Klohn Crippen Berger

# Santos Ltd

## SWQ Cooper Basin

## *Underground Water Impact Report 2022*

## *Final*

ISO 9001 14001 45001

DX70010A02

June 2022

30 June 2022

Santos Ltd
Level 22, Santos Place
32 Turbot Street
Brisbane, Queensland
4000

**Principal Environmental Advisor**

Dear Mr :

**South Western Queensland Cooper Basin**
**Underground Water Impact Report 2022: Rev 1**

KCB Australia Pty Ltd is pleased to provide this final report to Santos Ltd for the 2022 Underground Water Impact Report for the South Western Queensland Cooper Basin Project.

Should you have any queries regarding this document, please do not hesitate to contact the undersigned on .

Yours truly,

**KCB AUSTRALIA PTY LTD.**

Senior
Hydrogeologist

CW:JN:BO:JJ



KCB Australia Pty Ltd.
Level 1, 154 Melbourne Street ▪ South Brisbane QLD 4101 ▪ Australia
t +617.3004.0244 ▪ f +617.3004.0299 ▪ www.klohn.com

# Santos Ltd

## SWQ Cooper Basin

## *Underground Water Impact Report 2022*

## *Final*

# TABLE OF CONTENTS

# TABLE OF CONTENTS
(continued)

# TABLE OF CONTENTS
(continued)



## List of Tables



## List of Figures

# TABLE OF CONTENTS
(continued)



## List of Appendices

# 1 INTRODUCTION

KCB Australia Pty Ltd (KCB) has been commissioned by Santos Ltd (Santos[1]) to undertake the update of the South Western Queensland (SWQ) Cooper Basin Underground Water Impact Report (UWIR) (the Project). This UWIR is the three yearly update to the 2019 UWIR.

This report has been prepared in accordance with the *Queensland Water Act 2000* (the Water Act) (State of Queensland 2021b) and the Guideline for Underground Water Impact Reports and Final Reports (the Guideline) (DES 2021).

## 1.1 Project Overview

Santos currently operates conventional oil and gas fields within the Cooper Basin of SWQ, located in the vicinity of the townships of Windorah and Thargomindah on the Queensland – South Australia border (Figure 1.1). Santos discovered natural gas at the Project site in 1963 and oil in 1970; and has since developed these resources for the production of natural gas, ethane, crude oil and gas liquids (Santos 2021).

Santos' Petroleum Licenses (PLs) occupy an area in excess of 8,160 km$^2$ in SWQ (Figure 1.2) and currently comprises of approximately 258 producing gas wells and 257 producing oil wells.

- *Conventional oil* originates from the formations of the Eromanga Basin, a sub-basin within the Great Artesian Basin (GAB) with minor secondary production occurring within the Tirrawarra Formation and basal Patchawarra Formation of the deeper Cooper Basin.
- *Conventional gas* production is from porous sandstone formations of the Cooper Basin at depths often exceeding 2,000 m. Unlike coal seam gas reservoirs, the formations of the Cooper Basin do not require the depressurisation of the target beds through the removal of groundwater to produce gas at economic quantities; some water may be produced from the formation as a by-product however the volumes are relatively minor.

The Project Area comprises active Santos tenements including PLs and exploration tenements (ATPs), in SWQ, which includes the Cooper and Eromanga Basins and is referred to collectively as the Cooper Basin (see Figure 1.1).

[1] "Santos" refers to Santos and its subsidiary companies that operate the oil and gas tenements on behalf of various joint venture parties.

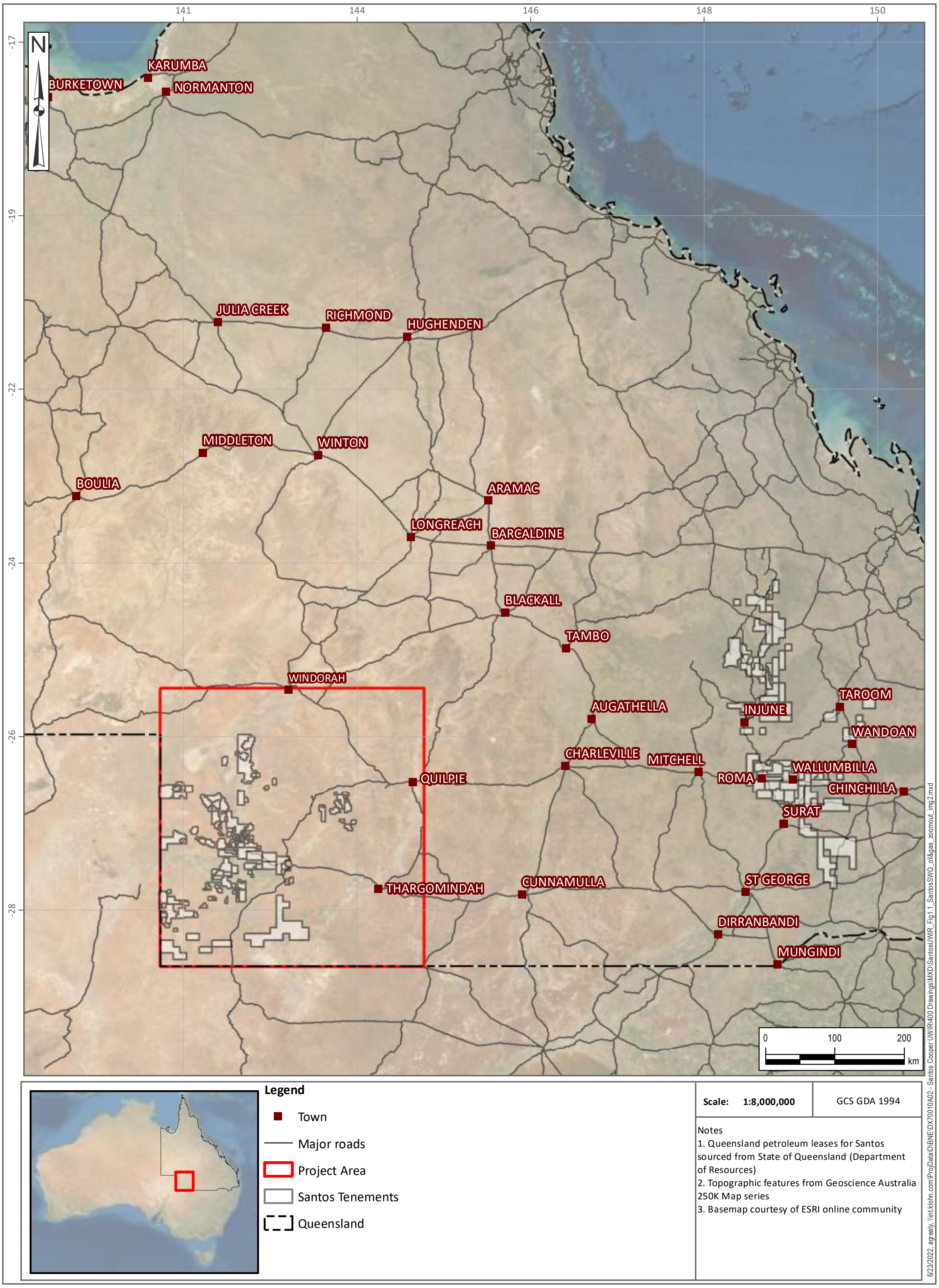



**Figure 1.1 Project Study Area and Location of Active Santos Tenements (PL and ATP) in Queensland**

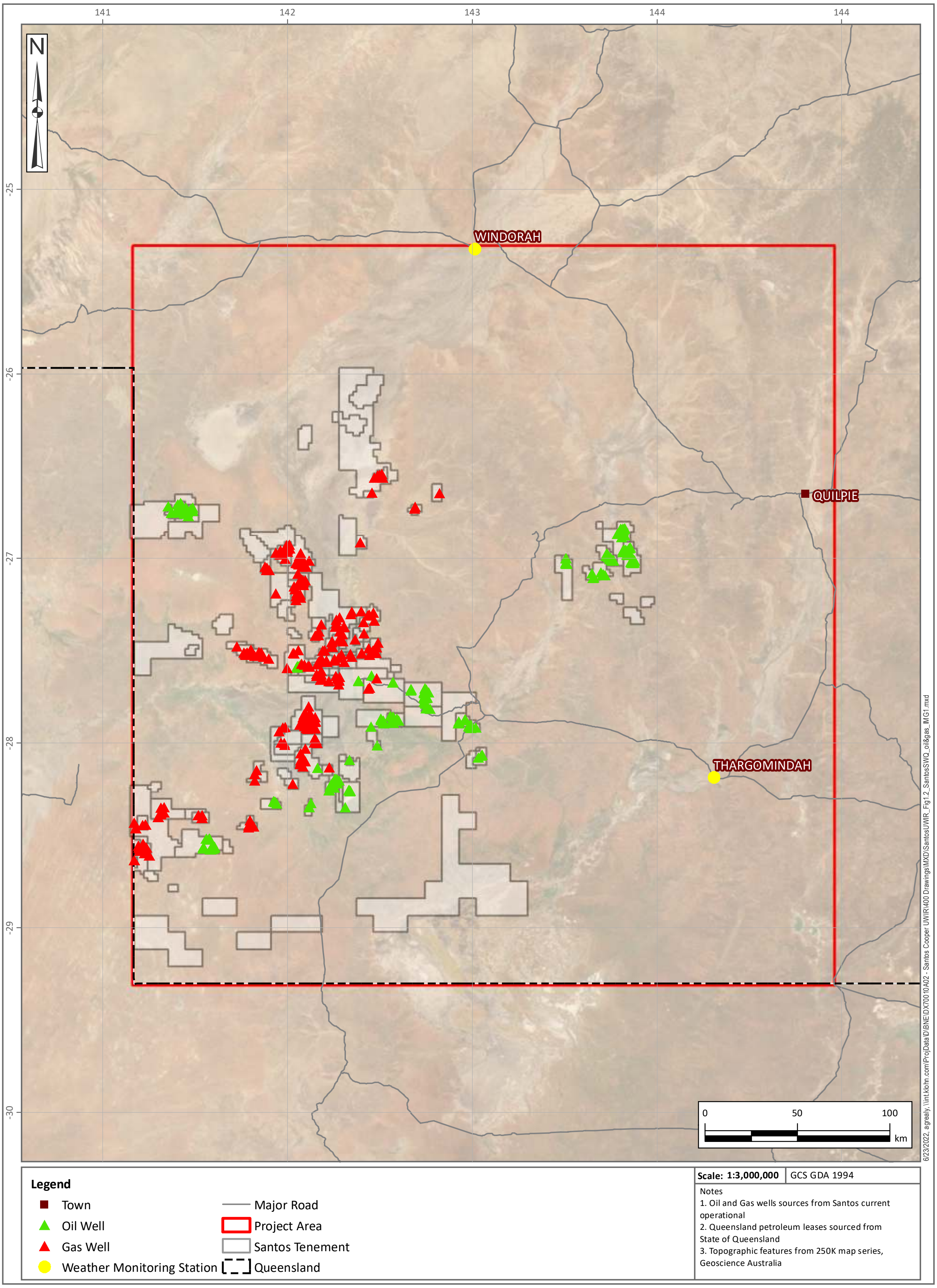



**Figure 1.2 Project Area with Active Tenements**

## 1.2 Background to the UWIR

The *Petroleum and Gas (Production and Safety) Act 2004* (State of Queensland 2020a; 2021a) [P&G Act] and Petroleum Act 1923 (Petroleum Act) entitles the holder of a petroleum tenure to take or interfere with underground water (i.e. groundwater) as part of approved petroleum operations. This entitlement is termed the petroleum tenure holder's 'underground water rights'. Further detail on the P&G Act and Petroleum Act is provided in Section 2.1.

Groundwater that is taken or interfered with while exercising the underground water rights is termed 'associated water'. The holder of the PL is entitled to use associated water for any purpose. In order to exercise the underground water rights for the project, the PL holder must:

- Obtain an Environmental Authority (EA) under the *Environmental Protection Act 1994* (EP Act); and
- Comply with its reporting obligations under Chapter 3 of the Water Act. The administering authority for Chapter 3 of the Water Act is the Department of Environment and Science (DES). Lease holder obligations under Chapter 3 of the Water Act include undertaking baseline assessments of the groundwater regime and water supply bores, preparing UWIRs to provide for ongoing assessment and reporting of groundwater take and (where necessary) entering into make good agreements with owners of affected water supply bores.

## 1.3 UWIR Scope and Structure

Santos submitted its initial UWIR for the Project in 2013 (Golder 2013), in accordance with the Water Act. Santos is required to update the UWIR for petroleum operations within the SWQ Cooper Basin every three years. The main purpose of the UWIR is to describe the groundwater take due to the proposed development and any associated impacts over a three year period (the UWIR period) (DES 2021).

This UWIR addresses the three-year period of Project development from 2022 to 2025, with the previous UWIRs also completed in 2019 and 2016. Planned operations in this period include operations associated with existing oil and gas fields as well as the construction and development of new operations, both within existing oil and gas fields, and PLs currently under application.

The UWIR has been prepared in accordance with the UWIR content requirements described in Section 376 of the Water Act and the DES guideline *Underground water impact reports and final reports* ESR/2016/2000 (the UWIR guideline) (DES 2021), where relevant. The requirements in Section 376 of the Water Act are complimentary to the information requirements of Sections 126A and 227AA of the EP Act.

Consistent with Section 2.3 of the UWIR guideline, this UWIR is based on the information provided in the EA and previous UWIR applications, where relevant, this information has been included within this updated UWIR with the information used to create the groundwater conceptualisation described in Section 5.

The UWIR comprises the following sections:

- Section 1 – Introduction
- Section 2 – Regulatory Requirements
- Section 3 – Physiographic Setting
- Section 4 – Assessment Methodology
- Section 5 – Groundwater Regime
- Section 6 – Numerical Groundwater Model
- Section 7 – Santos SWQ Operations
- Section 8 – Groundwater Impact Assessment
- Section 9 – Groundwater Monitoring Program
- Section 10 – UWIR Updates and Review

# 2 REGULATORY REQUIREMENTS

This section provides a summary of the key Queensland and Commonwealth legislative requirements related to the extraction of groundwater and management of produced water.

Santos' activities in the Cooper Basin are subject to general Queensland and/or Commonwealth regulation, and to site specific EAs determined under the EP Act.

## 2.1 Petroleum Act 1923 and Petroleum and Gas (Production and Safety) Act 2004

The *Petroleum Act 1923* (State of Queensland 2020b) and the P&G Act are Acts relevant to exploring for, recovering and transporting by pipeline, petroleum and fuel gas, and ensuring the safe and efficient undertaking of these activities. The key purpose of these Acts is to facilitate and regulate the undertaking of responsible petroleum activities and the development of a safe, efficient and viable petroleum and fuel gas industry.

These acts identify underground water rights for petroleum tenures, and states that the holder of a petroleum tenure may take or interfere with underground water in the area of the tenure if the taking or interference happens during the course of, or results from, the carrying out of another authorized activity for the tenure.

The *Water and Other Legislation Amendment Act 2010* (State of Queensland 2010), sanctioned on 1 December 2010, amends the Water Act and other relevant legislation with the aim of improving the management of impacts associated with groundwater extraction that form part of petroleum activities. These amendments transfer the regulatory framework for underground water from the P&G Act to the Water Act.

The P&G Act originally provided all rights of water extraction to a petroleum activity. However, through recent updates of the P&G Act and the Water Act, a petroleum tenure holder has an obligation to identify impact, establish baseline conditions and maintain groundwater supplies in private bores in the vicinity of petroleum operations. Where a bore owner can demonstrate reduced access to groundwater supplies, or a reduction in beneficial use class due to water quality changes, as a result of petroleum operations, "make good" provisions are available to address the loss incurred by an affected bore owner.

## 2.2 Water Act 2000

### 2.2.1 General Purpose of the Water Act

The Water Act is an Act to provide for the sustainable management of water and the management of impacts on underground water, among other purposes. This Act provides a framework for:

- The sustainable management of Queensland's water resources by establishing a system for the planning, allocation and use of water;
- The sustainable and secure water supply and demand management for designated regions;
- The management of impacts on underground water caused by the exercise of underground water rights by the resource sector; and

- The effective operation of water authorities.

This Act covers water in a watercourse, lake or spring, underground water (or groundwater), overland flow water, or water that has been collected in a dam.

### 2.2.2 Water Act and Conventional Petroleum and Gas Related Activities

The Water Act provides for the identification and management of potential impacts on underground water, caused by the exercise of underground water rights by resource tenure holders, which are regulated under the P&G Act. The Water Act also outlines the requirements for make good agreements, if required, associated with the impacts to underground water.

Chapter 3 of the Water Act has a stated purpose to provide for the management of impacts on underground water caused by the exercise of underground water rights by resource tenure holders, which includes petroleum tenure holders. To achieve the stated purpose, a regulatory framework is provided which requires:

- Resource tenure holders monitor and assess the impacts of the exercise of underground water rights on water bores and to enter into make good agreements with the owners of the groundwater bores as necessary;
- The preparation of UWIRs that establish underground water obligations, including obligations to monitor and manage impacts on aquifers and springs; and
- Manage the cumulative impacts of the activities of two or more resource tenure holders' underground water rights on underground water.

### 2.2.3 Trigger Thresholds

Under Section 362 of the Water Act, a bore trigger threshold, for a consolidated aquifer, of 5 m applies (2 m for an unconsolidated aquifer). The 5 m threshold represents the maximum allowable groundwater level decline in a groundwater bore, due to petroleum tenure holder's activities, prior to triggering an investigation into the water level decline.

Under Section 379 of the Water Act a spring trigger threshold for an aquifer applies. This includes vent springs / complexes and watercourse springs (i.e., gaining streams). This threshold value (0.2 m) represents the maximum allowable decline in the water level of an aquifer in connection with a spring, at the spring location, prior to triggering an investigation into the water level decline.

### 2.2.4 UWIR Requirements

Section 376 of the Water Act specifies the UWIR content requirements. Table 2.1 lists the specific content requirements and provides an explanation of where each requirement is addressed in this UWIR.

**Table 2.1 UWIR Content Requirements (DES 2021; State of Queensland 2021b)**

| Water Act Section No. | Water Act Section Content | UWIR Cross Reference |
|---|---|---|
| 376(1)(a) | An underground water impact report must include each of the following — for the area to which the report relates: | (i) Section 6.3 describes the reported quantities of water produced or taken in previous UWIR periods. |

| Water Act Section No. | Water Act Section Content | UWIR Cross Reference |
|---|---|---|
| | (i) the quantity of water produced or taken from the area because of the exercise of any previous relevant underground water rights; and<br>(ii) an estimate of the quantity of water to be produced or taken because of the exercise of the relevant underground water rights for a 3-year period starting on the consultation day for the report. | (ii) Section 6.5 describes the estimated groundwater take over the UWIR period. |
| 376(1)(b) | For each aquifer affected, or likely to be affected, by the exercise of the relevant underground water rights:<br>(i) a description of the aquifer;<br>(ii) an analysis of the movement of underground water to and from the aquifer, including how the aquifer interacts with other aquifers; and<br>(iii) an analysis of the trends in water level change for the aquifer because of the exercise of the rights mentioned in paragraph (a)(i);<br>(iv) a map showing the area of the aquifer where the water level is predicted to decline, because of the taking of the quantities of water mentioned in paragraph (a), by more than the bore trigger threshold within 3 years after the consultation day for the report; and<br>(v) a map showing the area of the aquifer where the water level is predicted to decline, because of the exercise of relevant underground water rights, by more than the bore trigger threshold at any time. | (i) and (ii) Section 5 describes the groundwater regime in the relevant aquifers.<br>(iii) Groundwater level trends and analysis for aquifer within the Project study area are discussed in Section 5.4. Potential groundwater impacts from the Project for the UWIR period are discussed in Section 9.<br>(iv) Figure 8.5 and Figure 8.6 show the areas where depressurisation due to the Project activities is predicted to exceed the bore trigger threshold during the UWIR period.<br>(iv) Figure 8.7 and Figure 8.8 shows the areas where depressurisation due to the Project activities is predicted to exceed the bore trigger threshold during the life of the Project. |
| 376(1)(c) | A description of the methods and techniques used to obtain the information and predictions under paragraph (b). | Section 4 describes the UWIR methodology. |
| 376(1)(d) | A summary of information about all water bores in the area shown on a map mentioned in paragraph (b)(iv), including the number of bores, and the location and authorised use or purpose of each bore. | Section 4.1 and Section 4.2 describe the water bores identified during the UWIR bore census. Section 5.8 describes the potential impacts to third-party groundwater users. |
| 376(1)(da) | A description of the impacts on environmental values that have occurred, or are likely to occur, because of any previous exercise of underground water rights. | See Santos 2013 UWIR (Golder Associates, 2013) |
| 376(1)(db) | An assessment of the likely impacts on environmental values that will occur, or are likely to occur, because of the exercise of underground water rights:<br>i. during the period mentioned in paragraph (a)(ii); and<br>ii. over the projected life of the resource tenure. | Section 9 presents an assessment of potential groundwater impacts due to groundwater take. |

| Water Act Section No. | Water Act Section Content | UWIR Cross Reference |
|---|---|---|
| 376(1)(e) | A program for:<br>i. conducting an annual review of the accuracy of each map prepared under paragraph (b)(iv) and (v); and<br>ii. giving the chief executive a summary of the outcome of each review, including a statement of whether there has been a material change in the information or predictions used to prepare the maps. | Section 11 describes the UWIR review and reporting process for the affected aquifers. |
| 376(1)(f) | A water monitoring strategy. | Section 9 describes the groundwater monitoring program. |
| 376(1)(g) | A spring impact management strategy. | The potential spring impacts are discussed in Section 5.7.1 |
| 376(1)(h) | If the responsible entity is the office:<br>i. a proposed responsible tenure holder for each report obligation mentioned in the report; and<br>ii. for each immediately affected area—the proposed responsible tenure holder or holders who must comply with any make good obligations for water bores within the immediately affected area. | Not applicable. |
| 376(1)(i) | The information or matters prescribed under a regulation. | No other relevant information or matters have been prescribed under a regulation. |
| 376(2) | However, if the underground water impact report does not show any predicted water level decline in any area of an affected aquifer by more than the bore trigger threshold during the period mentioned in subsection (1)(b)(iv) or at any time as mentioned in subsection (1)(b)(v), the report does not have to include the program mentioned in subsection (1)(e). | Section 11 describes the UWIR review and reporting process for the affected aquifers. |

Section 378 of the Water Act lists the content requirements for the water monitoring strategy. Table 2.2 lists the specific water monitoring content requirements and provides an explanation of where each requirement is addressed in this UWIR.

**Table 2.2 UWIR Water Monitoring Strategy Content Requirements (DES 2021; State of Queensland 2021b)**

| Water Act Section No. | Water Act Section Content | UWIR Cross Reference |
|---|---|---|
| 378(1) | A responsible entity's water monitoring strategy must include the following for each immediately affected area and long term affected area identified in its underground water impact report or final report:<br>a) a strategy for monitoring—<br>(i) the quantity of water produced or taken from the area because of the exercise of relevant underground water rights; and<br>(ii) changes in the water level of, and the quality of water in, aquifers in the area because of the exercise of the rights;<br>b) the rationale for the strategy;<br>c) a timetable for implementing the strategy;<br>d) a program for reporting to the office about the implementation of the strategy. | Section 10.2.2 describes the groundwater monitoring program. |
| 378(2) | The strategy for monitoring mentioned in subsection (1)(a) must include:<br>a) the parameters to be measured;<br>b) the locations for taking the measurements; and<br>c) the frequency of the measurements. | Section 10 describes the groundwater monitoring program. |
| 378(3) | If the strategy is prepared for an underground water impact report, the strategy must also include a program for the responsible tenure holder or holders under the report to undertake a baseline assessment for each water bore that is:<br>a) outside the area of a resource tenure; but<br>b) within the area shown on the map prepared under section 376(b)(v). | Baseline assessment done as part of 2013 UWIR (Golder Associates, 2013). |
| 378(4) | If the strategy is prepared for a final report, the strategy must also include a statement about any matters under a previous strategy that have not yet been complied with. | Not applicable. |

## 2.3 Other Applicable Water Regulations

Additional legislative requirements applicable to the Project are summarised in Table 2.3.

**Table 2.3 Additional Legislative Requirements Related to Groundwater**

| Legislation/Section | Driver | Key Points as the Apply to the Santos Operation |
|---|---|---|
| *Environmental Protection Act 1994*[1] | Section 309Z can be imposed on a petroleum activity and cause the activity to prepare an environmental report and/or implement water management plans. | Conditions are issued through Environmental Authorities |
| *Environmental Protection (Water) Policy, 2009*[2] | An environmental plan must be developed and implemented for water management, including plans for managing stormwater, sewage and trade waste for protection of surface and groundwater. In the case of produced water recycling, water releases on land, water releases to surface water or stormwater management, the administrating authority must consider the existing quality of waters that may be affected, the cumulative effect of the release in question, the water quality objectives for waters affected and the maintenance of acceptable health risks. | Contamination must be minimised or prevented and any release, or potential release, must be monitored against site baseline conditions. |
| *Water Plan (Great Artesian Basin and other Regional Aquifers, 2017*[3] | Defines the maximum amount of water that can sustainably be extracted from the recognised aquifers within each groundwater management area. Requires monitoring for all licensed bores. | Santos production wells are not licensed for water extraction with DNRM as they are covered by the Petroleum Legislation. |
| *Environmental Protection and Biodiversity Conservation (EPBC) Act 1999*[4] | Provides the regulatory framework for Matter of National and Environmental Significance (MNES). | The most significant groundwater related MNES in the GAB are GAB artesian discharge springs. |
| *Water Resource (Cooper Creek) Plan 2011*[5] | The plan applies to surface water and overland flow within the Cooper Creek management area. | Defines rules and requirements for interacting and management of surface water within the region of the Project study area. |

1) (State of Queensland 2022),
2) (DES 2009)
3) (DNRM 2017b)
4) (Government of Australia 2016)
5) (DNRM 2017a)

# 3 PHYSIOGRAPHIC SETTING

## 3.1 Project Location and Land Use

The Project area for the Santos Cooper operations in Queensland is situated in the southwestern corner of Queensland near the localities of Ballera, Jackson, Eromanga and Thargomindah (Figure 1.2).

The Queensland portion of the operations is situated in the central Cooper Basin. The geological Cooper Basin covers a total area of approximately 130,000 $km^2$ across southwest Queensland and northwestern South Australia and is overlain by formations of the Great Artesian Basin (GAB).

The Project area is dominated by sparse, riparian flora and fauna communities which have a high dependency on the frequency of flooding and occurrence of permanent waterholes. The existing land use is dominated by agriculture and oil/gas infrastructure.

## 3.2 Topography and Drainage

The Project area topography is generally flat and is defined by the heavily braided Cooper Creek and associated flood plains. Cooper Creek flows from north to south directly through the Project area to approximately 40 km south of Durham, where it meanders west and continues into South Australia discharging into Lake Eyre approximately 350 km west of the Project. Cooper Creek has several ephemeral tributaries across the Project area, which typically only flow during the wet season and discharge overland flow towards the Cooper Creek.

Santos operations within the Project area are predominantly situated with the Cooper Creek sub-catchment. ATP 1063 is located in the Bulloo River sub-catchment, flowing from northeast to southwest across the southeastern extent of the Project area. Numerous springs associated with regional GAB flow (Evans et al. 2020) discharge into the Paroo River catchment (DES 2022) to the east of the Project Area.

The flood plains of Cooper Creek extend up to 60 km from the main channel and has a variable flow regime influenced by frequent flood events. The flood plains are characterised by channels, lagoons and waterholes that concentrate drainage to enable permeant water features throughout the dry season. In some areas, inundation of the flood plains results in the creation of a hydraulic gradient from the floodplain out to low lying depressions to the west of Cooper Creek, resulting in the creation of terminal lakes and associated fringe wetlands that receive regular discharge from the main channel (Geoscience Australia et al. 2021). A similar topographic morphology is associated with the Bulloo River flood plains except the flood plains of the Bulloo River have a much narrower lateral extent of approximately 5 to 10 km from the main channel except along the southern border of the Project area where the Bulloo River heavily braids to form a large wetland environment (DES 2022).

Away from the flood plains of Cooper Creek and Bulloo River, the topography is characterised by low hills, mesas, clay pans and high sand dunes with poor drainage networks, resulting in the formation of temporary swale wetlands during the wet season due to the attenuation of meteoric water. Such features are short lived and typically absent throughout the dry season (Geoscience Australia et al. 2021).

Approximately 30 permanent waterholes exist within the Project area. These waterholes form as depressions within the landscape that become inundated following the flooding of Cooper Creek. The majority of the waterholes are permanent due bank storage in the alluvium along the Cooper Creek (Section 5.6) (DoR 2022).

The locations of key drainage features within the Project area have been provided in Figure 3.1.

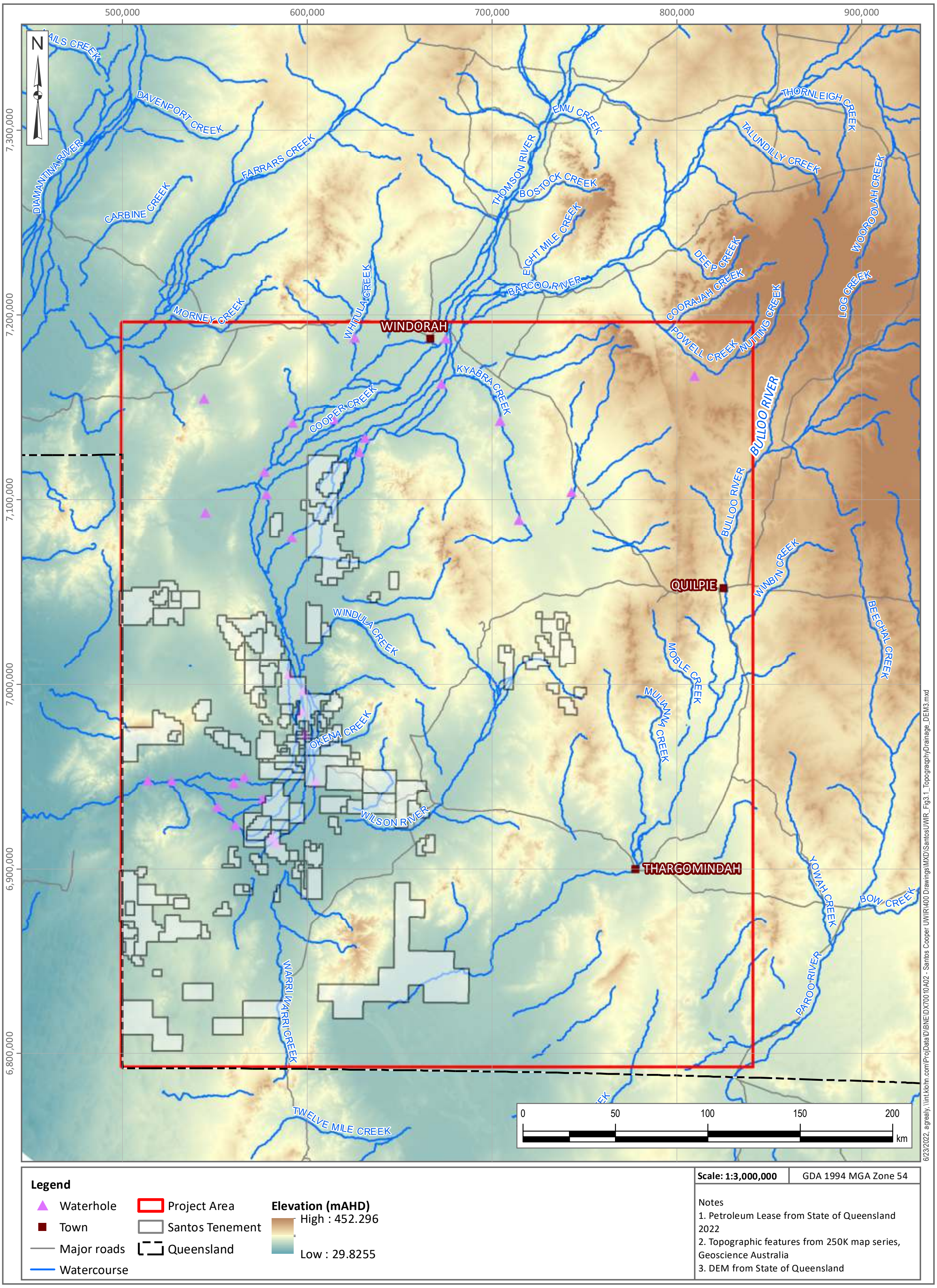



**Figure 3.1 Project Area Topography and Drainage**

## 3.3 Climate

The climate of the Project area is dry-arid, characterised by low total annual precipitation yet high seasonal variability in rainfall, temperature and evaporation, typical of the Central Australia regions, based on the modified Köppen classification system (BoM 2005). Mean minimum and maximum monthly temperatures range from 5.4°C in August to 38.8°C in December, respectively.

Climate data (daily rainfall) has been obtained from the Bureau of Meteorology (BoM) database for the Thargomindah Airport (Station 045025) and Windorah EVAP (Station 048024), located in the north and southwestern region of the Project area, respectively (Figure 1.1). Monitoring has been undertaken since 1999 whilst at Thargomindah Airport weather station and 1931 at Windorah EVAP weather station. Summary monthly and annual statistics for rainfall is presented in Table 3.1. A distinct wet season and dry season rainfall pattern can be observed, with highest rainfall occurring between January and March whilst the driest period occurring between July and September (Figure 3.2). Longer term synthetic rainfall data was also sourced from the Scientific Information for Landowners database (SILO). The synthetic rainfall data (1957 to current) is based on a point located within the Project area (presented in Table 3.1).

The daily rainfall dataset for the Thargomindah Airport and Windorah EVAP weather stations identify the average annual rainfall as 259.2 mm and 289.1 mm, respectively. The long-term average rainfall identified by the SILO data at the location of the Project area is 159.89 mm (Table 3.1). Whilst monthly trends are consistent between the BoM and SILO data, the discrepancy in long-term averages is likely due to major flood events in 2010 having greater weighting in the BoM data which ranges from 1999 to 2022.

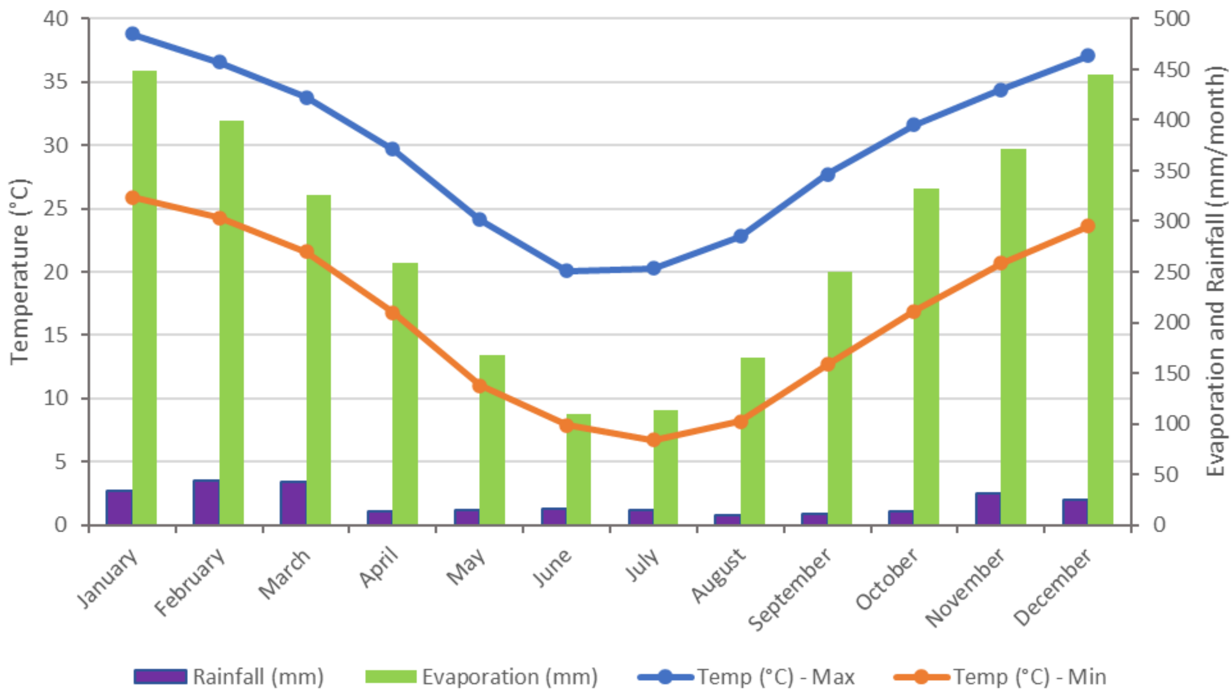



**Figure 3.2 Rainfall and Temperature Data – 1999 to 2022 for Windorah Station (BoM, 2022)**

**Table 3.1 Climate Statistics – Thargomindah Airport, Windorah EVAP and SILO Data (BOM 2022; SILO 2022)**

| Statistic Element | Thargomindah Airport – Station 045025 | | | | Windorah EVAP – Station 038024 | | | | SILO Data – Durham Downs |
|---|---|---|---|---|---|---|---|---|---|
| | Mean Monthly Maximum Temp (°C) | Mean Monthly Minimum Temperature (°C) | Mean Daily Rainfall (mm) | Mean Daily Evaporation (mm) | Mean Monthly Maximum Temp (°C) | Mean Monthly Minimum Temperature (°C) | Mean Daily Rainfall(mm) | Mean Daily Evaporation (mm) | Average Rainfall (mm) |
| Period of Record | 1999 to 2022 | 1999 to 2022 | 1999 to 2022 | 1999 to 2019 | 1931 to 2014 | 1931 to 2014 | 1999 to 2022 | 1999 to 2022 | 1957 to current |
| January | 38.8 | 25.9 | 33.8 | 14.7 | 38.1 | 24.2 | 43.7 | 11.9 | 37.7 |
| February | 36.6 | 24.3 | 43.4 | 13.1 | 36.5 | 23.5 | 48 | 10.8 | 24.6 |
| March | 33.8 | 21.6 | 41.9 | 10.7 | 34.5 | 21.1 | 42.6 | 9.1 | 28.3 |
| April | 29.7 | 16.8 | 13.0 | 8.5 | 30.2 | 16.1 | 18.6 | 7.1 | 11.3 |
| May | 24.1 | 11.0 | 15.1 | 5.6 | 25.4 | 11.3 | 18.1 | 4.6 | 12.9 |
| June | 20.1 | 7.9 | 16.5 | 3.6 | 21.7 | 7.6 | 16.7 | 3.5 | 12.9 |
| July | 20.3 | 6.7 | 14.1 | 3.7 | 21.4 | 6.6 | 14.4 | 3.6 | 12.5 |
| August | 22.8 | 8.2 | 9.8 | 5.4 | 24.1 | 8.1 | 10.0 | 5.2 | 9.5 |
| September | 27.7 | 12.7 | 11.0 | 8.2 | 28.5 | 12.2 | 10.7 | 7.3 | 8.5 |
| October | 31.6 | 16.9 | 13.5 | 10.9 | 32.6 | 16.5 | 17.0 | 9.5 | 5.6 |
| November | 34.4 | 20.7 | 30.7 | 12.2 | 35.5 | 19.9 | 21.9 | 11.2 | 17.8 |
| December | 37.1 | 23.6 | 25.2 | 14.6 | 37.8 | 22.6 | 30.2 | 12.4 | 13.5 |
| **Annual** | **29.8** | **16.4** | **259.2** | **9.3** | **30.5** | **15.8** | **289.1** | **8.0** | **159.6** |

# 4 ASSESSMENT METHODOLOGY

This section describes the UWIR methodology, including the desktop study of relevant groundwater bores, geological and environmental information, and groundwater monitoring data. It also provides an overview of the groundwater modelling methodology. A detailed description of the groundwater modelling method is provided in Section 8.

## 4.1 Information and Data Sources

A desktop assessment was undertaken based on data and information from Santos and publicly available reports and data. Primary data and information sourced for this assessment include:

### Datasets

- Registered bore data from the Department of Regional Development, Manufacturing and Water (DRDMW) Groundwater Database (GWDB) (DRDMW 2021);
- Queensland Spring Register, published by the Queensland Herbarium (Queensland Herbarium 2018);
- Potential Groundwater Dependent Ecosystem (GDE) mapping published by the DES (DES 2018b);
- The Queensland Spatial Catalogue (QSpatial), via Queensland Globe – comprising records of petroleum and gas exploration, production and monitoring wells; and
- Geoscience Australia Geological and Bioregional Assessment Program, various datasets.

### Reports

A review of relevant groundwater studies and previous UWIR assessments was undertaken to collect local and regional hydrogeological data. This was undertaken to support the development and validation of the hydrogeological setting of the Project area (described in Section 5). The review included the following groundwater studies undertaken within the vicinity of the Project area and within comparable geological and environmental settings:

- Previous UWIR reports. Santos prepared the UWIR for 2016 and 2019, whilst Golder Associates prepared the previous UWIRs for 2011 and 2013. These UWIRs were prepared for the same Project area extent as this report (Golder Associates 2013b; Santos 2016; 2019).
- Cooper Basin geological and bioregional assessments (GBA) region reports were completed as part of the Australian Government GBA program. The GBA program aims to increase the understanding of potential environmental impacts of unconventional gas resource and to inform regulatory frameworks and appropriate management approaches. The GBA program involved three stages, comprising, Stage 1: rapid regional basin prioritisation, Stage 2: Geological and environmental baseline assessments and Stage 3: Impact assessment. The Cooper GBA assessed the interactions between the deep unconventional resources of the Cooper Basin (below the conventional Cooper reservoirs) and the surface ecosystems, but did not explicitly assess the Santos oil and gas operations targeting the Cooper and Eromanga Basins.

- Update to the groundwater impact estimations in 2021 to support an EA amendment application to increase the number of oil and gas wells on Santos' tenements. This report outlines the vulnerability of groundwater users to drawdown activities associated with the Project (Golder Associates 2021).

## 4.2 Assessment Methodology

This assessment has been completed to identify potential impacts on the groundwater system from the Project for the UWIR period (Immediately Affected Areas (IAA)) and for the proposed overall development (Long Term Affected Areas (LTAA)).

All relevant data (as identified in Section 4.1) was collated and analysed to develop a conceptual understanding of the groundwater regime, including the key geology, groundwater flow and groundwater quality characteristics. This conceptualisation served as the basis for the development and simulation of the numerical groundwater model, which was used to undertake the prediction of potential impacts to the groundwater regime. Details of the groundwater model are provided in the following section.

## 4.3 Groundwater Modelling

An analytical groundwater flow model was developed to predict the extents of depressurisation and the associated impacts on the groundwater regime and the surrounding environment. The groundwater modelling platform adopted for this Project is AnAqSim software. AnAqSim employs the analytic element method (AEM), which superposes analytic solutions to yield a composite solution consisting of equations for head and discharge as functions of location and time. A detailed description of the groundwater model is provided in Section 8.

The physical structure of the groundwater model was based on the 2018 Cooper GBA assessments (Evans et al. 2020), and data sets sourced from the public domain. Model development was supplemented by published geological maps, digital geological surfaces, DRDMW groundwater database, and information from Santos operations and published approval documents. The model was calibrated against measured groundwater levels and published pre-development pressure head distributions for the deeper Cooper Basin.

The model represents the key hydrostratigraphic units of the Cooper GBA region using seven layers and extends ~500 km north-south and ~700 km east-west. The Project area was located in the center of the model domain.

The groundwater model has specifically been developed to simulate the impacts of the extraction of groundwater co-produced as part of conventional oil and gas development in the Cooper and overlying Eromanga Basins in SWQ. The model does not include extraction of groundwater by other activities (e.g. water for town water supply and stock watering). Third party groundwater extractions in the region predominantly target shallow hydrostratigraphic units such as the Winton–Mackunda partial aquifer and Cenozoic aquifers and not the deeper formations targeted for oil and gas production. Once calibrated, the model was used to identify the IAA and LTAA for the UWIR. These predictions have also been used to assess the impacts of the Project on groundwater users and potential groundwater dependent ecosystems (GDEs).

# 5 GROUNDWATER REGIME

## 5.1 Geology

The surface geology of the area is dominated by Quaternary alluvium deposits associated with the flood plains and consolidated sediments of the Glendower Formation (Tertiary) or Winton Formation (Cretaceous).

The Eromanga Basin (the largest sub-basin within the GAB) underlies the Quaternary alluvium in the Project Area. The Eromanga Basin extends beneath a large portion of Queensland, South Australia, New South Wales and the Northern Territory.

The GAB is underlain by several older sedimentary basins, of which the Permian-age Cooper Basin is one example.

### 5.1.1 Cooper Basin

The Cooper Basin is of Carboniferous-Triassic age and occurs at depths of approximately 1,000 to 4,500m below ground level. The geology of the Cooper Basin may be divided into two groups:

- The Gidgealpa Group of late Carboniferous to late Permian age; and
- The Nappamerri Group of late Permian to mid-Triassic age.

The geology of the Gidgealpa Group is summarised below from oldest to youngest depositional age (Geoscience Australia 2015).

- **Merrimelia Formation:** fluvioglacial Merrimelia Formation consisting of interbedded diamictite, conglomerate, sandstones, mudstones and shales.
- **Tirrawarra Sandstone Formation:** consisting of fine to coarse grained sandstones with minor shale interbeds and rare coal seams deposited within a glacial retreat and melt-water stream environment. The Tirrawarra sandstone has transitional boundary with the underlying Merrimelia Formation and overlying Patchawarra Formation.
- **Patchawarra Formation:** consists of lower carbonaceous siltstones with miner sandstone and thin coal seams which transition to a middle assemblage dominated by sandstone, with grey-black shale interbeds and thick coal seams. The upper units comprise of an assemblage of siltstone and shale with minor sandstone intervals. This is the thickest unit of the Gidgealaba Group and most widespread.
- **Murteree Shale:** comprises black to dark grey-brown argillaceous siltstone with minor fine-grained sandstone. Carbonaceous material, muscovite and fine-grained pyrite are characteristic of the unit. The Murteree Shale represents the transition to a deep lake environment with restricted circulation. The Murteree Shale is comformable with the Patchawarra Formation below and overlying Epsilon Formation but on structural highs where significant erosion has occurred the Murteree Shale may be uncomfortably overlain by the Toolachee Formation.
- **Epsilon Formation:** comprises fine to medium-grained quartz rich sandstones interbedded with carbonaceous siltstone and shales and thin to occasionally thick coal seams.

- **Roseneath Shale:** comprises of siltstone, mudstone and minor-fine grained sandstone units deposited within a lacustrine environment.
- **Daralingie Formation:** interbedded of carbonaceous and micaceous siltstone, mudstone, coal and minor sandstone.
- **Toolachee Formation:** represents the uppermost unit of the Gidgealpa Group and comprises interbedded fine to coarse-grained quartzose sandstone, mudstone, carbonaceous shale with thin coal seams and conglomerates. The Toolachee Formation is the most widespread of the Gidgealpa Group and forms a blanket deposit, uncomfortably overlying the Daralingie Formation or older rocks on ridges.

The Nappamerri Group consists of only two formations: the Arrabury Formation and the Tinchoo Formation. The Arrabury Formation comprises basal mudstones and siltstones but is dominated by fine to medium sandstones. The Tinchoo Formation forms the upper section of the Nappamerri Group and consists of siltstones and sandstones of the Doonmulla Member overlain by siltstones and minor coal seams of the Gilpepee Member.

The key source rocks for conventional petroleum resources are the coals and coaly shales of the Patchawarra and Toolachee Formations which extend from southeast to northwest across the northern part of the Project area. The Epsilon Formation and Roseneath and Murteree Shales also represent key source rocks, but their distribution is limited to the southeastern extent of the Project area as are dominantly situated within South Australia. The Roseneath Shale and Murteree Shale represent regional aquitards, acting as a geological traps to the Epsilon and Patchawarra Formations reservoirs, respectively (Geoscience Australia 2016).

The Nappamerri Group is generally regarded as a major basin wide seal to the Gidgealpa Group (Figure 5.2) due to the occurrence of basal mudstone and siltstones in the Arrabury Formation. The Arrabury Formation should be considered as a leaky seal with notable oil and gas accumulations being found within sandstone units due to the upward migration from the Gidgealpa Group through faults and conduits (Geoscience Australia 2015).

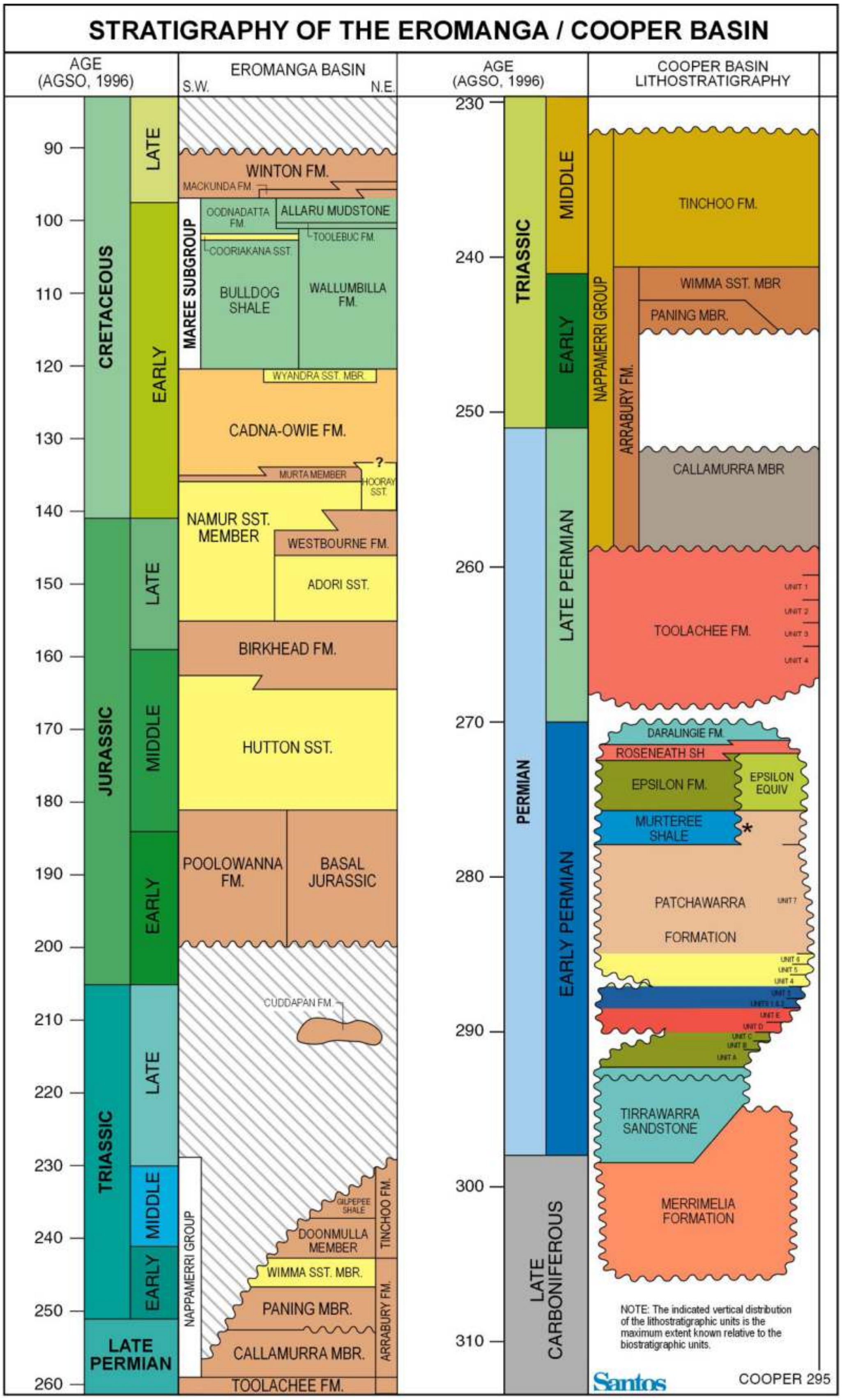



**Figure 5.1 Regional Stratigraphy of the Cooper Basin**

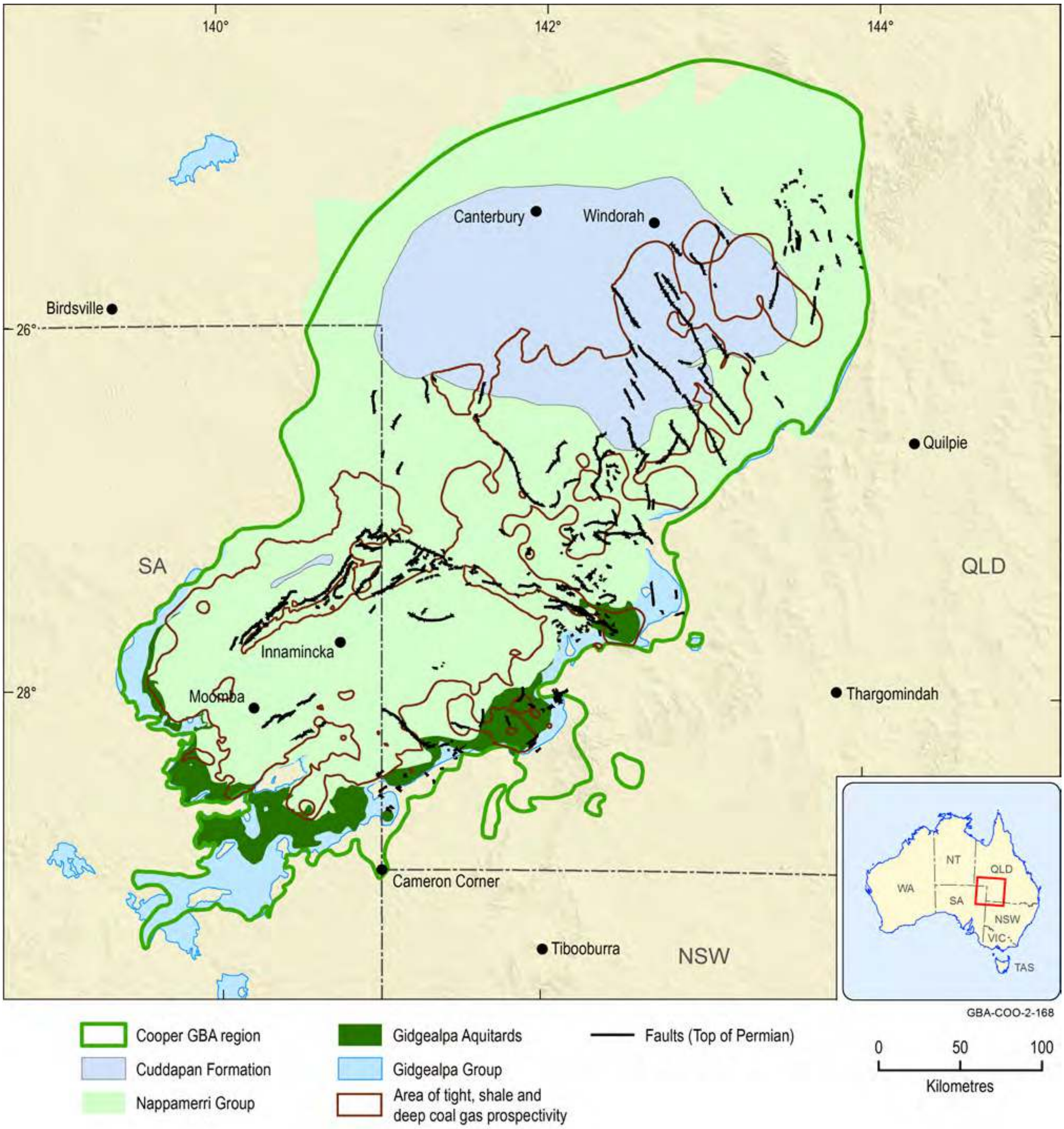



**Figure 5.2 Potential Connectivity across the Cooper Basin – Eromanga Basin Contact (Evans et al. 2020)**

### 5.1.2 Eromanga Basin

The Eromanga Basin (Jurassic–Cretaceous age) covers the entirety of the Cooper Basin and varies in thickness from around 1,000 m (near the Cooper Basin margins) to 2,800 m (over the Cooper Basin depocentres) (Owens et al. 2020). The hydrostratigraphic equivalents of these lithostratigraphic units (Figure 5.1) form a sequence of aquifers and aquitards that comprise a part of the Great Artesian Basin (GAB) (Ransley and Smerdon 2012).

For some formations of the Eromanga Basin the lithology can vary considerably, making a simplified lithological based categorisation on a regional basis difficult. Broadly, the GAB aquifer sequence in the Eromanga Basin consists of the following (from oldest to youngest):

- Predominantly artesian GAB aquifers, of which the most widely utilised is the Cadna-owie–Hooray aquifer and equivalents;
- The Rolling Downs aquitard; and
- The sub-artesian Winton–Mackunda partial aquifer.

The Cadna-owie Formation, Murta Formation, Hooray, Namur and Algebuckina Sandstones constitute the uppermost, predominantly artesian, GAB aquifer sequence. Due to depth constraints of the deeper GAB aquifers, these units are predominantly the main artesian GAB aquifers utilised in the Cooper Basin region and are interpreted to be the source aquifer for some of the artesian GAB springs in the Eromanga basin to the east of the Cooper Basin (Evans et al. 2020).

The Rolling Downs Group comprises a thick basal aquitard and upper unconfined partial aquifer. The aquitard, termed the Rolling Downs aquitard (Ransley et al 2015) consists of the Wallumbilla and Toolebuc Formations, Allaru Mudstone, Bulldog Shale, Coorikiana Sandstone and Oodnadatta Formation. The Coorikiana Sandstone forms a thin, discrete aquifer along the southwestern margin of the Eromanga Basin, and is considered to be a source aquifer for some springs near the western margin of the Cooper Basin region (Keppel et al. 2016).

The sub-artesian Winton–Mackunda partial aquifer is the uppermost GAB aquifer system and is visible on the surface geology map provided in Figure 5.3. A partial aquifer is defined by Evans et al. 2020 as a permeable geological material with variable groundwater yields that are lower than in an aquifer and range from fair to very low yielding locally. Unlike the artesian GAB aquifers, this aquifer is in generally not confined by a regional aquitard. This aquifer is an important source of water for the Cooper Basin region due to its shallow depth and lower costs of drilling compared to deeper artesian GAB aquifers (DNRM 2016).

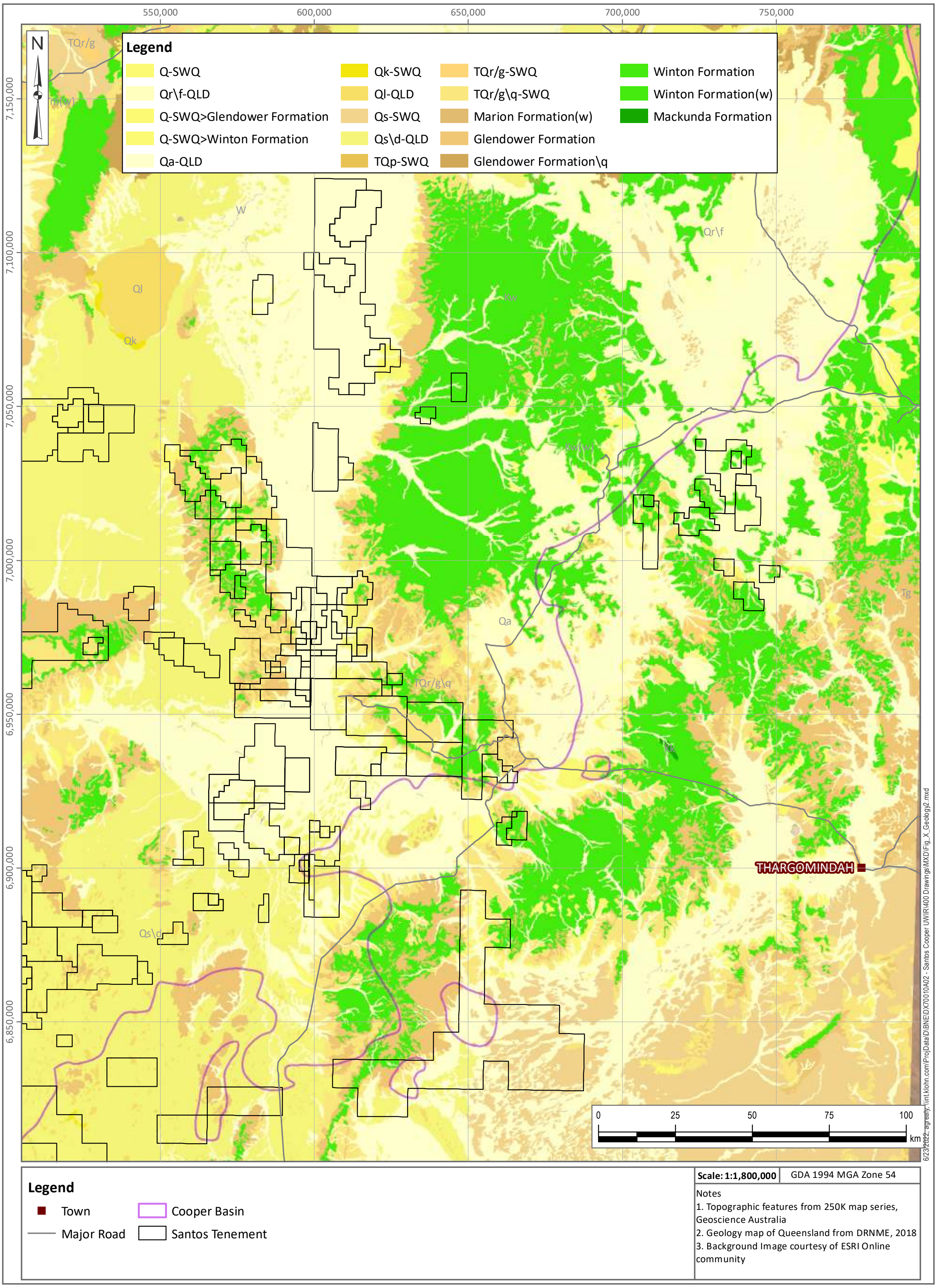



**Figure 5.3 Study Area Surface Geology Map**

## 5.2 Hydrocarbon Trapping Mechanisms

### 5.2.1 Cooper Basin

Anticlinal and faulted anticlinal traps in the Cooper Basin have been relied on as proven exploration targets in the Cooper Basin, however there is potential for discoveries in stratigraphic and sub-unconformity traps in the basin, especially where the Permian sediments are truncated by the overlying Eromanga Basin succession. Economic oil and gas in the Nappamerri Group are hosted in reservoir sands, with the majority of mudrocks in this unit forming a regional seal to the Cooper Basin. Intra-formational shale and coals form local seals in the major reservoir units. Underlying the Daralingie Unconformity are two important early Permian regional seals - the Roseneath and Murteree Shales. The Roseneath Shale is the top seal of the Epsilon Formation and the Murteree Shale seals the Patchawarra Formation.

### 5.2.2 Eromanga Basin

Trapping mechanisms in the Eromanga Basin are predominantly structural, with a minor stratigraphic component (e.g. Hutton–Birkhead transition, Poolowanna facies, McKinlay Member and Murta Formation). Seals consist of intraformational siltstones and shales of the Poolowanna, Birkhead and Murta Formations.

Where these units are absent, potential seals higher in the sequence include the Bulldog Shale and Wallumbilla Formation (SA DPI, 1998).

## 5.3 Hydraulic Properties

Intra-formational seals/aquitards can be identified in the Cooper Basin region with some units acting as regional seals or barriers to hydrocarbon migration from the deep oil and gas plays to the near-surface environmental assets (Keppel et al. 2016). Due to the layered nature of the deposition environment, some degree of horizontal hydraulic conductivity can be expected in most of the hydrostratigraphic units. Some vertical heterogeneity can be conceptualised in the basin on a regional scale, but realistically virtually no vertical flow of oil, gas or water is expected near the conventional oil and gas traps associated with the Santos exploration and development. This will be a function of rock permeability, fluid viscosity and density as well as temperature.

The composition of various formations, with depth, highlights the limited hydraulic connectivity between oil and gas targets (stressors) with the surficial groundwater and GDEs.

The Rolling Downs aquitard sequence occurs as a lateral continuity across the basin's domain, with average thickness of 310 m and hydraulic conductivity values as low as 3 $x10^{-9}$ m/day. In the central-western region of the basin, this low permeability sequence reaches over 970 m in thickness. Due to these hydraulic properties, particularly its relatively homogenous thickness distribution over the basin footprint, this unit has been classified as a regional aquitard, with a low hydraulic conductivity relative to the overlying formations. The likelihood of faults disrupting the continuity of the aquitard and acting as conduits of deep aquifer leakage into shallow aquifers has been conceptualised (Evans et al 2020). However, available published reports acknowledge that limited data identifies this process from occurring, therefore, it is not considered a significant process.

Dillinger et al. (2016) found that even Hutton Sandstone in the Nappamerri Trough had reduced hydraulic conductivity due to diagenetic clays (kaolinite and illite) in conjunction with silica cements resulting in anomalously low flow rates for a hot sedimentary aquifer geothermal play in the region. Horizontal groundwater flow approaches near-stagnant conditions in artesian GAB aquifers where they directly overlay the Cooper Basin depocentres. (Evans et al. 2020).

The thick siltstones of the Nappamerri Group can be regarded as an aquitard, acting as a regional seal to vertical gas migration at the centre of the Cooper Basin. However, the Nappamerri Group is heterogeneous and comprises various lithofacies and consequently contains both leaky aquitards and some aquifers. In addition, this unit abuts against basement highs, which in combination with faults could possibly create preferential pathways for vertical fluid migration on its boundaries (Evans et al. 2020). Only literature-based indirect hydraulic conductivity data is available for this unit, showing that porosity and hydraulic conductivity reduces with depth due to burial compaction and pore volume reduction (Evans et al. 2020).

A review of available literature values in the vicinity of the site was conducted by Golder (Golder Associates 2013b) (Table 5.1).

**Table 5.1 Hydraulic Parameters for Hydrostratigraphic Units in the Vicinity of the Project Area (Golder Associates 2013b)**

| Basin | Formation | Hydraulic Conductivity (m/d) | | Porosity (%) |
|---|---|---|---|---|
| | | Min | Max | |
| Eromanga Basin | Hooray Sandstone | $4.3 \times 10^{-4}$ | $4.3 \times 10^{-1}$ | |
| | Westbourne Formation, Adori Sandstone and Birkhead Formation | $8.0 \times 10^{-7}$ [2] | $2.5 \times 10^{-4}$ [2] | 0.2 [2] |
| | Hutton Sandstone | $3.5 \times 10^{-1}$ | $9.8 \times 10^{-3}$ | |
| | Poolowanna Formation | $1.0 \times 10^{-7}$ [2] | $3.7 \times 10^{-3}$ [2] | 0.18 [2] |
| Cooper Basin | Toolachee Formation | $2.0 \times 10^{-3}$ [1] | $4.3 \times 10^{-3}$ | 0.15 [1]<br>0.08 to 0.12[3] |
| | Patchawarra Formation | $3.3 \times 10^{-4}$ [1] | $3.5 \times 10^{-3}$ [1] | 0.13 [1]<br>0.08 to 0.12[3] |
| [1] Gov. of South Australia, Primary Industries and Resources, SA. Petroleum and Geothermal in South Australia – Cooper Basin, 2009 (PIRSA 2009). | | | | |
| [2] Alexander, E.M., Reservoirs and Seals of the Eromanga Basin (1996). | | | | |
| [3] Santos | | | | |

## 5.4 Groundwater Levels, Flow, Recharge and Discharge

### 5.4.1 Regional GAB

Primary recharge of the GAB aquifers occurs through uptake at the Eromanga boundary of the system and do not form part of this Project Area. Regional groundwater flow is from the east to southwest across the Cooper Region, with potentiometric sinks occurring in South Australia, over the Nappamerri and Patchawarra Troughs. Hydraulic head is highest in the east (greater than 300 m AHD) dropping to 50 to 100 m in western parts of GAB hydrostratigraphic units forming part of the Cooper Region.

While there are broad trends in potentiometric pressures, there is considerable variability across the Cooper Basin, including potentiometric sinks (with sub-artesian hydraulic head pressures) near petroleum fields on the southwestern flank of the Cooper Basin. Very high hydraulic heads could be due to the presence of hydrocarbons, or to some broader hydrodynamic change such as aquifer compartmentalisation or changes to transmissivity. Overall, the broadly spaced contours suggest sluggish groundwater flow and presence of a groundwater sink, particularly around western portion of the Cooper Basin in South Australia (Evans et al. 2020).

The Rolling Downs aquitard is likely to be acting as a competent aquitard, in part due to the lack of artesian GAB springs and artesian pressures in Winton-Mackunda partial aquifer in the Cooper Region (Evans et al. 2020).

### 5.4.2 Local Eromanga Basin

Water levels in the shallow aquifers indicates groundwater flow are strongly influenced by local topography. Overall, there is a regional southwesterly flow towards regional topographic low points (e.g. Lake Blanche). It is possible that during dry periods these points of low topography can act as regional discharge zones for Cenozoic aquifers.

Across the Cooper Region, recharge to groundwater in the Cenozoic and Winton–Mackunda partial aquifer of the Eromanga Basin, is driven by regional diffuse recharge during rain events or localised recharge from watercourses and lakes during flood-events.

The contribution from upward leakage of artesian GAB groundwater to shallow aquifers remains to be quantified. It should be noted that in the Cooper Region any leakage from artesian GAB aquifers would have to pass through Rolling Downs aquitard as well as the Winton-Mackunda partial aquifer to reach the shallow aquifers.

Aside from depth, hydrostatic pressures can also vary due to a number of factors. These include the presence of hydrocarbons, whether the fluids are in flux (moving), fluid composition and density (if groundwater the density is controlled by temperature and salinity), stress regime, lithology, porosity, hydraulic conductivity and pressure compartmentalisation, and whether nearby producing wells have lowered surround groundwater levels/pressures. Some under-pressured measurements may also be due the influence of low hydraulic conductivity and the duration of test, resulting in a measurement prior to pressure stabilisation.

A network of groundwater monitoring bores was selected by the Queensland government to monitor groundwater pressures over the extent of the GAB (Figure 5.4). Eight (8) groundwater GAB monitoring locations are located within the Project area, which target Eromanga Basin aquifers (Table 5.2). Although water level data is available from 1974 to 2011, records are limited, and the quality of the data cannot be substantiated. Hydrographs for the representative bores are presented in Figure 5.5 and have been selected based on their proximity to Santos' tenements and the number of data points available for review.

It is noted that there is no current water level information available for these bores in the Queensland Government Open Data Portal database.

### Table 5.2 GAB Monitoring Network - Target Aquifers

| RN | Easting[1] | Northing[1] | Formation* |
|---|---|---|---|
| 358 | 726181 | 7048168 | Hooray Sandstone |
| 16768 | 505678 | 6963605 | Hutton Sandstone |
| 22946 | 521920 | 7142708 | Hooray Sandstone |
| 23233 | 760843 | 7151644 | Cadna-owie/Hooray |
| 23569 | 654269 | 6932959 | Hooray Sandstone |
| 23059 | 661145 | 6909983 | Wallumbilla - Hooray Sandstone |
| 23093 | 756058 | 7208663 | Cadna-owie /Adori |
| 23372 | 662602 | 6938778 | Hooray Sandstone |

*Target formation either provided/ or inferred from the Queensland Government Open Data Portal.
[1]Datum – GDA94, Zone 54

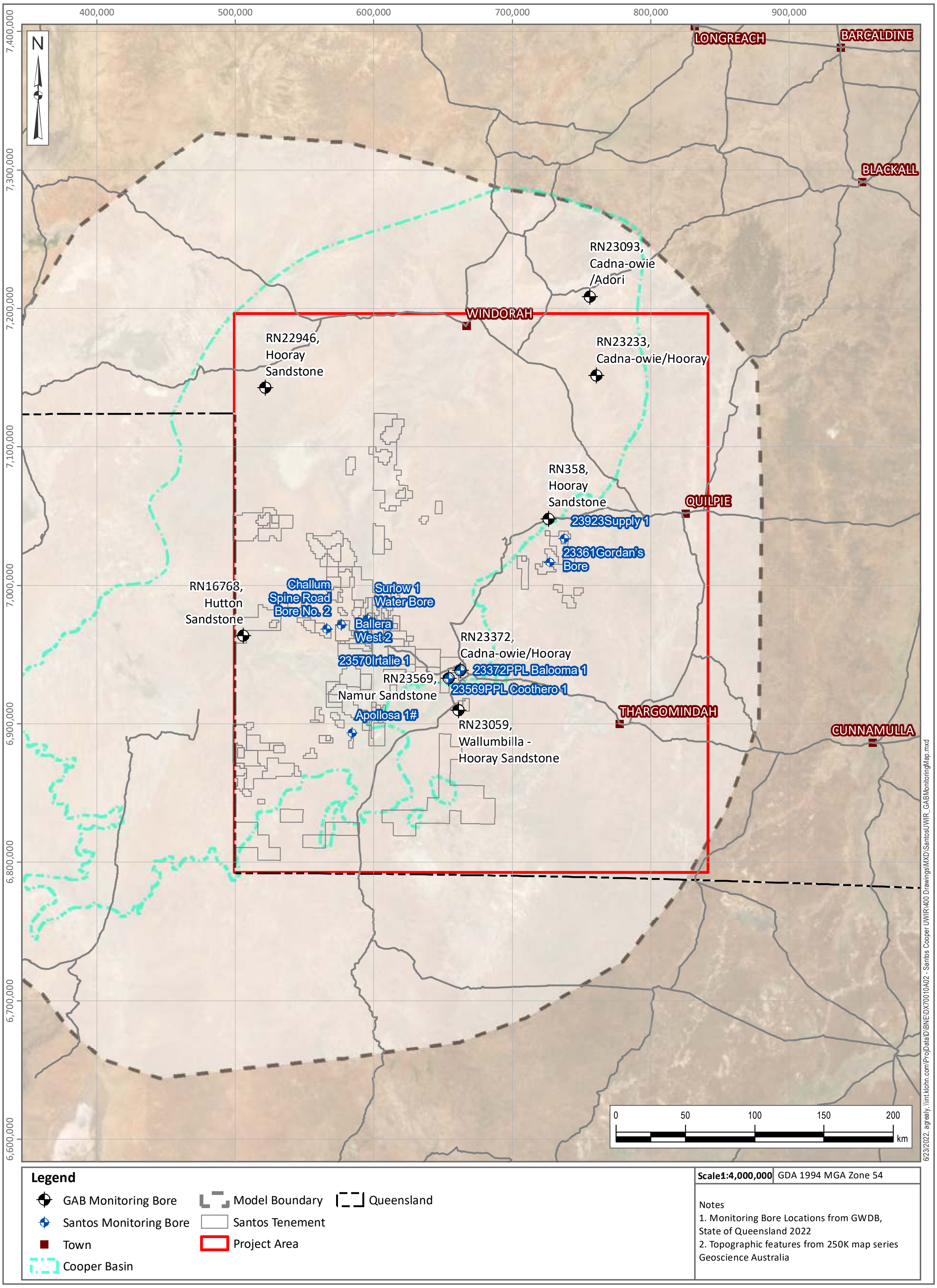
Groundwater levels for the Hutton and Hooray Sandstones, and Wallumbilla and Cadna-Owie Formations are shown in Figure 5.5. The recorded monitoring data is sporadic and seasonal trends cannot be interpreted.

The limited data for the Hutton Sandstone and Wallumbilla Formation are combined on one graph (Figure 5.5). There are only three available groundwater level measurements for the Hutton Sandstone (RN 16768), located within the Santos tenements, which is significantly deeper than the Wallumbilla Formation. The available data does not indicate significant water level variations between the first and most recent measurements in these formations.

The Hooray Sandstone shows significant variations in water level since 1970, with measurements between 118 to 290 mAHD between three monitoring bores (Figure 5.5). The static head in bore RN23569 indicates a 73 m decline between 1988 and 2021; RN23372 shows a 53 m decline between 1988 and 2021; RN358 static head shows an increase over time.

The lower hydrostatic pressure gradient in the wells accessing the Hooray Sandstone (Cadna-owie–Hooray aquifer, Eromanga basin) suggest some degree of connection with the overlying aquifers (Evans et al. 2020). Hydrocarbon production from the Cadna-owie–Hooray aquifer may locally reduce groundwater pressures, which in turn would influence the groundwater flow potentials both laterally and vertically.

Santos monitoring of the different hydrostratigraphic units shows no evidence of consistent decline when compared to historical data (Figure 5.5).




## Figure 5.4 Locations of GAB Monitoring Bores

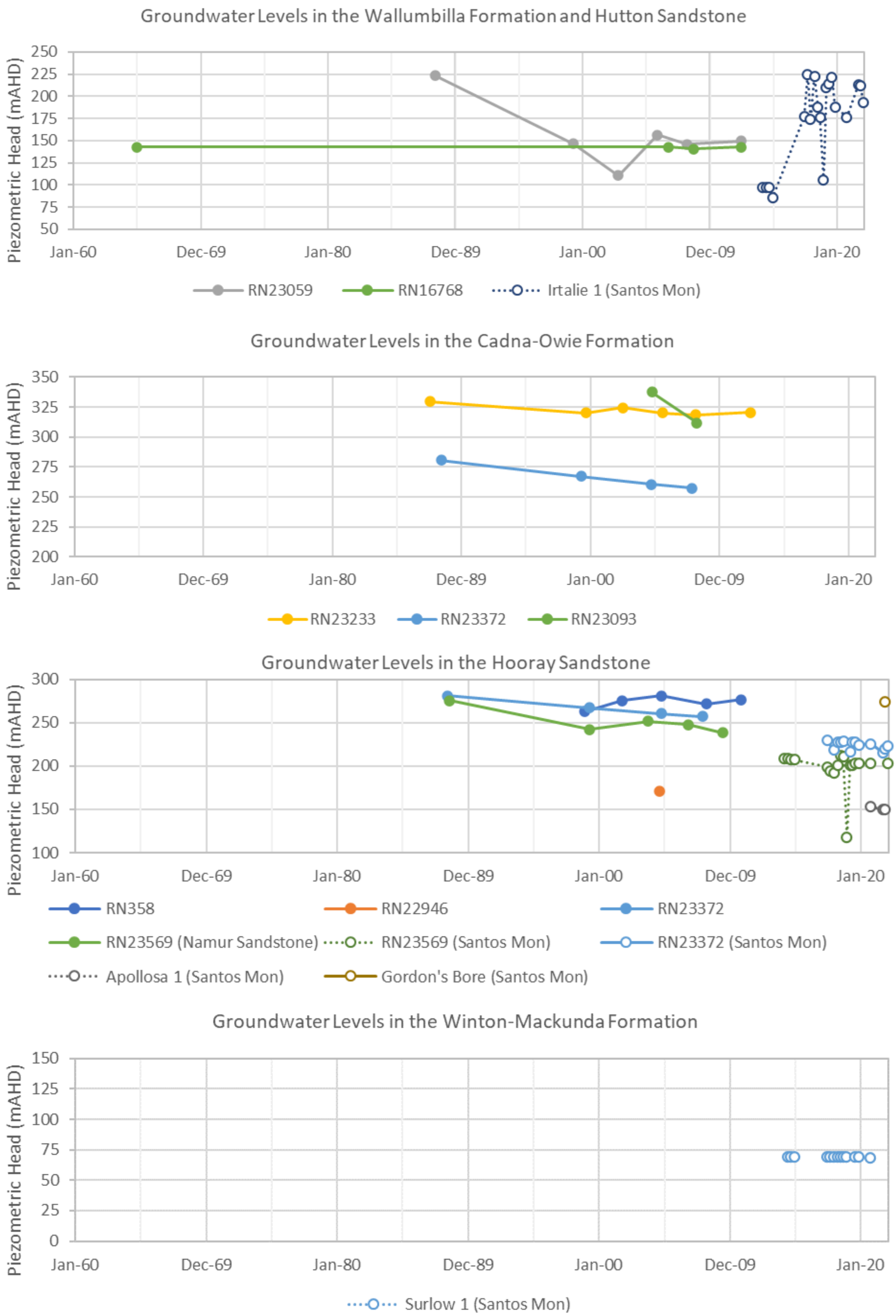



**Figure 5.5 Available Water Level Data for GAB Monitoring Bores**

### 5.4.3 Cooper Basin

Final shut-in pressures from petroleum wells for the Santos Cooper operations in Queensland (Figure 5.6) demonstrate that pressures in the underlying Toolachee and Patchawarra Formations (Cooper Basin) have higher hydrostatic pressures compared to the Hooray Formation (Eromanga basin ). Final shut-in pressures from formation tests in Cooper Basin are mostly showing over pressure (Right of the line on Figure 5.6) probably due to the presence of hydrocarbons (Webster et al. 2000). The low yielding wells (left of the lines on Figure 5.6) shows depleted pressure. The data represents formation test data recorded over a 30-year record (1982 to 2011) suggesting that formation pressures do not vary significantly with time. The difference in pressures for each of the formations also suggest that the Cooper Basin formations are not connected vertically with the overlying Eromanga basin in the areas where the Santos gas exploration are conducted.

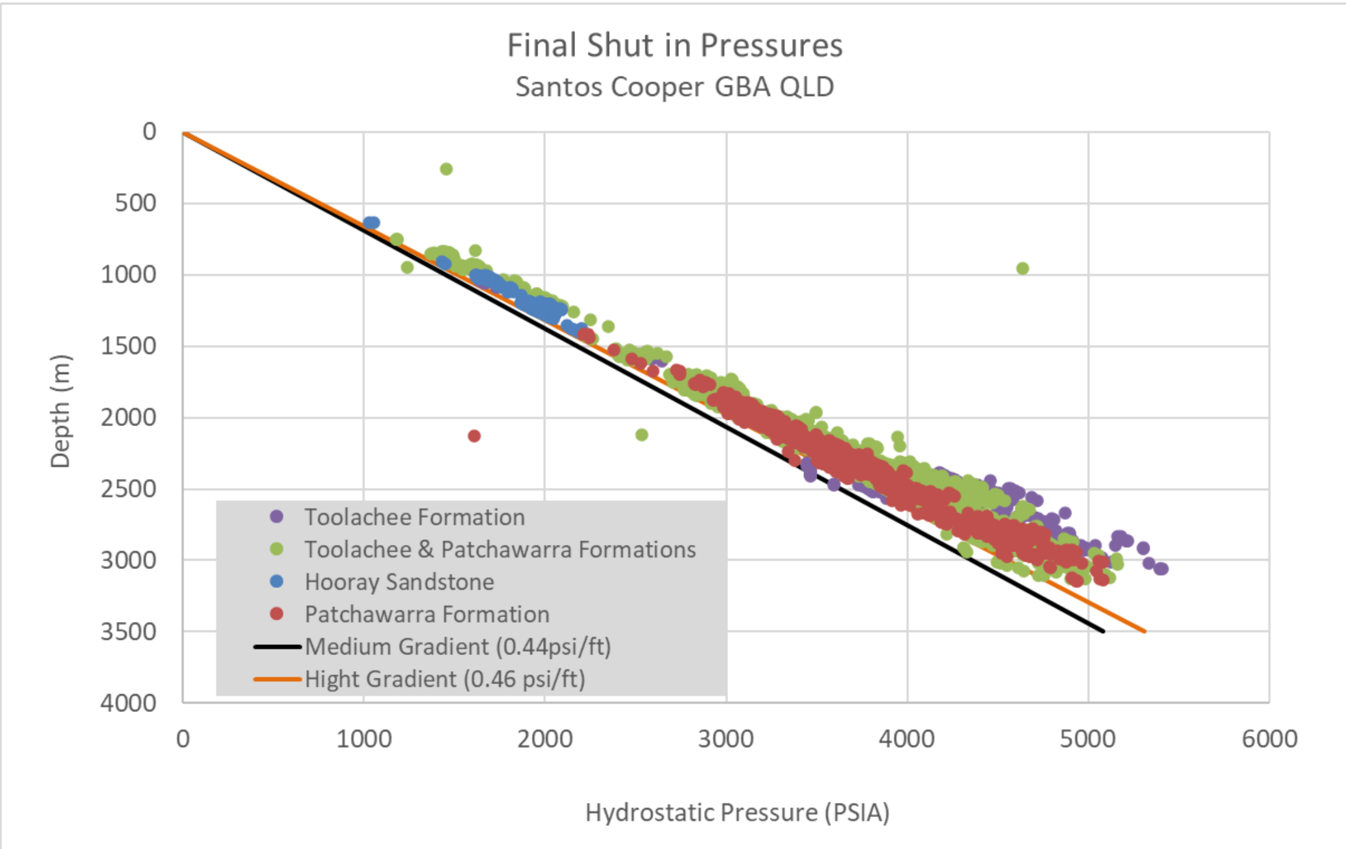



**Figure 5.6 Final shut-in pressures from formation tests in Cooper Region**

## 5.5 Groundwater Chemistry

Evaluation of the major ionic and isotopic constituents of groundwater can provide an indication of the source of water (i.e. from which aquifer formation it comes) and the potential for interaction between different hydrostratigraphic units (i.e. communication or mixing of waters due to recharge or discharge).

One of the most common methods of comparing the ionic composition of groundwater is to use a Piper diagram. Piper diagrams provide a graphical representation of the ionic proportions of water and allows for classification based on the relative major ion composition.

The dominant ions in groundwater collected from the Project area are sodium, bicarbonate and chloride. The corresponding water types can be described as either sodium-bicarbonate or sodium-bicarbonate-chloride (Figure 5.7).

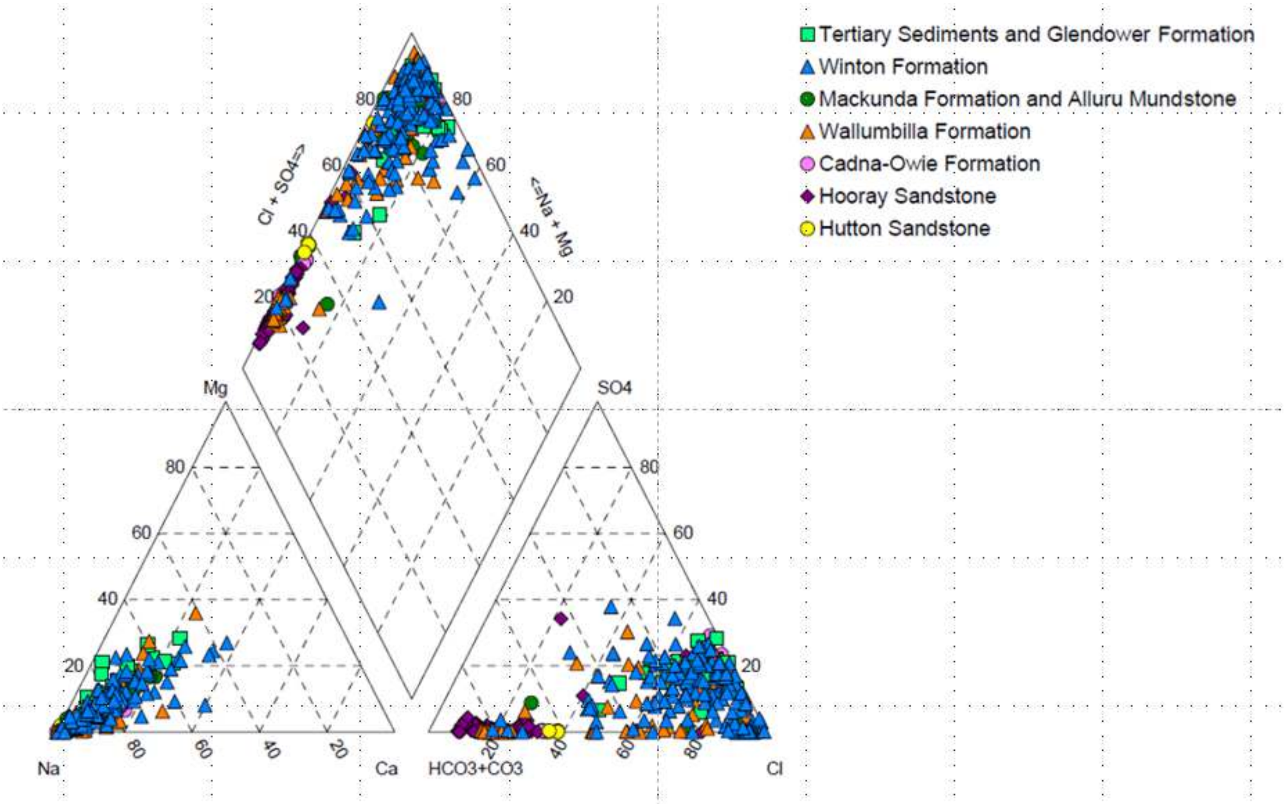



**Figure 5.7 Piper Diagram of Groundwater Collected within the Project Area.**

The shallow Cenozoic aquifer shares some similarities in groundwater type with some groundwater in the Winton–Mackunda partial aquifer and the Winton Formation. The Piper diagram also shows that Cenozoic groundwater hydrochemistry is distinct from the artesian GAB aquifers. An apparent trend from the Na+K vertex towards the centre of the cation subplot, and anions dominated by Cl with highly variable contents very little $SO_4$, results in a cluster near the top right of the central diamond.

Environmental tracers, such as chlorine-36 ($^{36}Cl$), have been used to characterise aquifer processes and estimate the age of groundwater in artesian GAB aquifers (Evans et al. 2020). High $^{36}Cl$ values are present in the major recharge zones of the artesian GAB aquifers, decreasing towards the central portions of the aquifer in the Cooper GBA region, (Ransley et al 2015) and with depth (Hasegawa et al. 2016).

The present artesian groundwater flow directions in the GAB have been in place for at least one million years based on $^{14}C$, $^{36}Cl$ and noble gas studies (Ransley and Smerdon 2012). Near-stagnant groundwater flow in the central Eromanga Basin has been inferred from $^{36}Cl$ and $^{4}He$ data (Radke et al. 2000)(Ransley and Smerdon 2012), which suggests that the groundwater could be in excess of 1 million years old. Vertical leakage or cross-formational flow occurs at undetermined rates but is presumed to be significant over timescales of thousands to millions of years (Evans et al. 2020).

## 5.6 Groundwater-Surface Water Interactions

Permanent waterholes form important habitats and refuge for flora and fauna during sustained dry periods. Many of the waterholes have additional cultural value due to customary, spiritual and economic ties to Traditional Owners. DAWE, BOM, CSIRO and Geoscience Australia, conducted a Stage 3 Impact Assessment for the Cooper GBA region (Geoscience Australia et al. 2021), which involved the analysis of groundwater levels, water chemistry, analysis of chemical tracers and water balance estimations. The investigations concluded that surface water flow generated north of the Project Area was the source of periodic freshwater recharge to the shallow surface aquifers, which sustain the permeant waterholes and the fringing riparian vegetation (Geoscience Australia et al. 2021).

Episodic flooding of the Cooper Creek floodplain contributes local recharge to shallow aquifers, forming freshwater lenses (Miles and Costelloe 2015) in the vicinity of some large near permanent waterholes (Cendon et al. 2010). These freshwater lenses either lay on top of a more saline regional water-table or alternatively are perched above the water-table. Deep-rooted vegetation may utilise the fresher shallow groundwater near the Cooper Creek as a water source during dry periods (Cendon et al. 2010; Evans et al. 2020).

Based on the results of these investigations, groundwater drawdown associated with operations for the Project is not anticipated to impact the groundwater dependent habitats along the floodplains of Cooper Creek.

## 5.7 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems (GDEs) can be defined as those ecosystems whose ecological processes and biodiversity are wholly or partially reliant on groundwater. The extent of GDE dependency on groundwater can range from being marginally or episodically dependent, to being entirely dependent on groundwater (SKM 2001).

Examples of GDEs include:

- Terrestrial vegetation supported by shallow groundwater.
- Aquatic ecosystems in rivers and streams that receive groundwater baseflow. Baseflow typically accounts for a significant portion of total flow volume in major rivers and streams.
- Baseflow can sustain streamflow volumes long after rainfall events, or throughout dry seasons, and is therefore critical to the maintenance of aquatic ecosystems in rivers and streams in many Australian environments. Baseflow can occur as springs discharging into a river or stream, or as diffuse influx of groundwater through banks and bed sediments.
- Wetlands, which are often established in areas of groundwater discharge.
- Springs and associated aquatic ecosystems in spring pools.
- Aquifers and caves, where stygofauna (groundwater-inhabiting organisms) reside.

GDE mapping provided in Queensland Globe (DNRME 2021) collates information from a number of sources into a central database, including published research and interpreted remote sensing data. These areas mapped in the GDE Atlas represent potential GDEs that access groundwater to meet all or some of the GDE water requirements. This includes terrestrial vegetation, subsurface fauna communities and some vegetation which is associated with a surface water body. Although confidence levels are placed on the mapped extents of the GDEs, ground-truthing of the mapped areas is required to confirm presence of the GDEs. Potential GDEs in the Project area are presented in Figure 5.8.

Field verification surveys, completed as part of the Santos internal investigations and the Impact Assessment for the Cooper GBA region (Geoscience Australia et al. 2021) confirmed the presence of several riparian, wetland and flood plain vegetation communities associated with the corresponding bioregions located within mapped potential GDE areas.

### 5.7.1 Spring Complexes

Whilst outcrop of the artesian GAB aquifers is relatively distant from the Cooper region, significant changes to recharge rates of the GAB aquifers are likely to have a bearing on the water balance of artesian GAB aquifers, potentially affecting the aquifer throughflow into and out of the Cooper region. Aquifer throughflow in and out of the Project Area is likely to be a significant component of the water balance due to the Eromanga Basin boundaries extending beyond the Cooper region boundary.

Whilst GAB springs do not occur in the Cooper region, some significant springs do occur within 20 km of the region boundary, near Lake Blanche. Ecosystems dependent on artesian GAB springs are listed as endangered (Department of the Environment and Energy, 2018) under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act; Australian Government, 1999), so are considered a matter of national environmental significance.

The lack of springs that source groundwater from artesian GAB aquifers in the *Cooper GBA region* suggests that the Rolling Downs aquitard for the most part impedes connectivity between artesian GAB aquifers and Winton-Mackunda partial aquifer (Evans et al. 2020).

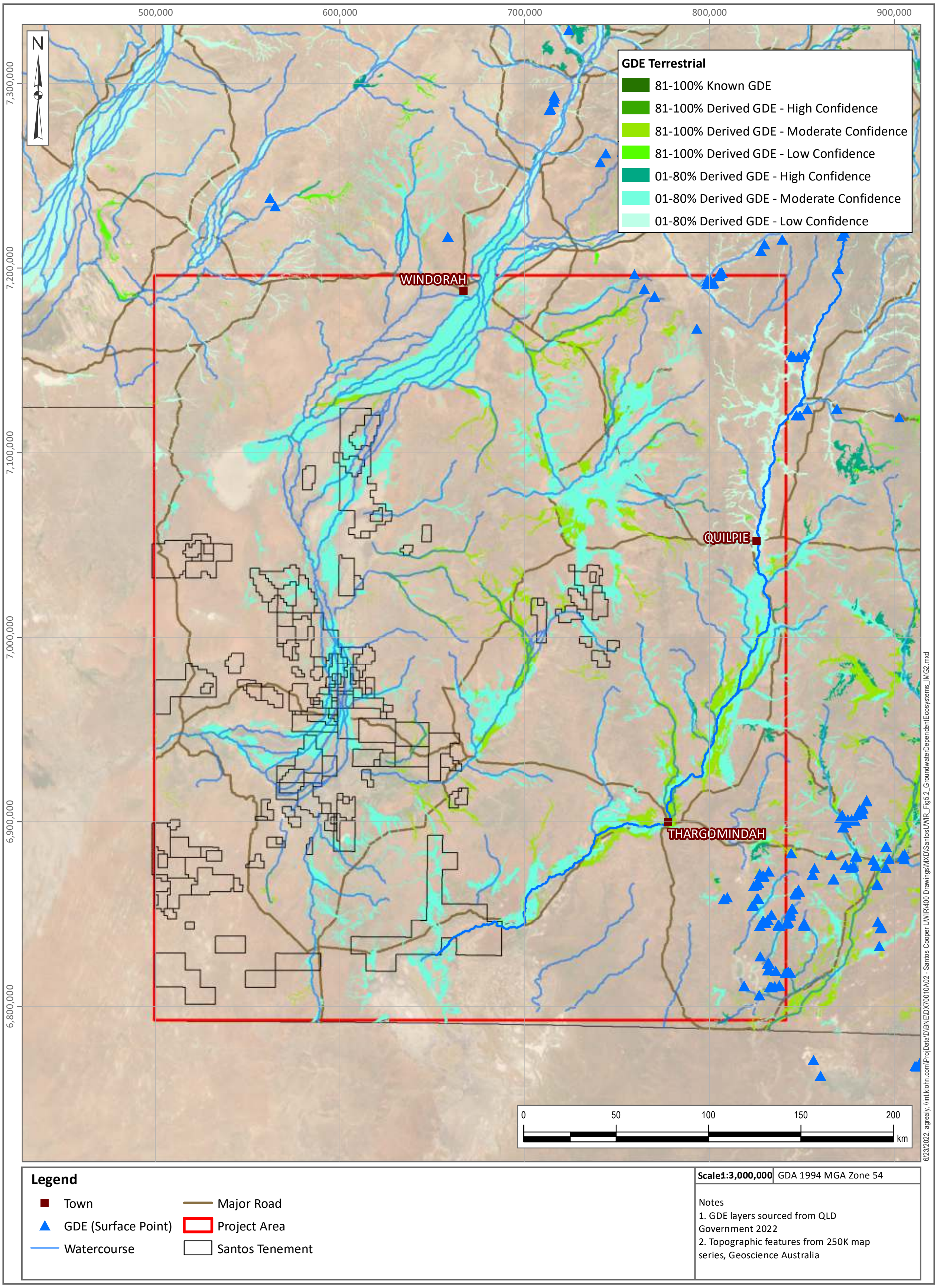



**Figure 5.8 Mapped GDEs in the Vicinity of the Project Area (GDE % is percentage of the polygon that is potentially a GDE)**

## 5.8 Third-Party Groundwater Users

### 5.8.1 Database searches for Groundwater Bores

A search of relevant Queensland Databases and Santos' internal EQUIS system was undertaken for the Project area. The purpose of this search was to:

- Identify the presence of current and historical 'water bores' and groundwater monitoring bores; and
- Collate drilling records and groundwater level, yield and quality data from relevant bores.

The database search of bores in the Project area was considered suitably representative of the geological and hydrogeological setting of the Project Area and includes the maximum potential extent of potential groundwater level drawdown as a result of the proposed Project activities.

The following databases and mapping tools were searched to support the assessment of bores and impacts for the assessment:

- The Queensland Government Groundwater Database of registered water bore data. This database provided information on bore location, groundwater levels, bore construction details, stratigraphic logs, hydrogeological testing and groundwater quality.
- The Queensland Spatial Catalogue (QSpatial), via Queensland Globe. Records of registered groundwater bores associated with petroleum exploration, production and monitoring wells are contained within this database.

A total of 2,300 groundwater bores registered under the Water Act ('registered water bores') were identified within the Project area. The location of these bores are presented in Figure 5.9.

Of the 2,300 registered groundwater bores:

- 903 bores identified as destroyed and abandoned;
- 410 bores identified as Petroleum bores;

This left 987 water bores assessed as part of impact assessment.

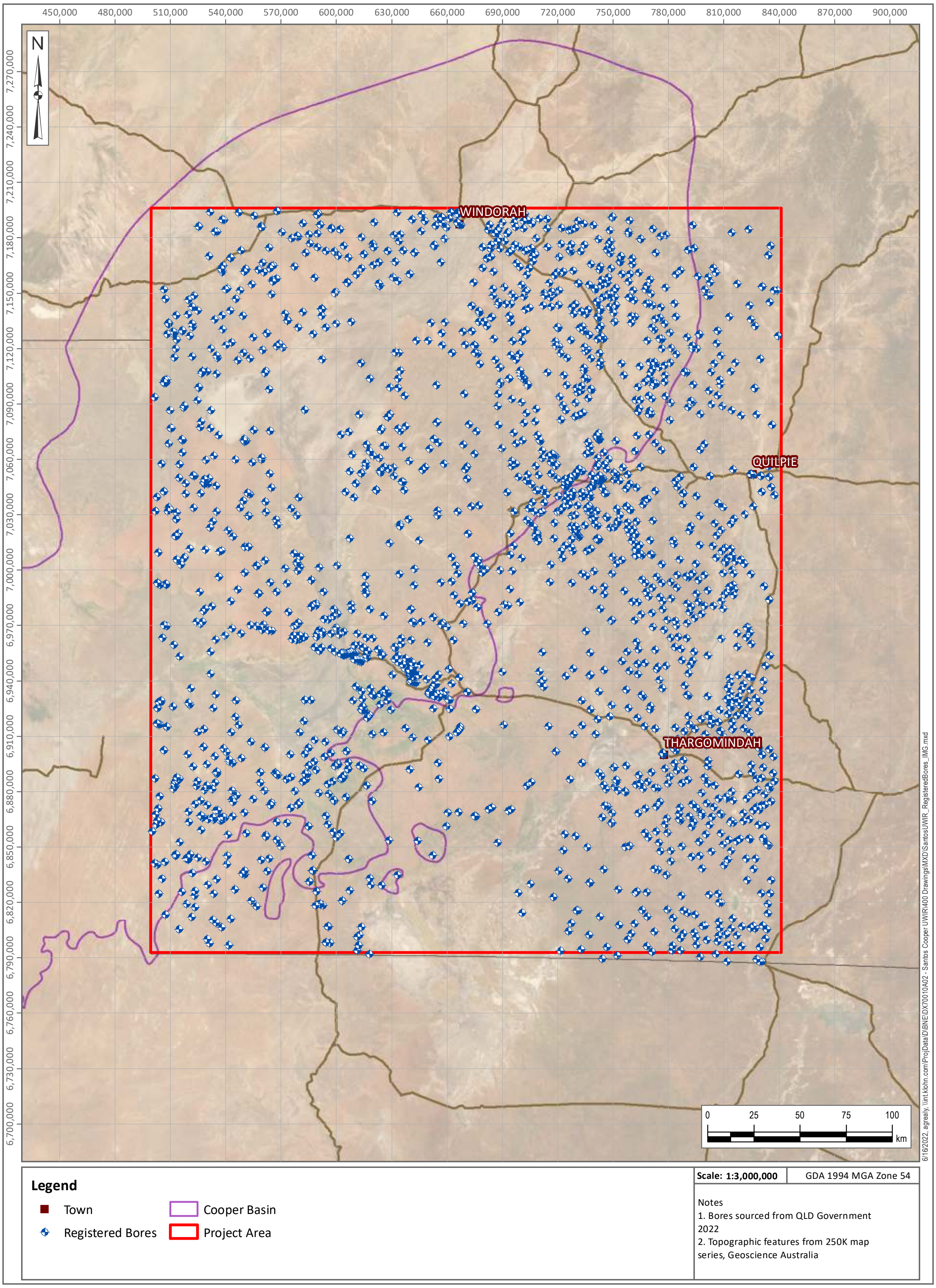



**Figure 5.9 Registered Groundwater Bores within the Project Area (QLD Government 2022)**

### 5.8.2 Bore Baseline Assessment

A water bore baseline assessment (WBAA) was undertaken in 2011 to 2013 (Golder Associates 2013a) to collect baseline information with regards to existence, construction, condition and accessibility of water bores, and where possible, aquifer data including water level, water quality, groundwater yield and use.

The initial WBAA identified that the confirmed number of bores that exist within the area of interest is less than that indicated in the DRDMW groundwater bore database. A total of 242 bores were assessed, 171 bores were identified with 117 in use. Of the bores in use, 107 were less than 100 m deep.

### 5.8.3 Groundwater Use and Purpose

Groundwater abstraction within the Project area provides a water source for the pastoral industry, population centres, mining activities, and other extractive industries. Most bores target shallow aquifers in the Winton–Mackunda partial aquifer and Cenozoic aquifers, as these aquifers are relatively shallow when compared to the artesian GAB aquifers. However, the relatively small number of groundwater bores (often repurposed petroleum wells) tapping into artesian GAB aquifers providing higher flow rates and suitable water quality for stock watering.

The majority of current groundwater bores (90%) are less than 300 m deep and abstract groundwater from the Winton–Mackunda partial aquifer and Cenozoic aquifers. There is significant lateral and vertical separation between these shallow aquifers and host stratigraphy of the oil and gas resource. Some oil and gas wells are however converted to water bores, providing some overlap of aquifers used for domestic and stock watering.

The hydrostratigraphic units of the Cooper Geological Basin is not used for groundwater supply (Evans et al. 2020).

# 6 SANTOS SWQ OPERATIONS

## 6.1 Gas Extraction: Areas of Production and Target Beds

Gas is extracted primarily from the formations of the Cooper Basin. Details on the geology of the Cooper Basin is presented in Section 5. These major gas reservoirs are hosted within:

- The Toolachee Formation.
- The Epsilon Formation.
- The Patchawarra Formation.

These reservoirs are porous sandstone formations separated by finer grained siltstones and mudstone formations (refer to detailed stratigraphy in Figure 6.1). The finer grained siltstones and mudstone formations are typically referred to as the seal or cap rock beds located over the reservoirs.

At the time of this UWIR, there are approximately 258 producing gas wells within Santos SWQ tenements.

The deep geological setting, and water quality, of the gas targets prohibits access by domestic and municipal users.

## 6.2 Oil Production: Areas of Production and Target Beds

Oil is extracted primarily from the GAB formations within the Eromanga Basin at depth averaging 1,000 m below ground level. Details on the geology of the Cooper Basin is presented in Section 5.1.2.

The stratigraphic units that host the major oil reservoirs include:

- The Murta Formation and the Namur Formation: these are the upper and lower formations of the Hooray Sandstone. Oil reservoirs are not frequent in the Namur Formation (a sandstone) but more abundant in the Murta Formation (interbedded mudstones, siltstones and fine-grained sandstones).
- The Birkhead Formation: the Birkhead Formation comprises interbedded siltstone, mudstone and fine sandstone. Oil reservoirs are mostly present in the basal strata of the Birkhead Formation, while some reservoirs are found in the middle Birkhead Formation.
- The Hutton Sandstone: this is the main extraction unit for oil over the Santos tenements in SWQ.

Minor oil reservoirs are also found in other formations in the Project area, including:

- The Wyandra Sandstone Member: this is the upper formation of the Cadna-Owie Formation, however, oil occurrence is not frequent
- The Westbourne Formation and the Adori Sandstone.

Figure 6.2 summarises the occurrence of oil reservoir through the stratigraphic profile.

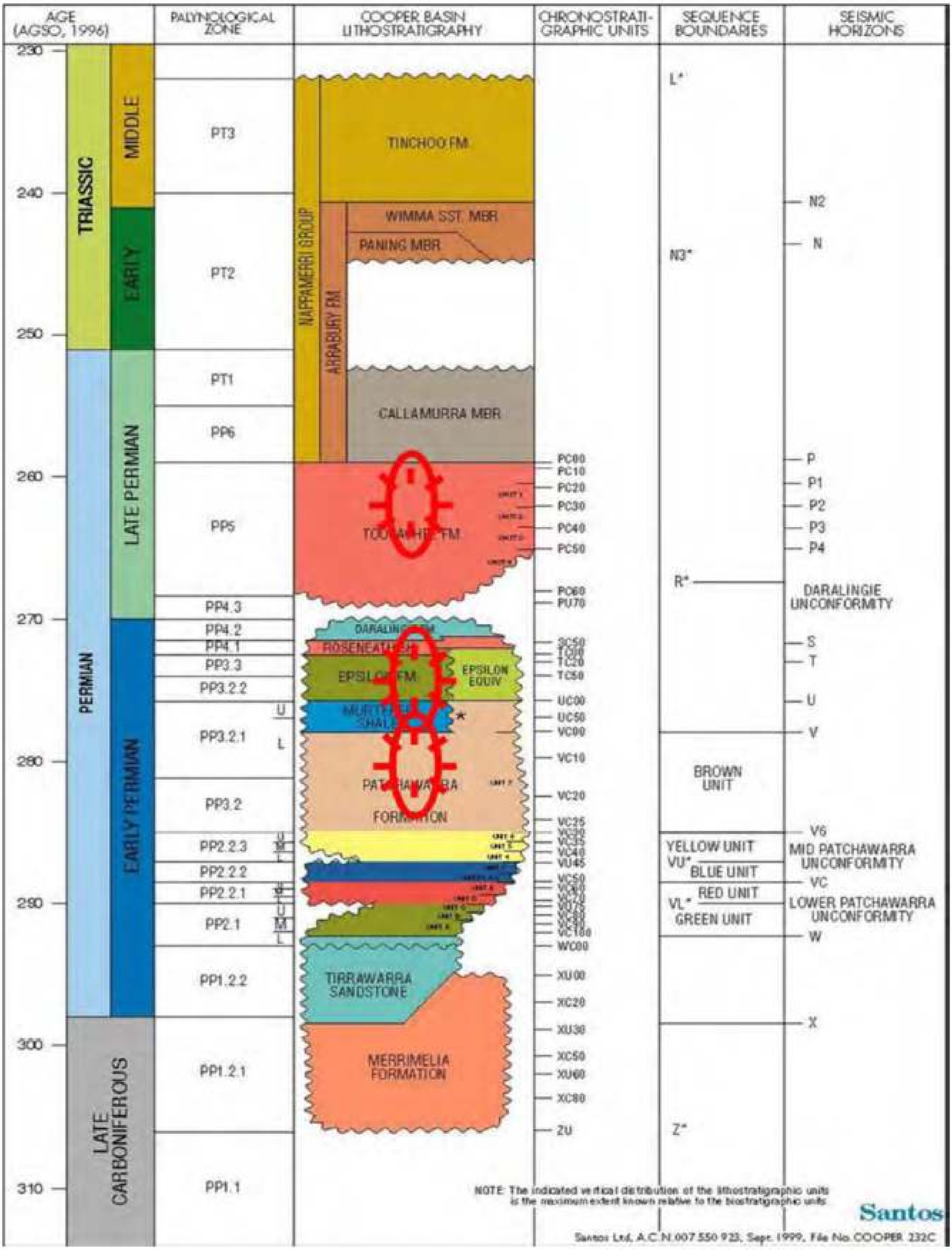



**Figure 6.1 Gas Reservoirs Stratigraphic Distribution**

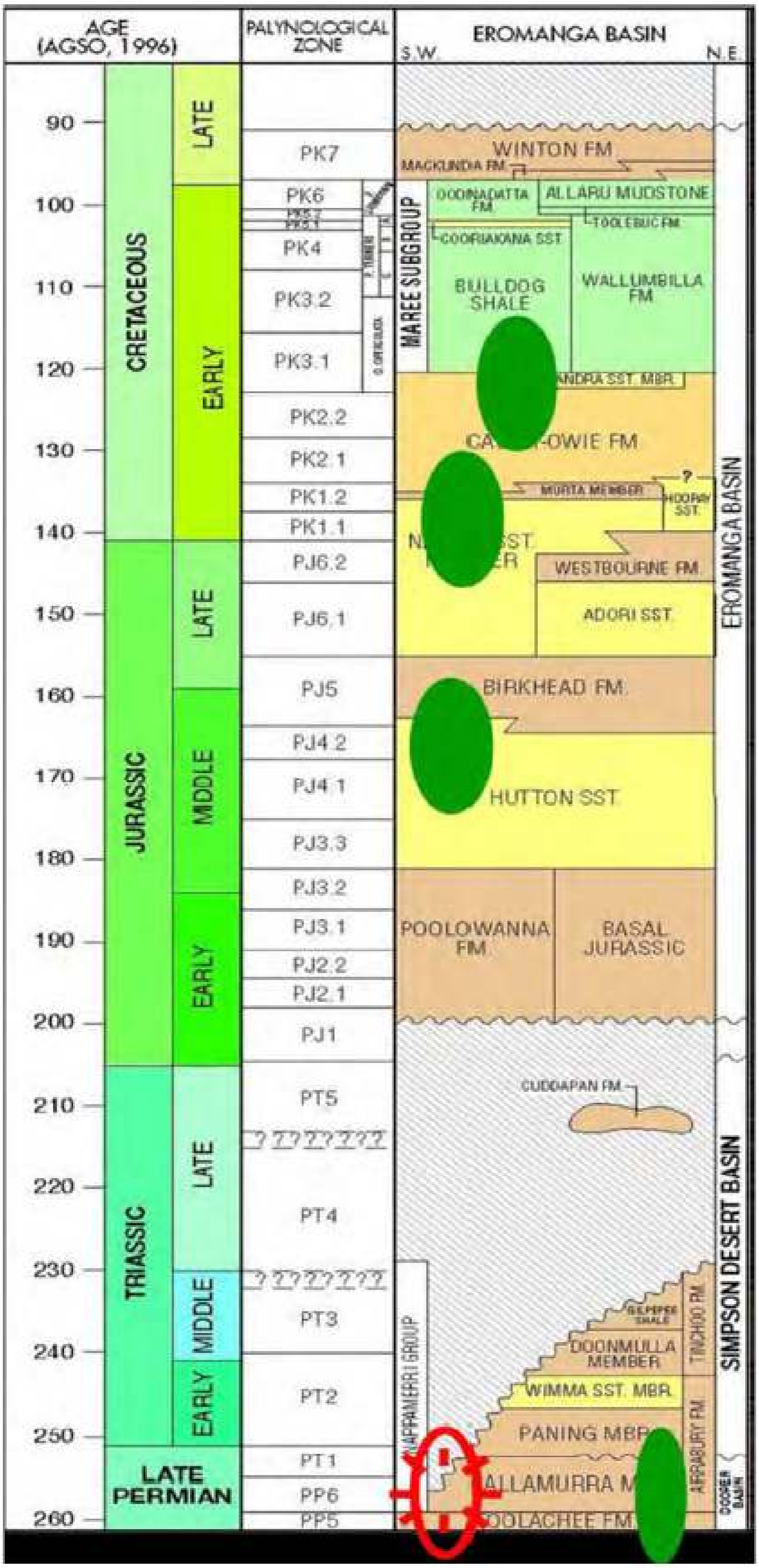



**Figure 6.2 Oil Reservoirs Stratigraphic Distribution**

## 6.3 Associated Water

Water is produced as a co-product of oil and gas operations in the Project area, this is referred to as associated water. The volume of associated water depends on a number of factors including (but not limited to) the type of well (i.e. oil well versus gas well), the hydrocarbon formation and the age of the well. By comparison, gas wells generate smaller volumes of water than oil wells.

Santos currently (2021) operate 257 oil wells and 258 gas wells and in the Project area.

## 6.4 Associated Water Monitoring Methodology

### 6.4.1 Associated Water Monitoring – Gas

The volume of associated water as part of Santos' gas operations is estimated based on the average water content of the gas produced.

The certainty around the volume of water produced as a result of gas production is lower than that for oil. However, given that gas production accounts for only 3% (approximately) of the total volume of water produced, as a result of Santos' SWQ Cooper and Eromanga Basin operations, small variations in estimated versus actual produced volumes will not have a material impact on the overall drawdown calculations.

### 6.4.2 Associated Water Monitoring – Oil

The methodology for monitoring associated water as a result of oil operations includes:

- Individual well water-cut meters (Red-eye or DNOC).
- Wellhead water-cut samples.
- Tank dips.

Monthly estimates of water production for any given well are based on:

- Estimation of the theoretical monthly oil and water production by well (using latest individual well test rates multiplied by the number of days the well was producing (i.e. uptime)).
- Summing the theoretical volume of a well or wells that collect into some fixed, known gathering point to give the monthly total theoretical oil and water volumes.
- Comparing theoretical volumes to actual monthly oil and water production at a fixed, known gathering point (where the monthly actual oil and water production is based on measurement of trucked oil loads, or oil piped through a fiscal metering point).
- Allocating (pro-rating) the total theoretical volumes to the individual wells based on the ratio of "actual total"/"theoretical total".

Santos' monitoring methodology for associated water (i.e. the approximately 4 GL/year abstracted through oil production) is a reasonable approximation of actual volumes based on the premise that the total volume for each well is recorded at two points i.e. a known gathering point and a fiscal metering point.

## 6.5 Methodology for Predicting Water Extraction

For the purposes of predictive modelling of the Eromanga and Cooper Basins, historical extraction data was used to estimate future extraction rates, taking into account an allowance for planned new wells within existing petroleum leases and also development of new leases. The history of activities in the Cooper and Eromanga Basins demonstrate an overall declining trend in water production rates (Figure 6.3). Assuming the water production rates will stay similar to the current rate, is a conservative approach for determining produced water volumes and to assess the depressurisation impact to groundwater. Current water production rates are likely to be similar or may even decline in the future, based on the observed long-term trend, therefore resulting in potentially lower depressurisation impacts.

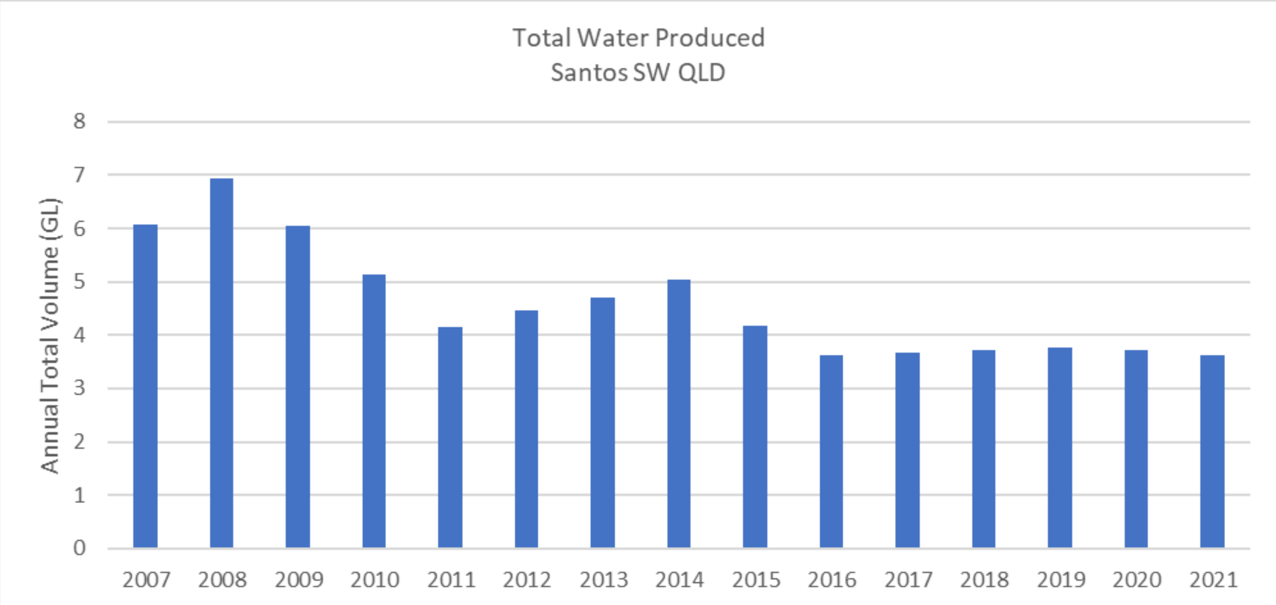



**Figure 6.3 Annual Total Estimated Water Production Rates for Santos SWQ Operations**

The methods used to determine these rates for both the IAA and LTAA for both the Eromanga and Cooper Basins are detailed below. For the purposes of predictive modelling:

- The water production rate from the last year of historical data (2021) was used to represent future water production rates. The average annual water production rates from an oil well (mostly from the Eromanga Basin) were calculated by dividing the total water produced from oil wells by the number of oil wells. The same was undertaken for the water produced from gas wells (mostly from the Cooper Basin) to get an average annual water production rate per gas well.
- The number of oil and gas wells per petroleum lease area are multiplied by the average rates calculated above, to determine the distribution of water extraction spatially and between the Eromanga and Cooper Basins;
- For the purposes of IAA the current (2021) distribution and count of wells for each petroleum lease area were used; and
- For the purposes of LTAA the number of planned future wells for each petroleum lease area, according to Santos' plans, in addition to the count of existing operational wells, were used to obtain a long-term representative total extraction per lease.

## 6.6 Water Flooding

Water flooding is being undertaken at Cranstoun, Mulberry, Gimboola, Talgeberry and Endeavour fields (in ATP299P) with the objective of enhancing oil recovery by maintaining pressure in the Birkhead and Murta oil reservoirs and improving sweep efficiency[2]. Water flooding comprises the injection of water into the oil reservoir in order to restore and maintain pressure and enhance production (Golder Associates 2013b). Where water flooding is undertaken, water for the water flooding is sourced from treated produced water at the Tarbat treatment plant (Golder Associates 2013b).

The risks associated with water flooding activities comprise the risk of creating inter-formation hydraulic connection, degrading water quality of the receiving aquifer and over-pressurising the receiving aquifer. A risk assessment for water flooding was undertaken by URS (2010), which identified that the risks from water flooding were low. Risk management procedures for water flooding include adherence to the water flooding design, well integrity and effective management and monitoring of the water flooding program (Golder Associates 2013b).

Water flooding is not represented in the 2022 UWIR groundwater analytical modelling, which increases the level of conservatism in the drawdown prediction.

[2] Sweep efficiency is the measure of effectiveness of an enhanced oil recovery process that depends on the volume of the reservoir contacted by the injected fluid.

# 7 CONCEPTUAL MODEL SUMMARY

The Cooper GBA Program Stage 2 (Evans et al. 2020) considered various sources of data (including data from Santos) to compile an up-to-date conceptual model for the Cooper Basin incorporating the Cooper–Eromanga Basin hydrocarbon system. The conceptual model proposed by Evans et al. (2020) (Figure 7.1) is summarised below:

- The Cooper Basin contains gas reservoirs occurring at significant depths in depocentres such as the Patchawarra, Nappamerri and Windorah troughs. These gas reservoirs are separated from the Eromanga Basin aquifers (e.g. the Hutton Sandstone aquifer) by the Nappamerri Group.
- Due to the layered nature of the deposition environment, limited vertical flow of gas or water is expected near the conventional gas traps associated with the Santos exploration and development. There are potential for connectivity between the Eromanga and Cooper basins where the Nappamerri Group do not cover the deeper formations completely towards the edges of the Cooper basin (Figure 7.1).
- Primary recharge of the Eromanga Basin occurs on the boundary of the system and do not form part of this project area. Regional groundwater flow is from the northeast to southwest across the Cooper GBA region towards regional topographic low points (e.g. Lake Blanche). The artesian Hutton aquifer, forming part of the Eromanga Basin, is one of the main target areas for oil development for Santos in Queensland.
- The limited GAB water level data (1974 to 2009) shows no basin wide trends in the Cooper GBA region. Isotopic data suggests that these artesian pressures have been in place for at least a million years. The Rolling Downs aquitard prevents upward vertical leakage between the artesian Hutton aquifer, towards the sub-artesian Winton–Mackunda partial aquifer (Figure 7.1). GAB springs do not occur in the Cooper GBA region.
- Episodic flooding of losing streams in the parts of the Cooper Creek floodplain contributes recharge to shallow aquifers in the Cenozoic and Winton–Mackunda partial aquifer, forming freshwater lenses in the vicinity of some large near permanent waterholes (Figure 7.2).
- Most bores target shallow aquifers in the Winton–Mackunda partial aquifer (Figure 7.2) as these aquifers are relatively shallow when compared to the artesian GAB aquifers.

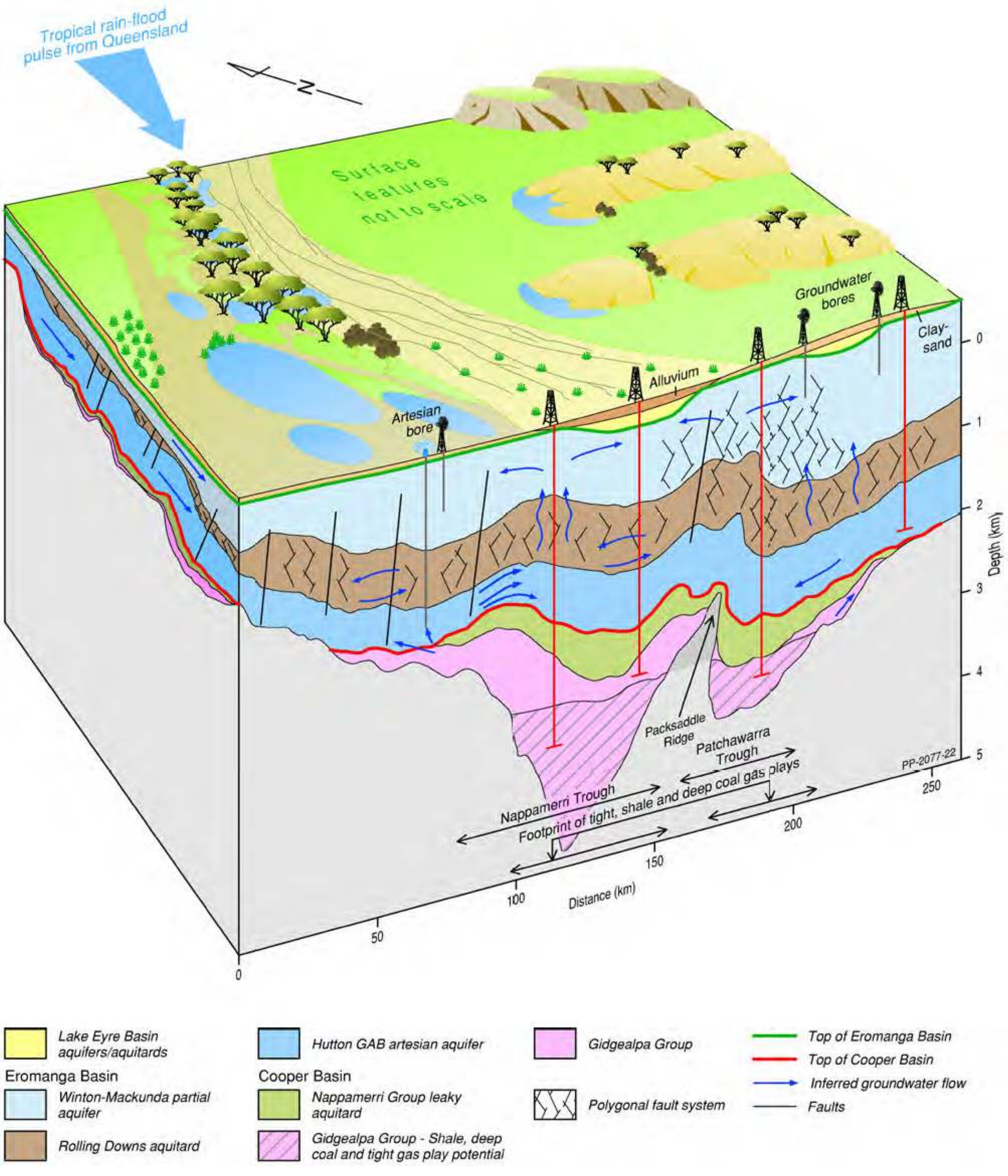



**Figure 7.1 Conceptualisation of Cooper and Eromanga Basins (Evans et al. 2020)**

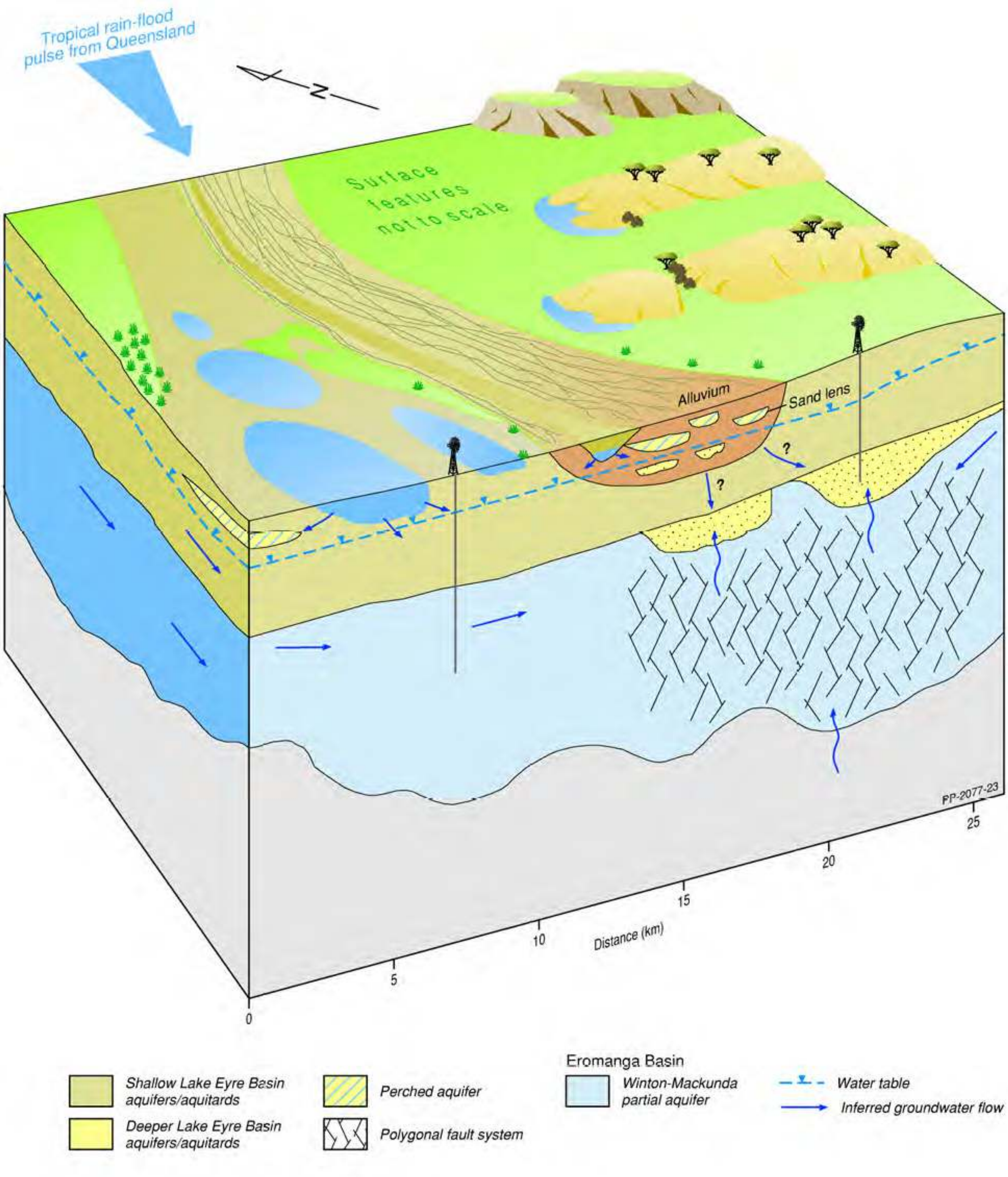



**Figure 7.2 Shallow Aquifer Interactions with Surface Water Features Including Lakes and Drainages**

# 8 GROUNDWATER MODEL

## 8.1 Model Design, Domain and Calibration

### 8.1.1 Model Code Selection

Analytical groundwater modelling has been undertaken to provide estimates of the decline in groundwater level/pressures in response to the extraction of co-produced water as a result of the Project development. The modelling platform adopted for the prediction of groundwater level/pressure changes in this UWIR is the same platform adopted for the 2013, 2016 and 2019 UWIRs, which have been previously approved by the regulatory authorities. Improvements to the 2019 model framework were undertaken for this UWIR.

The analytical modelling platform adopted for the Project is Analytical Aquifer Simulator (AnAqSim release 2021-2 27 Oct2021)(Fitts Geosolutions 2021), a pre- and post-processing package that uses analytic elements for the simulation of groundwater flow. AnAqSim (Fitts Geosolutions, LLC) employs high-order line elements, spatially-variable area sinks, and specified time steps to allow simulation of multi-level aquifer systems and wide-ranging flow simulations.

In the analytical element method (AEM), boundaries of the domain are discretised, but the domain itself is not. The AEM is fundamentally different than numerical methods like finite elements and finite differences, where the domain is distributed into small blocks or elements with simple head distributions (e.g. linear) assumed within these blocks or elements.

AnAqSim employs the AEM, which superposes analytic solutions to yield a composite solution consisting of equations for head and discharge as functions of location and time. The AEM is described in detail in Strack (1989) and Haitjema (1995).

AnAqSim uses a variation of the AEM that allows the model domain to be divided into subdomains, each with its own definition of aquifer parameters. Each subdomain model is written in terms of two-dimensional functions, with three-dimensional flow simulated using multiple layers in a model. In multi-level models, the resistance to vertical flow is accounted for in the vertical leakage between levels. This subdomain approach allows for a high degree of flexibility with respect to a model's heterogeneity, anisotropy and layering.

Like any flow model, the flow equation in AnAqSim is based on Darcy's Law and conservation of mass (and volume, with constant density). The conservation equation, in its simplest form is:

$$-\nabla Q = \gamma = L_t + L_b + S\partial h/\partial t$$

where $\nabla Q$ is the divergence of the two-dimensional aquifer discharge vector field and $\gamma$ is the net extraction per area (sink term, units of L/T). The sink term $\gamma$ may have contributions from leakage out the top of the subdomain ($L_t$), leakage out the bottom of the subdomain ($L_b$), and transient discharge/area into storage ($S\partial h/\partial t$).

In many practical cases, the model needs spatially variable extraction ($\gamma$ varies with x, y) due to spatially-variable vertical leakage and/or spatially-variable storage changes. When that is the case, the model needs spatially variable area (SVA) sinks to approximate the proper distribution of $\gamma$. The spatially-variable area sink functions in AnAqSim create a smooth, continuous and irregular $\gamma$ surface within a subdomain.

### 8.1.2 Model Dimension

The groundwater model was developed in three-dimensions (3D) in order to simulate groundwater movement in both the horizontal and vertical planes. This is particularly important in the vicinity of the oil and gas wells where the co-produced water is expected to flow towards the well laterally, as well as potentially from the hydrostratigraphic units above and below the producing unit. Furthermore, the conceptual model identified that more than one overlying hydrostratigraphic unit above the producing unit, therefore, the incorporation of the horizontal flow of these individual units, and the vertical flow between adjoining units, is required for the model domain.

### 8.1.3 Time Discretisation

Calibration simulations were completed to steady state conditions. The available datasets do not provide useful time series data for a transient calibration. The calibration was therefore undertaken using a multiple steady-state approach where the model parameters were tested against a series of basin development phases where data for calibration is available in a specific area of the basin.

This is regarded as conservative considering:

- Regional artesian pressures in the Eromanga basin expected to be relatively consistent over large time scales, which is confirmed by the available time series data (Section 5.4.2).
- Artesian pressures in the Cooper Basin are reported to be present over time scales of thousands of years (Section 5.5).

Predictive simulations were simulated in steady state conditions, which is considered a conservative approach for predicting a maximum drawdown for the assessment of groundwater impact for the number of wells operational at any stage.

### 8.1.4 Model Layers

The compilation of the AEM using the AnAqSim graphic user interface facilitated the construction of the model domain, as well as vertical geometry provided for each of the 3D layers (Table 8.1). The AnAqSin platform allows for a 2D layer where mostly horizontal flow is expected, with the possibility to defining 3D areas where vertical flow might be important. For the Cooper GBA system both 2D and 3D aquifer units were defined in the model to represent the near horizontal flow in the regional GAB hydrostratigraphic units, and potentially vertical gradients in the Cooper GBA region respectively.

Layers 1, 2, 3 and 4 of the model interacts on its boundaries with the outer 2D layer (numbered as Layer 2), which is conceptually represented in Figure 8.1.

**Table 8.1 Model Layers and Vertical Discretisation**

| Label | Level | Domain Type | Top Elevation (mAHD) | Bottom Elevation (mAHD) |
|---|---|---|---|---|
| Eromanga Ecological Inner 3D | 1 | confined/unconfined | 170 | -300 |
| Eromanga 2D Boundary | 2 | confined/unconfined | 170 | -2300 |
| Eromanga Inner 3D | 2 | confined | -300 | -1000 |
| Eromanga Rolling Downs Aquitard | 3 | confined | -1000 | -1800 |
| Eromanga Hutton Oil Extraction | 4 | confined | -1800 | -2300 |
| Cooper Nappamerri Aquitard | 5 | confined | -2300 | -2800 |
| Cooper Gas Extraction | 6 | confined | -2800 | -3300 |
| Deep Cooper Below Gas | 7 | confined | -3300 | -4500 |

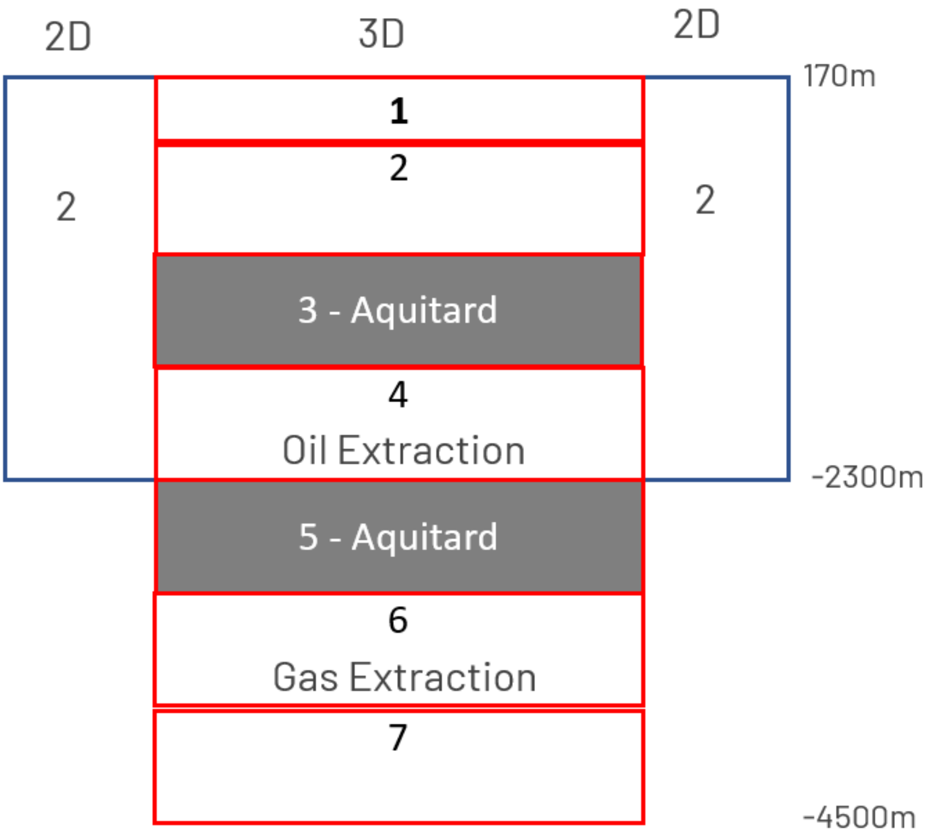



**Figure 8.1 Conceptual Representation of Groundwater Model Layers**

The layered stratigraphy of the two basins overlying each other allows for this simplified numerical simulation to represent the system's key behaviour and assessing the potential impacts of the deep oil and gas development on the shallow aquifers. The regional GAB hydrostratigraphic units are represented by the 2D outer layer. The model interaction with the regional GAB flow field is achieved via specified head and specified flux boundaries. These boundaries are presented in Figure 8.2.

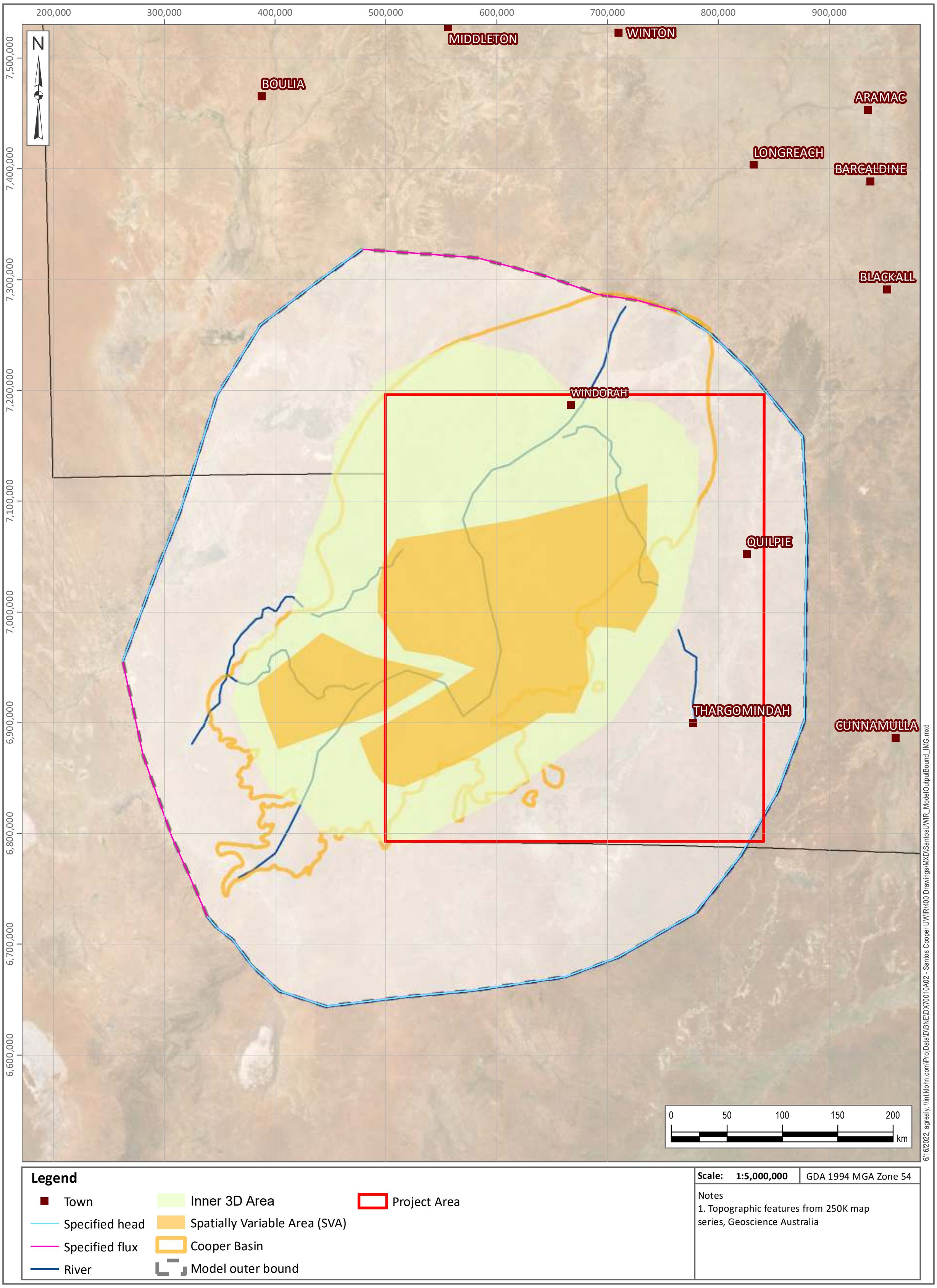



**Figure 8.2 Groundwater Model Boundary Conditions and SVA Vertical Flow Computation Areas**

### 8.1.5 Model Extent and Boundary Conditions

A suitably larger model domain was selected in order to mitigate any influence that the boundary conditions may have on the modelling outcomes. For the purpose of this assessment the boundary conditions were selected to represent the regional processes in the Eromanga and Cooper Basin as realistic as possible, while allowing for the current and future oil and gas well placements of the SWQ operations at the appropriate target depths. Only the SWQ component of the Santos operations are assessed in this model. The predictions of the potential impacts of the current and proposed operations will therefore only be applicable to the SWQ area. Predicted impacts on the Cooper Basin within South Australia is not expected to change the impacts predicted in Queensland due to the reported compartmentalisation and limited vertical connectivity expected between the deep oil and gas resources and the shallow aquifer systems.

Boundary conditions represent the hydrogeological setting of a model domain by establishing flux conditions along the boundary and the associated hydraulic head. Different boundary conditions result in different solutions, hence the importance of stating the correct boundary conditions. Boundary condition options in AnAqSim can be specified either as:

- Specified head or Dirichlet; or
- Specified flux or Neumann boundary conditions.

Conceptually, it was essential to meet three criteria as part of the modelling process:

- To define the appropriate model boundaries for both the Eromanga and Cooper basins by natural geological and hydrogeological boundary conditions;
- Allow for correct vertical flow solution (3D flow equations) in areas where oil and gas wells are operational; and
- Allow for correct horizontal flow solution (2D flow equations) in the model where the horizontal flow in the regional Eromanga basin dominates the flow.

Boundaries were delineated on the basis of the potential radius of influence, hydrogeological units, landscape/topography, and surface water bodies such as streams. In AnAqSim these boundaries are implemented with lines and polygons, rather than defining properties for individual cells. For the 3D model domain areas it is possible to define vertical flow boundaries over the defined area. The SVA areas provide the opportunity to define a different boundary conditions over the defined subsections.

The model boundaries are shown in Figure 8.2 together with the 2D and 3D model domain areas, as well as the SVA areas. Table 8.2 provides a summary of the boundaries, boundary descriptions and boundary conditions specified in the hydrogeological model.

**Table 8.2 Correlation of Real-World Boundaries with Adopted Model Boundary Conditions**

| Boundary | Boundary Description | Boundary Condition |
|---|---|---|
| 2D outer model area | Shallow groundwater interacts with streams. | River Lines representing rivers or streams.<br>Zero flux from top and bottom. |
| North East | Regional GAB heads in North East | Specified Head Line<br>(220mAHD to 190 mAHD) |
| South East | Regional GAB heads in South East | Specified Head Line |

| Boundary | Boundary Description | Boundary Condition |
|---|---|---|
| | | (190mAHD to 50 mAHD) |
| South | GAB Outflow to South | Specified Head Line<br>(50mAHD to 0 mAHD) |
| South West | Flow parallel to boundary towards Lake Blanche | Specified Flux Line<br>Zero Flux |
| North West | GAB inflow from North West | Specified Head Line<br>(50mAHD to 0 mAHD) |
| North | No known GAB flow from North | Specified Flux Line<br>Zero Flux |
| Inner 3D Area | Oil and gas extraction area where vertical flow important (Node Spacing 10km) | Specified Flux from bottom over entire area<br>(200 mAHD) |
| SVA 1 | Higher density SVA points (Node Spacing 5km)<br>Cooper Basin gas overpressure area<br>(Webster et al. 2000) | Specified Flux from bottom over SVA 1<br>(400 mAHD) |
| SVA 2 | Higher density SVA points (Node Spacing 5km)<br>Cooper Basin gas overpressure area<br>(Webster et al. 2000) | Specified Flux from bottom over SVA 2<br>(300 mAHD) |

### 8.1.6 Calibrated Hydraulic Parameters

The hydraulic conductivity for each of the model layers in AnAqSim represent bulk hydrostratigraphic unit properties and do not represent small scale variations within the model layers. The steady-state model comprises of seven layers which holistically represents the main aquifers and hydrostratigraphic units relevant to the proposed oil and gas development. The final horizontal and vertical hydraulic conductivities and transmissivity values for each model layer are listed in Table 6.2. These hydraulic conductivity values are similar to the values used in the modelling assessment used in the 2013 UWIR (Golder Associates 2013) and it subsequent revisions.

**Table 8.3 Calibrated Horizontal and Vertical Hydraulic Conductivities**

| Label | Level | Domain Type | Top Elevation (mAHD) | Bottom Elevation (mAHD) | K Horizontal (m/d) | K Vertical (m/d) |
|---|---|---|---|---|---|---|
| Eromanga 2D Outer | 2 | confined/ unconfined | 170 | -2300 | 0.3 | 1.00E-07 |
| Ecological Inner 3D | 1 | confined/ unconfined | 170 | -300 | 0.55 | 1.00E-06 |
| Eromanga Inner 3D | 2 | confined | -300 | -1000 | 0.5 | 1.00E-04 |
| Rolling Downs Aquitard | 3 | confined | -1000 | -1800 | 0.001 | 1.00E-06 |
| Hutton | 4 | confined | -1800 | -2300 | 0.25 | 1.00E-04 |
| Cooper Nappamerri Aquitard | 5 | confined | -2300 | -2800 | 0.001 | 1.00E-07 |
| Deep Gas | 6 | confined | -2800 | -3300 | 0.01 | 1.00E-04 |
| Deep Cooper Below Gas | 7 | confined | -3300 | -4500 | 0.001 | 1.00E-04 |

### 8.1.7 Model Calibration

A number of performance measures can be proposed to indicate when a model fits historical field measurements closely enough to be acceptable for use in future predictions. These may include Root mean squared error (RMS), Scaled mean sum of residuals (SRMS), Residual mean (RM), Absolute residual mean (ARM), Scaled absolute mean (SAM) and Scaled mean sum of residuals (SMSR).

The analytical model has been calibrated against various measured and published data sets providing detail of a specific hydrostratigraphic unit during the development of the oil and gas fields. The following data was used to guide the calibration of the model:

- **Pre-development Steady-State**: Webster et al. (2000) published a paper with spatial trends of the pre-development pressures compiled from Santos deep oil and gas development. These spatial trends were used as a guide to establish the Pre-development simulation without oil and gas extraction.
- **2011 Steady State:** A hydrocensus conducted by Golder in 2011 providing spatial measurements of accessible bores and wells, providing water levels/pressure heads. This data set mostly represents the shallow aquifers, with some data for oil and gas wells converted to water wells. Some of the water levels measured as part of the GAB monitoring is available between 2009 and 2011 (Section 5.4.2) and is included in this data set.

The following numerical stability and calibration performance measurements were evaluated during the calibration of the Santos Cooper basin model:

1. Model convergence: Model convergence was obtained during calibration and a maximum change in heads between iterations was set to 1.0E-03 m.
2. Water Balance: The model demonstrated an accurate water balance at all times the during steady state simulation. The water balance error was below one percent.
3. Quantitative measures: The steady state calibration was regarded as sufficient based on an average residual of 7.8m, and a Scaled Root mean square error (Scaled-RMSE) of 9.4%. The graph provided in Figure 8.3 shows the correlation between measured and simulated heads from the steady-state calibration. In case of absolute conformity, the points should create a 45-degree straight line (Line of perfect fit). As it can be seen, the level of conformity is tolerable especially when the uncertainty in spatial variation of hydraulic properties is taken into account.
4. Qualitative measures: The regional “pre-development” steady state water level contours are illustrated in Figure 8.4 The Pre-Development Steady State model results attempts to replicate the of broad trends in the Eromanga and Cooper Basins. In general, satisfactory trends could be reproduced showing the regional northeast to southwest flow within the Eromanga GAB Basin (Figure 8.4) (as reported by Webster et al. 2000) and the distribution of pressures in the Cooper Basin (Figure 8.4) (Webster et al. 2000). Small scale variations in hydraulic conductivity and the role of structural influences could not be reproduced in the simplified analytical model.

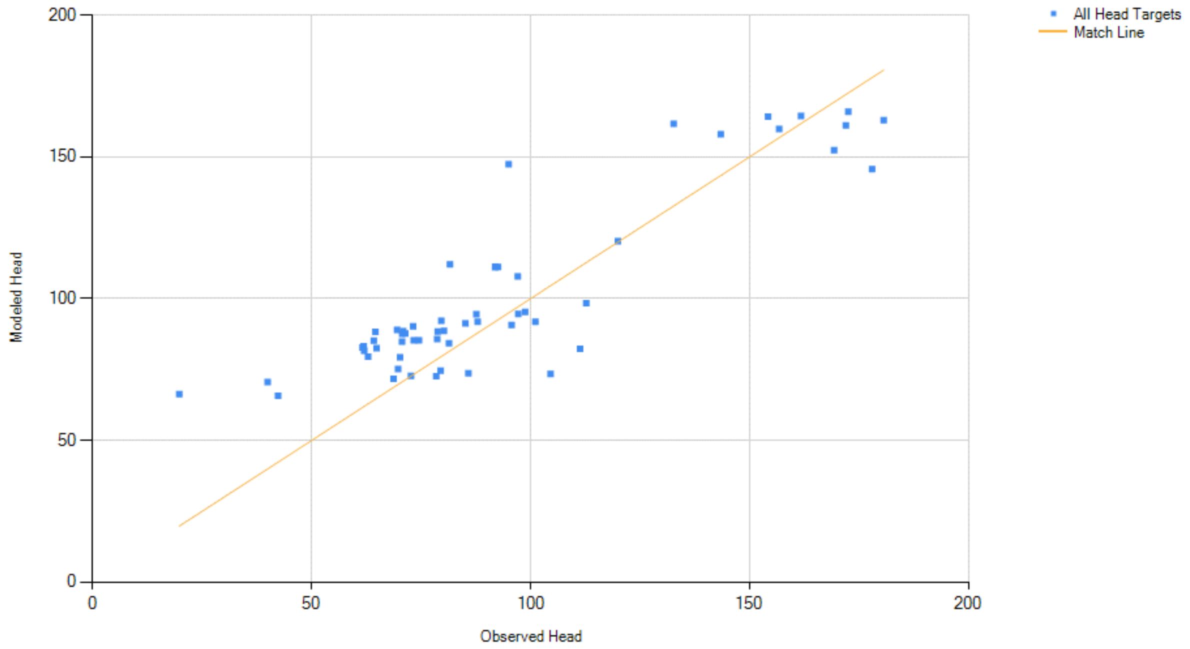



**Figure 8.3 Correlation of Observed and Modelled Heads**

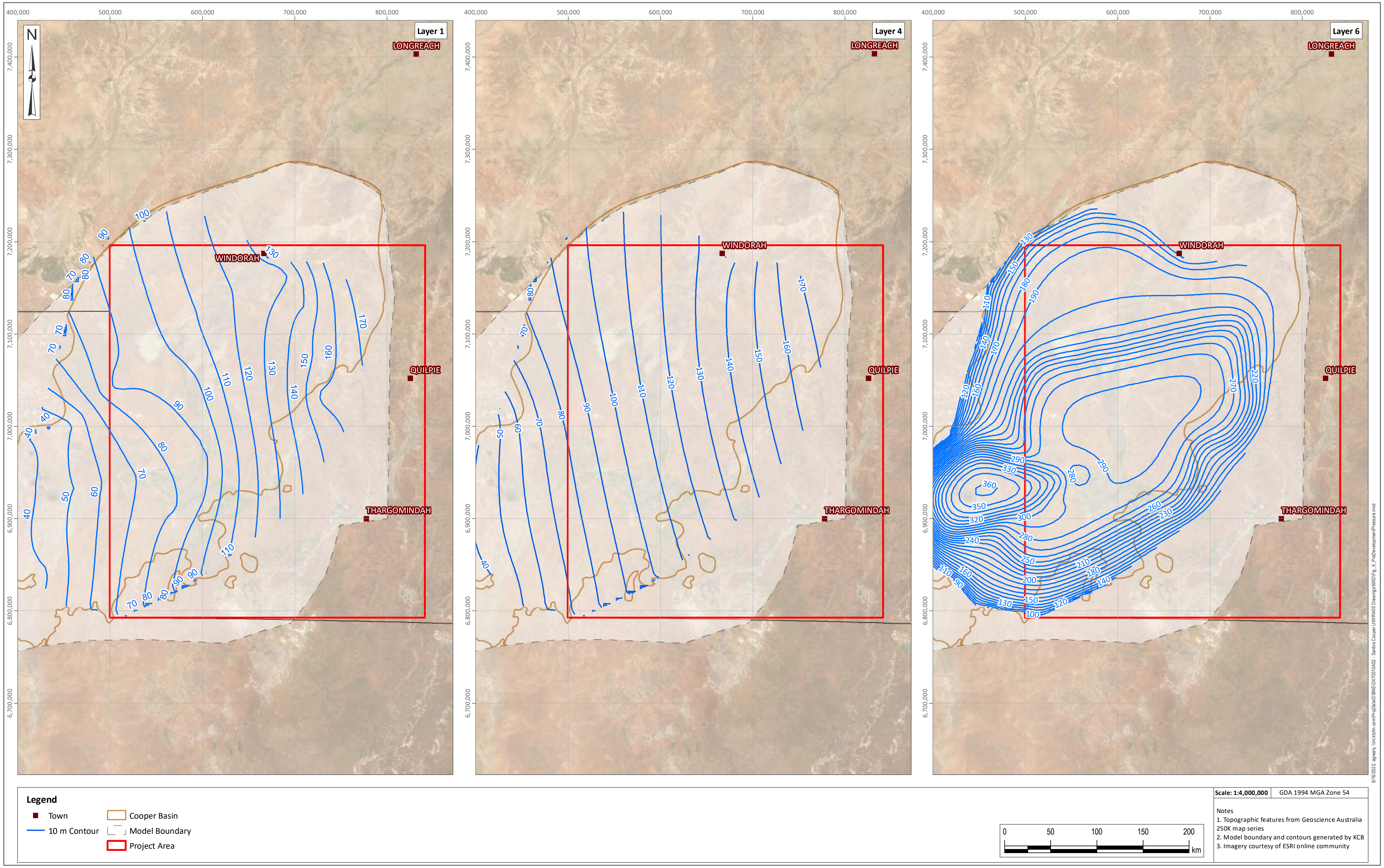



**Figure 8.4 Simulated Pre-development Pressures for Surface Layers (Layer1), the Hutton Sandstone Aquifer (Layer 4) and Cooper Gas Extraction (Layer6)**

### 8.1.8 Model Confidence Level

The level of confidence in the model constructed and calibrated for the Santos Cooper Basin can be assessed based on criteria defined in the Australian Government National Water Commission groundwater modelling guidelines (Barnett et al. 2012). These guidelines classify model confidence according to three classes, where Class 3 is assigned the highest confidence and Class 1 the lowest. The model confidence classification provides an indication of the type of modelling applications for which the particular model is suitable for use.

The model confidence, for the model developed as part of this assessment, is regarded as above a Class 1 (with some reasonable calibration, regional data available for calibration, used to predict regional impacts, and numerical stability), but do not meet the criteria to qualify for a Class 2. According to the guidelines a Class 1 model is suitable for "developing course relationships between groundwater extraction locations and rates and associated impacts". This is regarded as appropriate for estimating the drawdown impacts associated with the Santos Cooper operations in Queensland.

### 8.1.9 Model Assumptions and Limitations

Groundwater flow models are inherently simplified mathematical representations of complex aquifer systems. The simplification limits the accuracy with which groundwater systems can be simulated in general. There are numerous sources of error and uncertainty in groundwater flow models. Model error commonly stems from practical limitations of time discretisation, parameter structure, insufficient calibration data, and the effects of processes not simulated by the model. These factors, alongside unavoidable error in historic field observations and measurements, result in uncertainty in the model predictions. Additional spatial and time series monitoring data will be required for the various hydrostratigraphic units to improve these predictions.

The hydraulic conductivity estimates used in the model are selected based on the functioning of relatively thick and extensive model layers covering the Cooper Basin and even larger Eromanga Basin. These hydraulic conductivity properties are selected to simulate the broad hydrogeological processes described in conceptual model presented by Evans et al. (2020). Small scale variability in hydraulic properties within layers might result in model uncertainty, as it may not reflect the true complexity of the geology.

## 8.2 Scenario Results

Following calibration, the model can be used to simulate the proposed development scenario to predict potential impacts on the groundwater resource. Scenarios simulated for the Santos SWQ operations include:

- Baseline pre-development regional trends: the baseline simulation of the Cooper GBA region without oil and gas development;
- Immediate Affected Area (current development); and
- Long Term Affected Area (includes all current and proposed developments).

The predicted drawdown for the Project development of the next three years (Figure 8.5 and Figure 8.6) and for the total Project development (Figure 8.7 and Figure 8.8) is calculated as the difference in groundwater levels/pressures from the baseline pre-development scenario.

Key points from the model predictions include:

- The impact of Project development in the Cooper Basin does do not influence any registered bores (Figure 8.6 and Figure 8.8).
- There is no predicted drawdown in the unconfined Tertiary and Quaternary strata. This prediction is considered to be a conservative worst-case prediction as the simulation was completed under steady state conditions.
- The predicted IAA extent in the Eromanga Basin extends over one potential water supply bore potentially extracting from the Hutton Sandstone (model layer 4). This is bore RN22691. (Figure 8.7).
- The predicted LTAA extent in the Eromanga Basin extends over eight potential water supply bores which are potentially extracting from the Hutton sandstone (model Layer 4) and overlying Rolling Downs Aquitard (model layer 3). These are RN 16066, RN23102, RN16768, RN23081, RN23372, RN5092, RN23227 (Figure 8.7 and Figure 8.8).

Potential IAA and LTAA are screened further in Section 8.3 to determine the status of the potentially impacted bores.

**Table 8.4 Potential Water Supply Bores Predicted to be Triggered Under the IAA and LTAA Project Development Scenarios**

| Bore Name | Bore Number | Easting * | Northing * | Total Depth (m) | IAA | IAA Drawdown (m) | LTAA | LTAA Drawdown (m) |
|---|---|---|---|---|---|---|---|---|
| Orientos 1 | 16066 | 542108 | 6896737 | 1594 | | | LTAA L3 | 5.5 |
| Wills 1 | 23102 | 521710 | 6863712 | 1861 | | | LTAA L4 | 8.4 |
| Roseneath 1 | 22691 | 523575 | 6884172 | 2193 | IAA L4 | 5.3 | LTAA L4 | 9.5 |
| Innamincka 2 | 16768 | 505530 | 6963581 | 1885 | | | LTAA L4 | 7.9 |
| Jackson water well no.1 | 23081 | 640342 | 6943883 | 1260 | | | LTAA L3 | 6.6 |
| Balooma 1 | 23372 | 662618 | 6938773 | 1310 | | | LTAA L3 | 5.5 |
| No.9 | 5092 | 671140 | 7020167 | 1551 | | | LTAA L3 | 5.2 |
| Boldrewood 1 | 23227 | 655041 | 7032349 | 1380 | | | LTAA L3 | 5.1 |

* Datum - GDA94 / MGA Zone 54

## 8.3 Screening of Potentially Impacted Water Bores

Potentially impacted water bores have been screened to identify their current bore status. The screening process included a review of the Geoscience Queensland Open Data Portal (Geoscience Queensland 2022 formerly QDEX), aerial imagery and bore reports. The results of this screening assessment are summarised in Table 8.5.

**Table 8.5 Screening of Potential Impacted Water Bores**

| Bore Number | Bore Name | Bore Depth (m) | Status | Source |
|---|---|---|---|---|
| 16066 | Orientos 1 | 1593.5 | Converted oil/gas well, now abandoned. | Bore Baseline Assessment (Golder Associates 2013a) |
| 23102 | Wills 1 | 1860.8 | Suspended exploration bore | GSQ Open Data Portal (Geoscience Queensland 2022) |
| 22691 | Roseneath 1 | 2192.7 | Suspended exploration bore | GSQ Open Data Portal (Geoscience Queensland 2022) |
| 16768 | Innamincka 2 | 1884.9 | GAB Monitoring bore | See section 5.4.2. |
| 23081 | Jackson water well no.1 | 1260.3 | Industrial water supply bore | Bore Baseline Assessment (Golder Associates 2013a) |
| 23372 | Balooma 1 | 1310.0 | Water bore | Santos has a Make Good Arrangement in place for this bore. |
| 5092 | No.9 | 1550.8 | Potentially free-flowing bore and bore drain. Bore report suggests estimated use if 5.1 ML/year for 2000 sheep (stock water) | Aerial imagery<br>Registered bore report |
| 23227 | Boldrewood 1 | 1380.1 | Potential water supply bore, bore report suggests estimated use is 3 ML/year for 1200 sheep (stock water). Depth needs to be confirmed. | Registered bore report<br>Aerial imagery |

The screening assessment concludes the following:

- There are no predicted IAA bores in the Project Area; and
- There are six potential LTAA bores:
  - RN16066 Orientos 1
  - RN16768 Innamincka 2
  - RN23081 Jackson Water Well No.1
  - RN23372 Balooma 1
  - RN5092 No.9
  - RN23227 Boldrewood 1

These bores are discussed further in Section 9.3.2.

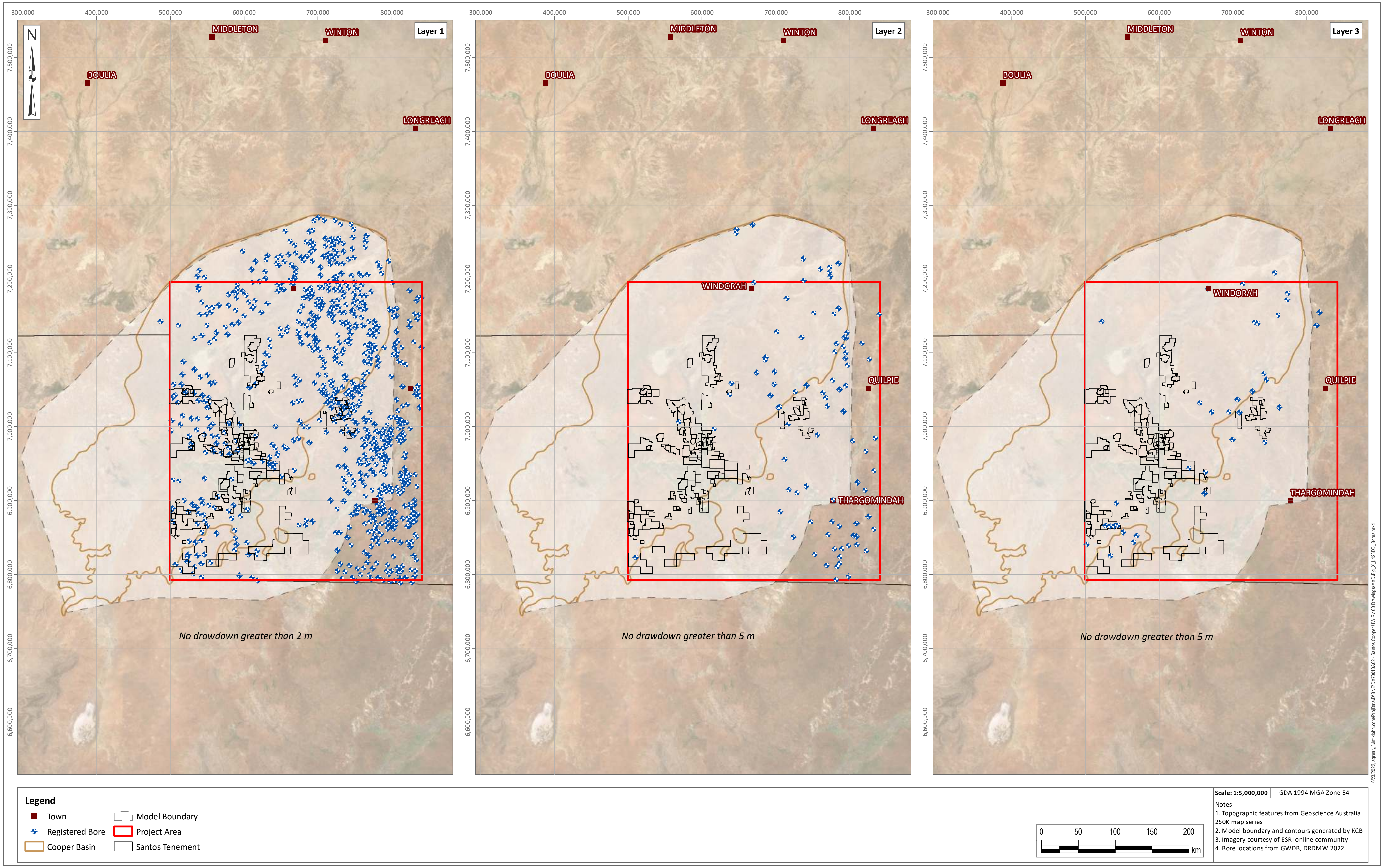



**Figure 8.5 Drawdown for the Simulated 3-year Project Development Relative to Pre-development Levels, for Layer 1 (170 to -300mAHD), Layer 2 (-300 to -1000mAHD) and Layer 3 (-1000 to -1800mAHD)**

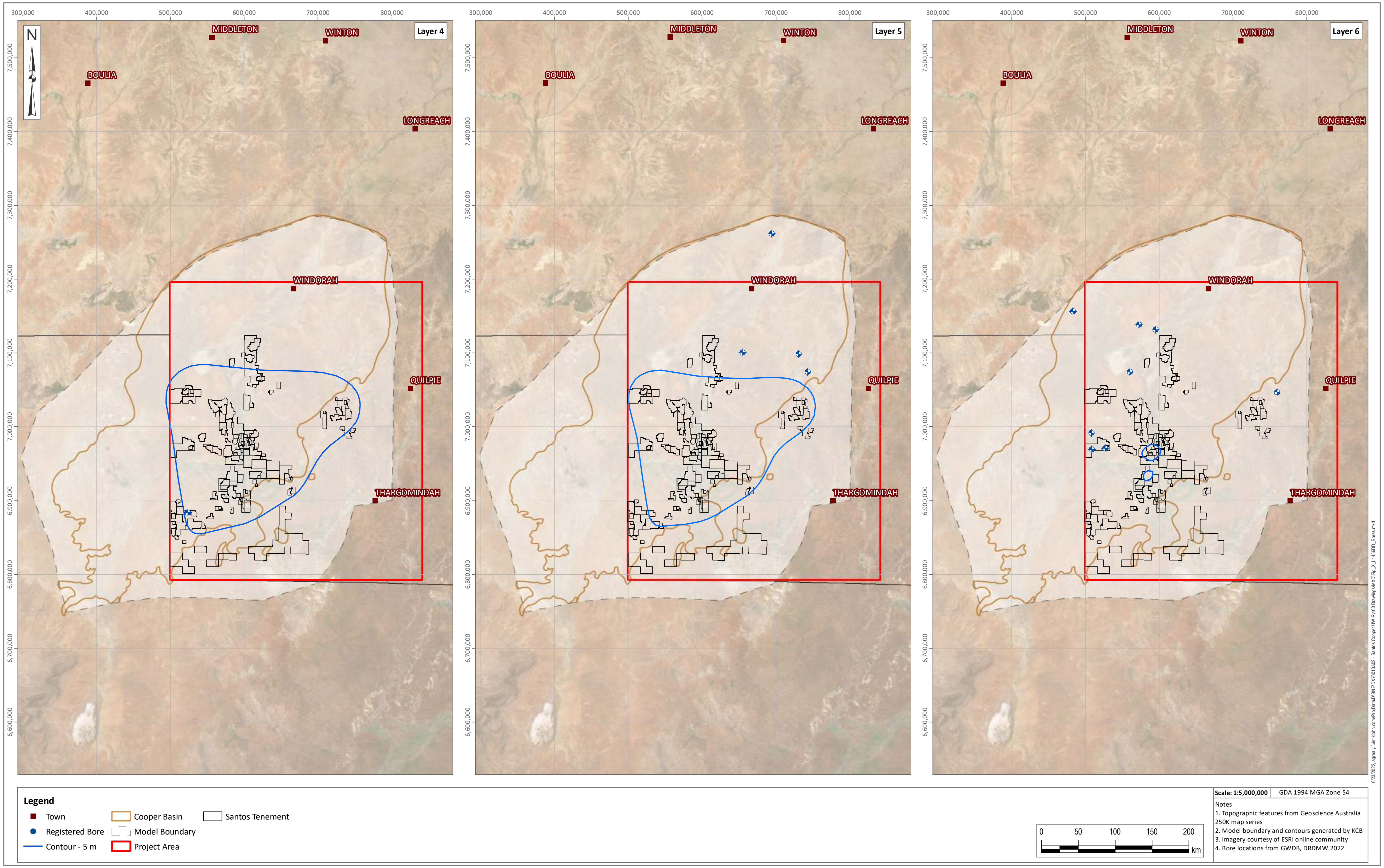



**Figure 8.6 Drawdown for the predicted IAA Drawdown contour (5m) relative to pre-development, Layer 4 (-1800 to -2300mAHD), Layer 5 (-2300 to -2800mAHD) and Layer 6 (-2800 to -3300mAHD), with existing water bore positions for the depth horizons**

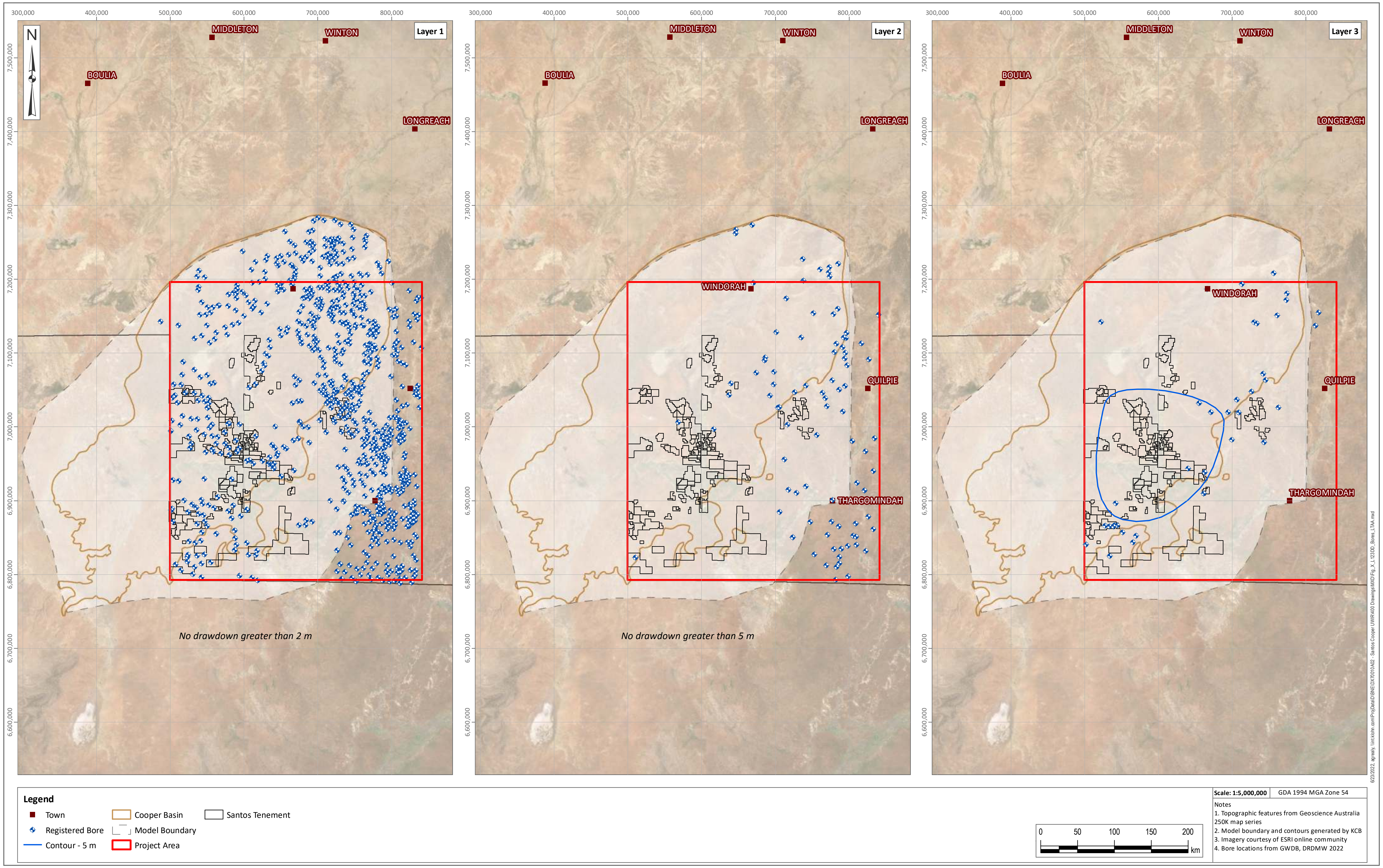



**Figure 8.7 Drawdown for the simulated LTAA impact relative to pre-development, for Layer 1 (170 to-300mAHD), Layer 2 (-300 to -1000mAHD) and Layer 3 (-1000 to -1800mAHD).No Drawdown within 2m for Layer 1 or 5m for Layer 2 are predicted**

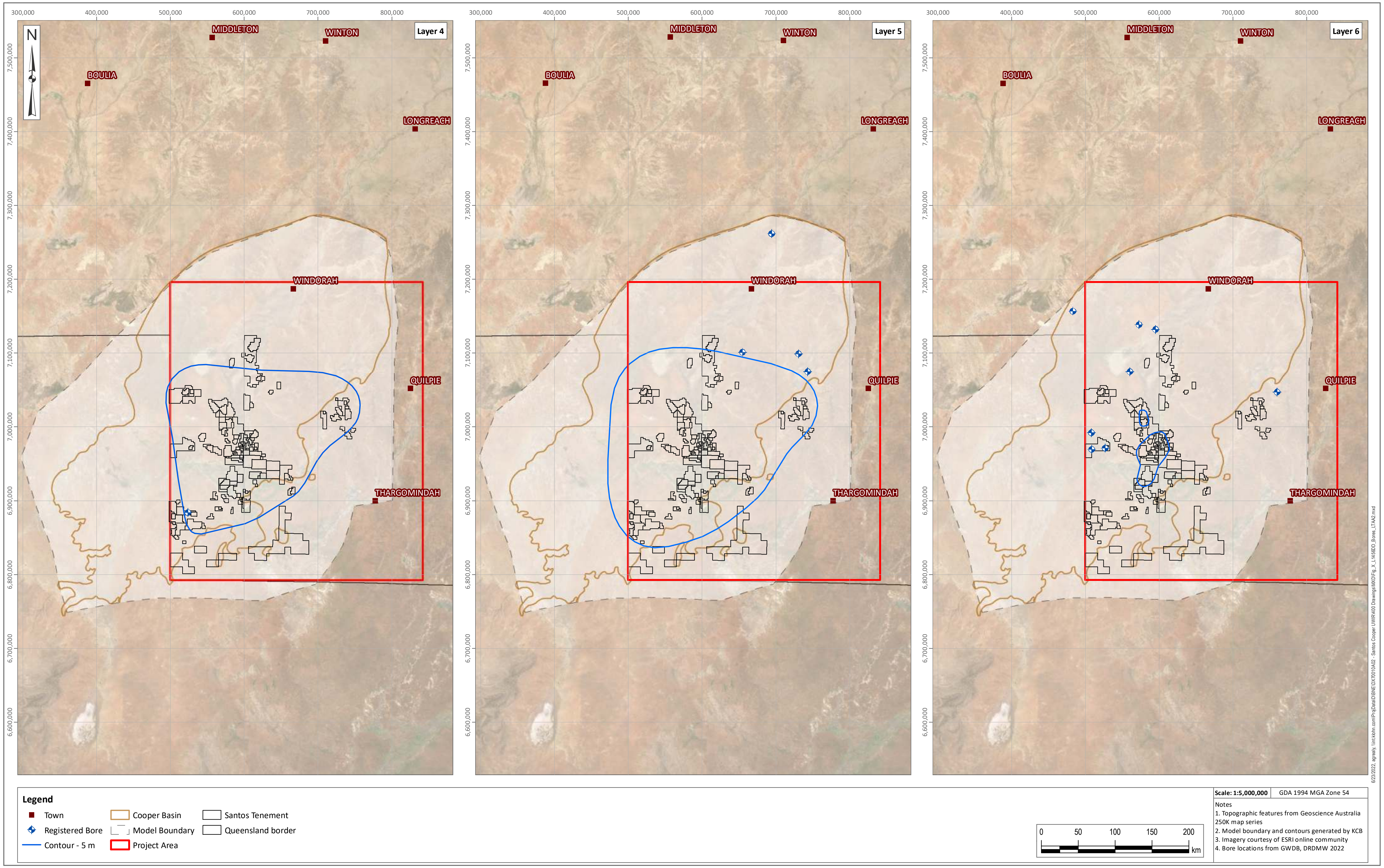



**Figure 8.8 Drawdown for the predicted LTAA Drawdown contour (5m) relative to pre-development, Layer 4 (-1800 to -2300mAHD), Layer 5 (-2300 to -2800mAHD) and Layer 6 (-2800 to -3300mAHD), with existing water bore positions for the depth horizons**

# 9 GROUNDWATER IMPACT ASSESSMENT

## 9.1 Groundwater Depressurisation during the UWIR Period (2022-2025)

The abstraction of groundwater as part of the Project development during the IAA Period (2022-2025) is not predicted to result in a basin wide depressurisation of the formations.

Groundwater extraction from gas production in the Cooper Basin will have negligible impact to groundwater.

Groundwater production from oil production would have limited impacts on the Hutton Sandstone (Layer 4 in model) over the Project area. The spatial extent of drawdown was limited to the vicinity of the production wells (Figure 8.6).

Heavily utilised (third-party groundwater abstraction) near surface aquifers (the Quaternary, Tertiary and Winton Formations) show no impacts exceeding the trigger levels defined under the Water Act 2000 (Figure 8.5).

## 9.2 Groundwater Depressurisation Over the Total Project Duration

The abstraction of groundwater as part of the Project development during the LTAA Period is not predicted to result in a basin wide depressurisation of the formations.

Groundwater extraction from gas production in the Cooper Basin will still have negligible impact to groundwater.

Groundwater production from oil production would have limited impacts on the Hutton Sandstone (Layer 4 in model) and the Rolling Downs Aquitard (Layer 3 in model) over the Project area. The spatial extent of drawdown was limited to the vicinity of the production wells (Figure 8.8).

Heavily utilised groundwater aquifers near the surface (the Quaternary, Tertiary and Winton Formations, show no impact exceeding the trigger levels defined under the Water Act 2000 (Figure 8.7).

## 9.3 Environmental Impacts

### 9.3.1 Impact on Groundwater Resources

Groundwater is produced as a by-product of the Project. Water production is authorised under the *Petroleum and Gas (Production and Safety) Act 2004.* Potential impacts as result of water production may include:

- Decline in groundwater level / pressure at water bores, reducing water availability;
- Reduction in groundwater head resulting in degradation of groundwater discharge at spring complexes, potentially causing degradation of GDEs; and
- Reduction to baseflow to watercourses, potentially resulting in reduced availability of water to GDEs and reduced water availability to potential users downstream.

There is no expected decline in water levels in the shallow aquifer systems as a result of the project, or any associated impacts on GDEs or TGDEs, within the vicinity of the Project.

Monitoring, management, and mitigation practices associated with the above activities are discussed further in Section 10.

### 9.3.2 Impact on Groundwater Users

Potential short term and long-term impacts to groundwater bores have been assessed against the *Water Act 2000* bore trigger threshold of 2 m for an unconsolidated aquifer (e.g. alluvium) and 5 m for a consolidated aquifer (e.g. Hooray Sandstone), using the drawdown predictions for the analytical model. The results indicate limited impacts to third party groundwater users.

Based on the Queensland Groundwater Database (Department of Resources, 2021) and the simulated drawdown contours for IAA and LAA, six registered landholder bores are identified within the IAA and the LAA (Table 9.1).

RN23372, Balooma 1, is a water bore that has been identified as being impacted in previous UWIRs. A Make Good Agreement, as required under the provision in the Water Act, was executed in 2017. However, the amount of drawdown in this bore in this assessment is greater than previously estimated but is not expected to be immediately impacted.

Make Good Agreements will be established for bores in the identified IAA only. Given the remaining five bores are only triggered in the LTAA, there are no requirements for additional Make Good Agreements in this UWIR period.

**Table 9.1 Registered Groundwater Bores Affected by Modelled Impacts**

| Bore Number | Easting* | Northing* | Bore Name | Depth (m) | Model Layer | IAA Drawdown (m) | LTAA Drawdown (m) |
|---|---|---|---|---|---|---|---|
| 16066 | 542108 | 6896737 | Orientos 1 | 1594 | 3 | | 5.52 |
| 16768 | 505530 | 6963581 | Innamincka 2 | 1885 | 4 | | 7.87 |
| 23081 | 640342 | 6943883 | Jackson water well no.1 | 1260 | 3 | | 6.56 |
| 23372 | 662618 | 6938773 | Balooma 1 | 1310 | 3 | | 5.45 |
| 5092 | 671140 | 7020167 | No.9 | 1551 | 3 | | 5.18 |
| 23227 | 655041 | 7032349 | Boldrewood 1 | 1380 | 3 | | 5.13 |

* Datum - GDA94 / MGA Zone 54

### 9.3.3 Impact on Surface Drainage

The Project does not include any planned discharge to, or abstraction from (including abstraction due to groundwater impacts), the surface water system. Analytical modelling did not predict drawdown within the surficial Quaternary alluvium or Cenozoic aquifer within the trigger value of 2m (Layer 1).

There will be no discernible impacts to the surface water system, or surface water users as a result of the Project development.

### 9.3.4 Impact on Springs

No springs are located within Santos' SWQ tenements. The nearest springs are located more than 90 km beyond the tenement boundaries.

The *spring trigger threshold* for a decline in groundwater level, beyond which a spring impact management strategy for any potentially affected springs may be required, is defined in the *Water Act* as a decline of more than 0.2 m.

# 10 GROUNDWATER MONITORING PROGRAM

In accordance with Section 376(f) of the Water Act 2000, an underground water monitoring strategy is required for the IAA and the LTAA. Monitoring is required to track the quantity of water produced and to monitor changes in groundwater levels and water quality.

## 10.1 Groundwater Monitoring and Management Measures

### 10.1.1 Rationale

The groundwater impact assessment suggests that the groundwater resources at most risk from the Project are the Hooray and Hutton Sandstone aquifer, which are used by local community for domestic and municipal supply. The monitoring strategy will focus on early detection and protection of these water resources.

The monitoring strategy includes evaluation and assessment of the following:

- Changes in water level in shallow unconsolidated aquifers (>2 m); evaluate potential to impact third party users.
- Changes in water level in consolidated aquifers i.e. Hooray Sandstone aquifer (>5 m) to evaluate potential impact to third party users.
- Changes in water quality in unconsolidated aquifers and consolidated aquifers (i.e. Hooray Sandstone aquifer: evaluate the potential to impact third party users.
- Results of previous water monitoring events/programs.

The 2021 Annual Groundwater Monitoring Program (GWMP) (LBWco 2021) reported the following analysis of groundwater monitoring trends:

- Water pressure measurements in artesian wells showed no evidence of consistent decline when compared to historical data.
- Concentrations of key analytes, in both artesian and subartesian wells, showed no evidence of significant change from historical ranges (where data was available).

### 10.1.2 Monitoring Strategy

A groundwater monitoring network was established through the 2013 UWIR development and the SWQ Water Bore Baseline Assessment. The network provides information on formation pressure, water levels and water quality in unconsolidated and consolidated aquifer formations. This network was revised in the 2019 UWIR to incorporate recommendations from the annual groundwater reporting. This change was intended to improve the overall quality of the monitoring strategy.

The proposed monitoring and sampling schedule for year's 2022 to 2025 considers the limited observed changes to groundwater level and quality over the previous reporting period (i.e. no discernible change in water level, artesian pressures or quality).

The groundwater monitoring network is presented in Table 10.1 and presented in Figure 5.4.

All bores are sampled for the following analytes on an annual basis:

- pH
- TDS
- Major ions
- Dissolved heavy metals

A groundwater level is measured annually immediately prior to groundwater sampling.

## Table 10.1 UWIR Monitoring Network

| Bore Name | WBBA ID | Bore RN | Easting^ | Northing^ | Tenure | Monitoring Formation | Primary Use | Water Quality? | Water Level? | Water Level Measurement Method* | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Challum Spine Road Bore No. 2 | 5018 | - | 566004 | 6968840 | PL59 | Winton Mackunda | Roadwork and construction bore | Yes | No | Not feasible | Shallow (sub-artesian) |
| Irtalie 1 | 5028 | 23570 | 623669 | 6932913 | PL36 | Hutton Sandstone | Roadwork and construction | Yes | Yes | Pressure gauge | Hutton SS (artesian) |
| PPL Coothero 1 | 5033 | 23569 | 654269 | 6932959 | PL33 | Hooray Sandstone | Livestock and roadwork | Yes | Yes | Pressure gauge | Artesian |
| Gordan's Bore | - | 23361 | 727308 | 7016801 | PL170/ PL1029 | Namur Sandstone | Roadwork and construction | Yes | Yes | Pressure gauge | Artesian |
| Surlow 1 Water Bore | 5094 | - | 166021 | 10000000 | PL205 | Winton Mackunda | Not in use | Yes | Yes | Manual dip reading | Shallow (sub-artesian) |
| Supply 1 | 5229 | 23923 | 595451 | 6975889 | ATP636 | | Industrial | Yes | Yes | Pressure gauge | Artesian |
| PPL Balooma 1 | - | 23372 | 737660 | 7034142 | - | Hooray Sandstone | Livestock | Yes | Yes | Pressure gauge | Artesian |
| Apollosa 1# | - | - | 662602 | 6938778 | - | Namur Sandstone | Livestock | Yes | Yes | Pressure gauge | Artesian |
| Ballera West 2 | 5015 | - | 584523 | 6893653 | PL61/1073 | | Livestock | Yes | Yes | Pressure gauge | Artesian |

WBBA – Water Bore Baseline Assessment (Golder Associates, 2013)
*If current condition of bore headwork allows
^ Datum - GDA94 / MGA Zone 54

#Ownership of this bore was transferred to another landholder on 21 December 2018 and primary use is now for livestock water supply.

## 10.2 Production Water Monitoring and Management

### 10.2.1 Regulatory Requirements

As per the requirements outlined in the *Petroleum and Gas (Production and Safety) Act 2004,* the volume of produced water will be monitored and recorded and provided to the relevant authority as required.

### 10.2.2 Monitoring Strategy

In accordance with the requirements of the *Petroleum and Gas (Production and Safety) Act 2004,* Santos will continue to assess actual groundwater abstraction using the acceptable methods. The method used will be reviewed annually and reviewed, as necessary.

#### Produced Water Monitoring - Gas

The volume of water co-produced as part of Santos' gas operations is estimated based on the average water content of the gas produced. There is some uncertainty in the volume of water produced, however gas production accounts for ~3% of the total volume of water produced from the Project. Small variations in estimated versus actual produced volumes will not have a material impact on drawdown predictions.

#### Produced Water Monitoring - Oil

The methodology for monitoring water produced as a result of oil operations includes:

- Individual well water-cut meters (Red-eye or DNOC).
- Wellhead water-cut samples.
- Tank dips.

Monthly allocation to any given well is based on:

- Estimation of the theoretical monthly oil and water production by well (using latest individual well test rates multiplied by the number of days the well was producing (i.e. uptime)).
- Summing the theoretical volume of a well or wells that collect into some fixed, known gathering point to give the monthly total theoretical oil and water volumes.
- Comparing theoretical volumes to actual monthly oil and water production at a fixed, known gathering point (where the monthly actual oil and water production is based on measurement of trucked oil loads, or oil piped through a fiscal metering point).
- Allocating (pro-rating) the total theoretical volumes to the individual wells based on the ratio of "actual total"/"theoretical total".

Santos' monitoring methodology for produced water (i.e. the approximately 4 GL/year abstracted through oil production) is reasonable approximation of actual volumes based on the premise that the total volume for each well is recorded at 2 points i.e. a known gathering point and a fiscal metering point.

# 11 UWIR UPDATES AND REVIEW

In accordance with the Water Act, a review period of no greater than three years will be undertaken. Site data including the following, will be reviewed annually:

- Groundwater level and quality data from the water monitoring plan.
- Santos extraction volumes.
- Santos pressure data.

It is the intention that data will be reviewed and compared to the assumptions made in the UWIR. Significant discrepancies between the assumptions in this UWIR and the monitoring data will trigger a review of the UWIR.

The review cycle will be incorporated into the water monitoring plan. In addition to the review schedule, reporting to the regulator will be undertaken as required.

# 12 CONCLUSIONS

The impacts to groundwater from Santos' oil and gas operations in the Cooper region of SWQ have been assessed in this UWIR, and are based on:

- A description of the geological settings of the gas and oil fields and the development of a conceptual geological cross-section and geological contour maps for the top of, and thicknesses of, key formations.
- A review of the hydrogeological settings of the gas and oil fields and the development of a hydrogeological conceptual model and hydrogeological maps.
- An identification of environmental values related to the groundwater system, and in particular groundwater dependent ecosystem including GAB artesian discharge springs.
- Characterisation of produced water volumes.
- An assessment of impacts from groundwater extract on the target petroleum reservoir and surrounding formations and on potential groundwater users.

The key conclusions of this UWIR are:

- The oil development will result in localised depressurisation of the Hutton and associated oil target areas forming part of the Eromanga Basin.
- The shallow surficial deposits are not predicted to experience drawdown as a result of the Project due to the laterally extensive, homogeneous and thick low permeability of the Rolling Downs Aquitard that limits propagation of drawdown from the coal measures to the surficial deposits.
- The Project will not impact surface waters, TGDEs or spring complexes because:
  - Groundwater extractions with the oil and gas operations produce limited volumes of water which do not result in large scale depressurisation of the target aquifers. Drawdown is largely confined to the oil fields.
  - Santos oil and gas fields in SWQ are located away from any major GDEs. The nearest spring complex is approximately 90 km away from the project and will not be impacted by drawdown/depressurisation.
  - Mapped TGDEs are interpreted to source groundwater from storage in the alluvium units recharged during floods and are not interpreted to be impacted by the Project development.
- Drawdown/depressurisation greater than the 5 m trigger threshold for consolidated aquifers (under Section 362 of the Water Act), is predicted to occur in six (6) water supply bores.

This groundwater report demonstrates that impacts to GAB aquifers as a result of the Project is limited based on the IAA predictions. Some depressurisation of the Eromanga layers used for oil production can be expected, with minimal propagation to the layers immediately above it. The depressurisation do not propagate to the surface. It is considered that Santos' current SWQ activities pose little risk to the Cooper GBA region surface water, shallow groundwater systems and associated ecosystems.

# 13 CLOSING

We would like to thank you for the opportunity to work on this assignment. Should you have any questions, please do not hesitate to contact the undersigned.

**KCB AUSTRALIA PTY LTD.**

Senior Hydrogeologist

# REFERENCES

Alexander. 1996. 'Reservoirs and Seals. In: Alexander, E.M. and Hibburt, J.E. (Eds), 1996, The Petroleum Geology of South Australia, Vol. 2: Eromanga Basin. South Australia. Department of Primary Industries and Resources. Petroleum Geology of South Australia Series, Pp. 141-147.'

Barnett et al. 2012. 'Australian Groundwater Modelling Guidelines'. Waterlines Report. Canberra: National Water Commission.

BOM. 2005. 'Climate Classification of Australia'. Australian Government Bureau of Meteorology. http://www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp?maptype=kpngrp#maps.

———. 2022. 'Bureau of Meteorology (BOM) Climate Data Online'. 2022. http://www.bom.gov.au/climate/data/.

Cendon et al. 2010. 'Freshwater Recharge into a Shallow Saline Groundwater System, Cooper Creek Floodplain, Queensland, Australia. Journal of Hydrology 392(3), 150–163. Doi: Https://Doi.Org/10.1016/j.Jhydrol.2010.08.003.'

DES. 2009. *Environmental Protection (Water) Policy 2009*.

———. 2021. 'Underground Water Impact Reports and Final Reports - Guideline. Reviewed June 2021.' ESR/2016/2000. Department of Envionment and Science.

———. 2022. 'Wetlands Info Interactive Map Viewer.' 2022. https://wetlandinfo.des.qld.gov.au/wetlandmaps/?extent=138.954,-30.141,145.546,-24.283.

Dillinger et al. 2016. 'Impact of Diagenesis on Reservoir Quality in a Sedimentary Geothermal Play: A Case Study in the Cooper Basin, South Australia. Basin Research 28(2), 252-272. Doi: Doi:10.1111/Bre.12109.'

DNRM. 2016. 'Sediments above the Great Artesian Basin: Groundwater Background Paper. Https://Www.Mdba.Gov.Au/Sites/Default/Files/Pubs/23-DNRM-2016%28a%29-Sediments-above-Great-Artesian-Basin-D16-40872.Pdf.'

———. 2017a. *Water Plan (Cooper Creek) 2011. Reprint Current as of September 2017.*

———. 2017b. *Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017. Repring Current as of 2017.*

DNRME. 2021. 'Queensland Groundwater Database - September 2021'. Queensland Government, Department of Natural Resources, Mines and Energy.

DoR. 2022. 'Queensland Globe Datasets: Water Bores - Petroleum & Gas Act.' 2022.

DRDMW. 2021. 'Queensland Groundwater Database - July 2021'. Queensland Government, Department of Regional Development, Manufacturing and Water.

———. 2022. 'Registered Groundwater Database - Queensland'. 2022. https://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={E314CC59-7466-4A9E-AFE2-A36645B1C29E}.

Evans, TJ, J Martinez, ECS Lai, M Raiber, BM Radke, B Sundaram, TR Ransley, et al. 2020. 'Hydrogeology of the Cooper GBA Region; Technical Appendix for the Geological and Bioregional Assessment: Stage 2. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.'

Fitts Geosolutions. 2021. 'AnAqSim User Guide: Analytic Aquifer Simulator.'

Geoscience Australia. 2015. 'Cooper Basin Architecture and Lithofacies: Regional Hydrocarbon Prospectivity of the Cooper Basin, Part 1'.

———. 2016. ‘Source Rocks of the Cooper Basin’.

Geoscience Australia, CSIRO, Department of Agriculture, Water and Environment, and Bureau of Meteorology. 2021. ‘Impact Assessment for the Cooper GBA Region Geological and Bioregional Assessment: Stage 3 Synthesis’.

Geoscience Queensland. 2022. ‘Geoscience Queensland (GSQ) Open Data Portal. Replacement to QDEX. Https://Geoscience.Data.Qld.Gov.Au/’.

Golder Associates. 2013a. ‘Santos South West Queensland, Regional Water Bore Baseline Assessment Report (Priority 1 and 2 Bores)’.

———. 2013b. ‘Underground Water Impact Report  Santos Cooper Basin Oil and Gas  Fields, South-West Queensland.’ 0007-650-REP-0025.

———. 2021. ‘UPDATING GROUNDWATER IMPACT ESTIMATION – SANTOS COOPER BASIN OIL AND GAS FIELDS, SOUTH-WEST QUEENSLAND’.

Government of Australia. 2016. *Environment Protection and Biodiversity Conservation Act 1999. Ammended as of 2016.*

Haitjema. 1995. ‘Analytic Element Modeling of Groundwater Flow, Academic Press, San Diego.’

Hasegawa et al. 2016. ‘Characterization of a Diffusion-Dominant System Using Chloride and Chlorine Isotopes (36Cl, 37Cl) for the Confining Layer of the Great Artesian Basin, Australia. Geochimica et Cosmochimica Acta 192, 279-294. Doi: Https://Doi.Org/10.1016/j.Gca.2016.08.002.’

Keppel et al. 2016. ‘A Hydrogeological and Ecological Characterisation of Springs near Lake Blanche, Lake Eyre Basin, South Australia. Department of Environment, Water and Natural Resources (SA), Adelaide. Viewed 10 May 2019, Https://Www.Waterconnect.Sa.Gov.Au/Content/Publications/DEW/LEBSA_Hydroecological_Characterisation_of_Lake_Blanche_springs.Pdf.’

Miles, CR, and JF Costelloe. 2015. ‘Lake Eyre Basin (South Australia): Mapping and Conceptual Models of Shallow Groundwater Dependent Ecosystems, DEWNR Technical Note 2015/22, Government of South Australia, through the Department of Environment, Water and Natural Resources, Adelaide’.

Owens et al. 2020. ‘Geology of the Cooper GBA Region. Technical Appendix for the Geological and Bioregional Assessment: Stage 2. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.’

PIRSA. 2009. ‘Petroleum and Geothermal in South Australia – Cooper Basin. Primary Industries and Resources, SA’.

Radke et al. 2000. ‘Hydrochemistry and Implied Hydrodynamics of the Cadna-Owie – Hooray Aquifer, Great Artesian Basin. Bureau of Rural Sciences, Canberra.’

Ransley et al. 2015. ‘Hydrogeological Atlas of the Great Artesian Basin. Geoscience Australia, Canberra. Http://Www.Ga.Gov.Au/Scientific-Topics/Water/Groundwater/Gab/Digital-Datasets-from-the-Gab-Atlas.’

Ransley, TR, and BD Smerdon. 2012. ‘Hydrostratigraphy, Hydrogeology and System Conceptualisation of the Great Artesian Basin. A Technical Report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia.’

Santos. 2016. ‘Underground Water Impact Report, Santos Cooper Basin Oil and Gas Fields, South-West Queensland.’

———. 2019. ‘Underground Water Impact Report  Santos Cooper Basin Oil and Gas  Fields, South-West Queensland August 2019’.

———. 2021. 'Santos Cooper Basin Website Information'. 2021. https://www.santos.com/what-we-do/five-core-assets/cooper-basin/.

SILO. 2022. 'SILO - Australian Climate Data from 1889 to Yesterday.' 2022. https://www.longpaddock.qld.gov.au/silo/point-data/.

SKM. 2001. 'Environmental Water Requirements of Groundwater Dependent Ecosystems, Environmental Flows Initiative Technical Report Number 2, Commonwealth of Australia, Canberra'.

State of Queensland. 2010. *Water and Other Legislation Amendment Act 2010. Current as of December 2010.*

———. 2020a. *Petroleum and Gas (Production and Safety) Act 2004. Current as of October 2020.*

———. 2020b. *Petroleum Act 1923*. https://www.legislation.qld.gov.au/view/pdf/inforce/2020-07-01/act-1923-026.

———. 2021a. *Petroleum Act 1923. Current as of November 2021.*

———. 2021b. *The Water Act 2000. Reprring Current from June 2021.*

———. 2022. *Environmental Protection Act 1994. Current as of March 2022.*

URS. 2010. 'Further Information to Support Assessment of Potential Impacts to Water Flooding in PL295.'

Webster et al. 2000. 'Hydrodynamics in the Queensland Sector of the Cooper/Eromanga Basins: Identifying Non-Conventional Exploration Plays Using Water Pressure and Chemistry Data. Society of Petroleum Engineers Inc. Asia Pacific Oil and Gas Conference and Exhibition Held in Brisbane, Australia, 16–18 October 2000. Paper SPE 64281.'

# APPENDIX I

## Oil and Gas Wells used in Model Predictions

| Santos Acreage | IAA Gas Wells (Count) | IAA Oil Wells (Count) | LTAA Wells Gas (Count) | LTAA Wells Oil (Count) |
|---|---|---|---|---|
| ATP1174 | | | | 4 |
| ATP1189 | 11 | 1 | 22 | 3 |
| PL1013 | 4 | | 6 | |
| PL1014 | 1 | | 1 | |
| PL1016 | 1 | | 1 | |
| PL1046 | 2 | | 10 | 4 |
| PL1047 | 2 | | 6 | |
| PL1054 | 2 | | 2 | |
| PL1055 | 1 | | 11 | |
| PL1058 | 1 | | 11 | 10 |
| PL1060 | | | | 8 |
| PL1077 | | | 12 | 5 |
| PL108 | 1 | | 1 | |
| PL1087 | | | 5 | |
| PL1093 | | | 1 | |
| PL1107 | | | 5 | |
| PL1108 | | | 4 | |
| PL111 | 2 | | 2 | |
| PL1119 | | | 4 | |
| PL112 | 10 | | 16 | |
| PL113 | 3 | | 3 | |
| PL114 | 2 | | 2 | |
| PL129 | 4 | | 4 | |
| PL130 | 1 | | 1 | |
| PL131 | 33 | | 44 | |
| PL132 | 1 | | 1 | |
| PL134 | | | 4 | |
| PL140 | 3 | | 5 | |
| PL141 | 1 | | 3 | |
| PL143 | 1 | | 1 | |
| PL144 | 1 | | 1 | |
| PL145 | 2 | | 2 | |
| PL146 | 5 | | 7 | |
| PL147 | 2 | | 2 | |
| PL148 | 5 | | 5 | |
| PL149 | 1 | | 1 | |
| PL150 | 10 | | 13 | |
| PL152 | | | 2 | |
| PL155 | 12 | | 21 | |
| PL156 | 1 | | 1 | |
| PL158 (PL1105) | | | 5 | |
| PL169 | | 3 | | 3 |
| PL170 | | 7 | | 11 |
| PL175 | 2 | | 2 | |
| PL177 | 4 | | 4 | |
| PL181 | 2 | | 2 | |
| PL182 | 1 | | 1 | |
| PL186 | 1 | | 1 | |
| PL187 | 1 | | 1 | |
| PL193 (PL513) | | | 2 | 2 |

| Santos Acreage | IAA Gas Wells (Count) | IAA Oil Wells (Count) | LTAA Wells Gas (Count) | LTAA Wells Oil (Count) |
|---|---|---|---|---|
| PL205 | 2 | | 2 | |
| PL23 | | 30 | | 34 |
| PL24 | | 5 | | 5 |
| PL244 | | 1 | | 1 |
| PL25 | 4 | 1 | 7 | 1 |
| PL254 | 2 | | 7 | |
| PL26 | 2 | 2 | 4 | 2 |
| PL287 | 8 | | 8 | |
| PL288 | 2 | | 2 | |
| PL29 | | 3 | | 3 |
| PL295 | | 6 | | 10 |
| PL301 | | 13 | | 27 |
| PL302 | | | 3 | |
| PL303 | | 22 | | 33 |
| PL33 | | | | |
| PL34 | | 16 | | 27 |
| PL35 | | 6 | | 21 |
| PL36 | | 9 | | 9 |
| PL37 | 1 | | 1 | |
| PL38 | | 5 | | 5 |
| PL39 | | 33 | | 33 |
| PL495 | 1 | | 1 | 0 |
| PL496 | 1 | | 1 | 0 |
| PL50 | | 3 | | 3 |
| PL502 | | 6 | | 12 |
| PL508 | | 5 | | 8 |
| PL509 | | 10 | | 12 |
| PL51 | | 10 | | 10 |
| PL52 | | 17 | | 17 |
| PL57 | | 22 | | 22 |
| PL58 | 10 | | 10 | 0 |
| PL59 | 10 | | 10 | 0 |
| PL60 | 8 | | 8 | 0 |
| PL61 (PL1073) | 18 | 8 | 21 | 8 |
| PL62 (PL1118) | 3 | | 3 | 0 |
| PL63 | 7 | | 7 | 0 |
| PL68 | | 3 | | 3 |
| PL75 | 2 | 3 | 2 | 3 |
| PL76 | | 1 | | 4 |
| PL77 | | 5 | | 5 |
| PL78 | | 1 | | 1 |
| PL79 (PL1078) | 2 | | 2 | 0 |
| PL80 | 16 | | 22 | 0 |
| PL81 | 3 | | 3 | 0 |
| PL83 (PL1092) | 1 | | 1 | 0 |
| PL84 | 11 | | 11 | 0 |
| PL86 | 3 | | 3 | 0 |
| PL88 | 3 | | 5 | 0 |
| PPL12 | 1 | | 1 | 0 |