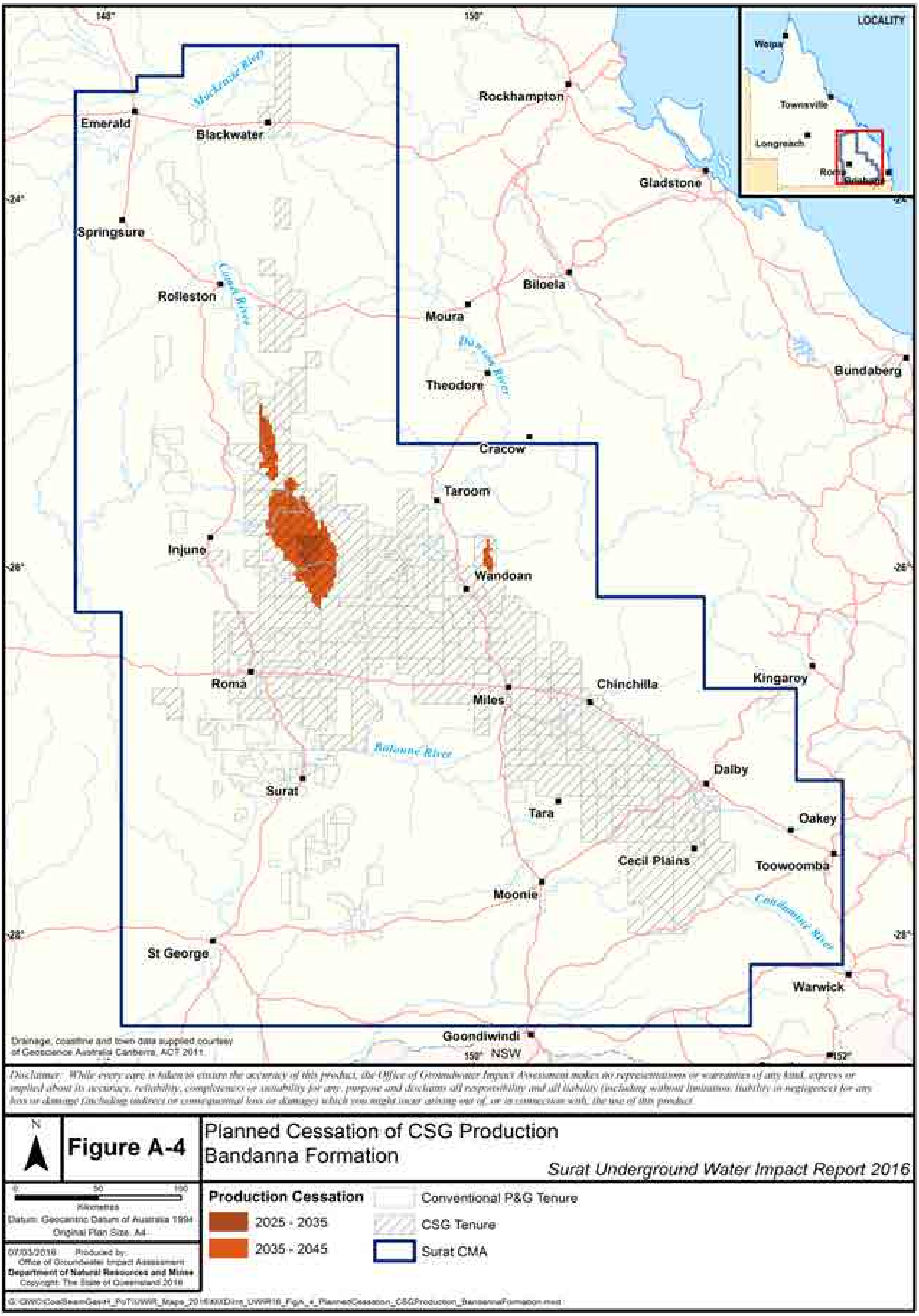

Figure A-4 Planned cessation of CSG production – Bandanna Formation

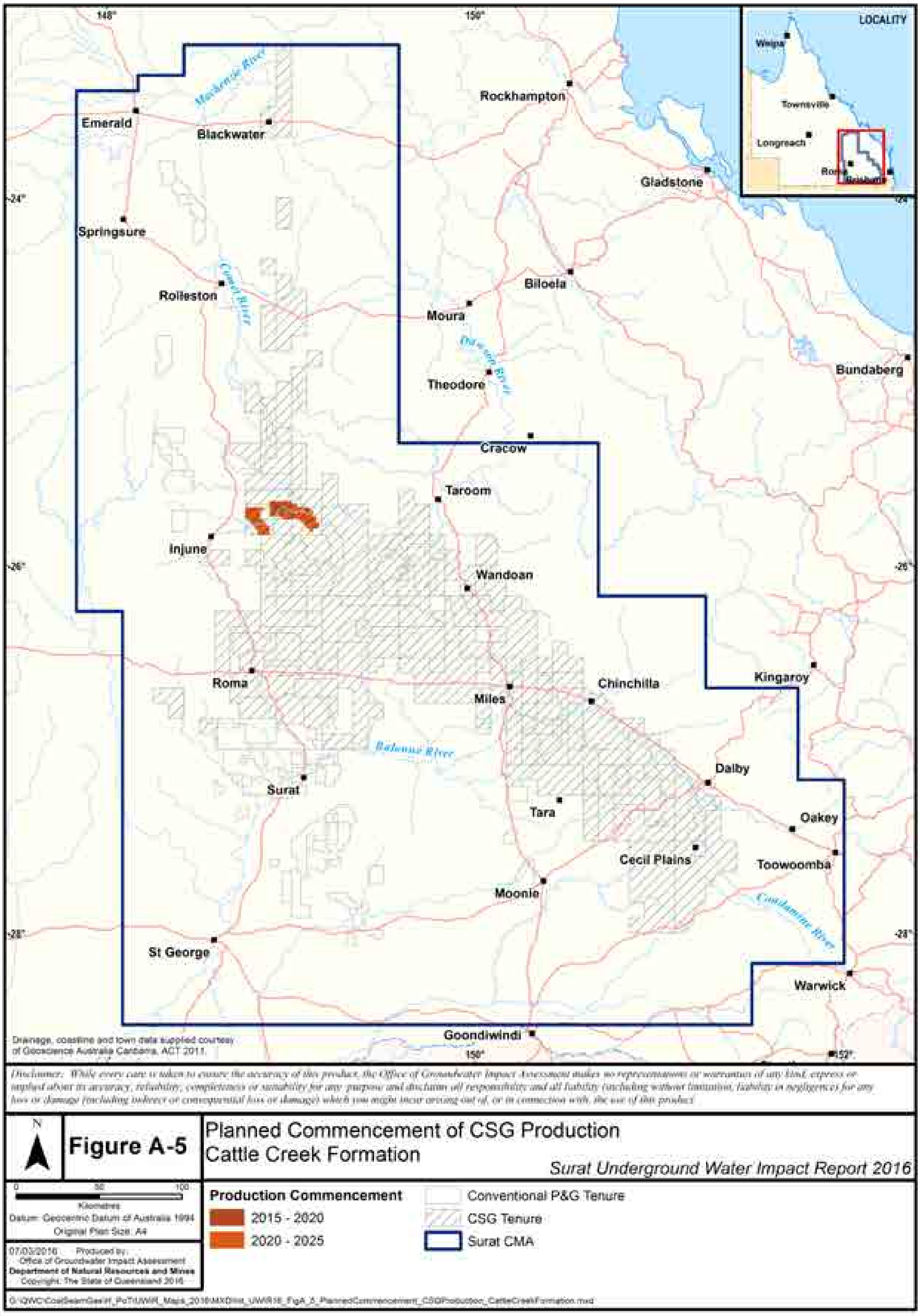

Figure A-5 Planned commencement of CSG production – Cattle Creek Formation

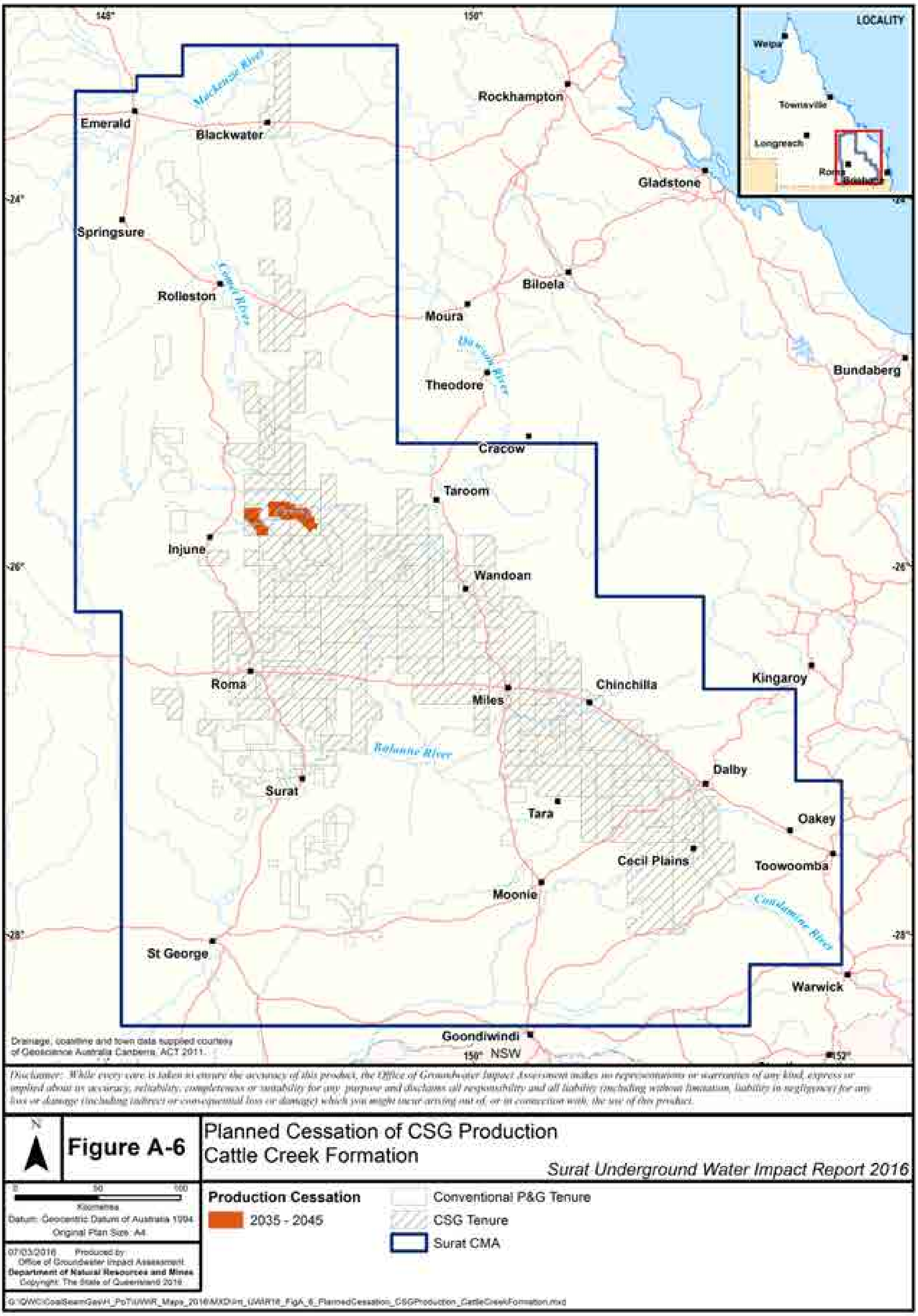

Figure A-6 Planned cessation of CSG production – Cattle Creek Formation

Appendix A-2 High development scenario

Introduction

As discussed in Section 2.4.2 environmental approvals have been granted or are in process for CSG development over the tenure areas shown in Figure 2.5. This includes areas of current production, planned production and potential production. Tenure holders currently have no plans to develop the potential production areas. Predictions in the UWIR are based on development in the current and planned production areas.

In order to assess the extent to which impacts could increase if changed market conditions did result in development in the potential production areas, OGIA prepared a high development scenario. This scenario provided for development of the potential production areas within practical limits. The high development scenario is a hypothetical scenario constructed by OGIA. It does not relate to current industry planning.

Number of wells in the high development scenario

Some CSG environmental approval documents set limits on the number of CSG wells which can be developed. In the other cases although environmental impact statements and other approval documentation do not set limits on the number of wells, they include a limit on the overall size of a project and give estimates of the number of CSG wells likely to be installed. These data suggest that up to 34,000 CSG wells could be constructed over the current, planned and potential production areas shown in Figure 2.5.

However, there are other constraints that would reduce the number of wells that could be installed. Well installation may be limited by a project reaching a defined end point in time under current approvals which is related to the design lifetime of the processing facilities and other infrastructure.

The number and timing of well installations for the high development scenario was established by continuing current or planned peak installation rates until the number of well installations was constrained by a limit on the number of wells approved, the area that could be developed, or time available for well installation. The high development scenario comprises 31,000 CSG wells.

Scheduling of well construction in the high development scenario

The location and timing of the additional development under the high development scenario was based on initial scheduling information provided to OGIA or included in EIS or other project documentation. This information was used to identify the likely order of development of each individual tenure block within the potential production areas. Timing was designed to maintain peak rates of development. Well spacing was based on current practice in the Surat CMA.

Results

The high development scenario was assessed using the regional groundwater flow model. The scenario resulted in a 17 percent increase in the number of water supply bores affected in the long term, and a 43 percent increase in the total volume of water produced, compared to the predictions presented in Chapter 7.

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Appendix B. Stratigraphy

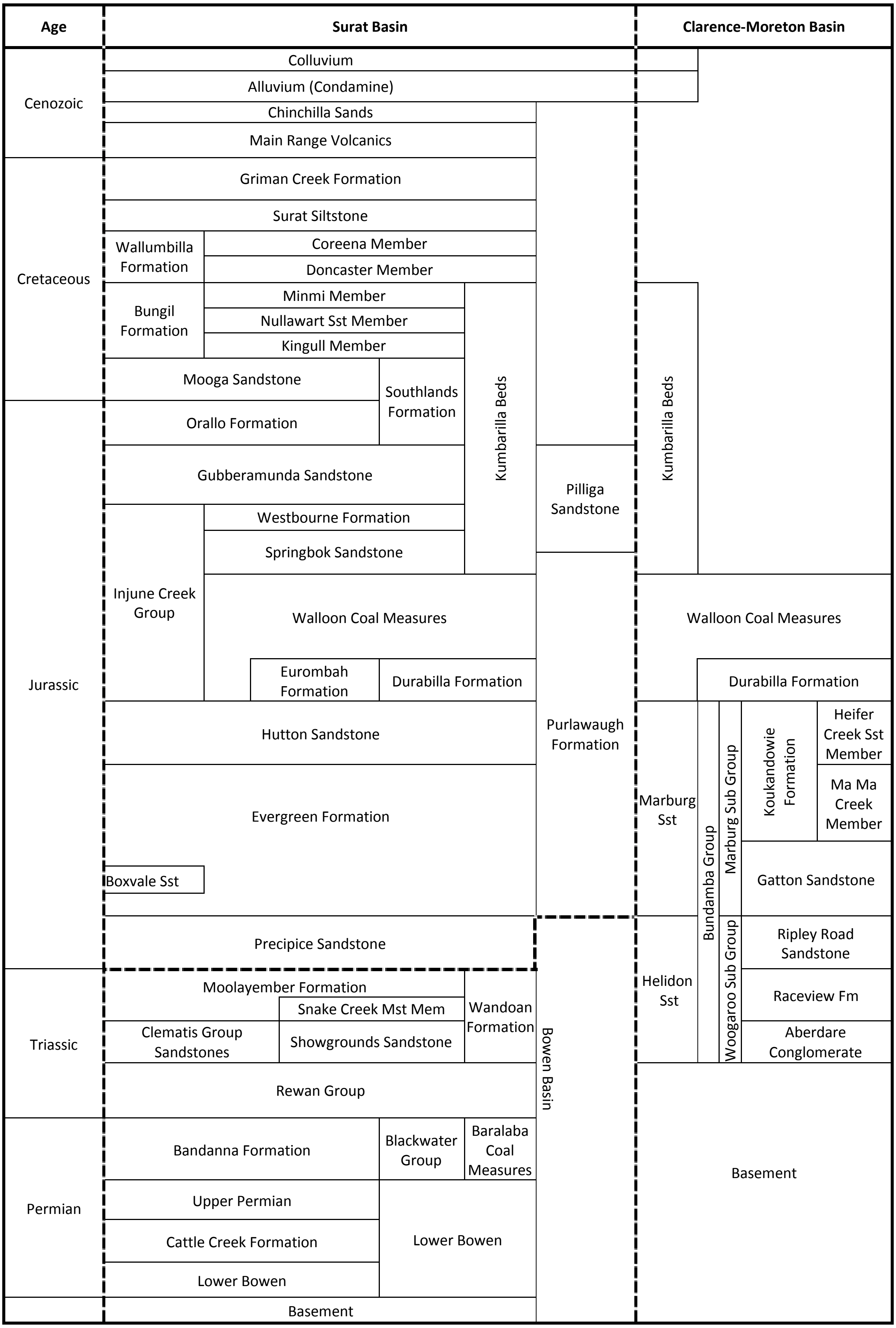

Figure B-1 Stratigraphic Table

Appendix C. Hydraulic conductivity data for geologic formations

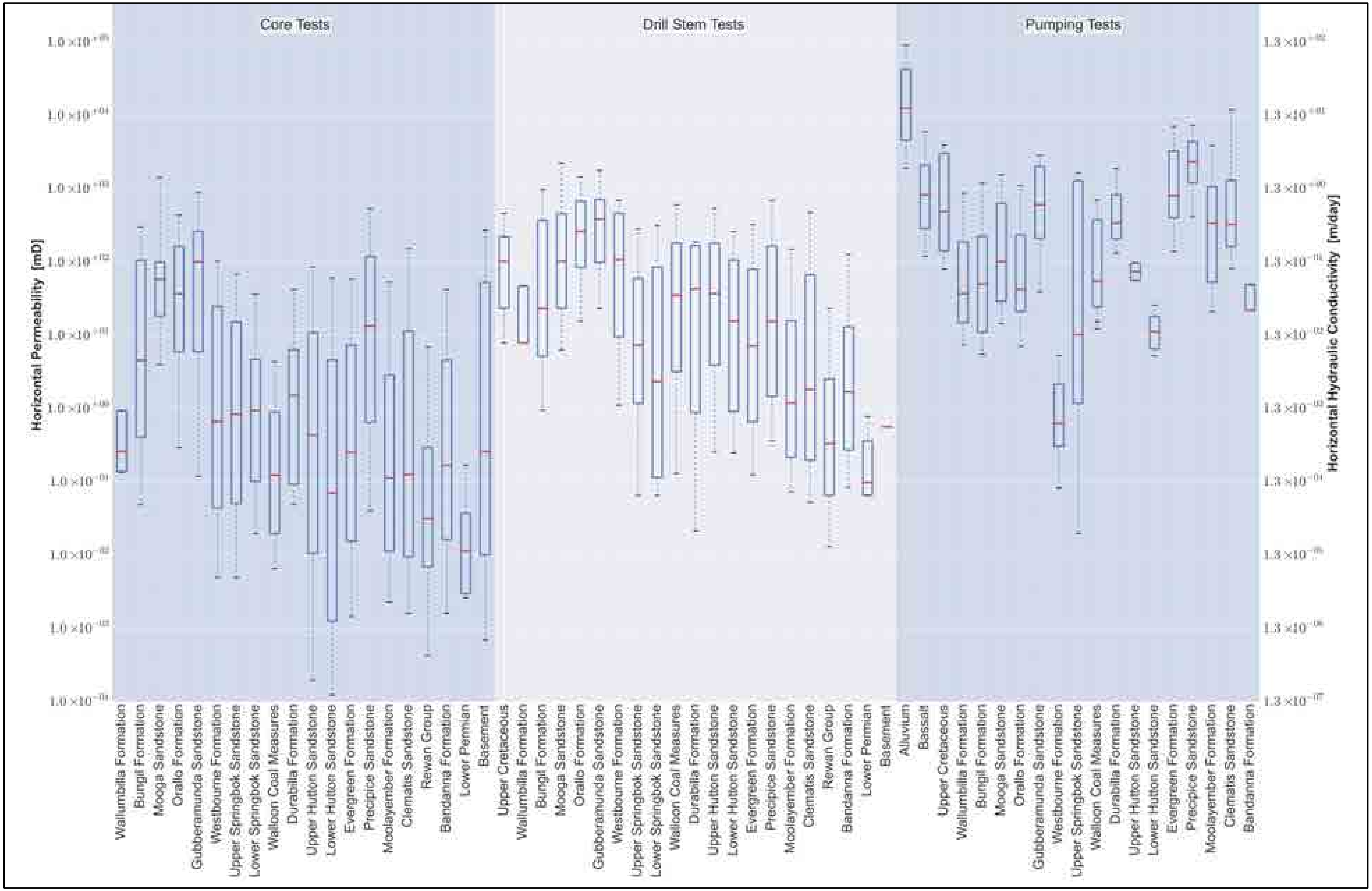

Figure C-1 Available hydraulic conductivity data

Appendix D. Understanding depressurisation in a multilayered aquifer system

Types of aquifers

An ***aquifer*** is a geological formation that largely consists of permeable material such as sand and sandstone that is capable of storing water within pore spaces and fractures, and releasing water in a reasonable quantity when pumped from a bore that taps the geological formation.

A bore is used to extract water from an aquifer. A bore is constructed by first drilling a borehole. Casing is installed in the bore to prevent the bore hole from collapsing. There are slots near the bottom of the casing to allow water to enter the bore while screening out the entry of sand grains. The section of water entry is called the 'screened' section of the bore. A pump is typically installed just above the screened section.

An ***unconfined aquifer*** is an aquifer that generally occurs at shallower depth or near ground surface (Figure D-1). Pore spaces and fractures are filled with water (i.e. saturated) to a level below the top surface of the aquifer. This upper surface of saturation level is called the water table. These aquifers are also known as ‘water table aquifers’. Unconfined aquifers receive recharge directly from the infiltration of rainfall and surface water.

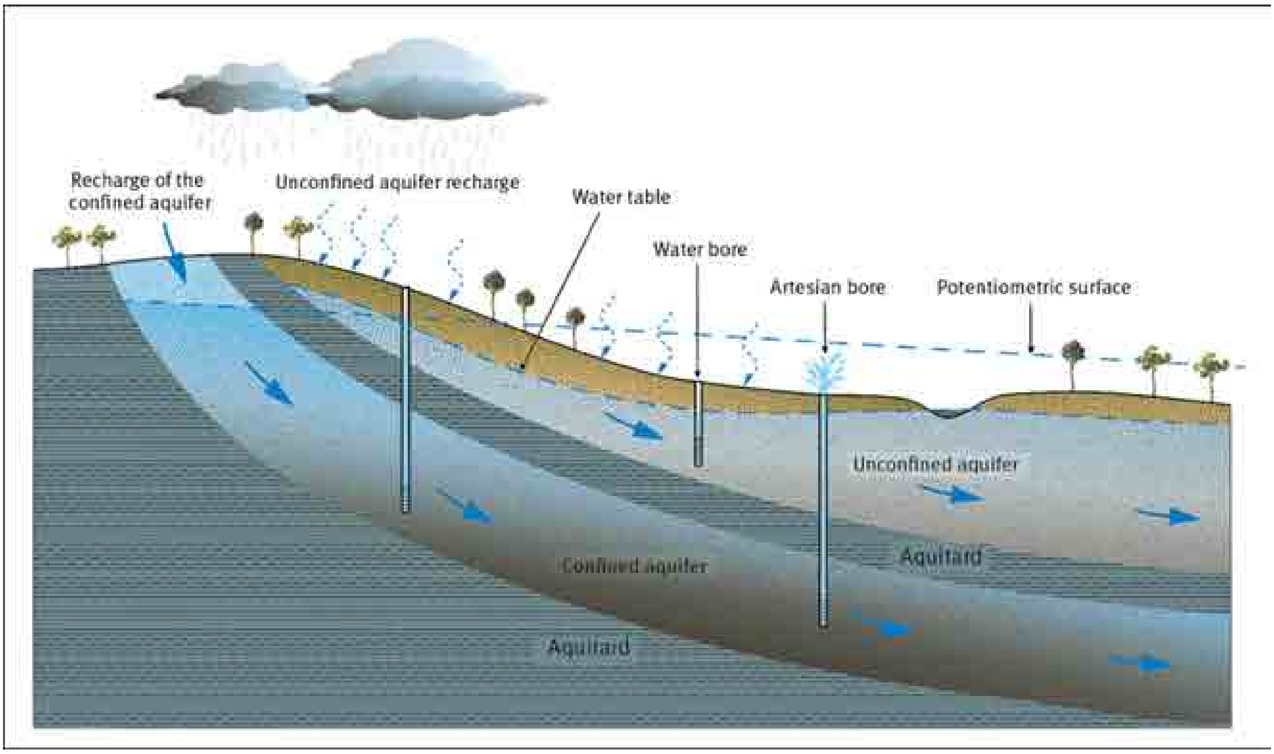

Figure D-1 Confined and unconfined aquifers

A bore in an unconfined aquifer is drilled to a depth below the water table and is typically screened in the lower most part of the bore, where more permeable material is often encountered. Water enters the bore through the screened section and rises to the height of the water table in the unconfined aquifer. When water is pumped of the bore, it is replenished by water flowing from the aquifer through the screen into the bore. The rate of replenishment depends on the permeability of the aquifer. A higher permeability results in a faster rate of replenishment. For this reason, a high pumping rate can be sustained in bores that tap high permeability aquifers.

If the water table declines, then the water level in a bore tapping the aquifer will decline to the same level. A decline in the water table may result from a seasonal reduction in recharge or collective storage depletion caused by water extraction by all water users.

The pumping rate of a bore also depends upon the height of the water column above the pump. In comparison to a shallow bore, a deep bore with a deep screened section and a pump set at greater depth will have a greater height of water column above the pump. This means that a water table decline is likely to affect the pumping rate of shallow bore more than a deep bore, and may even render it dry if the water table declines to near the level of the pump.

Confined aquifers are aquifers that are covered (confined) by an impermeable or semi-permeable layer of rock such as clay, silt or mudstone. These confining layers are referred to as 'aquitards'. Unlike an unconfined aquifer, a confined aquifer remains fully saturated. Water is held in pores and fractures under pressure because it cannot easily escape through the confining aquitard.

Confined aquifers are generally found beneath unconfined aquifers, often at significant depths. Confined aquifers often occur as multilayered systems where aquifer layers are separated by aquitard layers, as is the case for the aquifers of the GAB.

Confined aquifers are more readily recharged in areas where confining aquitards are absent or the aquifer is exposed at the land surface, allowing infiltrating rainfall or river flow to enter. However, a confined aquifer can also be recharged by the slow transfer of groundwater into the aquifer through an aquitard.

A bore is constructed to tap a confined aquifer by setting the screened section in the aquifer and sealing the outside of the casing with cement. The water pressure in the aquifer causes the water level in the bore to rise. The level to which water rises is the ***piezometric surface or pressure level*** of the aquifer although it is also common to refer to this surface as the ‘water level’ in the aquifer.

The water level in a confined aquifer can be so high that it is above the ground level and water can flow naturally from the bore. Such bores are referred to as ***artesian*** bores.

Aquifer depressurisation

Where multiple confined aquifers occur at a single location, it is common practice that a water bore will tap only one of the aquifers. Typically, shallower formations are the preferred target because shallower bores cost less to construct. Deeper confined aquifers are only targeted if they contain water of higher quantity or if larger supplies are available.

In a multilayer aquifer system a water level decline in one aquifer does not necessarily affect the other surrounding aquifers to same degree. This is illustrated in Figure D-2 and D-3 which represent conditions in a three layered system with an unconfined aquifer (A) at the top underlain by two confined aquifers (B and C). The aquifers are separated by aquitards. The blue shading represents saturation in the aquifers.

Figure D-2 illustrates ***pre-development*** conditions which exist before bore pumping commences. Bore 1 taps the unconfined aquifer and therefore the water level in the bore is at the same level as the water table. Bores 2 and 3 are tapping the confined aquifers. Because they are under pressure the water levels are above the confining layer and reflects the pressure levels in the aquifers, which are little different to each other.

Figure D-3 illustrates ***post-development*** conditions which exist after pumping from Bore 3 is well established. The water level in the Bore 3 has dropped and pressure in Aquifer C declines to a corresponding level close to the bore and to lesser degree further form the bore. However, the pressure remains above the confining aquitard and therefore the aquifer remains fully saturated. This is sometimes referred to as ***depressurisation***. As the bore is pumped water is instantly released from storage within pores and fractures of the aquifer due to the slight expansion of water that result from the reduction in pressure. At the same time the aquifer material also expands very slightly because of the reduced pressure, ‘squeezing’ water out of the pores and fractures. The aquifer remains fully saturated.

Because of the pressure difference between Aquifer B and C that has been established, there will be some leakage of water from Aquifer B to C through the aquitard that separates the aquifers. This leakage will reduce the pressure in Aquifer B, although to a much lesser degree because the leakage volume will be smaller than the volume pumped from Aquifer C.

Aquifer storage depletion

During depressurisation the confined aquifers remain saturated. In Figure D-3 there will be some leakage from water table Aquifer A to confined Aquifer B because of the change in pressure in Aquifer B. As a result there will be some lowering of the water table in Aquifer A. The decline will be smaller than it would be if Aquifer A was a confined aquifer, because the leakage water comes from draining of the pores at the top of the water table aquifer rather than from the storage of a confined aquifer. A small depth of pore storage from an unconfined aquifer yields the same volume of water as a much larger reduction of pressure in a confined aquifer.

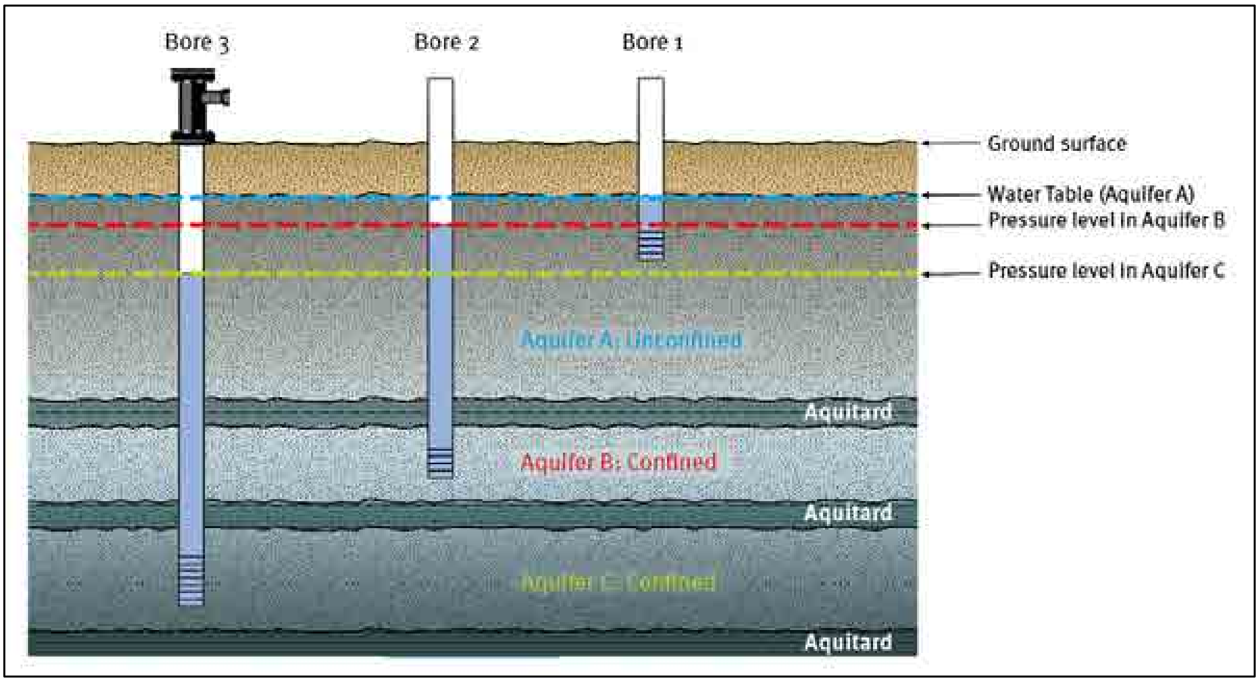

Figure D-2 Multilayered aquifer under pre-development conditions

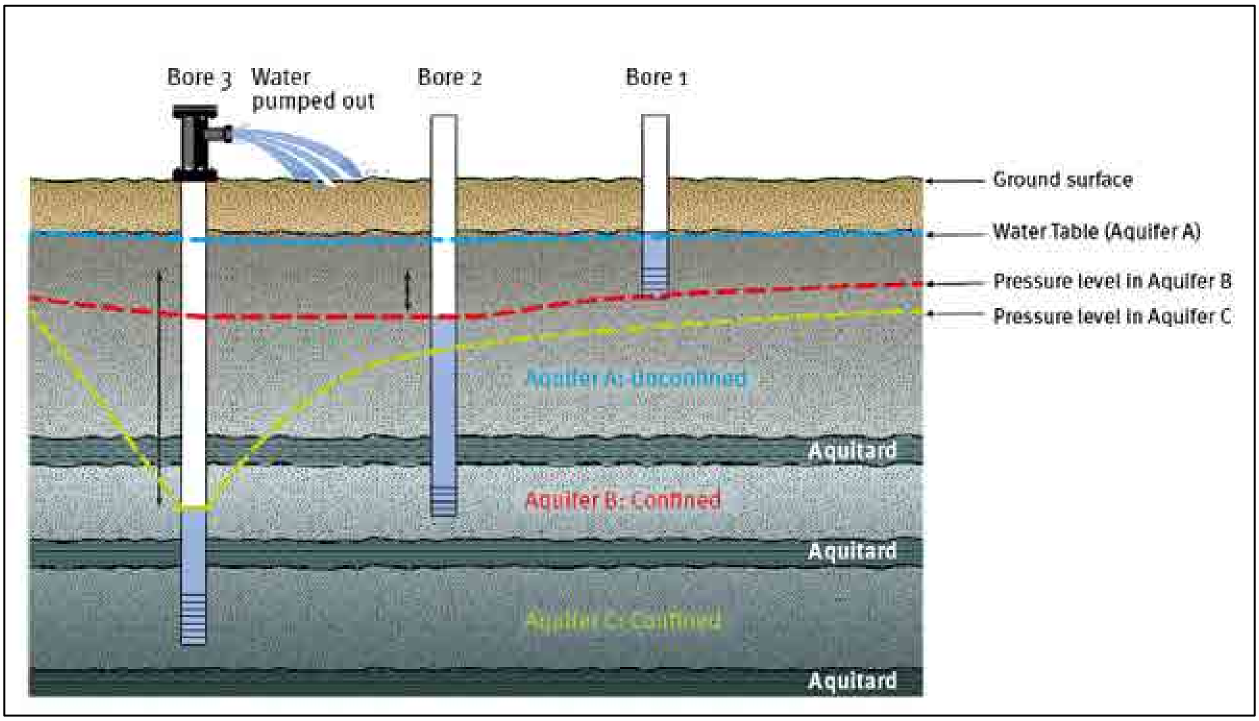

Figure D-3 Multilayered aquifer under post development conditions with depressurisation

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Appendix E. Details of private bores in Immediately Affected Areas

Table E-1 below provides details of authorised bores that as a result of UWIR 2016 are predicted to experience an impact of more than the trigger threshold of five metres within three years.

Table E-1 Additional bores identified in 2016 which are currently authorised

RN	Latitude	Longitude	Formation	Purpose	Current Responsible Tenure Holder
11590	-26.0765	149.5317	Walloon Coal Measures	Stock & Domestic	QGC
14533	-26.0904	149.4850	Walloon Coal Measures	Stock & Domestic	Origin
14595	-25.9794	149.6357	Walloon Coal Measures	Stock & Domestic	QGC
14596	-25.9956	149.6264	Walloon Coal Measures	Stock & Domestic	QGC
14618	-25.9562	149.5592	Walloon Coal Measures	Stock & Domestic	QGC
14632	-26.0530	149.6146	Walloon Coal Measures	Stock & Domestic	QGC
14888	-25.8795	149.7464	Walloon Coal Measures	Stock & Domestic	QGC
15784	-26.7815	150.5787	Walloon Coal Measures	Stock & Domestic	Origin
15820	-25.8568	149.7022	Walloon Coal Measures	Stock & Domestic	QGC
15831	-25.9844	149.8147	Walloon Coal Measures	Stock & Domestic	QGC
15855	-26.0829	149.8322	Walloon Coal Measures	Stock & Domestic	QGC
15892	-26.0643	149.7858	Walloon Coal Measures	Stock & Domestic	QGC
16040	-26.0595	149.7375	Walloon Coal Measures	Stock & Domestic	QGC
16119	-25.9993	149.5400	Walloon Coal Measures	Stock & Domestic	QGC
16855	-27.1466	151.0181	Walloon Coal Measures	Stock & Domestic	Arrow
18197	-25.9340	149.7917	Walloon Coal Measures	Stock & Domestic	QGC
24469	-26.8648	150.5992	Walloon Coal Measures	Stock & Domestic	Arrow
24478	-26.8158	150.5611	Walloon Coal Measures	Stock & Domestic	Origin
26429	-25.9534	149.7615	Walloon Coal Measures	Stock & Domestic	QGC
33830	-26.7488	150.5020	Walloon Coal Measures	Stock & Domestic	Origin
34709	-26.1143	149.6615	Walloon Coal Measures	Stock & Domestic	QGC
36143	-26.1386	149.3933	Walloon Coal Measures	Stock & Domestic	Origin
37949	-25.9931	149.5589	Walloon Coal Measures	Stock & Domestic	QGC
38191	-26.8466	150.5857	Walloon Coal Measures	Stock & Domestic	Arrow
44246	-26.0380	149.6406	Walloon Coal Measures	Stock & Domestic	QGC
48811	-25.9401	149.7956	Walloon Coal Measures	Stock & Domestic	QGC
55365	-27.1659	151.0698	Walloon Coal Measures	Stock & Domestic	Arrow
58005	-25.9168	149.7804	Walloon Coal Measures	Stock & Domestic	QGC
58064	-25.9898	149.6567	Walloon Coal Measures	Stock & Domestic	QGC
58077	-25.9979	149.5839	Walloon Coal Measures	Stock & Domestic	QGC
58079	-26.0518	149.6803	Walloon Coal Measures	Stock & Domestic	QGC
58304	-25.9032	149.7760	Walloon Coal Measures	Stock & Domestic	QGC
58537	-26.0356	149.6495	Walloon Coal Measures	Stock & Domestic	QGC
58541	-25.9734	149.5956	Walloon Coal Measures	Stock & Domestic	QGC
58612	-25.9909	149.5528	Walloon Coal Measures	Stock & Domestic	QGC
58768	-26.0877	149.6283	Walloon Coal Measures	Stock & Domestic	QGC
94135	-27.0403	150.9678	Walloon Coal Measures	Industrial	Arrow

RN	Latitude	Longitude	Formation	Purpose	Current Responsible Tenure Holder
119484	-26.8313	150.6036	Walloon Coal Measures	Stock & Domestic	Arrow
147108	-26.7504	150.5160	Walloon Coal Measures	Stock & Domestic	Origin
147393	-26.8097	150.5239	Walloon Coal Measures	Stock & Domestic	Origin
147832	-26.8131	150.5628	Walloon Coal Measures	Stock & Domestic	Origin

Table E-2 below provides details of bores that as a result of UWIR 2016 are predicted to experience an impact of more than the trigger threshold of five metres within three years, for which water licences are not current and therefore are not currently authorised under section 363 of the *Water Act 2000*.

Table E-2 Additional bores identified in 2016 which are not currently authorised

RN	Latitude	Longitude	Formation	Purpose	Current Responsible Tenure Holder
6505	-27.0842	151.0111	Walloon Coal Measures	Stock & Domestic	Arrow
13322	-26.1943	149.4997	Springbok Sandstone	Stock & Domestic	Origin
14648	-25.9939	149.5027	Walloon Coal Measures	Stock & Domestic	QGC
15992	-25.8660	149.6598	Walloon Coal Measures	Stock & Domestic	QGC
16022	-25.8624	149.6512	Walloon Coal Measures	Stock & Domestic	QGC
16191	-26.0287	149.7428	Walloon Coal Measures	Stock & Domestic	QGC
16552	-27.1044	151.0173	Walloon Coal Measures	Stock & Domestic	Arrow
22724	-26.4040	149.3069	Walloon Coal Measures	Stock & Domestic	Origin
23060	-27.0254	150.3614	Walloon Coal Measures	Stock & Domestic	QGC
23424	-26.9553	150.3977	Walloon Coal Measures	Stock & Domestic	QGC
23469	-27.0081	150.3456	Walloon Coal Measures	Stock & Domestic	QGC
34718	-26.0943	149.7313	Walloon Coal Measures	Stock & Domestic	QGC
34929	-26.0859	149.6997	Walloon Coal Measures	Stock & Domestic	QGC
43380	-25.9979	149.7178	Walloon Coal Measures	Stock & Domestic	QGC
58301	-25.9783	149.7127	Walloon Coal Measures	Stock & Domestic	QGC
58600	-26.0512	149.5344	Walloon Coal Measures	Stock & Domestic	QGC

Table E-3 below provides details of bores that were previously identified as IAA bores in the 2012 UWIR or added as a result of other processes and for which make good obligations are ongoing.

Table E-3 Details of IAA bores remaining from the UWIR 2012

RN	Latitude	Longitude	Formation	Purpose	Current Responsible Tenure Holder
12340	-26.7383	150.3675	Walloon Coal Measures	Stock & Domestic	QGC
12646	-27.0600	150.8610	Walloon Coal Measures	Stock & Domestic	Arrow
13117	-26.1861	149.2948	Walloon Coal Measures	Stock & Domestic	Origin
14219	-26.2081	149.3021	Walloon Coal Measures	Stock & Domestic	Origin
15810	-26.7665	150.3396	Walloon Coal Measures	Stock & Domestic	Origin
16102	-26.1913	149.5370	Walloon Coal Measures	Stock & Domestic	Origin
16135	-26.1548	149.6473	Walloon Coal Measures	Stock & Domestic	QGC
16943	-26.1725	149.4641	Walloon Coal Measures	Stock & Domestic	Origin
17414	-27.1388	150.9910	Walloon Coal Measures	Stock & Domestic	Arrow
24280	-27.4664	151.1799	Walloon Coal Measures	Stock & Domestic	Arrow
24288	-27.4290	151.1877	Walloon Coal Measures	Stock & Domestic	Arrow
24465	-26.8676	150.5499	Walloon Coal Measures	Stock & Domestic	Origin
30409	-26.7722	150.4496	Walloon Coal Measures	Stock & Domestic	Origin
30564	-26.2298	149.2268	Walloon Coal Measures	Stock & Domestic	Origin
32939	-26.2142	149.2025	Walloon Coal Measures	Stock & Domestic	Origin
33319	-27.0632	150.7945	Walloon Coal Measures	Stock & Domestic	QGC
33435	-26.1454	149.6124	Walloon Coal Measures	Stock & Domestic	QGC
34708	-26.1018	149.6656	Walloon Coal Measures	Stock & Domestic	QGC
34846	-26.8316	150.5511	Walloon Coal Measures	Stock & Domestic	Origin
35754	-26.1913	149.3494	Walloon Coal Measures	Stock & Domestic	Origin
37301	-26.1762	149.3286	Walloon Coal Measures	Stock & Domestic	Origin
43660	-26.1792	149.4123	Walloon Coal Measures	Stock & Domestic	Origin
44605	-26.0772	149.6596	Walloon Coal Measures	Stock & Domestic	QGC
48886	-26.2234	149.3442	Walloon Coal Measures	Stock & Domestic	Origin
48965	-26.1507	149.6401	Walloon Coal Measures	Stock & Domestic	QGC
58253	-26.2259	149.2492	Walloon Coal Measures	Stock & Domestic	Origin
58288	-26.2568	149.2433	Walloon Coal Measures	Stock & Domestic	Origin
58435	-26.1795	149.2179	Walloon Coal Measures	Stock & Domestic	Origin
58646	-26.1723	149.3680	Walloon Coal Measures	Stock & Domestic	Origin
87471	-27.1559	151.0046	Walloon Coal Measures	Agriculture	Arrow
87611	-26.7632	150.4859	Walloon Coal Measures	Stock & Domestic	Origin
107910	-27.0896	150.9214	Walloon Coal Measures	Stock & Domestic	Arrow
119267	-27.1094	150.9111	Walloon Coal Measures	Industrial	QGC
137175	-27.1232	150.8189	Walloon Coal Measures	Agriculture	QGC

Table E-4 below provides details of bores that are located within the IAA for the Walloon Coal Measures but which are not predicted to experience an impact of more than the trigger threshold of five metres within three years, because of the shallow penetration of the bores into the formation.

Table E-4 Shallow bores in the IAA not affected in the short term

RN	Latitude	Longitude	Formation	Purpose	Current Responsible Tenure Holder
8666	-26.8454	150.66208	Walloon Coal Measures	Stock & Domestic	Arrow
10678	-26.8919	150.64935	Walloon Coal Measures	Stock & Domestic	Arrow
10790	-26.9053	150.66009	Walloon Coal Measures	Stock & Domestic	Arrow
10898	-26.8332	150.64452	Walloon Coal Measures	Stock & Domestic	Arrow
11751	-26.8451	150.61971	Walloon Coal Measures	Stock & Domestic	Arrow
13600	-26.8337	150.61764	Walloon Coal Measures	Stock & Domestic	Arrow
14361	-25.9311	149.47058	Walloon Coal Measures	Stock & Domestic	QGC
15052	-27.0734	151.00755	Walloon Coal Measures	Stock & Domestic	Arrow
15118	-26.8128	150.63774	Walloon Coal Measures	Stock & Domestic	Arrow
15811	-26.9226	150.66221	Walloon Coal Measures	Stock & Domestic	Arrow
15828	-26.0756	149.83694	Walloon Coal Measures	Stock & Domestic	QGC
15832	-26.8873	150.6786	Walloon Coal Measures	Stock & Domestic	Arrow
15868	-26.9141	150.67406	Walloon Coal Measures	Stock & Domestic	Arrow
16708	-27.0632	151.01292	Walloon Coal Measures	Stock & Domestic	Arrow
17301	-26.9255	150.67836	Walloon Coal Measures	Stock & Domestic	Arrow
17322	-26.888	150.67692	Walloon Coal Measures	Stock & Domestic	Arrow
19951	-26.8475	150.66297	Walloon Coal Measures	Stock & Domestic	Arrow
19988	-26.8515	150.64746	Walloon Coal Measures	Stock & Domestic	Arrow
19997	-26.8317	150.65991	Walloon Coal Measures	Stock & Domestic	Arrow
23150	-27.3931	150.73194	Walloon Coal Measures	Stock & Domestic	QGC
24466	-26.9323	150.6403	Walloon Coal Measures	Stock & Domestic	Arrow
24467	-26.8825	150.60426	Walloon Coal Measures	Agriculture	Arrow
24479	-26.8922	150.61626	Walloon Coal Measures	Agriculture	Arrow
24480	-26.765	150.60086	Walloon Coal Measures	Stock & Domestic	Arrow
24485	-26.8868	150.66335	Walloon Coal Measures	Stock & Domestic	Arrow
24524	-26.7375	150.56953	Walloon Coal Measures	Stock & Domestic	Origin
26082	-26.8054	150.57394	Walloon Coal Measures	Stock & Domestic	Origin
34651	-26.7386	150.5222	Walloon Coal Measures	Stock & Domestic	Origin
35141	-27.1824	151.05	Walloon Coal Measures	Stock & Domestic	Arrow
35405	-27.0287	150.96704	Walloon Coal Measures	Stock & Domestic	Arrow
35623	-27.1989	151.0694	Walloon Coal Measures	Stock & Domestic	Arrow
58129	-26.1063	149.83677	Walloon Coal Measures	Stock & Domestic	QGC
61172	-27.0483	150.95661	Walloon Coal Measures	Stock & Domestic	Arrow
66152	-26.9263	150.68839	Walloon Coal Measures	Stock & Domestic	Arrow
87718	-26.825	150.62434	Walloon Coal Measures	Stock & Domestic	Arrow
87835	-27.0092	150.95848	Walloon Coal Measures	Stock & Domestic	Arrow
94738	-26.7658	150.60934	Walloon Coal Measures	Stock & Domestic	Arrow

RN	Latitude	Longitude	Formation	Purpose	Current Responsible Tenure Holder
94831	-27.1957	151.053	Walloon Coal Measures	Stock & Domestic	Arrow
107260	-26.6321	150.46162	Walloon Coal Measures	Stock & Domestic	Arrow
107739	-26.8875	150.61118	Walloon Coal Measures	Agriculture	Arrow
107868	-26.8937	150.65295	Walloon Coal Measures	Stock & Domestic	Arrow
107873	-27.0044	150.95637	Walloon Coal Measures	Agriculture	Arrow
119048	-27.0514	150.99217	Walloon Coal Measures	Stock & Domestic	Arrow
147001	-26.8622	150.66355	Walloon Coal Measures	Agriculture	Arrow
147607	-26.9337	150.65748	Walloon Coal Measures	Stock & Domestic	Arrow

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Appendix F. Drawdown patterns for long-term impacts

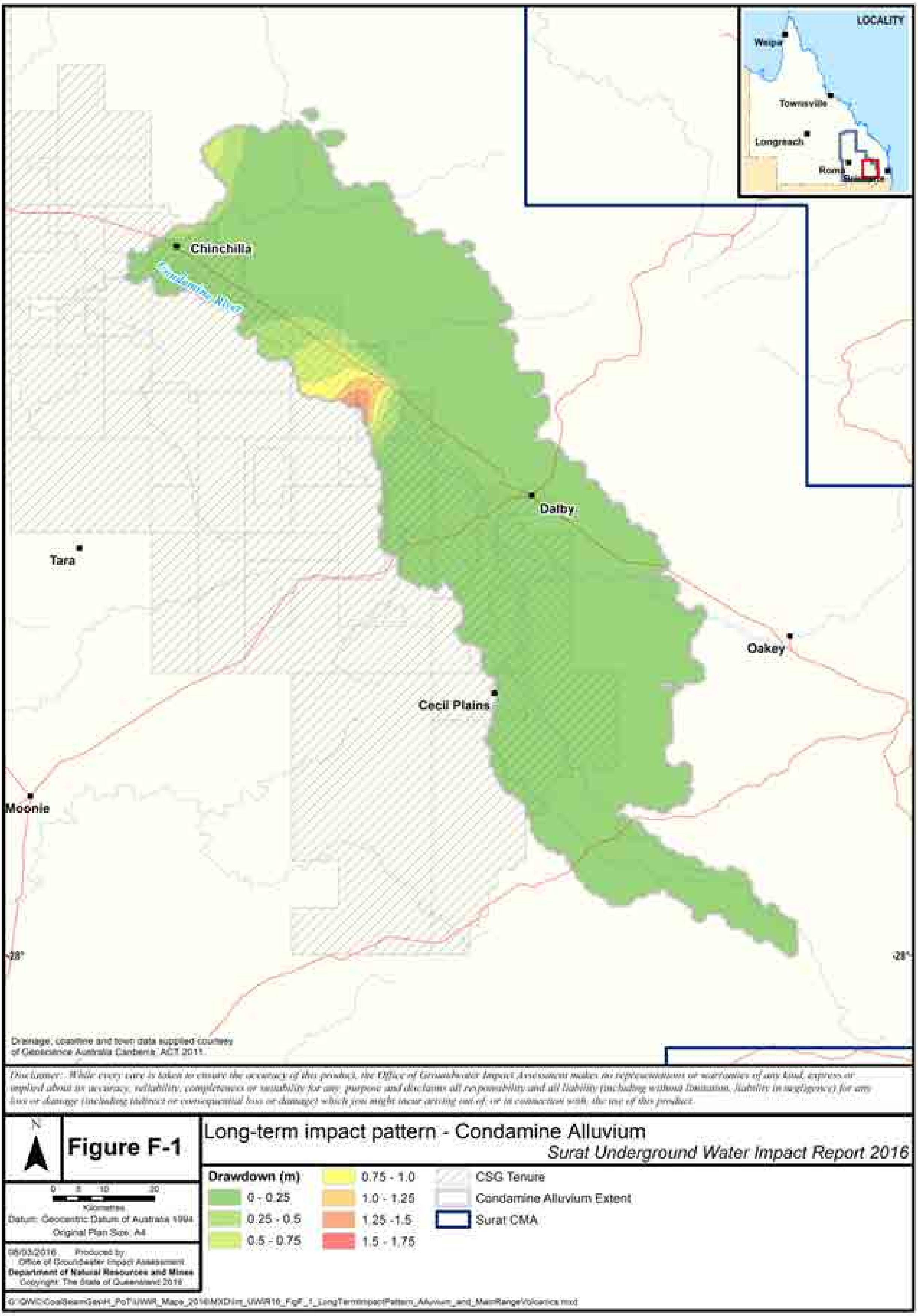


Figure F-1 Long-term impact pattern – Condamine Alluvium

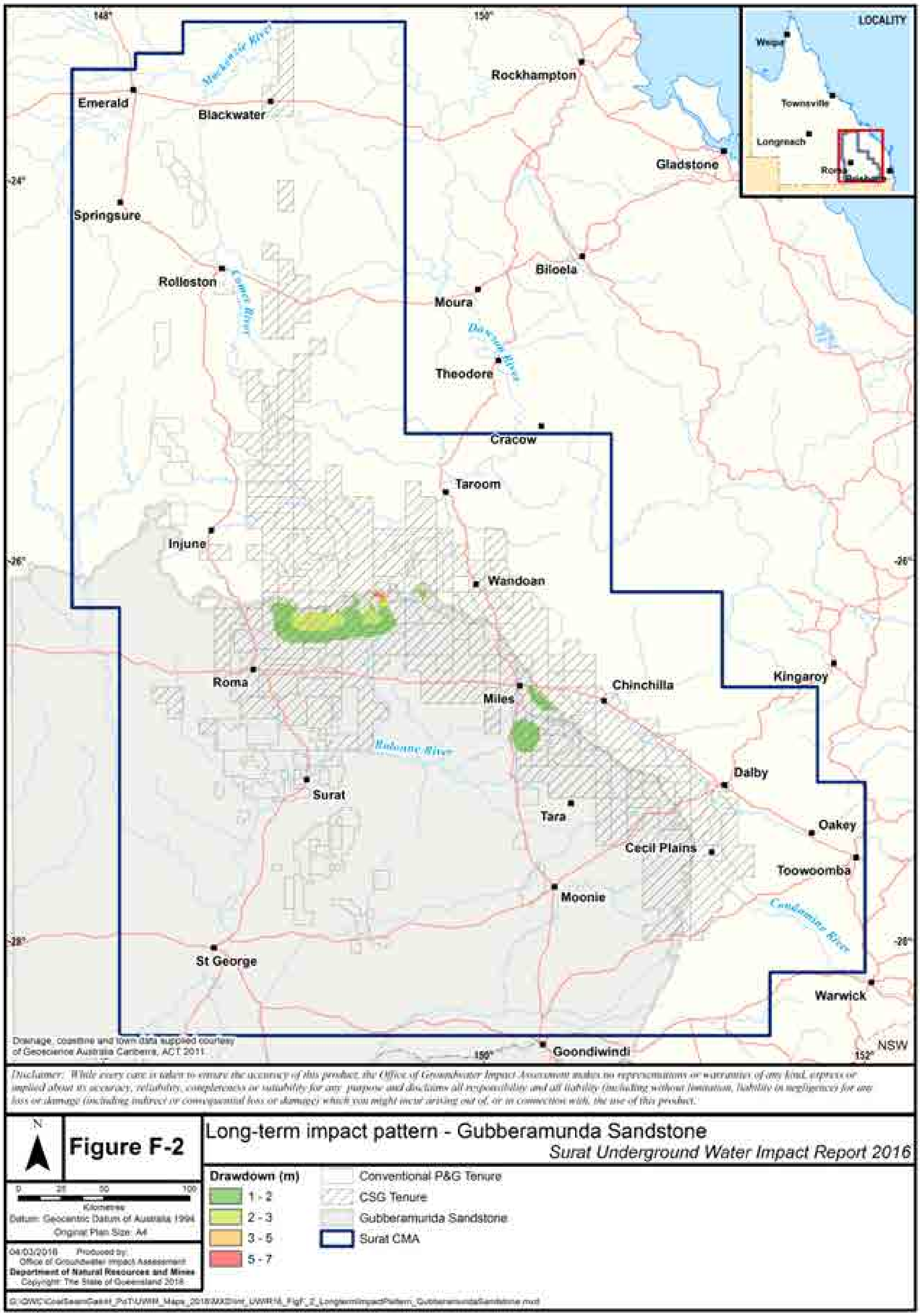


Figure F-2 Long-term impact pattern – Gubberamunda Sandstone

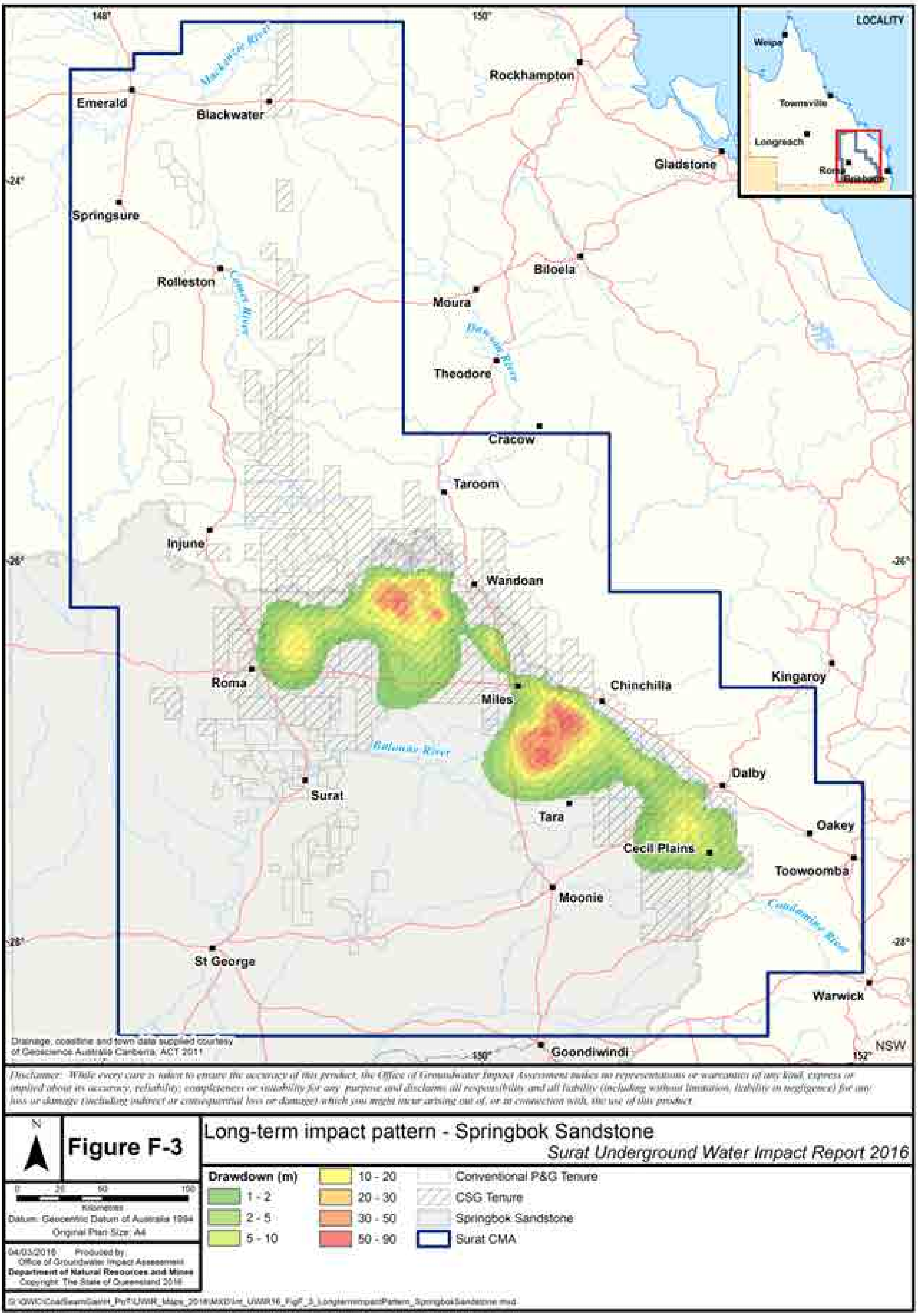


Figure F-3 Long-term impact pattern – Springbok Sandstone

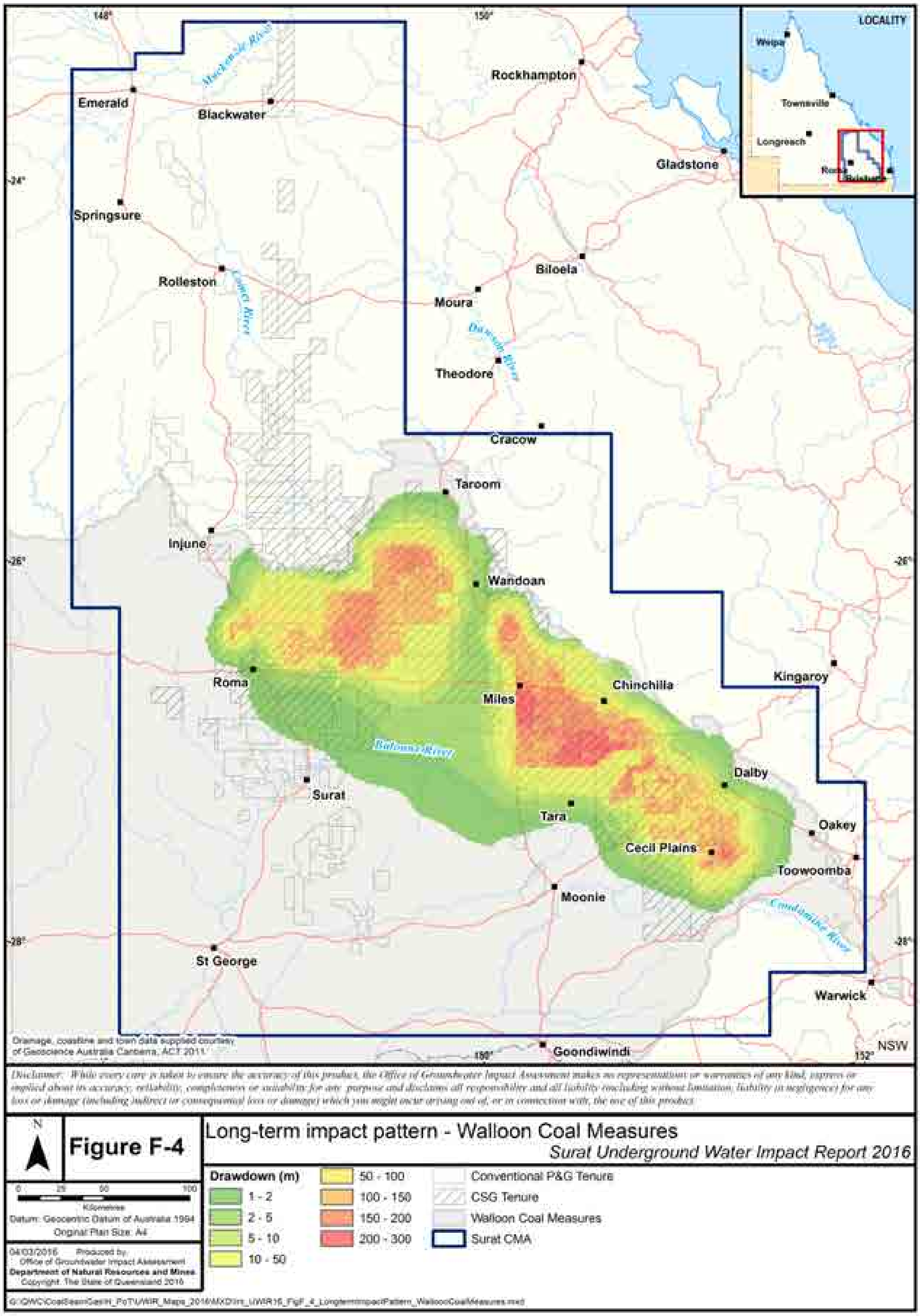


Figure F-4 Long-term impact pattern – Walloon Coal Measures

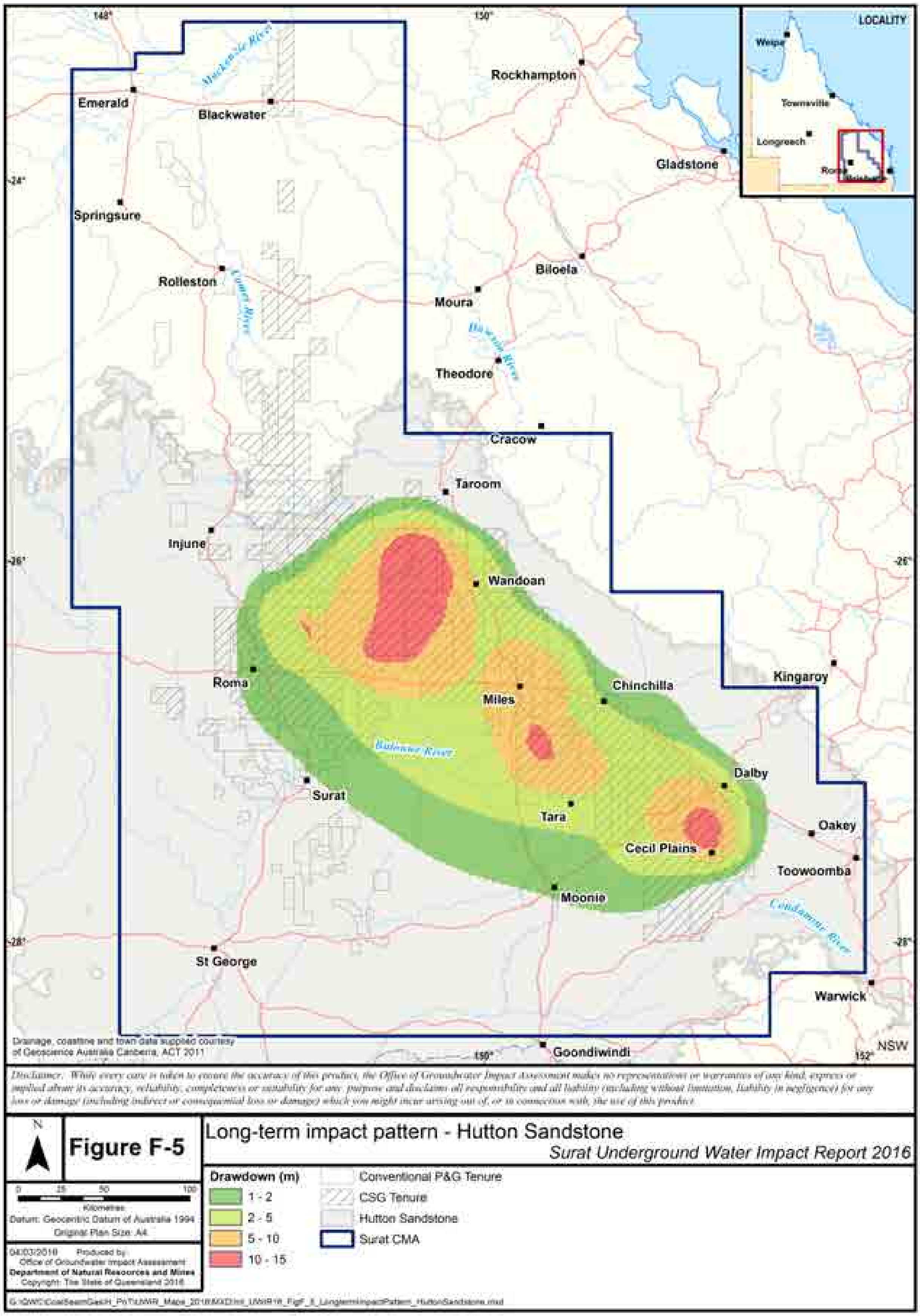


Figure F-5 Long-term impact pattern – Hutton Sandstone

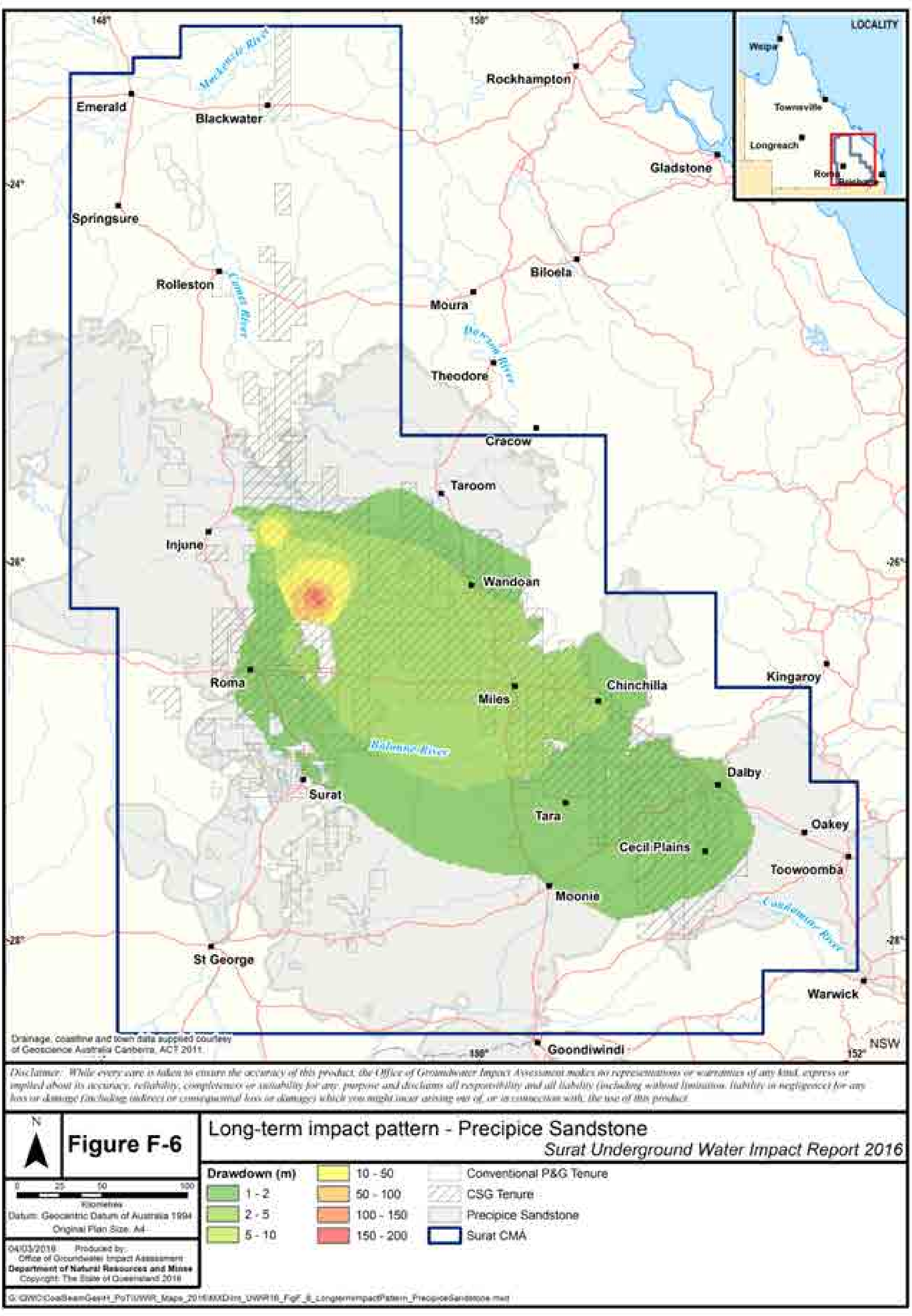


Figure F-6 Long-term impact pattern – Precipice Sandstone

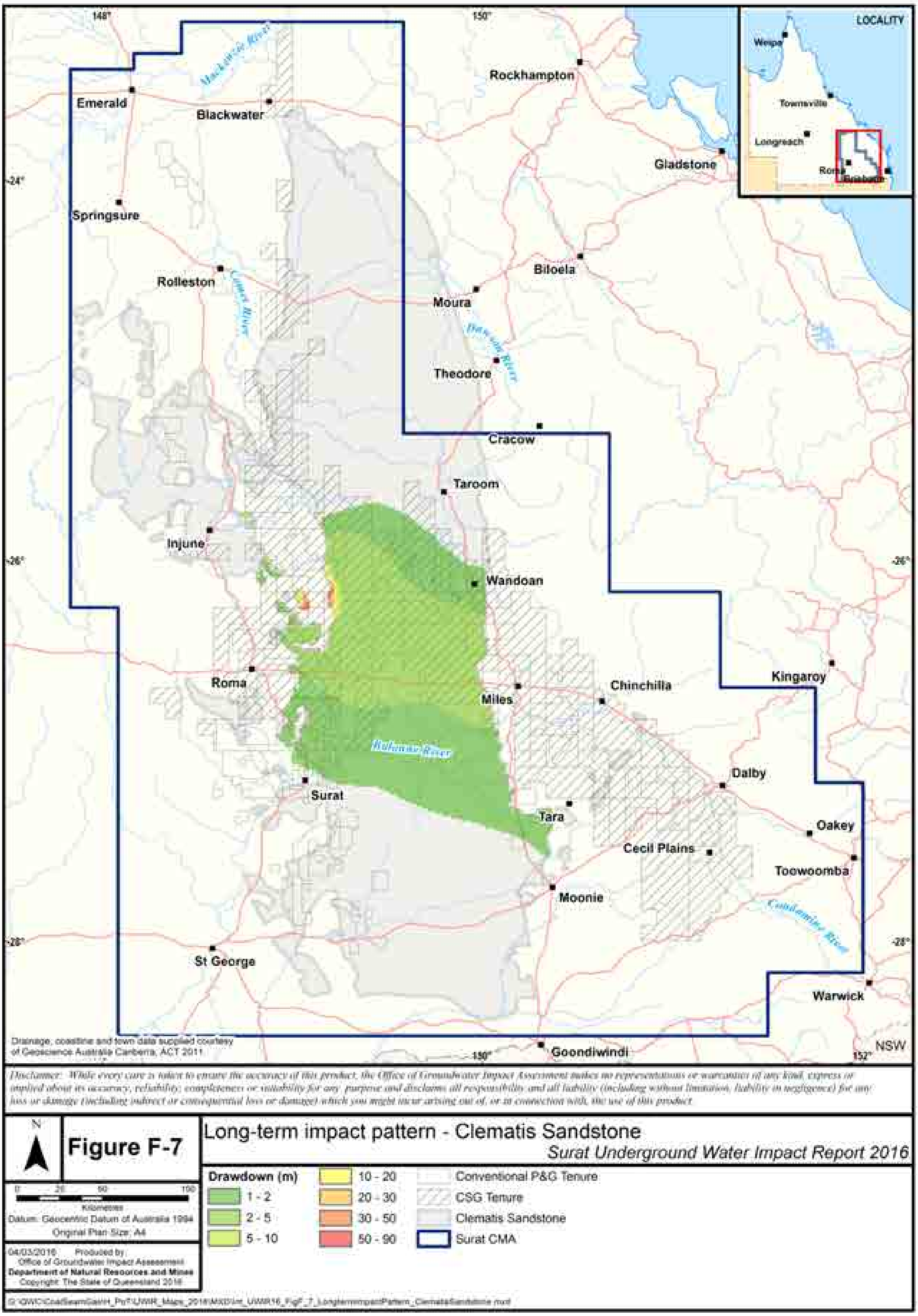


Figure F-7 Long-term impact pattern – Clematis Sandstone

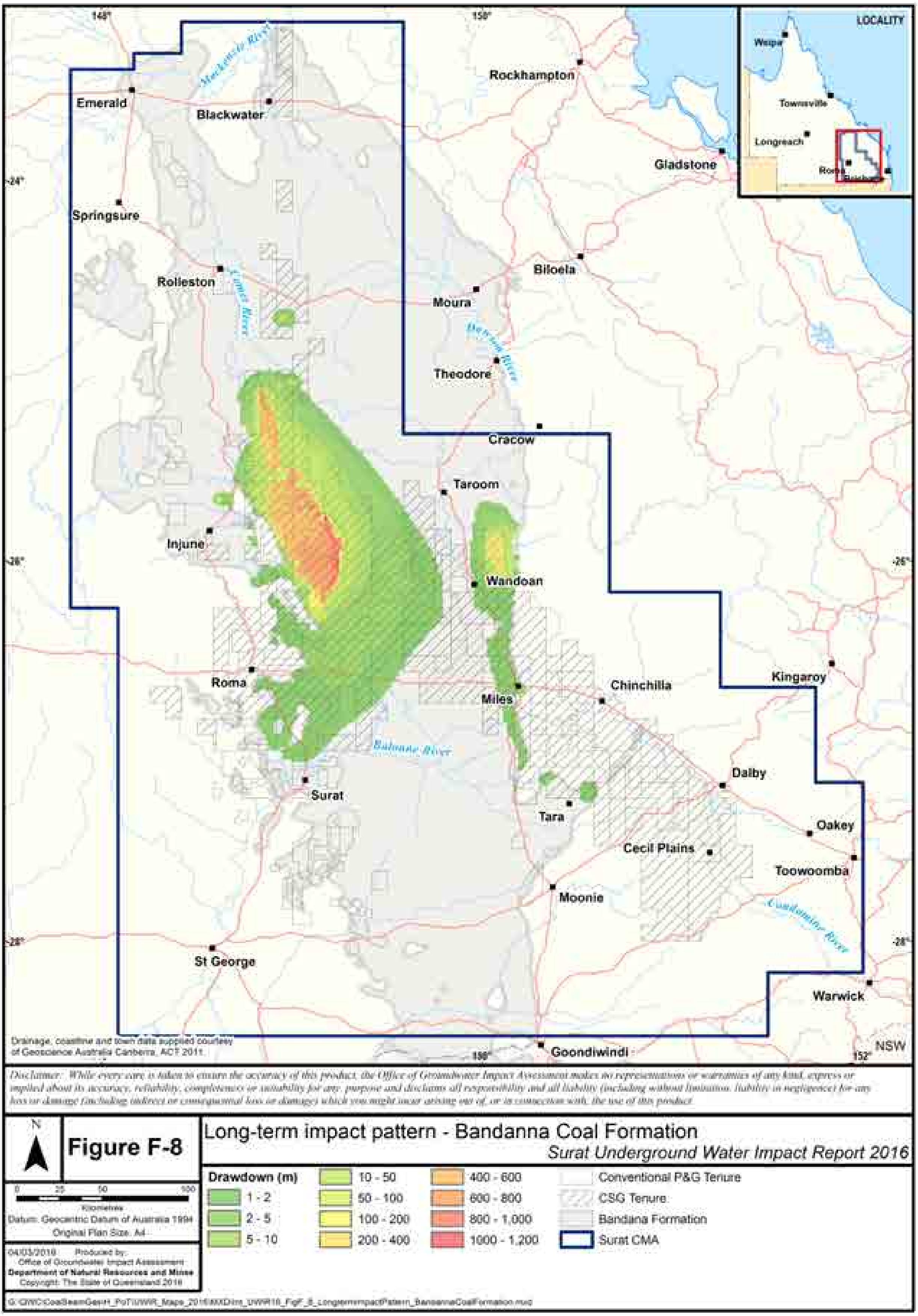


Figure F-8 Long-term impact pattern – Bandanna Formation

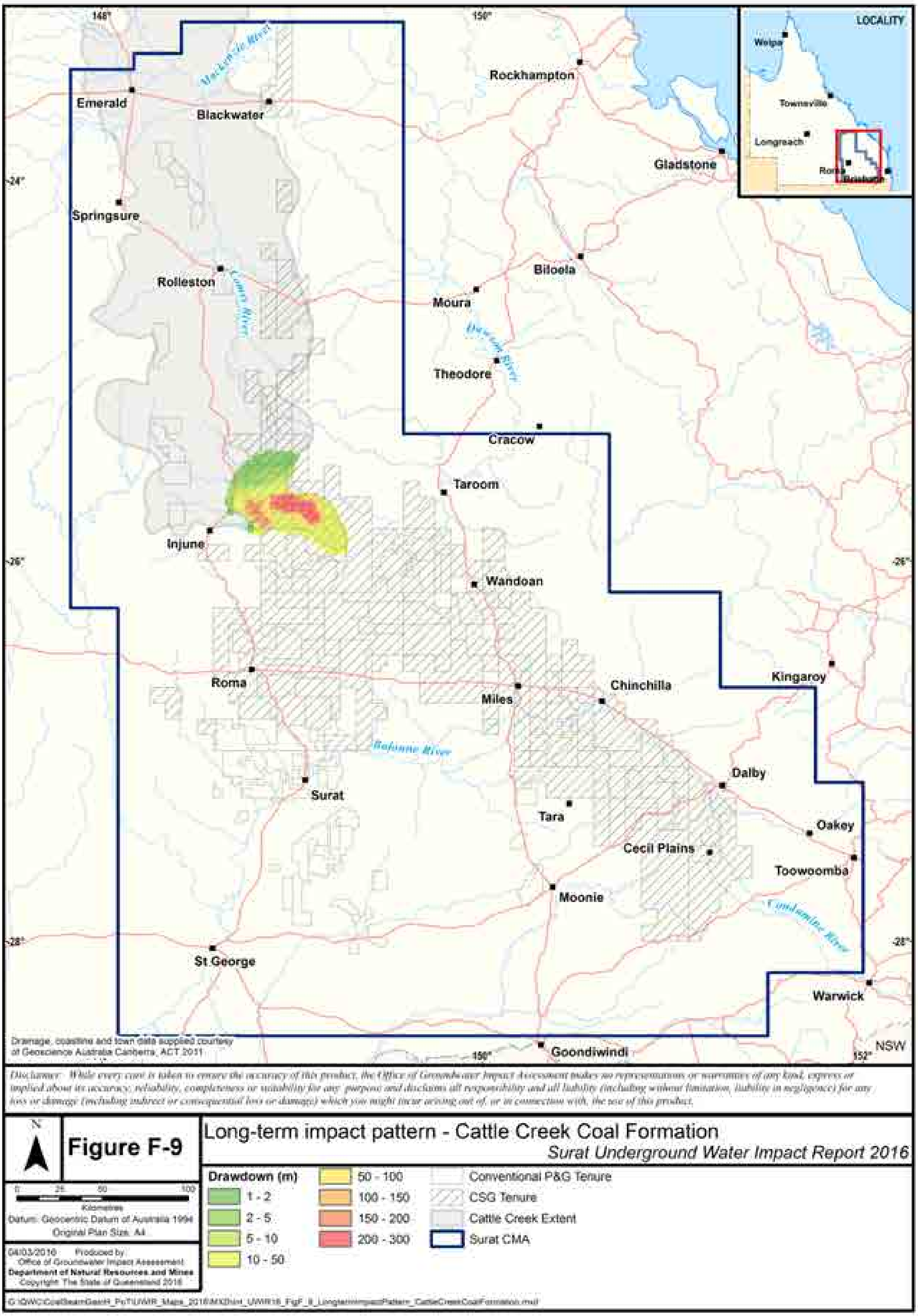


Figure F-9 Long-term impact pattern – Cattle Creek Formation

Appendix G. Regional monitoring network

Appendix G-1 Regional groundwater monitoring network

The Water Monitoring Strategy (WMS) is described in Chapter 8 of the UWIR. Table G-1 provides details of the regional monitoring network described in Section 8.3.1. The following explanations apply to this table:

Monitoring point no: The monitoring point number assigned by OGIA.

Status: ‘Existing’ means that as a minimum, the drilling phase of the installation has been completed.

‘Proposed’ means that drilling has not yet commenced.

‘Other existing’ means monitoring point installations which have typically already been completed by tenure holders for other monitoring purposes and have been incorporated into the monitoring network. In some cases, these are private bores equipped for monitoring purposes by tenure holders.

‘Not required’ means OGIA no longer requires the monitoring point. There are several reasons why a monitoring point may no longer be required at the specified location including: i) the target formation is absent; ii) a reduction in the area of predicted impact in the formation and/or iii) the use of other nearby monitoring points to meet the monitoring need.

‘Completed’ means the installation of the monitoring point has been completed.

Target formation: The geological units where monitoring is occurring or will be targeted.

Water pressure monitoring frequency: The required frequency of pressure monitoring at the specified location.

Water quality monitoring frequency: The required frequency of water quality monitoring at the specified location. Table G-3 provides the details of the water quality suite for monitoring.

Required by: The required completion date for the installation and commencement of data recording at the monitoring location. ‘2 years prior to production within 10km’ means the specified monitoring is required two years prior to production by the RTH on a sub-block within 10km of the specified location. The need for these installations will be triggered based on the tenure holder’s annual development plans.

Responsible tenure holder (RTH): The current responsible tenure holder for the required monitoring based on tenure ownership information as at December 2015. In the event that ownership of the tenure changes then the tenure holder responsibilities for monitoring will be transferred.

UWIR site no: The site number assigned by OGIA.

Table G-1 Regional Groundwater Monitoring Network

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
1	160541A	-27.9667	150.9196	Existing	Gubberamunda Sandstone	Fortnightly		Completed	APLNG	1
2	160541A	-27.9667	150.9196	Existing	Gubberamunda Sandstone		six-monthly	Completed	APLNG	1
3	ZigZag-MB4-S	-27.9651	150.9236	Existing	Springbok Sandstone	Fortnightly		Dec 2016	APLNG	1
4	ZigZag-MB4-S	-27.9651	150.9236	Existing	Springbok Sandstone		six-monthly	Dec 2016	APLNG	1
5	160797C	-27.9650	150.9231	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	1
6	160797B	-27.9650	150.9231	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	1
7	160797A	-27.9650	150.9231	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	1
8	160670A	-27.7948	150.9438	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	2
9	160670A	-27.7948	150.9438	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	2
10	160798C	-27.7942	150.9458	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	2
11	160798B	-27.7942	150.9458	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	2
12	160798A	-27.7942	150.9458	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	2
13	160724A	-27.7948	150.9443	Existing	Hutton Sandstone	Fortnightly		Completed	APLNG	2
14	3 GW1	-27.6820	150.6830	Proposed	Springbok Sandstone	Fortnightly		2017	QGC	3
15		-27.6820	150.6830	Not required	Springbok Sandstone					3
16	3 GW1	-27.6820	150.6830	Proposed	Upper Juandah Coal Measures	Fortnightly		2017	QGC	3
17	3 GW1	-27.6820	150.6830	Proposed	Lower Juandah Coal Measures	Fortnightly		2017	QGC	3
18	3 GW1	-27.6820	150.6830	Proposed	Taroom Coal Measures	Fortnightly		2017	QGC	3
19	3 GW1	-27.6820	150.6830	Proposed	Hutton Sandstone	Fortnightly		2017	QGC	3
20	3 GW1	-27.6820	150.6830	Proposed	Hutton Sandstone		six-monthly	2017	QGC	3

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
21		-27.6820	150.6830	Proposed	Precipice Sandstone	Fortnightly		If impact in Hutton	QGC	3
22		-27.6820	150.6830	Not required	Precipice Sandstone					3
23	160633A	-27.6390	151.1676	Existing	Walloon Coal Measures	Fortnightly		Completed	Arrow	4
24	42230088A	-27.5898	151.2342	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	5
25	Pampas-5	-27.5889	151.2423	Proposed	Taroom Coal Measures	Fortnightly		Dec 2016	Arrow	5
26	160554A	-27.5973	150.8963	Existing	Gubberamunda Sandstone	Fortnightly		Completed	APLNG	6
27	160554A	-27.5973	150.8963	Existing	Gubberamunda Sandstone		six-monthly	Completed	APLNG	6
28	160728A	-27.5975	150.8964	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	6
29	160728A	-27.5975	150.8964	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	6
30	160752C	-27.5983	150.8988	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	6
31	160752B	-27.5983	150.8988	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	6
32	160752A	-27.5983	150.8988	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	6
33	160732A	-27.5779	151.1338	Existing	Juandah and Taroom Coal Measures	Fortnightly		Completed	Arrow	7
34	Meenawarra-21	-27.5798	151.1335	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Dec 2016	Arrow	7
35	Meenawarra-21	-27.5798	151.1335	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Dec 2016	Arrow	7
36	Meenawarra-21	-27.5798	151.1335	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Dec 2016	Arrow	7
619		-27.5780	151.1340	Proposed	Springbok Sandstone	Fortnightly		2018	Arrow	7
37	42231463A	-27.5488	151.3130	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	8
38	160657A	-27.5330	151.3665	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	8
39	160657A	-27.5330	151.3665	Existing	Condamine Alluvium		six-monthly	Completed	Arrow	8
40	160688C	-27.5330	151.3663	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	Arrow	8

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
41	160688C	-27.5330	151.3663	Existing	Coal seam of the Lower Juandah Coal Measures		six-monthly	Completed	Arrow	8
42	160688B	-27.5330	151.3663	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	Arrow	8
43	160688A	-27.5330	151.3663	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	Arrow	8
44	160689B	-27.5330	151.3662	Existing	Hutton Sandstone	Fortnightly		Completed	Arrow	8
45	160689B	-27.5330	151.3662	Existing	Hutton Sandstone		six-monthly	Completed	Arrow	8
46	160689A	-27.5330	151.3662	Existing	Evergreen Formation	Fortnightly		Completed	Arrow	8
47	160632A	-27.5330	151.3660	Existing	Precipice Sandstone	Fortnightly		Completed	Arrow	8
48	160632A	-27.5330	151.3660	Existing	Precipice Sandstone		six-monthly	Completed	Arrow	8
49	42231339A	-27.5306	151.5037	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	9
50	42231340A	-27.5318	151.5148	Existing	Walloon Coal Measures	Fortnightly		Completed	Arrow	9
51	42231370A	-27.4915	151.3932	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	10
52	42231370A	-27.4915	151.3932	Existing	Condamine Alluvium		six-monthly	Completed	Arrow	10
53		-27.4915	151.3932	Not required	Condamine Alluvium - Walloon transition layer/Springbok					10
54		-27.4915	151.3932	Not required	Coal seam of the Upper Juandah Coal Measures					10
55		-27.4915	151.3932	Not required	Coal seam of the Lower Juandah Coal Measures					10
56		-27.4915	151.3932	Not required	Coal seam of the Taroom Coal Measures					10
57	160810A	-27.4675	150.6165	Existing	Gubberamunda Sandstone	Fortnightly		Completed	QGC	11
58	160672F	-27.4675	150.6166	Existing	Springbok Sandstone	Fortnightly		Completed	QGC	11
59	160672E	-27.4675	150.6166	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	QGC	11
60	160672D	-27.4675	150.6166	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	QGC	11
61	160672C	-27.4675	150.6166	Existing	Taroom Coal Measures	Fortnightly		Completed	QGC	11
62	160672B	-27.4675	150.6166	Existing	Hutton Sandstone	Fortnightly		Completed	QGC	11
63	160672A	-27.4675	150.6166	Existing	Precipice Sandstone	Fortnightly		Completed	QGC	11

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
64	160811A	-27.3630	151.0419	Existing	Gubberamunda Sandstone	Fortnightly		Completed	QGC	12
65	Harry GW1	-27.3661	151.0316	Existing	Westbourne Formation	Fortnightly		Mar 2016	QGC	12
66	Harry GW1	-27.3661	151.0316	Existing	Springbok Sandstone	Fortnightly		Mar 2016	QGC	12
67	Harry GW1	-27.3661	151.0316	Existing	Upper Juandah Coal Measures	Fortnightly		Mar 2016	QGC	12
68	Harry GW1	-27.3661	151.0316	Existing	Lower Juandah Coal Measures	Fortnightly		Mar 2016	QGC	12
69	Harry GW1	-27.3661	151.0316	Existing	Taroom Coal Measures	Fortnightly		Mar 2016	QGC	12
70	Harry GW1	-27.3661	151.0316	Existing	Hutton Sandstone	Fortnightly		Mar 2016	QGC	12
71		-27.4074	151.1404	Not required	Juandah & Taroom Coal Measures					13
72	160799C	-27.3981	151.0889	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	Arrow	13
73	160799B	-27.3981	151.0889	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	Arrow	13
74	160799A	-27.3981	151.0889	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	Arrow	13
75	42231294A	-27.3993	151.5484	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	14
76	42231295A	-27.3975	151.5619	Existing	Walloon Coal Measures	Fortnightly		Completed	Arrow	14
77	160735A	-27.3858	151.2165	Existing	Juandah Coal Measures	Fortnightly		Completed	Arrow	15
78	160696A	-27.3627	150.8242	Existing	Gubberamunda Sandstone	Fortnightly		Completed	QGC	16
79	Cougals GW13	-27.3627	150.8241	Existing	Springbok Sandstone	Fortnightly		Mar 2016	QGC	16
80	Cougals GW13	-27.3627	150.8241	Existing	Upper Juandah Coal Measures	Fortnightly		Mar 2016	QGC	16
81	Cougals GW13	-27.3627	150.8241	Existing	Lower Juandah Coal Measures	Fortnightly		Mar 2016	QGC	16
82	Cougals GW13	-27.3627	150.8241	Existing	Taroom Coal Measures	Fortnightly		Mar 2016	QGC	16
83	160731A	-27.3431	151.1242	Existing	Juandah Coal Measures	Fortnightly		Completed	Arrow	17
620	Tipton 153	-27.3586	151.1531	Other existing	Hutton Sandstone	Fortnightly		2018	Arrow	17
84	160717A	-27.3205	151.2054	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	18

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
85	160717A	-27.3205	151.2054	Existing	Condamine Alluvium		six-monthly	Completed	Arrow	18
86	160750A	-27.3202	151.2050	Existing	Condamine Alluvium - Walloon transition layer	Fortnightly		Completed	Arrow	18
87		-27.3134	151.1986	Not required	Juandah & Taroom Coal Measures					18
88	160751C	-27.3202	151.2053	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	Arrow	18
89	160751C	-27.3202	151.2053	Existing	Coal seam of the Upper Juandah Coal Measures		six-monthly	Completed	Arrow	18
90	160751B	-27.3202	151.2053	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	Arrow	18
91	160751A	-27.3202	151.2053	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	Arrow	18
92	Carn Brea 21	-27.3870	151.3270	Proposed	Condamine Alluvium	Fortnightly		Mar 2016	Arrow	19
93	Carn Brea 21	-27.3870	151.3270	Proposed	Condamine Alluvium - Walloon transition layer	Fortnightly		Mar 2016	Arrow	19
94	Carn Brea 21	-27.3870	151.3270	Proposed	Lower Juandah Coal Measures	Fortnightly		Mar 2016	Arrow	19
621		-27.3870	151.3270	Proposed	Springbok Sandstone	Fortnightly		2018	Arrow	19
95	160695A	-27.2990	150.6368	Existing	Gubberamunda Sandstone	Fortnightly		Completed	QGC	20
96	160562D	-27.2990	150.6369	Existing	Springbok Sandstone	Fortnightly		Completed	QGC	20
97	160562C	-27.2990	150.6369	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	QGC	20
98	160562B	-27.2990	150.6369	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	QGC	20
99	160562A	-27.2990	150.6369	Existing	Taroom Coal Measures	Fortnightly		Completed	QGC	20
662	Will GW3	-27.2974	150.6371	Proposed	Hutton Sandstone	Fortnightly		2018	QGC	20
100	160674A	-27.2743	151.0648	Existing	Condamine Alluvium	Fortnightly		Completed	QGC	21
101	160635A	-27.2714	151.0705	Existing	Springbok Sandstone	Fortnightly		Completed	QGC	21
102	160635A	-27.2714	151.0705	Existing	Springbok Sandstone		six-monthly	Completed	QGC	21
103	160599C	-27.2713	151.0703	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	QGC	21
104	160599B	-27.2713	151.0703	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	QGC	21

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
105	160599A	-27.2713	151.0703	Existing	Taroom Coal Measures	Fortnightly		Completed	QGC	21
106	160600A	-27.2714	151.0704	Existing	Hutton Sandstone	Fortnightly		Completed	QGC	21
107	160600A	-27.2714	151.0704	Existing	Hutton Sandstone		six-monthly	Completed	QGC	21
108		-27.2673	151.0676	Not required	Precipice Sandstone					21
109		-27.2673	151.0676	Not required	Precipice Sandstone					21
110	Ironbark MB3-S	-27.2414	150.3420	Proposed	Springbok Sandstone	Fortnightly		2 years prior to production within 10km	APLNG	22
111	Ironbark MB3-S	-27.2414	150.3420	Proposed	Springbok Sandstone		six-monthly	2 years prior to production within 10km	APLNG	22
112	Ironbark MB4-W	-27.2412	150.3404	Proposed	Coal seam of the Upper Juandah Coal Measures	Fortnightly		2 years prior to production within 10km	APLNG	22
113	Ironbark MB4-W	-27.2412	150.3404	Proposed	Coal seam of the Lower Juandah Coal Measures	Fortnightly		2 years prior to production within 10km	APLNG	22
114	Ironbark MB4-W	-27.2412	150.3404	Proposed	Coal seam of the Taroom Coal Measures	Fortnightly		2 years prior to production within 10km	APLNG	22

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
115	Ironbark MB5-H	-27.2412	150.3408	Proposed	Hutton Sandstone	Fortnightly		2 years prior to production within 10km	APLNG	22
116	Ironbark MB5-H	-27.2412	150.3408	Proposed	Hutton Sandstone		six-monthly	2 years prior to production within 10km	APLNG	22
117		-27.2800	150.3300	Not required	Precipice Sandstone					22
118		-27.2800	150.3300	Not required	Precipice Sandstone					22
631		-27.2410	150.3410	Proposed	Gubberamunda Sandstone	Fortnightly		2 years prior to production within 10km	APLNG	22
119	160800C	-27.2520	151.2924	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	23
120	160800B	-27.2520	151.2924	Existing	Condamine Alluvium - Walloon transition layer	Fortnightly		Completed	Arrow	23
121	160800A	-27.2520	151.2924	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	Arrow	23
122	160639A	-27.2591	150.9374	Existing	Gubberamunda Sandstone	Fortnightly		Completed	QGC	24
123	160639A	-27.2591	150.9374	Existing	Gubberamunda Sandstone		six-monthly	Completed	QGC	24
124	160638F	-27.2638	150.9684	Existing	Springbok Sandstone	Fortnightly		Completed	QGC	24
125	160638D	-27.2638	150.9684	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	QGC	24
126	160638C	-27.2638	150.9684	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	QGC	24
127	160638A	-27.2638	150.9684	Existing	Taroom Coal Measures	Fortnightly		Completed	QGC	24
128		-27.2439	150.4559	Not required	Gubberamunda Sandstone					25
129		-27.2439	150.4559	Not required	Springbok Sandstone					25

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
130		-27.2439	150.4559	Not required	Coal seam of the Upper Juandah Coal Measures					25
131		-27.2439	150.4559	Not required	Coal seam of the Lower Juandah Coal Measures					25
132		-27.2439	150.4559	Not required	Coal seam of the Taroom Coal Measures					25
133	160685A	-27.1663	150.8642	Existing	Springbok Sandstone	Fortnightly		Completed	QGC	26
134	Jordan 14	-27.1606	150.6773	Existing	Upper Juandah Coal Measures	Fortnightly		Mar 2016	QGC	26
135	Jordan 14	-27.1606	150.6773	Existing	Lower Juandah Coal Measures	Fortnightly		Mar 2016	QGC	26
136	Jordan 14	-27.1606	150.6773	Existing	Taroom Coal Measures	Fortnightly		Mar 2016	QGC	26
137	160439A	-27.1663	150.8641	Existing	Hutton Sandstone	Fortnightly		Completed	QGC	26
663		-27.1660	150.8640	Proposed	Gubberamunda Sandstone	Fortnightly		2018	QGC	26
664		-27.1660	150.8640	Proposed	Gubberamunda Sandstone		six-monthly	2018	QGC	26
138		-27.1952	151.3179	Proposed	Condamine Alluvium	Fortnightly		Dec 2016	Arrow	27
139		-27.1952	151.3179	Proposed	Condamine alluvium - Walloon transition layer	Fortnightly		Dec 2016	Arrow	27
140		-27.1952	151.3179	Proposed	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Dec 2016	Arrow	27
141		-27.1952	151.3179	Proposed	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Dec 2016	Arrow	27
142		-27.1952	151.3179	Proposed	Coal seam of the Taroom Coal Measures	Fortnightly		Dec 2016	Arrow	27
143		-27.1793	151.1249	Not required	Springbok Sandstone					28
144		-27.1793	151.1249	Not required	Springbok Sandstone					28
145	Longswamp-7	-27.1843	151.1274	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Dec 2016	Arrow	28
146	Longswamp-7	-27.1843	151.1274	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Dec 2016	Arrow	28
147	Longswamp-8	-27.1843	151.1274	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Dec 2016	Arrow	28

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
148	160703A	-27.1795	151.0439	Existing	Juandah Coal Measures	Fortnightly		Completed	Arrow	29
622	Stratheden -63	-27.1989	151.0268	Other existing	Springbok Sandstone	Fortnightly		Dec 2016	Arrow	29
623	Stratheden -63	-27.1989	151.0268	Other existing	Springbok Sandstone		six-monthly	Dec 2016	Arrow	29
149	160801C	-27.1496	151.2094	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	30
150	160801B	-27.1496	151.2094	Existing	Condamine Alluvium - Walloon transition layer	Fortnightly		Completed	Arrow	30
151	160801A	-27.1496	151.2094	Existing	Taroom Coal Measures	Fortnightly		Completed	Arrow	30
152	160521A	-27.1713	150.7825	Existing	Springbok Sandstone	Fortnightly		Completed	QGC	31
153	160521A	-27.1713	150.7825	Existing	Springbok Sandstone		six-monthly	Completed	QGC	31
154	160690D	-27.1337	150.7746	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	QGC	31
155	160690C	-27.1337	150.7746	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	QGC	31
156	160690A	-27.1337	150.7746	Existing	Taroom Coal Measures	Fortnightly		Completed	QGC	31
157	160349A	-27.1441	150.9480	Existing	Westbourne Formation / Springbok Sandstone	Fortnightly		Completed	Arrow	32
158	160349A	-27.1441	150.9480	Existing	Westbourne Formation / Springbok Sandstone		six-monthly	Completed	Arrow	32
159	160347A	-27.1441	150.9481	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	Arrow	32
160	160802B	-27.1441	150.9482	Existing	Juandah Sandstone	Fortnightly		Completed	Arrow	32
161	160802A	-27.1441	150.9482	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	Arrow	32
162	160553C	-27.1440	150.9482	Existing	Tangalooma Sandstone	Fortnightly		Completed	Arrow	32
163	160553B	-27.1440	150.9482	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	Arrow	32
164	160553A	-27.1440	150.9482	Existing	lower aquitard of the Walloon Coal Measures	Fortnightly		Completed	Arrow	32
165	42231548A	-27.1153	151.4978	Existing	Walloon Coal Measures	Fortnightly		Completed	Arrow	33
166	160643A	-27.1185	151.0756	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	34

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
167	160676A	-27.1200	151.0759	Existing	Condamine Alluvium - Walloon transition layer	Fortnightly		Completed	Arrow	34
168	160678A	-27.1200	151.0760	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	Arrow	34
169	160701A	-27.1113	150.3897	Existing	Gubberamunda Sandstone	Fortnightly		Completed	APLNG	35
170	160682A	-27.1083	150.3942	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	35
171	160682A	-27.1083	150.3942	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	35
172	160806C	-27.1111	150.3901	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	35
173	160806B	-27.1111	150.3901	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	35
174	160806A	-27.1111	150.3901	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	35
175	160681A	-27.1083	150.2213	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	36
176	160681A	-27.1083	150.2213	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	36
177	Ironbark MB11-W	-27.1077	150.2213	Existing	Walloon Coal Measures	Fortnightly		Dec 2016	APLNG	36
178		-27.1083	150.2213	Not required	Coal seam of the Lower Juandah Coal Measures					36
179		-27.1083	150.2213	Not required	Coal seam of the Taroom Coal Measures					36
180	Ironbark MB10-H	-27.1163	150.2008	Proposed	Hutton Sandstone	Fortnightly		Dec 2016	APLNG	36
181	160707A	-27.1024	150.9614	Existing	Juandah and Taroom Coal Measures	Fortnightly		Completed	Arrow	37
182	160350A	-27.1004	150.9557	Existing	Hutton Sandstone	Fortnightly		Completed	Arrow	37
183	160350A	-27.1004	150.9557	Existing	Hutton Sandstone		six-monthly	Completed	Arrow	37
184		-27.0500	150.7399	Not required	Gubberamunda Sandstone					38
185		-27.0500	150.7399	Not required	Gubberamunda Sandstone					38
186	160564A	-27.0395	150.7806	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	38

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
187	160564A	-27.0395	150.7806	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	38
188	160753C	-27.0396	150.7803	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	38
189	160829A	-27.0902	150.7971	Existing	Walloon Coal Measures		six-monthly	Completed	APLNG	38
190	160753B	-27.0396	150.7803	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	38
191	160753A	-27.0396	150.7803	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	38
192	160518A	-27.0286	150.5485	Existing	Gubberamunda Sandstone	Fortnightly		Completed	QGC	39
193	160518A	-27.0286	150.5485	Existing	Gubberamunda Sandstone		six-monthly	Completed	QGC	39
194	160519A	-27.0284	150.5486	Existing	Springbok Sandstone	Fortnightly		Completed	QGC	39
195	160519A	-27.0284	150.5486	Existing	Springbok Sandstone		six-monthly	Completed	QGC	39
196	160601C	-27.0230	150.5628	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	QGC	39
197	160601B	-27.0230	150.5628	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	QGC	39
198	160601A	-27.0230	150.5628	Existing	Taroom Coal Measures	Fortnightly		Completed	QGC	39
199	160429A	-27.0229	150.5628	Existing	Hutton Sandstone	Fortnightly		Completed	QGC	39
200	160462A	-27.0291	150.5744	Existing	Precipice Sandstone	Fortnightly		Completed	QGC	39
665	Kenya East GW8	-27.0226	150.5629	Other existing	Westbourne Formation	Fortnightly		Dec 2016	QGC	39
201	160665A	-27.0370	150.3062	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	40
202	160665A	-27.0370	150.3062	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	40
203		-27.0100	151.1140	Proposed	Condamine Alluvium	Fortnightly		Dec 2016	Arrow	41
204		-27.0100	151.1140	Proposed	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Dec 2016	Arrow	41
205		-27.0100	151.1140	Proposed	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Dec 2016	Arrow	41
206		-27.0100	151.1140	Proposed	Coal seam of the Taroom Coal Measures	Fortnightly		Dec 2016	Arrow	41
207	160702B	-26.9987	150.9017	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	42

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
208	160702A	-26.9987	150.9017	Existing	Condamine Alluvium - Walloon transition layer	Fortnightly		Completed	Arrow	42
209	160730A	-27.0093	150.9003	Existing	Juandah and Taroom Coal Measures	Fortnightly		Completed	Arrow	42
210	160597A	-26.9493	150.4437	Existing	Springbok Sandstone	Fortnightly		Completed	QGC	43
211	160597A	-26.9493	150.4437	Existing	Springbok Sandstone		six-monthly	Completed	QGC	43
212	160773A	-26.9282	150.4474	Existing	Walloon Coal Measures		six-monthly	Completed	QGC	43
213	160826C	-26.9492	150.4436	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	QGC	43
214	160826B	-26.9492	150.4436	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	QGC	43
215	160826A	-26.9492	150.4436	Existing	Taroom Coal Measures	Fortnightly		Completed	QGC	43
216	160628A	-26.9417	150.2119	Existing	Gubberamunda Sandstone	Fortnightly		Completed	APLNG	44
217	160628A	-26.9417	150.2119	Existing	Gubberamunda Sandstone		six-monthly	Completed	APLNG	44
218	160627A	-26.9417	150.2119	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	44
219	160627A	-26.9417	150.2119	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	44
220	160755C	-26.9314	150.2292	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	44
221	160754A	-26.9350	150.2072	Existing	Juandah and Taroom Coal Measures composite sample		six-monthly	Completed	APLNG	44
222	160755B	-26.9314	150.2292	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	44
223	160755A	-26.9314	150.2292	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	44
224		-26.8760	150.0195	Not required	Springbok Sandstone					45
225		-26.8760	150.0195	Not required	Springbok Sandstone					45
226		-26.8745	150.0195	Not required	Coal seam of the Upper Juandah Coal Measures					45
227		-26.8745	150.0195	Not required	Coal seam of the Lower Juandah Coal Measures					45

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
228		-26.8745	150.0195	Not required	Coal seam of the Taroom Coal Measures					45
229		-26.8749	150.0195	Not required	Hutton Sandstone					45
230		-26.8749	150.0195	Not required	Hutton Sandstone					45
231	160049A	-26.8930	150.3703	Existing	Gubberamunda Sandstone	Fortnightly		Completed	APLNG	46
232	160049A	-26.8930	150.3703	Existing	Gubberamunda Sandstone		six-monthly	Completed	APLNG	46
233	160051A	-26.8932	150.3713	Existing	Westbourne Formation	Fortnightly		Completed	APLNG	46
234	160050A	-26.8930	150.3703	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	46
235	160050A	-26.8930	150.3703	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	46
236	160756C	-26.8937	150.3683	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	46
237	160757B	-26.8930	150.3703	Existing	Juandah Sandstone	Fortnightly		Completed	APLNG	46
238	160756B	-26.8937	150.3683	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	46
239	160757A	-26.8930	150.3703	Existing	Tangalooma Sandstone	Fortnightly		Completed	APLNG	46
240	160756A	-26.8937	150.3683	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	46
241	Talinga 14	-26.9137	150.3555	Existing	lower aquitard of the Walloon Coal Measures	Fortnightly		Mar 2016	APLNG	46
242	160634A	-26.8924	150.3689	Existing	Hutton Sandstone	Fortnightly		Completed	APLNG	46
243	160634A	-26.8924	150.3689	Existing	Hutton Sandstone		six-monthly	Completed	APLNG	46
244	42230203A	-26.8989	150.9792	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	47
245		-26.8989	150.9792	Proposed	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Dec 2016	Arrow	47
246	160642A	-26.8661	150.7551	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	48
247		-26.8600	150.7500	Not required	Springbok Sandstone					48
248	160642A	-26.8661	150.7551	Existing	Condamine Alluvium		six-monthly	Completed	Arrow	48

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
249	160658C	-26.8660	150.7552	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	Arrow	48
250	160658B	-26.8660	150.7552	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	Arrow	48
251	160658A	-26.8660	150.7552	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	Arrow	48
252	160563A	-26.8660	150.7551	Existing	Precipice Sandstone	Fortnightly		Completed	Arrow	48
253	160563A	-26.8660	150.7551	Existing	Precipice Sandstone		six-monthly	Completed	Arrow	48
624	13878	-26.8400	150.7866	Other existing	Hutton Sandstone	Fortnightly		2018	Arrow	48
254	160515A	-26.8470	150.3001	Existing	Springbok Sandstone	Fortnightly		Completed	QGC	49
255	160515A	-26.8470	150.3001	Existing	Springbok Sandstone		six-monthly	Completed	QGC	49
256	160719A	-26.8086	150.1710	Existing	Gubberamunda Sandstone	Fortnightly		Completed	APLNG	50
257	160719A	-26.8086	150.1710	Existing	Gubberamunda Sandstone		six-monthly	Completed	APLNG	50
258	160734A	-26.8085	150.1710	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	50
259	160734A	-26.8085	150.1710	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	50
260	160758A	-26.8061	150.1817	Existing	Composite Upper & Lower Juandah and Taroom Coal Measures		six-monthly	Completed	APLNG	50
261	160759C	-26.7887	150.2176	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	50
262	160759B	-26.7887	150.2176	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	50
263	160759A	-26.7887	150.2176	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	50
264	160655A	-26.8079	150.1708	Existing	Hutton Sandstone	Fortnightly		Completed	APLNG	50
265	160655A	-26.8079	150.1708	Existing	Hutton Sandstone		six-monthly	Completed	APLNG	50
266	Orana MB6-H	-26.8097	150.5415	Proposed	Hutton Sandstone	Fortnightly		Mar 2016	APLNG	51
267	Orana MB6-H	-26.8097	150.5415	Proposed	Hutton Sandstone		six-monthly	Mar 2016	APLNG	51

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
633	Orana MB5-W	-26.8026	150.5502	Other existing	Upper Juandah Coal Measures	Fortnightly		Dec 2016	APLNG	51
634	Orana MB5-W	-26.8026	150.5502	Other existing	Lower Juandah Coal Measures	Fortnightly		Dec 2016	APLNG	51
635	Orana MB5-W	-26.8026	150.5502	Other existing	Taroom Coal Measures	Fortnightly		Dec 2016	APLNG	51
268	160637C	-26.7922	148.7417	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	52
269	160637B	-26.7922	148.7417	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	Santos	52
270	160637A	-26.7922	148.7417	Existing	Upper Taroom Coal Measures	Fortnightly		Completed	Santos	52
271	160693A	-26.7580	150.3603	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	53
272	160693A	-26.7580	150.3603	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	53
273	160692C	-26.8231	150.3492	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	53
274	160402A	-26.7825	149.1969	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	54
275	160402A	-26.7825	149.1969	Existing	Gubberamunda Sandstone		six-monthly	Completed	Santos	54
276	Wallabella - WBLMLS1	-26.7874	149.2012	Existing	Springbok Sandstone	Fortnightly		Dec 2016	Santos	54
277	Wallabella - WBLMLUJ1	-26.7874	149.2012	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Dec 2016	Santos	54
278	Wallabella - WBLMLLJ1	-26.7874	149.2012	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Dec 2016	Santos	54
279	Wallabella - WBLMLT1	-26.7874	149.2012	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Dec 2016	Santos	54
280	Wallabella - WBLMLH1	-26.7874	149.2012	Existing	Hutton Sandstone	Fortnightly		Dec 2016	Santos	54
281	42230209A	-26.7422	150.6799	Existing	Condamine Alluvium	Fortnightly		Completed	Arrow	55
282	42230209A	-26.7422	150.6799	Existing	Condamine Alluvium		six-monthly	Completed	Arrow	55

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
283	160803C	-26.7435	150.6784	Existing	Coal seam of the Lower Juandah Coal Measures (Argyle)	Fortnightly		Completed	Arrow	55
284	160803B	-26.7435	150.6784	Existing	Coal seam of the Taroom Coal Measures (Upper)	Fortnightly		Completed	Arrow	55
285	160803A	-26.7435	150.6784	Existing	Coal seam of the Taroom Coal Measures (Condamine)	Fortnightly		Completed	Arrow	55
286	160547A	-26.7404	150.4269	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	56
287	160547A	-26.7404	150.4269	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	56
288	160713C	-26.7405	150.4274	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	56
289	160713B	-26.7405	150.4274	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	56
290	160713A	-26.7405	150.4274	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	56
291	160705A	-26.7037	150.2460	Existing	Gubberamunda Sandstone	Fortnightly		Completed	QGC	57
292	160705A	-26.7036	150.2460	Existing	Gubberamunda Sandstone		six-monthly	Completed	QGC	57
293	160526A	-26.6908	150.2670	Existing	Springbok Sandstone	Fortnightly		Completed	QGC	57
294	160526A	-26.6908	150.2670	Existing	Springbok Sandstone		six-monthly	Completed	QGC	57
295	160775C	-26.6911	150.2672	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	QGC	57
296	160775B	-26.6911	150.2672	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	QGC	57
297	160775A	-26.6911	150.2672	Existing	Taroom Coal Measures	Fortnightly		Completed	QGC	57
298	160647G	-26.6833	148.9923	Existing	Mooga Sandstone	Fortnightly		Completed	Santos	58
299	160647F	-26.6833	148.9923	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	58
300	160647C	-26.6833	148.9923	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	Santos	58
301	160647B	-26.6833	148.9923	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	Santos	58
302	160647A	-26.6833	148.9923	Existing	Lower Taroom Coal Measures	Fortnightly		Completed	Santos	58
303	160749A	-26.7145	150.0002	Existing	Gubberamunda Sandstone	Fortnightly		Completed	APLNG	59
304	160749A	-26.7145	150.0002	Existing	Gubberamunda Sandstone		six-monthly	Completed	APLNG	59

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
305	Carinya MB4-S	-26.7141	150.0001	Existing	Springbok Sandstone	Fortnightly		Dec 2016	APLNG	59
306	Carinya MB4-S	-26.7141	150.0001	Existing	Springbok Sandstone		six-monthly	Dec 2016	APLNG	59
307		-26.6737	148.8464	Not required	Taroom Coal Measures					60
308	160641B	-26.6737	148.8464	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	Santos	60
309	160641A	-26.6737	148.8464	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	Santos	60
310	Carinya MB2-S	-26.6346	149.6850	Existing	Springbok Sandstone	Fortnightly		Dec 2016	APLNG	61
311	Carinya MB2-S	-26.6346	149.6850	Existing	Springbok Sandstone		six-monthly	Dec 2016	APLNG	61
312	160194A	-26.6295	150.1455	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	62
313	160194A	-26.6295	150.1455	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	62
314	160760C	-26.6315	150.1460	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	62
315	160821A	-26.6813	150.2295	Existing	Composite Upper & Lower Juandah and Taroom Coal Measures		six-monthly	Completed	APLNG	62
316	160760B	-26.6315	150.1460	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	62
317	160760A	-26.6315	150.1460	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	62
318	160680A	-26.6840	150.2262	Existing	Precipice Sandstone	Fortnightly		Completed	APLNG	62
319	160680A	-26.6840	150.2262	Existing	Precipice Sandstone		six-monthly	Completed	APLNG	62
636	Condabri-INJ4-H	-26.6840	150.2256	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	APLNG	62
320		-26.6450	149.8519	Proposed	Coal seam of the Upper Juandah Coal Measures		six-monthly	2 years prior to production within 10km	APLNG	63

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
321	160748C	-26.6450	149.8519	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	63
322	160748B	-26.6450	149.8519	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	63
323	160748A	-26.6450	149.8519	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	63
324	160648E	-26.6366	149.1119	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	64
325	160648D	-26.6366	149.1119	Existing	Springbok Sandstone	Fortnightly		Completed	Santos	64
326	160648C	-26.6366	149.1119	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	Santos	64
327	160648A	-26.6366	149.1119	Existing	Lower Taroom Coal Measures	Fortnightly		Completed	Santos	64
328	160399A	-26.6033	149.3932	Existing	Mooga Sandstone	Fortnightly		Completed	Santos	65
329	160399A	-26.6033	149.3932	Existing	Mooga Sandstone		six-monthly	Completed	Santos	65
330	160397A	-26.6035	149.3931	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	65
331	160397A	-26.6035	149.3931	Existing	Gubberamunda Sandstone		six-monthly	Completed	Santos	65
332	Boxgrove	-26.6035	149.3736	Proposed	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Dec 2016	Santos	65
333	160727E	-26.5826	148.8511	Existing	Mooga Sandstone	Fortnightly		Completed	Santos	66
334	160727D	-26.5826	148.8511	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	66
335	160668A	-26.5830	148.8512	Existing	Springbok Sandstone	Fortnightly		Completed	Santos	66
336	160727C	-26.5826	148.8511	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	Santos	66
337	160727B	-26.5826	148.8511	Existing	Lower Taroom Coal Measures	Fortnightly		Completed	Santos	66
338	160727A	-26.5826	148.8511	Existing	Eurombah Formation	Fortnightly		Completed	Santos	66
339	Site 67M - UJ	-26.5920	150.4100	Proposed	Upper Juandah Coal Measures	Fortnightly		Dec 2016	QGC	67
340	Site 67M - LJ	-26.5920	150.4100	Proposed	Lower Juandah Coal Measures	Fortnightly		Dec 2016	QGC	67
341	Site 67M - TC	-26.5920	150.4100	Proposed	Taroom Coal Measures	Fortnightly		Dec 2016	QGC	67
342	Site 67 GW1 HUT	-26.5920	150.4100	Proposed	Hutton Sandstone	Fortnightly		Dec 2016	QGC	67

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
343		-26.5920	150.4100	Not required	Hutton Sandstone					67
344	160193A	-26.5536	150.1040	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	68
345	160193A	-26.5536	150.1040	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	68
346	160761C	-26.5543	150.1042	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	68
347	160761B	-26.5543	150.1042	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	68
348	160761A	-26.5543	150.1042	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	68
349	160807A	-26.5546	150.1043	Existing	Hutton Sandstone	Fortnightly		Completed	APLNG	68
638	Dalwogan MB3-G	-26.5535	150.1040	Other existing	Gubberamunda Sandstone	Fortnightly		Dec 2016	APLNG	68
350	123130A	-26.5398	149.9590	Existing	Orallo Formation	Fortnightly		Completed	APLNG	69
351	123130A	-26.5398	149.9590	Existing	Orallo Formation		six-monthly	Completed	APLNG	69
352	160582A	-26.5332	149.0546	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	70
353	160581E	-26.5331	149.0548	Existing	Springbok Sandstone	Fortnightly		Completed	Santos	70
354		-26.5331	149.0543	Not required	Springbok Sandstone					70
355	160581D	-26.5331	149.0548	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	Santos	70
356	160581C	-26.5331	149.0548	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	Santos	70
357	160581A	-26.5331	149.0548	Existing	Taroom Coal Measures	Fortnightly		Completed	Santos	70
358	160581A	-26.5331	149.0548	Existing	Hutton Sandstone	Fortnightly		Completed	Santos	70
359		-26.5331	149.0543	Not required	Precipice Sandstone					70
360	160652F	-26.5268	149.2130	Existing	Mooga Sandstone	Fortnightly		Completed	Santos	71
361	160652E	-26.5268	149.2130	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	71
362	160652C	-26.5268	149.2130	Existing	Springbok Sandstone	Fortnightly		Completed	Santos	71
363	160652A	-26.5268	149.2130	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	Santos	71

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
364	160583A	-26.5059	149.7527	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	72
365	160583A	-26.5059	149.7527	Existing	Gubberamunda Sandstone		six-monthly	Completed	Santos	72
366	160812A	-26.5059	149.7527	Existing	Springbok Sandstone	Fortnightly		Completed	Santos	72
367	160812A	-26.5059	149.7527	Existing	Springbok Sandstone		six-monthly	Completed	Santos	72
368		-26.5060	149.7530	Proposed	Upper Juandah Coal Measures	Fortnightly		2 years prior to production within 10km	Santos	72
369		-26.5060	149.7530	Proposed	Lower Juandah Coal Measures	Fortnightly		2 years prior to production within 10km	Santos	72
370		-26.5060	149.7530	Proposed	Taroom Coal Measures	Fortnightly		2 years prior to production within 10km	Santos	72
371	160813A	-26.5060	149.7530	Existing	Hutton Sandstone	Fortnightly		Completed	Santos	72
372	160813A	-26.5060	149.7530	Existing	Hutton Sandstone		six-monthly	Completed	Santos	72
373		-26.5230	149.8220	Not required	Precipice Sandstone					72
374		-26.5230	149.8220	Not required	Precipice Sandstone					72
375	160687D	-26.5529	150.2220	Existing	Springbok Sandstone	Fortnightly		Completed	Arrow	73
376	160687C	-26.5529	150.2220	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	Arrow	73
377	160687B	-26.5529	150.2220	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	Arrow	73
378	160687A	-26.5529	150.2220	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	Arrow	73
379	160646F	-26.4948	149.3649	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	74

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
380	160646E	-26.4948	149.3649	Existing	Westbourne Formation	Fortnightly		Completed	Santos	74
381	160646D	-26.4948	149.3649	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	Santos	74
382	160646C	-26.4948	149.3649	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	Santos	74
383	160646B	-26.4948	149.3649	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	Santos	74
384	160646A	-26.4948	149.3649	Existing	Lower Taroom Coal Measures	Fortnightly		Completed	Santos	74
675		-26.4948	149.3649	Proposed	Springbok Sandstone	Fortnightly		2018	Santos	74
676		-26.4948	149.3649	Proposed	Hutton Sandstone	Fortnightly		2018	Santos	74
385	160640D	-26.4652	149.0189	Existing	Orallo Formation	Fortnightly		Completed	Santos	75
386	160640A	-26.4652	149.0189	Existing	Westbourne Formation	Fortnightly		Completed	Santos	75
387	160814A	-26.4375	148.9212	Existing	Springbok Sandstone	Fortnightly		Completed	Santos	76
388	Beverley - BEVMLUJ1	-26.4392	148.9152	Proposed	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Dec 2016	Santos	76
389	Beverley - BEVMLLJ1	-26.4392	148.9152	Proposed	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Dec 2016	Santos	76
390	Beverley - BEVMLT1	-26.4392	148.9152	Proposed	Coal seam of the Taroom Coal Measures	Fortnightly		Dec 2016	Santos	76
677		-26.4392	148.9152	Proposed	Hutton Sandstone	Fortnightly		2018	Santos	76
391	160733D	-26.4391	148.8004	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	77
392	160733C	-26.4391	148.8004	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	Santos	77
393	160733B	-26.4391	148.8004	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	Santos	77
394	160733A	-26.4391	148.8004	Existing	Lower Taroom Coal Measures	Fortnightly		Completed	Santos	77
395	12728A	-26.4303	149.3612	Existing	Mooga Sandstone		six-monthly	Completed	Santos	78
396	160636C	-26.4303	149.3612	Existing	Mooga Sandstone	Fortnightly		Completed	Santos	78
397	160391A	-26.4302	149.3612	Existing	Orallo Formation	Fortnightly		Completed	Santos	78
398	160391A	-26.4302	149.3612	Existing	Orallo Formation		six-monthly	Completed	Santos	78
399	160684A	-26.4819	149.7866	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	79
400	160762C	-26.3987	149.6964	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	79

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
401	160808A	-26.4527	149.7087	Existing	Composite Upper & Lower Juandah and Taroom Coal Measures		six-monthly	Completed	APLNG	79
402	160762B	-26.3987	149.6964	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	79
403	160762A	-26.3987	149.6964	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	79
404	160617A	-26.3998	149.5829	Existing	Gubberamunda Sandstone	Fortnightly		Completed	APLNG	80
405	160617A	-26.3998	149.5829	Existing	Gubberamunda Sandstone		six-monthly	Completed	APLNG	80
406	Lucky Gully MB2-S	-26.4002	149.5828	Existing	Springbok Sandstone	Fortnightly		Mar 2016	APLNG	80
407	160777A	-26.4002	149.5828	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	80
408	160763C	-26.4024	149.5772	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	80
409	160763B	-26.4024	149.5772	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	80
410	160763A	-26.4024	149.5772	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	80
639		-26.4000	149.5800	Proposed	Hutton Sandstone	Fortnightly		2018	APLNG	80
411	160704A	-26.3657	149.9788	Existing	Gubberamunda Sandstone	Fortnightly		Completed	QGC	81
412	160704A	-26.3657	149.9788	Existing	Gubberamunda Sandstone		six-monthly	Completed	QGC	81
413	160694A	-26.3657	149.9785	Existing	Springbok Sandstone	Fortnightly		Completed	QGC	81
414	160694A	-26.3657	149.9785	Existing	Springbok Sandstone		six-monthly	Completed	QGC	81
415	160720C	-26.3656	149.9790	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	QGC	81
416	160720B	-26.3656	149.9790	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	QGC	81
417	160720A	-26.3656	149.9790	Existing	Taroom Coal Measures	Fortnightly		Completed	QGC	81
666		-26.3660	149.9780	Proposed	Hutton Sandstone	Fortnightly		2 years prior to production within 10km	QGC	81
418	160822A	-26.3871	149.1256	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	82

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
419	160823A	-26.3872	149.1257	Existing	Springbok Sandstone	Fortnightly		Completed	Santos	82
420	160823A	-26.3872	149.1257	Existing	Springbok Sandstone		six-monthly	Completed	Santos	82
421	160776G	-26.3873	149.1259	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	Santos	82
422	160776F	-26.3873	149.1259	Existing	sandstone /siltstone /mudstone of Juandah Coal Measures	Fortnightly		Completed	Santos	82
423	160776E	-26.3873	149.1259	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	Santos	82
424	160776D	-26.3873	149.1259	Existing	Tangalooma Sandstone	Fortnightly		Completed	Santos	82
425	160776C	-26.3873	149.1259	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	Santos	82
426	160776B	-26.3873	149.1259	Existing	lower aquitard of the Walloon Coal Measures	Fortnightly		Completed	Santos	82
427	160776A	-26.3873	149.1259	Existing	Hutton Sandstone	Fortnightly		Completed	Santos	82
428		-26.3685	149.1060	Not required	Hutton Sandstone					82
678	Armidale - ARMGWP01	-26.3871	149.1256	Proposed	Precipice Sandstone	Fortnightly		Dec 2016	Santos	82
429	160395A	-26.3789	148.9636	Existing	Mooga Sandstone	Fortnightly		Completed	Santos	83
430	160395A	-26.3789	148.9636	Existing	Mooga Sandstone		six-monthly	Completed	Santos	83
431	160393A	-26.3788	148.9634	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	83
432	160393A	-26.3788	148.9634	Existing	Gubberamunda Sandstone		six-monthly	Completed	Santos	83
433	Woleebee MB3-S	-26.3857	149.8478	Existing	Springbok Sandstone	Fortnightly		Mar 2016	APLNG	84
434	Woleebee MB3-S	-26.3857	149.8478	Existing	Springbok Sandstone		six-monthly	Mar 2016	APLNG	84
435	160764C	-26.3853	149.8476	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	84
436	160764B	-26.3853	149.8476	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	84

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
437	160764A	-26.3853	149.8476	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	84
438	160187A	-26.3563	149.4267	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	85
439	160187A	-26.3563	149.4267	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	85
440	160765C	-26.3574	149.4258	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	85
441	160766A	-26.3581	149.4235	Existing	Composite Upper & Lower Juandah Coal Measures		six-monthly	Completed	APLNG	85
442	160765B	-26.3574	149.4258	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	85
443	160765A	-26.3574	149.4258	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	85
444	160546A	-26.3577	149.4266	Existing	Hutton Sandstone	Fortnightly		Completed	APLNG	85
445	160546A	-26.3577	149.4266	Existing	Hutton Sandstone		six-monthly	Completed	APLNG	85
640	Reedy Creek MB1-G	-26.3579	149.4256	Other existing	Gubberamunda Sandstone	Fortnightly		Dec 2016	APLNG	85
641	Reedy Ck-SC1	-26.3579	149.4256	Other existing	Westbourne Formation	Fortnightly		Dec 2016	APLNG	85
642	Reedy Ck INJ2-P	-26.3571	149.4267	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	APLNG	85
446	160651D	-26.3365	148.8384	Existing	Gubberamunda Sandstone	Fortnightly		Completed	Santos	86
447	160651C	-26.3365	148.8384	Existing	Springbok Sandstone	Fortnightly		Completed	Santos	86
448	160472A	-26.3206	149.2630	Existing	Gubberamunda Sandstone	Fortnightly		Completed	APLNG	87
449	160472A	-26.3206	149.2630	Existing	Gubberamunda Sandstone		six-monthly	Completed	APLNG	87
450	160507A	-26.3206	149.2632	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	87
451	Muggleton MB2-S	-26.3206	149.2632	Existing	Springbok Sandstone		six-monthly	Mar 2016	APLNG	87
452	160679C	-26.3183	149.2637	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	87
453	RN14395	-26.1799	149.1448	Existing	Composite Upper & Lower Juandah Coal Measures		six-monthly	Mar 2016	APLNG	87

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
454	160679B	-26.3183	149.2637	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	87
455	160679A	-26.3183	149.2637	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	87
456	160683C	-26.2952	148.6330	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	Santos	88
679	Mt Eden 1	-26.2952	148.6330	Other existing	Tangalooma Sandstone	Fortnightly		Dec 2016	Santos	88
680	Mt Eden 1	-26.2952	148.6330	Other existing	Taroom Coal Measures	Fortnightly		Dec 2016	Santos	88
457	160522A	-26.2820	149.7149	Existing	Gubberamunda Sandstone	Fortnightly		Completed	QGC	89
458	160522A	-26.2820	149.7149	Existing	Gubberamunda Sandstone		six-monthly	Completed	QGC	89
459	160430A	-26.2819	149.7144	Existing	Springbok Sandstone	Fortnightly		Completed	QGC	89
460	160430A	-26.2819	149.7144	Existing	Springbok Sandstone		six-monthly	Completed	QGC	89
461	160432E	-26.2819	149.7141	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	QGC	89
462	160431A	-26.2819	149.7144	Existing	Westbourne Formation	Fortnightly		Completed	QGC	89
463	160432D	-26.2819	149.7141	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	QGC	89
464	160432C	-26.2819	149.7141	Existing	Tangalooma Sandstone	Fortnightly		Completed	QGC	89
465	160432B	-26.2819	149.7141	Existing	Taroom Coal Measures	Fortnightly		Completed	QGC	89
466	160432A	-26.2819	149.7141	Existing	Eurombah Formation	Fortnightly		Completed	QGC	89
467	160433A	-26.2819	149.7142	Existing	Hutton Sandstone	Fortnightly		Completed	QGC	89
468	WCK GW3	-26.2819	149.7142	Existing	Hutton Sandstone		six-monthly	Mar 2016	QGC	89
667	WCK GW10	-26.2558	149.6988	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	QGC	89
668	WCK GW10	-26.2558	149.6988	Other existing	Precipice Sandstone		six-monthly	Dec 2016	QGC	89
469	Lawton 5	-26.3005	149.9134	Proposed	Springbok Sandstone	Fortnightly		2 years prior to production within 10km	QGC	90

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
470	Lawton 5	-26.3005	149.9134	Proposed	Upper Juandah Coal Measures	Fortnightly		2 years prior to production within 10km	QGC	90
471	Lawton 5	-26.3005	149.9134	Proposed	Lower Juandah Coal Measures	Fortnightly		2 years prior to production within 10km	QGC	90
472	Lawton 5	-26.3005	149.9134	Proposed	Taroom Coal Measures	Fortnightly		2 years prior to production within 10km	QGC	90
473	160677F	-26.2429	150.0500	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	Arrow	91
474	160677E	-26.2429	150.0500	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	Arrow	91
475	160677D	-26.2429	150.0500	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	Arrow	91
476	160677B	-26.2429	150.0500	Existing	Hutton Sandstone	Fortnightly		Completed	Arrow	91
477	160677B	-26.2429	150.0500	Existing	Hutton Sandstone		six-monthly	Completed	Arrow	91
478	160686A	-26.2427	150.0502	Existing	Precipice Sandstone	Fortnightly		Completed	Arrow	91
479	160686A	-26.2427	150.0502	Existing	Precipice Sandstone		six-monthly	Completed	Arrow	91
625	Burrunga Lane 174	-26.2427	150.0502	Other existing	Evergreen Formation	Fortnightly		Dec 2016	Arrow	91
480	160664A	-26.2310	149.5642	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	92
481	160664A	-26.2310	149.5642	Existing	Springbok Sandstone		six-monthly	Completed	APLNG	92
482	Combabula 14	-26.2272	149.5631	Existing	Composite Juandah & Taroom Coal Measures		six-monthly	Mar 2016	APLNG	92
483	160767C	-26.2306	149.5651	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	92

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
484	160767B	-26.2306	149.5651	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	92
485	160767A	-26.2306	149.5651	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	92
643	Combabula MB1-G	-26.2310	149.5642	Other existing	Gubberamunda Sandstone	Fortnightly		Dec 2016	APLNG	92
486	Meeleebee MB1-S	-26.2228	149.1645	Proposed	Springbok Sandstone	Fortnightly		Mar 2016	APLNG	93
487	Meeleebee MB1-S	-26.2228	149.1645	Proposed	Springbok Sandstone		six-monthly	Mar 2016	APLNG	93
488	Meeleebee MB3-W	-26.2227	149.1650	Proposed	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Mar 2016	APLNG	93
489	Meeleebee MB3-W	-26.2227	149.1650	Proposed	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Mar 2016	APLNG	93
490	Meeleebee MB3-W	-26.2227	149.1650	Proposed	Coal seam of the Taroom Coal Measures	Fortnightly		Mar 2016	APLNG	93
491	Meeleebee MB2-H	-26.2227	149.1654	Proposed	Hutton Sandstone	Fortnightly		Mar 2016	APLNG	93
492	Meeleebee MB2-H	-26.2227	149.1654	Proposed	Hutton Sandstone		six-monthly	Mar 2016	APLNG	93
493	Meeleebee MB5-P	-26.2202	149.1693	Proposed	Precipice Sandstone	Fortnightly		Mar 2016	APLNG	93
494		-26.2301	149.9534	Proposed	Coal seam of the Upper Juandah Coal Measures	Fortnightly		2 years prior to production within 10km	Arrow	94
495		-26.2301	149.9534	Proposed	Coal seam of the Lower Juandah Coal Measures	Fortnightly		2 years prior to production within 10km	Arrow	94

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
496		-26.2301	149.9534	Proposed	Coal seam of the Taroom Coal Measures	Fortnightly		2 years prior to production within 10km	Arrow	94
497		-26.2301	149.9534	Proposed	Hutton Sandstone	Fortnightly		2 years prior to production within 10km	Arrow	94
498	160768B	-26.0794	149.1723	Existing	Bandanna Formation coal seam	Fortnightly		Completed	APLNG	95
499	160830A	-26.0564	149.1691	Existing	Bandanna Formation coal seam		six-monthly	Completed	APLNG	95
500		-26.0527	149.4342	Not required	Upper Juandah Coal Measures					96
501		-26.0527	149.4342	Not required	Lower Juandah Coal Measures					96
502		-26.0527	149.4342	Not required	Taroom Coal Measures					96
503	Philip 5M	-26.0870	149.6308	Existing	Springbok Sandstone	Fortnightly		Mar 2016	QGC	97
504	160722C	-26.0870	149.6308	Existing	Upper Juandah Coal Measures	Fortnightly		Completed	QGC	97
505	160722B	-26.0870	149.6308	Existing	Lower Juandah Coal Measures	Fortnightly		Completed	QGC	97
506	160722A	-26.0870	149.6308	Existing	Taroom Coal Measures	Fortnightly		Completed	QGC	97
507	160714A	-26.0239	149.6471	Existing	Hutton Sandstone	Fortnightly		Completed	QGC	97
508	16659A	-26.0132	149.1933	Existing	Hutton Sandstone	Fortnightly		Completed	APLNG	98
645	Echo Hills Flowing Bore	-26.0348	149.2137	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	APLNG	98
509	160656A	-25.9765	149.1042	Existing	Bandanna Formation	Fortnightly		Completed	APLNG	99
510	Cassio 6M	-25.9458	149.7756	Existing	Upper Juandah Coal Measures	Fortnightly		Dec 2016	QGC	100
511	Cassio 6M	-25.9458	149.7756	Existing	Lower Juandah Coal Measures	Fortnightly		Dec 2016	QGC	100
512	Cassio 6M	-25.9458	149.7756	Existing	Taroom Coal Measures	Fortnightly		Dec 2016	QGC	100

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
669		-25.9458	149.7756	Proposed	Springbok Sandstone	Fortnightly		2018	QGC	100
513	13030812	-25.9725	149.4042	Existing	Birkhead Formation	Fortnightly		Mar 2016	QGC	101
514	13030812	-25.9725	149.4042	Existing	Birkhead Formation		six-monthly	Mar 2016	QGC	101
670		-25.9725	149.4042	Proposed	Springbok Sandstone	Fortnightly		2018	QGC	101
671		-25.9725	149.4042	Proposed	Hutton Sandstone	Fortnightly		2018	QGC	101
515	160793A	-25.8666	149.2169	Existing	Hutton Sandstone	Fortnightly		Completed	APLNG	102
516	160691A	-25.8666	149.2169	Existing	Precipice Sandstone	Fortnightly		Completed	APLNG	102
517		-25.8932	149.2161	Proposed	Clematis Sandstone	Fortnightly		Mar 2016	APLNG	102
518	160809A	-25.9121	149.1985	Existing	Bandanna Formation coal seam	Fortnightly		Completed	APLNG	102
519	Charlotte GW3	-25.9099	149.5404	Proposed	Upper Juandah Coal Measures	Fortnightly		Dec 2016	QGC	103
520	Charlotte GW3	-25.9099	149.5404	Proposed	Lower Juandah Coal Measures	Fortnightly		Dec 2016	QGC	103
521	Charlotte GW3	-25.9099	149.5404	Proposed	Taroom Coal Measures	Fortnightly		Dec 2016	QGC	103
522	160509A	-25.9089	149.5400	Existing	Hutton Sandstone	Fortnightly		Completed	QGC	103
523	Charlotte GW1	-25.9089	149.5400	Existing	Hutton Sandstone		six-monthly	Dec 2016	QGC	103
524	160508A	-25.9089	149.5401	Existing	Precipice Sandstone	Fortnightly		Completed	QGC	103
525	Charlotte GW2	-25.9089	149.5401	Existing	Precipice Sandstone		six-monthly	Dec 2016	QGC	103
526	160824A	-25.7994	149.0646	Existing	Hutton Sandstone	Fortnightly		Completed	Santos	104
527	160667A	-25.7995	149.0646	Existing	Precipice Sandstone	Fortnightly		Completed	Santos	104
528	160832A	-25.7996	149.0648	Existing	Bandanna Formation coal seam	Fortnightly		Completed	Santos	104
529	160736A	-25.8375	148.8510	Existing	Precipice Sandstone	Fortnightly		Completed	APLNG	105
530	160736A	-25.8375	148.8510	Existing	Precipice Sandstone		six-monthly	Completed	APLNG	105
531		-25.7974	148.8635	Not required	Boxvale Sandstone					106

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
532	OK Station	-25.7974	148.8635	Proposed	Precipice Sandstone	Fortnightly		Dec 2016	Santos	106
533	160698C	-25.7975	148.8635	Existing	Bandanna Formation coal seam	Fortnightly		Completed	Santos	106
534	160778A	-25.7658	148.8936	Existing	Bandanna Formation coal seam		six-monthly	Completed	Santos	106
681		-25.7970	148.8630	Proposed	Cattle Ck Formation	Fortnightly		2019	Santos	106
535		-25.7700	149.8900	Not required	Upper Juandah Coal Measures					107
536		-25.7700	149.8900	Not required	Lower Juandah Coal Measures					107
537		-25.7700	149.8900	Not required	Taroom Coal Measures					107
538	160473A	-25.7635	149.9772	Existing	Hutton Sandstone	Fortnightly		Completed	QGC	107
539	160473A	-25.7635	149.9772	Existing	Hutton Sandstone		six-monthly	Completed	QGC	107
672	Coochiemudlo GW2	-25.7630	149.9770	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	QGC	107
540	160653A	-25.7539	148.7948	Existing	Precipice Sandstone	Fortnightly		Completed	Santos	108
541	160779A	-25.7345	149.1252	Existing	Precipice Sandstone	Fortnightly		Completed	Santos	109
542	160779A	-25.7345	149.1252	Existing	Precipice Sandstone		six-monthly	Completed	Santos	109
543	160833A	-25.7347	149.1255	Existing	Bandanna Formation coal seam	Fortnightly		Completed	Santos	109
544	160716A	-25.8023	149.0897	Existing	Bandanna Formation coal seam		six-monthly	Completed	Santos	109
545	160780A	-25.7539	149.0420	Existing	Precipice Sandstone	Fortnightly		Completed	Santos	110
546	160780A	-25.7539	149.0420	Existing	Precipice Sandstone		six-monthly	Completed	Santos	110
547	160700A	-25.7537	149.0423	Existing	Bandanna Formation coal seam	Fortnightly		Completed	Santos	110
548	160715A	-25.7288	148.9867	Existing	Bandanna Formation coal seam		six-monthly	Completed	Santos	110
682		-25.7540	149.0420	Proposed	Cattle Ck Formation	Fortnightly		2019	Santos	110
549	13030814A	-25.7486	149.7333	Existing	Birkhead Formation	Fortnightly		Completed	QGC	111

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
550	160820A	-25.6441	149.1648	Existing	Clematis Sandstone	Fortnightly		Completed	Santos	112
551	160781A	-25.6583	149.1410	Existing	Bandanna Formation coal seam	Fortnightly		Completed	Santos	112
552	160787A	-25.6075	148.7654	Existing	Clematis Sandstone	Fortnightly		Completed	Santos	113
553	160815A	-25.6076	148.7650	Existing	Bandanna Formation coal seam	Fortnightly		Completed	Santos	113
554	160816A	-25.4896	148.9205	Existing	Bandanna Formation coal seam	Fortnightly		Completed	Santos	114
555	Lynd Range 1	-25.3898	149.0275	Proposed	Clematis Sandstone	Fortnightly		Dec 2016	Santos	115
556	Lynd Range 1	-25.3898	149.0275	Existing	Bandanna Formation coal seam	Fortnightly		Dec 2016	Santos	115
557		-25.2420	148.9269	Not required	Clematis Sandstone					116
558	160817A	-25.2919	148.9283	Existing	Bandanna Formation coal seam	Fortnightly		Completed	Santos	116
559	Cattle Creek 2H	-25.1086	148.9111	Existing	Clematis Sandstone	Fortnightly		Dec 2016	Santos	117
560	Cattle Creek 4	-25.1333	148.9132	Existing	Bandanna Formation coal seam	Fortnightly		Dec 2016	Santos	117
561	57565A	-24.8935	149.0941	Existing	Clematis Sandstone	Fortnightly		Completed	Santos	118
562	57565A	-24.8935	149.0941	Existing	Clematis Sandstone		six-monthly	Completed	Santos	118
563	57522A	-24.8460	149.0977	Existing	Clematis Sandstone	Fortnightly		Completed	Santos	119
564	57522A	-24.8460	149.0977	Existing	Clematis Sandstone		six-monthly	Completed	Santos	119
565	160770A	-25.6911	149.1875	Existing	Boxvale Sandstone	Fortnightly		Completed	APLNG	120
566	160771A	-25.6915	149.1877	Existing	Precipice sandstone	Fortnightly		Completed	APLNG	120
567		-25.6843	149.1875	Not required	Bandanna Formation coal seam					120
568		-25.6843	149.1875	Not required	Bandanna Formation coal seam					120
569		-27.2470	150.0230	Not required	Springbok Sandstone					121

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
570		-27.2470	150.0230	Not required	Upper Juandah Coal Measures					121
571		-26.9346	149.6603	Proposed	Springbok Sandstone	Fortnightly		2017	Santos	122
572		-26.9346	149.6603	Proposed	Coal seam of the Upper Juandah Coal Measures	Fortnightly		2017	Santos	122
573		-26.9346	149.6603	Proposed	Coal seam of the Lower Juandah Coal Measures	Fortnightly		2017	Santos	122
574	Karana - KNAGWW CM01	-25.9266	148.6359	Proposed	Walloon Coal Measures	Fortnightly		Dec 2016	Santos	123
575	160818A	-25.9266	148.6359	Existing	Hutton Sandstone	Fortnightly		Completed	Santos	123
576	160819A	-25.9267	148.6359	Existing	Precipice Sandstone	Fortnightly		Completed	Santos	123
577	Karana - KNAGWBA 01	-25.9266	148.6359	Proposed	Bandanna Formation coal seam	Fortnightly		Dec 2016	Santos	123
578	41620043A	-27.9222	151.1214	Existing	Springbok Sandstone	Fortnightly		Completed	Arrow	124
579		-27.9245	151.1249	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Dec 2016	Arrow	124
580	42220101A	-26.3381	149.5033	Existing	Mooga Sandstone	Fortnightly		Completed	APLNG	125
581	Moonie 35	-27.7612	150.2458	Existing	Precipice Sandstone	Fortnightly		Dec 2016	Santos	126
582	160782A	-25.9297	150.0297	Existing	Bandanna Formation coal seam	Fortnightly		Completed	Santos	127
583	Peat MB1-B	-26.0022	150.0841	Existing	Bandanna Formation coal seam	Fortnightly		Mar 2016	APLNG	128
646	Peat MB2-P	-26.0152	150.0958	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	APLNG	128
584	160660A	-25.8245	148.7916	Existing	Hutton Sandstone	Fortnightly		Completed	Santos	129
585	160783A	-25.6221	148.9619	Existing	Precipice Sandstone	Fortnightly		Completed	Santos	130
586	160783A	-25.6221	148.9619	Existing	Precipice Sandstone		six-monthly	Completed	Santos	130
587	160784A	-25.6223	148.9619	Existing	Bandanna Formation coal seam	Fortnightly		Completed	Santos	130

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
588	160834A	-25.6333	148.9452	Existing	Bandanna Formation coal seam		six-monthly	Completed	Santos	130
589	160737A	-26.0751	149.0138	Existing	Precipice Sandstone	Fortnightly		Completed	APLNG	131
590	160737A	-26.0751	149.0138	Existing	Precipice Sandstone		six-monthly	Completed	APLNG	131
591	160825A	-26.0428	149.0524	Existing	Bandanna Formation coal seam	Fortnightly		Completed	APLNG	131
592	160831A	-25.9642	148.9525	Existing	Precipice Sandstone	Fortnightly		Completed	APLNG	132
593		-25.9452	148.9736	Not required	Precipice Sandstone					132
594	160743A	-25.9508	148.9734	Existing	Bandanna Formation coal seam	Fortnightly		Completed	APLNG	132
647	Spring Gully MB14-H	-25.9642	148.9525	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	APLNG	132
595	42231591A	-27.5913	151.8467	Existing	Main Range Volcanics	Fortnightly		Completed	Arrow	133
596		-27.5913	151.8467	Not required	Coal seam of the Upper Juandah Coal Measures					133
597	42231597A	-27.7309	151.7628	Existing	Main Range Volcanics	Fortnightly		Completed	Arrow	134
598	160804A	-27.7272	151.7633	Existing	Coal seam of the Taroom Coal Measures (Upper)	Fortnightly		Completed	Arrow	134
599	42231411A	-27.8251	151.4764	Existing	Condamine alluvium	Fortnightly		Completed	Arrow	135
600		-27.7540	151.3116	Proposed	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Dec 2016	Arrow	135
601	160805A	-26.9308	151.2881	Existing	Main Range Volcanics	Fortnightly		Completed	Arrow	136
602	42231553A	-26.9214	151.2871	Existing	Hutton Sandstone	Fortnightly		Completed	Arrow	136
603	42231523A	-27.2743	151.6934	Existing	Main Range Volcanics	Fortnightly		Completed	Arrow	137
604	42231524A	-27.2493	151.6915	Existing	Walloon Coal Measures	Fortnightly		Completed	Arrow	137
605	42231590A	-27.2681	151.7701	Existing	Hutton Sandstone	Fortnightly		Completed	Arrow	137

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
606		-23.4558	148.9483	Proposed	Bandanna Formation coal seam	Fortnightly		2 years prior to production within 10km	Arrow	138
607	Wallaroo Creek 1	-25.3570	148.7511	Existing	Bandanna Formation coal seam	Fortnightly		Dec 2016	Santos	139
608	Polaris GW24	-26.1568	149.7998	Proposed	Upper Juandah Coal Measures	Fortnightly		Mar 2016	QGC	140
609	Polaris GW24	-26.1568	149.7998	Proposed	Lower Juandah Coal Measures	Fortnightly		Mar 2016	QGC	140
610	Polaris GW24	-26.1568	149.7998	Proposed	Taroom Coal Measures	Fortnightly		Mar 2016	QGC	140
611	160630A	-26.1619	149.4143	Existing	Springbok Sandstone	Fortnightly		Completed	APLNG	141
612	160772C	-26.1623	149.4140	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	APLNG	141
613	160772B	-26.1623	149.4140	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	APLNG	141
614	160772A	-26.1623	149.4140	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	APLNG	141
615	160699D	-26.9732	150.6118	Existing	Springbok Sandstone	Fortnightly		Completed	Arrow	142
616	160699C	-26.9732	150.6118	Existing	Coal seam of the Upper Juandah Coal Measures	Fortnightly		Completed	Arrow	142
617	160699B	-26.9732	150.6118	Existing	Coal seam of the Lower Juandah Coal Measures	Fortnightly		Completed	Arrow	142
618	160699A	-26.9732	150.6118	Existing	Coal seam of the Taroom Coal Measures	Fortnightly		Completed	Arrow	142
626	Kedron570	-26.4134	150.1537	Other existing	Upper Juandah Coal Measures	Fortnightly		Dec 2016	Arrow	143
627	Kedron570	-26.4134	150.1537	Other existing	Tangalooma Sandstone	Fortnightly		Dec 2016	Arrow	143
628	Kedron570	-26.4134	150.1537	Other existing	Eurombah Formation	Fortnightly		Dec 2016	Arrow	143

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
629	Kedron570	-26.4134	150.1537	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	Arrow	143
630	Kedron570	-26.4134	150.1537	Other existing	Springbok Sandstone	Fortnightly		Dec 2016	Arrow	143
648	Condabri-INJ3	-26.7867	150.2248	Other existing	Gubberamunda Sandstone	Fortnightly		Dec 2016	APLNG	144
649	Condabri-INJ1-H	-26.7864	150.2239	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	APLNG	144
650	Condabri-INJ2-P	-26.7870	150.2245	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	APLNG	144
651	Reedy Ck INJ3-H	-26.3472	149.3758	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	APLNG	145
652	Reedy Ck INJ4-P	-26.3473	149.3763	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	APLNG	145
653	Spring Gully DMH01	-26.0005	149.0710	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	APLNG	146
654	Spring Gully DMP01	-26.0004	149.0714	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	APLNG	146
655	14881	-25.8881	149.3314	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	APLNG	147
656	Spring Gully MB4-H	-26.0750	149.0138	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	APLNG	148
657	Peat MB3-H	-26.0152	150.0958	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	APLNG	149
658	Kinnoul MB2-H	-25.6648	149.5973	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	APLNG	150
659	Scotts Ck Sawmill Bore	-25.8765	149.0627	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	APLNG	151
660	Strathblane WB1-P	-25.9002	149.1444	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	APLNG	152

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
661	PB3	-25.9818	149.0465	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	APLNG	153
673	Cassio GW1	-25.9454	149.7754	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	QGC	154
674	Cassio GW2	-25.9454	149.7754	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	QGC	154
683	MW0904	-25.7095	148.9516	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	Santos	155
684	23147	-25.9143	150.0739	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	Santos	156
685	MW0902	-25.7347	149.0829	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	Santos	157
686	MNHGWP 02	-25.7310	148.8458	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	Santos	158
687	Scotia OBS#1 (AVLOP01)	-25.9419	150.0742	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	Santos	159
688	160287A	-25.7283	149.0819	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	Santos	160
689	160351A	-25.7236	149.0628	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	Santos	161
690	160352A	-25.7267	149.0183	Other existing	Precipice Sandstone	Fortnightly		Dec 2016	Santos	162
691	Glenora-4M	-26.3025	149.1085	Proposed	Gubberamunda Sandstone	Fortnightly		Dec 2016	Senex	163
692	Glenora-4M	-26.3025	149.1085	Proposed	Springbok Sandstone	Fortnightly		Dec 2016	Senex	163
693	Glenora-4M	-26.3025	149.1085	Proposed	Upper Juandah Coal Measures	Fortnightly		Dec 2016	Senex	163
694	Glenora-4M	-26.3025	149.1085	Proposed	Lower Juandah Coal Measures	Fortnightly		Dec 2016	Senex	163
695	Glenora-4M	-26.3025	149.1085	Proposed	Taroom Coal Measures	Fortnightly		Dec 2016	Senex	163

Monitoring Point	Existing Reference	Location		Status	Target Formation	Water Pressure Monitoring Frequency	Water Quality Monitoring Frequency	Required By	RTH	UWIR Site No
		Latitude	Longitude							
696	Glenora-4M	-26.3025	149.1085	Proposed	Hutton Sandstone	Fortnightly		Dec 2016	Senex	163
697	Tethys-6M	-26.2627	148.8662	Proposed	Gubberamunda Sandstone	Fortnightly		Dec 2016	Senex	164
698	Tethys-6M	-26.2627	148.8662	Proposed	Springbok Sandstone	Fortnightly		Dec 2016	Senex	164
699	Tethys-6M	-26.2627	148.8662	Proposed	Upper Juandah Coal Measures	Fortnightly		Dec 2016	Senex	164
700	Tethys-6M	-26.2627	148.8662	Proposed	Lower Juandah Coal Measures	Fortnightly		Dec 2016	Senex	164
701	Tethys-6M	-26.2627	148.8662	Proposed	Taroom Coal Measures	Fortnightly		Dec 2016	Senex	164
702	Tethys-6M	-26.2627	148.8662	Proposed	Hutton Sandstone	Fortnightly		Dec 2016	Senex	164
703	Pegasus-2M	-26.1608	148.9135	Proposed	Hutton Sandstone	Fortnightly		2018	Senex	165
704	Maisey 1M	-26.4506	149.2111	Proposed	Gubberamunda Sandstone	Fortnightly		2018	Senex	166
705	Maisey 1M	-26.4506	149.2111	Proposed	Springbok Sandstone	Fortnightly		2018	Senex	166
706	Maisey 1M	-26.4506	149.2111	Proposed	Upper Juandah Coal Measures	Fortnightly		2018	Senex	166
707	Maisey 1M	-26.4506	149.2111	Proposed	Lower Juandah Coal Measures	Fortnightly		2018	Senex	166
708	Maisey 1M	-26.4506	149.2111	Proposed	Taroom Coal Measures	Fortnightly		2018	Senex	166
709	Maisey 1M	-26.4506	149.2111	Proposed	Hutton Sandstone	Fortnightly		2018	Senex	166
632	107800	-26.9968	150.8498	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	APLNG	167
637	160708	-26.5439	149.8864	Other existing	Hutton Sandstone	Fortnightly		Dec 2016	APLNG	168
644	42231522	-26.8646	150.4870	Other existing	Springbok Sandstone	Fortnightly		Dec 2016	QGC	169
710	123050	-26.3225	148.8975	Other existing	Hutton Sandstone		six-monthly	Dec 2016	Santos	170

Table G-2 below provides details of a complementary network of private bores (Section 8.3.1) some of which already form part of the CSG Online network. The remainder will be added into this network, subject to confirmation that these bores are suitable for monitoring purposes.

Table G-2 Complementary Monitoring Network

Existing reference	Location		Status	Target formation
	Latitude	Longitude		
Bore 1	-27.94	149.31	Existing	Gubberamunda Sandstone
Bore 2	-28.16	150.47	Existing	Gubberamunda Sandstone
Bore 3	-25.55	149.81	Existing	Hutton Sandstone
Bore 4	-25.55	149.81	Existing	Hutton Sandstone
Bore 5	-25.61	147.98	Existing	Hutton Sandstone
Bore 6	-25.41	148.11	Existing	Hutton Sandstone
Bore 7	-27.12	148.33	Existing	Hutton Sandstone
Bore 8	-25.43	150.05	Existing	Precipice Sandstone
Bore 9	-24.38	149.14	Existing	Clematis Sandstone
Bore 10	-23.95	149.23	Existing	Clematis Sandstone
Bore 11	-25.61	148.04	Existing	Evergreen Formation
13030613	-25.6775	148.5269	Existing	Hutton Sandstone
13030882	-25.8028	148.7728	Existing	Precipice Sandstone
13030883	-25.8028	148.7727	Existing	Evergreen Formation
13030884	-25.8028	148.7728	Existing	Hutton Sandstone
123444	-26.1928	149.3433	Existing	Hutton Sandstone
62284	-25.5588	149.4358	Existing	Precipice Sandstone

Table G-3 Regional Monitoring Network Water Quality Parameter Suite

Suite		Parameters to be measured as part of suite
Water quality suite	Field parameters	Electrical Conductivity (µS/cm @ 25°C), pH, Redox Potential (Eh), Temperature (°C), Free gas at wellhead (CH_4)
	Laboratory analytes	Major cations and anions: Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Sodium (Na^+), Bicarbonate(HCO_3^-), Carbonate (CO_3^-), Chloride (Cl^-), Sulphate (SO_4^{2-}), Total Alkalinity
		Metals (dissolved): Arsenic (As), Barium (Ba), Boron (B), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Mercury (Hg), Nickel (Ni), Selenium (Se), Strontium (Sr^{2+}), Zinc (Zn)
		Fluoride (F^-), Total Dissolved Solids
		Gas (dissolved): Methane (CH_4)

Appendix G-2 Guidelines for the construction of new monitoring points

Three standards apply to the construction of monitoring bores in the Surat CMA:

- Minimum construction requirements for water bores in Australia (NUDL, 2012)
- Minimum standards for the construction and reconditioning of water bores that intersect the sediments of artesian basins in Queensland (DNRM, 2014) and
- Code of practice for the construction and abandoning of coal seam gas wells and associated water bores in Queensland (DNRM, 2013).

The following section provides additional guidance on matters such as borehole access, effective monitoring intervals and instrumentation for new pressure and water quality monitoring points. All new monitoring points required under the Water Monitoring Strategy (WMS) are to be constructed in a way that is consistent with the above standards and the following guidelines.

Water pressure monitoring points

1. *Borehole access*

   Access to down-hole equipment and instrumentation should be able to be undertaken by a small crew and generally completed within a single day (including removal and replacement of well caps and monitoring instrumentation) without the need for specialist equipment or a workover rig.

2. *Isolation of the target horizon and the effective monitoring interval*

   Monitoring bore and screen design should effectively isolate a small number of permeable units which are all considered to be part of the same target formation.

   Where multiple permeable units are logged within the same formation, the screened section should target the units in closest proximity to the targeted coal reservoirs, whilst maintaining at least five metres separation from adjacent formations.

   For pressure monitoring points in formations other than target coal reservoirs, the effective screened interval should be within the range of six to 24 metres to minimise the potential for inadvertently completing the bore within a low-permeability unit or extending the bore substantially into an adjacent formation.

   For pressure monitoring points installed into target coal reservoirs, the effective screen interval should mimic the design of local CSG production wells and should therefore typically comprise multiple screened sections and relatively long effective screen intervals. The effective screen interval should be no less than six metres with maximum lengths governed by the logged thickness of the target formation. This design incorporating long effective screen intervals is intended to minimise the possibility of installing monitoring points into isolated coal horizons and/or interburden which may not be affected by CSG extraction in the short term.

   Screen designs should be finalised on site based on downhole geophysics and geological logs.

3. *Pressure monitoring instrument selection and accuracy*

   The type and make of instrumentation installed should achieve the following:

   - Be of proven reliability, easy to obtain, serviceable, long lasting and appropriate for the conditions (including water quality, temperature and operating environment)
   - Can operate at the deployed depth and monitor the expected range of water pressures in the bore
   - Capable of measuring temperature as well as pressure

- Capable of accurately recording and resolving pressure changes or drawdowns of less than 1 percent of the predicted maximum drawdown at each monitoring point or 1 centimetre whichever is the larger.
- Can be calibrated, easily and reliably deployed (including cabling and connections) and is replaceable.

4. *Pressure data validation*

The bore design should allow for the following:

- Data validation, either via regular manual check readings or through the use of temporarily or permanently installed duplicate gauges
- As a minimum, data validation readings should be undertaken every six months and/or at the end of each download period (whichever period is shorter)
- Quality assurance of multi-level facilities should include regular comparison of data from different monitoring levels to look for trends, data anomalies and identify any evidence of within bore communication
- Where possible/applicable, validation readings should be used to correct for logger ‘drift’ and other artefacts prior to the final data sets being provided to OGIA.

5. *Data access*

Where a logger is installed, pressure should be logged continuously at a frequency of one reading per hour (i.e. 24 readings per day) to assist with identifying trends and possible reasons for variations.

6. *Monitoring bore completion diagram*

All relevant details relating to the pressure monitoring point should be recorded on a suitable monitoring bore completion diagram or diagrams. These diagrams should be provided to OGIA prior to the monitoring point being considered active. As a minimum each completion diagram should include:

- The location, type and dimensions of all seals installed to prevent water movement within the bore
- The location, type and dimensions of all screens installed to allow water ingress into the bore
- Lithological, geophysical and interpreted stratigraphic logs of the bore
- Detail on the installed headworks sufficient to identify/confirm any access constraints
- The location and type of all pressure and water quality monitoring instruments or other equipment installed in the bore
- Observed post completion standing water level and any available information on water strikes identified during drilling
- Surveyed ground, datum levels and location information
- Date of drilling, installation and commissioning and
- Confirmation of data logging frequencies, data download methods, purging and sampling methods and whether/how data validation checks are undertaken.

Water quality monitoring points

In addition to the above, the following guidance on water quality monitoring points is provided:

7. *Purging and sampling*

   Collection of the water sample should be able to be undertaken in less than one day.

   Purging and monitoring of field water quality parameters (for stabilisation) is undertaken to ensure representative groundwater samples from the targeted formation. Water quality sampling should not have a significant effect on water pressure and 90 per cent recovery should occur within two weeks of sampling.

   Sampling equipment is dedicated within the bore, thereby limiting potential cross contamination. Sampling techniques limit any contamination/interaction with groundwater that may alter chemical and/or physical properties.

   Sampling technique minimises volumes of purge water generated to reduce possible handling and disposal requirements.

   Sampling intake is at or near the centre of the screen to promote flow through the borehole screen rather than sampling from the annulus.

Monitoring bore types

Consistent with the standards mentioned above, for relatively shallow bores where there is no gas risk an aquifer monitoring bore completion is preferred, while for monitoring points where there is a potential gas risk a coal seam gas type completion is preferred. Cemented in vibrating wire piezometers are not preferred based on sections 1-7 above.

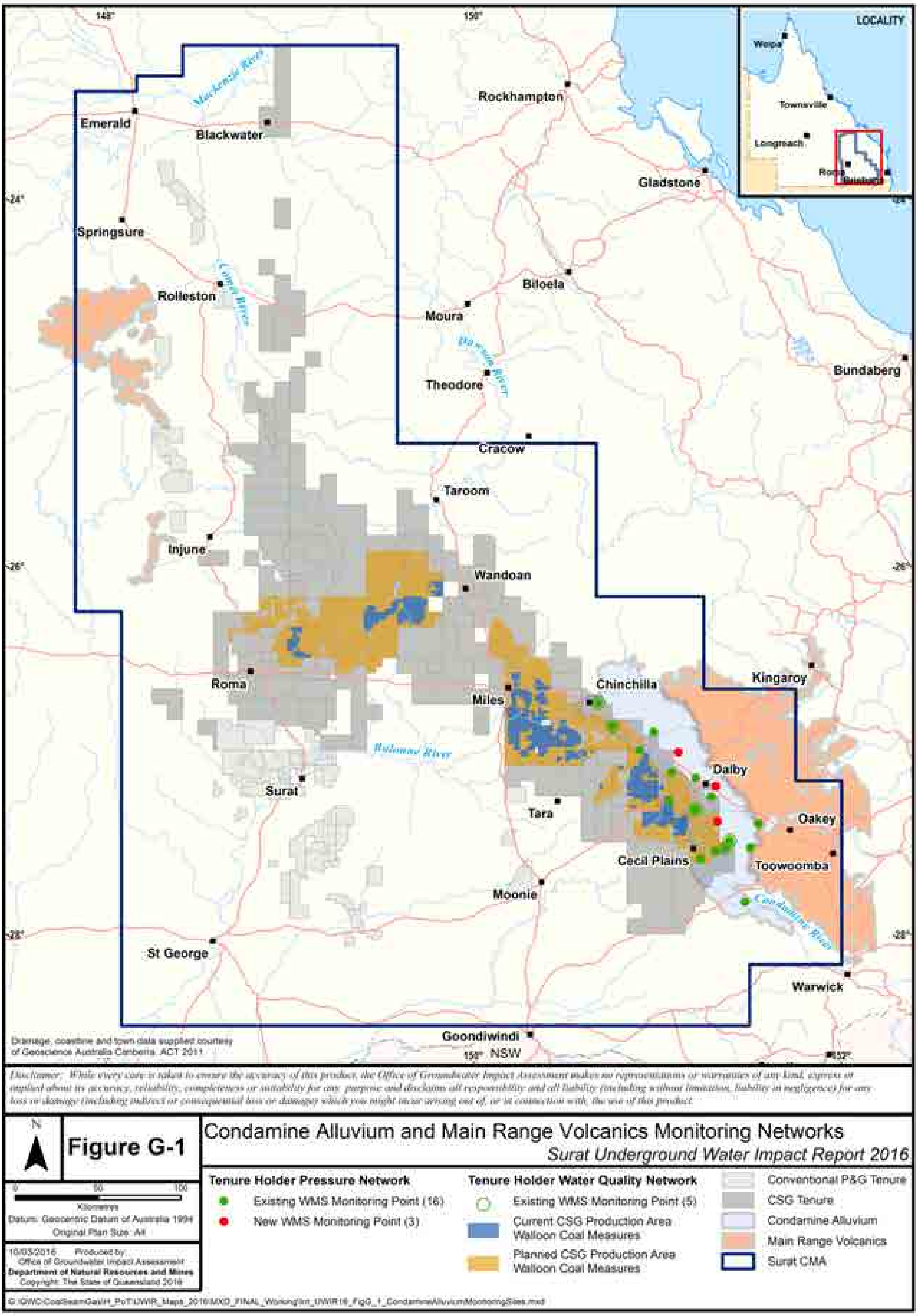


Figure G-1 Condamine Alluvium and Main Range Volcanics Monitoring Networks

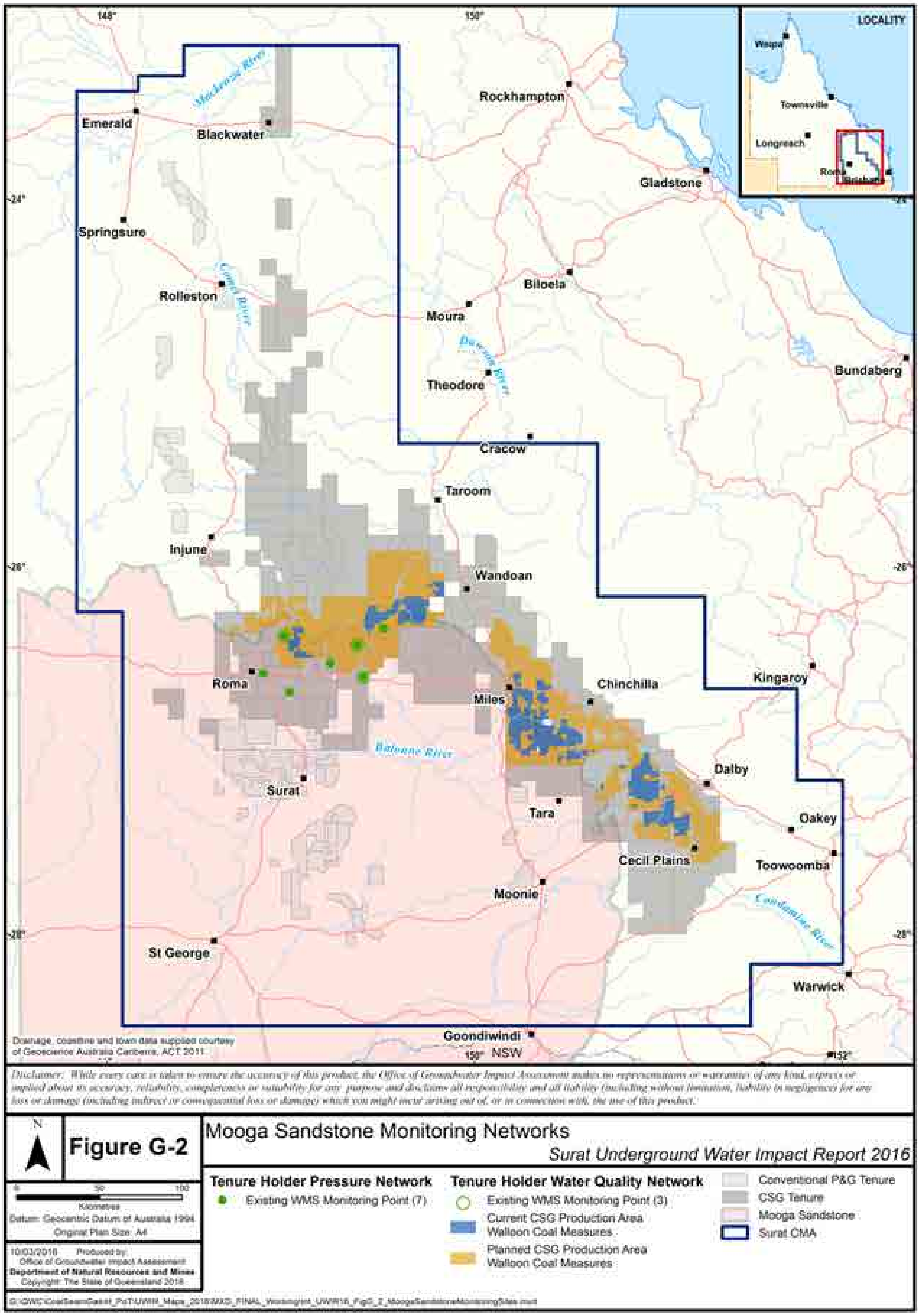


Figure G-2 Mooga Sandstone Monitoring Networks

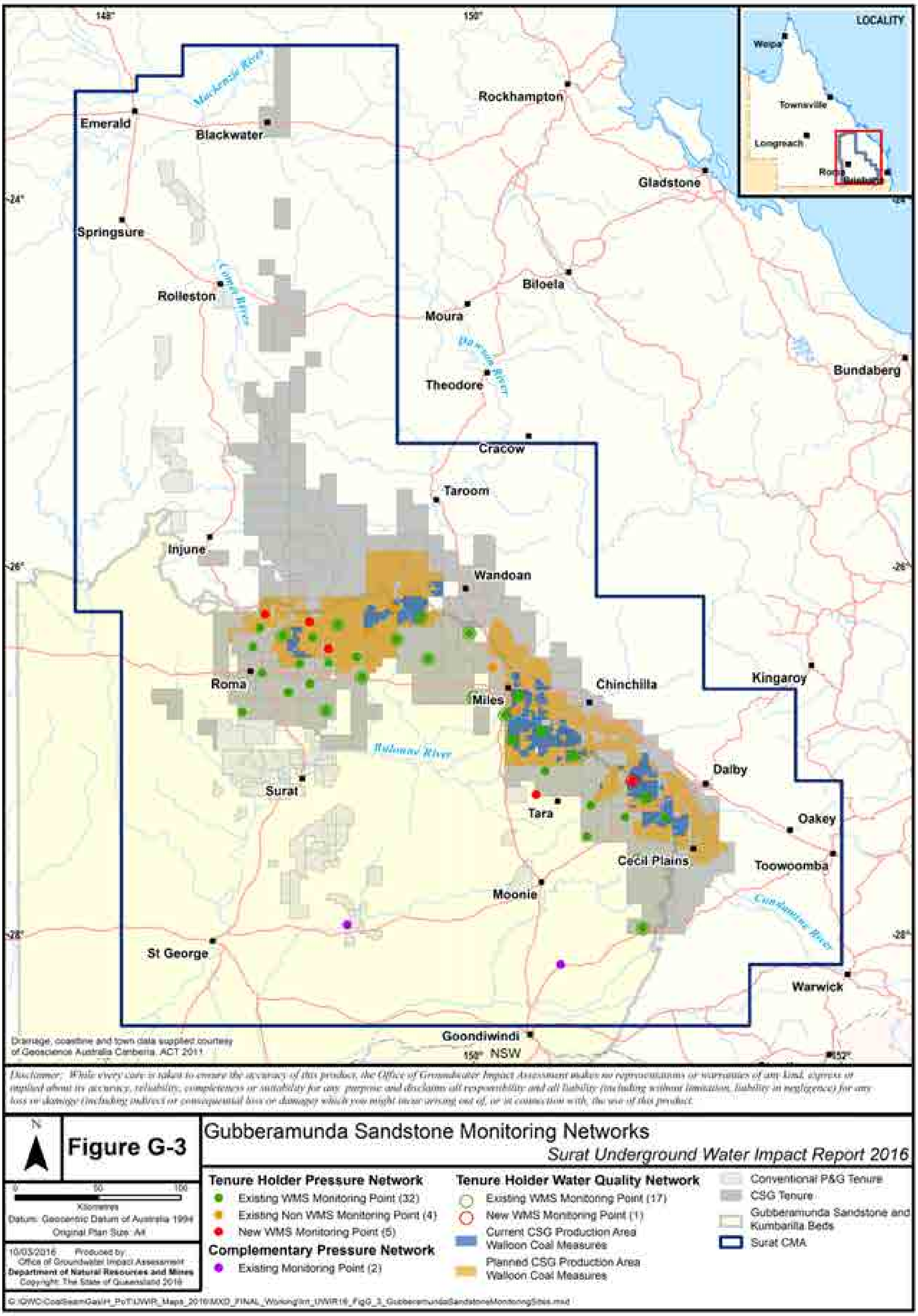


Figure G-3 Gubberamunda Sandstone Monitoring Networks

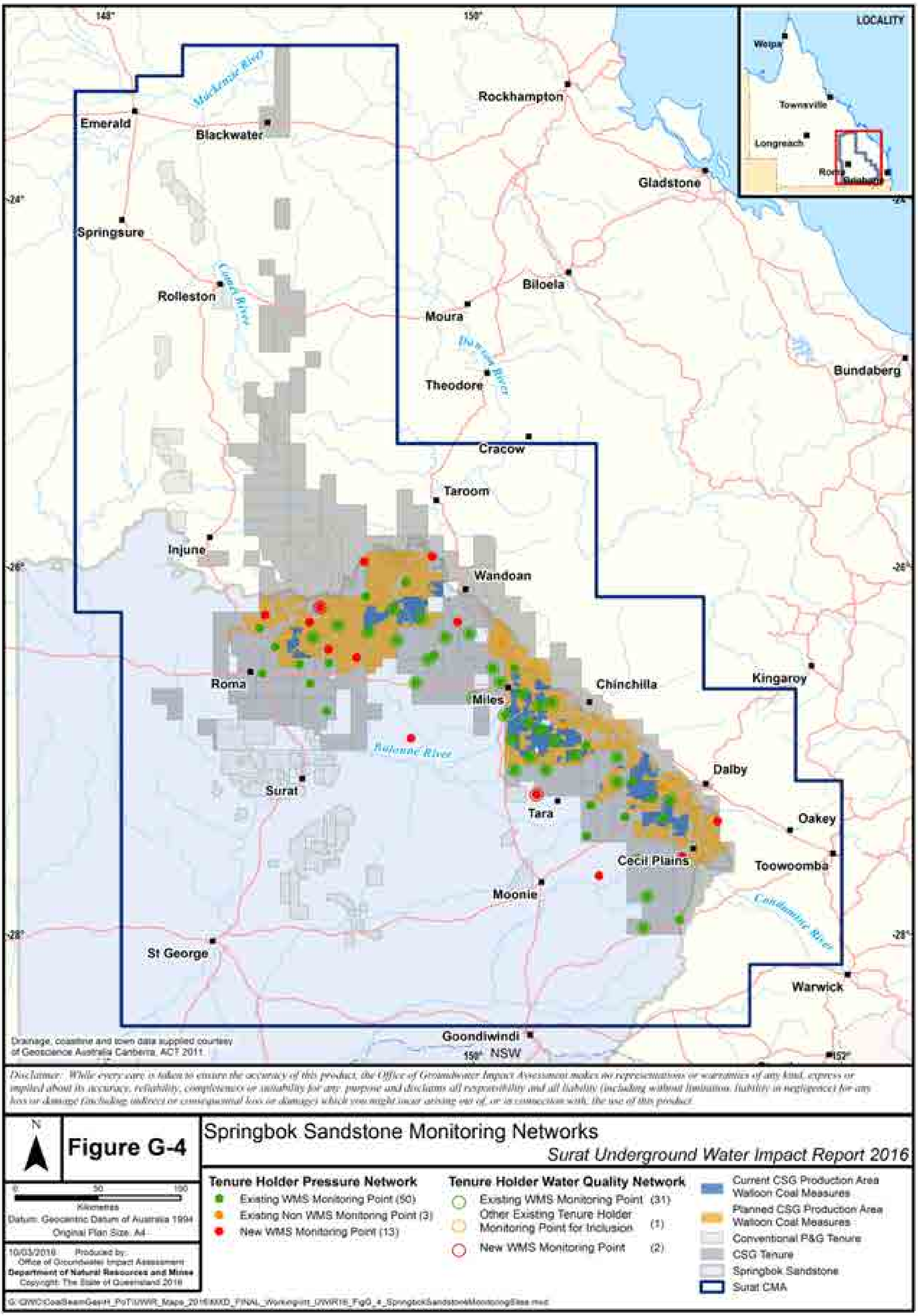


Figure G-4 Springbok Sandstone Monitoring Networks

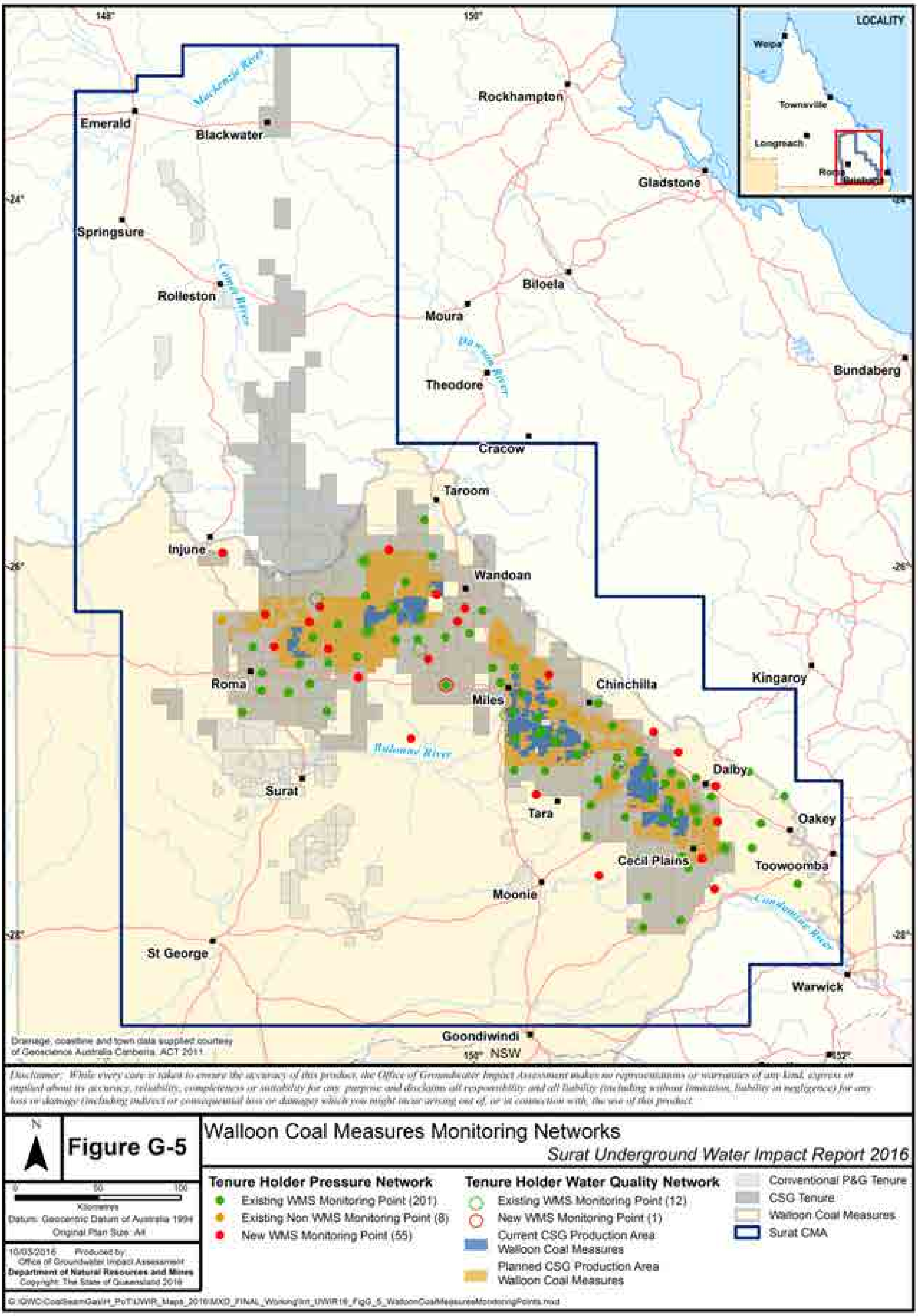


Figure G-5 Walloon Coal Measures Monitoring Networks

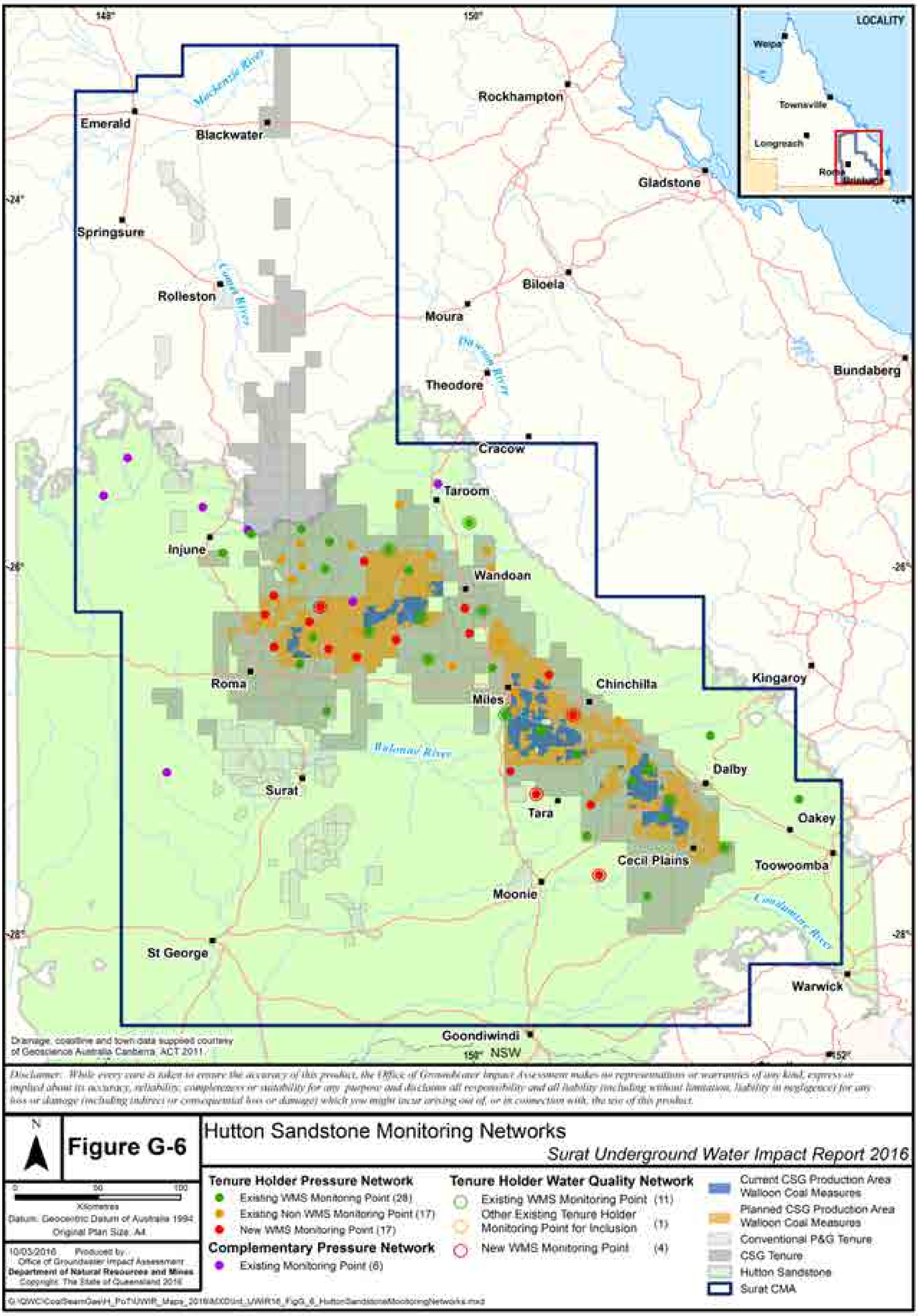


Figure G-6 Hutton Sandstone Monitoring Networks

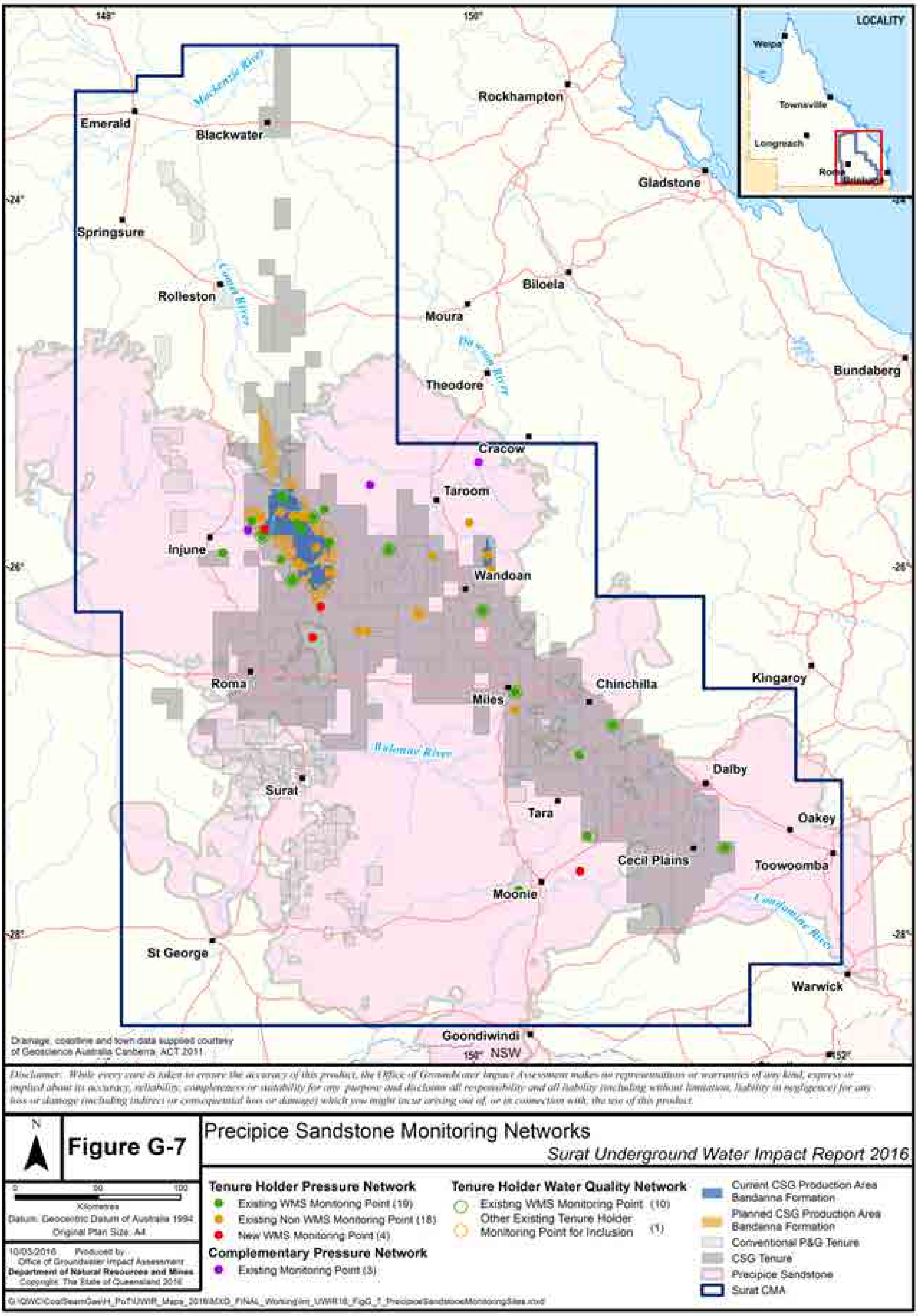
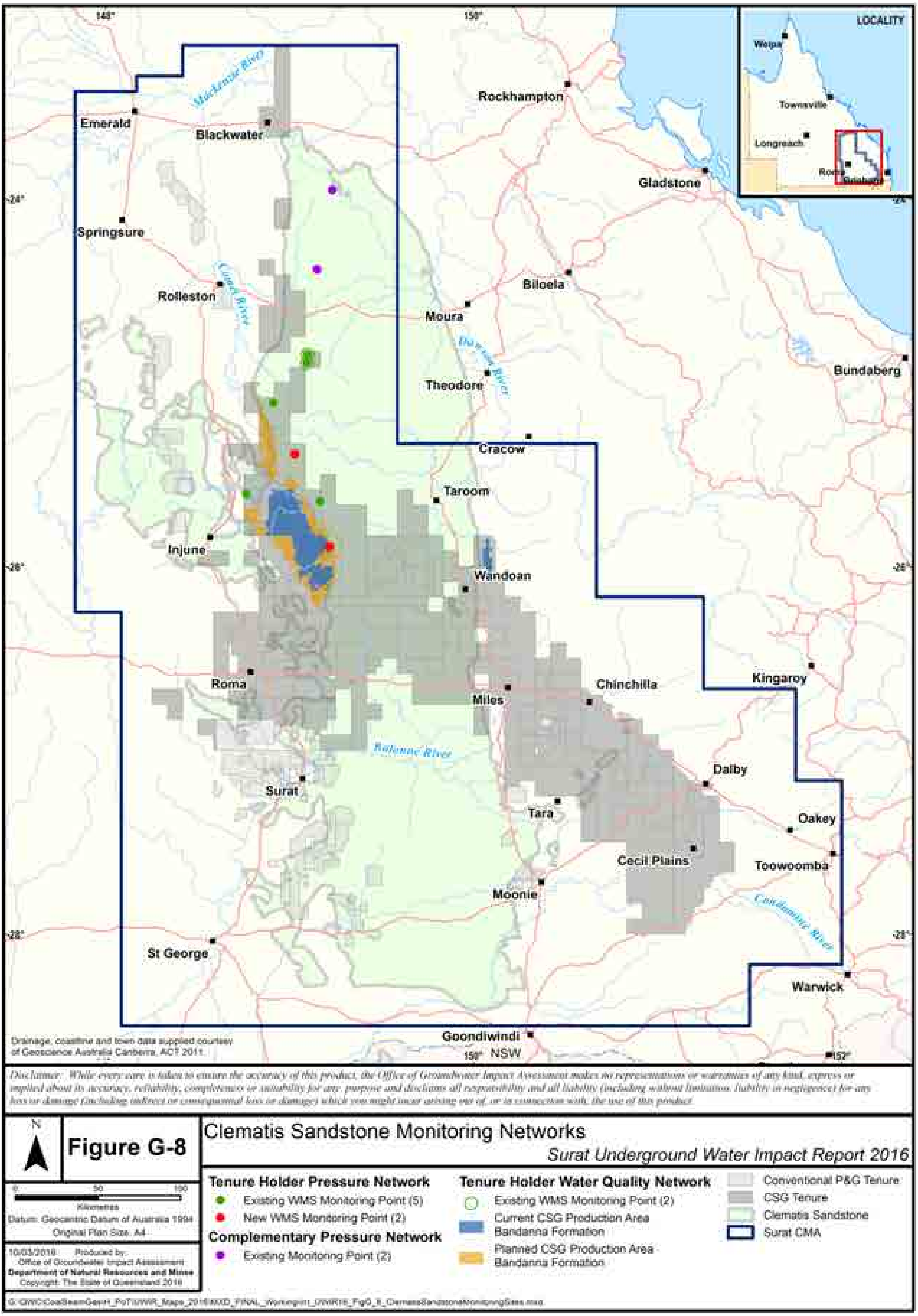


Figure G-7 Precipice Sandstone Monitoring Networks



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

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Datum: Geocentric Datum of Australia 1994
Original Plan Size: A4

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Figure G-8 Clematis Sandstone Monitoring Networks

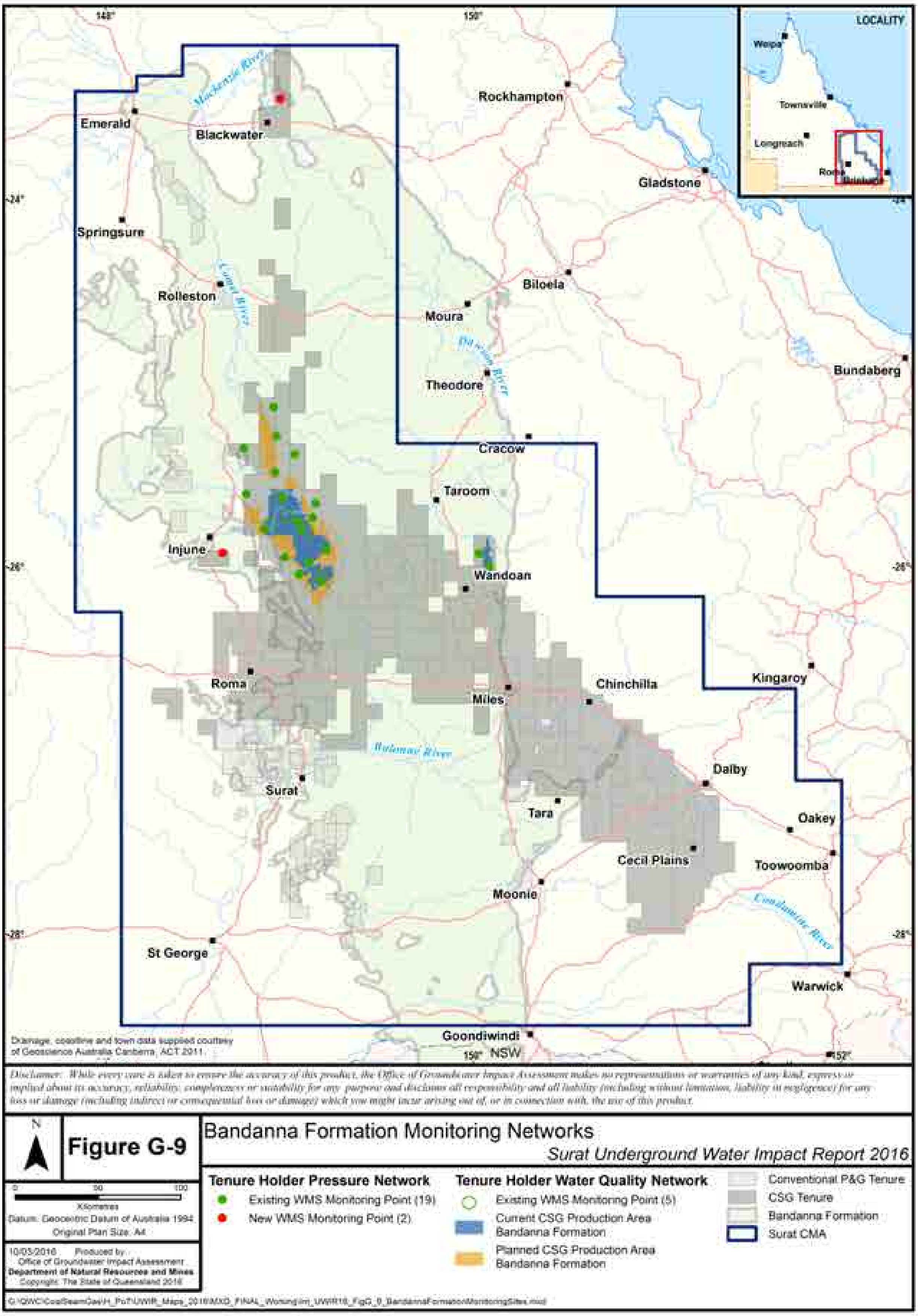

Figure G-9 Bandanna Formation Monitoring Networks

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Appendix H. Details of the Spring Impact Management Strategy

Appendix H-1. Springs in the Surat CMA

The Water Act provides that a spring is a ***potentially affected spring*** if it overlies an aquifer where the long-term predicted impact on water levels at the location of the spring resulting from the extraction of water by petroleum tenure holders exceeds 0.2 metres. There are 61 spring vents and 19 watercourse springs identified as potentially affected.

Table H-1 and Table H-2 list the potentially affected spring vents and watercourse springs. The following definitions apply to the table columns.

Complex – As defined by the Queensland Springs Dataset held by the Queensland Herbarium. Watercourse springs do not have a complex number.

Vent – As defined by the Queensland Springs Dataset held by the Queensland Herbarium. For the watercourse springs the ***site number*** is defined in the GAB Springs Register held by DNRM.

Source aquifer – The aquifer providing the greatest contribution to groundwater discharge at the spring.

Geological control – The dominant geological control for groundwater discharge to the spring.

Type – The spring type using the spring typology (Section 4.7.2).

Confidence – 'High' means field data has been collected to support site understanding and classification. 'Low' means that some attributes for classification have been inferred in the absence of field data.

Table H-1 Spring vents – location and hydrogeology

Location					Hydrogeology			
Complex	**Name**	**Vent**	**Latitude**	**Longitude**	**Source aquifer**	**Geological control**	**Type**	**Confidence**
74	Yebna	1182_1	-25.648424	149.201115	Evergreen Formation (Boxvale Sandstone Member)	Outcrop	3	High
229	Ponies	284_1	-25.829550	149.041382	Hutton Sandstone	Outcrop	4b	High
229	Ponies	284_2	-25.829805	149.040104	Hutton Sandstone	Outcrop	4b	High
230	Lucky Last	287_1	-25.798065	148.775579	Evergreen Formation (Boxvale Sandstone Member)	Fault	1a	High
230	Lucky Last	340_1	-25.793992	148.773174	Evergreen Formation (Boxvale Sandstone Member)	Fault	1a	High
230	Lucky Last	686_1	-25.794778	148.773408	Evergreen Formation (Boxvale Sandstone Member)	Fault	1a	High
230	Lucky Last	687.1_1	-25.794624	148.773846	Evergreen Formation (Boxvale Sandstone Member)	Fault	1a	High
230	Lucky Last	687.2_1	-25.794561	148.773783	Evergreen Formation (Boxvale Sandstone Member)	Fault	1a	High
230	Lucky Last	687.3_1	-25.794202	148.773613	Evergreen Formation (Boxvale Sandstone Member)	Fault	1a	High
230	Lucky Last	687.4_1	-25.794118	148.773541	Evergreen Formation (Boxvale Sandstone Member)	Fault	1a	High
230	Lucky Last	687.5_1	-25.793680	148.773296	Evergreen Formation (Boxvale Sandstone Member)	Fault	1a	High
230	Lucky Last	687.6_1	-25.793595	148.773319	Evergreen Formation (Boxvale Sandstone Member)	Fault	1a	High
230	Lucky Last	687_1	-25.794811	148.773780	Evergreen Formation (Boxvale Sandstone Member)	Fault	1a	High
230	Lucky Last	688_1	-25.795114	148.773748	Evergreen Formation (Boxvale Sandstone Member)	Fault	1a	High
230	Lucky Last	689_1	-25.793990	148.772839	Evergreen Formation (Boxvale Sandstone Member)	Fault	1a	High
260	Scotts Creek	189_1	-25.891509	149.285983	Hutton Sandstone	Fault	1a	High
260	Scotts Creek	190_1	-25.888437	149.287415	Hutton Sandstone	Fault	1b	High
260	Scotts Creek	191_1	-25.891755	149.287484	Hutton Sandstone	Fault	1a	High

Location					Hydrogeology			
Complex	**Name**	**Vent**	**Latitude**	**Longitude**	**Source aquifer**	**Geological control**	**Type**	**Confidence**
260	Scotts Creek	192.1_1	-25.888114	149.279189	Hutton Sandstone	Fault	1b	High
260	Scotts Creek	192_1	-25.888958	149.279041	Hutton Sandstone	Fault	1b	High
283	Barton	702_1	-26.270303	149.243285	Gubberamunda Sandstone	Outcrop	3	High
283	Barton	703_1	-26.285333	149.234459	Gubberamunda Sandstone	Outcrop	3	High
311	311	699_1	-25.725790	149.086617	Precipice Sandstone	Outcrop	3	High
311	311	499_1	-25.700240	149.128935	Precipice Sandstone	Outcrop	3	High
311	311	500.1_1	-25.728175	149.100451	Precipice Sandstone	Outcrop	3	High
311	311	500_1	-25.719758	149.104836	Precipice Sandstone	Outcrop	3	High
311	311	535_1	-25.720200	149.027508	Precipice Sandstone	Outcrop	3	High
311	311	536.1_1	-25.713623	149.065391	Precipice Sandstone	Outcrop	3	High
311	311	536.2_1	-25.715544	149.064819	Precipice Sandstone	Outcrop	3	High
311	311	536_1	-25.714499	149.065431	Precipice Sandstone	Outcrop	3	High
311	311	537_1	-25.728340	149.093903	Precipice Sandstone	Outcrop	3	High
311	311	692_1	-25.725986	149.103740	Precipice Sandstone	Outcrop	3	High
311	311	693_1	-25.720666	149.029633	Precipice Sandstone	Outcrop	3	High
311	311	694_1	-25.712394	149.072622	Precipice Sandstone	Outcrop	3	High
311	311	695_1	-25.725415	149.086946	Precipice Sandstone	Outcrop	3	High
311	311	696_1	-25.725471	149.086885	Precipice Sandstone	Outcrop	3	High
311	311	697_1	-25.725599	149.086748	Precipice Sandstone	Outcrop	3	High
311	311	698_1	-25.725630	149.086671	Precipice Sandstone	Outcrop	3	High
311	311	704_1	-25.679718	149.127267	Precipice Sandstone	Outcrop	3	High
358	Gubberamunda	187_1	-26.218956	148.670302	Gubberamunda Sandstone	Outcrop	4b	High
358	Gubberamunda	188_1	-26.269476	148.705438	Gubberamunda Sandstone	Outcrop	4b	High
358	Gubberamunda	679_1	-26.278483	148.695873	Gubberamunda Sandstone	Outcrop	4b	Low
358	Gubberamunda	680.1_1	-26.273627	148.687319	Gubberamunda Sandstone	Outcrop	4b	Low
358	Gubberamunda	680_1	-26.273135	148.686824	Gubberamunda Sandstone	Outcrop	4b	Low
437	Horror	682.1_1	-25.807686	148.733995	Hutton Sandstone	Outcrop	2	High
437	Horror	682_1	-25.808097	148.734199	Hutton Sandstone	Outcrop	2	High

Location					Hydrogeology			
Complex	**Name**	**Vent**	**Latitude**	**Longitude**	**Source aquifer**	**Geological control**	**Type**	**Confidence**
506	Spring Ridge	184_1	-26.233352	148.868584	Gubberamunda Sandstone	Outcrop	4b	High
506	Spring Ridge	185_1	-26.232091	148.869386	Gubberamunda Sandstone	Outcrop	4b	High
506	Spring Ridge	186_1	-26.236716	148.868972	Gubberamunda Sandstone	Outcrop	4b	High
561	Springrock Creek	285_1	-25.763428	148.768250	Precipice Sandstone	Outcrop	3	High
584	Wambo	711.1	-26.873960	150.437172	Cainozoic Sediments	Contact	4a	High
591	Yebna 2	534_1	-25.732642	149.102779	Precipice Sandstone	Outcrop	1a	High
592	Abyss	286.1_1	-25.798153	148.770287	Hutton Sandstone	Outcrop	2	High
592	Abyss	286.2_1	-25.797951	148.770193	Hutton Sandstone	Outcrop	2	High
592	Abyss	286.3_1	-25.797621	148.768713	Hutton Sandstone	Outcrop	2	High
592	Abyss	286_1	-25.798174	148.769141	Hutton Sandstone	Outcrop	2	High
649	Kangaroo Creek	1162_1	-26.187090	149.378070	Cainozoic Sediments	Outcrop	3	Low
649	Kangaroo Creek	1291_1	-26.163480	149.363250	Cainozoic Sediments	Outcrop	4a	Low
649	Kangaroo Creek	1292_1	-26.171750	149.371800	Cainozoic Sediments	Outcrop	4a	Low
737	Nugget	1497_1	-26.001969	149.127739	Upper Hutton Sandstone	Outcrop	4b	Low
765	Orana	711.2_1	-26.906024	150.586605	Cainozoic Sediments	Contact	4a	Low

Table H-2 Watercourse springs – location and hydrogeology

Location						Hydrogeology			
Site number	Name	Start		End		Source aquifer	Geological control	Type	Confidence
		Latitude	Longitude	Latitude	Longitude				
W10	Blyth Creek	-26.424712	149.083838	-26.473330	149.016965	Mooga Sandstone, Orallo Formation	Outcrop	3	Low
W14	Bungaban Creek	-25.836635	150.061238	-25.922420	150.234950	Upper Hutton Sandstone	Outcrop	3	Low
W15	Bungaban Creek	-25.922420	150.234950	-25.903614	150.261079	Upper Hutton Sandstone	Outcrop	3	Low
W16	Bungeworgorai Creek	-26.210447	148.442854	-26.228380	148.474480	Gubberamunda Sandstone	Outcrop	3	Low
W17	Bungeworgorai Creek	-26.395378	148.650913	-26.418003	148.643829	Mooga Sandstone	Outcrop	3	Low
W18	Bungil Creek	-26.255209	148.709508	-26.309723	148.735984	Gubberamunda Sandstone	Outcrop	3	Low
W19	Bungil Creek	-26.421967	148.787404	-26.450046	148.805048	Mooga Sandstone	Outcrop	3	Low
W39	Dawson River	-25.725580	149.303075	-25.676722	149.235056	Upper Hutton Sandstone	Outcrop	3	Low
W40	Dawson River	-25.679460	149.137341	-25.684793	149.066451	Precipice Sandstone	Outcrop	3	Low
W59	Eurombah Creek	-25.979855	149.194107	-25.982412	149.145238	Upper Hutton Sandstone	Outcrop	3	Low
W76	Horse Creek (East Branch)	-26.201700	149.593600	-26.220195	149.619557	Gubberamunda Sandstone	Outcrop	3	Low
W77	Horse Creek (East Branch)	-26.264262	149.652155	-26.306200	149.667970	Mooga Sandstone, Orallo Formation	Outcrop	3	Low
W78	Horse Creek (East Branch) Tributary	-26.309704	149.674781	-26.344366	149.657824	Mooga Sandstone, Orallo Formation	Outcrop	3	Low
W79	Horse Creek (East Branch) Tributary	-26.306200	149.667970	-26.309704	149.674781	Mooga Sandstone, Orallo Formation	Outcrop	3	Low
W80	Hutton Creek	-25.743438	148.685682	-25.697695	148.427269	Upper Hutton Sandstone	Outcrop	3	Low
W81	Hutton Creek	-25.712680	149.083680	-25.715116	149.028281	Upper Hutton Sandstone	Outcrop	3	Low
W82	Injune Creek	-25.803812	148.779898	-25.811890	148.732691	Upper Hutton Sandstone	Outcrop	3	Low
W160	Western Creek	-27.752520	150.682180	-27.793570	150.696364	Mooga Sandstone	Outcrop	3	Low
W164	Yuleba Creek	-26.364111	149.437886	-26.472280	149.400310	Mooga Sandstone	Outcrop	3	Low

Appendix H-2. Spring risk assessment

This appendix provides details of how the spring risk assessment was completed.

For each spring, a risk level between 1 (low) and 5 (very high) was assigned on the basis of the ***likelihood*** of there being reductions in the flow of water to the spring and the ***consequences*** on known spring values if a reduction in flow was to occur.

The ***likelihood*** of a reduction in the flow of water to a spring was based on the predicted impact in the spring's source aquifer. A likelihood score ranging from 1 (lower) to 5 (higher) was assigned on the basis of uncertainty in modelled predictions.

The criterion used is as follows:

L1: The magnitude of predicted impacts in the spring's source aquifer

> The predicted reduction in groundwater pressure in the spring's source aquifer was assessed using the regional groundwater flow model. The model outputs provide details of the magnitude and timing of the predicted impact.
>
> The likelihood score was based on the maximum modelled impact in the source aquifer at the location of the spring. If no impacts are predicted, then a score of '1' was assigned. If the maximum modelled impact was greater than 1 metre, then a score of '5' was assigned.

The ***consequence*** assessment relates to a measure of impact on the ecological functioning of the spring that may result if the predicted decrease in pressure was to occur. This provides a measure of the sensitivity of the spring to a changed groundwater regime.

Springs are subject to a range of groundwater and non-groundwater related influences that may affect their condition and ecological function. Within the context of the UWIR 2015, only consequences resulting from changes in the groundwater flow regime are assessed.

The overarching principle is that changes in groundwater pressure will affect groundwater flow to springs, which is necessary to maintain the integrity of the associated ecosystem. Three equally weighted criteria have been applied to assess the consequence of a reduction in pressure in a spring's source aquifer:

C1: Percentage change in available pressure above ground

> Groundwater pressure above ground in the spring's source aquifer at the location of a spring provides a hydrogeological measure of the resilience of a spring to a change in formation pressure. Where there is significant available pressure above ground, it is likely that a small change in source aquifer pressure will reduce flow, but maintain some continuity of discharge. In this situation, the change may have comparatively minor consequences. In contrast, where a spring has minimal available pressure above ground, the spring is considered more vulnerable to a change in pressure.
>
> The risk score is based on predicted impact in source aquifer pressure in relation to formation pressure above ground. If the predicted pressure reduction was less than 20 per cent of the pressure above ground then a score of '2' was assigned. If the predicted reduction in pressure was greater than 80 per cent of pressure above ground then a score of '5' was assigned.

C2: *The conservation ranking*

The conservation ranking highlights the spring wetlands that are critically important for conservation relative to springs with degraded habitat. The use of the conservation ranking provides an opportunity to highlight ecological values not recognised under statute for their relative importance.

If a spring is significantly modified by impoundment or excavation and has no known important ecological assemblages, then a score of ‘1’ was assigned. If a spring is in sound physical condition and hosts ecologically important species, then a score of ‘5’ was assigned.

C3: *The spring typology*

A typology for springs in the Surat CMA has been developed (Section 4.7.2). The typology describes the dominate processes that influence the occurrence of the springs. The key attributes describe how springs occur within the landscape and how they are likely to respond to a change in the groundwater regime. The four types identified under the typology have varied potential for impact from a change in the groundwater regime due to other their landscape position and the availability of other water sources.

Type 4 springs are least vulnerable to reductions in flow from regional aquifers as flow is dominantly from local flow systems. These springs are assigned a score of ‘1’. Type 1 springs more vulnerable to reductions in flows from regional aquifers and are assigned a score of ‘5’.

Total scores for likelihood and for consequence of impact were then calculated as follows:

Likelihood of impact (max 5) = L1

Consequence of impact (max 15) = C1 + C2 + C3

The matrix presented in Figure H 1 was applied to assign overall risk.

			Consequence				
			0 - 3	4 - 7	8 - 9	10 - 12	13 - 15
			Very low	Low	Moderate	High	Very high
Likelihood	1	Rare	Very low (1)	Very low (1)	Low (2)	Low (2)	Low (2)
	2	Unlikely	Very low (1)	Low (2)	Moderate (3)	Moderate (3)	Moderate (3)
	3	Possible	Low (2)	Low (2)	Moderate (3)	High (4)	High (4)
	4	Likely	Low (2)	Moderate (3)	High (4)	High (4)	Very high (5)
	5	Highly likely	Low (2)	Moderate (3)	High (4)	Very high (5)	Very high (5)

Figure H-1 Risk assessment matrix

The outcomes have informed the priorities for monitoring, mitigation and have informed the selection of pressure monitoring locations under the WMS. The total risk score for each spring is provided in Tables H-3 and H-4 in Appendix H-30.

Appendix H-3. Risk assessment results

Appendix H-2 provides the details of the spring risk assessment. The assessment has informed the selection of spring monitoring and where mitigation actions are required. The outcomes from the risk assessment at a spring complex and watercourse spring scale are summarised in Table H-3 and Table H-4. The spring vent and watercourse spring sites selected for monitoring and mitigation are provided in Table H-5 and Table H-6. Responsible tenure holders are assigned where monitoring or mitigation actions are required.

The following explanation applies to these tables:

Complex – As defined by the Queensland Springs Dataset held by the Queensland Herbarium. Watercourse springs have a ***site number***.

Years before impact exceeds 0.2 metres (from 2016) – The time before predicted impact is to exceed 0.2 metres in the source aquifer at the location of the spring complex.

Maximum drawdown – The magnitude and timing of the maximum impact predicted from the regional groundwater model in the source aquifer at the location of the spring complex.

Risk assessment scores – The highest risk score assigned for each criterion to a spring within the complex (see also Appendix H-2).

Table H-3 Spring complexes – predicted impacts and risk assessment results

Location details				Summary of model predictions			Risk assessment scores				
Complex	Name	Latitude	Longitude	Years before impacts exceed 0.2 metres	Maximum drawdown		Risk criterion				Total
					Magnitude (metres)	Timeframe (years)	L1	C1	C2	C3	
1	Rainbow Spring	-23.829928	149.085598	-	-	-	1	1	4	3	2
3	Dawson River 3	-25.466260	150.123737	-	-	-	1	1	4	5	2
4	Dawson River 4	-25.437008	150.087964	-	-	-	1	1	4	3	2
5	Boggomoss	-25.437490	150.027585	-	-	-	1	1	5	4	2
6	Dawson River 6	-25.488535	150.054159	-	-	-	1	1	4	4	2
8	Dawson River 8	-25.557783	149.805440	-	0.1 – 0.2	> 100	2	2	4	5	3
74	Yebna	-25.648424	149.201115	-	-	-	1	1	5	3	2
84	Conom	-24.389093	149.137439	-	-	-	1	1	5	3	2
85	Newton	-25.383424	149.372858	-	-	-	1	1	4	1	1
86	Eden Vale	-25.155301	148.118143	-	-	-	1	1	4	1	1
229	Ponies	-25.829678	149.040743	-	-	-	1	3	4	1	2
230	Lucky Last	-25.794628	148.773660	-	< 0.2	70	2	2	5	4	3
232	Crystal Ball	-25.507183	147.976381	-	-	-	1	1	4	4	2
233	Moolayember	-25.179415	148.565986	-	-	-	1	1	4	4	2
235	Moffat	-25.060433	148.044626	-	-	-	1	1	5	1	2
256	Dam Dyke	-24.748434	147.881126	-	-	-	1	1	5	1	2
260	Scotts Creek	-25.889755	149.283822	> 100	0.5 – 2.5	> 100	5	5	5	5	5
267	Anchovies	-25.231431	148.342624	-	-	-	1	1	5	1	2
283	Barton	-26.277818	149.238872	50	1 – 2	> 100	5	5	3	3	5
296	Carnarvon Gorge	-25.064002	148.220108	-	-	-	1	1	4	1	1
298	Carnarvon Gorge	-25.043919	148.205254	-	-	-	1	1	4	1	1
299	Carnarvon Gorge	-25.057558	148.186881	-	-	-	1	1	4	1	1
300	Sugarloaf	-24.831598	147.910139	-	-	-	1	1	4	3	2
302	Next	-24.853434	147.863127	-	-	-	1	1	4	3	2
303	Dooloogarah	-24.815434	147.984125	-	-	-	1	1	4	1	1

Location details				Summary of model predictions			Risk assessment scores				
Complex	Name	Latitude	Longitude	Years before impacts exceed 0.2 metres	Maximum drawdown		Risk criterion				Total
					Magnitude (metres)	Timeframe (years)	L1	C1	C2	C3	
304	Wounded	-24.944101	147.959793	-	-	-	1	1	4	1	1
305	Murder	-24.889433	148.026125	-	-	-	1	1	4	1	1
306	Deep Earth	-24.936346	148.162774	-	-	-	1	1	3	3	2
307	Elgin	-24.554311	149.111132	-	-	-	1	1	3	3	2
308	Phalus	-25.129873	148.193814	-	-	-	1	1	5	1	2
311	311	-25.718064	149.083437	30	1	> 100	5	5	4	3	5
312	Sleepy	-25.204275	148.229239	-	-	-	1	1	4	3	2
317	Injury	-25.230312	148.659147	-	-	-	1	1	3	3	2
320	Emailsent	-24.263717	149.151431	-	-	-	1	1	4	2	2
324	Kullanda	-24.034928	149.028604	-	-	-	1	1	4	2	2
327	Robin	-25.496000	148.989000	-	-	-	1	1	5	1	2
330	Tucker	-25.013425	149.224109	-	-	-	1	1	5	1	2
331	Ital	-25.106426	149.253111	-	-	-	1	1	4	3	2
332	Gasman	-24.956424	149.403106	-	-	-	1	1	5	3	2
334	Glapagos	-25.096007	149.541327	-	-	-	1	1	4	3	2
339	Lonely Eddie	-25.478719	148.732452	-	< 0.2	> 100	2	2	4	1	3
342	Mutinery	-23.809736	149.202071	-	-	-	1	1	4	1	1
343	Mimosa	-23.832427	149.112101	-	-	-	1	1	5	1	2
346	Mussel	-23.913069	149.101225	-	-	-	1	1	5	1	2
358	Gubberamunda	-26.262736	148.689149	-	< 0.2	40	2	2	4	1	3
362	Cockatoo	-25.725330	150.249787	-	< 0.2	> 100	2	2	5	5	3
370	Starling	-25.458634	150.047581	-	-	-	1	1	4	4	2
371	Sprocket	-25.460864	150.080141	-	-	-	1	1	5	4	2
383	Onkaparinga	-25.403001	150.168332	-	-	-	1	1	5	3	2
431	Elmer	-24.534120	149.169550	-	-	-	1	1	4	2	2
437	Horror	-25.807891	148.734097	-	< 0.2	> 100	2	2	4	5	3

Location details				Summary of model predictions			Risk assessment scores				
Complex	Name	Latitude	Longitude	Years before impacts exceed 0.2 metres	Maximum drawdown		Risk criterion				Total
					Magnitude (metres)	Timeframe (years)	L1	C1	C2	C3	
506	Spring Ridge[1]	-26.234053	148.868981	> 100	1 – 1.5	> 100	5	5	4	1	5
510	Cleanskins	-23.944322	149.184650	-	-	-	1	1	5	1	2
561	Springrock Creek	-25.763428	148.768250	6	5 - 6	30	5	5	3	3	5
580	Prices	-25.476208	150.128134	-	-	-	1	1	5	5	2
584	Wambo	-26.874077	150.437155	-	-	-	1	1	3	1	1
585	585	-27.327773	151.456998	-	< 0.2	> 100	2	1	5	1	3
586	Boxvale	-25.307033	148.447782	-	-	-	1	1	5	1	2
588	Springwood	-24.525927	148.215633	-	-	-	1	1	5	2	2
591	Yebna 2	-25.732642	149.102779	40	1 – 1.5	> 100	5	3	4	5	5
592	Abyss	-25.797975	148.769583	-	< 0.2	> 100	2	1	5	5	3
595	Moffat Basalt	-25.085662	148.137322	-	-	-	1	1	5	1	2
596	596	-26.877082	151.595896	-	-	-	1	1	5	2	2
597	597	-27.218628	151.760925	-	-	-	1	1	5	1	2
598	598	-27.426521	151.907104	-	-	-	1	1	5	1	2
599	599	-27.439267	151.956073	-	-	-	1	1	5	1	2
600	600	-27.589405	151.896995	-	-	-	1	1	5	3	2
601	601	-27.394642	151.573569	-	< 0.2	> 100	2	3	5	1	3
602	602	-27.657243	151.606421	-	< 0.2	> 100	2	2	5	3	3
603	603	-27.710738	151.725352	-	-	-	1	1	5	3	2
604	604	-27.959219	151.979382	-	-	-	1	1	5	1	2
649	Kangaroo Creek	-26.174107	149.371039	-	-	-	1	1	5	3	2
650	Morella	-25.115789	148.391283	-	-	-	1	1	5	3	2
710	Aldinga	-24.852056	148.170136	-	-	-	1	1	5	1	2
722	Carnassier	-25.183872	148.392645	-	-	-	1	1	3	1	1
725	Crusoe	-25.264210	149.137504	-	-	-	1	1	5	3	2

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[1] These springs are associated with a perched aquifer and are unlikely to be affected by the predicted impacts in the regional aquifer.

Location details				Summary of model predictions			Risk assessment scores				
Complex	Name	Latitude	Longitude	Years before impacts exceed 0.2 metres	Maximum drawdown		Risk criterion				Total
					Magnitude (metres)	Timeframe (years)	L1	C1	C2	C3	
736	Notonly	-24.824189	148.028826	-	-	-	1	1	5	3	2
737	Nugget	-26.001969	149.127739	-	-	-	2[2]	3	5	3	3
738	Nyanda	-24.946978	148.249946	-	-	-	1	1	5	3	2
744	Reincarnation	-25.031722	147.834530	-	-	-	1	1	3	1	1
750	White_Soaks	-25.110118	148.080951	-	-	-	1	1	5	1	2
758	Merlin	-25.478428	148.215835	-	-	-	1	1	5	2	2
760	911	-24.577754	148.252534	-	-	-	1	1	5	1	2
761	Ardurad	-23.918428	149.024103	-	-	-	1	1	5	1	2
763	Bedourie	-24.913000	148.945000	-	-	-	1	1	5	3	2
764	Flickit	-24.090426	149.217102	-	-	-	1	1	5	1	2
765	Orana	-26.906024	150.586605	-	-	-	1	1	5	1	2

Table H-4 Watercourse springs – predicted impacts and risk assessment results

Location details						Summary of model predictions			Risk assessment scores				
Site	Name	Start		End		Years before impacts exceed 0.2 metres	Maximum Drawdown		Risk criterion				Total
		Latitude	Longitude	Latitude	Longitude		Magnitude (metres)	Timeframe (years)	L1	C1	C2	C3	
W10	Blyth Creek	-26.424712	149.083838	-26.473330	149.016965	60	0.5 – 1	> 100	4	5	3	3	3
W14	Bungaban Creek	-25.836635	150.061238	-25.922420	150.234950	> 100	0.5 – 1	> 100	4	4	3	3	3
W15	Bungaban Creek	-25.922420	150.234950	-25.903614	150.261079	-	< 0.2	> 100	2	2	3	3	3

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[2] At this location, the model predicts impacts in the lower Hutton Sandstone of > 0.2 metres.

Location details						Summary of model predictions			Risk assessment scores				
Site	Name	Start		End		Years before impacts exceed 0.2 metres	Maximum Drawdown		Risk criterion				Total
		Latitude	Longitude	Latitude	Longitude		Magnitude (metres)	Timeframe (years)	L1	C1	C2	C3	
W16	Bungeworgorai Creek	-26.210447	148.442854	-26.228380	148.474480	-	-	-	1	1	3	3	2
W17	Bungeworgorai Creek	-26.395378	148.650913	-26.418003	148.643829	-	-	-	1	1	3	3	2
W18	Bungil Creek	-26.255209	148.709508	-26.309723	148.735984	-	-	-	1	1	3	3	2
W19	Bungil Creek	-26.421967	148.787404	-26.450046	148.805048	-	-	-	1	1	3	3	2
W22	Carnarvon Creek	-25.008800	148.134070	-25.051767	148.215057	-	-	-	1	1	3	3	2
W26	Clematis Creek	-25.003090	148.998523	-24.922329	148.855394	-	-	-	1	1	3	3	2
W28	Cockatoo Creek	-25.721042	150.264419	-25.710785	150.328609	-	-	-	1	1	3	3	2
W29	Cockatoo Creek	-25.718240	150.222610	-25.721042	150.264419	-	< 0.2	> 100	2	2	3	3	3
W35	Conciliation Creek	-24.625503	149.128897	-24.645650	149.074250	-	-	-	1	1	3	3	2
W39	Dawson River	-25.725580	149.303075	-25.676722	149.235056	> 100	0.2 – 0.5	> 100	3	3	3	3	3
W40	Dawson River	-25.679460	149.137341	-25.684793	149.066451	70	0.2 – 0.5	> 100	3	2	3	3	3
W41	Dawson River	-25.413803	150.164546	-25.466140	150.109545	-	-	-	1	1	3	3	2
W42	Dawson River	-25.382240	148.656288	-25.304246	148.590482	-	-	-	1	1	3	3	2
W50	Dooloogarah Creek	-24.867953	147.849201	-24.831737	147.892704	-	-	-	1	1	3	3	2
W51	Dooloogarah Creek	-24.845803	147.882158	-24.839170	147.890026	-	-	-	1	1	3	3	2
W59	Eurombah Creek	-25.979855	149.194107	-25.982412	149.145238	-	< 0.2	> 100		2	3	3	3
W76	Horse Creek	-26.201700	149.593600	-26.220195	149.619557	-	-	-	1	1	3	3	2
W77	Horse Creek	-26.264262	149.652155	-26.306200	149.667970	> 100	0.5 - 1	> 100	4	4	3	3	3

Location details						Summary of model predictions			Risk assessment scores				
Site	Name	Start		End		Years before impacts exceed 0.2 metres	Maximum Drawdown		Risk criterion				Total
		Latitude	Longitude	Latitude	Longitude		Magnitude (metres)	Timeframe (years)	L1	C1	C2	C3	
W78	Horse Creek Tributary	-26.309704	149.674781	-26.344366	149.657824	> 100	0.5 - 1	> 100	4	4	3	3	3
W79	Horse Creek Tributary	-26.306200	149.667970	-26.309704	149.674781	> 100	0.5 - 1	> 100	4	4	3	3	3
W80	Hutton Creek	-25.743438	148.685682	-25.697695	148.427269	-	-	-	1	1	3	3	2
W81	Hutton Creek	-25.712680	149.083680	-25.715116	149.028281	-	< 0.2	> 100	2	2	3	3	3
W82	Injune Creek	-25.803812	148.779898	-25.811890	148.732691	-	< 0.2	> 100	2	2	3	3	3
W99	MacIntyre Brook	-28.439300	150.991370	-28.635050	150.751470	-	< 0.2	> 100	2	2	3	3	3
W100	Macintyre Brook	-28.423196	151.135514	-28.413787	151.054829	-	-	-	1	1	3	3	2
W105	Maranoa River	-26.129403	147.907929	-26.157228	147.895437	-	-	-	1	1	3	3	2
W106	Maranoa River	-26.157228	147.895437	-26.293359	147.924150	-	-	-	1	1	3	3	2
W108	Maranoa River	-25.161602	147.837569	-25.288690	147.767520	-	-	-	1	1	3	3	2
W110	Merivale River	-25.348351	148.086467	-25.192381	148.093945	-	-	-	1	1	3	3	2
W111	Merivale River	-25.788335	147.960857	-25.348351	148.086467	-	-	-	1	1	3	3	2
W112	Merivale River	-25.850414	147.846513	-25.784399	147.927256	-	-	-	1	1	3	3	2
W113	Mimosa Creek	-23.803630	149.099990	-23.921101	149.238305	-	-	-	1	1	3	3	2
W114	Mimosa Creek Tributary	-23.793671	149.068009	-23.803630	149.099990	-	-	-	1	1	3	3	2
W141	Robinson Creek	-25.453519	149.479270	-25.433698	149.369395	-	< 0.2	> 100	2	2	3	3	3
W146	Sandy Creek	-25.595190	148.155840	-25.547208	148.183416	-	-	-	1	1	3	3	2
W160	Western Creek	-27.752520	150.682180	-27.793570	150.696364	-	-	-	1	1	3	3	2
W164	Yuleba Creek	-26.364111	149.437886	-26.472280	149.400310	-	-	-	1	1	3	3	2

Appendix H-4. Spring monitoring

The spring monitoring program is described in Section 9.5 of the UWIR. The details of springs to be monitored are identified in Table H-5 and H-6 below.

The following explanations apply to these tables:

Complex, name and vent ID – As identified in the Queensland Springs Dataset held by the Queensland Herbarium. For the watercourse springs, the ***site number*** is identified in the GAB Springs Register held by DNRM.

Wetland vegetation and discharge (extent) – The reference to the method to be used as defined in Table H-7.

Water chemistry – The reference to the chemistry suite to be measured as defined in Table H-8.

Discharge – The reference to the methods for measuring discharge as defined in Table H-7.

Flora – The reference to the methods for monitoring spring flora as defined in Table H-9.

Condition – The requirement to assess spring condition as defined in Table H-7.

Table H-5 Spring vent monitoring sites and methods

Complex	Name	Vent ID	Wetland vegetation (extent)	Wetland discharge (extent)	Water chemistry	Discharge	Flora	Condition	Monitoring frequency	RTH
8	Dawson River 8	26_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	QGC
8	Dawson River 8	28_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	QGC
8	Dawson River 8	38_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	QGC
230	Lucky Last	287_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	Santos
230	Lucky Last	340_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	Santos
230	Lucky Last	686_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	Santos
230	Lucky Last	687.1_1	B	B	-	-	B	Yes	6 monthly (Feb and August)	Santos
230	Lucky Last	687.2_1	B	B	-	-	B	Yes	6 monthly (Feb and August)	Santos
230	Lucky Last	687.3_1	B	B	-	-	B	Yes	6 monthly (Feb and August)	Santos
230	Lucky Last	687.4_1	B	B	-	-	B	Yes	6 monthly (Feb and August)	Santos
230	Lucky Last	687.5_1	B	B	-	-	B	Yes	6 monthly (Feb and August)	Santos
230	Lucky Last	687.6_1	B	B	-	-	B	Yes	6 monthly (Feb and August)	Santos
230	Lucky Last	687_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	Santos
230	Lucky Last	688_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	Santos
230	Lucky Last	689_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	Santos
260	Scotts Creek	189_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	Origin

Complex	Name	Vent ID	Wetland vegetation (extent)	Wetland discharge (extent)	Water chemistry	Discharge	Flora	Condition	Monitoring frequency	RTH
260	Scotts Creek	190_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	Origin
260	Scotts Creek	191_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	Origin
260	Scotts Creek	192.1_1	B	B	-	-	B	Yes	6 monthly (Feb and August)	Origin
260	Scotts Creek	192_1	B	B	-	-	B	Yes	6 monthly (Feb and August)	Origin
283	Barton	702_1	-	-	-	-	-	Yes	6 monthly (Feb and August)	Origin
311	311	699_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	499_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	500.1_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	500_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	535_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	536.1_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	536.2_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	536_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	537_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	692_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	693_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	694_1	-	-	See W40 and W81 (Table H-6)					Santos

Complex	Name	Vent ID	Wetland vegetation (extent)	Wetland discharge (extent)	Water chemistry	Discharge	Flora	Condition	Monitoring frequency	RTH
311	311	695_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	696_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	697_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	698_1	-	-	See W40 and W81 (Table H-6)					Santos
311	311	704_1	-	-	A and B	B	-	-	6 monthly (Feb and August)	Santos
437	Horror	682.1_1	A	A	-	-	B	Yes	6 monthly (Feb and August)	Santos
437	Horror	682_1	A	A	-	-	B	Yes	6 monthly (Feb and August)	Santos
561	Springrock Creek	285_1	-	-	A and B	B	-	Yes	6 monthly (Feb and August)	Santos
591	Yebna 2	534_1	-	-	See W40 and W81 (Table H-6)					Santos
592	Abyss	286.1_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	Santos
592	Abyss	286.2_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	Santos
592	Abyss	286.3_1	-	B	-	-	B	Yes	6 monthly (Feb and August)	Santos
592	Abyss	286_1	A	A	A and B	-	A and B	Yes	6 monthly (Feb and August)	Santos
649	Kangaroo Creek[3]	1162_1	-	A	A, B and C	-	B	Yes	Quarterly	Origin
649	Kangaroo Creek[2]	1291_1	-	A	A, B and C	-	B	Yes	Quarterly	Origin
649	Kangaroo Creek[2]	1292_1	-	A	A, B and C	-	B	Yes	Quarterly	Origin

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[3] Baseline monitoring is required at this complex.

Complex	Name	Vent ID	Wetland vegetation (extent)	Wetland discharge (extent)	Water chemistry	Discharge	Flora	Condition	Monitoring frequency	RTH
737	Nugget	1497_1	-	-	See W59 (Table H-6)				Quarterly	Origin

Table H-6 Watercourse spring monitoring sites and methods

Site	Name	Monitoring point	Location		Discharge	Water chemistry	RTH	Monitoring frequency
			Latitude	Longitude				
W40	Dawson River	Channel (S2)	149.0938883000	-25.7282138000	B	A	Santos	Hourly
		Channel (DRR1)	149.1571642000	-25.6883592700	B	A	Santos	Hourly
		Tributary (SC1)	149.0876490000	-25.7206500000	B	A	Santos	Hourly
W59	Eurombah Creek	Channel	149.0507768590	-26.0121525543	A	A and B	Origin	Quarterly
		Channel	149.0554772490	-26.0147575469	A	A and B	Origin	Quarterly
		Channel	149.0728206962	-26.0197767678	A	A and B	Origin	Quarterly
		Channel	149.0929311800	-26.0081995404	A	A and B	Origin	Quarterly
W81	Hutton Creek	Channel (S14)	149.0798150000	-25.7137170000	B	A	Santos	Hourly
		Channel (S17)	149.0505401000	-25.7018085700	B	A	Santos	Hourly
		Tributary (SC3)	149.0289790000	-25.7196140000	B	A	Santos	Hourly

Table H-7 Attributes and methods for spring monitoring

Attribute	Method and description	
Wetland vegetation (extent)	A list of aquatic and terrestrial species for each spring complex is provided in Table H-9. These species are to inform the delineation of the wetland vegetation extent.	
	Method A	For wetlands with an area greater than 1.5m^2, use a DGPS. The method is described in Fensham & Fairfax 2009.
	Method B	For wetlands with a total area of less than 1.5m^2, estimate total wetland area.
Wetland discharge (extent)	Some springs have seasonal areas of groundwater discharge and moist soil beyond the wetland vegetation extent. This attribute is to measure the extended wetland area.	
	Method A	For discharge areas greater than 1.5m^2, use a DGPS.
	Method B	For discharge areas with a total area of less than 1.5m^2, estimate the total discharge area.
Water Chemistry (Table H-9)	Measure and sample water quality in accordance with 'Monitoring and Sampling Manual 2009, Environmental Protection (Water) Policy' (DERM 2009). Measurements must be taken as close as possible to the primary discharge area.	
	Suite A	Field water quality measurements.
	Suite B	Collect a water sample for laboratory analysis.
	Suite C	Collect samples for isotope laboratory analysis.
Discharge	Method A	Identify a suitable control point. Use a standard low flow hydrology method suitable for the site. Record the method. Use the same control point and method each time the flow is measured.
	Method B	Where there is a sufficient depth of water, a logger is installed to measure changes in depth, flow and water chemistry.
	Method C	A visual estimate of discharge.
Flora	Method A	Estimate the percentage abundance of the terrestrial and aquatic species for each quadrat (see Table H-8). Transect and quadrat locations provided by OGIA.
	Method B	Presence or absence of the species listed in Table H-8.

Attribute	Method and description
Condition	Photograph the wetland from all aspects. For each photograph record the orientation and describe the features in the photograph. Photograph any significant disturbances noted at the wetland. Record the percentage (%) of wetland disturbance: • Evidence of pugging and animal disturbance; or • Evidence of anthropogenic disturbance at the wetland. Record evidence of the following: • Extent of salt scalding or iron staining at the periphery of the wetland. • Extent of shrinking or collapsing of mound structures. • Extent of surface water erosion at the periphery of the wetland. • Extent of woody emergent vegetation within and fringing the wetland.

Table H-8 Spring water chemistry suites

Suite A	Parameter
Field parameters	pH
	Electrical Conductivity (µS/cm @ 25°C)
	Redox (Eh)
	Temperature (°C)
Suite B	**Parameter**
Laboratory analytes	Total dissolved solids
	Alkalinity Total Alkalinity as $CaCO_3$ Bicarbonate as $CaCO_3$ Carbonate as $CaCO_3$ Hydroxide as $CaCO_3$
	Sulfate – SO_4 by ICPAES
	Chloride
	Major Cations – Calcium, Magnesium, Potassium, Sodium
	Bromide, Iodide, Fluoride
	Total Nitrogen as N (including NOx and TKN)
	Total Phosphorus as P
	Total Organic Carbon (TOC)
	Dissolved Organic Carbon (DOC)
Suite C	**Parameter**
Isotopes	Radon (^{222}Rn)
	Carbon (^{13}C and ^{14}C)
	Strontium (87/86Sr)
	Stable isotopes (^{18}O and ^{2}D)

Table H-9 Target species list

Target species name	Category	Species type	Listed species	Spring complex				
				Lucky Last	Abyss	Dawson River 8	Scotts Creek	Kangaroo Creek
Adenostemma lavenia	Disjunct	Aquatic	-	-	-	-	-	Y
Aeschynomene indica	Invasive Native	Aquatic	-	-	-	-	-	Y
Ammannia multiflora	Invasive Native	Aquatic	-	-	-	-	-	Y
Ampelopteris prolifera	Disjunct	Aquatic	-	-	-	-	-	Y
Arthraxon hispidus	Rare or Threatened	Aquatic	Y	-	-	-	-	Y
Azolla pinnata	Invasive Native	Aquatic	-	-	-	Y	-	Y
Baccharis halimifolia	Invasive Exotic	Aquatic	-	-	-	-	-	Y
Bacopa minima	Exotic	Aquatic	-	Y	Y	-	-	Y
Bare ground	-	-	-	Y	Y	Y	Y	Y
Baumea rubiginosa	Native	Aquatic	-	-	-	-	Y	Y
Carex appressa	Native	Aquatic	-	-	-	-	-	Y
Cenchrus ciliaris	Exotic	Terrestrial	-	-	-	-	-	Y
Cenchrus purpurascens	Disjunct	Aquatic	-	Y	-	-	Y	Y
Centella asiatica	Exotic	Aquatic	-	-	-	-	-	Y
Centipeda minima	Invasive Native	Aquatic	-	-	-	-	-	Y
Chloris gayana	Invasive Exotic	Terrestrial	-	-	Y	-	Y	Y
Cirsium vulgare	Native	Terrestrial	-	-	-	-	Y	Y
Cyclosorus interruptus	Disjunct	Aquatic	-	-	-	-	-	Y
Cynodon dactylon	Invasive Native	Terrestrial	-	Y	Y	Y	Y	Y
Cyperus difformis	Disjunct	Aquatic	-	Y	-	Y	-	Y
Cyperus laevigatus	Disjunct	Aquatic	-	-	-	-	Y	Y
Cyperus polystachyos	Invasive Native	Aquatic	-	Y	Y	Y	-	Y
Duma florulenta	Native	Terrestrial	-	-	-	Y	-	Y
Eleocharis cylindricus	Native	Aquatic	-	-	-		-	Y
Eleocharis sp.	Invasive Exotic	Aquatic	-	-	-	Y	-	Y
Eragrostis sp	Native	Terrestrial	-	-	-	-	-	Y
Eriocaulon carsonii	Rare or Threatened	Aquatic	Y	Y	Y	-	Y	Y
Eriocaulon scariosum	Native	Aquatic	-	-	-	-	-	Y
Fimbrisylis ssp.	Exotic	Aquatic	-	Y	Y	-	Y	Y
Isachne globosa	Disjunct	Aquatic	-	Y	-	-	-	Y

Target species name	**Category**	**Species type**	**Listed species**	***Spring complex***				
				Lucky Last	**Abyss**	**Dawson River 8**	**Scotts Creek**	**Kangaroo Creek**
Leersia hexandra	Native	Aquatic	-	Y	-	-	Y	Y
Livistona nitida	Rare or Threatened	Aquatic	Y	-	-	-	-	Y
Ludwigia octovalvis	Invasive Native	Aquatic	-	-	-	-	-	Y
Ludwigia peploides subsp. montevidensis	Invasive Native	Aquatic	-	Y	-	-	Y	Y
Melaleuca viminalis	Native	Terrestrial	-	-	-	Y	-	Y
Monochoria cyanea	Invasive Native	Aquatic	-	-	-	-	-	Y
Myriophyllum artesium	Rare or Threatened	Aquatic	Y	-	-	-	-	Y
Myriophyllum gracile	Native	Aquatic	-	-	-	-	-	Y
Opuntia tomentosa	Invasive Exotic	Aquatic	-	-	-	-	-	Y
Ottelia ovalifolia	Invasive Native	Aquatic	-	-	-	-	-	Y
Paspalum distichum	Invasive Native	Aquatic	-	Y	Y	Y	-	Y
Phaius australis	Native	Aquatic	Y	-	-	-	-	-
Philydrum lanuginosum	Native	Aquatic	-	-	-	-	-	Y
Phragmites australis	Invasive Native	Aquatic	-	-	-	Y	Y	Y
Rhynchospora brownii	Disjunct	Aquatic	-	-	-	-	-	Y
Rumex crispus	Exotic	Terrestrial	-	-	-	-	-	Y
Sacciolepis indica	Disjunct	Aquatic	-	Y	-	-	-	Y
Sesbania cannabina	Invasive Native	Aquatic	-	-	-	-	-	Y
Spirodela punctata	Invasive Native	Aquatic	-	-	-	Y	-	Y
Thelypteris confluens	Rare or Threatened	Aquatic	Y	-	-	-	-	Y
Typha domingensis	Invasive Native	Aquatic	-	-	-	-	-	Y
Typha orientalis	Invasive Exotic	Aquatic	-	-	-	-	-	Y
Urochloa mutica	Invasive Exotic	Aquatic	-	-	-	-	-	Y
Utricularia bifida disjunct	Disjunct	Aquatic	-	-	-	-	-	Y
Utricularia dichotoma	Native	Aquatic		-	-	-	-	Y

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