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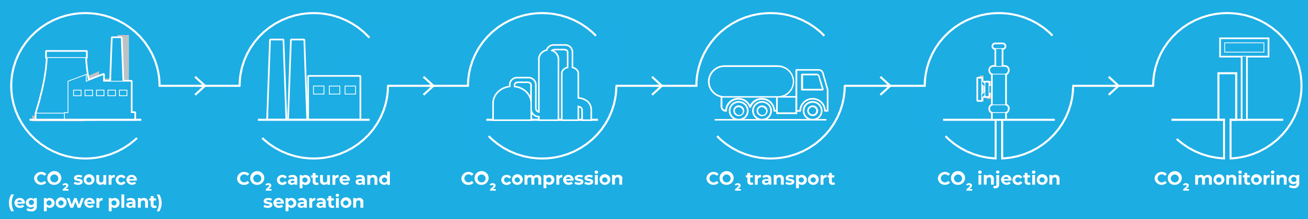

Surat Basin Carbon Capture and Storage Project

CHAPTER 09: GROUNDWATER

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9. Groundwater

9.1 Introduction

This chapter describes the groundwater associated with the Project and assesses the potential impacts to groundwater associated with construction, operation, monitoring and rehabilitation phases of the Project.

Geology has a major influence on the existing groundwater and potential impacts of the Project and should be read in conjunction with this chapter. Chapter 8 Geology assesses:

- geological structure including faults;
- rock properties including porosity, permeability and fluid saturation;
- geomechanics including earth stresses, fracture initiation and reactivation; and
- the overall geological properties as a whole system.

Chapter 9 Groundwater includes, but is not limited to, providing the methodologies of assessment, description of existing environmental conditions, potential impacts, cumulative impacts, avoidance and mitigation measures, residual impacts, and proposed amendments to existing Environmental Authority (EA) conditions associated with:

- hydrogeological properties including groundwater pressure and flow;
- groundwater uses and users; and
- groundwater chemistry and water quality.

Examination of groundwater pressure, flow, uses, users, chemistry and water quality is divided between:

- aquifers overlying the Storage Complex, being the Hutton Sandstone, Gubbermunda Sandstone, Mooga Sandstone and Griman Creek Formation; and
- the storage complex, being the Evergreen, Precipice and Moolayember Formations, with the Precipice Sandstone aquifer being the aquifer and GHG storage reservoir for the GHG storage injection testing, with specific impact assessment:
  - within the predicted GHG plume; and
  - outside the predicted GHG plume.

Potential impacts of the GHG stream and GHG plume are considered in:

- the area immediately surrounding the West Moonie-1 Injection Well;
- within the operational lands of the Project;
- to a radius of 50 km surrounding the West Moonie-1 Injection Well; and
- within the Surat Precipice groundwater sub-area.

Avoidance and mitigation measures, particularly monitoring, are considered in terms of:

- containment monitoring which focuses on the aquifers overlying the storage complex and in the Precipice Sandstone storage reservoir immediately outside of the predicted GHG plume;
- conformance monitoring which focuses on verification of the behaviour of the GHG plume during injection activities (operation phase) and in the monitoring phase, comparing the behaviour of what is observed, sampled and measured of the actual GHG stream and GHG plume to what has been predicted by the various models prior to injection commencing.

Further details of the groundwater impact assessment have been completed by suitably qualified and experienced personnel, and included in the following appendices:

- Appendix 9A Groundwater Impact Assessment Technical Report, prepared by WSP (2023);
- Appendix 9B *Hydrogeological Model Scenarios to determine fluxes around the proposed GHG stream injection site*, authored by Phil Hayes (2023);
- Appendix 9C *ANLEC Project 7-0320-C323 Final Report: South Surat metal mobilisation and fate of heavy metals released*, authored by G.K.W. Dawson, D.M. Kirste, J.K. Pearce, and S.D. Golding (2022);

- Appendix 9D *Comparison of the results of reactive transport modelling in ANLEC Project 7-0320-C323 and reservoir modelling and reaction path modelling undertaken by WSP Golder (2022) for EPQ10 and presented in the SBCCS Project draft EIS (2022) by CTSCo*, authored by S.D. Golding and J.K. Pearce (2023);
- Appendix 9E A review of safe fluoride levels in stock water, authored by Geoff Niethe (2023); and
- Appendix 9F Geochemistry Review, authored by James Tuff of EMM Consulting (2023).

Matters associated with groundwater dependent ecosystems (GDEs) are examined in Chapter 14B Aquatic Flora and Fauna.

9.2 Methodology of Assessment

Groundwater has been assessed using a range of methodologies including:

- legislation, policy and guidelines;
- desktop assessments;
- exploration and appraisal field investigations; and
- modelling.

For ease of readability, the methodologies of assessment are addressed in sections 9.3, 9.4, 9.5 and 9.6 of this chapter.

9.3 Legislation, Policies and Guidelines

The relevant Commonwealth and State legislation, policies, standards and guidelines are considered in undertaking groundwater impact assessment of the proposed GHG storage injection testing.

9.3.1 Commonwealth Legislation

9.3.1.1 ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION ACT 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is administered by the Commonwealth Department of Climate Change, Energy, the Environment and Water (DCCEEW) and protects Matters of National Environmental Significance (MNES), which are defined as:

- World Heritage;
- Great Barrier Reef Marine Park;
- National Heritage;
- Wetlands of international importance;
- Listed threatened species and communities;
- Listed migratory species;
- Protection of the environment from nuclear actions;
- Commonwealth marine environments; and
- A water resource, in relation to coal seam gas development and large coal mining development.

Under the EPBC Act, actions that have, or are likely to have, a significant impact on a MNES require approval from the DCCEEW and the relevant Minister. If it is determined that the proposed action will impact upon a MNES, then the action is declared a 'controlled action' and must go through an assessment and approval process. The nature, intensity and complexity of those impacts will determine the applicable level of assessment required by the Commonwealth.

CTSCo referred the Project under the EPBC Act to the Australian Government. On 9 February 2022, the authorised person of the Australian Government gave notice of their decision that the Project is not a controlled action under the EPBC Act, s.75 (reference EPBC 2021/9122).

9.3.2 State Legislation

9.3.2.1 GREENHOUSE GAS STORAGE ACT 2009

As defined by s.3 of the *Greenhouse Gas Storage Act 2009* (GHG Act), the main purpose of the Act is to help reduce the impact of GHG emissions on the environment. This is achieved through facilitating the process called GHG storage through:

- granting authority (called 'GHG authorities') to explore or use underground geological formations or structures to store carbon dioxide, or to carry out related activities; and
- creating a regulatory system for carrying out activities relating to GHG authorities.

Other purposes are to ensure these activities:

- minimise conflict with other land uses;
- allow constructive consultation with people affected by the activities;
- offer appropriate compensation for landowners or occupiers adversely affected by the activities; and
- follow responsible land and resource management.

The GHG Act defines *GHG storage exploration* as carrying out an activity for the purposes of finding GHG stream storage sites. It also defines *GHG storage injection testing* as the evaluation or testing of an underground geological formation or structure for GHG storage by injecting carbon dioxide or water into it.

Under the GHG Act*,* CTSCo was granted EPQ10, effective from 9 December 2019, which authorises injection testing of a GHG stream and associated activities. Prior to commencement of the Project, approval by the administering authority of an Injection Test Plan (ITP) which includes a Monitoring and Verification Plan (MVP) will be sought under the GHG Act.

The GHG Act, s.84 states that a "*GHG permit holder can not take or interfere with water as defined under the Water Act unless the taking or interference is authorised under that Act. Note – For relevant Water Act provisions, see sections 19 and 808 of that Act*." The provision of s.19 referred to in the *Water Act 2000* (version of 1 March 2023) no longer exists. Further details relevant to the *Water Act 2000* are provided in section 9.3.2.5 below.

9.3.2.2 ENVIRONMENTAL PROTECTION ACT 1994

The *Environmental Protection Act 1994* (EP Act) s.3 states that the objective of the Act is to protect Queensland's environment while allowing for developments that improve total quality of life, both now and in the future. This is to be done in a way that maintains the ecological processes on which life depends (ecologically sustainable development).

Under the EP Act, a proponent wishing to carry out an environmentally relevant activity (ERA) requires an EA. Activities under EPQ10 are subject to EA EPPG00646913 which authorises the drilling of GHG appraisal wells, water production, and geophysical surveys. However, the EA does not authorise the carrying out of GHG storage injection testing. Therefore, to proceed with the Project and undertake a GHG storage injection testing, it is necessary to amend the EA conditions to authorise the injection testing and associated activities, as proposed within this EIS.

The EIS Terms of Reference (ToR) for the Project and under the requirements for a site-specific resource activity EA, the groundwater impact assessment must address the requirements of s.126A of the EP Act. However, s.126A is not applicable to the Project, as the activity is not proposed on a mineral development licence, mining lease or petroleum lease; rather the resource tenure is a GHG Permit (EPQ10). Further, the Project does not involve the exercise of underground water rights as defined in the EP Act, s.112.

9.3.2.3 ENVIRONMENTAL PROTECTION REGULATION 2019

Under the *Environmental Protection Regulation 2019* (EP Regulation), the Project must demonstrate that it can meet the relevant objectives and performance outcomes as set out in Schedule 8 for Groundwater which requires the Project to be operated in a way that protects the environmental values (EVs) of groundwater and any associated surface ecological system. The performance outcomes of the Project are:

- no direct or indirect release of contaminants to groundwater from the operation of the Project;
- no actual or potential adverse effect on groundwater from the operation of the Project;
- the Project will be managed to prevent or minimise adverse effects on groundwater or any associated surface ecological systems.

EP Regulation s.41 sets out provisions specifically in relation to activities involving the direct release of waste to groundwater. An example of this being the release of contaminated water to groundwater through a well, deep-well injection or a bore. The authority administering the EP Act must refuse to grant an application for an approval, if the authority considers:

- the waste is not being or may not be released entirely within a confined aquifer (a confined aquifer is defined as an aquifer contained entirely within impermeable strata); or
- the release of the waste is affecting adversely, or may affect adversely, a surface ecological system; or

- the waste is likely to result in a deterioration in the EVs of the receiving groundwater.

Refer to Chapter 8 Geology, sections 8.7.1.1.2, 8.7.5.11, and 8.7.6.3 for discussion on confined aquifer in relation to the Project.

Refer to Chapter 14B Aquatic Flora and Fauna, sections 14B.3.7.2, 14B.5.1.3, 14B.6.1.3 and 14B.7 for discussion on potential impacts on surface ecological systems from the Project.

Refer to sections 9.7.5, 9.9.4, and 9.9.7 below for discussion on potential deterioration in the EVs of the receiving groundwater.

9.3.2.4 ENVIRONMENTAL PROTECTION POLICY (WATER AND WETLAND BIODIVERSITY) 2019

The *Environmental Protection (Water and Wetland Biodiversity) Policy 2019*, Schedule 1 identifies that the groundwater environmental values (EVs) and water quality objectives (WQOs) applicable to the groundwater within the Project Area are described in *Queensland Murray-Darling and Bulloo River Basins Groundwater Environmental Values and Water Quality Objectives* (QMDB) (October 2020).

The purpose of the QMDB *is to identify locally relevant environmental values (EVs) and water quality objectives (WQOs) for ground waters in the QMDB. EVs and WQOs are used to help set development conditions, influence local government planning schemes, and underpin report card grades for ecosystem health monitoring programs. Aquatic ecosystem water quality objectives have, where possible, been established using local data, and present a truer picture of the values and water quality of local waterways than national and state water quality guidelines. This ensures the values the community holds for its waterways can be maintained and improved, without imposing unrealistic standards from national guidelines that may be inappropriate for local conditions.* (QMDB, 2020, p.5).

Further discussion of the relevant EVs, and WQOs compared to the existing groundwater quality based on samples taken in 2020 and 2021 is provided in section 9.7.5. Comparative discussion of EVs and WQOs on the potential impacts of the Project, and avoidance and mitigation measures including proposed EA conditions are provided in sections 9.9.4, 9.9.7, 9.10 and 9.11.

9.3.2.5 WATER ACT 2000

The *Water Act 2000* regulates the planning, supply, and allocation management of water resources in Queensland. The *Water Act 2000* provides for Water Plans to be prepared on a catchment-by-catchment basis, as part of a consultative process. These Water Plans are developed to balance water consumptive use (human use) with environmental flows (that is, leaving water in a watercourse or aquifer to maintain natural processes).

The *Water Act 2000* relates to the Project through its focus on maintaining the health of ecosystems, water quality, and ecological processes relating to aquifers, as outlined in Chapter 3 of the *Water Act 2000*. The *Water Act 2000* also includes an intention to reverse, where practicable, ecosystem degradation which has occurred in the past.

The *Water Act 2000* manages the impacts on groundwater caused by activities. This includes the preparation of impact reports that establish underground water obligations, including obligations to monitor and manage impacts on aquifers and springs.

The *Water Act 2000* s.107 requires a water licence for the interference of water by a prescribed entity, with CTSCo considered a prescribed entity under s.104. Chapter 4 Approvals, section 4.4.23 provides further details associated with the water licence application process.

For the operational lands, the relevant Water Plan prepared under the *Water Act 2000* is the *Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017* (Water Plan (GABORA)), and the associated *GABORA Water Management Protocol (September 2017 and Revision 1 December 2019)* (GABORA Protocol), as discussed below in section 9.3.2.6.

9.3.2.6 WATER PLAN (GREAT ARTESIAN BASIN AND OTHER REGIONAL AQUIFERS) 2017, AND THE GABORA WATER MANAGEMENT PROTOCOL (SEPTEMBER 2017 AND REVISION 1 DECEMBER 2019)

The purpose of the Water Plan (GABORA) is to define the availability of water in the plan area, to provide a framework for sustainably managing water and for taking water in the plan area, to identify priorities and mechanisms for dealing with future water requirements, and to provide a framework for reversing, if practicable, the degradation of Groundwater Dependent Ecosystems (GDEs). The plan applies to water in or from underground water and spring water.

The proposed injection testing of the GHG stream into the Precipice Sandstone aquifer within the GABORA plan area, and any associated interference with groundwater that potentially affects intended uses or any influence on GDEs, has considered the framework of the Water Plan (GABORA) and the GABORA Protocol.

Injection testing of the GHG stream on the operational lands at West Moonie-1 Injection Well is proposed into the Precipice Sandstone aquifer, which is defined in the Water Plan (GABORA) as the geological formation of the Precipice Sandstone and the groundwater sub-area of the Surat Precipice. For the purposes of water entitlements, Schedule 2 of the Water Plan (GABORA) provides that the current Precipice groundwater unit and Surat Precipice groundwater sub-area are applicable. The Surat Precipice groundwater sub-area replaced the expired Surat 7, Surat East 4, and Surat North 3 management units, as defined in Schedule 5 of the Water Plan (GABORA). Water licences continue to be assigned to these expired management units of the expired Great Artesian Basin (GAB) water resource plan. In accordance with the Water Plan (GABORA), s.61 and Schedule 5, these water licences are taken as assigned to the Surat Precipice groundwater sub-area.

The GABORA Protocol, Chapter 2 identifies that the operational lands at West Moonie-1 Injection Well are outside of the Precipice Zone, with the Precipice Zone located more than 100 km to the north of the West Moonie-1 Injection Well. No other Zones influence the operation or water take / interference of the Surat Precipice groundwater sub-area.

The Project does interfere with groundwater through injection testing activities and as such, must demonstrate that it meets the specified outcomes of the Water Plan (GABORA), identified in Part 3, section 12. A summary of the outcomes for the management and allocation of water in the plan area and how the Project meets the outcomes is provided in Table 9-1.

Table 9-1 Summary of GABORA economic, social and environmental outcomes

Outcome	Project achievement measures
12 Water is to be managed and allocated in a way that – 12(a) seeks to achieve a sustainable balance between the following outcomes –	
12(a)(i) to protect the flow of water to groundwater-dependent ecosystems that support significant cultural or EVs;	The injection testing of the GHG stream will not impact on the quality or quantity of groundwater flowing to GDEs, as given in Chapter 14B Aquatic Flora and Fauna, sections 14B.3.6, 14B.3.7.2, 14B.3.9.2, 14B.5, 14B.5.3, and sections 9.7.4.3, 9.9.3.3 and 9.9.6.3 below.
12(a)(ii) to protect the continued use of authorisations to take or interfere with water;	The GHG storage injection testing will not impact on the water quality or availability within the Precipice Sandstone aquifer resource outside the GHG plume for the continued use of authorisations to take or interfere with water, as given in sections 9.7.4.2, 9.9.1.2, 9.9.2.4, 9.9.3, 9.9.6, and 9.9.7 below.
12(a)(iii) to maintain, and if practicable increase, water pressure in aquifers to preserve the supply of water to bores;	The GHG storage injection testing is unlikely to result in a significant change or increase of pressure within the aquifer, as given in Chapter 8 Geology, section 8.9.2, and section 9.9.1.1, 9.9.2, 9.9.5 below.
12(a)(iv) to make water available for future development and social and cultural activities that depend on water, including for the aspirations of Aboriginal peoples and Torres Strait Islanders;	The GHG storage injection testing is unlikely to impact on water availability within the aquifer for future development and social and cultural activities, as given in sections 9.7.4, 9.7.5, 9.9.3, 9.9.4, and 9.9.7 below.

Outcome	Project achievement measures
12(a)(v) to encourage the efficient use of water by requiring water bores to have watertight delivery systems or be controlled;	The Project does not propose to extract groundwater, except for monitoring purposes. All wells or bores are constructed to *Code of Practice for the construction and abandonment of petroleum wells and associated bores in Queensland* (DNRME, 2019), and will be controlled.
12(a)(vi) to facilitate the operation of efficient water markets and opportunities for the temporary or permanent movement of water; and	The Project will not have any interaction with the water market.
12(b) recognises the state of aquifers and groundwater-dependent ecosystems has changed because of the taking of, and interfering with, water	Potential changes to aquifers and GDEs due to interfering with water are described in section 9.9 below and Chapter 14B Aquatic Flora and Fauna, sections 14B.3.6, 14B.3.7.2, 14B.3.9.2, 14B.5, 14B.5.3.

9.3.3 Guidelines

9.3.3.1 AUSTRALIAN STANDARD ISO 31000:2018 RISK MANAGEMENT – GUIDELINE (STANDARDS AUSTRALIA, 2018)

The *Australian Standard ISO 31000:2018 Risk Management – Guidelines* provides a framework on which to build and develop a risk management approach which meets international standards and best practice. Alignment with these guidelines ensures a rigorous and holistic risk management approach has been used to support analysis.

9.3.3.2 DAFF ENVIRONMENTAL IMPACT ASSESSMENT COMPANION GUIDE

The *DAFF Environmental Impact Assessment Companion Guide* (DAFF, 2014), published by the Queensland Department of Agriculture, Fisheries and Forestry (DAFF), aims to provide information about matters that should be addressed through the EIS process as they relate to the agriculture, fisheries and forestry sectors, and biosecurity.

The document lists the government's legislative responsibilities, policies and interests, in relationship with these sectors to ensure early consideration in the EIS processes with the intent that this will facilitate a more streamlined review and approval process.

This guideline has been used to consider the potential impacts on groundwater quality as they relate to farm supply use and other potential agricultural users.

9.3.3.3 GREAT ARTESIAN BASIN STRATEGIC MANAGEMENT PLAN

The *Great Artesian Basin Strategic Management Plan* (DoA, 2020), prepared by the Australian, New South Wales, Queensland, South Australian and Northern Territory governments in consultation with the Great Artesian Basin Coordinating Committee, provides a framework to guide the actions of governments, Aboriginal and Torres Strait Islanders, water users and others, and to identify and respond to risks, issues, challenges and opportunities associated with the use of Basin water.

The Plan is not a statutory document, has a life of 15 years to 2034, and will be reviewed every five years to check progress. The Plan has seven guiding principles for managing the GAB, being: coordinated governance; a healthy resource; Aboriginal and Torres Strait Islander values, cultural heritage and other community values; secure and managed access; judicious use of groundwater; information, knowledge and understanding for management; and communicate and educate.

Injection of gases (as well as other matters) is identified as an emerging challenge for the GAB. As part of the principle of secure and managed access, gas storage is to be in accordance with rights and responsibilities specified in relevant authorisations.

9.3.3.4 GROUNDWATER DEPENDENT ECOSYSTEMS-EIS INFORMATION GUIDELINE

In addition to the *Water-EIS Information Guideline*, Department of Environment and Science (DES) has developed guidelines for specific matters, including GDEs. The *Groundwater Dependent Ecosystems-EIS information guideline* (ESR/2020/5301) (DES, 2022) sets out clear expectations for how to identify, and classify GDEs, and assess potential impacts. As stated in this guideline, identifying GDEs may rely on terrestrial and aquatic ecology assessments. For conciseness of the EIS, all matters associated with GDEs are discussed in Chapter 14B Aquatic Flora and Fauna.

9.3.3.5 GUIDELINES FOR GROUNDWATER QUALITY PROTECTION IN AUSTRALIA, NATIONAL WATER QUALITY MANAGEMENT STRATEGY

The National Water Quality Management Strategy *aims to promote ecologically sustainable development by improving water quality while supporting industry, the environment and communities that depend on water* (Australian Government, 2013, p.2). The Strategy consists of a range of documents, with the *Guidelines for groundwater quality protection in Australia, National Water Quality Management Strategy* (Australian Government, 2013) is one of the general management guidelines, and the only national guideline focused on groundwater quality protection.

The Guidelines identify geological storage of carbon dioxide as one of the current and emerging issues for the protection of groundwater quality (Appendix A, section 5.5 of the Guidelines). The Guidelines highlight that at depths greater than 1 km, CO_2 is no longer in the gaseous phase and needs to be hydro-geologically trapped. The presence of one or more thick impermeable regional seals to prevent the CO_2 rising to the surface or migrating to sources of useable groundwater is required as part of site selection.

These points were considered during development of the Project, as outlined further in this chapter.

9.3.3.6 WATER – EIS INFORMATION GUIDELINE

When preparing an EIS, the *Water – EIS information guideline* (ESR/2020/5312) (DES, 2020) provides details on assessment requirements and expected information to be presented in relation to water resources, water quality, and associated EVs, as mandated by the *Water Act 2000* and the EP Act. This guideline has been used to guide the preparation of the groundwater technical report and this chapter.

9.3.3.7 WATER QUALITY GUIDELINES

The following water quality and monitoring guidelines have been considered to characterise the existing water quality of the aquifers, determine impacts and appropriate ongoing water quality monitoring:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018);
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1, The Guidelines (Chapters 1-7), October 2000, Paper No. 4 (ANZECC, ARMCANZ, 2000);
- Groundwater Quality Assessment Guideline: Using monitoring data to assess groundwater quality and potential environmental impacts (DSITIA, 2017); and
- Monitoring and Sampling Manual – Environmental Protection (Water) Policy 2009 (DES, 2018).

9.4 Desktop Assessment

Desktop assessments were carried out for the regional assessment area, EPQ10, within 50 km of the West Moonie-1 Injection Well, and the operational lands to establish the baseline geology and groundwater conditions, potential for connectivity between aquifers, groundwater uses, groundwater users, and groundwater quality and chemistry.

Data and information were obtained from various sources including but not limited to:

- public domain datasets and published reports from government agencies;
- previous studies in the Surat Basin;
- existing carbon capture and storage (CCS) projects; and
- technical experts.

9.4.1 Public Domain Datasets and Published Reports

In addition to legislation, polices and guidelines, public domain geological and hydrogeological datasets were obtained from, but not limited to, the Australian Government, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Queensland State Government, Geological Survey of Queensland's (GSQ) Open Data Portal, GeoResGlobe, Queensland Globe, Business Queensland, the Office of Groundwater Impact Assessment (OGIA), and State Assessment and Referral Agency (SARA).

CTSCo has endeavoured to use the most currently available datasets on the respective websites, with datasets including, but are not limited to:

- geological maps for the Great Artesian Basin, including:
  - Great Artesian Basin major geological structural elements (GABWRA) including detailed surface geology and solid bedrock geology and structures of the GAB, from the Australian Government Bioregional Assessments Programs, link: https://data.gov.au/data/dataset/8dbe0a37-408a-4458-b4cb-fb896b830cc5;
- attributes for active water licences to identify holders of groundwater entitlements;
- groundwater database (GWDB) to identify water entitlements and registered bore data;
- bore reports for detailed bore data and information;
- bore attribution data as determined by OGIA;
- groundwater investigation and monitoring bore reports;
- resources data including petroleum, coal, and greenhouse gas exploration and production tenements, borehole data, infrastructure data, and production statistics;
- development permits, operational permits and associated approvals for water licencing and bores;
- spatial data including cadastral data, topography, water features, etc; and
- information provided by submitters on the draft EIS, and other interested and affected persons via various community and stakeholder engagement activities as outlined in Chapter 3 Community and Stakeholder Engagement.

Specific datasets and public reports are further referenced in the relevant sections of this chapter.

Data and information associated with GDEs and stygofauna are provided in Chapter 14B Aquatic Flora and Fauna and the associated technical report undertaken by frc environmental.

9.4.2 Previous Studies

To establish the existing environmental conditions of the geology and groundwater for the Project, and to determine the potential impacts of the Project, a combination of local well-scale data from field investigations, and regional-scale and Surat Basin-scale data and information from the public domain has been examined.

CTSCo conducted studies and site investigations in EPQ7 between 2010 to 2018, which included drilling the West Wandoan-1 Well, acquisition of the high-resolution 3D Glenhaven Seismic Survey, geomechanical modelling, plume migration modelling, geochemical modelling and field storage planning. Learnings from this work have been applied to the Project where applicable.

This Project falls within the Surat Cumulative Management Area (Surat CMA). Groundwater in the Surat CMA is generally extracted for stock, or stock and domestic water uses, as well as irrigation, intensive livestock, and town water supplies. The Surat CMA also supports extensive coal seam gas (CSG) production, coal mining, and conventional oil and gas (O&G) production, all of which have the potential to incidentally extract groundwater, or cause impact to groundwater quality. The Queensland Government's Office of Groundwater Impact Assessment (OGIA) produce Underground Water Impact Reports (UWIRs) for the Surat CMA every three years (2016, 2019, 2021), which present an assessment of impacts from existing and proposed resource tenure holders. The UWIRs also provide groundwater trends for the Hutton and Precipice Formations, mitigation and monitoring strategies in response to identified impacts, and potential cumulative impacts in the Surat Basin. Additionally, the Surat CMA UWIR (OGIA, 2021) has been relied upon to inform the discussion on potential cumulative impacts in section 9.9.8.

The University of Queensland Surat Deep Aquifer Appraisal Project (UQ-SDAAP) is a 10-year project (2016 to 2025) undertaking Carbon Capture and Storage Research. The UQ-SDAAP is funded by the Australian Government through the Carbon Capture and Storage Research Development and Demonstration (CCS RD&D) programme, ANLEC, and the University of Queensland. Studies conducted as part of the UQ-SDAAP in the southern Surat Basin include seismic interpretation – geophysics, regional static model, wireline log analysis, core data analysis, integrating petrophysics into modelling, Precipice Sandstone hydraulic property estimation from observed Managed Aquifer Recharge (MAR) responses (refer to section 9.7.4.1.2.2), Drill Stem Test (DST) analysis, Moonie Oil Field history match and re-evaluation, integrated facies analysis of the Precipice Sandstone and Evergreen Formation in Surat Basin, sequence stratigraphy of the Precipice Sandstone and Evergreen Formation in the Surat Basin, facies prediction from well logs in the Precipice Sandstone and Evergreen Formation in the Surat Basin, hydrogeology, geochemistry and metals mobilisation. These various studies have been used by CTSCo or otherwise contributed to CTSCo's understanding of the geology and groundwater in the southern Surat Basin. Reference to specific studies or datasets from the UQ-SDAAP are included in Table 9-2.

Further to the work undertaken by CTSCo, OGIA, and UQ-SDAAP, other previous studies in the Surat Basin relevant to the Project are summarised in Table 9-2.

Table 9-2 Other Previous Studies and Reporting for the Surat Basin relevant to the Project

Feature	Reference and source
Geological setting	*Regional geological study of the Hutton Sandstone* (Bianchi et al., 2019) *Outcrop mapping and photogrammetry of the Precipice Sandstone* (Bianchi *et al*., 2016) *Methodology for assessment of dynamic capacity* (Garnett & Underschultz, 2019) UQ-SDAAP *Regional static model* (Gonzalez *et al*., 2019) UQ-SDAAP *Sequence stratigraphy of the Precipice Sandstone and Evergreen Formation in the Surat Basin* (La Croix et al., 2019) UQ-SDAAP *Facies prediction from well logs in the Precipice Sandstone and Evergreen Formation in the Surat Basin* (La Croix *et al*., 2019) UQ-SDAAP *Integrated facies analysis of the Precipice Sandstone and Evergreen Formation in the Surat Basin* (La Croix *et al*., 2019) UQ-SDAAP *Updated Geology and Geological Model for the Surat Cumulative Management Area* (OGIA, 2019b) *Geological modelling - source data, information and method* (OGIA, 2021b) *Thickness of Lower and Upper Hutton Member, Evergreen Formation and Precipice Sandstone*, (UQ-SDAAP), received 13 May 2021
Permeability and porosity values of Precipice and Evergreen formations	*Core data analysis* (Harfoush *et al*., 2019) UQ-SDAAP *Integrating petrophysics into modelling* (Harfoush *et al*., 2019) UQ-SDAAP *DST Analysis* (Honari *et al*., 2019a) UQ-SDAAP *Multiscale static and dynamic modelling of Precipice Facies* (Knackstedt *et al*., 2020)
Structural elements	*Seismic interpretation – geophysics* (Gonzalez *et al*., 2019) UQ-SDAAP *Moonie oil field history match and re-evaluation* (Honari *et al*. 2019) UQ-SDAAP *Updated Geology and Geological Model for the Surat Cumulative Management Area* (OGIA, 2019b)
Recharge and discharge	*Precipice sandstone hydraulic property estimation from observed MAR responses* (Hayes *et al*. 2019) *Hydrogeology of the Southern Surat Basin: Memo report 1* (Wye *et al*., 2019)
Geochemistry and Hydrochemistry	*South Surat metal mobilisation and fate of heavy metals released* (Dawson *et al* 2022) *Hydrogeology of the southern Surat Basin* (Hofmann *et al.,* 2022) *Hydrogeochemical investigation of the Precipice Sandstone aquifer in the Moonie Area, Southern Surat Basin, Australia - Assessing up-fault discharge potential* (Mahlbacher, 2019) UQ-SDAAP *Precipice south Surat water chem JP.xlsx* (unpublished from J Pearce (UQ), 2021)

9.4.3 Existing CCS (GHG Injection) Projects

A literature review of CCS projects was undertaken to provide context for the Project, identify existing CCS knowledge and key learnings to date. Further details of the projects reviewed are provided in Appendix 9A, sections 2.3.2 and 2.3.3.

Relevant projects have been selected according to the following properties:

- availability of literature to review, specifically on water resources availability, water quality, GHG plume characteristics, and measurement, monitoring and verification (MMV) programs for comparison to the Surat Basin;
- storage reservoir characterisation similarities for comparison to the Surat Basin, for example:
  - storage reservoir descriptions:
    - lithology, thickness, depth, average porosity and permeability, pressure, temperature, geological structure;
  - estimated storage capacity;
  - estimated injectivity;
  - projected maximum injection rate; and
  - cap rock lithology;

- project scale, being whether the project is a commercial injection project, or a demonstration, trial or appraisal project. Preference was given to projects with a projected injection rate of greater than 1 $MtCO_2/y$;
- injectivity, with preferred projects having similar estimated injectivities to the Surat Basin, as estimated in Hofmann *et al* 2015.

The Project has comparable geological and storage complex properties to several existing and operational CCS projects, and is therefore anticipated to respond to injection in a similar manner. The storage complex formation (Precipice Sandstone aquifer) is located at depths similar to those used in other CCS projects.

A summary of key geological features and project operations of existing CCS projects are summarised in Table 9-3 compared to the storage complex formation of the Project. Key learnings from the existing CCS projects are presented in Table 9-4.

Operational water quality monitoring of the existing CCS projects has shown no statistically significant deviations in trace metals have occurred outside of the GHG plume area, which is consistent with the modelled predications for the Project.

Table 9-3 Comparison of key features of existing CCS projects to CTSCo's Project

Projects	Location	Status	Injection Rate ($MtCO_2/y$)(1)	Injectivity (mDm)(2)	Storage	Estimated storage capacity ($MtCO_2$)	Formation lithology	Caprock lithology	Formation unit depth (mbgl)(3)	Formation thickness (m)	Permeability (mD)(4)	Porosity (%)
CTSCo's Project	Australia	In development	0.11	33,500	brackish formation	2,962	Sandstone	Siltstone-dominated	2,258 to 2,336	50 to 150	2,000	<36.9%; 17.9% in Mimosa Syncline
Boundary Dam (Aquistore)	Canada	Operational	1.5	1,500 to 5,000	saline formation / enhanced oil recovery	34	Sandstone	Shale; halite and other evaporite minerals	3,200	150	100 to 1,000	11 to 17
Quest	Canada	Operational	1	44,000	saline formation	25	Sandstone	Shale and rock salts	2,000	44	1,000	17
Otway	Australia	Operational	0.05	–	depleted oil and gas	–	Sandstone	Silty mudstones, interbedded siltstones and fine-grained sandstones	2,100	25 to 30	100 to 600	17
Decatur	USA	Finished	0.3	146,600	saline formation	1	Sandstone	Shale	2,130	792.5	185	20
Sleipner	Norway	Operational	1	–	saline formation	42,356	Sandstone	Shale	1,000	900	100 to 300	35 to 40

Notes:
$MtCO_2/y$ = million tonnes of CO_2 per year
mDm = millidarcy-metres
mbgl = metres below ground level
mD = millidarcy

Table 9-4 Key learnings from existing CCS projects

Projects	Water supply status of formation	Key learnings
All projects	-	• Seismic processes demonstrate useful techniques to ensure the safe containment of CO_2 and monitoring of the GHG plume location, and for identifying any induced seismic activity from GHG stream injection process. • Seismic monitoring may provide the first indication of leakage from a storage reservoir, possibly before detection by shallow surface monitoring techniques.
Boundary Dam (Aquistore)	Aquifer consists of water not suitable for drinking or agricultural purposes	• Specific analyses such as for $\delta^{13}C$ (dissolved inorganic carbon (DIC) and its stable isotope) would allow different sources of CO_2 to be distinguishable and identifiable from groundwater sample analysis should leakage from the storage reservoir occur (Klappstein and Rostron, 2014) • Radiocarbon-CO_2 as a natural tracer in soil-gas monitoring to identify any CO_2 seepage (Worth *et al*., 2017) • Fluid Recovery System can collect fluid from the storage reservoir and bring it to surface under in situ conditions (Worth *et al*., 2014) and has provided useful monitoring information on CO_2-groundwater interactions
Quest	Storage reservoir is saline, with groundwater resources hosted in overlying aquifers	• Established a Community Advisory Panel of local leaders, regulatory agencies, and members from the academic community • The Community Advisory Panel reviews monitoring data and receives regular updates from Shell (Shell, 2021) which has been useful in terms of public acceptance • Underwent a comprehensive third-party expert audit of its storage development plan and is the first project globally to have received certification of fitness for safe CO_2 storage by Den Norske Veritas (DNV) of Norway (Shell, 2021)
Otway	Groundwater resources of primary concern above the storage reservoir	• Demonstrated how to secure and maintain the consent of the community • Communication strategy and proactive engagement with the local communities to gain public acceptance
Decatur	Storage reservoir is saline, with groundwater resources hosted in overlying aquifers	• Risks of contamination to groundwater above the underground source of drinking water (USDW) can be easily mitigated or remediated without causing significant harm
Sleipner	Aquifer consists of water not suitable for drinking or agricultural purposes, offshore facility	• For reactive chemistry, laboratory experiments showed rapid increases of Group II metals (in particular calcium (Ca), strontium (Sr) and iron (Fe)), and slight increases in silica • Data have been widely used as inputs for formation flow modelling (Singh, 2010; Cavanagh, 201; Furre *et al*., 2017) and can be useful to develop a formation scale model of long-term CO_2 containment • Project seismic, gravity, and Controlled Source Electromagnetic (CSEM) data have been used for a wide range of applications, such as improving formation characterisation, constraining flow modelling, and developing new techniques for seismic inversion and spectral decomposition (Furre *et al*., 2017)

9.4.3.1 LEARNINGS FROM EXISTING CCS PROJECTS

Protection of groundwater resources was identified to be of high importance for most of the existing CCS projects reviewed. Geological control of the target injection formation was the primary mitigating aspect, which includes the number and thickness of confining layers and the susceptibility of the confining layers to fracture.

The existing CCS projects have shown that MMV methods such as groundwater sampling and comparison with baseline datasets, are suitable methods to rapidly detect any slow leakage of CO_2 out of the target formation. If such leakage occurs, any CO_2 would likely be localised and quickly remediated.

Similarly, the risk assessments documented for most existing CCS projects concluded that it is highly unlikely that catastrophic leakage would occur, either through escape through a mis-managed wellbore, or through leakage via geological faults. Most of the existing CCS projects reviewed have been identified as tectonically quiet, with limited fracturing and faulting, which has made them ideal examples for secure GHG storage.

Sleipner, the oldest of the existing CCS projects reviewed, has comprehensive data from MMV programs which demonstrates the security of storage, with most of the methods used related to geophysical processes (seismic, etc.). Aquistore, a more recent project, has taken the route of adopting modern MMV techniques to serve as an example for future CCS projects (Halladay *et al*., 2018). Seismic survey is a reliable technique to monitor and confirm the safe containment of a GHG stream and observe the localised GHG plume extents.

Table 9-5 summarises MMV methods of critical importance for groundwater mitigation measures.

Table 9-5 Types of Measurement, Monitoring, and Verification (MMV) Methods

Monitoring location	MMV method	Purpose
Atmosphere	Flux	Differentiate between atmospheric CO_2 and possible ground emissions
Shallow Subsurface Techniques	Piezometers, groundwater chemistry monitoring, soil gas monitoring	To monitor groundwater and soil changes which might indicate leakage of CO_2 to ground and groundwater
Downhole Instrumentation	Fluid recovery system, pressure gauges, temperature gauges	To monitor rock-fluid properties and formation fluid chemistry which might indicate loss of containment
Seismic	Seismic tomography, broadband seismography, geophone areal seismic array, time-lapse 3D seismic imaging, continuous passive microseismic monitoring, vertical seismic profiling	To monitor GHG (CO_2) plume location, induced seismic activity, and geological changes, which might indicate lack of security of storage

The technologies listed in Table 9-5 are suitable for deployment in the Surat Basin, and would help to demonstrate effective containment of the GHG stream in the Precipice Sandstone. The shallow subsurface techniques are more applicable in terms of demonstrating protection of groundwater resources. They would require baseline surveys during the pre-injection phase to be conducted so that results from continual monitoring of the site during the injection phase are directly comparable. Continual monitoring would demonstrate that any deviation from the baseline could be identified quickly and, should the results indicate GHG (CO_2) leakage from the target formation, with investigations conducted and mitigation or remediation procedures activated.

Downhole instrumentation technologies are required to identify changes in the groundwater within the target reservoir of the storage complex, particularly in terms of fluid chemistry, temperature and pressure, enabling loss of containment to be identified early.

Based on the existing CCS projects, learnings that have been or will be implemented by CTSCo for the Project include the following from:

- all existing CCS projects: seismic processes demonstrate useful techniques to ensure the safe containment of CO_2 and monitoring of the GHG plume location, and also for identifying any induced seismic activity from the GHG injection process. These may provide the first indication of GHG leakage from the target formation of the storage complex, possibly before becoming detectable by shallow surface techniques, and so can be the first line of defence in an MMV program relating to groundwater protection;

- Aquistore: specific analyses such as for dissolved inorganic carbon (DIC) and $\delta^{13}C$ (stable isotope, being a measure of the ratio of two stable isotopes of ^{13}C and ^{12}C) would allow different sources of CO_2 to be distinguishable and identifiable from groundwater sample analysis should leakage from the storage reservoir occur (Klappstein and Rostron, 2014). Similarly, soil-gas monitoring could be of use due to the source of CO_2 being from a coal-fired power station, in order to use radiocarbon-CO_2 as a natural tracer to identify any CO_2 seepage (Worth et al., 2017);
- Aquistore: their Fluid Recovery System has the ability to collect fluid from the storage reservoir and bring it to surface under *insitu* conditions (Worth *et al*., 2014) and has provided useful monitoring information on CO_2-brine interactions;
- Quest: underwent a comprehensive third-party expert audit of its storage development plan and is the first project globally to have received certification of fitness for safe GHG storage by DNV of Norway (Shell, 2021);
- Quest: established a Community Advisory Panel of local leaders, regulatory agencies and members from the academic community. The panel reviews MMV data and receives regular updates from Shell (Shell, 2021). This has been a useful approach, particularly in terms of public acceptance;
- Otway: has demonstrated how to secure and maintain the consent of the community. Their communication strategy and proactive engagement with the local communities and decision makers can be applied to the Project to gain public acceptance; and
- Sleipner: data has been widely used as constraints for storage reservoir flow modelling since project inception (Singh, 2010; Cavanagh, 2012; Furre *et al*., 2017) and thus, can be useful to develop a storage reservoir scale model of long-term GHG plume containment in the Surat Basin.

Measurement, monitoring and verification (MMV) programs that are proposed to be used for the Project are identified in Chapter 2 Proposed Project Description, section 2.11, with those associated with groundwater provided in section 9.10.

9.4.3.2 OVERALL IMPLICATIONS FOR THE PROJECT

Based on existing CCS projects, the overall implications for the Project include:

- findings from the existing CCS projects demonstrate that the Project can be completed safely, and that MMV methods can be effectively used to further reduce risk;
- that the Project has comparable geological and storage reservoir properties to a number of existing CCS projects, therefore is expected to respond to GHG stream injection in a similar manner. Those analogous settings have been exposed to orders of magnitude higher injection rates without compromising GHG plume containment or impact to EVs;
- that the Project proposes injecting into the Precipice Sandstone aquifer which is located at similar depths to those used in existing CCS projects elsewhere. Injecting at these depths is not unique to the Project;
- seismic survey is a reliable technique to monitor and confirm the safe containment of the GHG stream and observe the localised GHG plume extents. Seismic modelling will be carried out in 2024 using parameters from the West Moonie 3D seismic survey (to be acquired in 2023) and the rock physics datasets acquired in the West Moonie-1 Injection Well and West Moonie-2 Monitoring Well to predict the expected seismic response from GHG stream injection; and
- operational water quality monitoring has shown that no statistically significant deviations in trace metals have occurred outside of the GHG plume area in the existing CCS projects. This is consistent with the modelled predictions for the Project.

9.4.4 Input and Review by Technical Experts

Industry technical experts in the fields of environmental science and engineering, geochemistry, hydrogeology, reservoir engineering, veterinary science, and water quality were engaged to undertake the groundwater assessment for the Project. Table 9-6 summarises the relevant technical experts, their experience and involvement in the Project.

Table 9-6 Technical Experts

Name (Organisation)	Experience	Area of Expertise	Project Involvement
Peter Allen (WSP)	25 years EIA / due diligence assessments	Environment	GIA Review
Elena Berges (WSP)	14 years Hydrogeologist	Mining and Environment	Project management and technical review for GIA

Name (Organisation)	Experience	Area of Expertise	Project Involvement
Amy Bloomfield-Clarke (WSP)	10 years CCS	CCS	Responsible for previous studies assessment for GIA
Liz Clarke (WSP)	15 years EIA, compliance	Environment	GIA Review
Helen D'Arcy (CTSCo)	25 years Environment	Environment	Project and approvals management
Scott Fidler (WSP)	25 years Environment	Environment	Lead GIA Review
Professor Sue Golding (UQ)	40 years Applied Geochemistry	Geochemistry	Gas, rock and water interactive chemistry experiments, and geochemical modelling
Nick Hall (CTSCo)	40 years Petroleum Industry	Geology	Geological database compilation and static modelling
Ray Hatley (WSP)	44 years Applied Hydrogeology	Hydrogeology	Technical Lead for GIA
Associate Professor Phil Hayes (UQ)	25 years Hydrogeologist	Hydrogeology	Hydrogeological modelling
Dr Harald Hofmann (UQ)	12 years Hydrogeologist	Hydrogeology	Hydrogeology database compilation and isotope hydrogeochemistry
Jenna Huckenswager (WSP)	10 years EIA / due diligence assessments	Environment	Responsible for legislation and involved in preparing the environmental impacts and mitigation measures
Ryan Morris (RDMHydro)	14 years Applied Hydrogeology	Hydrogeology	Independent model reviewer as required by the Australian Groundwater Modelling Guidelines (Barnett et al., 2012).
Geoffrey Niethe	48 years Veterinary Science	Livestock Production and Veterinary Medicine	Livestock health and wellbeing
Dr Julie Pearce (UQ)	12 years Applied Geochemistry	Geochemistry	Gas, rock and water interactive chemistry experiments, geochemical modelling, and hydrogeochemical compilation.
David Price (CTSCo)	40 years Petroleum Industry	Reservoir Engineer	Reservoir engineering and dynamic (plume) modelling
Iain Rodger (UQ)	10 years Applied Hydrogeology	Hydrogeology	Reservoir engineering and ground water modelling
Alfonso Tobio Donega (WSP)	14 years Applied Geology and Hydrogeology	Geology / Hydrogeology	Project management and technical review for GIA
Dr James Tuff (EMM)	22 years Geology	Geochemistry / Materials science / Hydrogeology	Technical review of groundwater quality
Rens Verburg (WSP)	30 years Applied Geochemistry	Geochemistry	Geochemistry and Geochemical modelling review for GIA
Hong Phuc Vu (WSP)	12 years Environmental Geochemistry	Geochemistry	Geochemistry and Geochemical modelling for GIA
Jie Yi (WSP)	6 years Groundwater Modelling	Reservoir Engineer	Hydrogeology for GIA

9.4.5 Advice to the Administering Authority

CTSCo has consulted with various government agencies during the development of the Project, which is outlined in Chapter 3 Community and Stakeholder Engagement.

However, in addition to CTSCo's consultation with government agencies, the Department of Environment and Science (DES) as the administering authority of the *Environmental Protection Act 1994* and the associated EIS processes, requested advice from three entities in relation to the Project.

9.4.5.1 OFFICE OF GROUNDWATER IMPACT ASSESSMENT (OGIA)

During the draft EIS public submission period, the Department of Environment and Science (DES) as the administering authority, requested advice from the OGIA in relation to the Project. OGIA provided this advice to DES on 15 March 2023. As part of the preparation of the final EIS, responses to OGIA's points raised in their advice to DES are provided throughout the final EIS, mostly within Chapter 2 Proposed Project Description, Chapter 8 Geology and Chapter 9 Groundwater. Appendix 1D Introduction EIS response to submissions includes OGIA's advice and CTSCo's responses to each point raised, with OGIA being submitter 84.

9.4.5.2 INDEPENDENT EXPERT SCIENTIFIC COMMITTEE ON COAL SEAM GAS AND LARGE COAL MINING DEVELOPMENT (IESC)

During the draft EIS public submission period, the Queensland Minister for the Environment and the Queensland Department of Environment and Science (DES) requested advice from the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) in relation to the Project, which was approved in writing by the Australian Government Environment Minister. The IESC provided this advice to the Queensland Minister for the Environment and DES on 5 February 2023. As part of the preparation of the final EIS, responses to the IESC's points raised in their advice are provided throughout the final EIS, mostly within Chapter 2 Proposed Project Description, Chapter 8 Geology and Chapter 9 Groundwater. Appendix 1D Introduction EIS response to submissions includes the IESC's advice and CTSCo's responses to each point raised, with the IESC advice being submitter 82 Attachment 1.

9.4.5.3 COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION (CSIRO)

The Department of Environment and Science (DES) as the administering authority, requested advice from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in relation to the Project. CSIRO provided this advice to DES on 5 October 2023. As part of the preparation of the final EIS, responses to the CSIRO's points raised in their advice to DES are provided throughout the final EIS, mostly within Chapter 2 Proposed Project Description, Chapter 8 Geology and Chapter 9 Groundwater. Appendix 1D Introduction EIS response to submissions includes the CSIRO's advice and CTSCo's responses to each point raised, with CSIRO being submitter 85.

9.5 Exploration and Appraisal Field Investigations

As described in detail in Chapter 2 Proposed Project Description, sections 2.8.1.2, and 2.10.4, and Chapter 8 Geology, section 8.5.2, the wells and bores at the Project site of West Moonie were drilled for the purposes of acquiring specific geological and water quality data of the overlying aquifers to, and storage complex of, the Precipice Sandstone aquifer. In summary:

- **2020:** CTSCo drilled and cored the West Moonie-1 Injection Well to a measured total depth of 2,713 m into the Moolayember Formation. The well is currently suspended and will be fully completed, then used for injection of the GHG stream into the Precipice Sandstone;
- **2021:** West Moonie-2 Monitoring Well was directionally drilled to a measured depth of 2,450 m. The Precipice Sandstone was intersected at a location 178 m east-north-east of the West Moonie-1 Injection Well location. Core was subsequently acquired in West Moonie-2 Monitoring Well. This well is currently suspended and will be fully completed, then used as a monitoring well of the groundwater in the Hutton Sandstone Formation and Precipice Sandstone Formation for the Project;
- **2021:** West Moonie Shallow Monitoring Bore located within the West Moonie-1 Injection Well drill pad was drilled to a depth of 48 m to sample the Griman Creek Formation water quality;
- **2021:** the existing Milgarra Bore, 14.5 km east of the West Moonie-1 Injection Well, was sampled to test the water quality of the Gubberamunda Sandstone aquifer which is 1,156 m below ground level (bgl). The Gubberamunda Sandstone aquifer is approximately 1,100 m shallower than the Precipice Sandstone aquifer at the West Moonie-1 Injection Well; and
- **2021:** CTSCo received additional triaxial test data from Stratum Reservoir for both West Moonie-1 Injection Well and West Moonie-2 Monitoring Well, which was analysed by Tech Limit (2021) and incorporated into the post-drill geomechanical model. Triaxial test results were used in preference when calibrating the geomechanical model.

An initial groundwater sampling program has been conducted for the Project, with groundwater samples taken from the West Moonie-1 Injection Well, West Moonie-2 Monitoring Well, Milgarra Bore, and West Moonie Shallow Monitoring Bore between 2020 and 2021. A summary of groundwater sampling details is presented in Table 9-7.

Table 9-7 Summary of groundwater sampling events

Well or Bore Name	Formation Sampled	Sample Date	Sampled by	Analysed by
West Moonie-1 Injection Well	Precipice	30/11/2020	CTSCo	ALS*
West Moonie-1 Injection Well	Precipice	16/07/2021	CTSCo	ALS*
West Moonie-1 Injection Well	Precipice	19/07/2021	UQ	ALS*
West Moonie Shallow Monitoring Bore	Griman Creek	19/07/2021	UQ	ALS*
Milgarra Bore	Gubberamunda	14/06/2021	CTSCo	ALS*
Milgarra Bore	Gubberamunda	25/08/2021	CTSCo	ALS*

*Note: NATA certified laboratory.

All laboratory analysis is NATA certified. Results of the groundwater sampling are discussed in section 9.7.5. Appendix 9A, sections 4.4 and 4.5, and (Appendix E) provide further details on the sampling and analysis conducted and results.

The field investigations produced a number of datasets that were then used to establish existing environmental conditions of the geology and groundwater, and were used to calibrate the various models (dynamic plume model, geomechanical models, geochemical model and hydrodynamic models) that inform the groundwater impact assessment. Table 9-8 summarises the key datasets obtained from field investigations.

Table 9-8 Summary of site-specific datasets acquired by or on behalf of CTSCo

Dataset from Field Investigations	Source
Drilling information, drilling logs and wireline logs	West Moonie-1 Injection Well, West Moonie-2 Monitoring Well
Groundwater quality data from a series of sampling events conducted, as listed in Table 9-7.	West Moonie-1 Injection Well, West Moonie Shallow Monitoring Bore, Milgarra Bore
Precipice Sandstone water quality data from West Moonie-1 Injection Well	ALS Report EB2123041-001 of 19 July 2021
Gubberamunda Sandstone water quality data from Milgarra Bore	ALS Report EB2118210-001 of 14 June 2021, and EB2124168-001 of 25 August 2021
Griman Creek water quality data from West Moonie Shallow Monitoring	ALS Reports EB2120349-002 and EB2123041-001 of 19 July 2021
Routine core analysis (RCA)	West Moonie-1 Injection Well, West Moonie-2 Monitoring Well
Rock strength core analysis	West Moonie-2 Monitoring Well
23 Modular Formation Dynamic Tester (MDT) tests carried out to determine pressure trends in the Hutton, Evergreen and Precipice Formations	West Moonie-2 Monitoring Well
Isotope ~ $\delta^{13}C$ CO_2 determination of the Evergreen, Precipice and Moolayember Formations	West Moonie-1 Injection Well, West Moonie-2 Monitoring Well
Rock chemistry analysis by whole-rock digestion (ICP-OES and ICP-MS)	ALS Analysis: Report BR21236194 of 16 September 2021 for Bungunya-1, Fantome-1, Giddi Giddi -1, Milgarra-1, Tasmania-1, Woodville-1 wells; Report BR19268646 of 7 November 2019 for West Moonie-1 Injection Well; Report BR21092657 of 4 May 2021 West Moonie-2 Monitoring Well; and UQ Analysis: Excel Spreadsheet results of 19 April 2021 for West Moonie-1 Injection Well.

As discussed in Chapter 2 Proposed Project Description, section 2.11 and Chapter 9 Groundwater sections 9.10 and 9.12, CTSCo also commits to undertaking further field investigations prior to commencement of injection in the operation phase of the Project.

9.5.1 Isotope Data of the Overlying Aquifers and the Storage Complex

During the drilling and appraisal activities of West Moonie-1 Injection Well and West Moonie-2 Monitoring Well, mud gas samples were collected in Isotech's Isotubes™ from a sampling manifold installed adjacent to gas chromatography equipment in the mudlogging unit at approximately 100 m intervals to establish the natural trend of alkanes (single-bonded carbon and hydrogen atoms including methane (C1), ethane (C2), propane (C3), butane (C4), and pentane (C5)), CO_2 concentrations, and isotopic signatures from approximately 350 mbgl to below the Precipice Sandstone aquifer in the Moolayember Formation.

Analysis of samples was conducted by Stratum Reservoir and is ISO 9001.2015 certified. Results of the samples are provided in section 9.7.6 below. Further details of the sampling and analysis methodology are provided in Appendix 8B EPQ10 – West Moonie-1 Well Completion Report, section 3.2, and EPQ10 West Moonie-2 Well Completion Report, section 4.2.

A key isotope carbon-13 (~$\delta^{13}C$ CO_2) is a suitable environmental tracer that allows for comparison between naturally occurring carbon-13 in the geological profile at West Moonie-1 Injection Well site, and carbon-13 in the GHG stream. Isotopic data of flue gas from Millmerran Power Station (MPS) has been collected and analysed as source of the GHG stream for injection testing.

The differences in the properties of the isotopes will allow for verification of the confinement and containment of the GHG stream and GHG plume within the injection infrastructure and storage complex throughout the operation phase and monitoring phase of the Project.

9.6 Modelling

Chapter 8 Geology provides a description of the Project geology including associated modelling. The relevant hydrogeological (groundwater) modelling is described below.

Table 9-9 lists the various models used for the geology and groundwater assessment, providing a description of the function and objective of each model. Further information describing the geological modelling methodology, assumptions and limitations is provided in Chapter 8 Geology, section 8.6, with the hydrogeological modelling methodology, assumptions and limitations provided below.

Table 9-9 Models used in Groundwater Impact Assessment

Model Type	Model	Objective	Further Details
Geology	Seismic	Definition of spatial geological structure including faults, and extent of GHG plume	Chapter 8 Geology, sections 8.6.2.1, 8.10.2, 8.10.4.3.2, and 8.12.
Geology	Petrophysics	Quantification of rock properties including porosity, permeability and fluid saturation	Chapter 8 Geology, section 8.6.2.2, 8.7.6, 8.9.3, 8.10, and 8.12.
Geology	Static Geological	Synthesis of seismic, petrophysics and sedimentological interpretations into a pre-injection 3D representation of the subsurface geology	Chapter 8 Geology, section 8.6.2.3, 8.10, and 8.12.
Geology	Geomechanics	Characterise current earth stresses and investigate effects that might result from the planned GHG stream injection such as fracture initiation and/or reactivation	Chapter 8 Geology, section 8.6.2.4, 8.9.2, 8.10, and 8.12.
Groundwater	Hydrogeological	Model aquifer and aquitard properties and changes in local and regional aquifer pressure conditions resulting from GHG stream injection	Chapter 9 Groundwater, sections 9.6.2.1, 9.7.3.2, 9.9.2, and 9.9.5.
Groundwater	Dynamic (Plume)	Dynamic modelling of groundwater pressure and flow, and GHG stream saturation within the geological model during injection and post injection phases of the Project	Chapter 9 Groundwater, section 9.6.2.2, 9.7.3.2, 9.9.2, and 9.9.5.

Model Type	Model	Objective	Further Details
Groundwater	Geochemical	Characterise existing rock and groundwater chemistry and model temporal and spatial changes that take place due to chemical reactions caused by interaction with the GHG stream	Chapter 9 Groundwater, sections 9.6.3, 9.6.4, 9.6.5, 9.7.5, 9.7.6, 9.9.4, and 9.9.7.

9.6.1 Groundwater Pressure and Flow and Interconnectivity with Overlying Aquifers

For the Project to determine groundwater pressure and flow differences, in situ measurements were conducted as described in Chapter 8 Geology, section 8.7.6.3 using a Modular Formation Dynamic Tester (MDT) and compared to other regional information as discussed in section 9.7.3.1.3 below.

As presented in sections 9.4.1 and 9.4.2 various studies and publications discuss groundwater pressure and flow differences or potential interconnectivity between aquifers in the GAB and/or Surat CMA, particularly the work by Hofmann *et al* (2022), and OGIA (2019a, 2021).

9.6.2 Groundwater Pressure and Flow within the Storage Complex

The majority of the groundwater modelling for the Project focuses on the storage complex, being the lower Precipice Sandstone Formation as the storage reservoir, and the Evergreen Formation and Moolayember Formation providing the geological seals.

Understanding the cumulative influence of regional groundwater flow (magnitude and direction) is important when predicting the temporal and spatial movement of the GHG plume within the storage reservoir. Conversely, understanding the impact from pressure changes by the GHG stream injection has on the storage reservoir and existing and future groundwater uses and users is equally important.

The evaluation of how groundwater flow and extraction may affect the GHG plume was carried out using a combination of regional far-field groundwater flow model (the hydrogeological model) and localised plume migration model (the dynamic (plume) model). GHG plume movement was modelled for three different scenarios including existing regional extraction from existing registered water bores, new potential extraction from existing water entitlements, and a hypothetical large extraction close to the West Moonie-1 Injection Well.

Far-field modelling uses MODFLOW-6™ software to build the hydrogeological model, and examines the broader region surrounding the West Moonie-1 Injection Well, covering approximately 150 km by 400 km, being approximately 60,000 km^2.

Near-field modelling uses tNavigator™ software to build the dynamic (plume) model, and examines a 4 km^2 area immediately surrounding West Moonie-1 Injection Well.

Further details of each of the models, their set-up, assumptions, limitations, and scenarios examined are discussed in the following sections. Results of the models showing the potential impacts on the existing hydrogeological conditions are given in section 9.9.

9.6.2.1 HYDROGEOLOGICAL MODEL

The GABORA Water Management Protocol, Chapter 4 – Protection of existing licences and particular authorisations, provides methods for estimating drawdown at existing water entitlements from new water entitlements, to ensure that drawdown at the location of existing water authorisations will not exceed 5 m. Section 26 of the GABORA Water Management Protocol provides for the use of a method for being satisfied that the drawdown at a location will not exceed the maximum drawdown, with supporting table given in Attachment 5 – Minimum separation distances (kilometres). As advised by the Department of Regional Development, Manufacturing and Water (RDMW) on 8 May 2023, for development of the minimum separation distances in Attachment 5, the Theis equation is used with particular parameters considered for an aquifer’s transmissivities, aquifer’s storativity, period of pumping, pumping rates, and volumes proposed to be taken.

However, s.27 of the GABORA Water Management Protocol provides for the use of hydrogeological assessment that can include, but need not be restricted to, groundwater flow modelling, analytical methods or similar. Given the nature of the Project, CTSCo has elected to undertake groundwater flow modelling and other analytical methods.

A hydrogeological model is a descriptive representation of a specific groundwater system that incorporates knowledge and interpretation of the geological and hydrogeological systems. A hydrogeological model consolidates the hydrogeological understanding of key processes such as recharge and discharge, and the influence of any boundaries and stresses that may be present. The conceptualisation process for the hydrogeological model involves simplifying an inherently complex groundwater system to a simplified version that describes the main features controlling groundwater flow. The degree of simplification is usually guided by the objectives and timescale of the study, and the amount and quality of data available.

The hydrogeological model for the Project's groundwater impact assessment is focused on the Storage Complex, with the GHG storage reservoir being the lower Precipice Sandstone, with the storage geological seals provided by the overlying Evergreen Formation and underlying Moolayember Formation. The Hutton Sandstone, which is a partial aquifer (OGIA (2021a)) that overlies the Evergreen Formation and the closest aquifer to the Precipice Sandstone aquifer, is also considered in the hydrogeological model. The hydrogeological model takes a regional scale approach when looking at geology, hydrodynamics and structural characteristics, while considering both local and regional scales with respect to the GHG storage reservoir properties themselves. These formation properties will govern the injection characteristics of the GHG stream locally and how the lower Precipice Sandstone will respond to pressure changes, both locally and regionally.

The hydrogeological model includes the main structural elements, the hydraulic properties of the geological formations, the conceptual boundaries, groundwater levels and interactions including recharge and discharge processes, water density, and hydrochemistry.

The impacts on groundwater pressures were simulated using a single-phase groundwater numerical modelling code, MODFLOW-6™ and MODFLOW-USG-Transport, which are industry standard software. The groundwater modelling approach was developed with knowledge of both the scale and duration of the proposed injection testing, and the size of the Precipice Sandstone aquifer being the GHG storage reservoir for the injected GHG stream. The approach uses a relatively simple model in a conservative manner. A simple model provides more flexibility to undertake hypothesis testing of the implications of various conceptual assumptions. For example, whether the Precipice Sandstone groundwater flow system is stagnant at the West Moonie-1 Injection Well site, or whether the eventual discharge is to the south or to the east (Wye et al., 2019).

The hydrogeological model that was used to assess pressure change (propagation) due to GHG stream injection and the movement of groundwater close to the injection site is a hybrid model developed from two existing regional models:

- a Precipice Sandstone Formation specific model developed by the University of Queensland's UQ-SDAAP Project by Hayes *et al* (2019); and
- the Underground Water Impact Report (UWIR) model developed by OGIA (2019b and 2021) for the Surat Cumulative Management Area (Surat CMA).

The integration of the two models incorporates the best available regional scale information. The primary focus of the UQ-SDAAP Project was the Evergreen Formation and Precipice Sandstone Formation, and the UQ-SDAAP Project enabled the best estimates to date of regional aquifer parameters for the Precipice Sandstone. The UWIR model developed by OGIA has a primary objective of predicting drawdown impacts due to CSG development in the Walloon Coal Measures and the coals of the Bowen Basin sequence. Whilst the OGIA model includes the Evergreen Formation and Precipice Sandstone, its calibration is highly targeted at the coals and the overlying formations e.g. Springbok Sandstone, and underlying formations, such as the Hutton Sandstone, directly in and around active CSG fields.

The hydrogeological model developed for this assessment used best available information, the UQ-SDAAP model layers and information, for the majority of the model domain. The UQ-SDAAP model considers the Surat Basin sediments, but the geological formations of interest, including the Precipice Sandstone, continue to the east into the Clarence-Moreton Basin. In order to assess the complete area where pressure change impacts may occur, the UQ-SDAAP datasets were supplemented to the east by incorporating information from OGIA's UWIR model.

The hydrogeological model for the Project was also updated with well data from West Moonie-1 Injection Well and West Moonie-2 Monitoring Well (Hofmann, H, *et al*, 2022) and includes the lower Precipice Sandstone, the upper Precipice Sandstone, and the Evergreen Formation, as well as the overlying Hutton Sandstone and the underlying Moolayember Formation. The hydrogeological model was run for a 1,000-year shut-in period post injection to allow assessment of long-term GHG plume migration.

The following sections describe in further detail the set-up of the base case hydrogeological model, with sensitivity analysis of nine variations then undertaken. Using the base case hydrogeological model, three scenarios were developed to predict the potential impacts associated with extraction of water from the Precipice Sandstone aquifer. A detailed description of the hydrogeological model work undertaken in reference to the three scenarios is provided in Appendix 9B.

9.6.2.1.1 Base case Hydrogeological Model Set-up

The hydrogeological model represents the flow regime of the southern Surat Precipice Sandstone aquifer based on estimates of pre-pumping (extraction and injection) groundwater elevations from research. The hydrogeological model then simulates the duration of extractions developed since the 1960s, including the largest extractions at the Moonie Oil Field and Kogan Creek Power Station, to derive initial conditions for simulations of GHG stream injection and local water extraction. The hydrogeological model makes two predictions:

- the change in pressure in the Precipice Sandstone aquifer due to the GHG stream injection; and
- how potential new extractions may change groundwater flows that could change GHG plume migration. Actual changes to GHG plume migration are assessed in detailed by the dynamic (plume) model, based on flow changes simulated by the regional hydrogeological model.

The hydrogeological model was set-up in MODFLOW 6™, using an unstructured mesh with regional grid cells of 1.5 km x 1.5 km, refined locally to cells of 187.5 m x 187.5 m around West Moonie-1 Injection Well. The model extent is approximately 150 km by 400 km. The model includes the upper Hutton Sandstone, lower Hutton Sandstone, the Evergreen Formation, and the Precipice Sandstone underlain by the Moolayember Formation. The Precipice Sandstone and the Evergreen Formation are subdivided into multiple layers, while the other formations are represented as one model layer. The vertical discretisation is summarised in Table 9-5.

The hydraulic properties selected for the base case hydrogeological model are summarised in Table 9-5. Hydraulic conductivity is related to permeability (k) and expresses how fast water flows through a rock at a given pressure and has a horizontal component (kh) and a vertical component (kv). Figure 9-1 shows how the hydraulic conductivity used in the hydrogeological model compare to OGIA's (2019a) regional model properties, with the kh and kv values used in the base case hydrogeological model within the range predicted by OGIA, except for the Boxvale Sandstone Member. The Boxvale Sandstone Member is not included as a separate layer in the hydrogeological model but contained within the Evergreen Formation. The Evergreen Formation hydraulic conductivity used in the hydrogeological model is at the lower end of the calibrated OGIA model. This is supported by detailed interpretation completed during the *Southern Surat Hydrogeology study* (Hofmann *et al*, 2022) that showed that the existing pressure gradient between the Hutton and Precipice Sandstone aquifers could only be sustained by very low vertical permeability in the Evergreen Aquitard. This is expected as the hydrogeological model reflects the deeper Evergreen Formation aquitard in the southern Surat Basin, while OGIA's model considers the whole Evergreen Formation from shallow outcrop to deep in the Surat Basin.

Table 9-10 Base Case properties of the hydrogeological model, porosity is constant at 13.5%

Formation Name	Model layer(s)	Specific storage (Ss) (1/m)	kh (m/day)	kv (m/day)
Upper Hutton	1	1.0×10^{-6}	3.0×10^{-2}	4.0×10^{-6}
Lower Hutton	2	1.0×10^{-6}	1.0×10^{-2}	1.0×10^{-6}
Evergreen	3-5	1.0×10^{-6}	6.0×10^{-5}	5.0×10^{-8}
Precipice	6-10	1.0×10^{-6}	4.0×10^{-1}	4.0×10^{-3}
Underlying	11	1.0×10^{-6}	1.0×10^{-4}	1.0×10^{-8}

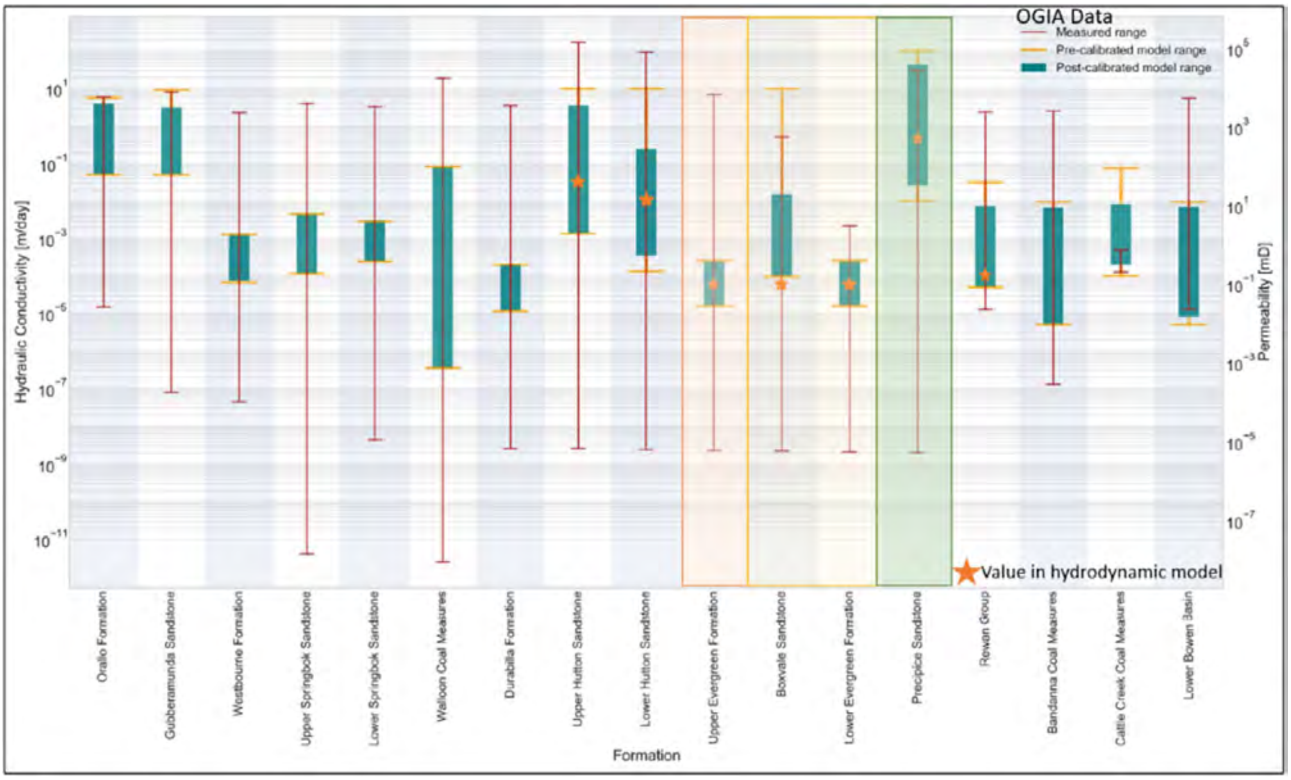

Figure 9-1 Hydraulic conductivity of the hydrogeological model (indicated with an orange star) compared with OGIA's model ranges (modified from OGIA, 2019a)

The hydrogeological model has been simulated to inform:

- change in hydraulic head due to GHG stream injection (hydraulic head impact model); and
- movement of GHG-impacted groundwater over time (particle tracking model).

The *hydraulic head impact model* was set up with closed boundary conditions, which is a conservative approach, as the added pressure cannot leave the model domain.

The boundary conditions for the *particle tracking model* are shown in Table 9-11. The head boundary conditions are based on reinterpreted head data from regional wells. The Hutton Sandstone boundary conditions are very uncertain in the south-west due to limited and conflicting data. The Precipice Sandstone boundary conditions in the north of the Surat Basin are difficult to quantify owing to the large amount of recharge and discharge features.

Despite uncertainty in the boundary conditions, the simulated steady-state heads match the observed heads reasonably well. Therefore, the model is expected to reasonably reflect the flow velocities in the southern Surat Basin.

Table 9-11 Boundary conditions for base case hydrogeological model (particle tracking model)

Area	Head Boundary condition (m)	Boundary condition (type)	Note
Hutton North	340	Time-variant specified head boundary	
Hutton East	350	Time-variant specified head boundary	
Hutton South	300	Time-variant specified head boundary	
Precipice North	350	General head boundary	Conductance = thickness x 0.03
Precipice East	140	General head boundary	Conductance = thickness x 0.006

Groundwater extraction from the Moonie Oil Field and Kogan Creek Power Station has been included in the particle tracking realisations with a combined extraction rate of 5,000 m^3/day from the regional hydrogeological model, as presented in Table 9-12. Kogan Creek Power Station is expected to close in 2042 (based on the expected closure year as defined in the National Electricity Rules (NER)). While the abandonment date of the Moonie Oil Field is uncertain, OGIA (2019a) expects production to cease in 2030. However, the lifetime of the field could be extended by using enhanced oil recovery (EOR) techniques.

The hydrogeological modelling uses a single-phase approximation of supercritical GHG stream injection. This approach, whilst not capable of representing detail of GHG plume and groundwater interaction in the near field close to the West Moonie-1 Injection Well, is suitable for calculating pressure changes in the far field beyond the GHG plume. The hydrogeological model GHG stream injection is approximated by simulating injection of water into the groundwater model, using the same volume of water as the supercritical liquid GHG stream (at downhole well pressure) as the two-phase reservoir modelling. The single-phase approach is sufficiently accurate to predict the far field pressure changes which propagate well beyond the GHG plume within groundwater.

To simulate injection, the West Moonie-1 Injection Well was assumed to inject a volume of 510 m^3/day for a 3-year period, which is the volumetric equivalent of 110,000 t/year of GHG stream, assuming a GHG stream-to-water density ratio of 0.6 (Price, 2020) and a groundwater density of 985 kg/m^3. This GHG stream volume is based on temperature estimates in the West Moonie-1 Injection Well. However, the West Moonie-2 Monitoring Well provided a more accurate (and lower) Precipice Sandstone temperature measurement. The West Moonie-2 Monitoring Well temperatures were lower than those assumed from the West Moonie-1 Injection Well and due to the lower temperature, the density of the GHG stream within the GHG storage reservoir is likely to be slightly higher. As the injection rate is mass based (110,000 t/year) the GHG stream volume will be slightly lower (approximately 450 m^3/day) than that used in the model. Therefore, the simulations may overestimate the injection volume and overpredict the pressure impact.

Table 9-12 Extraction and injection wells included in the hydrogeological model, with years relative to start of the GHG stream injection

Name	Start (year)	Stop (year)	Extraction / Injection rate (m^3/d)(1)
Moonie Oil Field	-55	10	-2,500
Kogan Creek Power Station	-14	20	-2,500
West Moonie-1 Injection Well	0	3	510

Note: (1) Negative number represents extraction and positive number represents injection

9.6.2.1.2 Sensitivity Analysis Set-up for Impact of Hydraulic Head

Four different model realisations (cases) were run in addition to the base case to analyse the sensitivity of predicted future hydraulic heads to different Precipice Sandstone hydraulic parameters, as presented in Table 9-13. The cases test different hydraulic conductivity and specific storage (Ss) values in the Precipice Sandstone. Case 1.4 tests the impact of a hypothetical transmissible fault or leakage window in the general vicinity of the West Moonie-1 Injection Well.

Table 9-13 Model cases for sensitivity analysis for impact on hydraulic head

Case	Case Name	Comment
1.0	Base case	Properties as in Table 9-10
1.1	Low storage	Ss in Precipice 5.0×10^{-7}
1.2	Low hydraulic conductivity	kv and kh in Precipice x 0.5
1.3	High hydraulic conductivity	kv and kh in Precipice x 2.0
1.4	Hypothetical fault at 7 km from West Moonie-1 Injection Well	1,125 m long strip of cells with kv increased to 1.0×10^{-2} m/d in all layers

Figure 9-2 provides a plan view of the model grid and gridding density, together with the location of the hypothetical fault in the Evergreen Formation for Case 1.4.

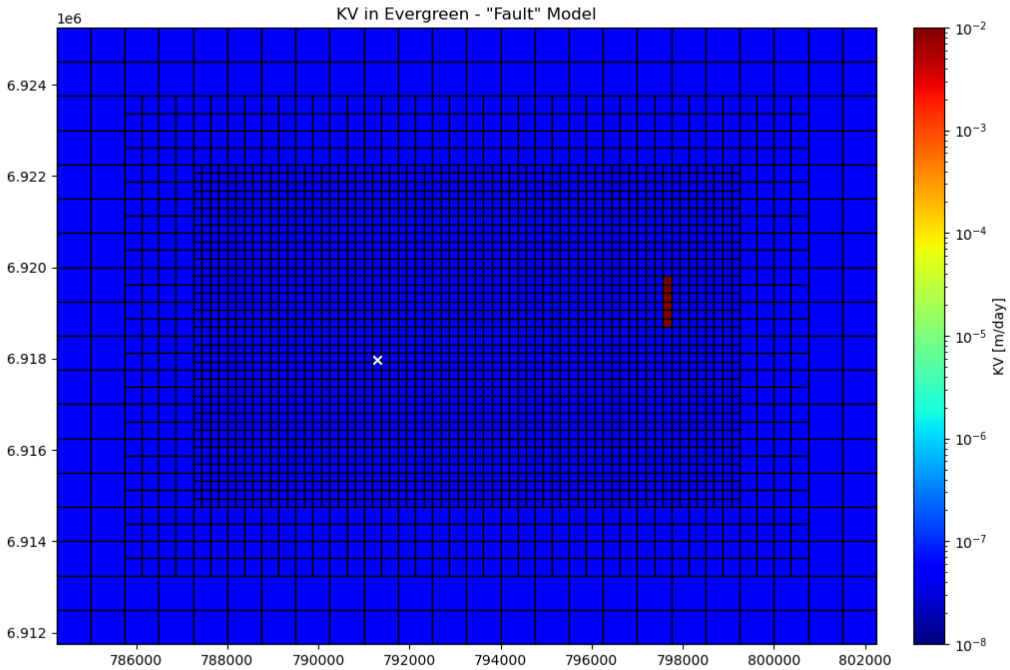

Figure 9-2 Plan view showing the location of the hypothetical fault in the Evergreen Formation (red cells) in Case 1.4, West Moonie-1 Injection Well is indicated with a white cross

9.6.2.1.3 Sensitivity Analysis Set-up for Impact on Groundwater Movement

Sensitivity analysis was conducted using five model cases to analyse the sensitivity of different conceptualisations on particle tracking (plume) movement. Particle tracking was completed to aid comparison between the single-phase groundwater model and the two-phase reservoir simulator. The latter model is the appropriate tool at the GHG plume scale. Table 9-14 provides the five model cases for particle (plume) tracking sensitivity analysis.

Table 9-14 Model cases for particle tracking (plume) movement sensitivity analysis

Case	Case Name	Comment
2.0	Base case	Properties and boundaries as in Table 9-12
2.1	Low southern head	Southern Hutton boundary set to 100 m (instead of 300 m), so as to force flow towards the south
2.2	Low southern head and high kv in south	As per Case 2.1, and Evergreen kv increased to 1.0 x 10^{-5} m/d in the south of the model, so as to force flow towards the south
2.3	Early decommissioning of Moonie Oil Field and Kogan Creek Power Station	Moonie Oil Field and Kogan Creek Power Station stop producing as soon as GHG stream injection ends
2.4	Low porosity	Porosity in the Precipice Sandstone reduced to 4.5% (instead of 13.5%) to represent flow occurring through only one third of GHG storage reservoir
2.5	High hydraulic conductivity	Precipice kv and kh doubled

Case 2.1 and Case 2.2 were set up to force flow to the south, as there is still uncertainty around the flow direction in the southern part of the Surat Basin. Case 2.3 was set up to address the uncertainty in abandonment of the Moonie Oil Field, as discussed in Appendix 9A, section 5.1.

9.6.2.1.4 Scenarios for Extraction of Water from the Precipice Sandstone aquifer

To understand the potential for movement and/or flow of the GHG plume away from the West Moonie-1 Injection Well associated with the extraction of water by existing or future potential water entitlement holders, three scenarios were developed:

- Scenario 1 Base Case: includes existing extraction from the Precipice Sandstone aquifer from the Moonie Oil Field and Kogan Creek Power Station;
- Scenario 2: builds on Scenario 1 and adds existing water entitlements to the model; and
- Scenario 3: builds on Scenario 2 and adds hypothetical future entitlements from unallocated water.

The boundary between the dynamic (plume) model and the hydrogeological model is shown in Figure 9-3, with the extent of the dynamic (plume) model being the 1,975 m x 1,975 m area surrounding West Moonie-1 Injection Well within the broader scale hydrogeological model.

Figure 9-3 Boundary between the Hydrogeological Model and the Dynamic (Plume) Model at West Moonie-1 Injection Well

Outputs from the hydrogeological model were used to provide flux boundary conditions in terms of flow per linear metre of model boundary to the dynamic (plume) model.

Each of the scenarios is further described below, and a detailed description of the hydrogeological model work undertaken is provided in Appendix 9B.

9.6.2.1.4.1 Scenario 1 – Base Case of existing extraction from the Precipice Sandstone aquifer

The Scenario 1 Base Case considers the existing large extractions from the Precipice Sandstone aquifer within the Surat Precipice groundwater sub-area, including the expired Surat 7, Surat East 4, and Surat North 3 management units. Table 9-15 and Figure 9-4 provide details of the locations of the extractions compared to the West Moonie-1 Injection Well, while Figure 9-5 shows the diagrammatic representation of the fluxes at the boundary of the hydrogeological model and the dynamic (plume) model.

Table 9-15 Scenario 1 Base Case – Fluxes of large existing extractions from the Precipice Sandstone aquifer within the Surat Precipice groundwater sub-area

	GDA2020 latitude	GDA2020 longitude	Distance from West Moonie-1 Injection Well (km)	Simulated extraction rate (ML/y)	Simulated daily extraction rate (m^3/d)[(1)]	Duration or end date
Moonie Oil Field	-27.757576	150.246037	29.45	-913	-2,500	65 years to 2030
Kogan Creek Power Station	-27.125074	150.689996	113.28	-913	-2,500	36 years to 2040
West Moonie-1 Injection Well[(2)]	27.830242	149.958101	0.00	+186	510	3 years

Notes:

(1) Extraction rate, the removal of water from the MODFLOW-6 model is represented as a negative, while injection as a positive

(2) West Moonie-1 Injection Well, represented as equivalent volume of water injection, with assumed density of 0.590 t/m^3

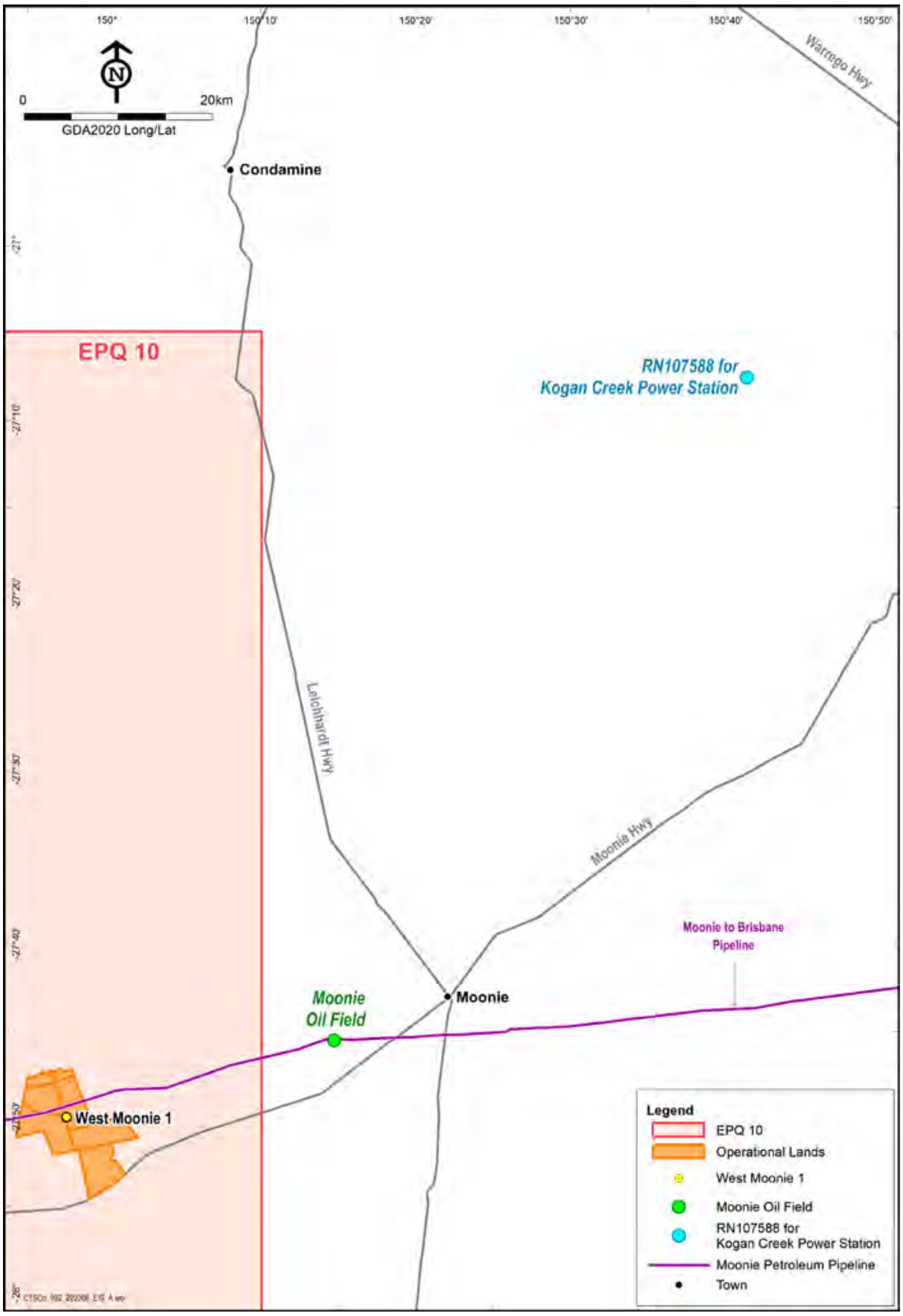

Figure 9-4 Locations of the existing large extractions compared to the West Moonie-1 Injection Well

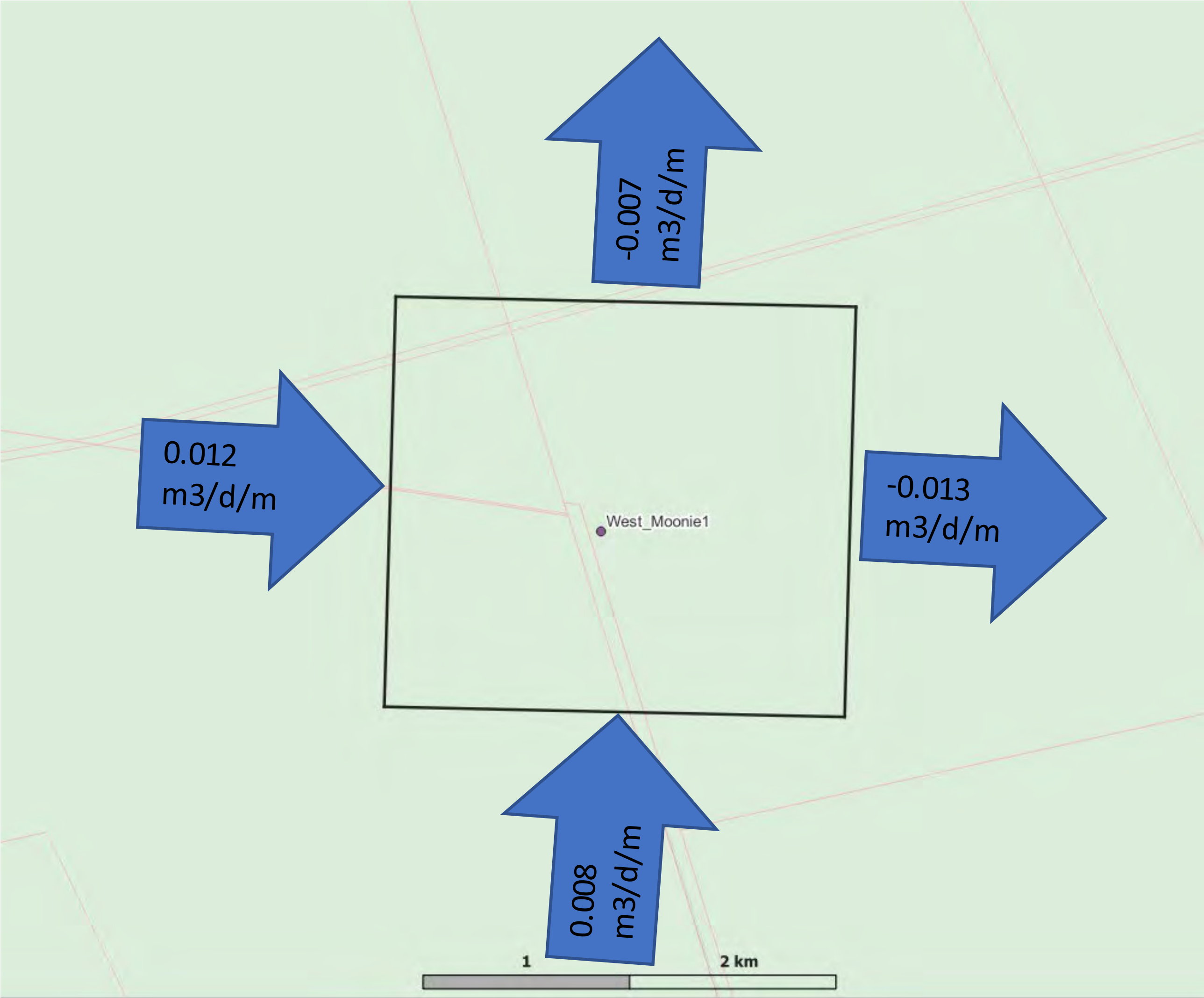

Figure 9-5 Scenario 1 Base Case – Diagrammatic representation of the cumulative fluxes at the boundary of the hydrogeological model and the dynamic (plume) model

9.6.2.1.4.2 Scenario 2 – Precipice Sandstone aquifer existing water entitlements

Under the *Water Act 2000*, water entitlements can be granted for a range of purposes, with either volumetric or no volumetric allocations, depending on the purpose of the water entitlement.

Within a 50 km radius of West Moonie-1 Injection Well, there are three existing water entitlements to the Precipice Sandstone aquifer, as shown in Figure 9-6, and summarised in Table 9-16.

Table 9-16 Precipice Sandstone water entitlements within a 50 km radius of West Moonie-1 Injection Well

Authorisation Reference	Expiry Date of Water Licence	Water Source	Lot on Plan	Authorised Purpose	Nominal Entitlement per Water Year (ML/y)
624712	30/06/2111	Precipice Sandstone	2 SP318366	Any	95
624713	30/06/2111	Precipice Sandstone	15 CVN281	Any	200
616843	30/06/2111	Precipice Sandstone	13 SP211193	Stock Intensive	220

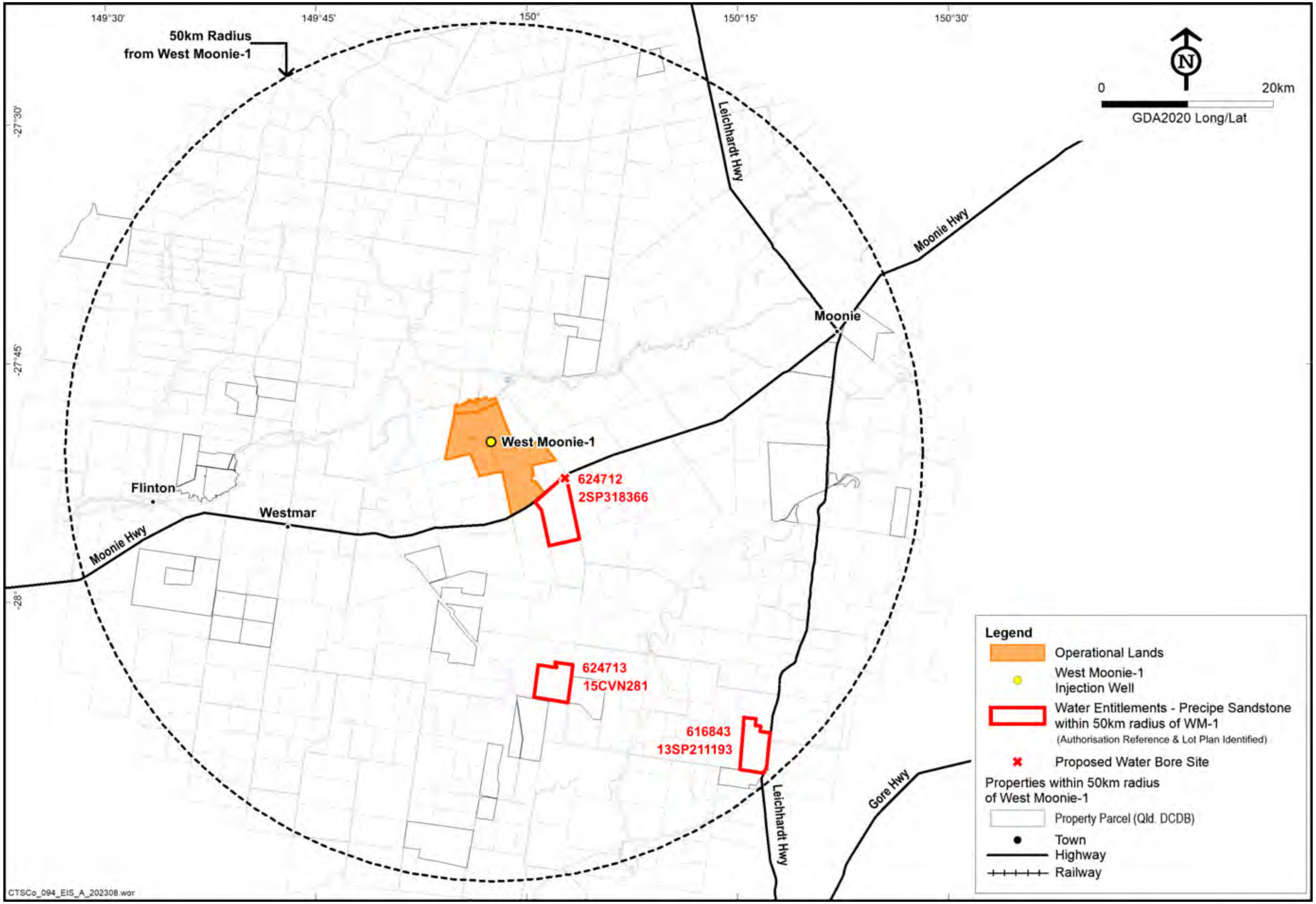

Figure 9-6 Scenario 2 – Locations of the existing water entitlements within a 50 km radius of West Moonie-1 Injection Well

The closest existing groundwater entitlement (624712) to West Moonie-1 Injection Well is associated with a lot on plan 2SP318366. Lot 2SP318366 is approximately 9 km to 15.4 km from West Moonie-1 Injection Well, and a bore is yet to be drilled. However, a development permit to drill was granted on 8 February 2023 by RDMW for location GDA2020 -27.86707 (latitude), 150.04627 (longitude).

The basics of aquifer hydraulics mean that drawdown, hydraulic gradient, and changes in aquifer flux are greatest close to an extraction point and diminish as distance increases from it. The potential for these entitlements to impact GHG plume movement is therefore greatest if the location of yet to be drilled water bores is assumed to be close to West Moonie 1 Injection Well, within their respective lot on plans. Figure 9-6 shows the well locations adopted for the assessment, with locations chosen to be close to West Moonie 1, whilst also being within the lot on plan boundary. The locations are also located at the centre of a groundwater model grid cell.

Scenario 2 builds on Scenario 1, with Table 9-17 providing the extraction rates for Scenario 2.

Table 9-17 Scenario 2 Extraction rates from the Precipice Sandstone aquifer for existing water entitlements within a 50 km radius of West Moonie-1 Injection Well

Lot on Plan	GDA2020 latitude	GDA2020 longitude	Distance from West Moonie-1 Injection Well (m)	Water Entitlement (ML/y)	Simulated daily extraction rate (m^3/d)[(1)]	Duration or end date
2 SP318366	-27.886	150.024	8,972	95	-260.3	100 years to 2125
15 CVN281	-28.076	150.014	27,673	200	-547.9	100 years to 2125
13 SP211193	-28.124	150.256	44,075	220	-602.7	100 years to 2125

Note:
(1) Extraction rate, the removal of water from the MODFLOW-6 model is represented as a negative

The fluxes extracted from the hydrogeological model for Scenario 2 for the existing water entitlements at the boundaries of the dynamic (plume) model are given in Table 9-18. The fluxes are given in cubic metres per day per metre ($m^3/d/m$) of the model boundary and have been calculated after 100 years of extraction for the existing water entitlements. The fluxes in Table 9-18 are represented diagrammatically in Figure 9-7, and show inflows from the north and west, with outflow toward the existing extraction points and existing water entitlements locations to the east and south.

Note that the boundary fluxes are depth averaged across the model layers representing the Precipice Sandstone in the hydrogeological model. The magnitude of the fluxes develops during the 100-year extraction duration reaching a maximum after 100 years. Only the maximum flux is used and applied to the hydrogeological model as constant rate boundary conditions. This simplifies the plume modelling and will tend to overestimate the potential impact of extraction.

Table 9-18 Scenario 2 – Fluxes from the existing water entitlements within a 50 km radius of West Moonie-1 Injection Well

Direction	Scenario 1 Base Case – simulated daily extraction ($m^3/d/m$) [(1)]	Scenario 2 Existing Water Entitlements – simulated daily extraction ($m^3/d/m$) [(1)]
North	-0.007	0.022
South	0.008	-0.022
East	-0.013	-0.005
West	0.012	0.005

Note:
(1) Extraction rate, the removal of water from the MODFLOW-6 model is represented as a negative

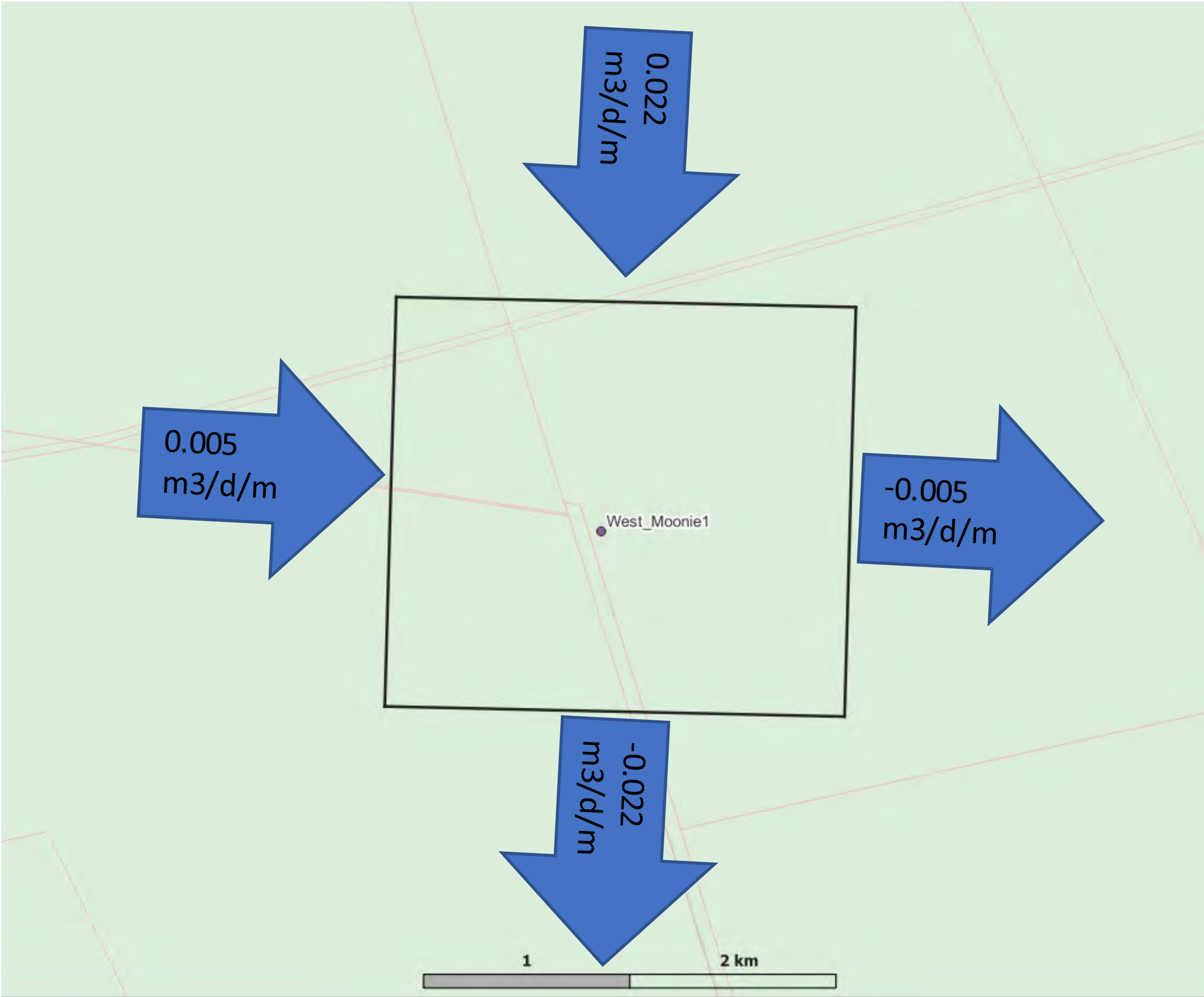

Figure 9-7 Scenario 2 Existing Water Entitlements – Diagrammatic representation of the cumulative fluxes at the boundary of the hydrogeological model and the dynamic (plume) model

9.6.2.1.4.3 Scenario 3 – Hypothetical future entitlements from unallocated water

In the broader area surrounding the West Moonie-1 Injection Well, it is foreseeable that future large water entitlements may be granted for the Precipice Sandstone aquifer. The most plausible future authorised purpose of water could be, but not limited to, Any, Stock Intensive, Irrigation, or Industrial, as several feedlots and piggeries are already located in the area. The existing Precipice Sandstone groundwater entitlements include 32 volumetric water entitlements, that vary from 41 ML/y to 1,500 ML/y.

Based on the *Water Plan (Great Artesian Basin and Other Regional Aquifer) 2017* (GABORA Water Plan), Schedule 4 – Volume of unallocated water for water licences to be granted from reserves, and feedback from RDMW on 8 May 2023, the following reserves that include the Surat Precipice groundwater sub-area are:

- General reserve = 840 ML/y;
- State reserve = 840 ML/y;
- Aboriginal people and Torres Strait Islanders economic reserve = 135 ML/y;
- Total volume of unallocated water that could be potentially granted in the Surat Precipice groundwater sub-area is 1,815 ML/y.

The degree to which such large extraction could potentially influence the GHG plume of the injection testing is assessed for a single hypothetical location close to West Moonie-1 Injection Well. The rationale for assessing the single hypothetical extraction close to the GHG stream injection point is that it has a greater potential to influence GHG plume migration. If GHG plume movement is minimal for the largest foreseeable groundwater entitlement, when located close by, then it can be concluded that smaller entitlements at greater distance from the West Moonie-1 Injection Well will exert less influence on GHG plume movement.

The distance adopted is 5 km due east of the West Moonie-1 Injection Well, as shown in Figure 9-8 by the location label “Hypothetical 1,815 ML/y”. The location due east is chosen to be in broadly the same direction as both the Moonie Oil Field and the closest existing water entitlement (624712). This means that groundwater movement induced by the 1,815 ML/y hypothetical future entitlement is additive to fluxes caused by existing nearby and large entitlements. The distance also coincides with the cell centre of the hydrogeological model grid. The extractions represented in Scenario 3 are listed in Table 9-19 and the fluxes shown in the Figure 9-9 and listed in Table 9-20.

Table 9-19 Scenario 3 Extraction rate from the Precipice Sandstone aquifer for a hypothetical extraction of unallocated groundwater within 5 km of West Moonie-1 Injection Well

Lot on Plan	GDA2020 latitude	GDA2020 longitude	Distance from West Moonie-1 Injection Well (m)	Water Entitlement (ML/y)	Simulated daily extraction rate (m3/d)(1)	Duration or end date
Hypothetical 1,815 ML/y on lot 29PG223	-27.832	150.008	5,608	1,815	-4,972.6	100 years to 2125

Note:

(1) Extraction rate, the removal of water from the MODFLOW-6 model is represented as a negative

Figure 9-8 Scenario 3 Location of a hypothetical extraction of unallocated groundwater within 5 km of West Moonie-1 Injection Well

Table 9-20 Scenario 3 – Fluxes from including a hypothetical extraction of unallocated groundwater within 5 km of West Moonie-1 Injection Well

Direction	Scenario 1 Base Case – simulated daily extraction ($m^3/d/m$) (1)	Scenario 2 Existing Water Entitlements – simulated daily extraction ($m^3/d/m$) (1)	Scenario 3 Hypothetical future entitlement from unallocated water – simulated daily extraction ($m^3/d/m$) (1)
North	-0.007	0.022	0.079
South	0.008	-0.022	-0.017
East	-0.013	-0.005	-0.230
West	0.012	0.005	0.160

Note:
(1) Extraction rate, the removal of water from the MODFLOW-6 model is represented as a negative

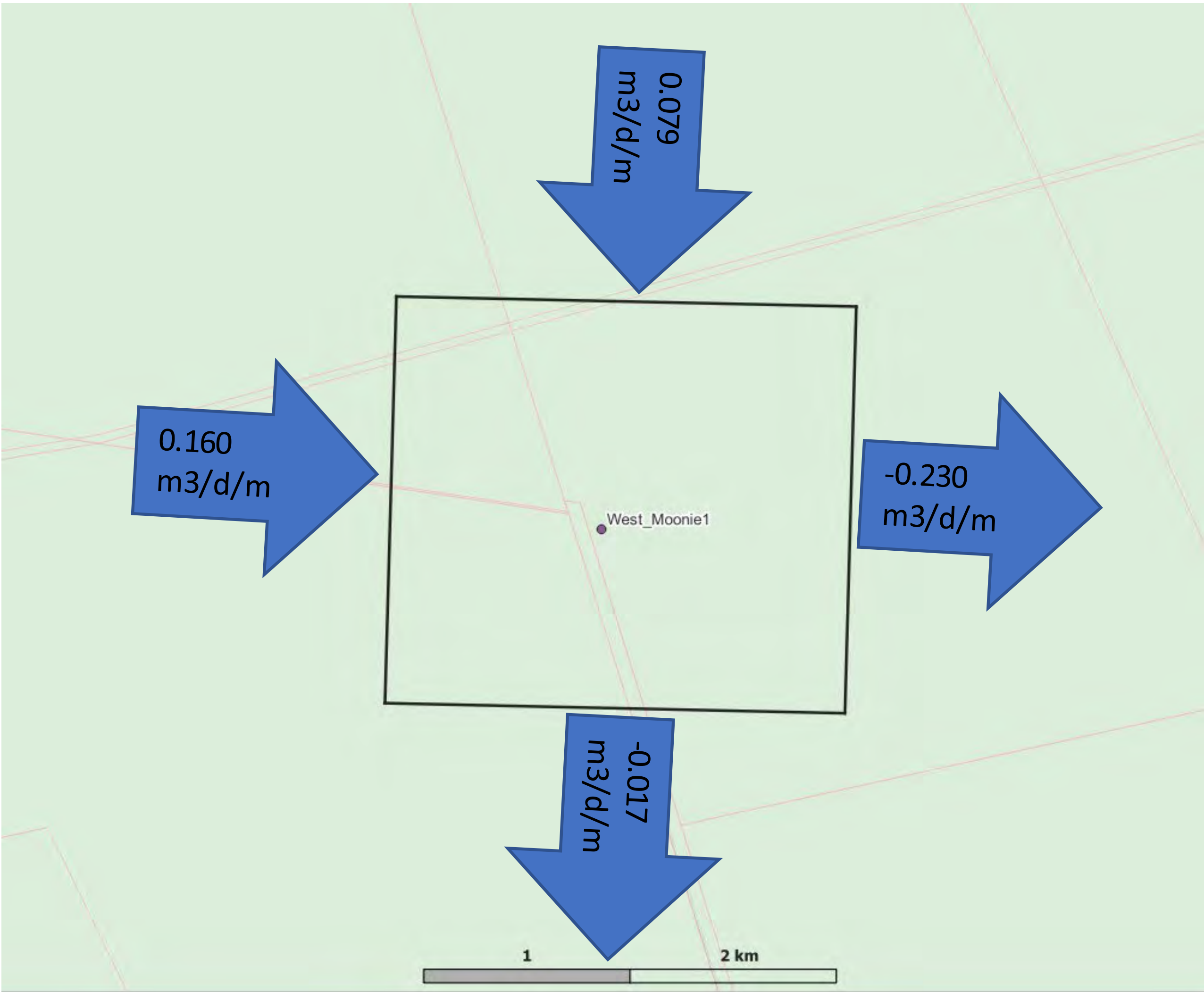

Figure 9-9 Scenario 3 Hypothetical future entitlement from unallocated water – Diagrammatic representation of the cumulative fluxes at the boundary of the hydrogeological model and the dynamic (plume) model

9.6.2.2 DYNAMIC (PLUME) MODEL

A detailed dynamic (plume) model was used to estimate near-field GHG stream plume migration and potential impacts on groundwater pressure/head in the Precipice Sandstone during the injection testing phase (operation phase). CTSCo developed a static geological model for EPQ10 taking into account data from 193 wells, and available seismic data within an area of 25,066 km^2 as described in Chapter 8 Geology, section 8.6.2.3. This static geological model was developed in Petrel™ software and formed the physical basis for the development of a 3D dynamic (plume) model using tNavigator™ software. Results from the EPQ7 Glenhaven plume modelling studies conducted between 2010 and 2020 showed that vertical GHG plume movement was effectively confined to the lower Precipice Sandstone due to the very low permeability within the upper Precipice Sandstone, before reaching the sealing Evergreen Formation and Moolayember Formation. The permeability data acquired in West Moonie-1 Injection Well and West Moonie-2 Monitoring Well confirmed this trend. Therefore, the West Moonie dynamic (plume) model focussed on the lower Precipice Sandstone.

The objective of the dynamic (plume) model is to predict the GHG plume behaviour (migration pathway/shape/size) and CO_2 saturation in the aquifer. During the early parts of the Project's exploration and appraisal program, the dynamic (plume) model was initially used to:

- predict the Precipice Sandstone Formation pressure changes and spatial movement of the GHG plume during the injection testing phase (operation phase), and to predict the maximum extent of the stablised GHG plume once injection has ceased. This information is used to assess the optimum placement of the conformance and containment monitoring network (monitoring wells and bores, and seismic infrastructure) to the assess the length of time that monitoring will be required to ensure that the GHG plume has ceased to expand;
- determine the optimum location for the West Moonie-2 Monitoring Well. The objective was to determine a well location along the path of the predicted GHG plume so that a well drilled at that location can be used to observe the GHG plume after the first year of injection. This is important for plume conformance monitoring purposes as it will allow sampling and analysis of Precipice Sandstone groundwater within the GHG plume and measurement of pressure, temperature and CO_2 saturation of the groundwater for comparison with values predicted from the models. Potential locations were modelled at 100 m, 200 m, and 300 m from the West Moonie-1 Injection Well location.

Adjustment of the rock property parameters within the dynamic (plume) model creates alternative scenarios that can result in differences in GHG plume migration pathways. Alternative geological models are imported into the dynamic simulator to investigate the parameters that will have the most significant effect on the dynamic movement of injected GHG stream. The likelihood of each alternative can then be assessed with geological and engineering experience. The utilisation of a static model acts as a validation mechanism to estimate the lateral extent and impact of GHG plume migration.

The dynamic (plume) modelling was conducted using Rock Flow Dynamic's (RFD) tNavigator® software, a finite element multi-phase simulator commonly used in the petroleum industry. The modelling workflow incorporated the following steps:

1) Import the relevant geological model 3D grid and properties;
2) Model CO_2 properties (density, viscosity and solubility using a dedicated CO_2 – brine Equation of State (EOS) model, and regional temperature and pressure gradient profile);
3) Create a permeability property using the hydraulic flow unit methodology;
4) Create saturation functions using data from regional digital core analysis (Lithicon, 2015);
5) Conduct simulations to include various time periods, being:
    - at the end of the three-year injection period when injection has ceased;
    - 2 years after GHG stream injection ceases;
    - 5 years after GHG stream injection ceases; and
    - 100 years after GHG stream injection ceases;
6) Plot changes in water CO_2 saturation and pressure versus time to illustrate the GHG plume movement, CO_2 saturation, and pressure changes as a result of the injection testing.

The dynamic (plume) modelling used the three static grid models to investigate model vertical grid cell size and rock quality (porosity, permeability) continuity on plume movement:

1) Grid Model 'A': 1 m layer thickness and 200 m horizontal continuity variogram (coarse model);
2) Grid Model 'B': 0.1524 m layer thickness and 200 m horizontal continuity variogram (mixed model); and
3) Grid Model 'C': 0.1524 m layer thickness and 50 m horizontal continuity variogram (fine model).

Permeability in the Grid Models was calibrated to West Moonie-1 Injection Well core data and is based on the hydraulic flow unit concept (Amaefule, M. A., 1993). The permeability of the rock is important as it controls the efficiency of injection into the formation and fluid movement within the formation. The higher the permeability of the rock, the easier it is for the injected fluid to move within that rock.

The vertical cell size (with the fine model having wireline log scale vertical resolution) impacts the level of detail that can be captured. The finer the scale of the grid, the more permeability contrast. In the coarse scale grid of Grid Model 'A', there is more averaging of permeability contrast. However, calculating the heterogeneity at the observation wells, for fine and coarse models, shows similar heterogeneity (Lorenz Coefficient – Lc) for each model. The 50 m variogram range model of Grid Model ‘C’ reduces lateral extent of features and visually looks more heterogeneous, but Lc shows this is not the case.

Competing viscosity (near injection points) and buoyancy (distant from injection points) forces control vertical and lateral movement of the injected GHG stream within the Precipice Sandstone. Buoyancy of the injected GHG stream is determined by the density ratio between CO_2 and water at reservoir conditions, and mobility of the GHG plume (CO_2) through the Precipice Sandstone aquifer is determined primarily from the viscosity ratio at reservoir conditions.

The GHG plume (CO_2) properties in the dynamic (plume) model were calculated using the Span Wagner Equation of State and is now considered as the most accurate reference equation for CO_2 (Giljarhus *et al*, 2011), and sensitivities were tested with temperature ranges from 80°C to 100°C as temperature affects the modelled CO_2 density and to a lesser extent viscosity in the dynamic (plume) model. The temperature of the Precipice Sandstone measured in West Moonie-2 Monitoring Well was 75°C.

Modelling sensitivity studies at the Glenhaven site in EPQ7, which also included the upper Precipice Sandstone and Evergreen Formation, showed that the ratio of vertical permeability (kv) to horizontal permeability (kh), that is kv/kh, has a significant effect on GHG plume behaviour and storage efficiencies. Therefore, three kv/kh sensitivities 0.001, 0.01 and 0.1 were investigated in the West Moonie dynamic (plume) modelling sensitivity study. The results are illustrated in Figure 9-10 which show that the smallest modelled kv/kh ratio (0.001) results in a GHG plume with the smallest height and largest lateral extent.

The Modular Dynamic Tester (MDT) dual packer test conducted in the Precipice Sandstone Formation in West Moonie-1 Injection Well provided a method for measuring *insitu* the kv/kh ratio, and analysis of this dataset indicated that the kv/kh ratio in the lower Precipice Sandstone is approximately 0.01.

The dynamic (plume) model for the Project also indicated that a monitoring well located 150 m from the West Moonie-1 Injection Well would encounter the GHG plume after 1 year of injection, and this result was used to plan the well design and trajectory of the West Moonie-2 Monitoring Well. The West Moonie-1 Monitoring Well has been located to optimise its use as a conformance monitoring location in a timeframe that was realistic for the purposes of the Project. The West Moonie-2 Monitoring Well was drilled in 2021, and the Precipice Sandstone Formation was intersected at a distance of 178 m from the West Moonie-1 Injection Well, shown in Chapter 8 Geology, Figure 8-1.

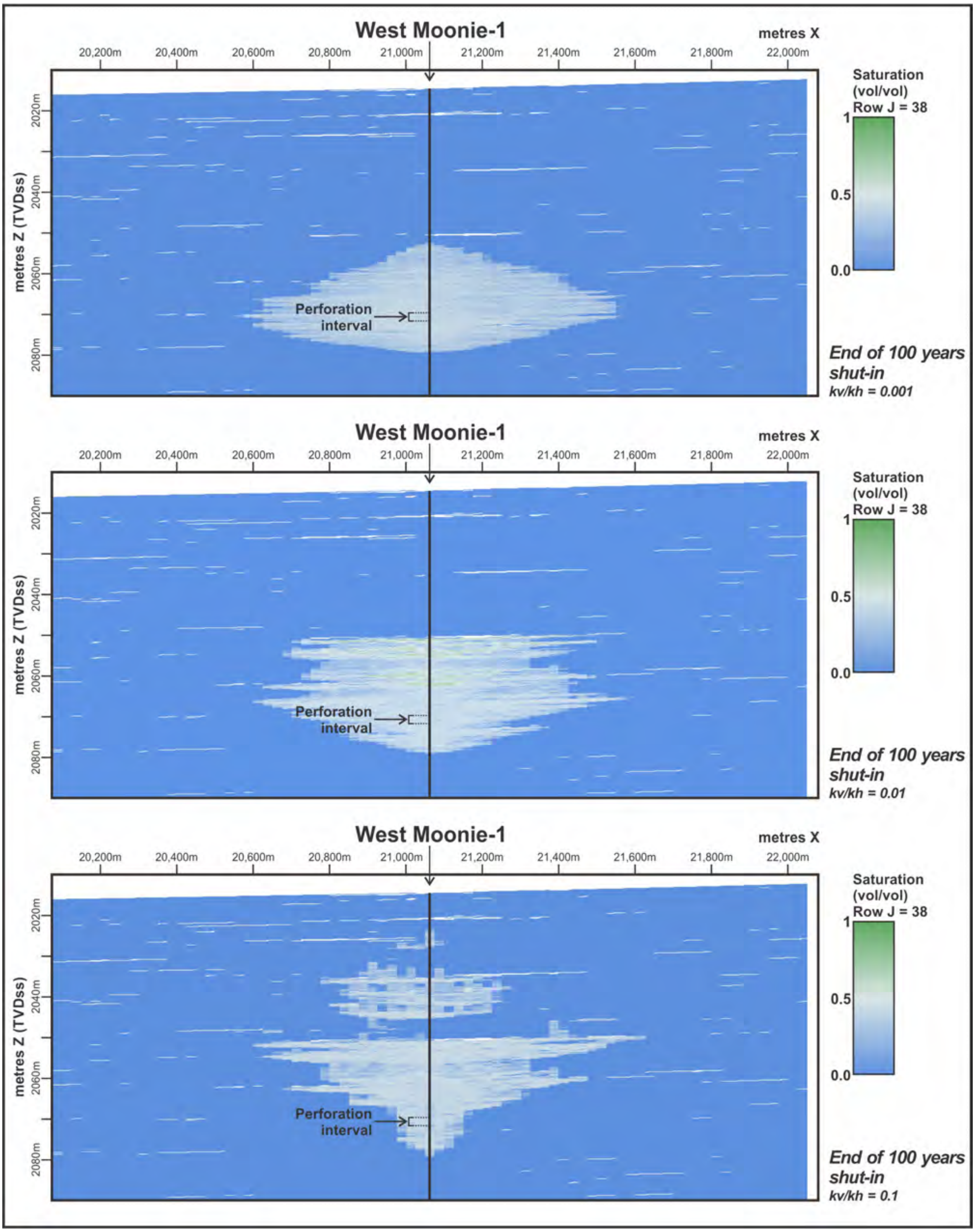

Figure 9-10 Influence of kv/kh ratio on GHG plume behaviour – West Moonie sensitivity study

For environmental impact assessment purposes, the outputs from the hydrogeological model for the three water extraction scenarios were then run through the dynamic (plume) model. Results from the dynamic (plume) are given sections 9.9.2.3 and 9.9.2.4 which provide the predicted shape and size of the GHG plume for the three scenarios, and aid in determining the potential impacts from the GHG plume on the existing environment, on groundwater uses and on groundwater users.

9.6.3 Groundwater Chemistry and Interconnectivity with Overlying Aquifers

For the Project to determine the existing environment and potential impacts on geochemistry and groundwater quality, sampling and testing of rock cores, rock chips, mud gas isotopes, and groundwater were undertaken, as described in Chapter 8 Geology, section 8.5.2 and this chapter, section 9.5.

As presented in section 9.4.2 various studies and publications discuss geochemistry and groundwater quality of overlying aquifers in the GAB and/or Surat CMA, particularly the work by Dawson *et al* (2022), Hofmann *et al* (2022), Mahlbacher (2013), and OGIA (2019a, 2021).

9.6.4 Groundwater Chemistry within the Storage Complex in the GHG Plume

The existing environmental conditions of geology, rock chemistry and water quality have been determined by sampling and testing of rock cores, rock chips, mud gas isotopes, and groundwater, as described in Chapter 8 Geology, section 8.5.2 and this chapter, section 9.5.

Geochemical modelling is used to predict changes to rock chemistry and water quality that result from the rock – water – GHG stream reactions within the GHG plume, and therefore the potential impacts of the Project on the existing geology and groundwater quality, and whether or not there is deterioration of environmental values (EVs) of the Precipice Sandstone aquifer, as the receiving groundwater. Changes in water quality within the GHG plume, particularly pH and various chemical parameters, and the dissolution and precipitation of minerals due to injection of the GHG stream, provide important insights in terms of geochemical processes within the predicted GHG plume extent.

To predict both temporal and spatial changes to rock chemistry and groundwater quality within the GHG plume, geochemical modelling has combined geochemical reaction path analysis and radial reaction transport modelling (RTM) with mineralogical, geochemical and petrophysical analysis and laboratory batch reactor experiments of selected core samples and rock typing chips from the West Moonie-1 Injection Well. The models were run under conditions that simulate actual pressure and temperature conditions using representative formation rock, groundwater and GHG stream compositions. The RTM modelling focuses on pH effects that have a major impact on groundwater chemistry.

Whole-rock digestion (ICP-OES and ICP-MS) was used to determine the total major, minor and trace element content (chemical parameters) of the Precipice Sandstone and Moolayember Formation samples from the West Moonie-1 Injection Well. The data provide a baseline for comparison with Precipice Sandstone and Moolayember Formation samples from the northern Surat Basin (EPQ7) and help to determine the relative significance of element mobilisation during leaching experiments.

A three-stage sequential extraction process was used to investigate mineral-element associations and likely elemental behaviour under GHG stream storage conditions. Step 1 (pure water) extracted salts and weakly adsorbed elements. Step 2 (dilute acetic acid buffered at pH 5) extracted mostly ferroan carbonates and strongly adsorbed elements. Step 3 (dilute acetic acid buffered at pH 3) extracted the remaining ferroan carbonates and acid-reactive silicates and sulphides. The intention of this procedure is to help isolate the mobility mechanisms and occurrences of elements in rocks, particularly elements extractable over a pH range of 3 to 7.

Batch reactions were completed on twelve West Moonie-1 Injection Well core samples from the lower Precipice Sandstone and Moolayember Formation with a mixed gas stream, and four core samples with pure carbon dioxide (CO_2). Experiments were run soaking West Moonie-1 Injection Well core samples with synthetic formation water and nitrogen (N_2) before adding CO_2 containing sulfur dioxide (SO_2), nitric oxide (NO) and oxygen (O_2) at concentrations reflecting the GHG stream composition for the Project. Experiments were run at West Moonie Precipice Sandstone Formation conditions, 20 Mpa (2,900 psi) and 80°C, and waters were sampled periodically with a range of elements measured.

In the last decade, Reactive Transport Modelling (RTM) has become part of the best practice approach when investigating the impact of injection or groundwater contamination. RTM refers to computer models that integrate geochemical reactions and fluid transport to predict the movements of groundwater plumes in geological sites. RTMs require input from many disciplines, the principal ones being fluid dynamics, chemistry (thermodynamics and kinetics) and geology. The West Moonie RTMs incorporate the current knowledge of the chemical processes from the batch reaction experiments, the complexity of mixtures as well as the heterogeneity and mineralogy of West Moonie rock types and mineralogy.

Refer to Dawson *et al* (2022), attached in Appendix 9C, for a full description of the sampling and analytical methods used in the West Moonie geochemical modelling experiments. Note that the draft EIS presented geochemistry modelling undertaken by WSP Golder (2022) and presented in the draft EIS in Appendix 9A, section 5.3 as the reporting by Dawson *et al* (2022) was in draft and awaiting completion at time of the draft EIS publication. The work by Dawson *et al* (2022) has since been finalised and published, and now wholly replaces the previous geochemical modelling work presented in the draft EIS, with discussion and comparison provided in Appendix 9D.

9.6.5 Groundwater Chemistry within the Storage Complex outside the GHG Plume

The existing geochemistry or groundwater quality outside of the predicted GHG plume will define the characteristics of the groundwater. The extent of the GHG plume is provided in sections 9.9.2.3 and 9.9.2.4. This will be confirmed by groundwater quality sampling as part of the monitoring phase of the Project as further described in section 9.10.

9.7 Existing Environment

A description of the existing geology environment is given in Chapter 8 Geology, section 8.3. The following section provides details on the existing hydrogeological environment of the operational lands, within a 50 km radius of the West Moonie-1 Injection Well, and the southern Surat Basin.

Geological formations can be classified into aquifers and aquitards as shown in Figure 9-11 (from OGIA (2019)). In summary, aquifers present within the operational lands are the Precipice Sandstone, the Hutton Sandstone, Gubbermunda Sandstone, Mooga Sandstone and Griman Creek Formation. They are separated and confined by regionally recognised aquitards that inhibit the flow of groundwater vertically.

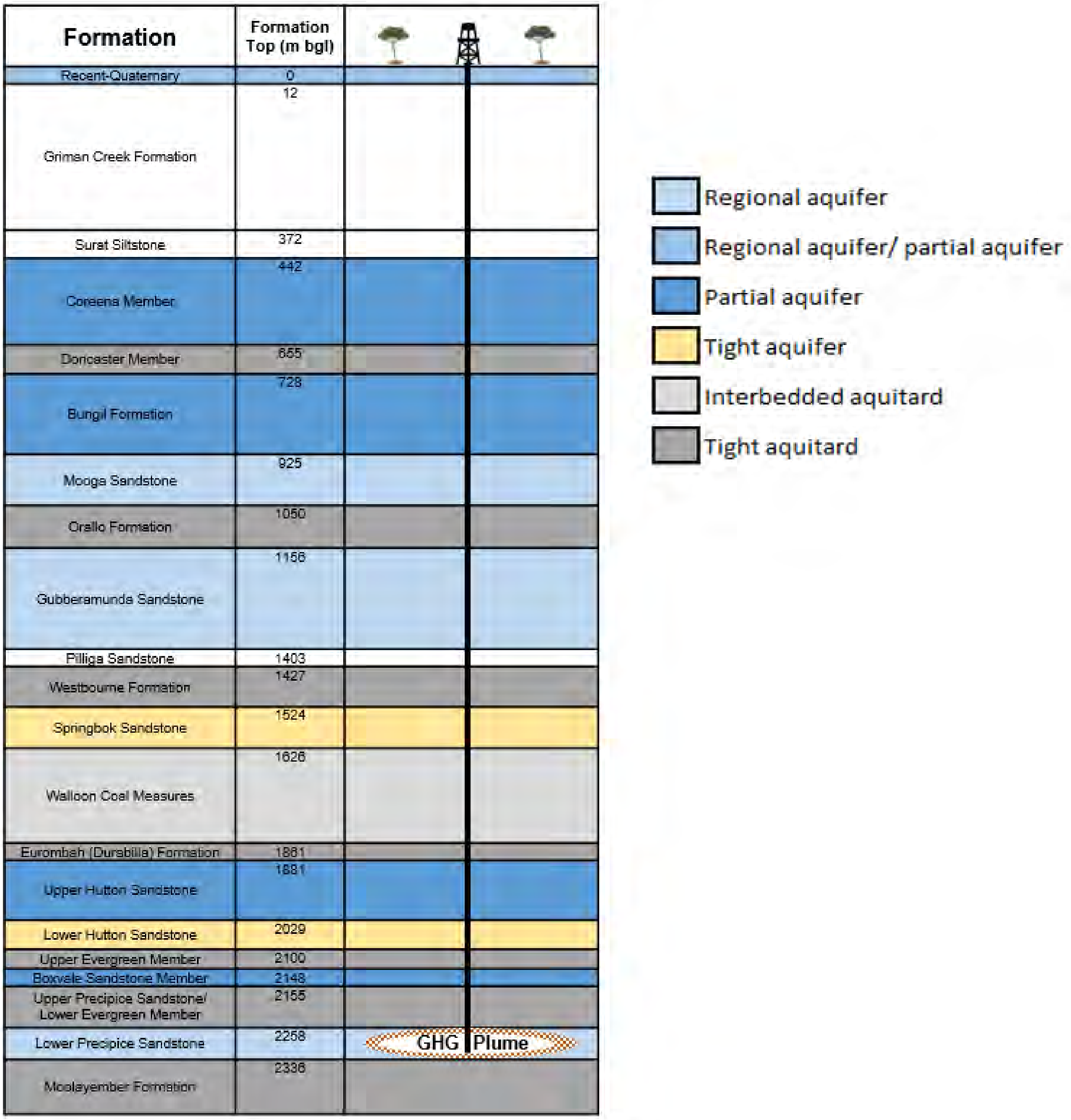

Figure 9-11 Simplified hydrostratigraphic classification of aquifers and aquitards showing overburden depths intersected at West Moonie-1 Injection Well, modified from OGIA (2019)

OGIA (2021a) uses the following generalised characterisations for aquifers and aquitards:

- regional aquifer: high transmissivity (where transmissivity is defined as the product of formation permeability and formation thickness and is used in representing an aquifer's capacity to yield water), high bore yields that are vertically and laterally consistent at a regional scale, e.g. Precipice Sandstone, and Gubberamunda Sandstone;
- partial aquifer: medium transmissivity, high to medium bore yields that are vertically and laterally inconsistent at a regional scale and exhibit a high degree of heterogeneity, e.g. Hutton Sandstone, and Mooga Sandstone;
- tight aquifer: medium to low transmissivity, low bore yields that are regionally inconsistent and exhibit a high degree of heterogeneity, e.g. Springbok Sandstone, and Griman Creek Formation;
- interbedded aquitard: similar to a tight aquifer but with thin, spatially limited but transmissive water-yielding zones interbedded in an otherwise tight aquitard, e.g. Walloon Coal Measures; and
- tight aquitard: predominantly low permeability, regionally extensive and thick formations.

Aquifers can be further classified as confined or unconfined. Under the Environmental Protection Regulation 2019, s.41(3), a ***confined aquifer*** *means an aquifer that is contained entirely within impermeable strata*.

The Precipice Sandstone is a confined aquifer at the West Moonie Project location, as shown in Figure 9-11 and schematically in Figure 9-12, owing to:

- it is underlain by an impermeable Moolayember Formation;
- it is overlain by an impermeable Evergreen Formation seal and is not in pressure communication with overlying aquifers in the Hutton Sandstone and Gubberamunda Sandstone, the evidence for this is provided in section 8.7.6.3; and
- the hydrogeological definition of a confined aquifer is where the formation is fully saturated with the piezometric head (i.e. pressure head + elevation head) is at an elevation higher than the top of the geological formation. At the West Moonie-1 Injection Well site, the Precipice Sandstone is deeply confined at an overburden depth of over 2 km and remains a confined aquifer for hundreds of kilometres from the operational lands.

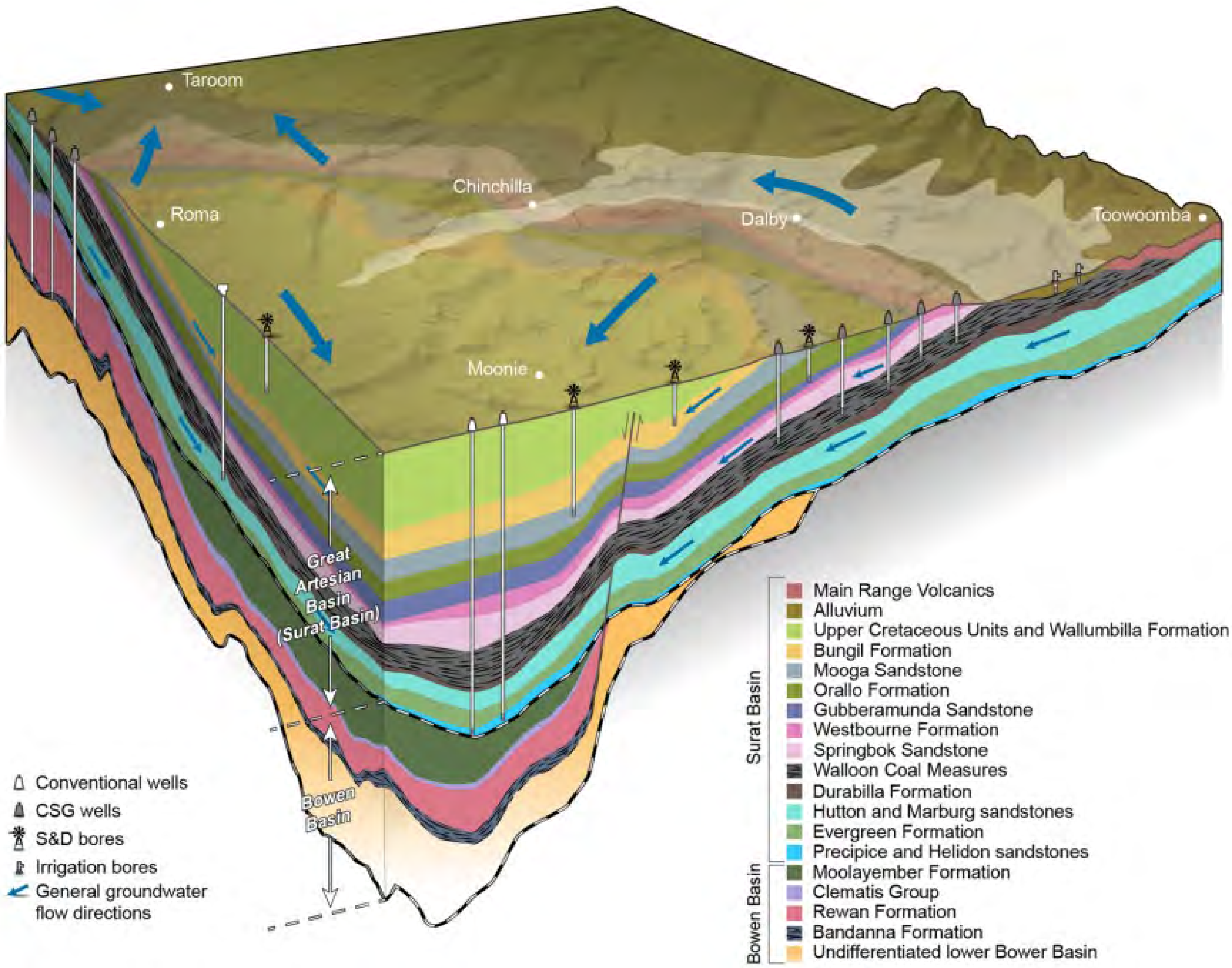

Figure 9-12 Schematic block diagram of the Surat Basin groundwater systems (from OGIA, 2019)

The only area where the Precipice Sandstone is known to become an unconfined aquifer is where it outcrops on the surface approximately 235 km north of the West Moonie-1 Injection Well, as shown in Figure 9-13. The Precipice Sandstone water table is located close to, or at surface in these areas, supporting natural springs.

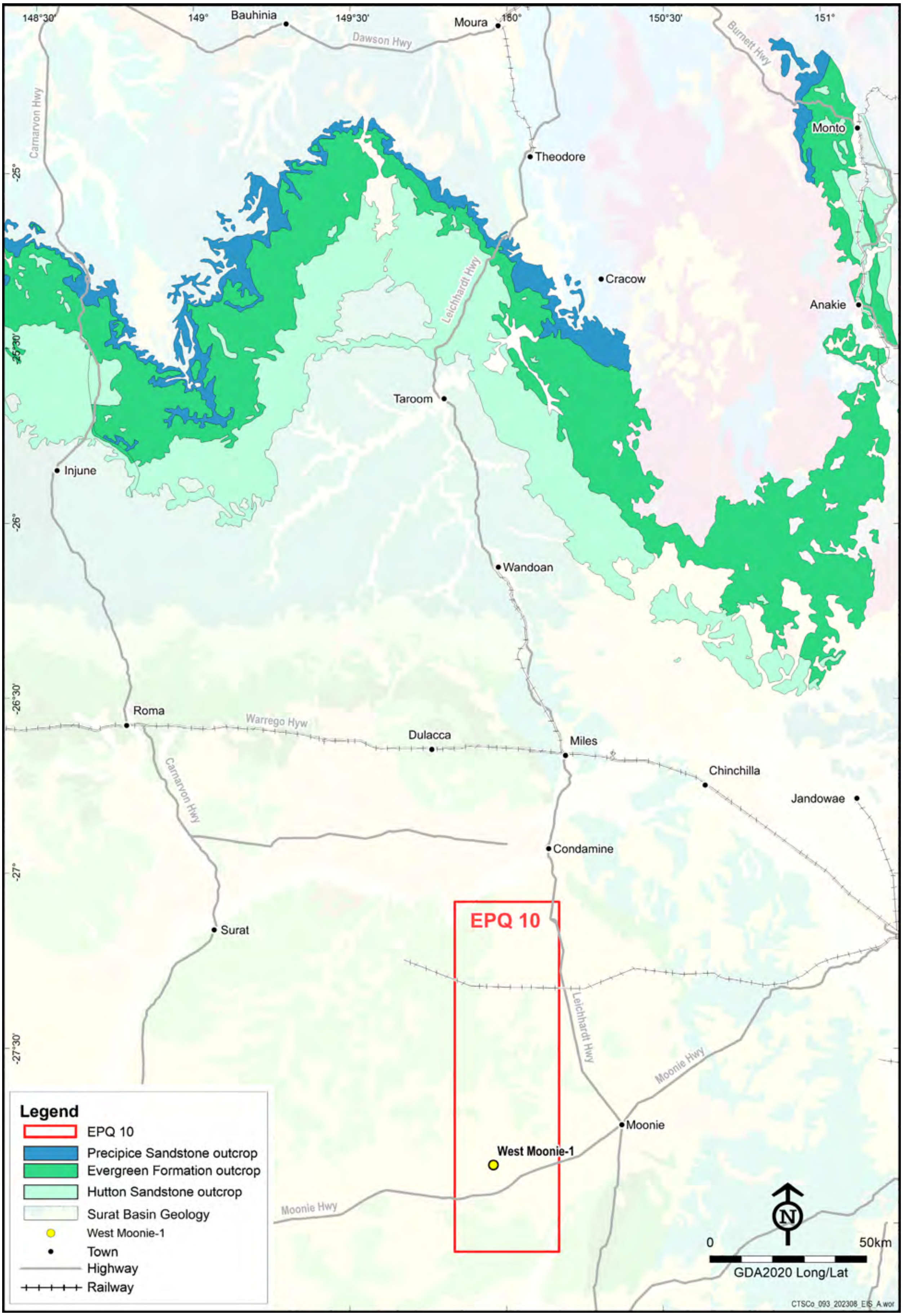

Figure 9-13 Outcrop edges of Hutton Sandstone, Evergreen Formation and Precipice Sandstone in the Surat Basin

9.7.1 Aquifers overlying the Storage Complex

9.7.1.1 GRIMAN CREEK FORMATION

The Griman Creek Formation is almost 300 m thick at the West Moonie site, and groundwater was initially intersected at 39 mbgl.

In July 2021, water from the West Moonie Shallow Monitoring Bore was sampled and field analysis recorded:

- standing water level in the bore = 10 m;
- temperature = 22.2°C;
- electrical conductivity (EC) = 48,316 µS/cm; and
- pH = 7.75.

The water sample was analysed by ALS laboratory in Brisbane (reports EB2120349-002 and EB2123041-001). The total chlorides content of the sample is 17,700 mg/L making the water unsuitable for stock use, with further details on water quality provided in section 9.7.5 below.

9.7.1.2 MOOGA SANDSTONE

The Mooga Sandstone is primarily sandstone with thin interbeds of siltstone and thin stringers of mudstone, and approximately 125 m thick at West Moonie site. The Mooga Sandstone is a regional aquifer, with the nearest Mooga groundwater bore to the West Moonie-1 Injection Well being RN86855 at 14 km to the north-east as shown in Figure 9-14.

9.7.1.3 GUBBERAMUNDA SANDSTONE

The Gubberamunda Sandstone is a regional aquifer and supplies the largest volume of groundwater to water entitlements holders within a 50 km radius of West Moonie-1 Injection Well. At the West Moonie-1 Injection Well, the Gubberamunda Sandstone aquifer is intersected at 1,160 m below ground level and is approximately 275 m thick.

Figure 9-14 shows the various water supply bores sourced from the Gubberamunda Sandstone aquifer surrounding the West Moonie-1 Injection Well. Water samples were collected from the Milgarra Bore in 2021, as discussed in section 9.7.5.2 below.

9.7.1.4 HUTTON SANDSTONE

The Hutton Sandstone is the most extensive aquifer in the Great Artesian Basin, and is generally 150 m to 200 m thick, although in the vicinity of the Mimosa Syncline, it can be up to 400 m thick (OGIA, 2016a). OGIA (2021) subdivides the Hutton Sandstone into an upper Hutton Sandstone and a lower Hutton Sandstone, and classifies the upper zone as a partial aquifer and the lower zone as a tight aquifer, as shown in Figure 9-11. At the West Moonie-1 Injection Well the Hutton Sandstone is 219 m thick, and its top was intersected at approximately 1,900m below ground level. It consists of interbedded sandstone and siltstone beds with minor coal, with the individual sandstone beds up to 10 m thick and separated by up to 35 m of fine-grained material that would limit fluid migration or pressure propagation. The closest registered water bore to access the Hutton Sandstone is RN87635, located approximately 23 km to the north-east of West Moonie-1 Injection Well as shown in Figure 9-14.

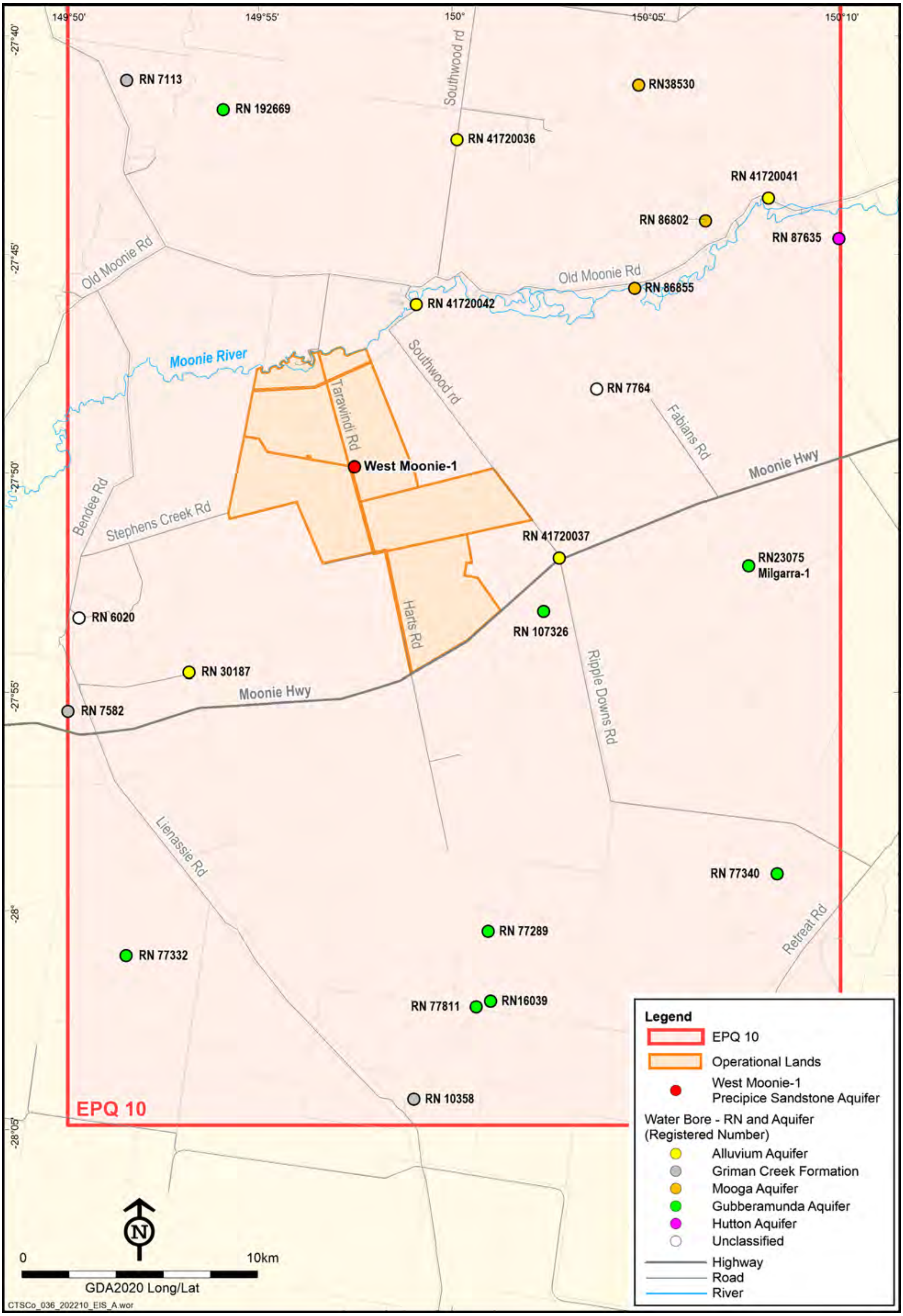

Figure 9-14 Nearest existing water bores to West Moonie-1 and the operational lands coloured by aquifer

9.7.2 Storage Complex

The storage complex is made up of the:

- Evergreen Formation, as the top geological seal or cap rock;
- Precipice Sandstone aquifer, as the GHG storage reservoir for the GHG plume; and
- Moolayember Formation, as the base geological seal.

9.7.2.1 EVERGREEN FORMATION

The Evergreen Formation is classified as a regional tight aquitard (OGIA, 2021), meaning it will act as a hydraulic seal to contain fluid and pressure within the underlying Precipice Sandstone aquifer.

At the West Moonie-1 Injection Well the Evergreen Formation occurs at approximately 2,100 m below ground level and is 158 m thick, with 142 m of that associated with fine-grained sediments with a high clay content, confirming the regional characterisation as a tight aquitard.

9.7.2.2 PRECIPICE SANDSTONE AQUIFER

The Precipice Sandstone aquifer is the deepest and oldest geological strata of the Surat Basin, extending from the north of the Surat Basin, where it outcrops 235 km to the north of the West Moonie-1 Injection Well, through the central and eastern portions of the Surat Basin to the south, where it is present at a depth of over 2 km below ground level in the vicinity of the West Moonie-1 Injection Well. Regionally, the lower Precipice Sandstone is dominated by braided river deposits that provide the high-quality formation characteristics suitable for GHG stream injection. The Precipice Sandstone hosts a regional confined aquifer, situated between the confining aquitards of the overlying Evergreen Formation and the underlying Moolayember Formation.

The Precipice Sandstone is up to 100 m thick within EPQ10 (Hall, 2020a). On a local scale, core recovered from West Moonie-1 Injection Well identified 78 m of high-quality Precipice Sandstone formation.

9.7.2.3 MOOLAYEMBER FORMATION

The Triassic-aged Moolayember Formation is the youngest Bowen Basin deposit, underlying the Jurassic-aged Precipice Sandstone of the Surat Basin. The Moolayember Formation is comprised primarily of fine-grained siltstone and mudstone, and is classified as a tight aquitard, separating the Precipice Sandstone from the underlying Bowen Basin aquifers such as the Clematis Group.

The West Moonie-1 Injection Well drilled into 375 m of the Moolayember Formation, with core recovered from the upper 202.5 m. Core analysis and geophysical logs completed in the West Moonie-1 Injection Well confirm the Moolayember Formation’s regional characterisation as a tight aquitard.

9.7.3 Groundwater Pressure and Flow

9.7.3.1 INTERCONNECTIVITY BETWEEN OVERLYING AQUIFERS AND THE STORAGE COMPLEX

9.7.3.1.1 Faults

Faults are present within the Surat and Bowen Basins due the tectonic movement of the Earth’s crust, and are evident by the relative displacement of geological strata on opposite sides of a fracture. The impacts of faults on groundwater systems are varied. Vertical displacement from a fault may result in aquifer discontinuity, and fracturing may result in enhanced conductivity around the fault plane, which can be particularly significant at increasing vertical connectivity.

No faults were identified from regional structural mapping within EPQ10 (Djamaludin, I., (2020)), and no faults are present in the West Moonie-1 Injection Well or West Moonie-2 Monitoring Well. The closest faults of any significant size are associated with the north-south trending Goondiwindi Moonie Fault Zone located approximately 23 km east of the West Moonie-1 Injection Well.

Understanding the impacts of the local faulting on the groundwater system represents one of the key uncertainties for future carbon storage at a basin scale (Mahlbacher, 2019). CTSCo proposes to complete a detailed 3D seismic survey around West Moonie-1 Injection Well, as described in Chapter 2 Proposed Project Description, section 2.8.1.3.2 to enhance the current structural interpretation of the injection site.

Based upon groundwater levels within the Precipice Sandstone and the Hutton Sandstone, the two units are hydraulically isolated by the Evergreen Formation, indicating that local faulting has not provided interconnections between the Precipice Sandstone and the overlying aquifers on either a local or regional scale.

9.7.3.1.2 Hydraulic Properties

Hydraulic conductivity is a measure of the capacity of soil or rock to transmit water and is related to the permeability of the rock, as discussed in section 9.6.2. The higher the value, the less resistance to groundwater flow and the greater the flow of groundwater.

Hydraulic conductivity is directionally dependent, and the vertical hydraulic conductivity of sedimentary rock is typically significantly less (orders of magnitude less) than the horizontal hydraulic conductivity due to the interbedded nature of the rock caused by variable deposition of sediment.

OGIA has compiled extensive datasets to assess the hydraulic conductivity of the Surat Basin, with this information used to inform their regional groundwater model. A summary of these data is presented in Figure 9-15 (with the data from the aquitard of the Evergreen Formation and the Precipice Sandstone aquifer highlighted) which illustrates there is approximately three to five orders of magnitude difference between the post-calibrated range of horizontal hydraulic conductivity between the transmissive aquifer of the Precipice Sandstone and the tight aquitard of the Evergreen Formation. Groundwater flow in aquifers is dominated by horizontal flow, which contrasts with aquitards where the dominant flow is typically vertical. As vertical hydraulic conductivity is typically significantly less than horizontal hydraulic conductivity, this adds further contrast to the hydraulic conductivities of the two formations and provides additional evidence of the protection that the Evergreen Formation will provide to overlying aquifers following injection of the GHG stream via the West Moonie-1 Injection Well into the Precipice Sandstone.

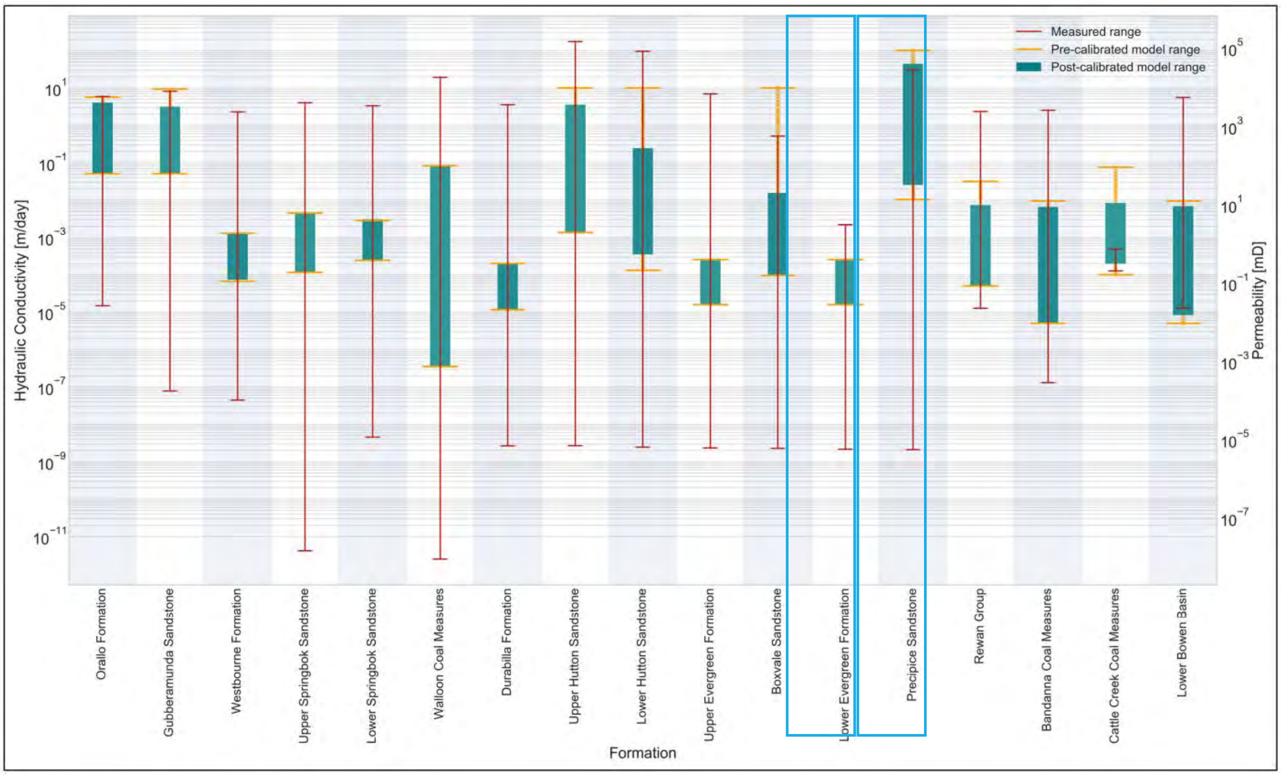

Figure 9-15 Horizontal hydraulic conductivity ranges in the Surat CMA (from OGIA, 2019)

CTSCo has completed porosity and permeability testing on core samples recovered from the West Moonie-1 Injection Well, and regional porosity and permeability data has been examined. Further details are presented in Appendix 9A, section 4.6.5.5, and summarised in Table 9-21 and Table 9-22. The data presented in Table 9-21 confirms the interpretation from UQ-SDAAP regional studies, demonstrating orders of magnitude difference in the permeability of the lower Precipice Sandstone aquifer compared to the overlying aquitard of the Evergreen Formation.

Table 9-21 Range of average porosity data per well from UQ-SDAAP regional studies and West Moonie-1 Injection Well data

Porosity	Lower Precipice Sandstone aquifer	Upper Precipice Sandstone and Lower Evergreen Formation (aquitard)	Upper Evergreen Formation (aquitard)
Regional core data analysis (Harfoush *et al.*, 2019b)	13 – 25 %	7 – 21 %	9 – 10 %
Regional wireline log analysis[(a)] (Harfoush *et al.*, 2019a)	9 – 23 %	0.1 – 15 %	<1 – 20 %
West Moonie-1 Injection Well core data analysis[(b)]	16 %	13 %	No data
West Moonie-1 Injection Well wireline log analysis[(c)]	14 % (net/gross 84%)	14 % (net/gross 10%)	12 % (net/gross 9%)

Notes: Table adapted from Appendix 9A, section 4.6.5.5, Table 4.18

(a) Effective porosity
(b) Helium porosity
(c) Average net total porosity (cut off: phie>10% & Vcl<50%)

Table 9-22 Range of average permeability data per well from UQ-SDAAP regional studies and West Moonie-1 Injection Well data

Permeability[(a)]	Precipice Sandstone (BSR) (aquifer)	Lower Evergreen Formation (TZ) (aquitard)	Upper Evergreen Formation (US) (aquitard)
Regional Core data analysis[(b)] (Harfoush *et al.* 2019b)	14 – 2,545l[(c)] (K[(d)] of ~ 10^{-2} to 1	a.50 0.01 – 829 mD (K of ~ 10^{-5} to 10^{-1} m/d)	< 0.1 mD (K of < ~ 10^{-4} m/d)
Regional DST[(e)] analysis (Honari *et al.* 2019a)	20 – 1,400 mD (K of ~ 10^{-2} t/d)	a.50 0.01 – 270 mD (K of ~ 10^{-5} to 10^{-1} m/d)	No data
Regional Wireline log analysis (Harfoush *et al.* 2019a)	5 – 3,943 mD (K of ~ 10^{-3} to 1 m/d)	<0.01 – 1,060 mD (K of <~ 10^{-5} to 1 m/d)	< 0.01 – 1,391 mD (K of < ~ 10^{-5} to 1 m/d)
West Moonie-1 Injection Well core data analysis	984 mD (K of ~ 1 m/d)	13.3 mD (K of ~ 10^{-2} m/d)	No data

Notes: Table adapted from Appendix 9A, section 4.6.5.5, Table 4.19

(a) Permeability to air
(b) Core water in-situ reservoir permeability
(c) mD = milli-Darcys
(d) K = hydraulic conductivity
(e) Drill stem test

At West Moonie-1 Injection Well the high permeability of the Precipice Sandstone characterises the potential for the formation to support injection of GHG stream. The overlying Evergreen Formation is an important formation to contain injected GHG stream within the Precipice Sandstone as the GHG storage reservoir of the overall storage complex.

9.7.3.1.3 Pressure Gradients

Regional pressure gradient data including pressure gradient trends acquired in West Moonie-2 Monitoring Well provide convincing evidence that the Precipice Sandstone is not in hydraulic communication with overlying aquifers.

There is a distinct pressure gradient offset between the Precipice Sandstone and the Hutton Sandstone measured from MDT data acquired in both West Moonie-2 Monitoring Well and West Wandoan-1 (drilled in EPQ7), as further described in Chapter 8 Geology, section 8.7.6.3. This observation shows that the two aquifers cannot be in hydraulic pressure communication at either location demonstrating that the intervening Evergreen Formation is an effective regional pressure seal.

Figure 9-16 (from OGIA (2021)) and Hofmann *et al* (2022) provide interpretations for groundwater levels, flow and pressure in the Hutton Sandstone and Precipice Sandstone. It is acknowledged that there is uncertainty in groundwater level, flow and pressure data in the southern Precipice Sandstone due to limited data, however the following conclusions can be drawn in relation the Project:

- a groundwater divide is evident in the Precipice Sandstone, separating flow in the northern part of the Surat Basin and associated outcrop areas, from the southern portion of the Surat Basin.
- groundwater flow is interpreted by OGIA in the southern portion of the Surat Basin to be in a southerly to easterly direction. Hofmann *et al* (2022) does not reject the hypothesis of outflow from the Precipice Sandstone to the south, however for this to occur hydraulic conductivities (vertical and horizontal) in the Hutton Sandstone, Evergreen Formation and Precipice Sandstone must increase by one or two orders of magnitude in order for approximately 25% of the Precipice Sandstone throughflow to discharge to the south and therefore Hofmann *et al* (2022) considers this scenario unlikely.
- historical and ongoing oil and water extraction from the Precipice Sandstone by the Moonie Oil Field has resulted in a lowering of groundwater levels in the Moonie area.
- pressure differentials measured in the West Moonie-2 Monitoring Well identified a pressure differential of approximately 70 m of water head between the Precipice Sandstone and the Hutton Sandstone. This pressure differential between these two aquifers indicates that the aquitard of the Evergreen Formation provides effective hydraulic isolation to the underlying Precipice Sandstone to any overlying aquifers.

The Moonie Oil Field has been in production since the early 1960s and is currently extracting approximately 1,000 ML per year of 'associated water', which is defined as water take associated with the exercise of oil and gas rights. The oil field is located 30 km east of the West Moonie-1 Injection Well, and reduced groundwater levels within the Precipice Sandstone are evident in the vicinity of the Moonie Oil Field, as shown on Figure 9-17. The Hutton Sandstone in comparison does not exhibit similar evidence of drawdown from the Moonie Oil Field, demonstrating evidence of the effectiveness of the hydraulic separation provided by the Evergreen Formation.

Hofmann *et al* (2022) demonstrated from detailed analysis of regional historic drill stem tests, and modelling the hydraulic heads that existed prior to oil and gas production, that up to 75 m to 100 m downward head difference between the Hutton Sandstone and Precipice Sandstone exists in the central southern Surat Basin. Groundwater modelling shows this can only be explained by the bulk vertical hydraulic conductivity in the Evergreen Formation being lower than previously thought, and probably less than $5x10^{-8}$ m/day. Only with such low Evergreen Formation permeability can the separation between Precipice Sandstone groundwater and Hutton Sandstone groundwater be sustained.

Downward flow from the Precipice Sandstone is not expected due to the sealing nature of the underlying Moolayember Formation.

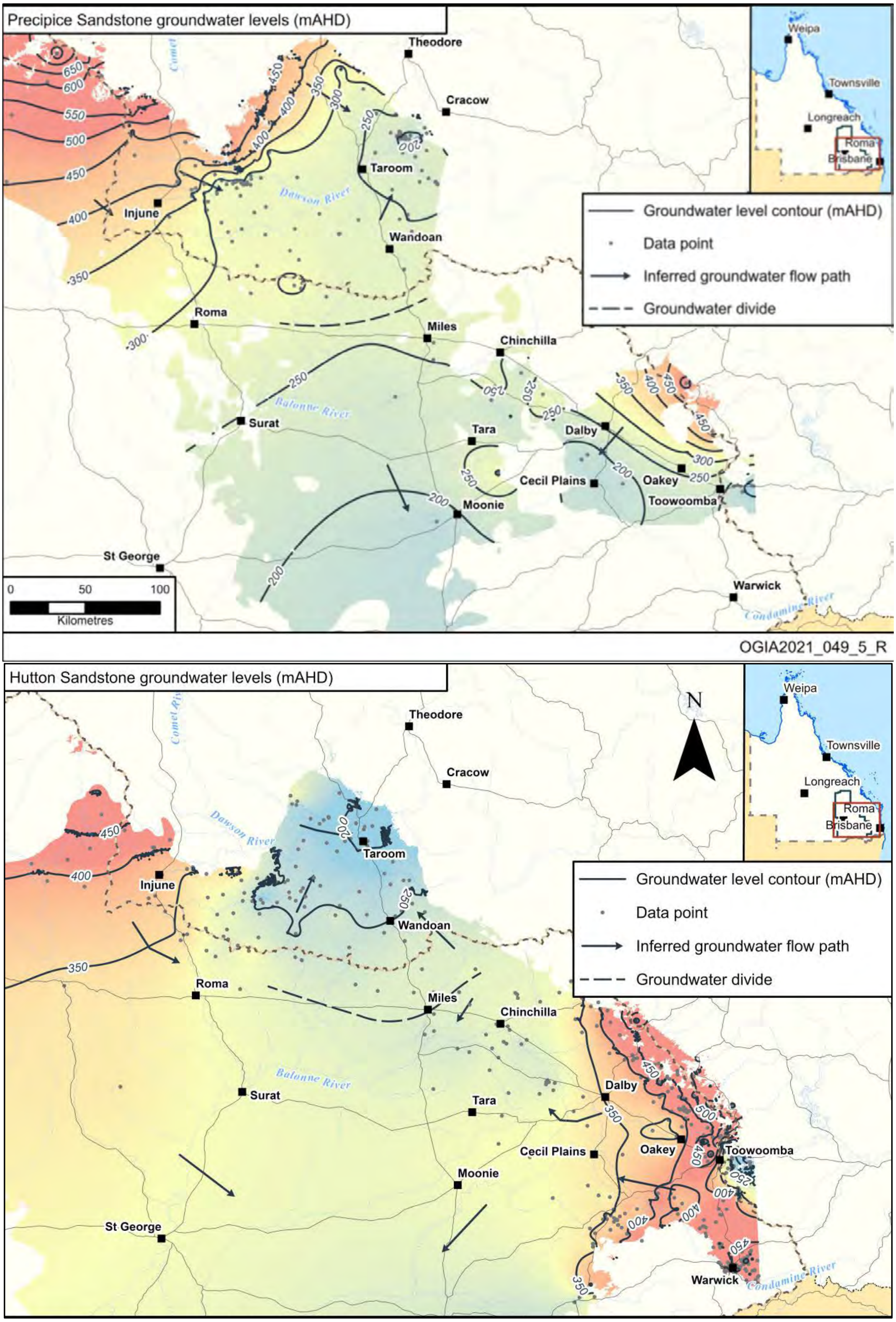

Figure 9-16 Interpreted groundwater levels and flow directions in the Precipice Sandstone and Hutton Sandstone (OGIA, 2021a)

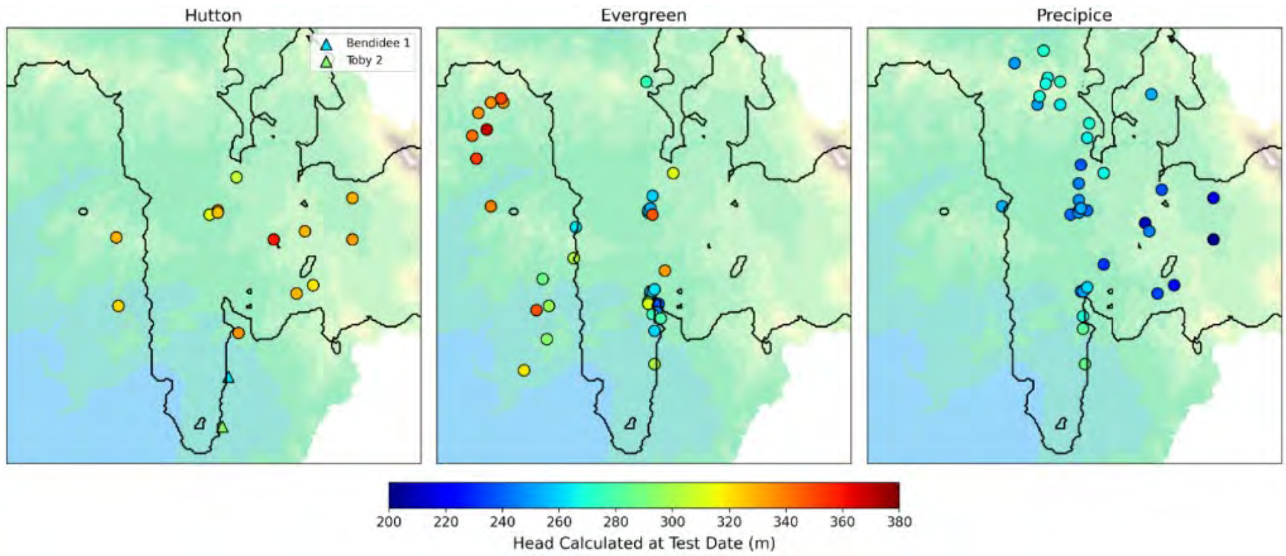

Figure 9-17 Calculated hydraulic heads in the Hutton Sandstone, Evergreen Formation and Precipice Sandstone. Coloured background shows surface elevation, black outline shows Precipice extent. The two triangles on the Hutton Sandstone show wells that flowed while drilling (from Rodger et al., 2020)

9.7.3.2 GROUNDWATER PRESSURE AND FLOW WITHIN THE STORAGE COMPLEX

9.7.3.2.1 Regional Context

Hofmann et al (2022) show that Precipice Sandstone groundwater flow from the north of the Surat Basin is predominately toward the south and the east towards the Clarence- Moreton Basin. Outflow may be to springs and GDEs around Helidon, east of the Great Dividing Range. Estimated throughflow is approximately 1,500 m^3/d within the Precipice Sandstone (Hoffman *et al*, 2022), a value that is both lower and consistent with the work of Suckow *et al* (2018) who calculated "*total recharge for the Precipice Sandstone of 1.1GL/y to 6.6GL/y in the Mimosa Syncline area*".

Flow in the north of the Precipice Sandstone is better characterised, where the formation is shallower and there is a greater density of data, as further discussed in Appendix 9A, section 4.6.7.

Southward flow to/from northern New South Wales as presented in Figure 9-16 shows that groundwater contours support a southerly flow in the region of EPQ10, although the hydraulic gradient is relatively flat, and there are few supporting data points. Further south, as shown on Figure 9-17, heads in the Precipice Sandstone increase, indicating that southerly outflow is not significant, although data density in the southern Precipice Sandstone is low, and there is associated uncertainty in the characterisation of flow conditions in the Precipice Sandstone southern extent of the Surat Basin.

In summary, there is uncertainty regarding the groundwater flow conditions in the southern Precipice Sandstone, largely due to the low data density within this region. Refer to Hofmann et al (2022) for additional discussion on Precipice Sandstone flow direction uncertainty within the southern Surat Basin.

9.7.3.2.2 Groundwater Pressure and Flow within the Storage Complex surrounding West Moonie-1 Injection Well

Further to section 9.6.2.1, the hydrogeological model included a particle tracking model to predict movement of the GHG plume. The basis of the particle tracking model includes the existing groundwater flow conditions of the Precipice Sandstone aquifer surrounding the West Moonie-1 Injection Well. The natural groundwater flow of the Precipice Sandstone aquifer within the area of the West Moonie-1 Injection Well is largely stagnate, with the simulated steady state heads of the model matching the observed heads based on available well data. The existing environmental conditions for groundwater flow in the Precipice Sandstone aquifer in the southern Surat Basin include groundwater extraction from the Moonie Oil Field and Kogan Creek Power Station, with a combined total extraction rate of 5,000 m^3/day.

9.7.4 Groundwater Uses and Users

The main uses of groundwater within the Surat Basin are:

- groundwater extracted or recharged as part of resource production, such as coal mining, coal seam gas (CSG) production, managed aquifer recharge (MAR) by the CSG industry, and oil and natural gas production;
- water extraction under water entitlements for agriculture, drinking water, industrial use, and cultural and spiritual values;
- aquatic ecosystems including springs, natural recharge areas, groundwater dependent ecosystems (GDEs), and stygofauna.

Groundwater use at a regional scale within the Surat Basin has been characterised by the Office of Groundwater Impact Assessment (OGIA, 2019).

9.7.4.1 GROUNDWATER USE AND RESOURCE PRODUCTION

9.7.4.1.1 Overlying Aquifers

9.7.4.1.1.1 Coal Mining

Several coal mines operate in the Surat Basin, however they are concentrated on the edges of the basin where coal is shallower and more assessable. The closest coal mines to the Project are the Commodore mine located near Millmerran, approximately 120 km east of West Moonie-1 Injection Well, and Kogan Creek and Wilkie Creek mines located approximately 120 km north. Due to the distance and shallow profile of mining, overlapping impacts are not predicted.

9.7.4.1.1.2 Coal Seam Gas Production

Unlike conventional oil and gas production which targets gas trapped in geological structures, CSG production targets gas stored within coal seams which is released through depressurisation. Consequently, CSG activities target large areas and extract a significant volume of water. Current CSG production tenements (petroleum leases) are located well away from the Project, primarily to the north, north-east and north-west. The target coal seams within these petroleum leases are within the Jurassic Walloon Subgroup at depths that are over 1 km shallower than the Precipice Sandstone at the Project location and are stratigraphically separated from the Precipice Sandstone by two regional aquitards, being the Evergreen Formation and Eurombah Formation, as shown in Figure 9-11.

OGIA report in the 2019 Underground Water Impact Report that there are approximately 8,600 CSG wells over 26,000 km^2 of tenure footprint, responsible for the extraction of approximately 54,000 ML/y of groundwater (OGIA, 2021a).

9.7.4.1.2 Storage Complex – Precipice Sandstone aquifer

9.7.4.1.2.1 Conventional Oil Production

Conventional hydrocarbon production in the Surat Basin is dominated by the Moonie Oil Field. The term conventional oil and gas refers to the method of production, where wells target geological structural features, such as domes that act to trap oil and gas, which are lighter than water. In the case of the Moonie Oil Field, oil is trapped within the Precipice Sandstone and the trap is sealed by the overlying Evergreen Formation.

The Moonie Oil Field, located 30 km east of the West Moonie-1 Injection Well, has been in production since the early 1960s and is reaching the end of production life. The operation currently extracts approximately 1,000 ML/y as 'associated water', which is defined as water-take associated with the exercise of oil and gas or mineral rights.

The ongoing oil production at the Moonie Oil Field has resulted in local depressurisation of the Precipice Sandstone in the region of the Project (OGIA, 2019).

9.7.4.1.2.2 Managed Aquifer Recharge (MAR)

Origin Energy utilises the Precipice Sandstone to reinject treated water from their CSG operations through a process referred to as managed aquifer recharge (MAR). Origin currently operates two MAR projects in the northern Surat Basin at Spring Gully and Reedy Creek, approximately 220 km and 170 km north-west of the West Moonie-1 Injection Well respectively, with approximately 4,500 ML/y injected into the Precipice Sandstone (OGIA, 2021).

9.7.4.1.3 Stratigraphy Underlying the Storage Complex

9.7.4.1.3.1 Coal Seam Gas Production

For stratigraphy underlying the storage complex, the Bowen Basin CSG extraction is from Permian coal seams in tenements that are located even further away from the Project than the Walloon Sub-Group CSG tenements, and these are separated from the Precipice Sandstone by other regional aquitards. Therefore, there are no predicted overlapping impacts.

9.7.4.2 GROUNDWATER USE AND WATER ENTITLEMENTS

In 2022 in the Water Plan (GABORA) area of Queensland, there were about 23,500 water supply bores, drawing an estimated 262,000 ML/y from 49 groundwater management units (RDMW, 2022). In the vicinity of the operational lands, the GAB extends from the base of the Surat Basin, being Precipice Sandstone aquifer, to surficial aquifers near ground surface.

9.7.4.2.1 Overlying Aquifers, and the Precipice Sandstone aquifer

The *Water Act 2000* provides for water licences having allocations with either nominal volume, a maximum rate of water take, or volumetric limit associated with the authorised purposes of the water licence. The purposes include, but are not limited to:

- any;
- industrial;
- group domestic;
- domestic supply;
- irrigation;
- stock;
- stock intensive;
- town water supply;
- educational facility;
- amenities;
- aquaculture;
- Petroleum and Gas – Non Associated Water; or
- combinations thereof.

The *Water Act 2000* also allows for non-volumetric water licences for the following purposes:

- *domestic purposes, including household purposes, watering of animals kept as pets, and watering a garden (not exceeding 0.5 ha); or*
- *stock purposes, including watering of stock of a number that would normally be depastured on the land on which the water is, or is to be, used, or watering travelling stock on a stock route*.

In the granting of a water licence:

- a water licence is granted to one land parcel (lot on plan) as the nominated location of the bore, but the water licence can apply to multiple attached land parcels allowing distribution of water across multiple land parcels from a single bore;
- a land parcel may have more than one water licence, authorising water take from multiple aquifers;
- a water licence may authorise more than one use or purpose; and/or
- a water licence may authorise water take from more than one bore.

Landowners and resource tenement holders have been granted water licences to access various aquifers within a 50 km radius of the West Moonie-1 Injection Well. A search of the GWDB of active water entitlements on 28 September 2023 identified 120 existing water licences that are within 50 km of the West Moonie-1 Injection Well across all GAB aquifers, as summarised in Table 9-23 and displayed in Figure 9-18.

Table 9-23 Summary of licenced groundwater use or purpose within 50 km of the West Moonie-1 Injection Well

Aquifer[a]	Number of licences	Authorised use or purpose[b]	Total entitlement (ML/y) with percent of total in brackets	Number of registered water bores within 50 km radius[c]
Griman Creek Formation	2	Stock Intensive (1) Irrigation (1)	120 (4.7%)	5
Coreena Member	1	Stock (1)	0	1
Wallumbilla Formation	1	Stock (1)	0	1

Aquifer[(a)]	Number of licences	Authorised use or purpose[(b)]	Total entitlement (ML/y) with percent of total in brackets	Number of registered water bores within 50 km radius[(c)]
Bungil Formation	3	Stock (1) Stock Intensive (1) Educational Facility (1)	12 (0.5%)	2
Mooga Sandstone	31	Stock (20) Stock & Domestic Supply (9) Stock & Stock Intensive (1) Stock, Stock Intensive & Domestic Supply (1)	30 (1.2%)	30
Orallo Formation	5	Stock (3) Stock & Domestic Supply (1) Stock, Stock Intensive & Domestic Supply (1)	10 (0.4%)	5
Gubberamunda Sandstone	48	Any (2) Any, Stock (2) Stock (32) Stock & Domestic Supply (5) Stock & Stock Intensive (3) Stock Intensive (2) Town Water Supply (1)	1,113 (44%)	36
Kumbarilla Beds[(d)]	20	Stock (18) Stock & Domestic Supply (1) Town Water Supply (1)	60 (2.4%)	30
Springbok Sandstone	2	Stock (2)	0	1
Hutton Sandstone	4	Any (2) Stock (1) Stock Intensive (1)	670 (26.5%)	1
Precipice Sandstone	3	Any (2) Stock Intensive (1)	515 (20.4%)	0
Summary for all Formations	120	Any (6) Any, Stock (2) Stock (80) Stock & Domestic Supply (16) Stock & Stock Intensive (4) Stock Intensive (6) Stock, Stock Intensive & Domestic Supply (2) Town Water Supply (2) Educational Facility (1) Irrigation (1)	2,530 (100%)	112

Notes:

a) Based on review of GWDB water sources list data for active water entitlements
b) More than one use or purpose can be authorised for a water licence
c) Note that some water licences have multiple bores assigned

Not all water entitlements have been exercised, in that 26 bores are yet to be drilled and registered with RDMW against water licences within 50 km radius of West Moonie-1 Injection Well.

As outlined in Table 9-23 above, within 50 km of West Moonie-1 Injection Well groundwater is predominately licenced to be taken from the Gubberamunda Sandstone aquifer with 48 water licences granted to take 44% of the total volumetric entitlement. However, greater volumetric entitlements have been granted for the Hutton Sandstone aquifer and Precipice Sandstone aquifer, at 26.5% from four water licences and 20.4% from three water licences respectively. For the Hutton Sandstone aquifer, one bore RN87635 has been drilled and registered, located approximately 25 km east-north-east from the West Moonie-1 Injection Well. For the Precipice Sandstone aquifer, water licences are discussed further in section 9.7.4.2.2 below.

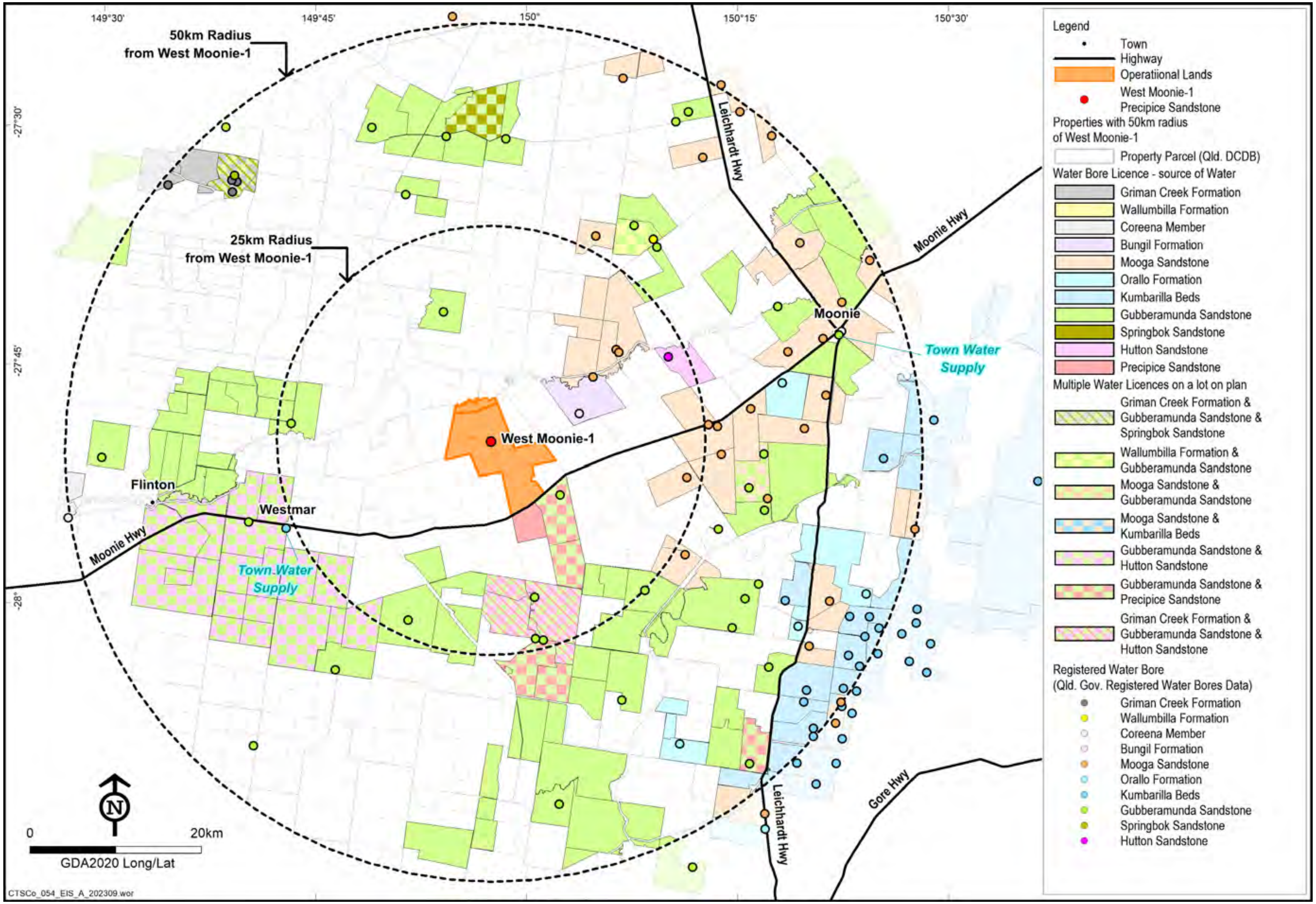

Figure 9-18 Water licences and registered bores for groundwater within 50 km of the West Moonie-1 Injection Well

9.7.4.2.2 Storage Complex – Precipice Sandstone aquifer

Further to sections 9.3.2.5 and 9.3.2.6 outlining the *Water Act 2000*, Water Plan (GABORA), and the GABORA Water Management Protocol and section 9.7.4.2.1 above, a search of the GWDB (23 June 2023) for water licences assigned to the Surat Precipice groundwater sub-area, including the expired Surat 7, Surat East 4, and Surat North 3 management units shows 193 active water entitlements, including 32 volumetric licences totalling 8,502 ML/y, and 161 other licences which are mostly stock, or stock and domestic supply, both of which have no volumetric allocation. Figure 9-19 shows the location of active water entitlements by lot on plan and the registered water bores that have been drilled into the Precipice Sandstone groundwater sub-area. A total of 167 water bores have been drilled and registered associated with the active water entitlements, with groundwater take from the Precipice Sandstone dominated by extraction in the north of the Surat Basin, where the Precipice Sandstone groundwater sub-area is shallower with fresher water quality.

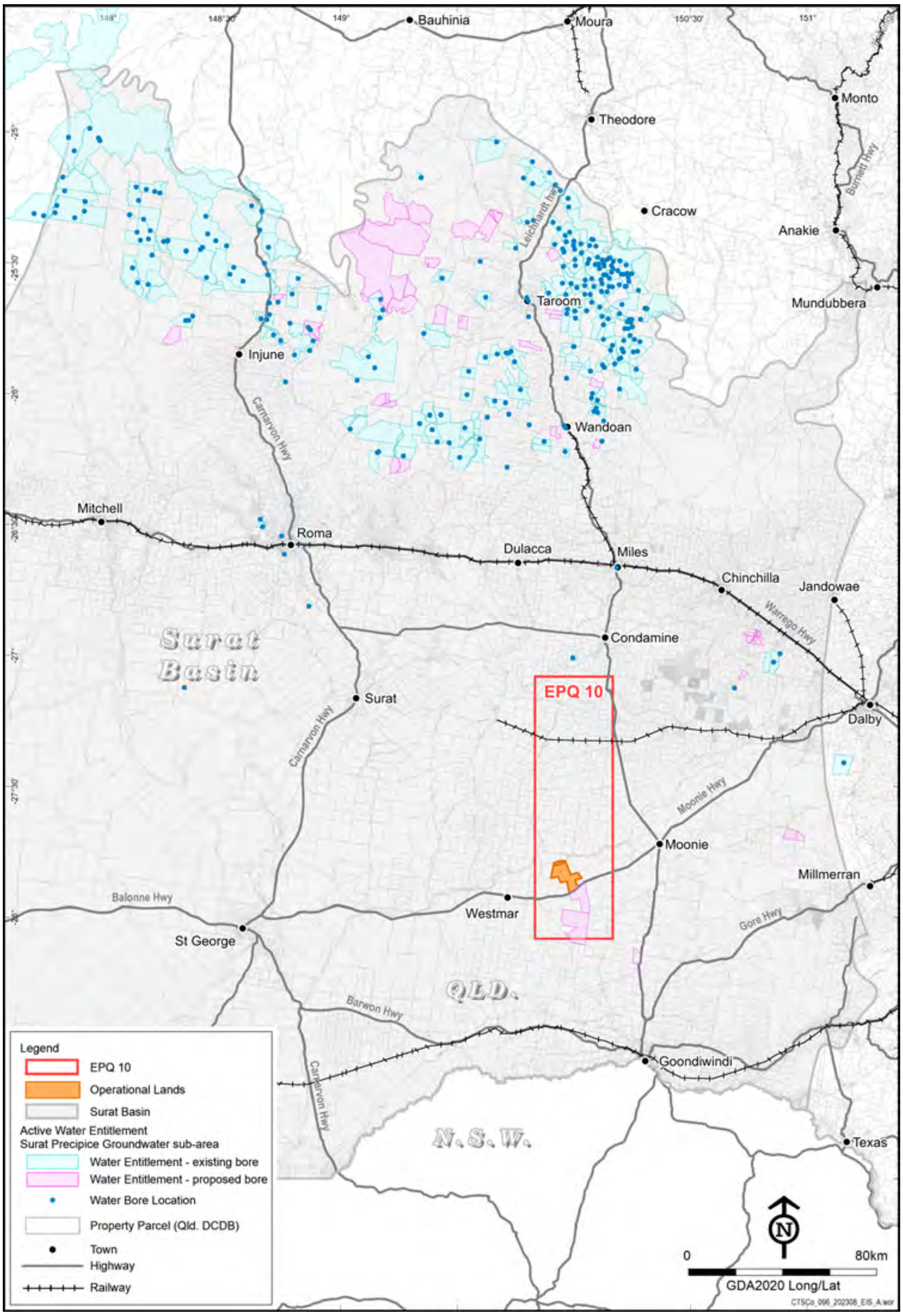

Figure 9-19 Active Water Entitlements in the Surat Precipice groundwater sub-area, including the expired Surat 7, Surat East 4, and Surat North 3 management units

Within a 50 km radius of the West Moonie-1 Injection Well, there are three active water entitlements to the Precipice Sandstone aquifer, as shown on Figure 9-19 above. Table 9-24 summarises the water entitlements and status of registered water bores.

Table 9-24 Summary of Active Water Entitlements and Registered Water Bores for the Precipice Sandstone aquifer within 50 km radius of West Moonie-1 Injection Well

Water licence	Holder	Lot on Plan	Purpose	Licence Issued	Licence Expires	Nominal Entitlement (ML/y)	Registered Water Bore drilled?	Distance from West Moonie-1 Injection Well
624712	John and Ken Cameron, and CPC Land Pty Ltd	2 SP318366	Any	15/3/2022	30/6/2111	95	No. Development Permit to drill a water bore was approved on 8 February 2023 by RDMW (SARA reference 2212-32428 SDA)	9.6 km to -27.86707, 150.04627 (GDA2020)
624713	John and Ken Cameron, and CPC Land Pty Ltd	15 CVN281	Any	15/3/2022	30/6/2111	200	No.	27 km to northern boundary of lot on plan
616843	Walter Woods	13 SP211193	Stock Intensive	18/11/2016	30/6/2111	220	No.	44 km to northern boundary of lot on plan

The closest registered water bore to West Moonie-1 Injection Well is RN160672 located 75 km north-east, and is a water monitoring bore required under the Surat CMA UWIR. In RN160672, the depth of the Precipice Sandstone approximately 1,376 m to 1,409 m below ground level.

Further to section 9.6.2.1.3, based on the *Water Plan (Great Artesian Basin and Other Regional Aquifer) 2017* (GABORA Water Plan), Schedule 4 – Volume of unallocated water for water licences to be granted from reserves, and feedback from RDMW, the following reserves that include the Surat Precipice groundwater sub-area are:

- General reserve = 840 ML/y
- State reserve = 840 ML/y
- Aboriginal people and Torres Strait Islanders economic reserve = 135 ML/y
- Total volume of unallocated water that could be potentially granted in the Surat Precipice groundwater sub-area is 1,815 ML/y.

Under the GABORA Water Management Protocol, Chapter 5 – Rules for relocating a water licence, and Attachment 6 – Permitted water licence relocations and seasonal water assignments, a water licence that is subject to a volumetric allocation or limit, and is metered, can be relocated to other specified groundwater sub-areas. Table 9-25 summarises the groundwater sub-area sources and totals of the volumetric licences that could potentially be relocated to the Surat Precipice groundwater sub-area, with details provided by RDMW on 8 May 2023, based on 2022 licenced volumes.

Table 9-25 Current Volumetric Water Entitlements that could be relocated to the Surat Precipice

Groundwater sub-area source	Total of Volumetric Licences that could potentially relocate to Surat Precipice groundwater sub-area (ML/y)
Surat Wallumbilla	30
Bungil	324
Mooga	1,509
Gubberamunda	12,673.5
Surat Springbok Walloon	1,194
Eastern Downs Springbok Walloon	7,757.4
Surat Hutton	8,061
Eastern Downs Marburg	12,654.8
Eastern Downs Precipice	4,871
TOTAL	**49,074.7**

The Water Plan (GABORA) allows for the GABORA Water Management Protocol to declare an area a ***zone*** in a groundwater unit that may limit the granting of water licences to take water from unallocated water reserves in the zone, or other particular dealings with water licences to take water from within the zone. Chapter 2 of the GABORA Water Management Protocol identifies the Precipice Zone, with its location being more than 100 km north of the West Moonie-1 Injection. No other Zones are located in suitable proximity to influence the operation or water take / interference of the Surat Precipice groundwater sub-area.

9.7.4.3 GROUNDWATER USE AND ECOLOGICAL FUNCTIONS

Groundwater resources support ecological function where groundwater supplies springs and supports groundwater dependent ecosystems (GDEs) and stygofauna. To maintain ecological function associated with springs and GDEs, groundwater flow, level and quality needs to be maintained. To provide an assessment of potential receptors, searches have been completed to characterise springs and groundwater dependent ecosystems in the vicinity of the Project, and further afield in the Surat Basin.

9.7.4.3.1 Overlying Aquifers

9.7.4.3.1.1 Springs

Various active, inactive and GDE supporting springs are associated with aquifers overlying the Precipice Sandstone aquifer that exist within the spatial extent of the Surat Basin, as shown in Figure 9-20. Given the various aquitards present that overlay the Precipice Sandstone aquifer at the West Moonie-1 Injection Well, as discussed in section 9.7 above, and distance between the springs and West Moonie-1 Injection Well, the likelihood of interaction between the springs and the Project is considered negligible.

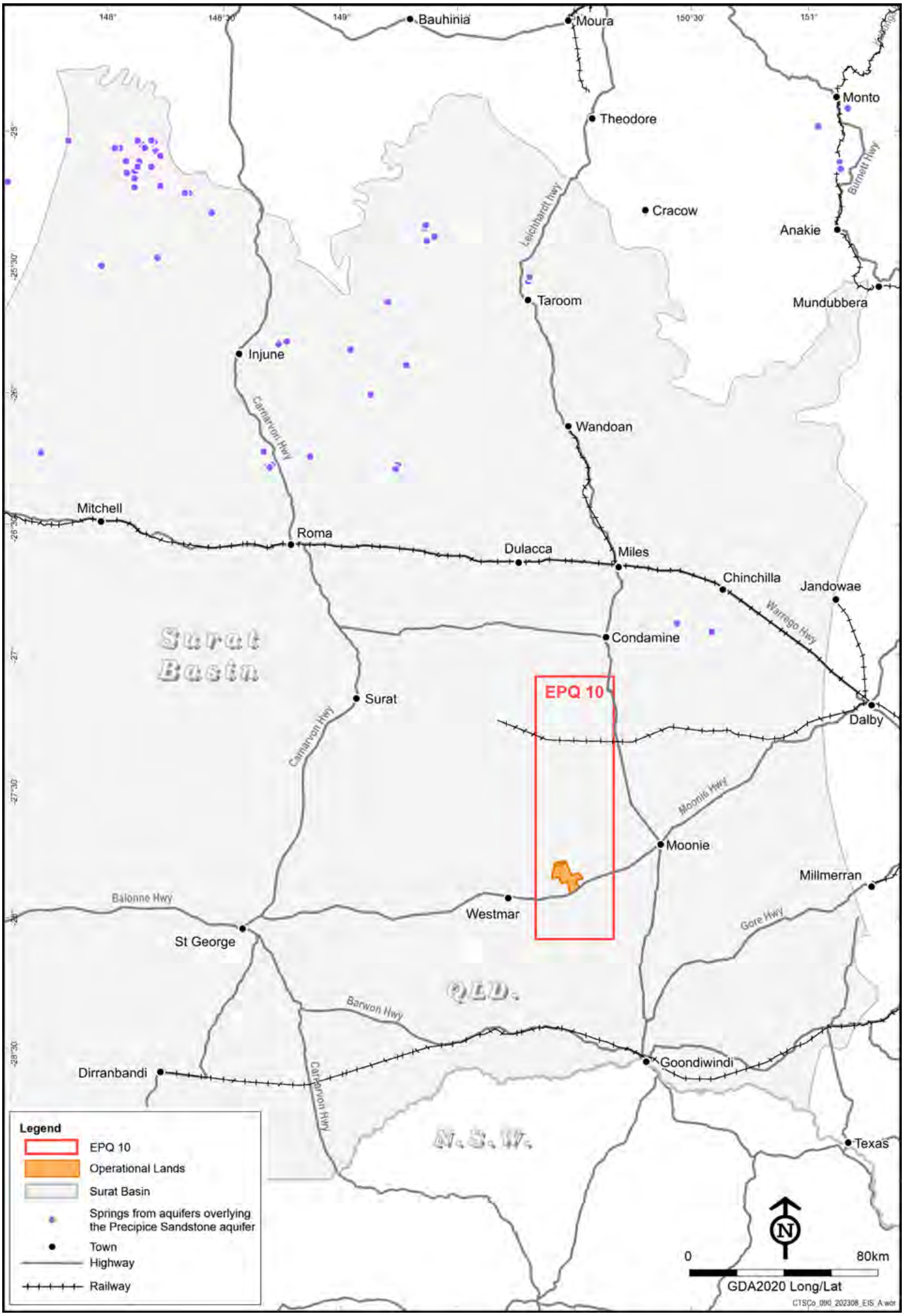

Figure 9-20 Springs of aquifer sources overlying the Precipice Sandstone aquifer

9.7.4.3.1.2 Groundwater Dependent Ecosystems

Chapter 14B Aquatic Flora and Fauna and Appendix 14B further discuss GDEs. For aquifers overlying the Precipice Sandstone aquifer, in summary:

- mapped surface expression GDEs are associated with the Moonie River approximately 4 km north of the West Moonie-1 Injection Well. The Moonie River is ephemeral, with flows only recorded 33% of the time, indicating that the river does not receive groundwater discharge to support baseflow. A desktop assessment and field survey support this assessment, with no groundwater dependent aquatic species identified.
- a stygofauna assessment identified that the water quality in the Griman Creek Formation at the injection site is unlikely to support stygofauna, based on the salinity recorded in the West Moonie Shallow Monitoring Bore (Table 9-31). A stygofauna sampling event was completed at the West Moonie Shallow Monitoring Bore, and no stygofauna were identified.

9.7.4.3.2 Storage Complex – Precipice Sandstone aquifer

A groundwater divide is located in the central portion of the Surat Basin as shown in Figure 9-16. The flow system to the north of the groundwater divide is dynamic with natural recharge and discharge processes driving local flow. To the south of the groundwater divide in the western portion of the Precipice Sandstone (away from the recharge areas of the Great Dividing Range), natural groundwater recharge and discharge processes are understood to be limited.

9.7.4.3.2.1 Recharge of the Precipice Sandstone aquifer

OGIA (2019) summarises that the dominant recharge mechanism for the Precipice Sandstone is likely to occur through preferential pathway flow. The Precipice Sandstone aquifer receives most of its recharge where the unit is present at outcrops at the northern end of the Surat Basin, either through direct infiltration of rainfall or leakage from streams or overlying aquifers.

Data for the southern Surat Basin is limited due to limited head monitoring in the southern reaches of the Precipice Sandstone.

9.7.4.3.2.2 Springs of the Precipice Sandstone aquifer

OGIA maintains a database of springs throughout the Surat Cumulative Management Area (CMA). OGIA (2016b) identified 22 spring complexes with 151 vents and 8 watercourse springs that are sourced from the Precipice Sandstone. The total discharge from the Precipice Sandstone in the north-east outcrop areas near the Dawson River is approximately 16,000 to 18,000 ML/year (OGIA, 2016a).

The springs that have been attributed to the Precipice Sandstone are plotted on Figure 9-21, which indicates that springs are concentrated along the northern flank of the Surat Basin, commensurate with where the Precipice Sandstone outcrops. The closest springs supported by the Precipice Sandstone are the Cockatoo Creek spring complex located over 235 km north of the Project, well beyond the influence of potential Project-related groundwater impacts.

9.7.4.3.2.3 Groundwater Dependent Ecosystems of the Precipice Sandstone aquifer

Chapter 14B Aquatic Flora and Fauna and Appendix 14B further discuss GDEs associated with the operational lands. For the Precipice Sandstone aquifer in the operational lands, groundwater measured in the West Moonie-2 Monitoring Well is 80°C, and is therefore highly unlikely to support subterranean GDEs due to the depth and temperature.

As shown in Figure 9-21, GDEs associated with the Precipice Sandstone aquifer are mostly associated with springs, and include boggomosses, located in the northern extent of the Surat Basin, approximately 235 km north of the Project.

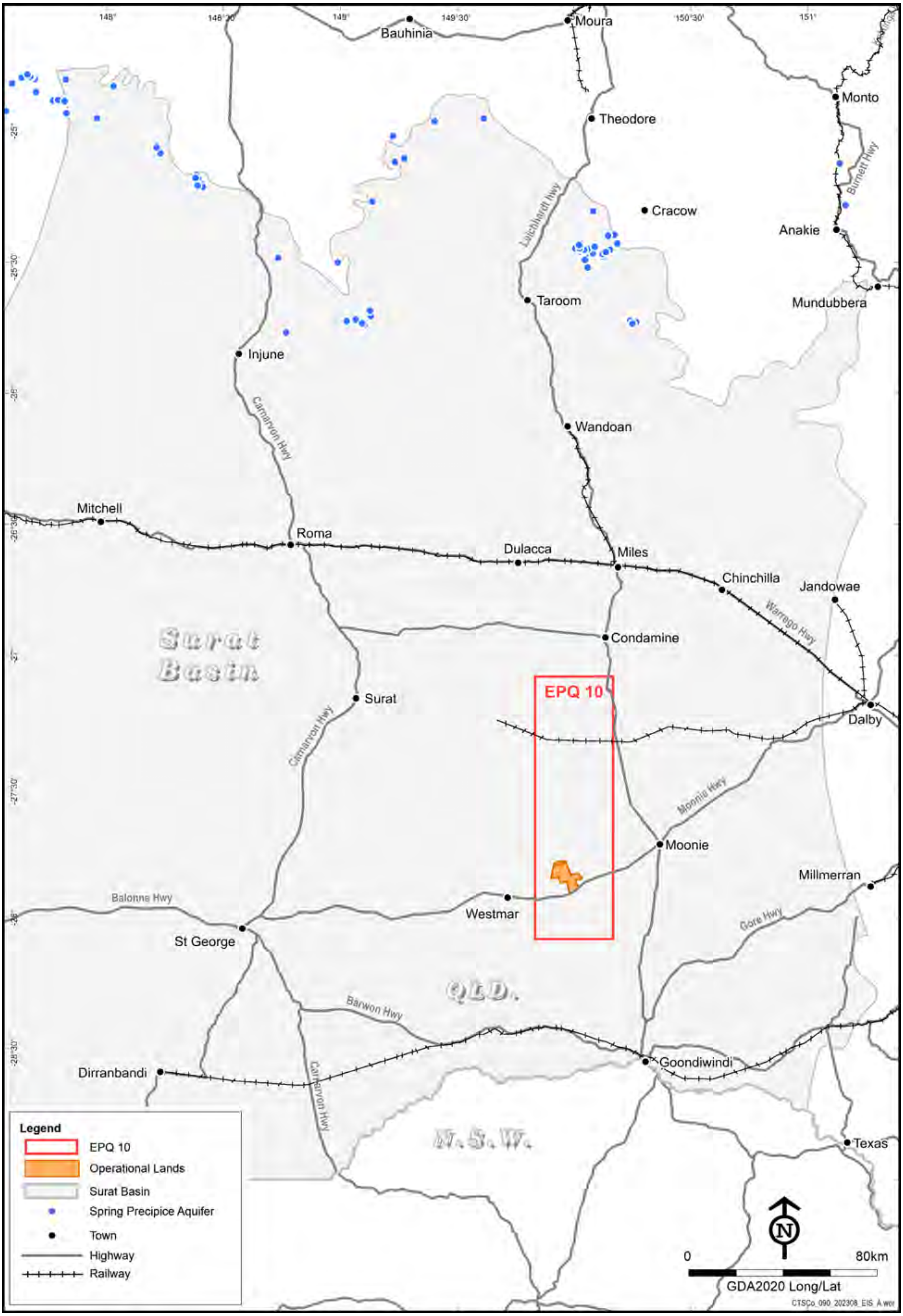

Figure 9-21 Springs attributed to the Precipice Sandstone

9.7.5 Water Quality

In groundwater, the chemical and biochemical constituents guide the potential water uses, known in the *EPP (Water and Wetland Biodiversity) Policy 2019* as environmental values.

Water quality parameters provide indicators for geological history; geology present including ore bodies and oil or gas accumulations; and human use influences such as mining, CSG production, and farming (Freeze & Cherry 1979). Water quality parameters are typically categorised as:

- physical parameters: temperature, pressure, colour, taste, odour, solids, turbidity and electrical conductivity (EC);
- chemical parameters: acidity, alkalinity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), pH, total dissolved solids (TDS);
  - major inorganic (greater than 5 mg/L): bicarbonate, calcium, chloride, magnesium, silicon, sodium, sulphate, and carbonic acid;
  - minor inorganic (0.01 to 10 mg/L): boron, carbonate, fluoride, iron, nitrate, potassium, strontium;
  - trace inorganic (less than 0.1 mg/L): aluminium, antimony, arsenic, barium, beryllium, bismuth, bromide, cadmium, cerium, caesium, chromium, cobalt, copper, gallium, germanium, gold, indium, iodide, lanthanum, lead, lithium, manganese, molybdenum, nickel, niobium, phosphate, platinum, rubidium, ruthenium, scandium, selenium, silver, thallium, tin, titanium, tungsten, vanadium, ytterbium, yttrium, zinc, zirconium;
  - trace inorganic – radioactive substances (less than 0.1 mg/L): radium, thorium, uranium;
  - organic substances; and
- biological parameters: algae, bacteria, protozoa, and viruses (Freeze & Cherry, 1979; Sushma J *et al*, 2021).

The concentration of total dissolved solids (TDS) in water provides a simple classification of water quality, as outlined in Table 9-26 (Freeze & Cherry, 1979, p.84, Table 3.2).

Table 9-26 Simple Groundwater Classification based on Total Dissolved Solids

Category	Total Dissolved Solids (mg/L)
Fresh water	0 to 1,000
Brackish water	1,000 to 10,000
Saline water	10,000 to 100,000
Brine water	more than 100,000

For most physical and chemical parameters, the WQOs are presented in milligrams per litre (mg/L). However, concentrations of physical and chemical parameters can be presented in a different units of measurement, with Table 9-27 summarising the typical units of measurement used in Queensland or Australian documents.

Table 9-27 Summary of typical units of measurement associated with water quality parameters

Units of Measurement					
kilograms per litre (kg/L)	grams per litre (g/L)	milligrams per litre (mg/L)	parts per million (ppm)	micrograms per litre (µg/L)	parts per billion (ppb)
0.000001	0.001	1	1	1,000	1,000
0.00001	0.01	10	10	10,000	10,000
0.0001	0.1	100	100	100,000	100,000
0.001	1	1,000	1,000	1,000,000	1,000,000
0.01	10	10,000	10,000	10,000,000	10,000,000
0.1	100	100,000	100,000	100,000,000	100,000,000
1	1,000	1,000,000	1,000,000	1,000,000,000	1,000,000,000

9.7.5.1 ENVIRONMENTAL VALUES FOR AQUIFER SYSTEMS

Further to section 9.3.2.4, the *EPP (Water and Wetland Biodiversity) Policy 2019, Queensland Murray-Darling and Bulloo River Basins, Groundwater Environmental Values and Water Quality Objectives* identifies the locally relevant environmental values (EVs) and water quality objectives (WQOs) for groundwaters in the Queensland Murray-Darling and Bulloo River Basins (QMDB) which coincide with the Project area, located in the Queensland Border Rivers and Moonie River Basins. Environmental values are categorised into protection of aquatic ecosystems and human use. Water quality associated with human uses is also compared to Australian or Queensland water quality guidelines relevant to the use, and are further described in the following sections. The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG, 2018) are also considered, as appropriate, for various chemical parameters, particularly in relation to the EVs of irrigation and farm supply/use. As per the advice from Water Quality Australia (17 October 2023) (source: https://www.waterquality.gov.au/anz-guidelines/resources/guidance/groundwater) the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1, The Guidelines* (ANZECC, ARMCANZ, 2000) remain applicable under ANZG (2018) for groundwater.

Under the QMDB, aquifers in the Project Area are characterised as belonging to various aquifer systems and differing EVs, as summarised in Table 9-28.

Table 9-28 Environmental Values of Aquifer Systems in the vicinity of the Project

Aquifer	Aquifer System	QMDB Plan Reference	Environmental Values											
			Aquatic ecosystems	Irrigation	Farm supply/use	Stock water	Aquaculture	Human consumption	Primary recreation	Secondary recreation	Visual recreation	Drinking water	Industrial use	Cultural and spiritual values
Griman Creek Formation	Main GAB Aquitard Zones	GWQ4165 Central Surat Mid Cretaceous Northern	✓		✓	✓								✓
Mooga Sandstone	Mid GAB Aquifer Zones	GWQ4166 Lower Balonne Gubberamunda	✓	✓	✓	✓						✓	✓	✓
Gubberamunda Sandstone	Mid GAB Aquifer Zones	GWQ4166 Lower Balonne Gubberamunda	✓	✓	✓	✓						✓	✓	✓
Hutton Sandstone	Basal GAB Zone	GWQ4168 Eastern Central Area	✓	✓	✓	✓						✓	✓	✓
Precipice Sandstone	Basal GAB Zone	GWQ4168 Eastern Central Area	✓	✓	✓	✓						✓	✓	✓

9.7.5.2 WATER QUALITY FOR AQUATIC ECOSYSTEMS – OVERLYING AQUIFERS

For the aquatic ecosystem WQOs of the overlying aquifers, Table 9-29 provides a summary of selected water quality parameters from the *Queensland Murray-Darling and Bulloo River Basins, Groundwater Environmental Values and Water Quality Objectives*.

Table 9-30 provides a summary of selected water quality parameters for the Hutton Sandstone aquifer as presented in the OGIA UWIR (2021), based on 1,748 samples.

Table 9-31 provides a summary of water quality samples taken from the overlying aquifers of Griman Creek Formation and Gubbermunda Sandstone aquifer in 2021 as part of gathering baseline water quality data for the Project. Further details of the sampling methods, NATA certified laboratory analysis, and sample results are provided in Appendix 9A, section 4.4.2.

Note that water quality samples were not taken from the Mooga Sandstone aquifer or Hutton Sandstone aquifer during sampling activities in 2021.

Additional baseline water quality sampling will be undertaken prior to commencement of injection testing, as further described in section 9.10.1.4.

Water quality sampled from the Griman Creek Formation as presented in Table 9-31, reported a TDS concentration of approximately 31,000 mg/L and a chloride concentration of 17,700 mg/L. These results indicate the Griman Creek Formation has saline groundwater with very low recharge with a limited ability to locally support environmental values.

The Gubberamunda Sandstone is a regional aquifer with high bore yields and good freshwater quality. As presented in Table 9-31, the water sampled from the Milgarra Bore, situated 17 km away from the West Moonie-1 Injection Well, is consistent with the WQOs. Located at a depth of approximately 1,200 m, the Gubberamunda Sandstone aquifer is used extensively within a 50 km radius of the West Moonie-1 Injection Well for farm supply/use and stock water.

The Hutton Sandstone is a tight/partial aquifer overlying the Evergreen Formation. It is the most extensive aquifer in the Great Artesian Basin (GAB) (OGIA, 2016a) and extends westward into the Eromanga Basin (Green, 1997). Within a 50 km radius of the West Moonie-1 Injection Well, the Hutton Sandstone is not used for human uses as extensively as the Gubberamunda Sandstone. However, the Hutton Sandstone is the regional aquifer system with the closest vertical separation from the storage complex (Precipice Sandstone). The Hutton Sandstone is separated from the Precipice Sandstone by the Evergreen Formation aquitard. Based on OGIA (2021) data in Table 9-30, the groundwater in the Hutton Sandstone aquifer is categorised as fresh to brackish.

Table 9-29 Summary of Aquatic Ecosystem WQOs for Overlying Aquifers from the QMDB

Aquifer	Zone	%ile	Sodium (Na) (mg/L)	Calcium (Ca) (mg/L)	Magnesium (Mg) (mg/L)	Bicarbonate Alkalinity (HCO_3) (mg/L)	Chloride (Cl) (mg/L)	Sulphate (SO_4) (mg/L)	Nitrate (NO_3) (mg/L)	Electrical Conductivity (EC) (µS/cm)	Hardness (mg/L)	pH	Alkalinity (mg/L)	Silica (SiO_2) (mg/L)
Griman Creek Formation	Main GAB Aquitard, GWQ4165 Central Surat Mid Cretaceous Northern	20th	468	29	14	90	365	45	BDL	3,746	151	6.8	101	35.8
		50th	2,010	256	169	253	3,282	465	1.3	26,400	1,322	7.5	222	56
		80th	6,017	1104	1,006	452	12,572	1,876	12.5	50,980	6,782	8	373	78.2
Mooga Sandstone	Mid GAB Aquifer, GWQ4166 Lower Balonne Gubberamunda	20th	255	2	BDL	416	88	BDL	BDL	1,070	5	8	352	21
		50th	341	2	0.3	561	130	5	0.3	1,360	8	8.4	496	26
		80th	508	4	1	862	260	29	1	2,022	15	8.6	761	29
Gubberamunda Sandstone	Mid GAB Aquifer, GWQ4166 Lower Balonne Gubberamunda	20th	255	2	BDL	416	88	BDL	BDL	1,070	5	8	352	21
		50th	341	2	0.3	561	130	5	0.3	1,360	8	8.4	496	26
		80th	508	4	1	862	260	29	1	2,022	15	8.6	761	29
Hutton Sandstone	Basal GAB, GWQ4168 Eastern Central Area	20th	87	2	0.2	157	40	BDL	BDL	390	6	7.5	163	14
		50th	255	3	1	420	99	5	0.3	1,055	11	8.2	347	19
		80th	342	8	5	673	163	28	1	1,484	32	8.6	568	26

Note: BDL – below detention limit

Table 9-30 Summary of Median values of water quality parameters of the Hutton Sandstone aquifer (OGIA (2021))

Aquifer	Data Source	Median of 1,748 samples	Sodium (Na) (mg/L)	Calcium (Ca) (mg/L)	Magnesium (Mg) (mg/L)	Potassium (K) (mg/L)	Chloride (Cl) (mg/L)	Sulphate (SO_4) (mg/L)	Total Dissolved Solids (TDS) (mg/L)	pH	Alkalinity (mg/L)	Fluoride (F) (mg/L)
Hutton Sandstone	OGIA UWIR 2021	Median	357	27	14	3	400	16	1,160	8.0	399	0.3

Table 9-31 Sampled Baseline Water Quality Parameters for Overlying Aquifers of the Project

Group	Water Quality Parameters	Units	Griman Creek Formation (from West Moonie Shallow Monitoring Bore), sampled 19/07/2021	Gubberamunda Sandstone (from Milgarra Bore), sampled 14/06/2021
Physico-chemical parameter and major and minor ions	Sodium (Na)	mg/L	10,600	330
	Calcium (Ca)	mg/L	1,320	<1
	Magnesium (Mg)	mg/L	1,150	<1
	Potassium (K)	mg/L	65	2
	Chloride (Cl)	mg/L	17,700	68
	Sulphate (SO_4)	mg/L	1,250	7
	Nitrate (NO_3)	mg/L	-	<0.01
	Ammonia (NH_3)	mg/L	-	0.33
	Electrical Conductivity (EC)	µS/cm	48,316	1,240
	Total Dissolved Solids (TDS)(1)	mg/L	31,405(a)	826
	pH (lab)	pH Units	7.75	8.74
	Total Alkalinity	mg/L	11	581
	Silica (SiO_2)	mg/L	-	24.9
	Fluoride (F)	mg/L	<0.1	0.5
	Dissolved Oxygen (DO)	mg/L	0.3	7.9
	Total Organic Carbon (TOC)	mg/L	-	5
Metals (Total) (trace inorganic chemical parameter)	Aluminium (Al)	mg/L	0.15	<0.01
	Arsenic (As)	mg/L	<0.005	<0.001
	Beryllium (Be)	mg/L	<0.005	<0.001
	Boron (B)	mg/L	0.51	0.13
	Cadmium (Cd)	mg/L	0.0008	<0.0001
	Chromium (Cr)	mg/L	<0.005	<0.001
	Cobalt (Co)	mg/L	0.128	<0.001
	Copper (Cu)	mg/L	-	<0.001
	Iron (Fe)	mg/L	7.19	0.06
	Lead (Pb)	mg/L	<0.005	<0.001
	Lithium (Li)	mg/L	0.120	0.011
	Manganese (Mn)	mg/L	3.75	0.002
	Mercury (Hg)	mg/L	<0.00004	<0.0001
	Molybdenum (Mo)	mg/L	<0.005	0.005
	Nickel (Ni)	mg/L	0.077	<0.001
	Selenium (Se)	mg/L	<0.05	<0.01

Group	Water Quality Parameters	Units	Griman Creek Formation (from West Moonie Shallow Monitoring Bore), sampled 19/07/2021	Gubberamunda Sandstone (from Milgarra Bore), sampled 14/06/2021
	Silver (Ag)	µg/L	0.6	<0.01
	Uranium (U)	mg/L	<0.005	<0.001
	Vanadium (V)	mg/L	<0.05	<0.01

Notes:
(1) To enable comparison, TDS has been calculated from EC. TDS = EC x 0.65

The Griman Creek samples were taken on 19 July 2021, and analysed by ALS (work orders EB2120349-002 and EB2123041) on 22 July 2021 and 19 August 2021 respectively (under W Moonie Shallow), with the certificate given in Appendix 9A, (Appendix E ALS Laboratory Certificates).

Two lots of samples were taken from the Milgarra Bore for sampling of the Gubberamunda Sandstone aquifer on 14 June 2021 and 25 August 2021. Samples were analysed by ALS (work orders EB2118210-001 and EB2124168-001 respectively). Certificates of the analysis are given in Appendix 9A, (Appendix E ALS Laboratory Certificates).

9.7.5.3 WATER QUALITY FOR AQUATIC ECOSYSTEMS – GHG STORAGE RESERVOIR

For the aquatic ecosystem WQOs of the Precipice Sandstone aquifer, Table 9-32 provides a summary of selected water quality parameters from the *Queensland Murray-Darling and Bulloo River Basins, Groundwater Environmental Values and Water Quality Objectives*.

Table 9-33 provides a summary of median values of selected water quality parameters for the Precipice Sandstone aquifer as presented in the OGIA UWIR (2021) based on 662 samples, *Hydrogeology of the southern Surat Basin* (Hofmann *et al* (2022)) based on 8 samples, Moonie Oil Field (Mahlbacher, 2019) based on 18 samples, and sampled from the West Moonie-1 Injection Well in July 2021 as part of gathering baseline water quality data for the Project based on 3 samples.

Groundwater is generally fresh near recharge areas and evolves when it moves through the formations (OGIA, 2021). The OGIA (2021) data is dominated by samples from the north of the Surat Basin where the Precipice Sandstone is located at shallower depths and the aquifer flow is more dynamic owing to the proximity of recharge and discharge environments. The groundwater quality sampled from the southern portion of the Surat Basin, being the Moonie Oil Field, Hofmann *et al* (2022), and from West Moonie-1 Injection Well is more brackish compared to the data presented by OGIA. This is attributed to the location in the deeper part of the Surat Basin, further from recharge areas, and in an area where there is no throughflow, with the water effectively stagnant at the West Moonie-1 Injection Well site.

Sampling from West Moonie-1 Injection Well was undertaken on 30 November 2020 and 16 July 2021. Multiple purge volumes were sampled on 30 November 2020, with a final purge volume of approximately 89,000 L. However, the water quality samples were potentially affected by drilling muds, as elevated concentrations of potassium and chloride were found. Potassium chloride is used as an additive to drilling muds to stabilise clays during drilling. Contamination with drilling fluid filtrate is a common issue when developing deep wells (APLNG, 2016). Three additional samples from West Moonie-1 Injection Well were taken on 16 July 2021 after purging an additional 129,000 L, 137,000 L and 145,000 L from the well. Table 9-34 shows results of 16 July 2021 for all three purge volumes, for all physiochemical parameters of major, minor and trace inorganics and organics. In summary, all of the water quality parameters sampled on 16 July 2021 from West Moonie-1 Injection Well are either similar or below the measured ranges from Hofmann *et al* (2022) and Moonie Oil Field, indicating that the West Moonie-1 Injection Well groundwater quality aligns with concentrations observed for the Precipice Sandstone across the south of the Surat Basin. Further details of the sampling methods, NATA certified laboratory analysis, sample results and comparison to Hofmann *et al* (2022) and Moonie Oil Field are provided in Appendix 9A Groundwater technical report, section 4.4.1 and (Appendix E ALS Laboratory Certificates).

Table 9-35 provides a comparison of aquatic ecosystem WQOs and existing groundwater quality within Precipice Sandstone aquifer at West Moonie-1 Injection Well. The chemical parameters of the existing water quality have naturally elevated concentrations compared to the aquatic ecosystem WQOs 80th percentile concentrations.

Table 9-32 Summary of Aquatic Ecosystem WQOs for the Precipice Sandstone aquifer from the QMDB

Aquifer	Zone	%ile	Sodium (Na) (mg/L)	Calcium (Ca) (mg/L)	Magnesium (Mg) (mg/L)	Bicarbonate Alkalinity (HCO_3) (mg/L)	Chloride (Cl) (mg/L)	Sulphate (SO_4) (mg/L)	Nitrate (NO_3) (mg/L)	Electrical Conductivity (EC) (µS/cm)	Hardness (mg/L)	pH	Alkalinity (mg/L)	Silica (SiO_2) (mg/L)
Precipice Sandstone	Basal GAB, GWQ4168 Eastern Central Area	20th	87	2	0.2	157	40	BDL	BDL	390	6	7.5	163	14
		50th	255	3	1	420	99	5	0.3	1,055	11	8.2	347	19
		80th	342	8	5	673	163	28	1	1,484	32	8.6	568	26

Note: BDL – below detention limit

Table 9-33 Summary of Median values of water quality parameters of the Precipice Sandstone aquifer from OGIA (2021), the Moonie Oil Field (Mahlbacher, 2019), Hofmann *et al* (2022), and West Moonie-1 Injection Well

Aquifer	Data Source	Sample size	Sodium (Na) (mg/L)	Calcium (Ca) (mg/L)	Magnesium (Mg) (mg/L)	Potassium (K) (mg/L)	Chloride (Cl) (mg/L)	Sulphate (SO_4) (mg/L)	Total Dissolved Solids (TDS) (mg/L)	pH	Alkalinity (mg/L)	Fluoride (F) (mg/L)
Precipice Sandstone	OGIA UWIR 2021	662	47	3	1	2.1	15	1	184	7.5	112	0.2
	Southern Surat Basin (Hofmann *et al* (2022))	8	1,200	49	9	55	1,240	<1	3,740	6.6	1,075	0.85
	Moonie Oil Field (Mahlbacher, 2019)	18	770	12	2	20	153	21	2,843	-	1,860 (HCO^{3-})	5.1
	West Moonie-1	3	598	6	1	150	319	8	1,850	8.16	1,080	6

Table 9-34 Baseline water quality for the Precipice Sandstone aquifer from West Moonie-1 Injection Well, sampled on 16 July 2021 (from Appendix 9A, Table 4.5)

Group	Water Quality Parameters	Units	Sample 1 at 129,000 L	Sample 2 at 137,000 L	Sample 3 at 145,000 L
Physico-chemical parameter and major and minor ions	Sodium (Na)	mg/L	518	598	611
	Calcium (Ca)	mg/L	5	6	6
	Magnesium (Mg)	mg/L	1	1	1
	Potassium (K)	mg/L	139	155	150
	Chloride (Cl)	mg/L	328	319	318
	Sulphate (SO_4)	mg/L	8	8	8
	Nitrate (NO_3)	mg/L	<0.01	<0.01	<0.01
	Ammonia (NH_3)	mg/L	0.92	0.84	0.70
	Electrical Conductivity (EC)	µS/cm	2,930	2,910	2,920
	Total Dissolved Solids (TDS)	mg/L	1,880	1,850	1,850
	pH (lab)	pH Units	8.12	8.16	8.35
	Bicarbonate Alkalinity	mg/L	1,080	1,060	1,060
	Carbonate Alkalinity	mg/L	<1	<1	19
	Hydroxide Alkalinity	mg/L	<1	<1	<1
	Total Alkalinity	mg/L	1,080	1,060	1,080
	Silica as SiO_2	mg/L	38.6	38.6	38.8
	Fluoride (F)	mg/L	5.7	6.0	6.3
	Dissolved Oxygen (DO)	mg/L	1.1	5.1	2.1
	Total Organic Carbon (TOC)	mg/L	6	-	8
	Reactive Phosphorus	mg/L	0.01	0.01	0.01
	Total Anions	meq/L	31.0	30.3	30.7
	Total Cations	meq/L	26.4	30.4	30.8
Metals (Total) (trace inorganic chemical parameter)	Aluminium (Al)	mg/L	0.14	0.03	0.05
	Arsenic (As)	mg/L	<0.001	<0.001	<0.001
	Beryllium (Be)	mg/L	<0.001	<0.001	<0.001
	Boron (B)	mg/L	0.68	0.83	0.73
	Cadmium (Cd)	mg/L	<0.0001	<0.0001	<0.0001
	Chromium (Cr)	mg/L	0.003	<0.001	<0.001
	Cobalt (Co)	mg/L	0.003	0.002	0.016
	Copper (Cu)	mg/L	<0.001	<0.001	<0.001
	Iron (Fe)	mg/L	3.12	2.84	2.78
	Lead (Pb)	mg/L	<0.001	<0.001	<0.001
	Lithium (Li)	mg/L	0.126	0.157	0.138

Group	Water Quality Parameters	Units	Sample 1 at 129,000 L	Sample 2 at 137,000 L	Sample 3 at 145,000 L
	Manganese (Mn)	mg/L	0.048	0.047	0.049
	Mercury (Hg)	mg/L	<0.0001	<0.0001	<0.0001
	Molybdenum (Mo)	mg/L	0.003	0.003	0.003
	Nickel (Ni)	mg/L	<0.001	0.001	0.001
	Selenium (Se)	mg/L	<0.01	<0.01	<0.01
	Silver (Ag)	µg/L	0.34	0.24	0.07
	Uranium (U)	mg/L	<0.001	<0.001	<0.001
	Vanadium (V)	mg/L	<0.01	<0.01	<0.01
	Zinc (Zn)	mg/L	<0.005	<0.005	<0.005
Total Petroleum Hydrocarbons (TPH)	TPH C6 – C9 Fraction	µg/L	-	<20	<20
	TPH C6 – C10 Fraction (minus BTEX)	µg/L	-	<20	<20
	Methane	µg/L	1,640	1,420	-
BTEXN	Benzene	µg/L	-	<1	<1
	Toluene	µg/L	-	3	<2
	Ethylbenzene	µg/L	-	<2	<2
	meta- & para-Xylene	µg/L	-	2	<2
	ortho-Xylene	µg/L	-	<2	<2
	Total Xylenes	µg/L	-	2	<2
	Sum of BTEX	µg/L	-	5	<1
	Naphthalene	µg/L	-	<5	<5
TPH(V)/BTEX Surrogates	1.2-Dichloroethane-D4	%	-	116	122
	Toluene-D8	%	-	111	118
	4-Bromofluorobenzene	%	-	110	120

General note: hydrocarbon analysis was also completed with results typically less than the laboratory level of reporting. A low-level detection for toluene and xylene was noted in one of the West Mooie-1 Injection Well samples, however this is unlikely to be associated with background water quality.

Table 9-35 Comparison of Aquatic Ecosystem WQOs and groundwater quality within Precipice Sandstone aquifer at West Moonie-1 Injection Well

Parameter	Units	WQO – (80th percentile, except where indicated)	Water Quality of the Precipice Sandstone aquifer at West Moonie-1 Injection Well		
			Sample 1 at 129,000 L	Sample 2 at 137,000 L	Sample 3 at 145,000 L
Sodium (Na)	mg/L	342	518	598	611
Calcium (Ca)	mg/L	8.0	5	6	6
Magnesium (Mg)	mg/L	1.0 – 50th %ile 5.0 – 80th %ile	1	1	1
Bicarbonate Alkalinity (HCO_3)	mg/L	673	1,080	1,060	1,060

Parameter	Units	WQO – (80th percentile, except where indicated)	Water Quality of the Precipice Sandstone aquifer at West Moonie-1 Injection Well		
			Sample 1 at 129,000 L	Sample 2 at 137,000 L	Sample 3 at 145,000 L
Chloride (Cl)	mg/L	163	328	319	318
Sulphate (SO_4)	mg/L	28	8	8	8
Nitrate (NO_3)	mg/L	1	<0.01	<0.01	<0.01
EC	µS/cm	1,484	2,930	2,910	2,920
pH	pH units	8.6	8.12	8.16	8.35
Total Alkalinity	mg/L	568	1,080	1,060	1,080

Note: Orange shading indicates exceedance for the 80th percentile.

9.7.5.4 WATER QUALITY FOR IRRIGATION AND FARM USE/SUPPLY – OVERLYING AQUIFERS

The irrigation EV aims to ensure that water is of sufficient quality for crops and does not limit crop yields or cause soil degradation. The Farm Use/Supply EV ensures that water for farm supply is of sufficient quality for produce preparation and domestic uses other than drinking.

As per Table 9-35 above, the WQOs associated with irrigation EVs do not apply to Griman Creek Formation, however they do apply to Gubberamunda Sandstone aquifer.

Table 9-36 below compares the WQOs relating to physico-chemical parameters and heavy metals and metalloids for agricultural irrigation, derived from the QMDB, ANZG (2018), and ANZECC (2000), for the existing aquifer water quality data of Griman Creek Formation and Gubberamunda Sandstone aquifer (as applicable). Exceedances of the trigger values for:

- Griman Creek Formation include high concentrations of sodium and chloride, indicating saline water; and
- Gubberamunda Sandstone aquifer include elevated pH and elevated concentrations of sodium and chloride compared to the WQO long-term trigger values, however, is still considered fresh water.

Table 9-36 Comparison of irrigation and farm use/supply WQOs for the Griman Creek Formation and Gubberamunda Sandstone aquifer

Water Quality Parameters	Units	WQO long-term trigger value	WQO short-term trigger value	Water quality of the Griman Creek Formation at West Moonie Shallow Monitoring Bore (sampled 19/07/2021)	Water quality of the Gubberamunda Sandstone aquifer at Milgarra Bore (sampled 14/06/2021)
pH	pH units	6 to 8.5	6 to 8.5	7.75	8.74
Sodium	mg/L	115		10,600	330
Chloride	mg/L	40		17,700	68
Fluoride	mg/L	1	2	<0.1 (WQO not applicable)	0.5
Aluminium	mg/L	5	20	(WQO not applicable)	<0.01
Arsenic	mg/L	0.1	2	(WQO not applicable)	<0.001
Beryllium	mg/L	0.1	0.5	(WQO not applicable)	<0.001
Boron	mg/L	0.5		(WQO not applicable)	0.13
Cadmium	mg/L	0.01	0.05	(WQO not applicable)	<0.0001
Chromium	mg/L	0.1	1	(WQO not applicable)	<0.001
Cobalt	mg/L	0.05	0.1	(WQO not applicable)	<0.001
Copper	mg/L	0.2	5	(WQO not applicable)	<0.001

Water Quality Parameters	Units	WQO long-term trigger value	WQO short-term trigger value	Water quality of the Griman Creek Formation at West Moonie Shallow Monitoring Bore (sampled 19/07/2021)	Water quality of the Gubberamunda Sandstone aquifer at Milgarra Bore (sampled 14/06/2021)
Iron	mg/L	0.2	10	7.19 (WQO not applicable)	0.06
Lead	mg/L	2	5	(WQO not applicable)	<0.001
Manganese	mg/L	0.2	10	3.75 (WQO not applicable)	0.002
Mercury	mg/L	0.002	0.002	<0.00004 (WQO not applicable)	<0.0001
Nickel	mg/L	0.2	2	(WQO not applicable)	<0.001
Selenium	mg/L	0.02	0.05	(WQO not applicable)	<0.01
Uranium	mg/L	0.01	0.1	(WQO not applicable)	<0.001
Vanadium	mg/L	0.1	0.5	(WQO not applicable)	<0.01
Zinc	mg/L	2	5	(WQO not applicable)	<0.005

Note:
Orange shading indicates exceedance for the long-term and short-term trigger values
Yellow shading indicates exceedance for the long-term trigger values

9.7.5.5 WATER QUALITY FOR IRRIGATION AND FARM USE/SUPPLY – GHG STORAGE RESERVOIR

When compared to the WQOs relating to heavy metals and metalloids for agricultural irrigation, as provided in Table 9-37 and derived from the QMDB, the existing aquifer water quality data exceeds the trigger values for a range of different elements, including sodium, chloride, fluoride, boron and iron. The use of this water for irrigation poses a risk of soil degradation, potentially causing sodic soils. This indicates that the groundwater is unlikely to support the long-term use for irrigation purposes.

The main consideration for farm supply is limiting corrosion and fouling of farm water supply equipment. For this, pH and water hardness are used as indicators of the corrosion and fouling potential. The pH of the Precipice Sandstone aquifer water from West Moonie-1 Injection Well indicates that the water has an increased fouling potential (as per Table 9.2.25 of ANZECC 2000), and the water hardness (average of 17.4 mg/L calculated) suggests an increased corrosion potential (less than 60 mg/L) (as per Table 9.2.24 of ANZECC 2000). These parameters are also indicators for other water quality related issues such as elevated levels of bicarbonate and sodium, which is already evident in the groundwater. This can lead to unwanted reactions with other farm chemicals reducing their efficiency (ANZECC, 2000).

Table 9-37 Comparison of irrigation and farm use/supply WQOs for the Precipice Sandstone aquifer from West Moonie-1 Injection Well

Water Quality Parameters	Units	WQO long-term trigger value	WQO short-term trigger value	Water quality of the Precipice Sandstone aquifer at West Moonie-1 Injection Well		
				Sample 1 at 129,000 L	Sample 2 at 137,000 L	Sample 3 at 145,000 L
pH	pH units	6 to 8.5	6 to 8.5	8.12	8.16	8.35
Sodium	mg/L	115		518	598	611
Chloride	mg/L	40		328	319	318
Fluoride	mg/L	1	2	5.7	6.0	6.3
Aluminium	mg/L	5	20	0.14	0.03	0.05

Water Quality Parameters	Units	WQO long-term trigger value	WQO short-term trigger value	Water quality of the Precipice Sandstone aquifer at West Moonie-1 Injection Well		
				Sample 1 at 129,000 L	Sample 2 at 137,000 L	Sample 3 at 145,000 L
Arsenic	mg/L	0.1	2	<0.001	<0.001	<0.001
Beryllium	mg/L	0.1	0.5	<0.001	<0.001	<0.001
Boron	mg/L	0.5		0.68	0.83	0.73
Cadmium	mg/L	0.01	0.05	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.1	1	0.003	<0.001	<0.001
Cobalt	mg/L	0.05	0.1	0.003	0.002	0.016
Copper	mg/L	0.2	5	<0.001	<0.001	<0.001
Iron	mg/L	0.2	10	3.12	2.84	2.78
Lead	mg/L	2	5	<0.001	<0.001	<0.001
Manganese	mg/L	0.2	10	0.048	0.047	0.049
Mercury	mg/L	0.002	0.002	<0.0001	<0.0001	<0.0001
Nickel	mg/L	0.2	2	<0.001	0.001	0.001
Selenium	mg/L	0.02	0.05	<0.01	<0.01	<0.01
Uranium	mg/L	0.01	0.1	<0.001	<0.001	<0.001
Vanadium	mg/L	0.1	0.5	<0.01	<0.01	<0.01
Zinc	mg/L	2	5	<0.005	<0.005	<0.005

Note: Orange shading indicates exceedance of the short-term trigger value, while yellow shading indicates exceedance of the long-term trigger value.

9.7.5.6 WATER QUALITY FOR STOCK WATER – OVERLYING AQUIFERS

The stock water EV aims to ensure that water provided to livestock is of sufficient quality to not cause deterioration in the health or condition of watered livestock. Table 9-38 provides TDS WQO for various livestock compared to Griman Creek Formation and Gubberamunda Sandstone aquifer groundwater. Table 9-39 provides stock water WQOs for heavy metals and metalloids compared to Griman Creek Formation and Gubberamunda Sandstone aquifer. The TDS of the Griman Creek Formation is unsuitable for stock consumption. All chemical parameters listed in Table 9-39 for the Griman Creek Formation and Gubberamunda Sandstone aquifer are below trigger values.

Table 9-38 TDS WQO for Stock water compared to the Griman Creek Formation and Gubberamunda Sandstone aquifer

Water Quality Parameter	WQO	Water quality of the Griman Creek Formation at West Moonie Shallow Monitoring Bore (sampled 19/07/2021)	Water quality of the Gubberamunda Sandstone aquifer at Milgarra Bore (sampled 14/06/2021)
TDS (No adverse effects threshold)	5,000 mg/L for sheep 4,000 for beef cattle, horses and pigs 2,500 mg/L for dairy cattle 2,000 mg/L for poultry	31,405	826

Note: Orange shading indicates exceedance.

Table 9-39 Stock water WQOs (low risk trigger values) for heavy metals and metalloids compared to the Griman Creek Formation and Gubberamunda Sandstone aquifer

Water Quality Parameter	WQO trigger value (low risk) (mg/L)	Water quality of the Griman Creek Formation at West Moonie Shallow Monitoring Bore (sampled 19/07/2021)	Water quality of the Gubberamunda Sandstone aquifer at Milgarra Bore (sampled 14/06/2021)
Aluminium	5	-	<0.01
Arsenic	0.5 (up to 5[a])	-	<0.001
Boron	5	-	0.13
Cadmium	0.01	-	<0.0001
Chromium	1	-	<0.001
Cobalt	1	-	<0.001
Copper	0.4 (sheep), 1 (cattle), 5 (pigs), 5 (poultry)	-	<0.001
Fluoride	2	<0.1	0.5
Lead	0.1	-	<0.001
Mercury	0.002	<0.00004	<0.0001
Molybdenum	0.15	-	0.005
Nickel	1	-	<0.001
Selenium	0.02	-	<0.01
Uranium	0.2	-	<0.001
Zinc	20	-	<0.005

Notes:

a) May be tolerated if not provided as a food additive and natural levels in the diet are low.

9.7.5.7 WATER QUALITY FOR STOCK WATER – GHG STORAGE RESERVOIR

Table 9-40 provides TDS WQO for various livestock compared to Precipice Sandstone aquifer groundwater sampled from West Moonie-1 Injection Well. Table 9-41 provides stock water WQOs for heavy metals and metalloids compared to the Precipice Sandstone aquifer at West Moonie-1 Injection Well.

Table 9-40 TDS WQO for Stock water compared to the Precipice Sandstone aquifer at West Moonie-1 Injection Well

Water Quality Parameter	WQO	Water quality of the Precipice Sandstone aquifer at West Moonie-1 Injection Well		
		Sample 1 at 129,000 L	Sample 2 at 137,000 L	Sample 3 at 145,000 L
TDS (No adverse effects threshold)	5,000 mg/L for sheep 4,000 for beef cattle, horses and pigs 2,500 mg/L for dairy cattle 2,000 mg/L for poultry	1,880	1,850	1,850

Table 9-41 Stock water WQOs (low risk trigger values) for heavy metals and metalloids compared to the Precipice Sandstone aquifer at West Moonie-1 Injection Well

Water Quality Parameter	WQO trigger value (low risk) (mg/L)	Water quality of the Precipice Sandstone aquifer at West Moonie-1 Injection Well		
		Sample 1 at 129,000 L	Sample 2 at 137,000 L	Sample 3 at 145,000 L
Aluminium	5	0.14	0.03	0.05
Arsenic	0.5 (up to 5[b])	<0.001	<0.001	<0.001
Boron	5	0.68	0.83	0.73
Cadmium	0.01	<0.0001	<0.0001	<0.0001
Chromium	1	0.003	<0.001	<0.001
Cobalt	1	0.003	0.002	0.016
Copper	0.4 (sheep), 1 (cattle), 5 (pigs), 5 (poultry)	<0.001	<0.001	<0.001
Fluoride[a]	2	5.7	6.0	6.3
Lead	0.1	<0.001	<0.001	<0.001
Mercury	0.002	<0.0001	<0.0001	<0.0001
Molybdenum	0.15	0.003	0.003	0.003
Nickel	1	<0.001	0.001	0.001
Selenium	0.02	<0.01	<0.01	<0.01
Uranium	0.2	<0.001	<0.001	<0.001
Zinc	20	<0.005	<0.005	<0.005

Notes:

a) Orange shading indicates exceedance.
b) May be tolerated if not provided as a food additive and natural levels in the diet are low.

Fluoride as provided in Table 9-41 is the only water quality parameter elevated compared to stock water WQOs.

Following public submissions on the potential use of the Precipice Sandstone aquifer for stock watering purposes, additional studies examining fluoride in stock have been undertaken and are presented in Appendix 9E A review of safe fluoride levels in stock water (Niethe, 2023).

With regards to consumption of water from the Precipice Sandstone aquifer, the key findings of the study by Niethe (2023) found:

- there is an immense variation in literature on what are safe levels of fluoride in stock water;
- the ANZECC 2000 Guidelines, Volume 3, for stock watering established a 2 mg/L threshold value for fluoride, which represents a low/zero risk recommendation for all livestock;
- the total dietary intake of fluoride for livestock is important to gauge the overall tolerance levels for fluoride not just the fluoride concentration in water;
- the species, age, duration of exposure, and concentration of fluoride in feed all impact on what a safe concentration of fluoride is in water;
- fluoride is a cumulative toxin, and the longer animals are exposed, the higher the fluoride concentration becomes, with young animals being the most vulnerable as the initial action of fluoride is on unerupted permanent teeth;
- clinical signs of higher fluoride concentrations range from mottling of teeth with no loss in productivity to severe dental and skeletal problems causing loss of productivity and even death in acute cases;
- high levels of calcium in groundwater reduce the risks associated with higher fluoride concentrations, therefore water with higher TDS is generally safer to use;
- stock water concentrations of fluoride of 2 mg/L to 8 mg/L can be managed if livestock producers are aware of the risks;

- for cattle, according to research by the National Research Council (NRC), maximum tolerable concentrations of fluoride of 40 mg/kg to 100 mg/kg (equivalent to mg/L) in the diet on a dry matter basis, "*when fed for a limited period, will not impair animal performance and should not produce unsafe residues in human food derived from the animal*";
- for cattle, water containing high levels of fluoride can be used for short term lot feeding especially with older cattle and also where the fluoride concentrations in the ration can be closely monitored. The main focus should be to ensure the total fluoride in the diet is less than 35 mg/kg of total feed ingested;
- pigs and poultry are less susceptible to fluorosis as they spend less time on farm;
- management techniques to manage higher concentrations of fluoride in stock water include:
  - mixing or blending of groundwater with other water with lower concentrations of fluoride;
  - avoiding evaporation of groundwater in surface dams, turkey nests, or drains by holding groundwater in tanks;
  - ensuring young cattle (<3 years of age) are not exposed to elevated concentrations of fluoride in water;
  - managing overall dietary intact of fluoride;
  - livestock species selection, as different species have different tolerance levels to fluoride;
  - duration of exposure by a species, with pigs, poultry and sheep being more tolerant to higher concentrations of fluoride because they typically leave the farm at a much younger age compared to cattle.

In summary, although the ANZECC 2000 Guidelines safe threshold of 2 ppm fluoride in the water is recommended for livestock, concentrations of between 3 ppm to 8 ppm of fluoride can be used if the producers are aware of the risks and the total amount of fluoride in the diet does not exceed 35 ppm for cattle. Management strategies can be employed to ensure livestock productivity is not comprised although some mottling of teeth may still occur.

9.7.5.8 WATER QUALITY FOR DRINKING WATER – OVERLYING AQUIFERS

The QMDB WQOs provide that the management goals relating to drinking water are based on raw water for drinking water consumption, being to:

- minimise the risk that the quality of the raw water taken for treatment for human consumption results in adverse human health effects;
- maintain palatability rating of water; and
- minimise risk that the odour of drinking water being offensive to consumers.

Water sampled from the Griman Creek Formation and Gubberamunda Sandstone aquifer only examined physical and chemical water quality parameters, and did not test for biological parameters such as *Giardia*, *Cryptosporidium*, *E. coli* or algal toxins.

As outlined in Table 9-42, the existing Griman Creek Formation and Gubberamunda Sandstone aquifer groundwater quality at the West Moonie-1 site and Milgarra Bore are elevated compared to raw water (before treatment) drinking water WQOs for all parameters.

The drinking water EV does not apply to the Griman Creek Formation. As a raw water source for drinking water, the water would be very unpalatable and would require significant treatment if it were to be used as drinking water for human consumption.

For the Gubberamunda Sandstone aquifer, as a raw water source for drinking water, the water would be unpalatable, and would require some treatment if it were to be used as drinking water for human consumption.

The townships of Moonie and Westmar currently source their town water supplies from bores into the Gubberamunda Sandstone (RN34273) and Kumbarilla Beds (OGIA attributes to Mooga Sandstone)(RN119045) respectively. However, these bores have their own water quality parameter concentrations that may differ from the Milgarra Bore.

Requirements for drinking water quality after treatment are stipulated in, but not limited to the *Public Health Act 2005*, *Water Supply (Safety and Reliability) Act 2008*, *Water Fluoridation Act 2008*, *Australian Drinking Water Guidelines (2011, updated September 2022)*, and the *Safe Water on Rural Properties guideline* (Queensland Health, 2015).

Table 9-42 Comparison of before-treatment drinking water WQOs and groundwater quality from the Griman Creek Formation and Gubberamunda Sandstone aquifer

Water Quality Parameter	Units	WQO	Water quality of the Griman Creek Formation at West Moonie Shallow Monitoring Bore (sampled 19/07/2021)	Water quality of the Gubberamunda Sandstone aquifer at Milgarra Bore (sampled 14/06/2021)
pH		6.5-8.5	7.75	8.74
TDS	mg/L	<600	31,405	826
Sodium	mg/L	180	10,600	330
Sulphate	mg/L	250	1,250	7

Note: Orange shading indicates exceedance.

9.7.5.9 WATER QUALITY FOR DRINKING WATER – GHG STORAGE RESERVOIR

Water sampled from the Precipice Sandstone aquifer only examined physical and chemical water quality parameters, and did not test for biological parameters such as *Giardia*, *Cryptosporidium*, *E. coli* or algal toxins.

As outlined in Table 9-43, the existing Precipice Sandstone aquifer groundwater quality at the West Moonie-1 Injection Well is elevated compared to raw water (before treatment) drinking water WQOs for TDS and sodium. As a raw water source for drinking water, the water would be unpalatable and would require some form of treatment if it were to be used as drinking water for human consumption.

The depth of the Precipice Sandstone aquifer at approximately 2.3 km deep would also limit the economic viability of using it as a source for raw water.

Table 9-43 Comparison of before-treatment drinking water WQOs and groundwater quality from the Precipice Sandstone aquifer at West Moonie-1 Injection Well

Water Quality Parameter	Units	WQO	Water quality of the Precipice Sandstone aquifer at West Moonie-1 Injection Well		
			Sample 1 at 129,000 L	Sample 2 at 137,000 L	Sample 3 at 145,000 L
pH		6.5-8.5	8.12	8.16	8.35
TDS	mg/L	<600	1,880	1,850	1,850
Sodium	mg/L	180	518	598	611
Sulphate	mg/L	250	8	8	8

Note: Orange shading indicates exceedance.

9.7.5.10 WATER QUALITY FOR INDUSTRIAL USE – OVERLYING AQUIFERS AND GHG STORAGE RESERVOIR

The QMDB does not provide WQOs for industrial use, recognising that "*industries usually treat water supplies to meet their specific needs*." (QMBD, 2020 p.34)

9.7.5.11 WATER QUALITY FOR CULTURAL AND SPIRITUAL VALUES – OVERLYING AQUIFERS AND GHG STORAGE RESERVOIR

This environmental value does not have numerical WQOs of specific water quality parameters, with the management goal to have the water resources remain fit for purpose in relation to cultural, spiritual and ceremonial values and uses of water. This EV seeks to allow the water quality to support:

- custodial, spiritual, cultural and traditional heritage, hunting, gathering and ritual responsibilities;
- symbols, landmarks and icons (such as flora, fauna, and waterways); and
- lifestyles (such as agriculture and fishing).

9.7.6 Isotope Data

Further to section 9.5.1, the results of the isotopic sampling and analysis from West Moonie-1 Injection Well and West Moonie-2 Monitoring Well found that carbon-13 (~$\delta^{13}C$ CO_2) is -10 ‰ to -12 ‰ in the storage complex (Evergreen Formation to Moolayember Formation interval) which is significantly heavier than the carbon-13 (~$\delta^{13}C$ CO_2) at -20.9 ‰ to -25.2 ‰ measured from the Millmerran Power Station flue gas which will be the source of the captured CO_2 for the GHG stream. Characterisations of isotopes will be used in event-based monitoring and verification processes as discussed in section 9.10.1.8.

As documented in further detail in Appendix 9A, section 4.2.3.2 from Rodger *et al* (2020), isotope data was gathered from water sampled from the Hutton and Precipice Sandstone aquifers and analysed for:

- Deuterium (δ^2H) and delta-O-18 ($\delta^{18}O$), and examined together with the global meteoritic water line (GMWL) and the local meteoric water line (LMWL);
- strontium ratio ($^{87}Sr/^{86}Sr$) providing radiogenic values; and
- carbon-14 (^{14}C) and chlorine-36 (^{36}Cl) ratios.

The isotope data is not as comprehensive as the water quality data, however the available isotope data draws some useful conclusions:

- isotopic data supports hydraulic disconnection between the Hutton Sandstone and the Precipice Sandstone aquifers, supporting the effectiveness of the Evergreen Formation as a regional tight aquitard;
- radiogenic values show a clear difference between the Hutton and Precipice Sandstone aquifers, indicating possibly different recharge sources; and
- radiometric data indicates a residence time of water within the Surat Basin of more than 30,000 years.

9.7.7 Summary of Existing Groundwater Conditions

A summary of the key existing groundwater conditions pertinent for the Project are for:

- the aquifers overlying the storage complex:
  - include the Griman Creek Formation, Mooga Sandstone aquifer, Gubberamunda Sandstone aquifer, and Hutton Sandstone aquifer;
  - the Griman Creek Formation was initially intersected at 39 m below ground level and is almost 300 m thick at the West Moonie site. Water quality sampled indicates that the water is saline and is unsuitable for stock water supply;
  - the Mooga Sandstone is primarily sandstone with thin interbeds of siltstone and thin stringers of mudstone, which was intersected at 925 m below ground level in the West Moonie-1 Injection where it is approximately 125 m thick. The Mooga Sandstone is a regional aquifer, supplying water entitlements within a 50 km radius of the West Moonie-1 Injection Well;
  - the Gubberamunda Sandstone is a regional aquifer and supplies the largest volume of groundwater to water entitlements holders within a 50 km radius of West Moonie-1 Injection Well. At the West Moonie-1 Injection Well, the Gubberamunda Sandstone aquifer is intersected at 1,160 m below ground level and is approximately 275 m thick. Water quality sampled indicates that the water is fresh and suitable for farm use, stock water, and as raw water for drinking water supply;
  - the Hutton Sandstone is the most extensive aquifer in the Great Artesian Basin, is 219 m thick at West Moonie-1 Injection Well, and its top was intersected at approximately 1,900m below ground level. The Hutton Sandstone at West Moonie-1 Injection Well consists of interbedded sandstone and siltstone beds with minor coal, with the individual sandstone beds up to 10 m thick and separated by up to 35 m of fine-grained material that would limit fluid migration or pressure propagation;
- the storage complex (the Evergreen Formation, Precipice Sandstone aquifer, and Moolayember Formation):
  - the Precipice Sandstone aquifer is a regional sandstone aquifer, representing the deepest and oldest unit of the Surat Basin;
  - regional groundwater levels of Precipice Sandstone aquifer suggest a flow divide just south of the Great Dividing Range, separating the Precipice Sandstone aquifer into a shallower northern flow system, and the deeper southern flow system;
  - recharge of the Precipice Sandstone aquifer occurs in the north of the Surat Basin, through rainfall and leakage from streams and overlying aquifers, as well as managed aquifer recharge;
  - the flow direction of the Precipice Sandstone aquifer in the southern Surat Basin is uncertain, but most likely flows towards the south and a component to the east;
  - groundwater movement within the Precipice Sandstone aquifer of the southern Surat Basin and at the Project site is very slow (Hofmann et al, 2022), and effectively stagnate at West Moonie-1 Injection Well site;
  - the Precipice Sandstone aquifer is a confined aquifer at the West Moonie Project location, as per the definition of a confined aquifer in the EP Regulation s.41(3);
  - the Moonie Oil Field is the main feature of groundwater extraction from the Precipice Sandstone in the southern Surat Basin. The oil field however is thought to be structurally isolated from the Precipice Sandstone aquifer at the Project site by the Moonie fault system, being the nearest regional fault structure over 20 km to the east of the West Moonie-1 Injection Well;

- the Precipice Sandstone has high permeability which supports injection of a GHG stream at the West Moonie-1 Injection Well site;
- overlying Evergreen Formation and underlying Moolayember Formation are heterogeneous, but consist predominantly of fine-grained lithologies, leading to effective, tight, regional aquitards with significant vertical resistance to groundwater flow;
- hydraulic head data indicates a downward hydraulic gradient from the Hutton Sandstone to the Precipice Sandstone (Hofmann et al 2022). There is no evidence of local fault-induced connectivity between the Hutton Sandstone and Precipice Sandstone in the Project area, with pressure testing at the West Moonie-2 Monitoring Well showing a 70 m head offset between Hutton Sandstone (higher pressure) and Precipice Sandstone (lower pressure);
- the Precipice Sandstone aquifer has three active water entitlements granted under the *Water Act 2000* within a 50 km radius of West Moonie-1 Injection Well, with 95 ML/y volumetric entitlement at 9.6 km, 200 ML/y volumetric entitlement at 27 km, and 220 ML/y volumetric entitlement at 44 km away. Registered bores are yet to be drilled, with a development permit to drill the bore associated with the 95 ML/y water licence granted in February 2023;
- for groundwater quality in the Precipice Sandstone aquifer, the *EPP (Water and Wetland Biodiversity) Policy 2019, Queensland Murray-Darling and Bulloo River Basins, Groundwater Environmental Values and Water Quality Objectives* identifies the locally relevant environmental values (EVs) and water quality objectives (WQOs) for groundwaters in the Queensland Murray-Darling and Bulloo River Basins (QMDB) which coincide with the Project area, located in the Queensland Border Rivers and Moonie River Basins, and the Basal GAB Zone, Eastern Central Area;
- groundwater quality sampled from the southern portion of the Surat Basin, including from West Moonie-1 Injection Well is brackish, based on Total Dissolved Solids (TDS) concentrations. This is attributed to the location in the deeper part of the Surat Basin, further from recharge areas, and in an area where there is no throughflow, with the water effectively stagnate at the West Moonie-1 Injection Well site;
- some existing water quality parameters are naturally outside the range of various EV WQOs listed in the QMDB including:
  - aquatic ecosystem WQOs: sodium, bicarbonate, chloride, electrical conductivity (EC), and total alkalinity all have higher concentrations than the WQO (80^{th} percentile);
  - irrigation/farm use WQOs: sodium, chloride, fluoride, boron and iron all have higher concentrations than the WQO long-term trigger values. The use of this water for irrigation poses a risk of soil degradation, potentially causing sodic soils, indicating that the groundwater is unlikely to support the long-term use for irrigation purposes. The use of the groundwater for farm supply potentially poses corrosion and fouling risks to farm water supply equipment due to the pH and water hardness;
  - stock water WQOs: fluoride has approximately 3 times higher concentration (approximately 6 mg/L) than the WQO trigger value (2 mg/L). Use of the groundwater for stock watering purposes needs to consider the potential health impacts on stock due to high concentrations of fluoride, including total dietary intake of fluoride for stock, age of stock, and duration of exposure to higher fluoride concentrations;
  - drinking water WQOs: total dissolved solids (TDS) and sodium concentrations are higher than the before-treatment drinking water WQOs, with the water requiring some form of treatment to improve palatability for human consumption;
- isotope and pressure data indicate hydraulic disconnection between the Hutton Sandstone and the Precipice Sandstone aquifers, supporting the effectiveness of the Evergreen Formation as a regional tight aquitard; and
- the naturally occurring carbon-13 (~$\delta^{13}C$ CO_2) isotope of the storage complex is significantly heavier than the carbon-13 (~$\delta^{13}C$ CO_2) of the GHG stream, as confirmed by sampling of both the West Moonie-1 Injection Well site and Millmerran Power Station flue gas, and therefore can be a suitable environmental tracer for monitoring and verification activities for the Project.

9.8 Proposed Project Description

9.8.1 Key Features for Groundwater Impact Assessment

The proposed Project is the injection testing of 110,000 t/y of GHG stream via the West Moonie-1 Injection Well for a period of 3 years, totalling 330,000 tonnes of GHG stream into the Precipice Sandstone aquifer for evaluating the feasibility of GHG stream storage by GHG storage injection testing approximately 2.3 km below ground level. The injection testing will provide critical data on GHG plume behaviour to assist in the EIS assessment processes for approvals for future CCS projects in Queensland.

As described in Chapter 2 Proposed Project Description, section 2.8.1.2, the potential of GHG stream releases through the West Moonie-1 Injection Well and West Moonie-2 Monitoring Well have been mitigated by ensuring that well construction was undertaken in accordance with best practice well design standards including the *Code of Practice for the construction and abandonment of petroleum wells and associated bores in Queensland* (DNRME, 2019). The well designs for all wells has incorporated multiple barriers to isolate the wells and bores from the surrounding aquifers and prevent well corrosion or leakage, including:

- a solid steel surface casing – this is a large-diameter pipe with high structural strength. The surface casing is cemented into the shallow geology;
- a solid steel production casing – this is a medium-diameter pipe that is designed to withstand high pressure. The production casing is cemented into the Precipice Sandstone aquifer seal to prevent any leakage from the Precipice Sandstone aquifer to the overlying aquifers;
- a chrome steel production tubing – this is a smaller diameter tube within the production casing. The GHG stream will be delivered to the Precipice Sandstone formation through the production tubing. The chrome steel construction will minimise the potential for well corrosion; and
- use of corrosion resistant cement across the Precipice Sandstone and Evergreen Formations.

The construction of the West Moonie-1 Injection Well and West Moonie-2 Monitoring Well have met or exceeded the requirements of *Code of Practice for the construction and abandonment of petroleum wells and associated bores in Queensland* (DNRME, 2019), and the International Energy Agency *Corrosion and Materials Selection in CCS Systems 2010*, to ensure materials used to construct the wells were fit for purpose.

Monitoring of well condition during and following the injection testing will further ensure the potential for GHG stream releases through the wells is adequately addressed including:

- casing wall thickness loss;
- constant pressure and temperature monitoring at West Moonie-1 Injection Well and West Moonie-2 Monitoring Well; and
- regular cement condition monitoring.

As described in Chapter 2 Proposed Project Description, section 2.10.4.1, the GHG stream will be injected into the wellhead at approximately 31°C and 1,377 psi (9.5 MPa). The GHG stream will take approximately 52 minutes to travel from the wellhead to the perforated injection zone in the lower Precipice Sandstone storage reservoir, during which the West Moonie-1 Injection Well is expected to act as an effective heat exchanger, warming the GHG stream as it travels between the surface and GHG storage reservoir. The relatively slow transport speed of the GHG stream within the well tubing results in the GHG stream being delivered to the GHG storage reservoir at a temperature of about 80°C and a pressure of 3,270 psi (22.54 MPa), which is consistent with natural pressure and temperature conditions of the Precipice Sandstone aquifer. This close alignment of pressure and temperature conditions between the GHG stream and GHG storage reservoir at the injection interface minimises potential for hydraulically or thermally induced fracturing.

Further to Chapter 2 Proposed Project Description, the key features of the Project although not subject to the EIS approval but relevant to the groundwater impact assessment are:

- at or immediately below ground surface level:
  - 3D seismic activities;
  - 2D seismic monitoring infrastructure;
  - air quality and atmospheric monitoring infrastructure;
  - soil CO_2 monitoring infrastructure in West Moonie-5 Soiling Monitoring Bore and West Moonie-6 Soiling Monitoring Bore;
- for the overlying aquifers:
  - West Moonie Shallowing Monitoring Bore of the Griman Creek Formation;
  - Gubberamunda Monitoring Bore;
  - West Moonie-2 Monitoring Well for monitoring of the Hutton Sandstone aquifer;
- for the storage complex (the Evergreen Formation, Precipice Sandstone aquifer, and Moolayember Formation):
  - West Moonie-1 Injection Well;
  - West Moonie-2 Monitoring Well for monitoring the Precipice Sandstone aquifer inside of the GHG plume; and
  - West Moonie Sentinel Monitoring Well for monitoring the Precipice Sandstone aquifer outside of the GHG plume.

As part of the draft EIS consultation process the advice from the IESC provided to DES with regard to mitigation, management and monitoring recommended:

- monitoring of soil gas associated with containment of the GHG stream, hence the inclusion of soil CO_2 monitoring infrastructure;
- additional monitoring targeting several aquifers, hence the inclusion of the monitoring of the Hutton Sandstone aquifer; and
- additional monitoring sites surrounding West Moonie-1 Injection Well and additional monitoring for potential changes in groundwater quality, hence the inclusion of the proposed West Moonie Sentinel Monitoring Well to be located to sample the Precipice Sandstone aquifer outside the predicted GHG plume.

9.8.2 Implementation of lessons learned from global case studies

CTSCo has taken the learnings from the CCS global case studies and is applying them to the Project, including:

- utilising seismic processes to verify the safe containment of the GHG stream and monitoring the GHG plume location, as well as also identifying any induced seismic activity from the GHG injection process;
- specific analyses such as for dissolved inorganic carbon (DIC) and its stable isotope δ^{13}C-DIC to allow different sources of CO_2 (injected vs natural) to be distinguishable and identifiable from groundwater sample analysis should leakage from the storage complex occur;
- implementation of a fluid recovery system to collect fluid from the GHG storage reservoir and bring it to the surface under in situ conditions to provide useful monitoring information on CO_2-formation water and rock interactions;
- collection of Project data to support and develop a regional scale model of long-term GHG storage and containment in the Surat Basin;
- completion of a comprehensive third-party expert audit of the Project’s storage development plan which includes the ITP and MVP.

9.9 Potential Impacts

For assessment of the potential impacts on groundwater, the overlying aquifers and the storage complex including the Precipice Sandstone aquifer are considered in:

- the area immediately surrounding the West Moonie-1 Injection Well;
- within the operational lands of the Project;
- to a radius of 50 km surrounding the West Moonie-1 Injection Well; and
- within the Surat Precipice groundwater sub-area.

Potential impacts of the Project on groundwater uses, users and EVs are addressed in the context of the potential exposure pathways of:

- groundwater pressure and flow:
    - interconnectivity between aquifers overlying the GHG storage reservoir and the Precipice Sandstone aquifer as the GHG storage reservoir;
    - movement of the GHG plume vertically to overlying aquifers;
    - movement of the GHG plume laterally within the Precipice Sandstone aquifer;
- groundwater quality including groundwater chemistry:
    - of aquifers overlying the GHG storage reservoir;
    - within the GHG plume in the Precipice Sandstone aquifer; and
    - outside of the GHG plume in the Precipice Sandstone aquifer.

9.9.1 Potential Impacts on Aquifers Overlying the Storage Complex due to GHG storage injection testing

9.9.1.1 POTENTIAL GROUNDWATER PRESSURE AND FLOW IMPACTS OF AQUIFERS OVERLYING THE STORAGE COMPLEX

Further to Chapter 8 Geology, section 8.7.6.3 and sections 9.5, 9.6.1, 9.7.3.1.3, and 9.8 above, MDT testing of the Hutton Sandstone aquifer, Evergreen Formation, and Precipice Sandstone aquifer has found that there is a distinct pressure gradient offset between the Hutton Sandstone aquifer and the Precipice Sandstone aquifer. This observation shows that the two aquifers cannot be in hydraulic pressure communication demonstrating that the intervening Evergreen Formation is an effective regional pressure seal, with the ability to contain the GHG stream and GHG plume within the Precipice Sandstone aquifer.

The hydrogeological model as presented in section 9.6.2.1 examined Scenario 1 Base Case, and in section 9.6.2.1.2 and Figure 9-2 examined Case 1.4. The combination of Scenario 1 and Case 1.4 means modelling of the GHG stream injection at a rate of 110,000 t/y for 3 years into the Precipice Sandstone with existing extraction from the Moonie Oil Field and Kogan Creek Power Station, combined with a hypothetical fault through the Evergreen Formation and Lower Hutton Formation 7 km from the West Moonie-1 Injection Well that is 1,125 m long with a vertical hydraulic conductivity (kv) of 1.0×10^{-2} m/d. Modelling results predicted a head change of less than 0.006 m in the Upper Hutton Sandstone after 200 years of injection ceasing. This potential impact is considered negligible. Further details of the modelling are presented in Appendix 9A, section 5.1.2.2 and (Appendix A).

As given in Chapter 2 Proposed Project Description, sections 2.8.1.2, 2.11.2, 2.11.5, and 2.11.7, and section 9.8 above, the potential for escape and movement of the GHG stream from within West Moonie-1 Injection Well or along the outside of the casing of the West Moonie-1 Injection Well during the operation phase and any subsequent timeframe after GHG storage injection testing is considered low.

In summary, the potential pressure impacts of GHG storage injection testing on overlying aquifers is considered negligible. Avoidance and mitigation measures, where relevant, are provided in section 9.10 below.

9.9.1.2 POTENTIAL IMPACTS ON GROUNDWATER USES AND USERS OF AQUIFERS OVERLYING THE STORAGE COMPLEX

Further to section 9.7.4.1, resource production activities such as mining and CSG production in formations above the Storage Complex are unlikely to be impacted by GHG stream activities due to target formations for resource activities being outside of the Precipice Sandstone. Avoidance and mitigation measures are provided in section 9.10 below.

Further to section 9.7.4.2, water entitlements granted under the *Water Act 2000* in overlying aquifers are unlikely to be impacted by GHG stream injection, as outlined in section 9.9.1.1 above, as the GHG stream and GHG plume are anticipated to be contained within the Storage Complex. Avoidance and mitigation measures are provided in section 9.10 below.

As outlined in section 9.7.4.2.2, water entitlements of overlying aquifers that apply to be relocated to the Precipice Sandstone aquifer may need to consider GHG storage injection testing and GHG plume extent during the Project's operation phase or subsequent timeframes, as part of the GABORA Water Management Protocol, Chapter 4 – Protection of existing licences and particular authorisations requirements on minimum separation distances. Avoidance and mitigation measures are provided in section 9.10 below.

As outlined in section 9.7.4.3 and Chapter 14B Aquatic Flora and Fauna, the potential impacts on ecological functions such as recharge to overlying aquifers, springs from overlying aquifers and GDEs of overlying aquifers are considered negligible due to no demonstrable interconnectivity between the Precipice Sandstone aquifer at the West Moonie-1 Injection Well site.

9.9.1.3 POTENTIAL GROUNDWATER CHEMISTRY AND WATER QUALITY IMPACTS ON OVERLYING AQUIFERS

As outlined in section 9.9.1.1 above, the escape and movement of the GHG stream from within West Moonie-1 Injection Well or along the outside of the casing of the West Moonie-1 Injection Well during the operation phase and any subsequent timeframe after GHG storage injection testing is complete, is considered low. Therefore, the potential impacts on or changes to the groundwater chemistry or water quality are also considered low. Avoidance and mitigation measures are provided in section 9.10 below.

9.9.2 Potential Groundwater Pressure and Flow Impacts on the Precipice Sandstone aquifer within the GHG plume

For the groundwater impact assessment, most of the groundwater pressure and flow modelling was focused on the Storage Complex and the GHG storage reservoir, being the Precipice Sandstone aquifer. Following from section 9.6.2, the hydrogeological model and the dynamic (plume) model were used to model existing environmental conditions, sensitivity analysis of pressure and groundwater flow conditions, and potential impacts on pressure and groundwater flow conditions from GHG storage injection testing.

9.9.2.1 POTENTIAL FOR FRACTURE INITIATION OF STORAGE COMPLEX FROM GHG STREAM INJECTION PRESSURE

As described in Chapter 8 Geology, sections 8.7.6.2 and 8.7.6.3, MDT testing of the Evergreen Formation found that with the application of 7,000 psi of pressure did not fracture rock in the Evergreen Formation, proving the lithologies of the Evergreen Formation seal are extremely hard. The injection pressure of the GHG stream at 3,270 psi which will match the existing pressure of the Precipice Sandstone aquifer, is significantly less than 7,000 psi, resulting in the potential for fracture initiation from GHG stream injection to be negligible.

9.9.2.2 POTENTIAL IMPACTS OF PRESSURE CHANGES WITHIN THE GHG PLUME

As shown in Figure 9-22, pressure within the GHG plume using results of Grid Model 'C' (0.01 kv:kh assumption), is predicted to be effectively contained within the Precipice Sandstone aquifer, with negligible pressure migration upwards in the GHG storage reservoir, indicating that the GHG stream injection is unlikely to compromise the integrity of the geological seal provided by the Evergreen Formation. Only limited increase is predicted in GHG storage reservoir pressures:

- when GHG stream injection ceases (end of 3 years injection), the maximum pressure increase is predicted to be equivalent to approximately 7.9 m of water head (approximately 11.2 psi);
- 2 years after GHG stream injection ceases (end of 2 years shut-in), the maximum pressure increase is predicted to be equivalent to approximately 1.8 m of water head (approximately 2.5 psi);
- 100 years after GHG stream injection ceases (end of 100 years shut-in), the maximum pressure increase is predicted to be equivalent to approximately 0.6 m of water head (approximately 0.8 psi).

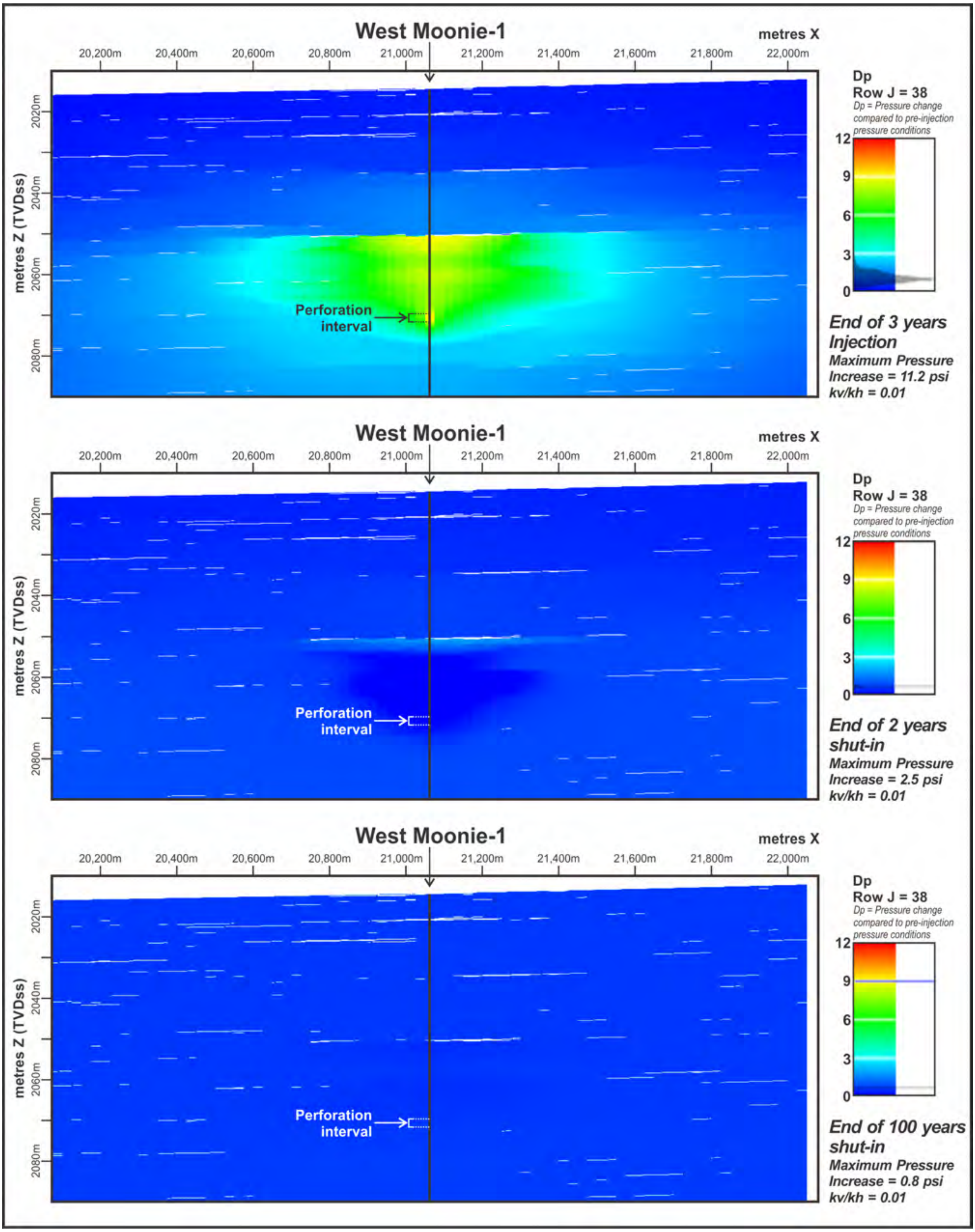

Figure 9-22 Pressure increases within the GHG plume, Grid Model 'C' (cross-section)

9.9.2.3 POTENTIAL EXTENT OF THE GHG PLUME WITHIN THE STORAGE COMPLEX

9.9.2.3.1 Potential Impact on Groundwater Movement

Further to sections 9.6.2.1.3 and 9.7.3.2, the Base case hydrogeological model set-up plus five sensitivity analysis cases of particle tracking (plume) movement, Cases 2.0 to 2.5 have been modelled. Results of the particle tracking (plume) movement are presented in Figure 9-23, showing the predicted travel of four groundwater "particles" over a 1,000-year simulation for the Base Case 2.0. Four groundwater particles are shown, one released from each green dot on the corners of a 750 m x 750 m square with West Moonie-1 Injection Well in the centre. The particle positions are shown in distance moved in the x (east-west) and y (north-south) directions, with the colouring of the points indicating the travel time. Step changes in particle travel direction are visible when GHG stream injection ceases, and when oil production from the Moonie Oil Field is anticipated to cease in 2030 (OGIA, 2019a). The net particle displacement is in the order of 20 m over the 1,000-year simulation. The low predicted particle displacement of 20 m is a result of the West Moonie-1 Injection Well being located in a deep region of the Surat Basin, away from the recharge and discharge areas in the north of the Surat Basin, consistent with the conceptual understanding of the groundwater flow of the Precipice Sandstone being relatively stagnate in the area of the West Moonie-1 Injection Well.

The five sensitivity analysis cases confirmed the predictions from the Base case model runs, small particle travel distances, and particle paths remained within the operational lands and EPQ10 boundary.

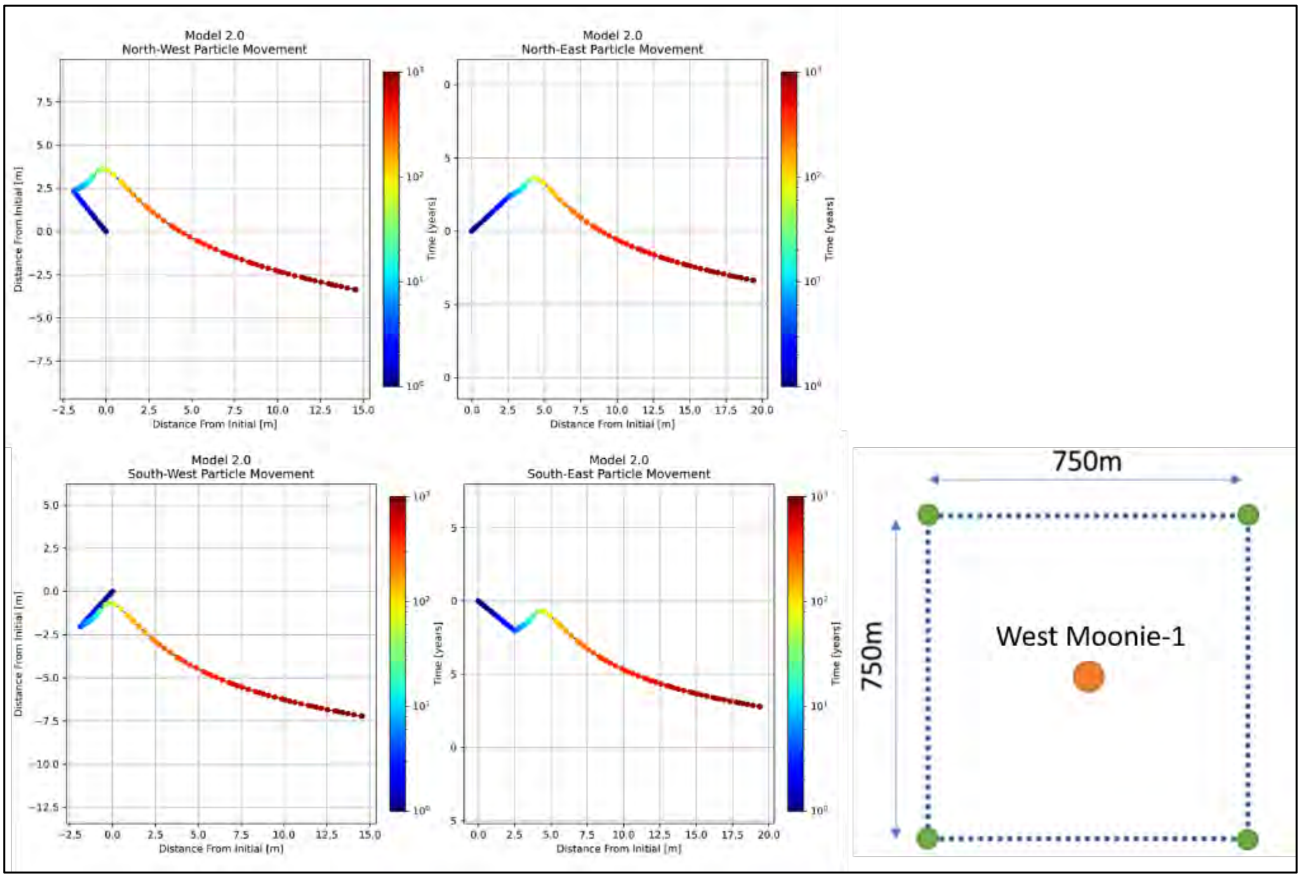

Figure 9-23 Groundwater Particle travel paths relative to starting position – the particles are released on the corners of a 750 m x 750 m square with West Moonie-1 in the centre

9.9.2.3.2 Potential Impacts on the Precipice Sandstone aquifer from CO_2 gas saturation and dissolved CO_2 gas within the GHG plume

Further to the dynamic (plume) model parameters described in section 9.6.2.2, the predicted impacts on the Precipice Sandstone aquifer from CO_2 gas saturation and dissolved CO_2 gas within the GHG plume, the results of Grid Model 'C' using the 0.01 kv:kh assumption are shown in Figure 9-24 for when GHG stream injection ceases (end of 3 years injection), 5 years after GHG stream injection ceases (end of 5 years shut-in), and 100 years after GHG stream injection ceases (end of 100 years shut-in).

For both CO_2 gas saturation and dissolved CO_2 gas within the GHG plume, over time the GHG stream concentration declines as the CO_2 reacts with the water and rock. Further discussion is given below in section 9.9.4 associated with potential groundwater chemistry and water quality impacts within the GHG plume.

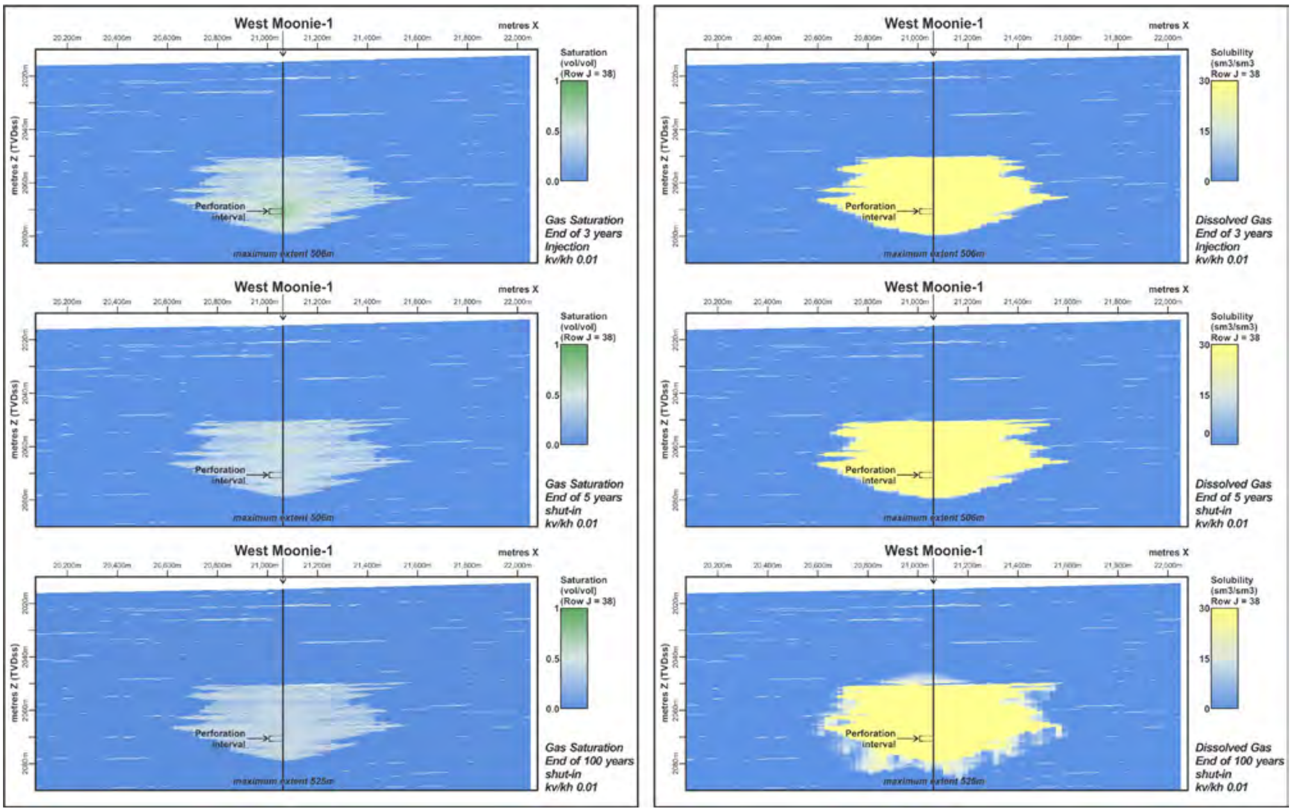

Figure 9-24 CO_2 gas saturation and dissolved CO_2 gas within the GHG plume, Grid Model 'C' (cross-section)

9.9.2.4 POTENTIAL IMPACTS ON THE EXTRACTION OF WATER FROM THE PRECIPICE SANDSTONE AQUIFER

Further to section 9.6.2.1.4, using the hydrogeological model and the dynamic (plume) model, three scenarios were prepared to examine groundwater extraction, being:

- Scenario 1 Base Case: includes existing extraction from the Precipice Sandstone aquifer from the Moonie Oil Field and Kogan Creek Power Station;
- Scenario 2: builds on Scenario 1 and adds existing water entitlements to the model; and
- Scenario 3: builds on Scenario 2 and adds hypothetical future entitlements from unallocated water.

9.9.2.4.1 Scenario 1 – Base Case of existing extraction from the Precipice Sandstone aquifer

Further to section 9.6.2.1.4.1 above, the GHG plume for the Base Case shows the predicted GHG plume extent of approximately 1,200 m to 1,500 m diameter centred around the West Moonie-1 Injection Well. Figure 9-25 shows the extent of the GHG plume when GHG stream injection ceases, 2 years after GHG stream injection ceases, 5 years after GHG stream injection ceases, and 100 years after GHG stream injection ceases. Figure 9-26 shows the predicted extent of the GHG plume within the operational lands.

In summary, the GHG plume:

- is predicted to be approximately 1,200 m in diameter when GHG stream injection ceases;
- is predicted to continue to expand from when the GHG stream ceases injection to approximately 2 years after injection ceases;
- will be less dense than the existing water in the Precipice Sandstone aquifer, so the GHG plume is predicted to rise as it expands through the Precipice Sandstone aquifer. The GHG plume will stop rising when it encounters the lower permeability rock of the Precipice Sandstone aquifer and the confining sediments of the upper Precipice Sandstone/lower Evergreen Formation;
- once injection ceases, gravity becomes the dominant force. Initially movement of the GHG plume is predicted to be upwards at West Moonie-1 Injection Well due to the low structural dip of approximately 2°, but as more CO_2 dissolves in the water, the contacted groundwater is predicted to increase in density, and movement of the GHG plume is predicted to be downwards;
- stability of the extent of the GHG plume from 2 years after injection ceases is shown by the limited differences in the contours of 2 years, 5 years, and 100 years after injection ceases;
- is predicted to extend to approximately 1,500 m in diameter around West Moonie-1 Injection Well.

The extent of the GHG plume for a total of 330,000 tonnes of GHG stream injected over a 3-year period is limited to approximately 1,500 m diameter GHG plume, which is all within the operational lands of lot 32PG223, 27PG462, 30PG222, and a parcel portion of the Tarawindi Road road reserve.

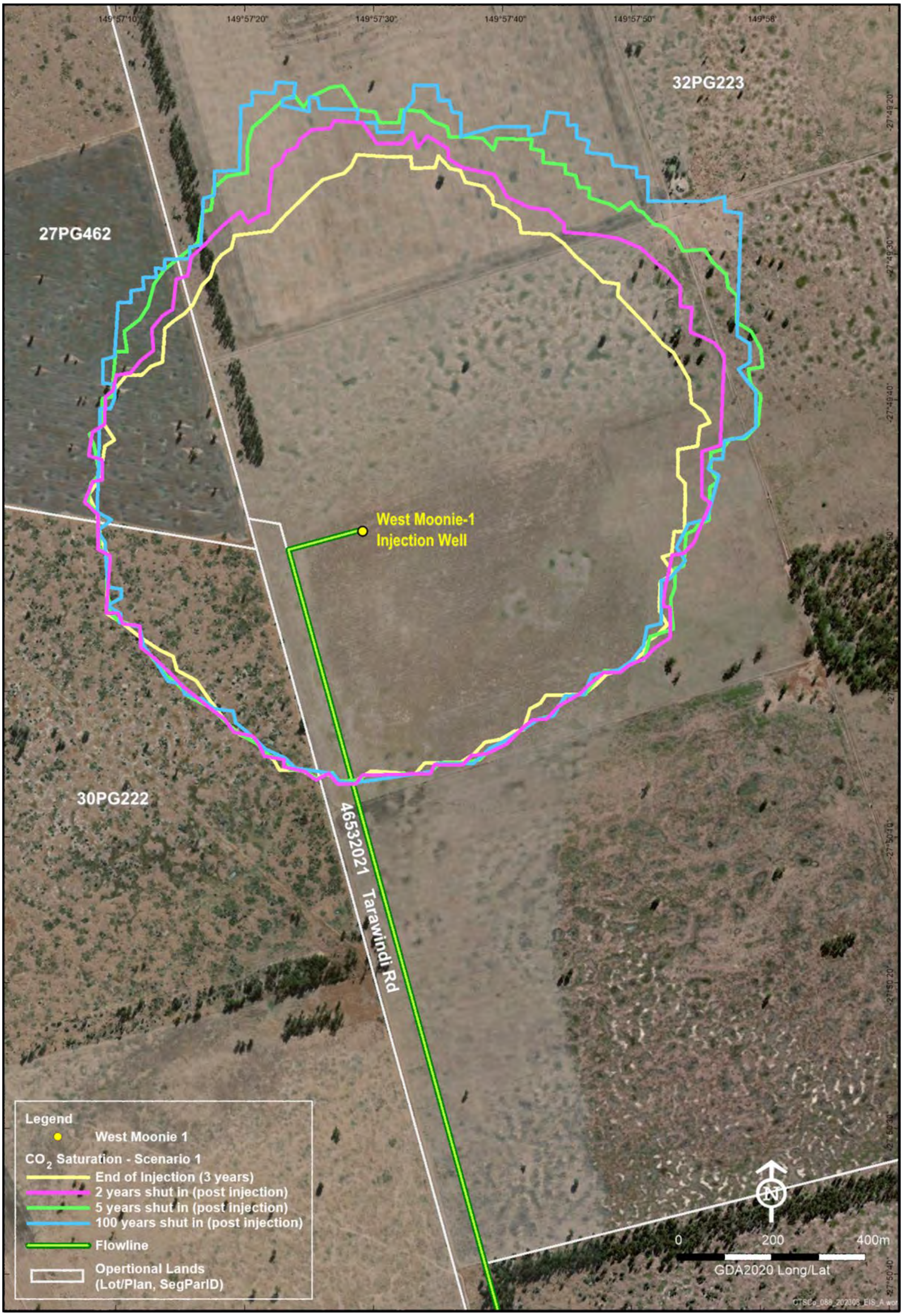

Figure 9-25 GHG Plume Extent for Scenario 1 – Base Case of existing extraction from the Precipice Sandstone aquifer

Figure 9-26 GHG Plume Extent within the operational lands for Scenario 1 – Base Case of existing extraction from the Precipice Sandstone aquifer

9.9.2.4.2 Scenario 2 – Precipice Sandstone aquifer existing water entitlements

Further to section 9.6.2.1.4.2 above, for Scenario 2 involving the extraction of groundwater under existing water entitlements for the Precipice Sandstone aquifer within a 50 km radius of the West Moonie-1 Injection Well the GHG plume is predicted to extend between 1,200 m to 1,500 m diameter centred around the West Moonie-1 Injection Well. Figure 9-27 shows the extent of the GHG plume when GHG stream injection ceases, 2 years after GHG stream injection ceases, 5 years after GHG stream injection ceases, and 100 years after GHG stream injection ceases. Figure 9-28 shows the predicted extent of the GHG plume within the operational lands.

In summary and further to Scenario 1 Base case, the GHG plume:

- is predicted to be approximately 1,200 m in diameter when GHG stream injection ceases;
- is predicted to continue to expand from when the GHG stream ceases injection to approximately 2 years after injection ceases;
- stability of the extent of the GHG plume from 2 years after injection ceases is shown by the limited differences in the contours of 2 years, 5 years, and 100 years after injection ceases;
- of Scenario 2 shows limited difference to the predicted GHG plume of Scenario 1;
- is predicted to extend to approximately 1,500 m in diameter around West Moonie-1 Injection Well.

Similar to Scenario 1, the GHG plume is predicted to extend to approximately 1,500 m diameter within the Precipice Sandstone aquifer within the operational lands.

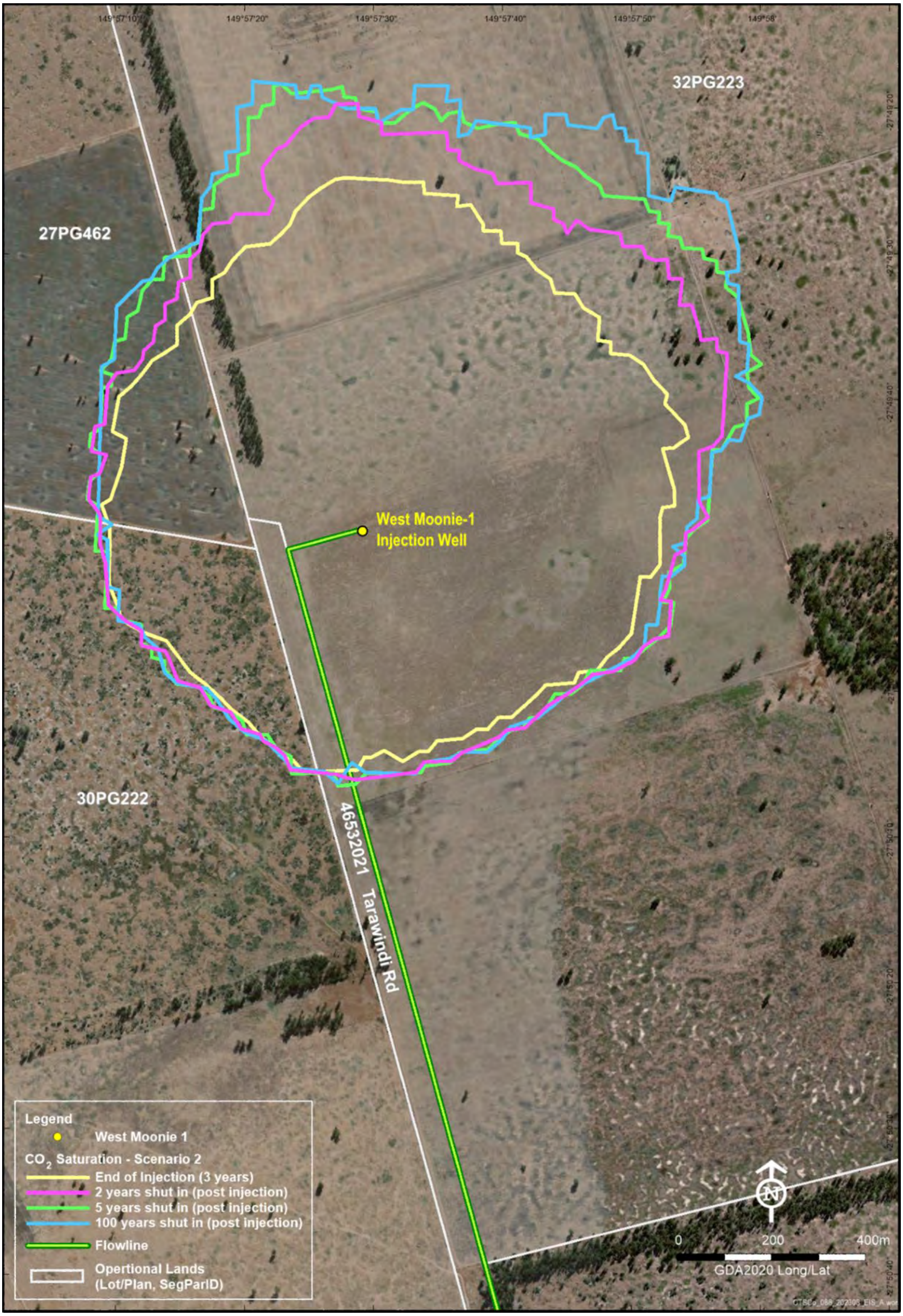

Figure 9-27 GHG Plume Extent for Scenario 2 – Existing Water Entitlements

Figure 9-28 GHG Plume Extent within the operational lands for Scenario 2 – Existing Water Entitlements

9.9.2.4.3 Scenario 3 – Hypothetical future entitlements from unallocated water

Further to section 9.6.2.1.4.3 above, for Scenario 3 involving the hypothetical future entitlements from unallocated water for the Precipice Sandstone aquifer, the GHG plume is predicted to extend between 1,300 m to 1,600 m diameter centred around the West Moonie-1 Injection Well. Figure 9-29 shows the extent of the GHG plume when GHG stream injection ceases, 2 years after GHG stream injection ceases, 5 years after GHG stream injection ceases, and 100 years after GHG stream injection ceases. Figure 9-30 shows the predicted extent of the GHG plume within the operational lands.

In summary and further to Scenario 1 Base case and Scenario 2 existing water entitlements, the GHG plume:

- is predicted to be approximately 1,300 m in diameter when GHG stream injection ceases;
- is predicted to continue to expand from when the GHG stream ceases injection to approximately 2 years after injection ceases;
- stability of the extent of the GHG plume from 2 years after injection ceases is shown by the limited differences in the contours of 2 years, 5 years, and 100 years after injection ceases;
- extends approximately 100 m more to the east for all years modelled compared to Scenarios 1 and 2, due to the additional hypothetical future entitlements from unallocated water for the Precipice Sandstone aquifer of 1,815 ML/y located 5 km due east of the West Moonie-1 Injection Well;
- is predicted to extend to approximately 1,600 m in diameter around West Moonie-1 Injection Well.

Similar to Scenarios 1 and 2, the GHG plume is predicted to extend to approximately 1,600 m diameter within the Precipice Sandstone aquifer within the operational lands.

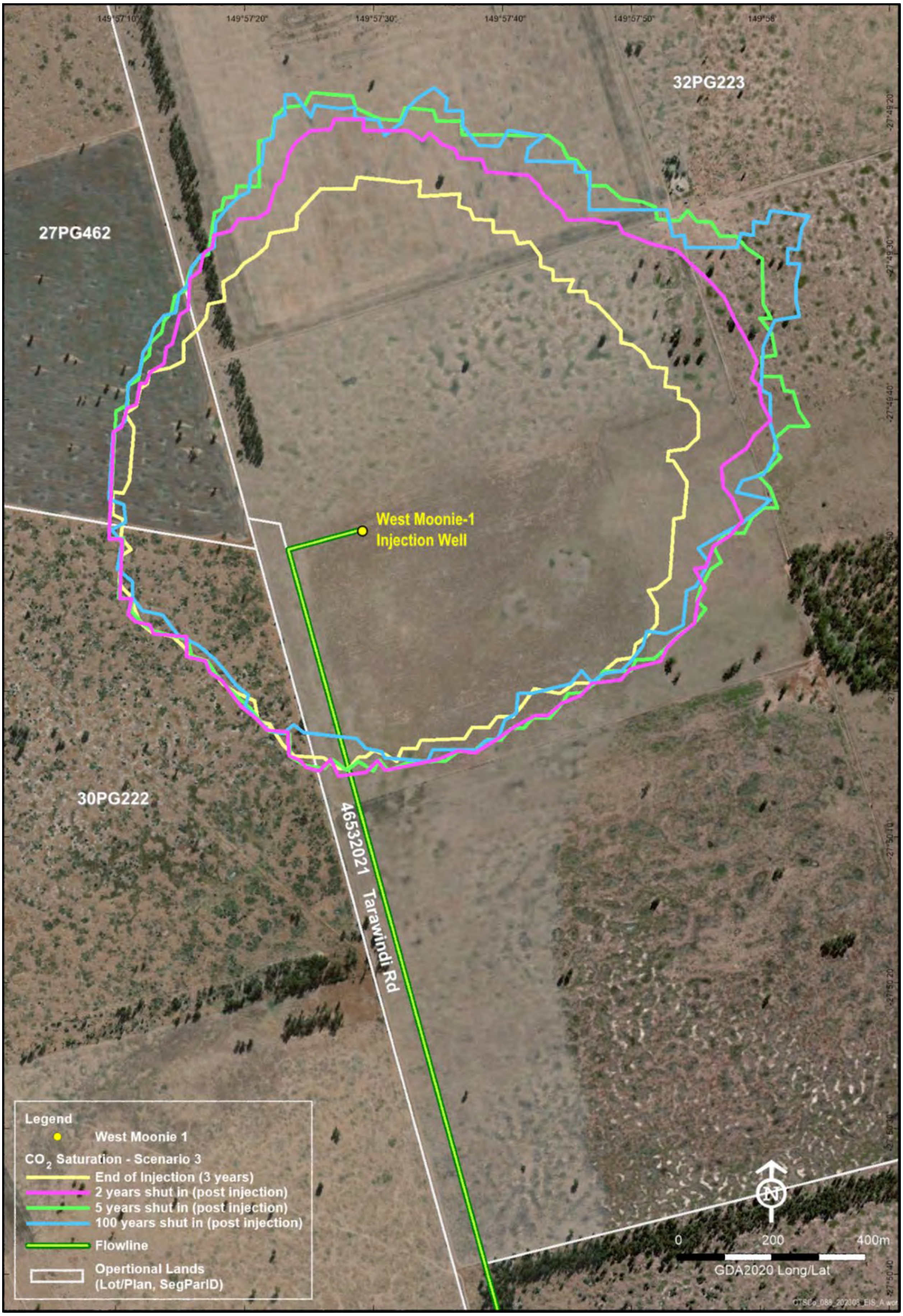

Figure 9-29 GHG Plume Extent for Scenario 3 – Hypothetical Future Entitlements from Unallocated Water

Figure 9-30 GHG Plume Extent within the operational lands for Scenario 3 – Hypothetical Future Entitlements from Unallocated Water

9.9.3 Potential Impacts on Groundwater Uses and Users of the Precipice Sandstone aquifer within the GHG Plume

The predicted extent of the GHG plume under the Scenarios in section 9.9.2.4 above has informed the assessment of potential impacts on groundwater uses and users of the Precipice Sandstone aquifer.

9.9.3.1 GROUNDWATER USE AND RESOURCE PRODUCTION OF THE PRECIPICE SANDSTONE AQUIFER WITHIN THE GHG PLUME

Further to section 9.7.4.1, no resource production activities are conducted or proposed to be conducted within the foreseeable future within the predicted GHG plume or within a 5 km radius of West Moonie-1 Injection Well within the Precipice Sandstone aquifer. Therefore, GHG storage injection testing activities are unlikely to potentially impact resource production activities. Avoidance and mitigation measures are provided in section 9.10 below.

9.9.3.2 GROUNDWATER USE AND WATER ENTITLEMENTS OF THE PRECIPICE SANDSTONE AQUIFER WITHIN THE GHG PLUME

Further to section 9.7.4.2, there are no water entitlements currently granted within the predicted GHG plume or within a 5 km radius of West Moonie-1 Injection Well within the Precipice Sandstone aquifer, therefore there are no potential impacts. Potential impacts associated with water entitlements outside of a 5 km radius from West Moonie-1 Injection Well are discussed further in section 9.9.6 below. Avoidance and mitigation measures are provided in section 9.10 below.

9.9.3.3 GROUNDWATER USE AND ECOLOGICAL FUNCTIONS OF THE PRECIPICE SANDSTONE AQUIFER WITHIN THE GHG PLUME

Further to section 9.7.4.3, there are no known recharge areas, springs or GDEs directly connected to the Precipice Sandstone aquifer that is predicted to be within the GHG plume or within a 5 km radius of West Moonie-1 Injection Well within the Precipice Sandstone aquifer, therefore there are no potential impacts. Potential impacts associated with recharge areas, springs or GDEs outside of a 5 km radius from West Moonie-1 Injection Well are discussed further in section 9.9.6 below. Avoidance and mitigation measures are provided in section 9.10 below.

9.9.4 Potential Groundwater Chemistry and Water Quality Impacts on the Precipice Sandstone aquifer within the GHG Plume

The potential impacts on groundwater chemistry and water quality due to GHG storage injection testing are driven by:

- the physical and chemical parameters of the GHG stream;
- the inherent physical and chemical properties of the geology of the GHG storage reservoir;
- the existing water quality parameters present, speciation and concentration;
- the interaction of the GHG stream as the GHG plume in GHG storage reservoir.

The scope and magnitude of a potential impact is dependent upon:

- legislative requirements of the EP Act, EP Regulation, EPP (Water and Wetland Biodiversity) Policy, QMDB and associated EVs and WQOs; and
- control and management measures as part of the Project's design and implementation, as described in Chapter 2 Proposed Project Description, and section 9.8 above.

Any additional avoidance and mitigation measures are given in section 9.10 below, and in Chapter 2 Proposed Project Description, section 2.11.

9.9.4.1 GHG STREAM PHYSICAL AND CHEMICAL PARAMETERS

The physical and chemical parameters of the GHG stream are described in Chapter 2 Proposed Project Description, section 2.4.1 and Table 2-2 which provide the Proposed GHG Stream Composition. Sections 9.9.2.3 and 9.9.2.4 above provide the key points associated with the GHG stream injection and GHG plume behaviour, with Chapter 2 Proposed Project Description, sections 2.8.1.2.1, 2.10.4.1 and 2.11.1 providing additional details.

As outlined in section 9.8, the GHG stream is injected into the Precipice Sandstone aquifer with similar pressure and temperature conditions therefore minimising the potential for hydraulically or thermally induced fracturing.

9.9.4.2 GHG PLUME STORAGE TRAPPING MECHANISM

The GHG stream will be trapped by a process termed Migration Assisted Trapping (MAT). The effectiveness of MAT is dependent on the permeability characteristics of the GHG storage reservoir and solubility of the injected GHG stream. The GHG plume is contained by a combination of mechanisms and reactions as it moves through a permeable stratigraphic unit, being the Precipice Sandstone aquifer. Three primary mechanisms will contribute to the storage of the GHG stream within the Precipice Sandstone storage reservoir as schematically illustrated in Figure 9-31, and summarised as:

- **Residual trapping** (capillary pressure hysteresis): is a mechanism where a proportion of the injected GHG stream remains as disconnected residual CO_2 within the pore spaces of the GHG storage reservoir and becomes immobile, which results in decreased saturation of supercritical CO_2 within the GHG storage reservoir.
- **Solubility trapping**: is a mechanism where the supercritical CO_2 is dissolved into the GHG storage reservoir groundwater. The CO_2 dissolves into the available water molecules within the porous formation rock. The CO_2-enriched water is then denser than the groundwater around it, resulting in the CO_2-enriched water sinking to the floor of the GHG storage reservoir whereby the CO_2 is further contained at the bottom of the GHG storage reservoir.
- **Mineralisation trapping**: when CO_2 is dissolved in water, chemical reactions take place between the CO_2 and the mineral composition of the GHG storage reservoir rock and groundwater. These reactions allow for some CO_2 to be bound (trapped) to the GHG storage reservoir rock.

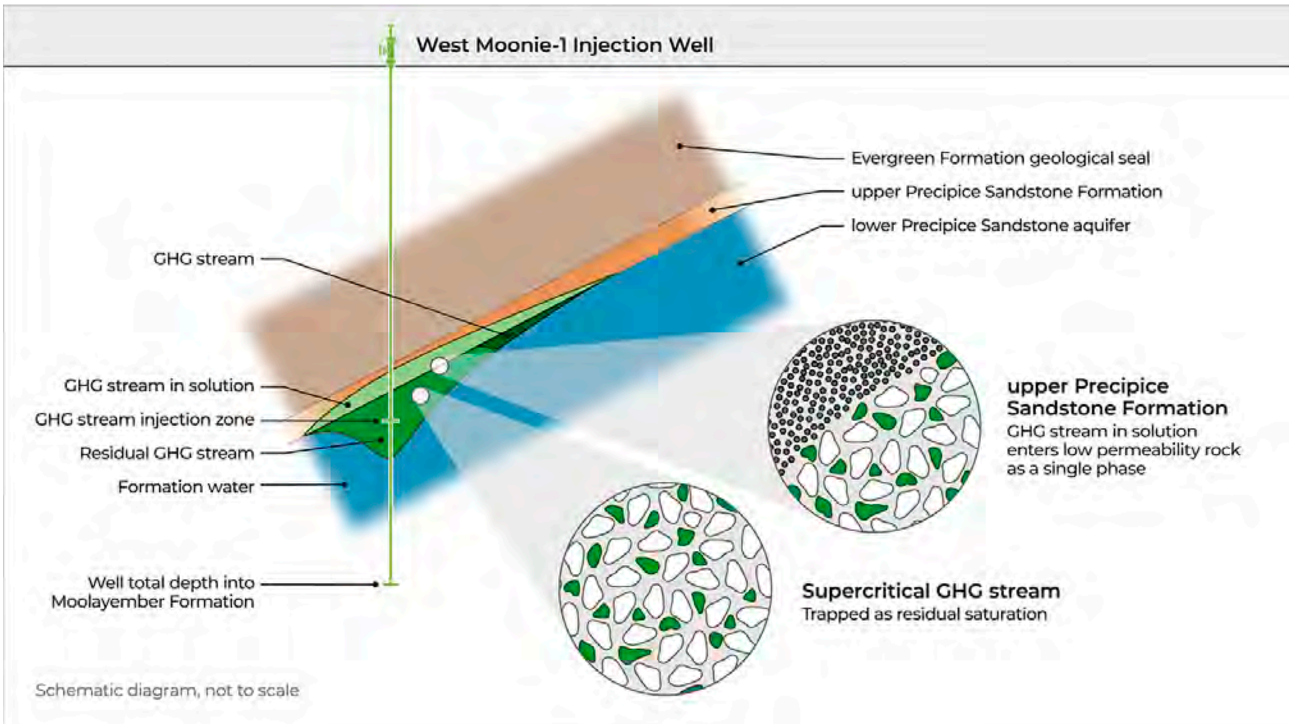

Figure 9-31 Schematic showing Migration Assisted Trapping (MAT) mechanisms

9.9.4.3 RADIAL REACTIVE TRANSPORT MODELLING (RTM) ASSESSMENT OF GHG PLUME POTENTIAL IMPACTS ON GEOCHEMISTRY AND GROUNDWATER QUALITY OF THE GHG STORAGE RESERVOIR

The draft EIS groundwater technical report (WSP Golder, 2022) reaction path modelling used a simple mineralogy (quartz, illite, kaolinite, siderite) and did not include minor or trace metals (chemical parameters) in siderite where carbonate mineral dissolution is the main source of trace metals. Reaction path modelling that does not include the major metal hosts and is not constrained by actual trace metal concentrations of any of the host phases cannot be used to predict trace metal concentrations in impacted groundwater values.

The RTM completed by Dawson *et al* (2022) in Appendix 9C does include actual minor and trace chemical parameters from quartz, illite, kaolinite and siderite where carbonate mineral dissolution is a source of trace chemical parameters, as described in Chapter 8 Geology, section 8.7.6.6. The RTM by Dawson *et al* (2022) replaces the previous geochemical modelling presented in draft EIS, with Appendix 9A of the final EIS amended to reflect the change. The RTM geochemical modelling by Dawson *et al* (2022) was not complete at the time of the draft EIS submission, with the work now finalised as presented in Appendix 9C. The RTM results presented in Appendix 9C vary spatially and temporarily as the GHG plume is predicted to evolve over time.

The RTM used a realistic range of mineralogy and mineral compositions that included minor and trace inorganic chemical parameters constrained by sequential core leaching, and reaction path modelling of batch reactor CO_2-water-rock experiments under simulated in situ conditions, as detailed in Appendix 9C (Dawson *et al*, 2022) and summarised Appendix 9D (Golding & Pearce, 2023). The RTM of the supercritical GHG stream (CO_2) saturation and pH was simulated to 100 years from time of injection. Figure 9-32 shows the GHG stream saturation and pH distribution over 3 years (end of injection, operation phase), 10 years, 50 years, and 100 years across an injection interval of 30 m (Dawson *et al*, 2022, Figure 62). The dynamic (plume) modelling predicts the extent of the GHG plume to be 1,200 m to 1,500 m in diameter centred around the West Moonie-1 Injection Well during the injection phase (operation phase) and proposed monitoring phase of 2 years. However, the RTM predicts that based on pH and water chemistry impacts, the GHG plume may extend some 800 m to 900 m in radius (1,600 m to 1,800 m in diameter) from the West Moonie-1 Injection Well at 100 years from the commencement of injection.

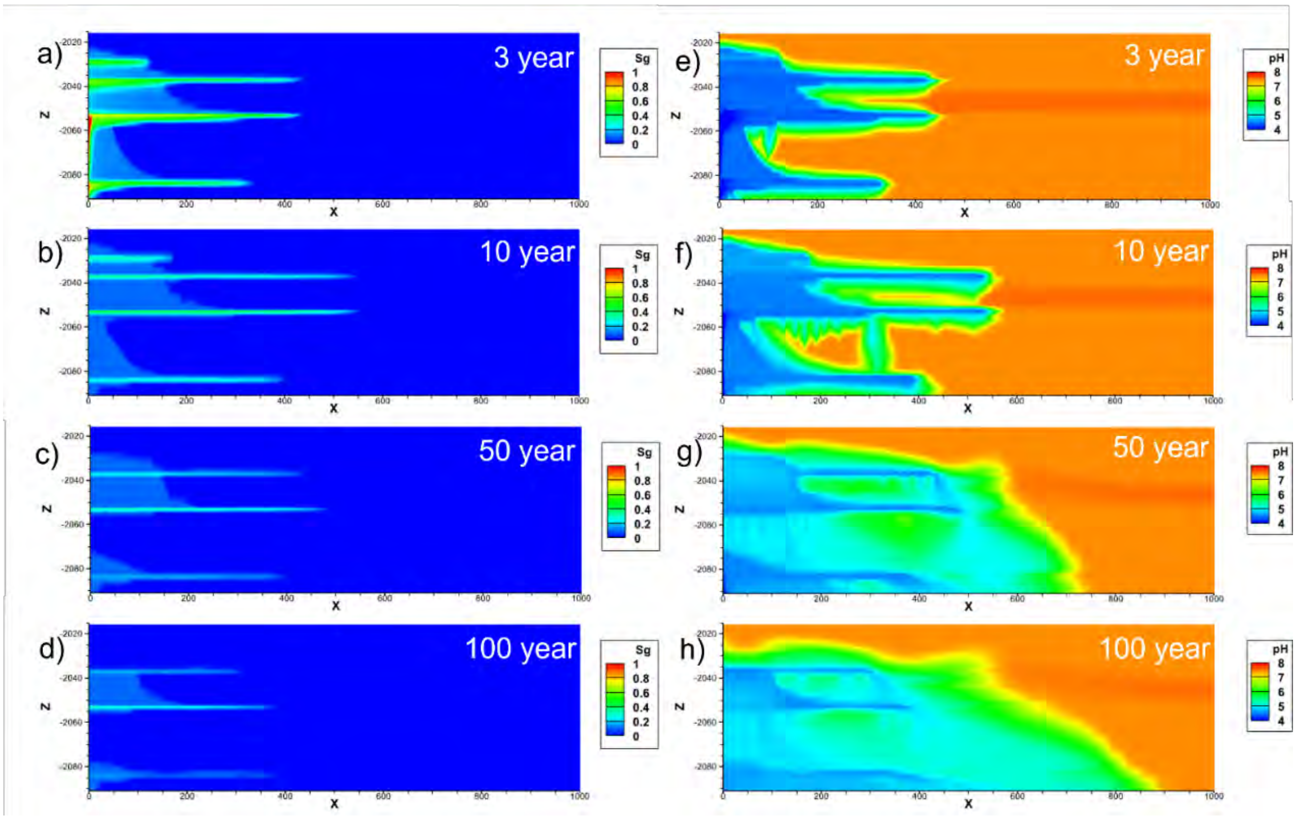

Figure 9-32 Supercritical GHG stream (CO_2) saturation (a - d– and pH (e - h) distribution over time at 3, 10, 50 and 100 years for the simulation across a 30 m injection interval (based on Figure 62 from Dawson *et al* (2022))

Different locations within the predicted GHG plume were modelled, as summarised in Table 9-44 and shown in Figure 9-33, for the temporal evolution of pH, dissolved iron (Fe), dissolved potassium (K), dissolved magnesium (Mg), and bicarbonate (HCO_3^-).

Table 9-44 Locations of Plots for Predication of Chemical Parameter Concentrations

Location of Plot	X (horizontal distance from West Moonie-1 Injection Well in metres)	Z (subsea total vertical depths (SSTVD) in metres)	Equivalent depth below ground level (in metres)
1	200	-2,054.5	-2,297.5
2	200	-2,065	-2,308
3	200	-2,043	-2,286
4	200	-2,031	-2,274
5	700	-2,088	-2,331

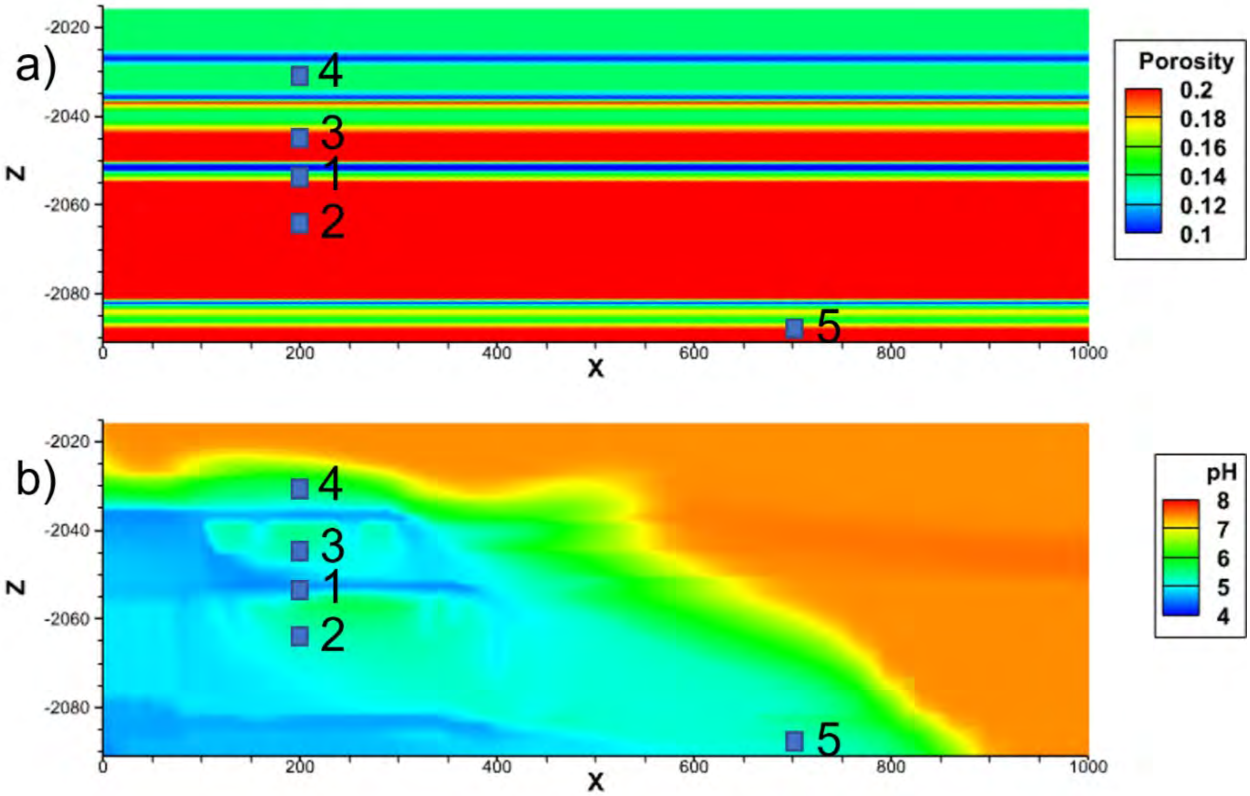

Figure 9-33 Locations of Plots for Chemical Parameters within the GHG Plume, based on a 30 m injection interval over a 100-year period

Figure 9-34, Figure 9-35, Figure 9-36 and Figure 9-37 show the temporal evolution of the chemical parameters predicted by the RTM. There are major differences in chemical parameter behaviour through time at different locations in the GHG plume, especially iron, as summarised in Table 9-45 below. Over time, the behaviour of the chemical parameters at different locations in the GHG plume show that impacts on water chemistry are highly variable in space and time.

The RTM shows major variation in chemical parameters composition where magnesium, potassium and bicarbonate increase through time; iron shows an increasing then a decreasing pattern with time at most locations, as given in Figure 9-34, Figure 9-35 and Figure 9-36 (Dawson *et al*, 2022, Figures 72, 74 and 76). The behaviour of iron is particularly important since the concentration of many trace metals (trace chemical parameters) is dynamically linked to the iron concentration since a major sink (and often source) of those trace metals is iron-containing minerals. Moreover, dissolved iron in experimental studies shows an increasing then decreasing concentration behaviour where oxygen (O_2) supply allows the precipitation of iron oxides acting as a sink for metals, which is consistent with the RTM results.

Table 9-45 RTM predicted groundwater quality impacts in the GHG plume for Locations shown in Figure 9-33, including comparison to WQOs for aquatic ecosystem and irrigation/farm use

Chemical Parameters	Aquatic Ecosystem WQO	Irrigation/Farm Use WQO	Existing water quality in Precipice Sandstone aquifer (Sample 3 at 145,000 L)	Predicted maximum concentration if not at 100 years(1)	Predicted concentration after 100 years(1)
pH	8.6 – 80th %ile	6 to 8.5	8.35	Locally as low as 4, excluding very small volume near the injector	≅ 5 [1] 5.1 [2] 5.4 [3] 5.1 [5]
Iron (Fe) (mg/L)	-	0.2 (long-term) 10 (short-term)	2.78	≅ 180 [1] 50 [2] 20 [3]	≤ 10 [1, 2, 3, 5]
Potassium (K) (mg/L)	-	-	150		≅ 75 [1] 80 [2] 45 [3] 140 [5]
Magnesium (Mg) (mg/L)	1.0 – 50th %ile 5.0 – 80th %ile	-	1		≅ 90 [1] 140 [2] 45 [3] 80 [5]
Bicarbonate (HCO_3^-) (mg/L)	673 – 80th %ile	-	1,060		1,780 [1] 2,050 [2] 1,550 [3] 1,900

Notes:
(1) numbers in [brackets] refer to Locations of Plots in Figure 9-33.

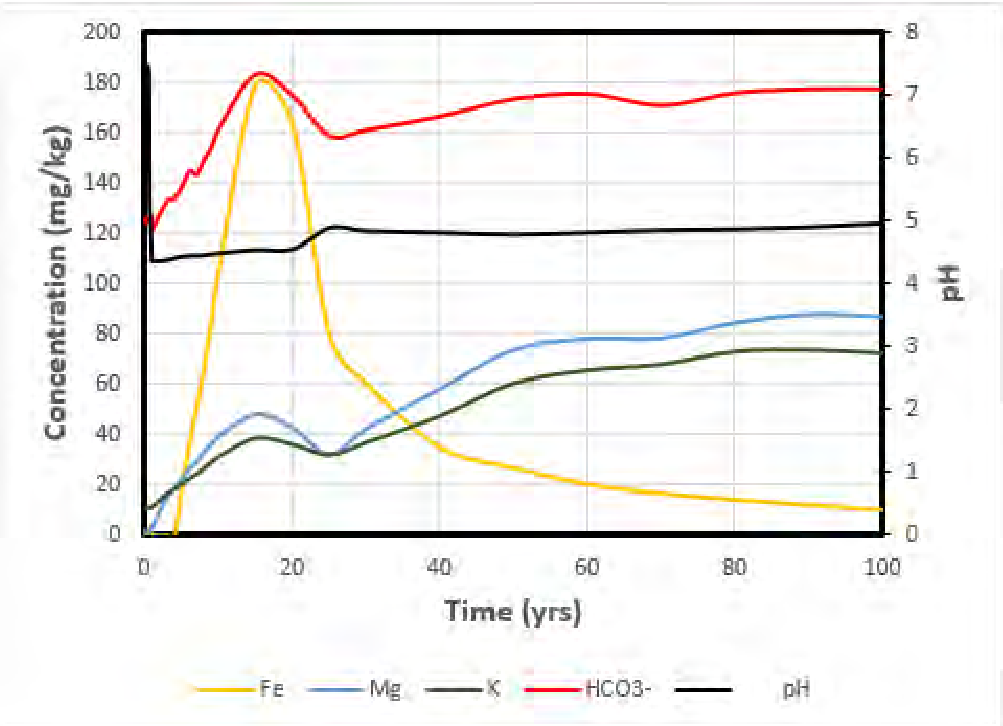

Figure 9-34 Major chemical parameters (Fe, K, Mg, HCO_3^- and pH) at Location 1. Concentrations in mg/kg (≅ mg/L) with HCO_3^- total decreased by an order of magnitude. (source: Figure 72 from Dawson et al. (2022)). Note that for the HCO_3^- concentration with the other elements on the Y scale, the HCO_3^- concentration shown is an order of magnitude less than predicted (e.g. HCO_3^- shown as 180 mg/L on graph is actually 1,800 mg/L).

The predictions from the RTM show major variation in major chemical parameter concentrations through time. By way of example, for Location 1 shown in Figure 9-34, the RTM predicts for the major chemical parameters pH, iron (Fe), potassium (K), magnesium (Mg), bicarbonate (HCO_3^-), that the pH begins to decrease at just before 0.5 years with a coinciding small increase in bicarbonate (HCO_3^-) and iron (Fe). Shortly thereafter, the magnesium (Mg) increases and by 5 years there are some significant increases in concentrations of all the chemical parameters. Mineral dissolution and precipitation reactions can result in increases or decreases in concentrations. Similarly, advective transport both during formation water displacement (displacement of the existing water in the Precipice Sandstone aquifer) by the GHG stream as it migrates, and through density driven convective flow can result in increases or decreases in chemical parameter concentrations. Siderite dissolution and iron (III) hydroxide ($Fe(OH)_3$) precipitation dominate in the first 5 years as indicated by the increases in bicarbonate (HCO_3^-) and magnesium (Mg) and the initial small increase in iron (Fe) then decrease as iron (III) hydroxide ($Fe(OH)_3$) precipitates. At 5 years, the oxygen (O_2) is exhausted and iron (Fe) increases, largely through siderite dissolution. Dissolution of the trace chemical parameters containing siderite stops at 10 years, although siderite (without trace chemical parameters) precipitation initiates at 5 years. The increase in iron (Fe) from 10 years to 15 years is largely through advective transport through density driven convection. After approximately 15 years, the iron (Fe) along with the other chemical parameters, begins to decrease through increasing siderite precipitation and advective transport. At 25 years, there is another shift in the flow dynamics, possibly through a reduction in the convective drive and chlorite and K-feldspar dissolution becomes dominant resulting in increases in potassium (K), magnesium (Mg), and bicarbonate (HCO_3^-).

Appendix 9C (Dawson *et al*, 2022) discusses in further detail the variation in major chemical parameters concentrations for each Location shown in Figure 9-33 and plotted in Figure 9-35, Figure 9-36, and Figure 9-37 below.

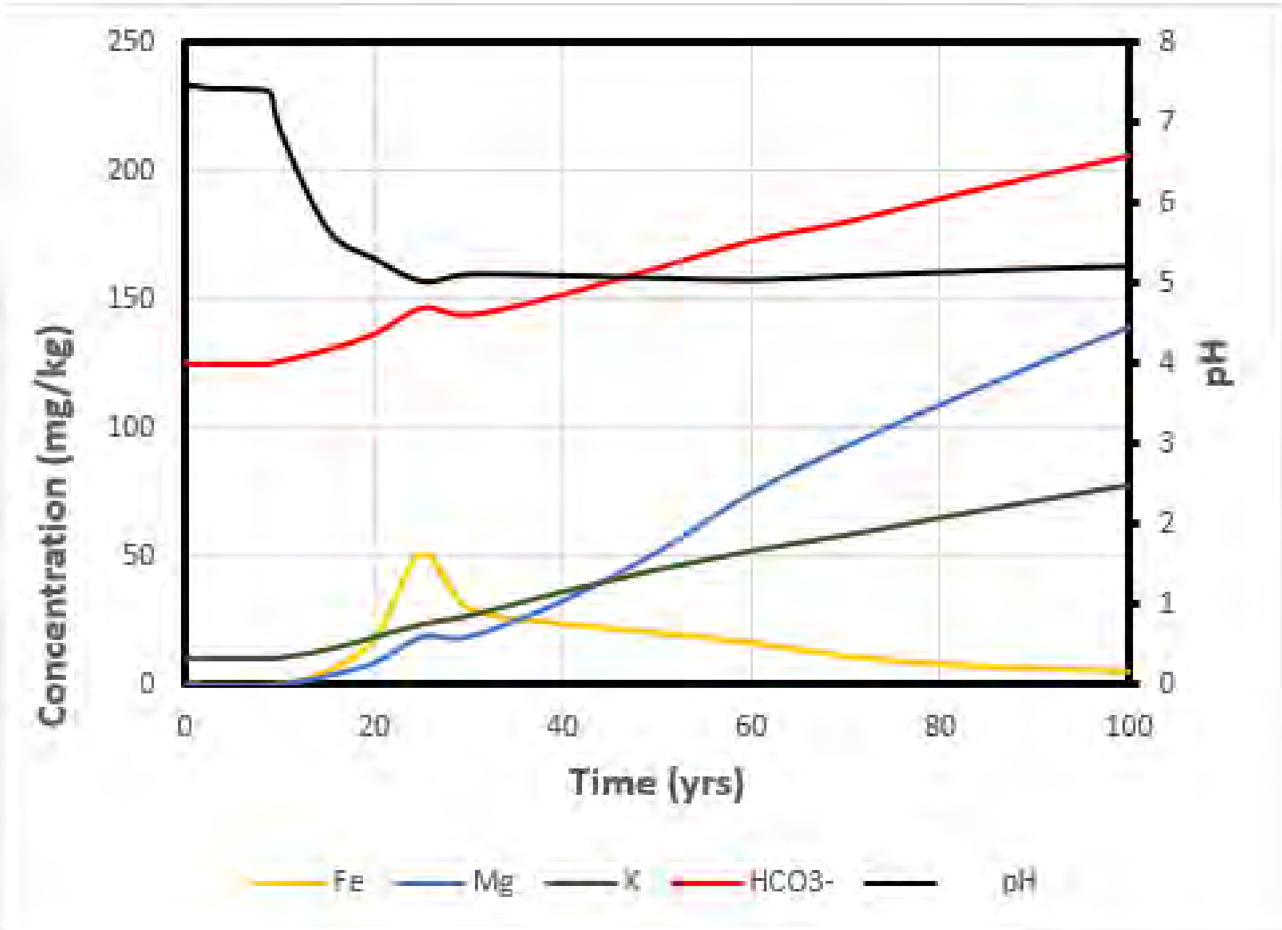

Figure 9-35 Major chemical parameters (Fe, K, Mg, HCO_3^- and pH) at Location 2. Concentrations in mg/kg (≅ mg/L) with HCO_3^- total decreased by an order of magnitude. (source: Figure 74 from Dawson *et al* (2022)). Note that for the HCO_3^- concentration with the other elements on the Y scale, the HCO_3^- concentration shown is an order of magnitude less than predicted (e.g. HCO_3^- shown as 150 mg/L on graph is actually 1,500 mg/L)

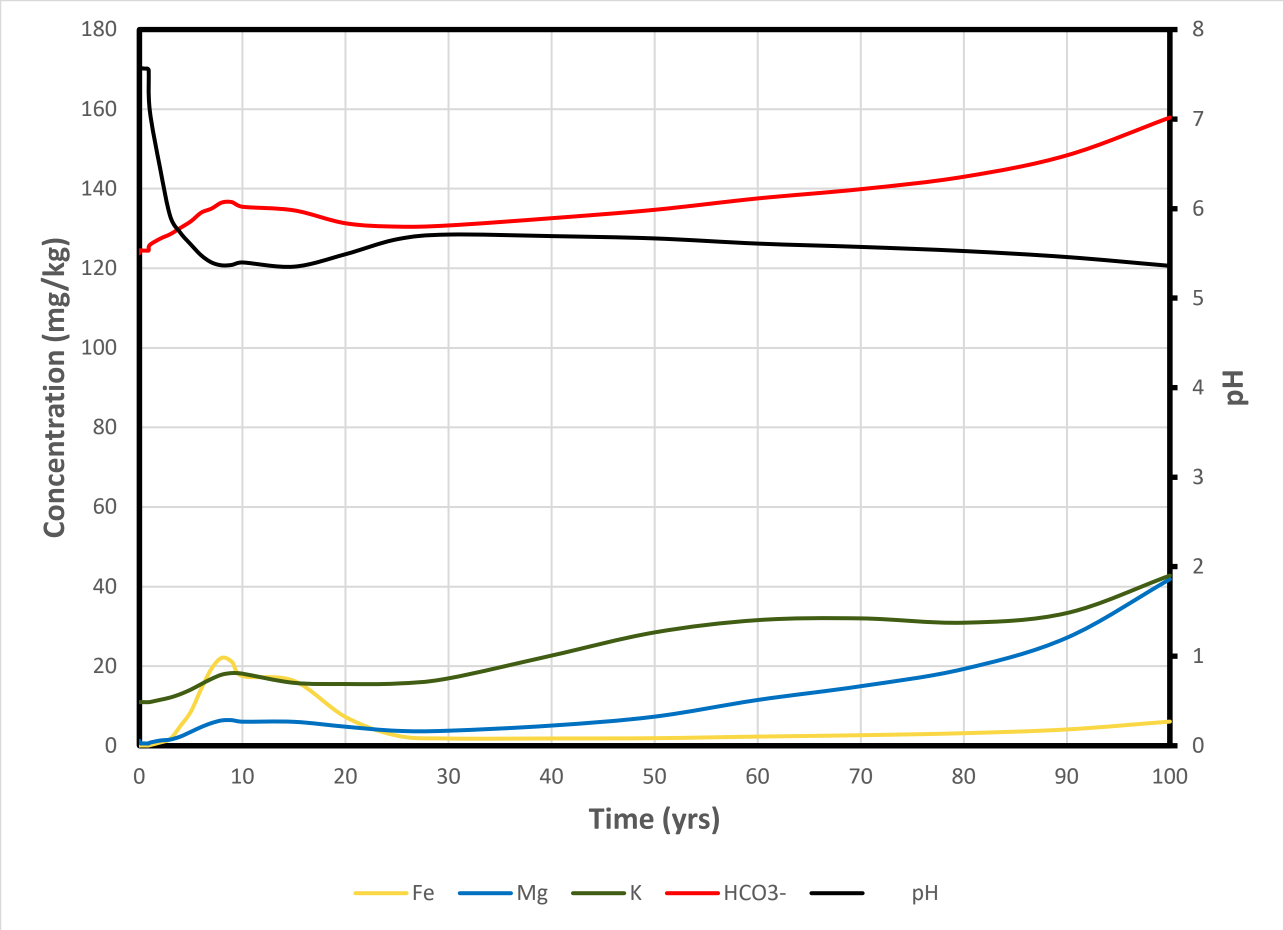

Figure 9-36 Major chemical parameters (Fe, K, Mg, HCO3- and pH) at Location 3. Concentrations in mg/kg (≅ mg/L) with HCO3- total decreased by an order of magnitude. (source: Figure 76 from Dawson *et al* (2022)). Note that for the HCO3- concentration with the other elements on the Y scale, the HCO3- concentration shown is an order of magnitude less than predicted (e.g. HCO3- shown as 140 mg/L on graph is actually 1,400 mg/L)

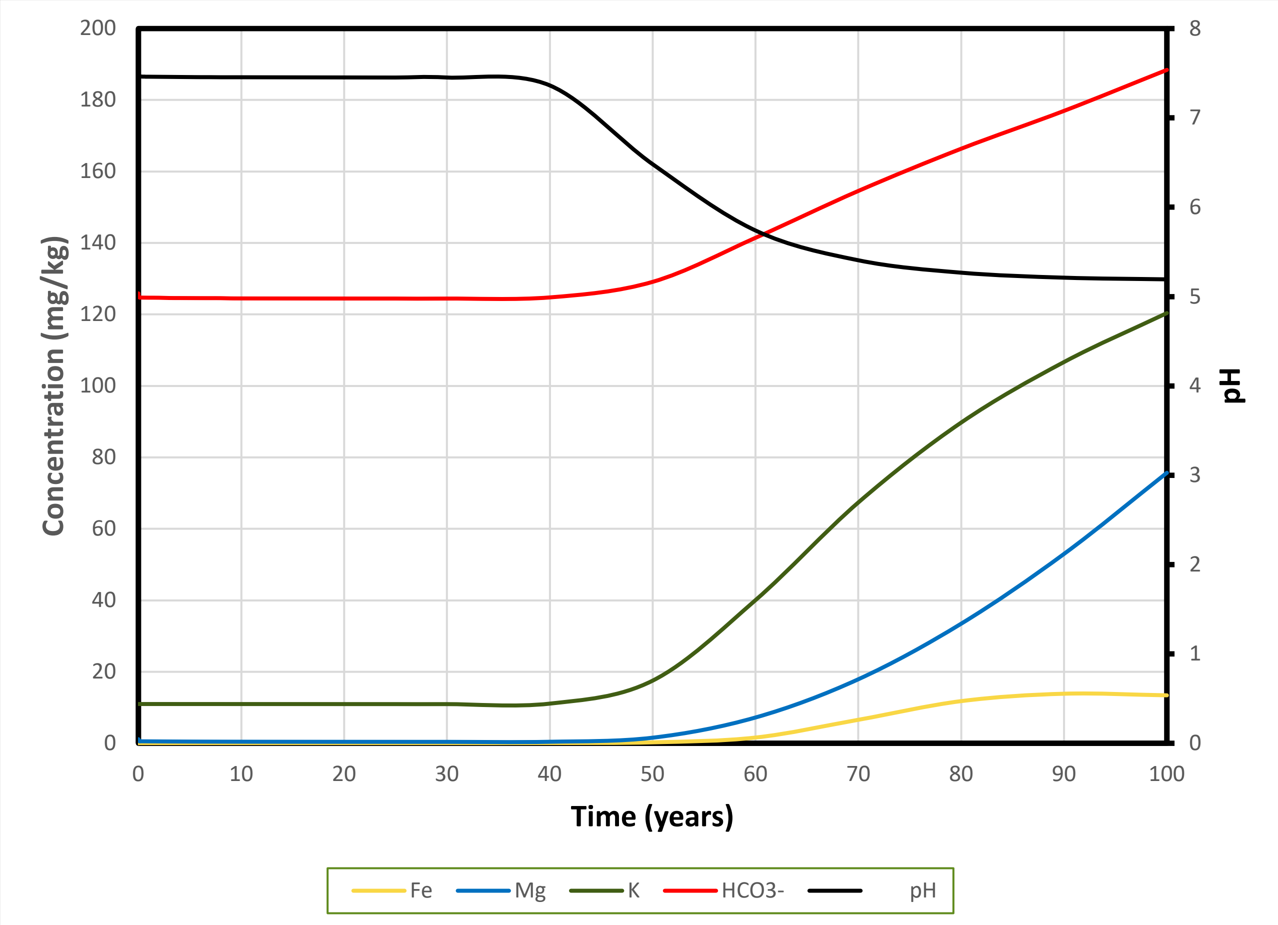

Figure 9-37 Major chemical parameters (Fe, K, Mg, HCO_3^- and pH) at Location 5. Concentrations in mg/kg (≅ mg/L) with HCO_3^- total decreased by an order of magnitude. (source: Figure 80 from Dawson *et al* (2022)). Note that for the HCO_3^- concentration with the other elements on the Y scale, the HCO_3^- concentration shown is an order of magnitude less than predicted (e.g. HCO_3^- shown as 140 mg/L on graph is actually 1,400 mg/L)

Like iron (Fe), dissolved arsenic (As) and lead (Pb) mostly display an increasing then decreasing trend in concentration where the arrival time of the highest chemical parameter concentration reflects the chemical controls on chemical parameter mobilisation and demobilisation, as well as distance from the West Moonie-1 Injection Well and the porosity and permeability of the individual Locations. Figure 9-38, Figure 9-39, Figure 9-40, Figure 9-41 and Figure 9-42 provide changes in arsenic and lead concentrations predicted over a 100-year period at the five Locations shown in Figure 9-33 and Table 9-44 (Dawson *et al*, 2022; Figures 73, 75, 77, 79, 81).

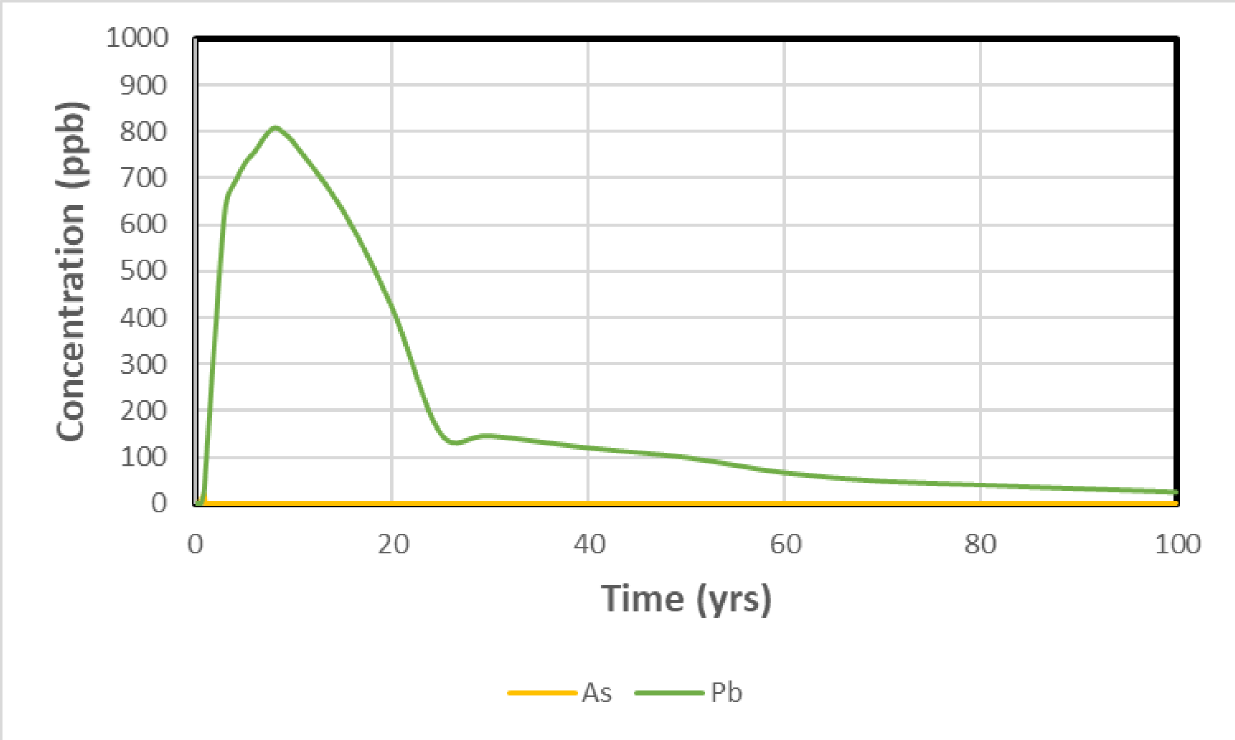

Figure 9-38 Location 1 Arsenic (As) and Lead (Pb) concentrations in ppb (where 1 mg/L approximately equals 1,000 ppb). (source: Figure 73 from Dawson *et al*, 2022)

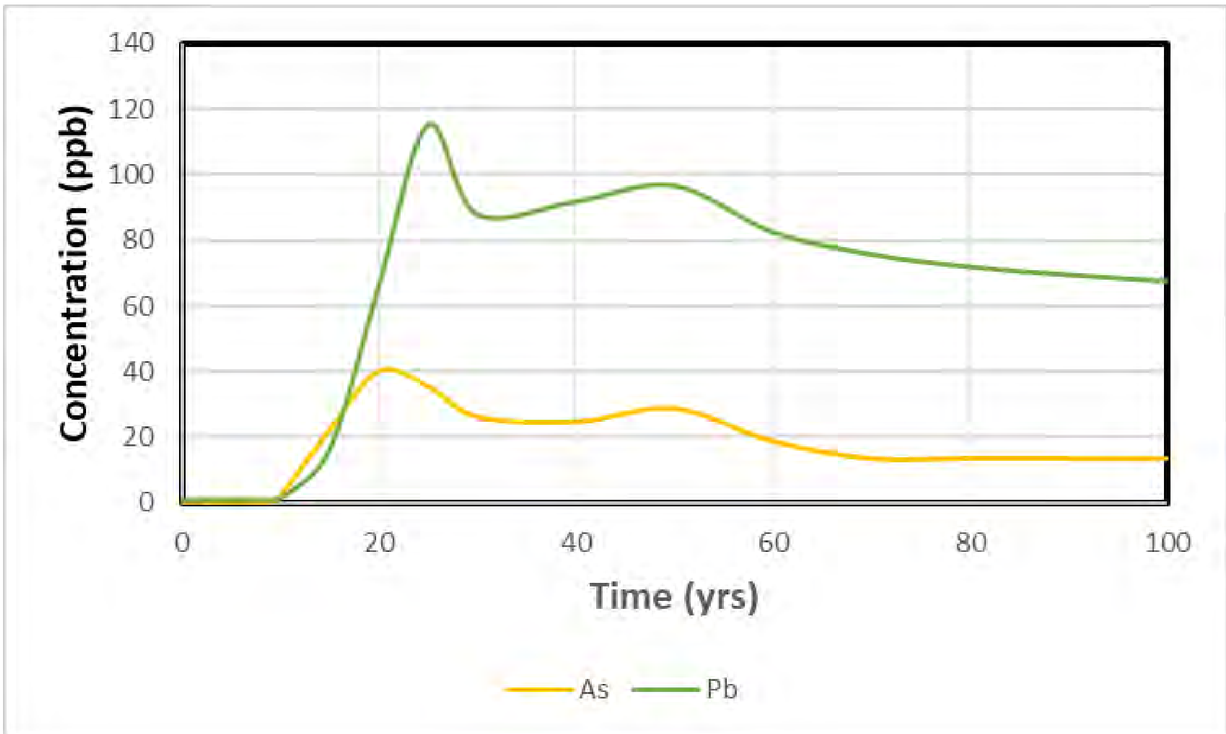

Figure 9-39 Location 2 Arsenic (As) and Lead (Pb) concentrations in ppb (where 1 mg/L approximately equals 1,000 ppb). (source: Figure 75 from Dawson *et al*, 2022)

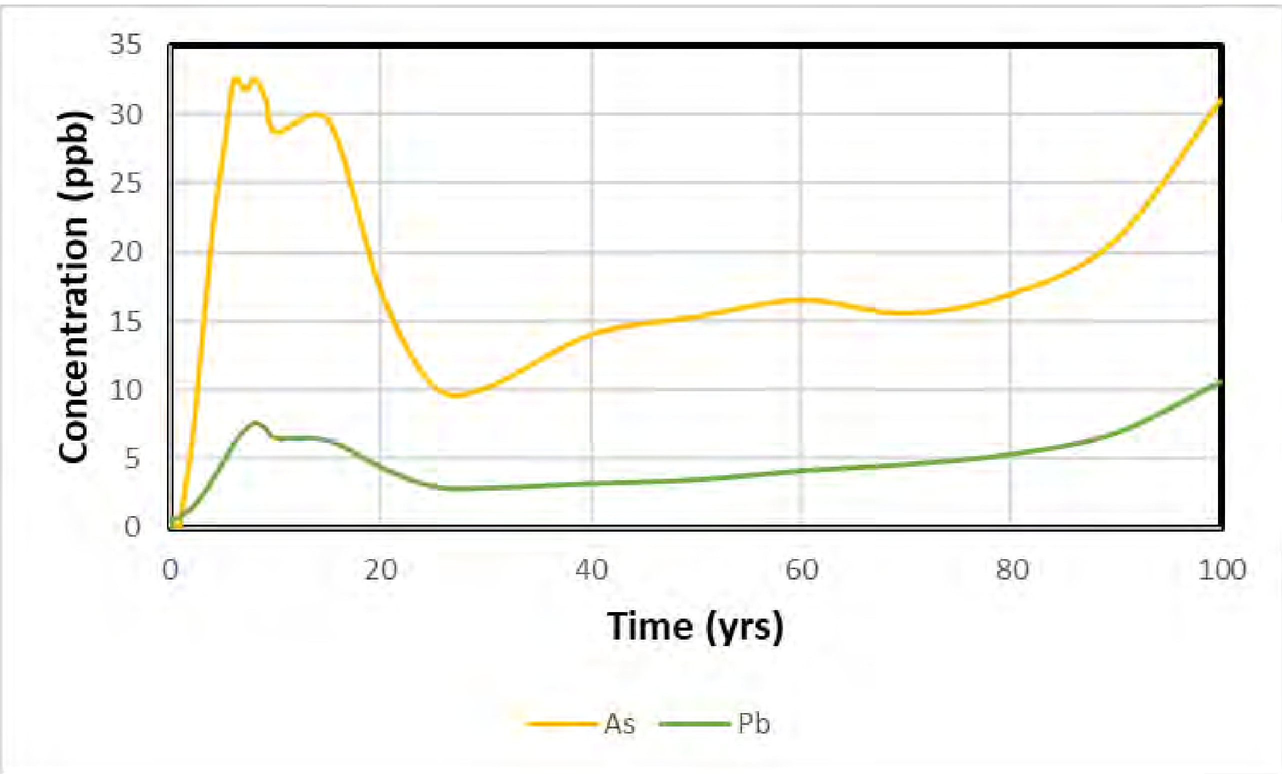

Figure 9-40 Location 3 Arsenic (As) and Lead (Pb) concentrations in ppb (where 1 mg/L approximately equals 1,000 ppb). (source: Figure 77 from Dawson *et al*, 2022)

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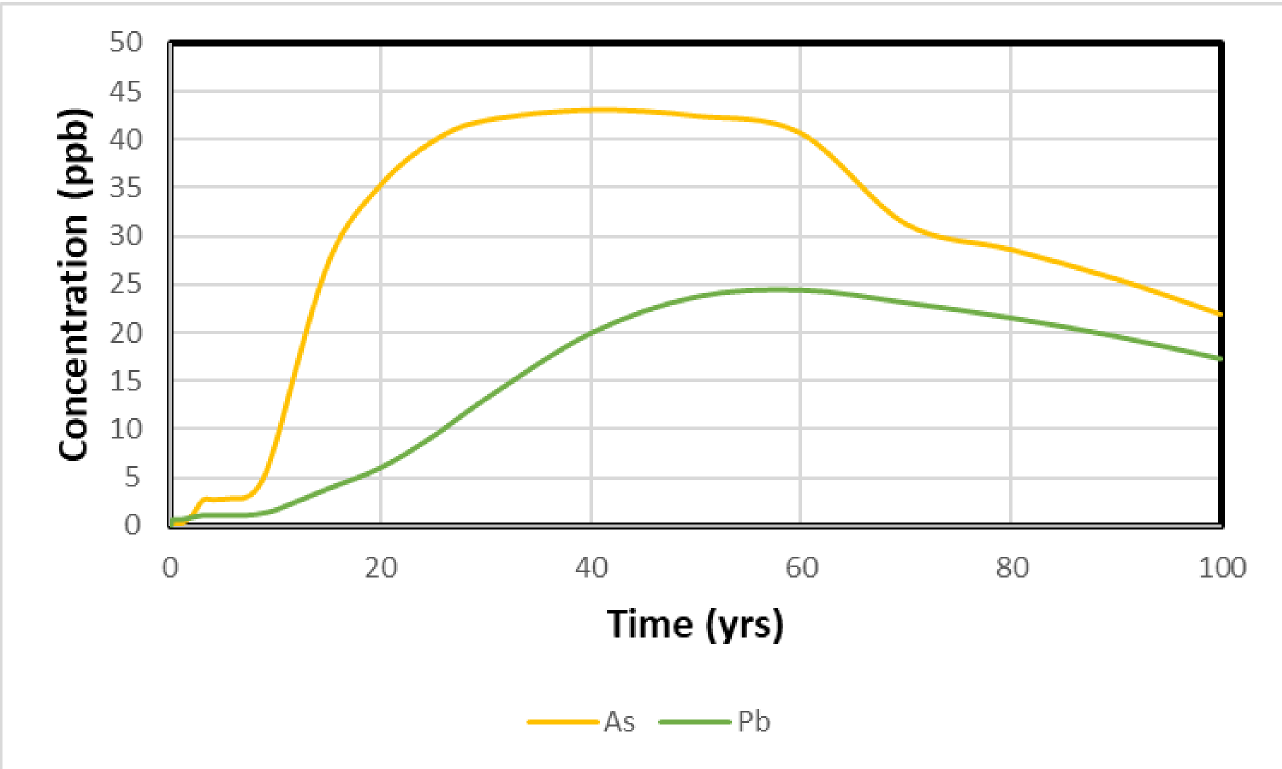

Figure 9-41 Location 4 Arsenic (As) and Lead (Pb) concentrations in ppb (where 1 mg/L approximately equals 1,000 ppb). (source: Figure 79 from Dawson *et al*, 2022)

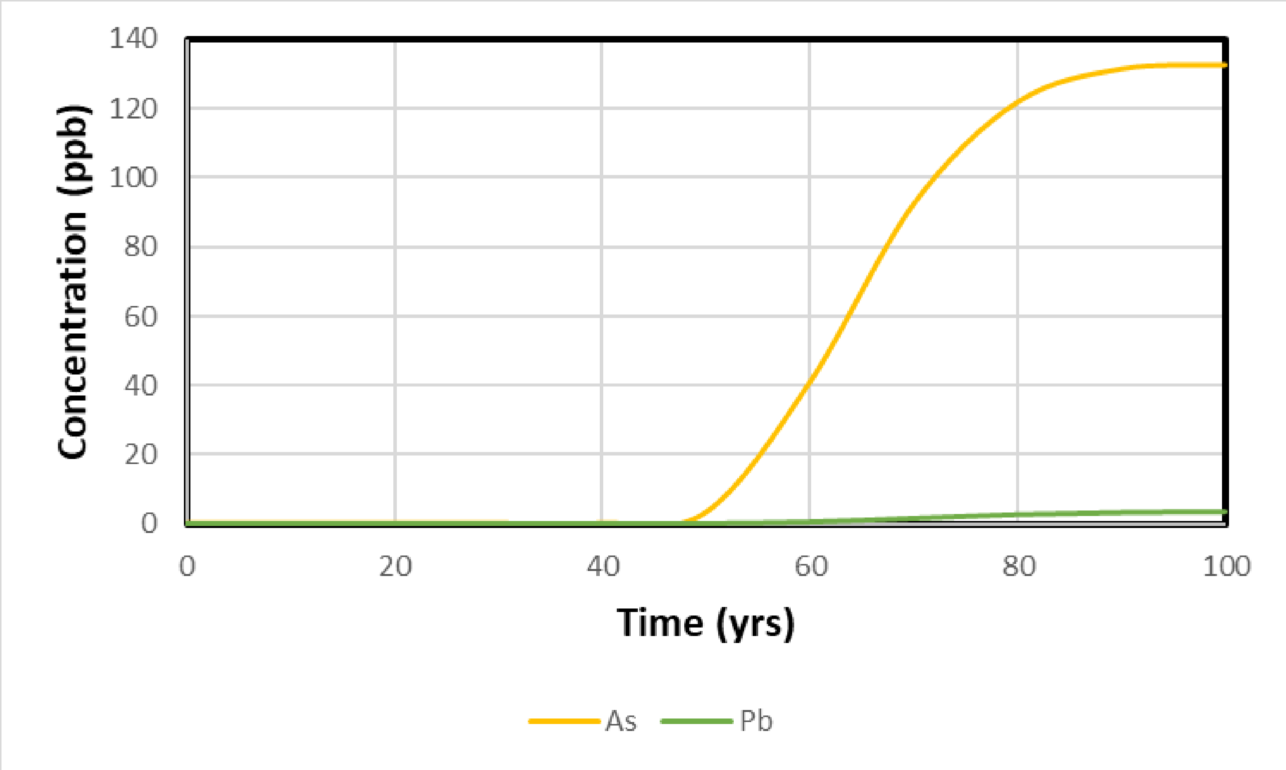

Figure 9-42 Location 5 Arsenic (As) and Lead (Pb) concentrations in ppb (where 1 mg/L approximately equals 1,000 ppb) (source: Figure 80 from Dawson *et al*, 2022)

Arsenic (As) and lead (Pb) are trace chemical parameters that can serve as proxies for the behaviour of other trace chemical parameters, and their mobilisation and demobilisation are important to understand in the context of GHG stream storage.

In the RTM, the highest predicted concentrations of arsenic occurred along the edges of the GHG plume (CO_2) impacted volume and low concentrations predicted to occur within the volume where Iron (III) hydroxide ($Fe(OH)_3$) precipitation takes place, as shown in Figure 9-43 (a-d). The distribution of arsenic reflects mobilisation by desorption and arsenic transport by advection from areas of higher concentrations.

Lead displays a very different predicted evolution of distribution than arsenic. Initially, the highest lead concentrations were where carbonate mineral dissolution dominates and then advective dispersion becomes the main process affecting lead distribution, as shown in Figure 9-43 (e-h).

The predicted distribution of cadmium (Cd), cobalt (Co), copper (Cu), manganese (Mn), nickel (Ni) and zinc (Zn) is predicted to be similar to lead, as shown in Figure 9-44.

Table 9-46 provides a comparison of the WQOs for Irrigation/Farm Use short-term and long-term WQOs for arsenic, cadmium, cobalt, copper, lead, manganese, nickel and zinc to existing water quality of the Precipice Sandstone aquifer at West Moonie-1 Injection Well, and the predicted maximum values by the RTM in the GHG plume.

Table 9-46 Comparison of Irrigation/Farm Use WQOs trigger values to existing water quality and predicted maximum concentrations in water quality in the GHG plume

Chemical Parameter	Irrigation/Farm Use WQO (long-term trigger)	Irrigation/Farm Use WQO (short-term trigger)	Existing water quality in Precipice Sandstone aquifer	Predicted maximum concentration	Predicted maximum concentrations at Locations(1) and time period
pH	6 to 8.5	6 to 8.5	8.35	Locally as low as 4, excluding very small volume near the injector	≅ 5 [1] at 100 years ≅ 5.1 [2] at 100 years ≅ 5.4 [3] at 100 years ≅ 5.1 [5] at 100 years
Arsenic (mg/L)	0.1	2	<0.001	Locally up to ≅0.5 mg/L	≅ 0.03 mg/L to 0.04 mg/L [2, 3, 4] at 10 years to 60 years ≅ 0.13 mg/L [5] at 80 years to 100 years
Cadmium (mg/L)	0.01	0.05	<0.0001	Locally up to ≅ 0.16 mg/L	at 100 years
Cobalt (mg/L)	0.05	0.1	<0.016	Locally up to ≅ 0.6 mg/L	at 100 years
Copper (mg/L)	0.2	5	<0.001	Locally up to ≅ 4 mg/L	at 100 years
Lead (mg/L)	2	5	<0.001	Locally up to ≅ 1 mg/L	≅ 0.8 mg/L [1] at 10 years ≅ 0.12 mg/L [2] at 25 years ≅ 0.01 mg/L [3] at 100 years ≅ 0.025 mg/L [4] at 60 years
Manganese (mg/L)	0.2	10	0.049	Locally up to ≅ 1 mg/L	at 100 years
Nickel (mg/L)	0.2	2	0.001	Locally up to ≅ 2 mg/L	at 100 years
Zinc (mg/L)	2	5	<0.005	Locally up to ≅ 10 mg/L	at 100 years

Notes:
(1) numbers in [brackets] refer to Locations of Plots in Figure 9-33

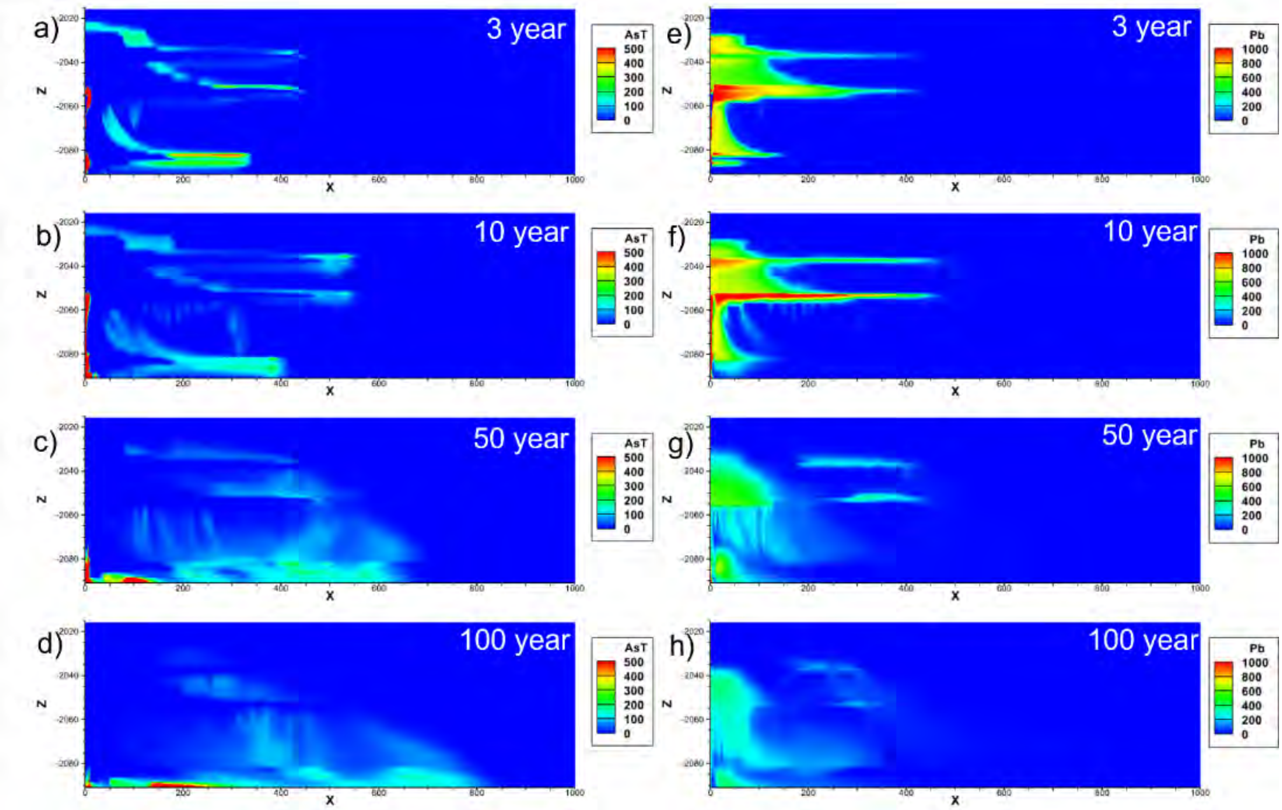

Figure 9-43 Arsenic (As) (a-d) and Lead (Pb) (e-h) predicted concentrations (in ppb, where 1,000 ppb is approximately 1 mg/L) distributions at 3 years, 10 years, 50 years and 100 years (Dawson *et al*, 2022, Figure 69)

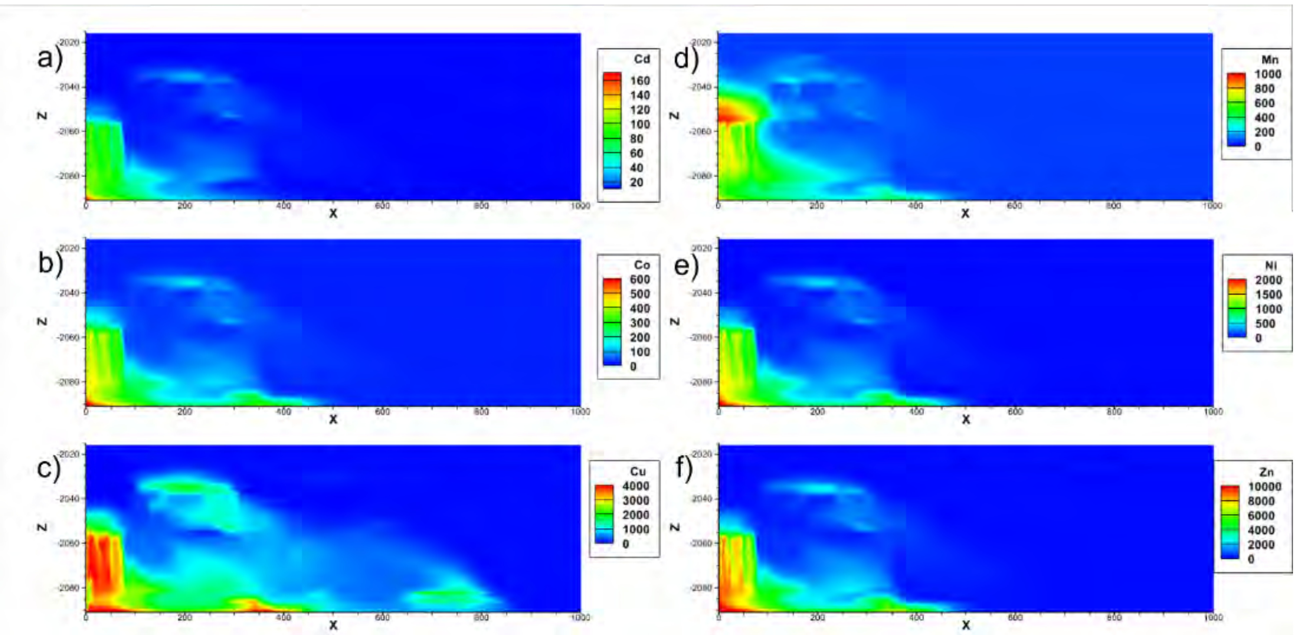

Figure 9-44 Predicted Trace Chemical Parameter concentrations (in ppb, where 1,000 ppb is approximately 1 mg/L) of Cadmium (Cd) (a), Cobalt (Co) (b), Copper (Cu) (c), Manganese (Mn) (d), Ikel (Ni) (e), and Zinc (Zn) (f) at 100 years (Dawson *et al*, 2022, Figure 70)

To meet the purpose of the GHG Act, it is important that the GHG stream and GHG plume remain within the storage complex. Within the GHG plume, the water quality chemical parameters are predicted to fluctuate over time as the GHG plume reacts with the rock and formation water of the Precipice Sandstone aquifer. The predicted impacts to rock geochemistry and groundwater quality will be confined to the extent of the GHG plume with Migration Assisted Trapping (MAT) processes important to limiting the flow and movement of the GHG plume.

The RTM used a realistic range of mineralogy and mineral compositions that included major, minor and trace inorganic chemical parameters that are specific to the West Moonie-1 Injection Well site, with further details on mineralogy and mineral compositions provided in Chapter 8 Geology, section 8.7.6.

Concentration changes of chemical parameters in the GHG plume are driven by:

- mineralogy and mineral compositions of the rock in the GHG storage reservoir;
- existing water quality of the formation water in the GHG storage reservoir, being the Precipice Sandstone aquifer;
- rate of migration/flow of the GHG stream in the GHG storage reservoir;
- displacement of the formation water by the GHG stream;
- GHG stream dissolution in the formation water;
- pH within the GHG plume;
- mineral dissolution and precipitation reactions;
- advective transport of chemical parameters:
  - during formation water displacement as the GHG stream migrates/flows;
  - through density driven convective flow of the GHG stream (CO_2);
- exhaustion of available oxygen; and
- availability of anions.

Following GHG stream injection the RTM predicts:

- pH decreasing long-term from approximately pH 8 to pH 5, being below the Irrigation/Farm Use WQO range of pH 6 to pH 8.5;
- magnesium increasing long-term from approximately 1 mg/L to predicted maximum concentrations at 100 years of between 45 mg/L to 140 mg/L, being above the 5.0 mg/L 80th percentile of the Aquatic Ecosystem WQO;
- bicarbonate increasing long-term from approximately 1,060 mg/L to predicted maximum concentrations at 100 years of between 1,550 mg/L to 2,050 mg/L, with existing water quality and predicted water quality all greater than the 673 mg/L 80th percentile of the Aquatic Ecosystem WQO;
- iron increasing short-term from approximately 3 mg/L to predicted maximum concentrations of 20 mg/L to 180 mg/L within 10 years to 25 years of injection, but reducing to less than 10 mg/L long-term by 100 years, approximating the Irrigation/Farm Use WQO short-term trigger value of 10 mg/L, but still above the Irrigation/Farm Use WQO long-term trigger value of 0.2 mg/L;
- arsenic increasing long-term from <0.001 mg/L to predicted maximum concentration of approximately 0.5 mg/L near the injection point within 100 years of injection, but ranging between approximately 0.03 mg/L to 0.13 mg/L maximum concentrations out to 100 years within the GHG plume, approximating the long-term trigger value for Irrigation/Farm Use WQO of 0.1 mg/L;
- cadmium increasing long-term from <0.0001 mg/L to predicted maximum concentration of approximately 0.16 mg/L at 100 years, which is greater than the Irrigation/Farm Use WQOs long-term trigger value of 0.01 mg/L and short-term value of 0.05 mg/L;
- cobalt increasing long-term from <0.016 mg/L to predicted maximum concentration of approximately 0.6 mg/L at 100 years, which is greater than the Irrigation/Farm Use WQOs long-term trigger value of 0.05 mg/L, and short-term value of 0.1 mg/L;
- copper increasing long-term from <0.001 mg/L to predicted maximum concentration of approximately 4 mg/L at 100 years, which is greater than the Irrigation/Farm Use WQOs long-term trigger value of 0.2 mg/L, but less than the short-term trigger value of 5 mg/L;
- lead increasing <0.001 mg/L to predicted maximum concentration of approximately 1 mg/L at 100 years, but fluctuates in concentration throughout the GHG plume. Compared to the Irrigation/Farm Use WQOs long-term trigger value of 2 mg/L and the short-term trigger value of 5 mg/L, the maximum predicted value for lead is below the long-term and short-term trigger values;
- manganese increasing long-term from 0.049 mg/L to predicted maximum concentration of approximately 1 mg/L at 100 years, which is greater than the Irrigation/Farm Use WQOs long-term trigger value of 0.2 mg/L, but less than the short-term trigger value of 10 mg/L;
- nickel increasing long-term from 0.001 mg/L to predicted maximum concentration of approximately 2 mg/L at 100 years, which is greater than the Irrigation/Farm Use WQOs long-term trigger value of 0.2 mg/L, but equivalent to the short-term trigger value of 2 mg/L;
- zinc increasing long-term from <0.005 mg/L to predicted maximum concentration of approximately 10 mg/L at 100 years, which is greater than the Irrigation/Farm Use WQOs long-term trigger value of 2 mg/L and short-term trigger value of 5 mg/L.

Based on the above, and as noted in Appendix 9F, the potential impacts to groundwater chemistry and water quality are predicted to be limited to within the GHG plume. Compared to aquatic ecosystem or irrigation/farm use WQOs, some chemical parameters within the GHG plume may change to be outside the WQOs values, while some parameters will remain within the WQOs trigger values or nominated percentiles of concentration.

For both CO_2 gas saturation and dissolved CO_2 gas within the GHG plume, the GHG stream concentration is predicted to decline over time as the CO_2 reacts with the groundwater and rock. Trace metal (trace chemical parameter) mobilisation and elevated concentrations of trace metals are predicted to be limited to the mobile component of the GHG plume and dominated by density driven convection that is directed towards the bottom of the GHG storage reservoir (Golding et al., 2022). The accumulation of trace chemical parameters in the dense fluid collecting at the bottom of the GHG storage reservoir is predicted, with a decrease in concentration in the GHG plume as time progresses as the sources of trace chemical parameters become depleted.

Section 9.10 below provides avoidance and mitigation measures associated with groundwater chemistry and water quality, including trigger investigation values that will form part of the ITP, MVP and EA amendment.

9.9.5 Potential Groundwater Pressure and Flow Impacts on the Precipice Sandstone aquifer outside the GHG plume

9.9.5.1 POTENTIAL IMPACTS OF PRESSURE CHANGES FROM THE GHG PLUME WITHIN THE STORAGE COMPLEX

Further to section 9.6.2, the hydrogeological model predicted pressure changes in the Precipice Sandstone Formation during and following injection of the GHG stream, with pressure peaking when injection ceases (end of operation phase). Figure 9-45 shows predicted pressure impacts as follows:

- End of Year 1 = end of first year of GHG stream injection;
- End of Year 2 = end of second year of GHG stream injection;
- End of Year 3 = end of third and final year of GHG stream injection, with a 1 m head increase predicted to extend 16.5 km from the West Moonie-1 Injection Well. Further detail is given in Figure 9-46;
- End of Year 4 = end of first year after GHG stream injection ceases;
- End of Year 5 = end of second year after GHG stream injection ceases;
- End of Year 10 = end of 7th year after GHG stream injection ceases;
- End of Year 50 = end of 47th year after GHG injection ceases; and
- End of Year 100 = end of 97th year after GHG injection ceases.

Hydrographs presenting the modelled head response in groundwater bores screening the Precipice Sandstone, Hutton Sandstone and the Evergreen Formation are included in Appendix 9A, section 5.1.2. The peak water level (head) response in the Precipice Sandstone aquifer was a head increase of slightly over 1 m, considering the Base case 1.0 and sensitivity analysis cases 1.1 to 1.4. Head response in the Hutton Sandstone was negligible, including the simulated fault scenario.

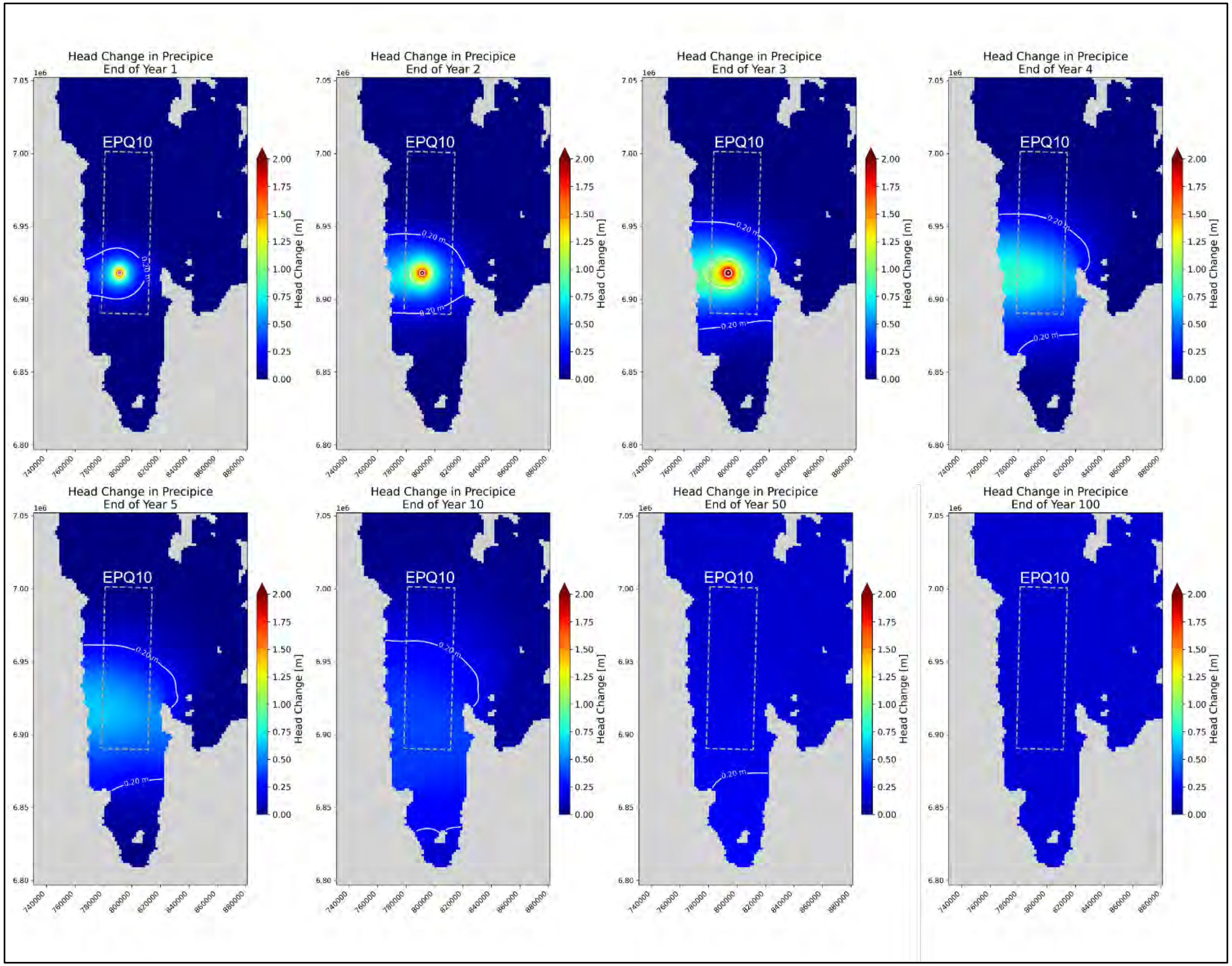

Figure 9-45 Predicted pressure head change in the Precipice Sandstone aquifer due to GHG stream injection

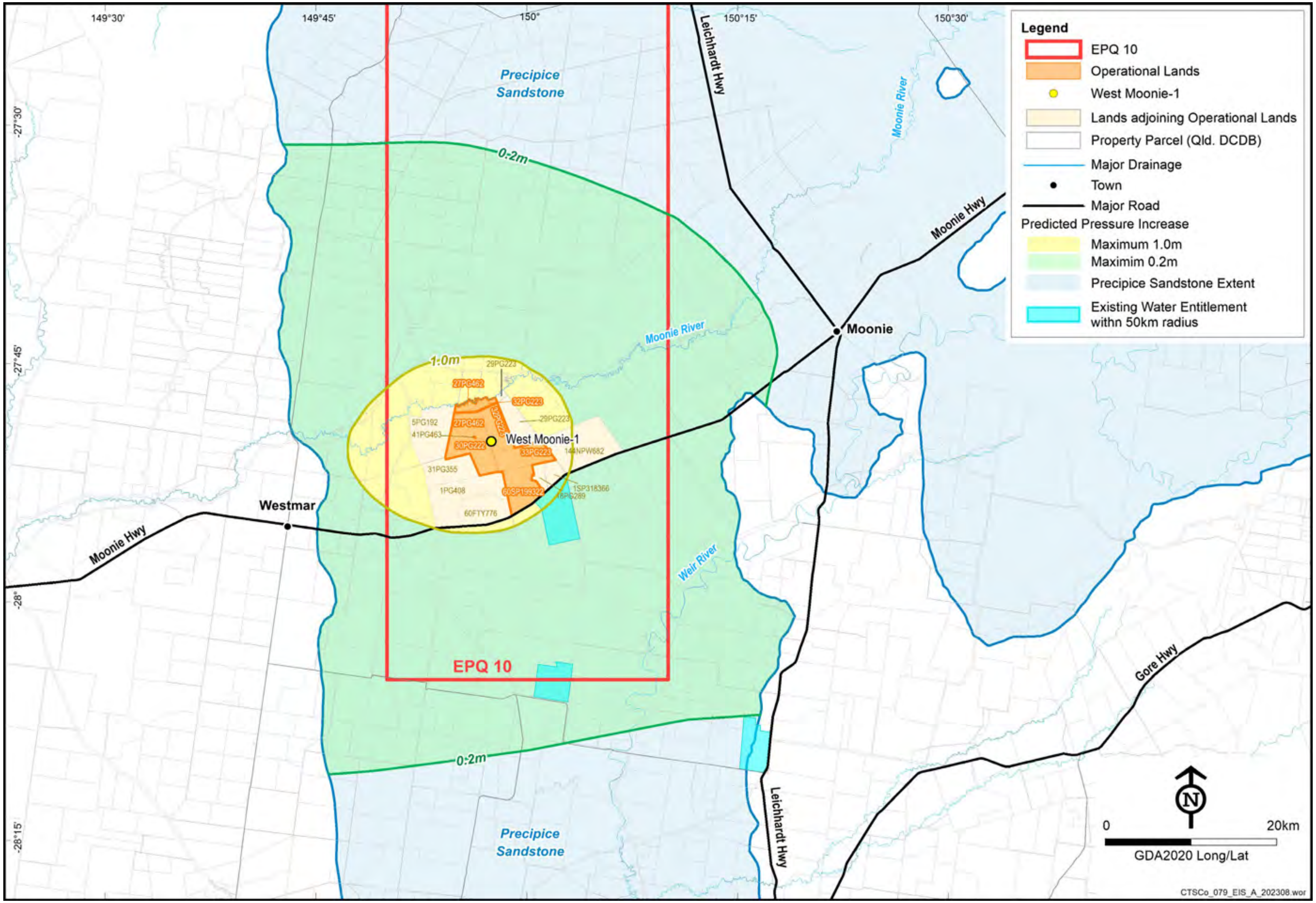

Figure 9-46 Predicted pressure head change in the Precipice Sandstone aquifer when GHG stream injection ceases

9.9.6 Potential Impacts on Groundwater Uses and Users of the Precipice Sandstone aquifer outside the GHG Plume

The predicted extent of the GHG plume under the Scenarios in section 9.9.2.4 above has informed the assessment of potential impacts on groundwater uses and users of the Precipice Sandstone aquifer outside of the predicted extent of the GHG plume.

9.9.6.1 GROUNDWATER USE AND RESOURCE PRODUCTION OF THE PRECIPICE SANDSTONE AQUIFER OUTSIDE THE GHG PLUME

Further to section 9.7.4.1.2, conventional oil production in the Moonie Oil Field is the closest resource activity within the Precipice Sandstone aquifer, located approximately 30 km east of the West Moonie-1 Injection Well. As shown in Figure 9-45 and Figure 9-46, the predicted pressure change from the GHG stream injection at the Moonie Oil Field is approximately 0.2 m head (approximately 0.3 psi). Given that the Moonie Oil Field has locally depressurised the Precipice Sandstone aquifer, the predicted pressure increase resulting from GHG stream injection is unlikely to have any perceptible impact within the resolution of measurement at or beyond the zone of influence of the Moonie Oil Field.

Avoidance and mitigation measures are provided in section 9.10 below.

9.9.6.2 GROUNDWATER USE AND WATER ENTITLEMENTS OF THE PRECIPICE SANDSTONE AQUIFER OUTSIDE THE GHG PLUME

Further to sections 9.7.4.2 and 9.9.2.4, there are three water entitlements currently granted within a 50 km radius of the predicted GHG plume of West Moonie-1 Injection Well within the Precipice Sandstone aquifer, as shown in Figure 9-46.

The greatest potential impact on pressure head within the Precipice Sandstone aquifer is predicted when GHG stream injection ceases. Potential pressure head impact:

- on the yet to be drilled registered bore approximately 9.6 km from West Moonie-1 Injection Well associated with water licence 624712 on lot 2SP318366, is predicted to be approximately 1.0 m of head (approximately 1.4 psi);
- approximately 27 km from West Moonie-1 Injection Well associated with water licence 624713 on lot 15CVN281 is predicted to be approximately in the order of 0.2 m to 0.3 m of head (approximately 0.3 psi to 0.4 psi); and
- approximately 44 km from West Moonie-1 Injection Well associated with water licence 616843 on lot 13SP211193 is predicted to be less than 0.2 m of head (approximately 0.3 psi), being beyond the resolution of measurement of pressure monitoring equipment.

As shown in Figure 9-26, Figure 9-28 and Figure 9-30, the extent of the GHG plume for all three Scenarios of water extraction have the GHG plume remaining within the operational lands. Therefore, the risk of potential impacts on existing water entitlements holders within the Precipice Sandstone aquifer are considered negligible.

Avoidance and mitigation measures associated with existing water entitlement holders and future potential water entitlement holders are provided in section 9.10 below.

9.9.6.3 GROUNDWATER USE AND ECOLOGICAL FUNCTIONS OF THE PRECIPICE SANDSTONE AQUIFER OUTSIDE THE GHG PLUME

Further to section 9.7.4.3.2 and similar to section 9.9.3.3, there are no known recharge areas, springs or GDEs connected to the predicted GHG plume or within a 50 km radius of West Moonie-1 Injection Well within the Precipice Sandstone aquifer, therefore there are no potential impacts. Avoidance and mitigation measures are provided in section 9.10 below.

9.9.7 Potential Groundwater Chemistry and Water Quality Impacts on the Precipice Sandstone aquifer outside the GHG Plume

Further to Chapter 2 Proposed Project Description sections 2.10.4, and 2.11.1, and sections 9.7.5, 9.8 and 9.9.4 above, due to the proposed volume, rate, pressure, and temperature conditions of the GHG stream during injection, and the MAT mechanisms during injection and any subsequent timeframe after GHG storage injection testing is complete, the potential impacts on groundwater chemistry and water quality outside the GHG plume are considered low.

Close alignment of pressure and temperature conditions between the GHG stream and GHG storage reservoir at the injection interface minimises potential for hydraulically or thermally induced fracturing.

Avoidance and mitigation measures are provided in section 9.10 below that are associated with groundwater chemistry and water quality of the Precipice Sandstone aquifer.

9.9.7.1 WATER QUALITY FOR AQUATIC ECOSYSTEMS – GHG STORAGE RESERVOIR, OUTSIDE THE GHG PLUME

For the aquatic ecosystem WQOs of the Precipice Sandstone aquifer, further to sections 9.7.5.3 and 9.9.4, no change is predicted to the existing groundwater chemistry and water quality outside of the GHG plume. The groundwater quality from the southern portion of the Surat Basin, will continue to be brackish, based on Total Dissolved Solids (TDS) concentrations. This is attributed to the location in the deeper part of the Surat Basin, further from recharge areas, and in an area where there is no throughflow. The existing water quality parameters that are naturally outside the range of the aquatic ecosystem WQOs, being sodium, bicarbonate, chloride, electrical conductivity (EC), and total alkalinity will continue to all have higher concentrations than the WQO (80^{th} percentile).

9.9.7.2 WATER QUALITY FOR IRRIGATION AND FARM USE/SUPPLY – GHG STORAGE RESERVOIR, OUTSIDE THE GHG PLUME

For the irrigation and farm use/supply WQOs of the Precipice Sandstone aquifer, further to sections 9.7.5.5 and 9.9.4, no change is predicted to the existing groundwater chemistry and water quality outside of the GHG plume. The existing water quality parameters that are naturally outside the range of the irrigation and farm use/supply WQOs, being sodium, chloride, fluoride, boron and iron all have higher concentrations than the WQO long-term trigger values. The use of this water for irrigation poses a risk of soil degradation, potentially causing sodic soils, indicating that the groundwater is unlikely to support the long-term use for irrigation purposes. The use of the groundwater for farm supply potentially poses corrosion and fouling risks to farm water supply equipment due to the pH and water hardness.

9.9.7.3 WATER QUALITY FOR STOCK WATER – GHG STORAGE RESERVOIR, OUTSIDE THE GHG PLUME

For the stock water WQOs of the Precipice Sandstone aquifer, further to sections 9.7.5.7 and 9.9.4, no change is predicted to the existing groundwater chemistry and water quality outside of the GHG plume. Fluoride is approximately 3 times higher concentration (approximately 6 mg/L) than the WQO trigger value (2 mg/L). Use of the groundwater for stock watering purposes needs to consider the potential health impacts on stock due to high concentrations of fluoride, including total dietary intake of fluoride for stock, age of stock, and duration of exposure to higher fluoride concentrations, as outlined in section 9.7.5.7.

9.9.7.4 WATER QUALITY FOR DRINKING WATER – GHG STORAGE RESERVOIR, OUTSIDE THE GHG PLUME

For the drinking water WQOs of the Precipice Sandstone aquifer, further to sections 9.7.5.9 and 9.9.4, no change is predicted to the existing groundwater chemistry and water quality outside of the GHG plume. The existing water quality parameters that are naturally outside the range of the drinking water WQOs, being total dissolved solids (TDS) and sodium have concentrations higher than the before-treatment drinking water WQOs, with the water requiring some form of treatment to improve palatability for human consumption.

9.9.7.5 WATER QUALITY FOR INDUSTRIAL USE – GHG STORAGE RESERVOIR, OUTSIDE THE GHG PLUME

The QMDB does not provide WQOs for industrial use. Further to sections 9.7.5.10 and 9.9.4, no change is predicted to the existing groundwater chemistry and water quality outside of the GHG plume.

9.9.7.6 WATER QUALITY FOR CULTURAL AND SPIRITUAL VALUES – GHG STORAGE RESERVOIR, OUTSIDE THE GHG PLUME

Due to the depth of groundwater in the Precipice Sandstone in the vicinity of the West-Moonie-1 Injection Well, with no known springs or discharge mechanisms to shallow groundwater or surface water systems in the locality, the Project is unlikely to impact upon cultural and spiritual values including those values that support:

- custodial, spiritual, cultural and traditional heritage, hunting, gathering and ritual responsibilities;
- symbols, landmarks and icons (such as flora, fauna, and waterways); and
- lifestyles (such as agriculture and fishing).

9.9.8 Cumulative Impacts

For the proposed injection of a total of 330,000 tonnes of GHG stream into the Precipice Sandstone storage reservoir for a period of 3 years, no cumulative impacts are predicted to occur on water entitlement holders in aquifers overlying the storage complex and within the Precipice Sandstone aquifer.

Potential impacts to groundwater chemistry and water quality are predicted to be localised within the extent of the GHG plume, approximately 1,200 m to 1,500 m in diameter centred around the West Moonie-1 Injection Well. No potential impacts have been predicted outside of the GHG plume with Migration Assisted Trapping (MAT) processes including residual trapping (capillary pressure hysteresis), solubility trapping, and mineralisation trapping helping to minimise the extent of the GHG plume.

As examined through the various existing and hypothetical water entitlement Scenarios predicted using the hydrogeological modelling and dynamic (plume) modelling and shown in Figure 9-26, Figure 9-28, and Figure 9-30, impacts on current water entitlements holders, and potential future water entitlement holders within 5 km of the West Moonie-1 Injection Well are predicted to be negligible.

Pressure impacts are predicted to extend beyond the boundaries of EPQ10, although the impacts are small and positive. In accordance with the Project ToR, the OGIA regional groundwater flow model has been used to assess cumulative impacts. The OGIA model (OGIA, 2021) was developed to predict the impact of existing and projected extraction from the Surat CMA. The model represents groundwater systems across the Surat Basin, and has been specifically developed to enable assessment of cumulative impacts. Figure 9-47 shows the OGIA predicted long-term drawdown impacts within the Precipice Sandstone. Model results are presented utilising a probabilistic approach to account for uncertainties within the model and underlying data, with drawdown predictions provided corresponding to the 5th, 50th (median), and 95th percentiles. The West Moonie-1 Injection Well is located within the impacted area from the Moonie Oil Field. Due to the operation of the Moonie Oil Field, the OGIA model predicts a 10 m to 20 m drawdown in the Precipice Sandstone at the West Moonie-1 Injection Well. As shown in Figure 9-45, the positive pressure impact of the GHG stream injection is negligible compared with the regional drawdown impacts from the Moonie Oil Field extraction.

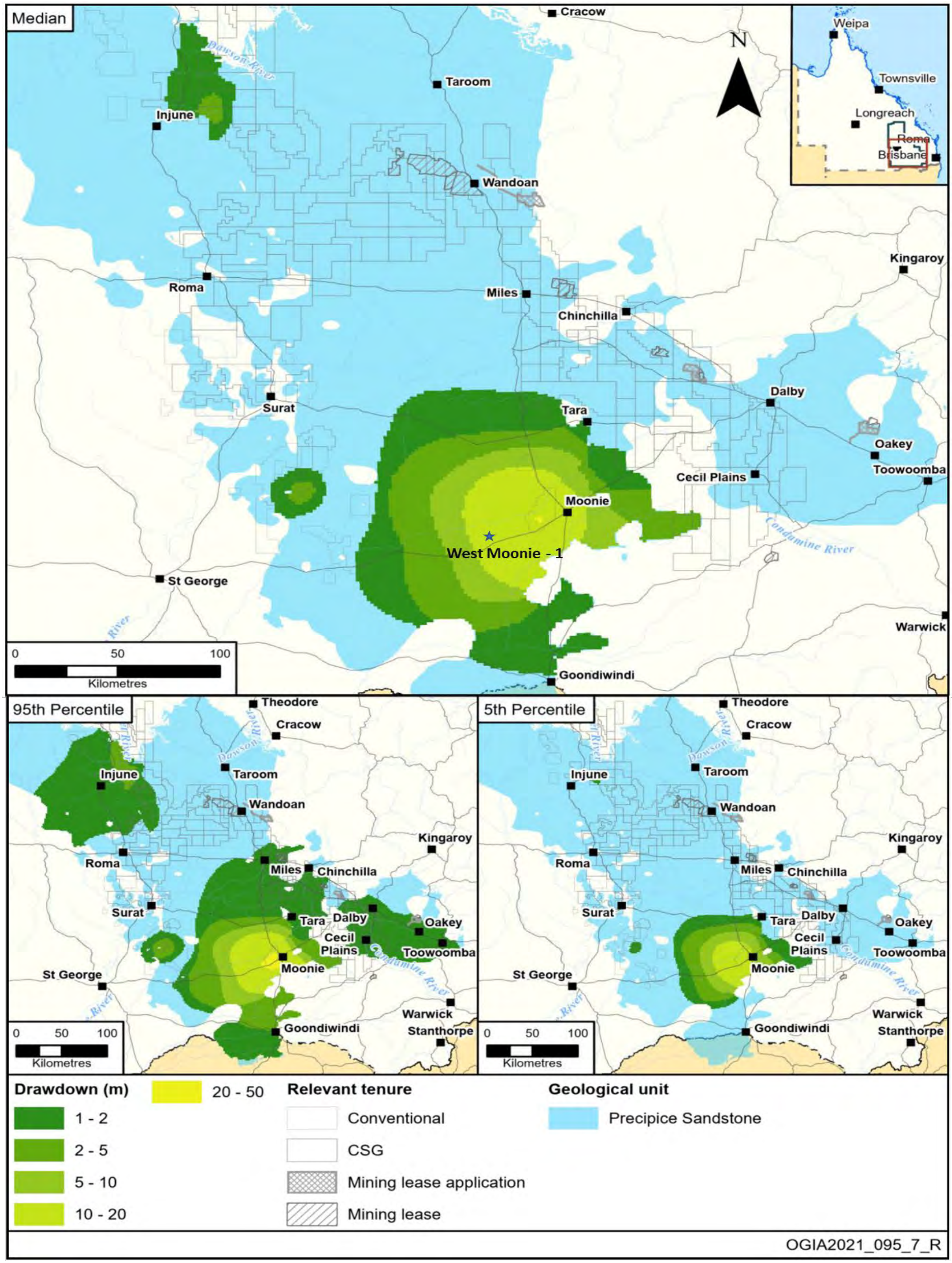

Figure 9-47 Extent of long-term affected areas from OGIA's model (modified from OGIA, 2021)

9.9.9 Summary of Potential Impacts

The assessment of potential impacts demonstrates that the GHG stream can be safely contained within the Precipice Sandstone formation at West Moonie-1 Injection Well, and confined to within a GHG plume.

9.9.9.1 POTENTIAL IMPACTS TO AQUIFERS OVERLYING THE GHG STORAGE RESERVOIR

Within the operational lands, aquifers overlying the storage complex include the Hutton Sandstone, the Springbok Sandstone, Gubbermunda Sandstone, Mooga Sandstone and Griman Creek Formation. They are separated and confined by regionally recognised aquitards that inhibit the flow of groundwater vertically. As part of the storage complex, the Evergreen Formation provides the key geological seal and aquitard between the GHG storage reservoir of the Precipice Sandstone aquifer and the overlying aquifers.

As discussed in sections 9.7.3.1, there are no faults identified from regional structural mapping within EPQ10, and no faults are present in the West Moonie-1 Injection Well or West Moonie-2 Monitoring Well. The closest faults of any significant size are associated with the north-south trending Goondiwindi Moonie Fault Zone located approximately 23 km east of the West Moonie-1 Injection Well. The differences measured in hydraulic properties and pressure gradients between the Hutton Sandstone aquifer and the Precipice Sandstone aquifer, demonstrate that the Evergreen Formation provides an effective geological seal, enabling the containment of the GHG stream within the storage complex.

Pressure testing conducted insitu on the Evergreen Formation demonstrated that a pressure increase of 7,000 psi did not result in fracturing of the rock. As described in Chapter 8 Geology, sections 8.6.2.4 and 8.9.2 and outlined in section 9.8 above, geomechanical modelling has predicted that injecting the GHG stream into the Precipice Sandstone aquifer with similar pressure (3,270 psi) and temperature (80°C) to the existing conditions of the Precipice Sandstone aquifer minimises the potential for hydraulically or thermally induced fracturing, with the injection pressure being insufficient to reactivate or open any pre-existing naturally occurring fractures or faults that could be present in the Evergreen Formation.

As described in Chapter 2 Proposed Project Description, section 2.8.1.2.1, and section 9.8 above, the West Moonie-1 Injection Well is constructed in accordance with "*Code of Practice for the construction and abandonment of petroleum wells and associated bores in Queensland*" (DNRME, 2019) and provides at least two barriers of cemented casing between the overlying aquifers and the GHG stream within the West Moonie-1 Injection Well, with cement integrity confirmed via cement bond logging. During the injection testing operation phase, this minimises the potential for escape or movement of the GHG stream from within the West Moonie-1 Injection Well, or up along the outside of the West Moonie-1 Injection Well from the injection point.

In summary, potential impacts predicted on aquifers overlying the GHG storage reservoir and the associated groundwater uses, groundwater users, and water quality are considered negligible.

9.9.9.2 POTENTIAL IMPACTS ON THE PRECIPICE SANDSTONE AQUIFER WITHIN THE GHG PLUME

The extent of the GHG plume is predicted to be approximately 1,200 m to 1,500 m in diameter centred around the West Moonie-1 Injection Well under existing environmental conditions, as shown in Figure 9-25 and Figure 9-26 above.

No resource production or exploration activities under the *Mineral Resources Act 1989* or *Petroleum and Gas (Production and Safety) Act 2004* are conducted or proposed to be conducted within the foreseeable future within the predicted GHG plume or within a 5 km radius of West Moonie-1 Injection Well within the Precipice Sandstone aquifer. Therefore, GHG storage injection testing activities are unlikely to potentially impact resource production or exploration activities.

There are no water entitlements currently granted under the *Water Act 2000* within the predicted GHG plume or within a 5 km radius of the West Moonie-1 Injection Well within the Precipice Sandstone aquifer, therefore there are no potential impacts. Consideration of the granting of future water entitlements within the predicted extent of the GHG plume are discussed below in section 9.11.

There are no known recharge areas, springs or GDEs directly connected to the Precipice Sandstone aquifer that is predicted to be within the GHG plume or within a 5 km radius of West Moonie-1 Injection Well within the Precipice Sandstone aquifer, therefore there are no potential impacts.

To meet the purpose of the GHG Act, it is important that the GHG stream and GHG plume remain within the storage complex. Within the GHG plume, the water quality chemical parameters are predicted to fluctuate over time as the

GHG plume reacts with the rock and formation water of the Precipice Sandstone aquifer. The predicted impacts to rock geochemistry and groundwater quality will be confined to the extent of the GHG plume with Migration Assisted Trapping (MAT) processes important to confining the flow and movement of the GHG plume.

Concentration changes of chemical parameters in the GHG plume are driven by:

- mineralogy and mineral compositions of the rock in the GHG storage reservoir;
- existing water quality of the formation water in the GHG storage reservoir, being the Precipice Sandstone aquifer;
- rate of migration/flow of the GHG stream in the GHG storage reservoir;
- displacement of the formation water by the GHG stream;
- GHG stream dissolution in the formation water;
- pH within the GHG plume;
- mineral dissolution and precipitation reactions;
- advective transport of chemical parameters:
  - during formation water displacement as the GHG stream migrates/flows;
  - through density driven convective flow of the GHG stream (CO_2);
- exhaustion of available oxygen; and
- availability of anions.

The potential impacts to groundwater chemistry and water quality are predicted to be limited to within the GHG plume. Compared to aquatic ecosystem or irrigation/farm use WQOs, some chemical parameters within the GHG plume may change to be outside the WQOs values, while some parameters will remain within the WQOs trigger values or nominated percentiles of concentration. Long-term within the GHG plume, the pH is predicted to decrease from approximately pH 8 to pH 5, being below the Irrigation/Farm Use WQO range of pH 6 to pH 8.5. Short-term at the West Moonie-1 Injection Well point, a localised pH decrease to as low as 4 is predicted.

The GHG stream (CO_2) concentration is predicted to reduce over time as the CO_2 reacts with the groundwater and rock. Elevated concentrations of trace chemical parameters and their mobilisation is predicted to be limited to the mobile component of the GHG plume and dominated by density driven convection that is directed towards the bottom of the GHG storage reservoir. The accumulation of trace chemical parameters in the dense fluid collecting at the bottom of the GHG storage reservoir is predicted, with a decrease in concentration in the GHG plume as time progresses as the sources of trace chemical parameters become depleted. Section 9.10 below provides avoidance and mitigation measures associated with groundwater chemistry and water quality, including trigger investigation values that will form part of the ITP and MVP.

9.9.9.3 POTENTIAL IMPACTS ON THE PRECIPICE SANDSTONE AQUIFER OUTSIDE THE GHG PLUME

The hydrogeological model predicted pressure changes in the Precipice Sandstone Formation during and following injection of the GHG stream, with pressure peaking when injection ceases (end of operation phase) with a 1 m head (1.4 psi) increase predicted to extend up to 16.5 km from the West Moonie-1 Injection Well, as shown in Figure 9-46. For the three existing water entitlement holders of the Precipice Sandstone aquifer within 50 km radius of the West Moonie-1 Injection Well, the potential pressure head impact:

- on the yet to be drilled registered bore, approximately 9.6 km from West Moonie-1 Injection Well associated with water licence 624712 on lot 2SP318366, is predicted to be approximately 1.0 m of head (approximately 1.4 psi);
- approximately 27 km from West Moonie-1 Injection Well associated with water licence 624713 on lot 15CVN281 is predicted to be approximately in the order of 0.2 m to 0.3 m of head (approximately 0.3 psi to 0.4 psi); and
- approximately 44 km from West Moonie-1 Injection Well associated with water licence 616843 on lot 13SP211193 is predicted to be less than 0.2 m of head (approximately 0.3 psi), being beyond the resolution of measurement of pressure monitoring equipment.

The potential impact from these pressure changes is considered low, with localised pressure increases during injection predicted to dissipate rapidly due to the large, connected volume of the Precipice Sandstone aquifer. Pressure gradients are predicted to drop off very quickly once injection ceases and therefore the driving force for GHG plume movement disappears. Pressure increases are very low and therefore the risk of either initiating fractures or reactivating existing fractures or faults is negligible, as discussed further in Chapter 8 Geology, sections 8.7.6.3 and 8.9.2.

For resource activities, the closest petroleum exploration tenement ATP2038 held by Cypress Petroleum overlaps land adjoining the operational lands. Information from the tenement holder indicates that formations approximately 2 km or more deeper than the Precipice Sandstone aquifer are of interest to them, therefore no potential impacts are envisaged. Conventional oil production in the Moonie Oil Field is the closest resource production activity within the Precipice Sandstone aquifer. The predicted pressure change from the GHG stream injection at the Moonie Oil Field is approximately 0.2 m head (approximately 0.3 psi). Given that the Moonie Oil Field has locally depressurised the Precipice Sandstone aquifer, the predicted pressure increase resulting from GHG stream injection is unlikely to have any perceptible impact within the resolution of measurement at or beyond the zone of influence of the Moonie Oil Field.

The extent of the GHG plume is predicted to be approximately 1,200 m to 1,500 m in diameter centred around the West Moonie-1 Injection Well under existing environmental conditions, with two large existing extractions from the Moonie Oil Field and Kogan Creek Power Station. Two further Scenarios were examined being:

- Scenario 2: adding to Scenario 1 the three existing Precipice Sandstone water entitlements within a 50 km radius of West Moonie-1 Injection Well; and
- Scenario 3: adding to Scenario 2 extraction from the Precipice Sandstone aquifer from a hypothetical extraction point within 5 km of West Moonie-1 Injection Well of the total volume of unallocated water that could be potentially granted in the Surat Precipice groundwater sub-area being 1,815 ML/y.

As shown in Figure 9-30 above, the extent of the GHG plume is predicted to wholly within the operational lands of the Project. Therefore, the potential impact of the GHG plume on existing water entitlement holders and hypothetical future water entitlement holders outside the GHG plume is predicted to be negligible. Consideration of the granting of future water entitlements outside the predicted extent of the GHG plume are discussed below in section 9.11.

There are no known recharge areas, springs or GDEs connected to the predicted GHG plume or within a 50 km radius of West Moonie-1 Injection Well within the Precipice Sandstone aquifer, therefore there are no potential impacts.

Potential impacts on groundwater chemistry and water quality within the Precipice Sandstone aquifer outside of the GHG plume are predicted to be negligible, with all EVs and WQOs associated with aquatic ecosystems, irrigation and farm use/supply, stock water, drinking water, industrial use, and cultural and spiritual values to remain unchanged from the existing environment conditions described in section 9.7.

9.10 Avoidance and Mitigation Measures

Further to Chapter 2 Proposed Project Description, and section 9.8 above, many of the key features of the Project are to act as avoidance, mitigation, monitoring and verification of the GHG stream injection activities. Avoidance and mitigation measures aim to reduce the risk of unexpected GHG plume containment breaches, and have been selected based on efficiency and effectiveness, and have been targeted to be proportional to the likelihood, magnitude and significance of a potential impact.

Containment monitoring focuses on the aquifers overlying the storage complex and in the Precipice Sandstone storage reservoir immediately outside of the predicted maximum extent of the stabilised GHG plume to ensure that the GHG steam is contained within the GHG storage reservoir.

Conformance monitoring focuses on verification of the behaviour of the GHG plume during injection activities (operation phase) and in the monitoring phase, comparing the behaviour of what is observed of the actual GHG stream and GHG plume to what has been predicted by the various models prior to injection commencing. Monitoring and sampling of the physical and chemical parameters, including pressure, temperature, CO_2 saturation, rock chemistry, and groundwater chemistry and water quality, have and will continue to contribute to conformance monitoring.

As described in Chapter 2 Proposed Project Description, sections 2.10.4.1, 2.11, and 2.16, Chapter 4 Approvals, section 4.4.9 and section 9.3.2.1 CTSCo will develop an Injection Test Plan (ITP) and a Monitoring and Verification Plan (MVP) as is required under the GHG Act, and apply to amend the EA. The following sections and tables provide a summary for consideration of monitoring data to be included in the ITP, MVP and EA amendment application. Ongoing monitoring will allow for the effectiveness of measures to be identified and adapted in response to changes in circumstances and unexpected trends in collected data.

The Project's key features and other technologies that have already or are proposed to be deployed are summarised in Table 9-47 and described in section 9.10.1. Table 9-48 outlines the detailed monitoring of sub-surface parameters associated with groundwater, the GHG stream and the GHG plume, including triggers and actions. These mitigation measures are for use under the proposed standard operating conditions of the Project, and not in extraordinary circumstances, events or incidents. As described in Chapter 2 Proposed Project Description, section 2.11.7 outlines potential impacts and potential remediation measures on a whole-of-Project basis, rather than given in Table 9-47 and in Table 9-48 below. Chapter 15 Hazards and Safety addresses matters of hazards, risks, health and safety.

Table 9-47 Summary of Key Features and Technologies for monitoring of aquifers, the GHG stream and GHG plume

Key Feature or Technology	Containment Monitoring?	Conformance Monitoring?	What is monitored	Where is the monitoring
Temperature, pressure and CO_2 concentration detectors	Yes	No	Fugitive emissions of CO_2	At and immediately adjacent to the well head of West Moonie-1 Injection Well
West Moonie-5 Soil Monitoring Bore and West Moonie-6 Soil Monitoring Bore	Yes	No	pH and fugitive emissions of CO_2	In-wellbore soil vapour monitoring adjacent to West Moonie-1 Injection Well and West Moonie Sentinel Well respectively
Pressure sensors	Yes	No	Wellbore integrity subsurface	Wellhead of West Moonie-1 Injection Well
Temperature and pressure sensors	Yes	No	Well bore integrity subsurface	Downhole of West Moonie-1 Injection Well
Pressure sensors	Yes	Yes	Standing water level in the wells and bores for spatial extent of GHG plume	Wellheads of West Moonie-2 Monitoring Well, Gubberamunda Monitoring Bore, and West Moonie Sentinel Well
Pulsed neutron logging	Yes	No	CO_2 saturation for presence of GHG stream	Downhole total depth to surface in West Moonie-2 Monitoring Well, Gubberamunda Monitoring Bore, and West Moonie Sentinel Well
Pulsed neutron logging	No	Yes	CO_2 saturation for spatial extent (vertical position) of GHG plume	Downhole in storage complex in West Moonie-1 Injection Well, West Moonie-2 Monitoring Well, and West Moonie Sentinel Well
West Moonie Shallow Monitoring Bore	Yes	No	Water quality of Griman Creek Formation	From downhole of West Moonie Shallow Monitoring Bore
Gubberamunda Monitoring Bore	Yes	No	Water quality of Gubberamunda Sandstone aquifer	From downhole of Gubberamunda Monitoring Bore
West Moonie-2 Monitoring Well	Yes	No	Water quality of Hutton Sandstone aquifer	From downhole of West Moonie-2 Monitoring Well
West Moonie-2 Monitoring Well	Yes	No	Water quality of Precipice Sandstone aquifer outside of GHG plume	From downhole of West Moonie-2 Monitoring Well outside the GHG plume before GHG plume reaches the well
West Moonie-2 Monitoring Well	No	Yes	Water quality of Precipice Sandstone aquifer within the GHG plume	From downhole of West Moonie-2 Monitoring Well within the GHG plume as the GHG plume expands during injection in the operation phase and monitoring phase
West Moonie Sentinel Well	Yes	No	Water quality of Precipice Sandstone aquifer outside of GHG plume	From downhole of West Sentinel Well outside the GHG plume
2D seismic surveys	Yes	Yes	Spatial extent of the GHG plume from ground surface level to below the depth of the Storage Complex	Monitors located at surface for surveys approximately 4km in all directions from West Moonie-1 Injection Well

Table 9-48 Monitoring of sub-surface parameters associated with the GHG plume and groundwater

Monitoring Purpose	Monitoring outcome	Measured Parameters	Measurement Location	Why?	How?	Project Phase	Measurement Frequency	Departure/Trigger	Mitigation Measures			Residual Risk
									Short-term action	Medium-term action	Long-term action	
Subsurface Containment	Operational safety	CO_2, O_2, CH_4, and N_2 concentrations	Soil	Monitor for CO_2 fugitive emissions to identify CO_2 concentrations that are unlikely to arise from metabolic activity in the soil	In-wellbore soil vapour monitoring in West Moonie-5 Soil Monitoring Bore and West Moonie-6 Soil Monitoring Bore located adjacent to West Moonie-1 Injection Well and West Moonie Sentinel Well respectively	Pre-injection (baseline)	Continuous monitoring to commence 12 months prior to injection commencing	Baseline survey to characterise the CO_2 content of the soil (diurnal, rain effected)	Not Applicable	None		Negligible
						Injection (operation phase)	Continuous	> 50% above baseline levels	Trigger internal investigation within CTSCo.	Remediation dependent on cause		
						Post Injection (monitoring phase)	Continuous until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	> 50% above baseline levels	Trigger internal investigation within CTSCo.	Remediation dependent on cause		
Subsurface Containment	Operational safety	Pressure	Wellhead	Monitor for well bore integrity	Pressure Sensors installed on wellhead of West Moonie-1 Injection Well	Pre-injection (baseline)	Commence 6 months prior to injection commencing	Baseline survey to confirm trigger values	Not Applicable	None		Negligible
						Injection (operation phase)	Continuous	> 10% above baseline levels	Trigger internal investigation within CTSCo to review changes in well operating conditions that require intervention.	Remediation dependent on cause		
						Post Injection (monitoring phase)	Continuous until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	> 10% above baseline levels	Trigger internal investigation within CTSCo to review monitoring conditions that require intervention.	Remediation dependent on cause		
Subsurface Containment	Operational safety	Temperature and pressure	Downhole	Monitor for well bore integrity	Downhole temperature and pressure sensors installed in West Monnie-1 Injection Well. All well monitoring will be integrated into the automated control system at the well. Measurements from the well monitoring system will be transmitted via a mobile telecommunication link (with satellite back-up) to allow remote monitoring, alarm notification and control (if required).	Pre-injection (baseline)	Commence 6 months prior to injection commencing	Baseline survey to confirm trigger values	Not Applicable	None		Negligible
						Injection (operation phase)	Continuous	> 10% above baseline levels	Immediate suspension of GHG stream injection operations should deviation from expected operating parameters is detected. Trigger internal investigation within CTSCo.	Remediation dependent on cause	Continue injection	
						Post Injection (monitoring phase)	Continuous until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	> 10% above baseline levels	Deviation from expected monitoring phase parameters is detected. Trigger internal investigation within CTSCo.	Remediation dependent on cause		
Subsurface Conformance & Containment	GHG plume spatial extent	Pressure	Wellhead	GHG plume migration conformance and GHG plume containment	Specialist surface pressure gauges deployed in West Moonie Shallow Monitoring Bore, Gubberamunda Monitoring Bore, West Moonie-2 Monitoring Well, and West Moonie Sentinel Monitoring Well to monitor standing groundwater levels in the Griman Creek Formation,	Pre-injection (baseline)	Commencing 6 months prior to injection commencing, twice daily monitoring of groundwater standing water level within each bore or well to enable natural groundwater pressure fluctuations to be distinguished from potential standing water level impacts due to injection activities	Baseline survey to confirm trigger values	Not Applicable			Negligible

Monitoring Purpose	Monitoring outcome	Measured Parameters	Measurement Location	Why?	How?	Project Phase	Measurement Frequency	Departure/Trigger	Mitigation Measures			Residual Risk
									Short-term action	Medium-term action	Long-term action	
					Gubberamunda Sandstone aquifer, Hutton Sandstone aquifer, and Precipice Sandstone aquifer respectively	Injection (operation phase)	Twice daily monitoring of groundwater standing water level within each bore or well to enable natural groundwater pressure fluctuations to be distinguished from potential standing water level impacts due to injection activities	> 10 % above baseline levels	Immediate suspension of GHG stream injection operations should any leak be detected and deviation from expected operating parameters detected. Trigger internal investigation within CTSCo.	Remediation dependent on cause. Notify administering authority of EA within Annual Report	Continue injection	
						Injection (operation phase)	Twice daily monitoring of groundwater standing water level within each bore or well to enable natural groundwater pressure fluctuations to be distinguished from potential standing water level impacts due to injection activities	> 20 % above baseline levels	Immediate suspension of GHG stream injection operations should any leak be detected and deviation from expected operating parameters detected. Immediately notify administering authority of EA. Immediately initiate investigations.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause.	
						Post Injection (monitoring phase)	6 monthly until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	> 10 % above baseline levels	If the monitoring shows any unexpected pressure changes or standing water level changes. Trigger internal investigation within CTSCo.	Remediation dependent on cause. Notify administering authority of EA within Annual Report		
Subsurface Containment	GHG plume spatial extent	CO_2 saturation	Downhole	GHG plume migration containment	Cased hole pulsed neutron logging from total depth to surface in West Moonie-2 Monitoring Well (for Hutton and Precipice Sandstone aquifers), Gubberamunda Monitoring Well and West Moonie Sentinel Well	Pre-injection (baseline)	6 months prior to injection commencing	Baseline survey to confirm trigger values	Not Applicable			Negligible
						Injection (operation phase)	Logging every 6 months	10% greater than baseline level of CO_2 saturation. If the monitoring shows presence of the GHG stream in Hutton or Gubberamunda Sandstone aquifers, or outside GHG plume in the Precipice Sandstone aquifer	Immediate suspension of GHG stream injection operations should any leak be detected, and initiate investigations. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Continue injection	
						Post Injection (monitoring phase)	6 monthly until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	10% greater than baseline level of CO_2 saturation. If the monitoring shows presence of the GHG stream in Hutton or Gubberamunda Sandstone aquifers, or outside GHG plume in the Precipice Sandstone aquifer	Immediately initiate investigations. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause	
Subsurface Conformance	GHG plume spatial extent	CO_2 saturation	Downhole		Cased hole pulsed neutron logging from	Pre-injection (baseline)	6 months prior to injection commencing	Baseline survey	Not Applicable			Negligible

Monitoring Purpose	Monitoring outcome	Measured Parameters	Measurement Location	Why?	How?	Project Phase	Measurement Frequency	Departure/Trigger	Mitigation Measures			Residual Risk
									Short-term action	Medium-term action	Long-term action	
				GHG plume migration conformance	total depth to surface in West Moonie-2 Monitoring Well (for Precipice Sandstone aquifer)	Injection (operation phase)	Logging every 6 months	Comparison of GHG plume vertical position within the Precipice Sandstone compared to predicted.	Trigger internal investigation within CTSCo. Review and update hydrogeology and dynamic (plume) models.	None	Continue injection	
						Post Injection (monitoring phase)	6 monthly until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	Comparison of GHG plume vertical position within the Precipice Sandstone compared to predicted.	Trigger internal investigation within CTSCo. Review and update hydrogeology and dynamic (plume) models.	None	None	
Subsurface Containment	Groundwater Water Quality	Griman Creek water chemistry and groundwater quality	Downhole	GHG plume migration containment	NATA laboratory analysis of pumped water recovery of groundwater samples from the West Moonie Shallow Monitoring Bore.	Pre-injection (baseline)	6 months prior to injection commencing	Baseline survey to obtain more water quality samples and confirm trigger values	Not Applicable			Negligible
						Injection (operation phase)	6 monthly	pH ≤ 3.5 As ≥ 1 mg/L Pb ≥ 2 mg/L	Immediate suspension of GHG stream injection operations and initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Continue injection	
						Injection (operation phase)	6 monthly	pH ≤ 3 As ≥ 2 mg/L Pb ≥ 5 mg/L	Immediate suspension of GHG stream injection operations and initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause.	
						Post Injection (monitoring phase)	6 monthly until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	pH ≤ 3.5 As ≥ 1 mg/L Pb ≥ 2 mg/L	Initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause.	
						Post Injection (monitoring phase)	6 monthly until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	pH ≤ 3 As ≥ 2 mg/L Pb ≥ 5 mg/L	Initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause.	
Subsurface Containment	Groundwater Water Quality	Gubberamunda Sandstone water chemistry and groundwater quality	Downhole	GHG plume migration containment	NATA laboratory analysis of pumped water recovery of groundwater samples from the Gubberamunda Monitoring Bore.	Pre-injection (baseline)	6 months prior to injection commencing	Baseline survey to obtain more water quality samples and confirm trigger values	Not Applicable			Negligible
						Injection (operation phase)	6 monthly	pH ≤ 3.5 As ≥ 1 mg/L Pb ≥ 2 mg/L	Immediate suspension of GHG stream injection operations and initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Continue injection	
						Injection (operation phase)	6 monthly	pH ≤ 3 As ≥ 2 mg/L Pb ≥ 5 mg/L	Immediate suspension of GHG stream injection operations and initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause.	

Monitoring Purpose	Monitoring outcome	Measured Parameters	Measurement Location	Why?	How?	Project Phase	Measurement Frequency	Departure/Trigger	Mitigation Measures			Residual Risk
									Short-term action	Medium-term action	Long-term action	
						Post Injection (monitoring phase)	6 monthly until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	pH ≤ 3.5 As ≥ 1 mg/L Pb ≥ 2 mg/L	Initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause.	
						Post Injection (monitoring phase)	6 monthly until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	pH ≤ 3 As ≥ 2 mg/L Pb ≥ 5 mg/L	Initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause.	
Subsurface Containment	Groundwater Water Quality	Hutton Sandstone water chemistry and groundwater quality	Downhole	GHG plume migration containment	NATA laboratory analysis of pumped water recovery of groundwater samples from the Hutton Sandstone aquifer via a sliding sleeve in West Moonie-2 Monitoring Bore	Pre-injection (baseline)	6 months prior to injection commencing	Baseline survey to obtain more water quality samples and confirm trigger values	Not Applicable			Negligible
						Injection (operation phase)	6 monthly	pH ≤ 3.5 As ≥ 1 mg/L Pb ≥ 2 mg/L	Immediate suspension of GHG stream injection operations and initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Continue injection	
						Injection (operation phase)	6 monthly	pH ≤ 3 As ≥ 2 mg/L Pb ≥ 5 mg/L	Immediate suspension of GHG stream injection operations and initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause.	
						Post Injection (monitoring phase)	6 monthly until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	pH ≤ 3.5 As ≥ 1 mg/L Pb ≥ 2 mg/L	Initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause.	
						Post Injection (monitoring phase)	6 monthly until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	pH ≤ 3 As ≥ 2 mg/L Pb ≥ 5 mg/L	Initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause.	
Subsurface Containment	Groundwater Water Quality	Precipice Sandstone groundwater chemistry **outside** of GHG plume	Downhole	GHG plume migration containment monitoring	NATA laboratory analysis of pumped water recovery of groundwater samples from the West Moonie Sentinel Well	Pre-injection (baseline)	6 months prior to injection commencing	Baseline survey to obtain more water quality samples and confirm trigger values	Not Applicable			Negligible
						Injection (operation phase)	6 monthly	pH ≤ 3.5 As ≥ 1 mg/L Pb ≥ 2 mg/L	Trigger internal investigation within CTSCo	Remediation dependent on cause. Notify administering authority of EA within Annual Report	Continue injection	
						Injection (operation phase)	6 monthly	pH ≤ 3 As ≥ 2 mg/L Pb ≥ 5 mg/L	Immediate suspension of GHG stream injection operations and initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause. Option to undertake remedial pumping from West Moonie-1 Injection Well to recover as much GHG stream as possible	

Monitoring Purpose	Monitoring outcome	Measured Parameters	Measurement Location	Why?	How?	Project Phase	Measurement Frequency	Departure/Trigger	Mitigation Measures			Residual Risk
									Short-term action	**Medium-term action**	**Long-term action**	
						Post Injection (monitoring phase)	6 monthly until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	pH ≤ 3.5 As ≥ 1 mg/L Pb ≥ 2 mg/L	Trigger internal investigation within CTSCo	Remediation dependent on cause. Notify administering authority within Annual Report		
						Post Injection (monitoring phase)	6 monthly until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	pH ≤ 3 As ≥ 2 mg/L Pb ≥ 5 mg/L	Initiate investigations including additional groundwater quality sampling. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause. Option to undertake remedial pumping from West Moonie-1 Injection Well to recover as much GHG stream as possible	
Subsurface Conformance	Groundwater Water Quality	Precipice Sandstone groundwater chemistry **within** the GHG plume	Downhole	Conformance of spatial GHG plume migration to geochemical model predictions	NATA laboratory analysis of pumped water recovery of groundwater samples from the West Moonie-2 Monitoring Well	Pre-injection (baseline)	6 months prior to injection commencing	Baseline survey to obtain more water quality samples and confirm trigger values	Not Applicable			Negligible
						Injection (operation phase)	6 monthly	pH ≤ 3.5 As ≥ 1 mg/L Pb ≥ 2 mg/L	Trigger internal investigation within CTSCo. Review and update geochemical models.	Remediation dependent on cause. Notify administering authority of EA within Annual Report	Continue injection	
						Injection (operation phase)	6 monthly	pH ≤ 3 As ≥ 2 mg/L Pb ≥ 5 mg/L	Immediate suspension of GHG stream injection operations and initiate investigations including additional groundwater quality sampling. Review and update geochemical models. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause. Option to undertake remedial pumping from West Moonie-1 Injection Well to recover as much GHG stream as possible	
						Post Injection (monitoring phase)	6 monthly until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	pH ≤ 3.5 As ≥ 1 mg/L Pb ≥ 2 mg/L	Trigger internal investigation within CTSCo. Review and update geochemical models	Remediation dependent on cause. Notify administering authority of EA within Annual Report		
						Post Injection (monitoring phase)	6 monthly until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	pH ≤ 3 As ≥ 2 mg/L Pb ≥ 5 mg/L	Initiate investigations including additional groundwater quality sampling. Review and update geochemical models. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause. Option to undertake remedial pumping from West Moonie-1 Injection Well to recover as much GHG stream as possible	
Subsurface Conformance & Containment	GHG plume spatial extent	Seismic amplitude	Subsurface (near ground level to below Storage Complex)	Conformance of spatial extent of GHG plume migration within Precipice Sandstone aquifer. Conformance compared to dynamic (plume) model predictions. Containment of GHG plume extent for all other formations.	Repeat 2D seismic surveys using permanent multi-component 2D seismic lines for time-lapse seismic surveying	Pre-injection (baseline)	Seismic survey will be undertaken using all 2D seismic monitoring lines at least 6 months prior to injection commencing.	Set seismic amplitude response trigger values	Not Applicable			Negligible
						Injection (operation phase)	Repeat seismic surveys using all 2D seismic monitoring lines on at least 6-monthly intervals.	Areal difference between actual GHG plume geometry and modelled (predicted) GHG plume geometry is greater than 50%	Immediate suspension of GHG stream injection operations and initiate investigations. Review and update seismic, hydrogeological and dynamic (plume) models. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.		
						Post Injection	Repeat 2D seismic surveys at 6 monthly intervals until monitoring has proven that the GHG plume has stabilised or 2 years, whichever is longer.	Areal difference between actual GHG plume geometry and modelled (predicted) GHG plume geometry is greater than 50%	Immediate suspension of GHG stream injection operations and initiate investigations. Review and update seismic, hydrogeological and dynamic (plume) models. Immediately notify administering authority of EA.	Remediation dependent on cause. Continue to update administering authority of EA on remediation actions.	Remediation dependent on cause. Option to undertake remedial pumping from West Moonie-1 Injection Well to recover as much GHG stream as possible	

9.10.1 Description of Key Technologies and Processes for Monitoring and Mitigation

9.10.1.1 2D SEISIMIC MONITORING NETWORK

The 2D seismic monitoring network will assess the GHG plume movement through the aquifer, as is described further in Chapter 2 Proposed Project Description, section 2.8.1.3.3.

9.10.1.2 AQUIFER PRESSURE MONITORING

The movement of the GHG plume will be accompanied by a propagating wave of pressure, the spatial footprint of which will far exceed the dimensions of the GHG plume itself. Therefore, head pressure is a simple and effective monitoring parameter.

9.10.1.3 WIRELINE PULSED NEUTRON LOGGING AND CARBON-OXYGEN LOGGING (C/O LOGGING)

Pulsed neutron capture (PNC) logs measure changes in residual saturation (water saturation) as a consequence of the presence of CO_2. Data produced by PNC logging tools are used to establish quantitative interpretations for CO_2 saturation. This logging effort will include a comparison of baseline and repeat data to determine changes in CO_2 and water saturations.

9.10.1.4 GROUNDWATER QUALITY MONITORING, SAMPLING AND ANALYSIS

Groundwater quality monitoring will be undertaken every 6 months, commencing at least 6 months prior to the commencement of GHG stream injection. Groundwater quality monitoring is to be undertaken by suitably qualified persons in accordance with sampling procedures, which should be reviewed and updated as required, based on the following guidelines (or more recent where available):

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018);
- Groundwater Quality Assessment Guideline: Using monitoring data to assess groundwater quality and potential environmental impacts (DSITIA, 2017); and
- Monitoring and Sampling Manual – Environmental Protection (Water) Policy 2009 (DES, 2018)

The groundwater quality monitoring will be incorporated into the MVP.

Samples are to be collected in accordance with the Queensland Government's *Monitoring and Sampling Manual* and stored in chilled eskies and transported to a NATA-accredited laboratory within the relevant holding times for all parameters. Other QA/QC measures are to include the collection of field duplicates and the calculation of relative percentage differences between the primary and duplicate samples. Due to short holding times, some parameters are to be measured on-site using a calibrated water quality meter, as follows:

- Dissolved oxygen (DO);
- Electrical conductivity (EC);
- pH;
- Temperature (°C);
- Redox Potential (ORP);
- Turbidity (NTU).

Groundwater samples will be analysed for the below list of parameters:

- Physico-chemical parameters and major and minor ions:
  - Sodium (Na);
  - Calcium (Ca);
  - Magnesium (Mg);
  - Potassium (K);
  - Chloride (Cl);
  - Sulfate (SO_4);
  - Nitrate (NO_3);
  - Ammonia (NH_3);
  - Phosphorus (P);
  - Electrical Conductivity (EC);
  - Total Dissolved Solids (TDS);
  - pH;

  - Total Alkalinity;
  - Silica (SiO_2);
  - Fluoride (F);
  - Dissolved Oxygen (DO);
  - Total Organic Carbon (TOC);
  - Total Dissolved Solids (TDS);
  - Hardness;
- Trace inorganic chemical parameters (trace metals):
  - Aluminium (Al);
  - Arsenic (As);
  - Beryllium (Be);
  - Boron (B);
  - Cadmium (Cd);
  - Chromium (Cr);
  - Cobalt (Co);
  - Copper (Cu);
  - Iron (Fe);
  - Lead (Pb);
  - Lithium (Li);
  - Manganese (Mn);
  - Mercury (Hg);
  - Molybdenum (Mo);
  - Nickel (Ni);
  - Selenium (Se);
  - Silver (Ag);
  - Uranium (U);
  - Vanadium (V);
  - Zinc (Zn);
- TRH/TPH/BTEXN/PAH, including C1 to C4 fractions;
- Dissolved Gases:
  - Methane (CH_4);
  - Carbon Dioxide (CO_2);
  - Hydrogen Sulphide (H_2S).

Monitoring will include the Griman Creek Formation, Gubberamunda Sandstone aquifer, Hutton Sandstone aquifer, and Precipice Sandstone aquifer (both inside and outside the GHG plume).

Following receipt of sampling and analysis results for each sampling event, a report will be prepared to compare the monitoring results with the baseline water quality measurements and the Water Quality Objectives (WQO) for each aquifer. Any exceedances will be identified and discussed in the report. The discussion may include identification of trends and comparison against model predictions.

All groundwater monitoring undertaken within the annual period is to be included in an annual monitoring report and submitted to the relevant administering authority. This report is to be prepared and/or verified by a suitably qualified and experienced person. The report will:

- identify sampling methodology, including any deviations of the method and any corrective actions required;
- date of sampling events;
- identify locations of all sampling points, and a rationale as to why a sampling location(s) were not included or sampled (dry, inaccessible due to weather, etc.);
- for monitoring wells and bore – the standing water level;
- detail of all exceedances of baseline values and relevant WQOs for each aquifer sampled;
- discuss exceedances and potential influence from Project activities and climate influences;
- compare to previous monitoring data;
- for the QA/QC of the sampling program, include:
  - Chain of Custody documentation;
  - calibration records for sampling and monitoring equipment;
  - field equipment inspections / calibration / testing logs (as required);

- field QA/QC – Blanks, Rinsate, Duplicate and Triplicate RPDs; and
- laboratory QA/QC.

The report will support the GHG storage injection testing completion assessment report and will be key to determining the success or otherwise of the GHG storage injection testing.

9.10.1.5 GROUNDWATER CHEMISTRY AND WATER QUALITY TRIGGER INVESTIGATION VALUES FOR MONITORING OF THE PRECIPICE SANDSTONE AQUIFER WITHIN THE GHG PLUME

As discussed in section 9.9.4 above and in Appendix 9D, pH is a key chemical parameter associated with GHG stream injection, indicating the dissolution of CO_2 in the water of the GHG storage reservoir. Arsenic (As) and lead (Pb) can serve as proxies for the behaviour of other trace chemical parameters, and their mobilisation and demobilisation are important to understand in the context of GHG stream storage. Table 9-49 provides a summary of the key chemical parameters and trigger investigation values.

Table 9-49 Groundwater quality monitoring trigger investigation values for the Precipice Sandstone aquifer for within the GHG plume during GHG stream injection

Water Quality Parameter	Trigger Investigation Value	Monitoring Location	Basis	Action	Reporting
pH	3.5	West Moonie-2 Monitoring Well	Sufficiently below the predicted minimum value of 4 to minimise false positive or false negative readings	Trigger internal investigation within CTSCo	Notify administering authority of EA within Annual Report
pH	3	West Moonie-2 Monitoring Well	An order of magnitude lower than the predicted minimum value of 4 but still only weakly acidic	Suspend GHG stream injection and initiate investigation	Notify administering authority of EA
Arsenic (mg/L)	1	West Moonie-2 Monitoring Well	Double the predicted maximum concentration of 0.5 mg/L, to minimise false positive or false negative readings, and is also equal to half of the WQO short term trigger value for irrigation / farm use	Trigger internal investigation within CTSCo	Notify administering authority of EA within Annual Report
Arsenic (mg/L)	2	West Moonie-2 Monitoring Well	Equal to the WQO short term trigger value Irrigation / farm use	Suspend GHG stream injection and initiate investigation	Notify administering authority of EA
Lead (mg/L)	2	West Moonie-2 Monitoring Well	Double the predicted maximum concentration of 1 mg/L, to minimise false positive or false negative readings, and is also equal to the WQO long term trigger value for irrigation / farm use	Trigger internal investigation within CTSCo	Notify administering authority of EA within Annual Report
Lead (mg/L)	5	West Moonie-2 Monitoring Well	Equal to the WQO short term trigger value for irrigation / farm use	Suspend GHG stream injection and initiate investigation	Notify administering authority of EA

As given in Table 9-49, the use of the above trigger investigation values has also been extended to outside the GHG plume both within the Precipice Sandstone aquifer, and to other aquifers overlying the storage complex, with actions and reporting modified accordingly.

9.10.1.5.1 Rationale for Trigger Investigation Values

For monitoring within the GHG plume, trigger investigation values are set above the predicted maximum concentrations while recognising that median concentrations of chemical parameters across the GHG plume may be significantly lower over the life of the GHG plume.

For pH the initial trigger investigation value for within the GHG plume is 3.5, which is sufficiently below the predicted minimum value by the RTM to minimise the likelihood of false positives. A trigger investigation value has been set for pH because this is a major control on elemental behaviour in the GHG plume.

In the RTM, the highest predicted concentrations of arsenic occurred along the edges of the GHG plume and low concentrations predicted to occur within the volume where Iron (III) hydroxide ($Fe(OH)_3$) precipitation takes place. The distribution of arsenic reflects mobilisation by desorption and arsenic transport by advection from areas of higher concentrations. For arsenic concentrations, the trigger investigation value for within the GHG plume are 1 mg/L (internal investigation) and 2 mg/L (suspend GHG stream injection, investigate and notify administering authority). These trigger investigation values are sufficiently above the maximum values in the GHG plume predicted by the RTM to minimise the likelihood of false positives, but less than the Irrigation/Farm Use WQO short term trigger values of 2 mg/L and 5 mg/L. Arsenic behaves differently to lead and the other chemical parameters.

Lead displays a very different predicted evolution of distribution than arsenic. Initially, the RTM predicted the highest lead concentrations were where carbonate mineral dissolution dominates and then advective dispersion becomes the main process affecting lead distribution. The predicted distribution of cadmium (Cd), cobalt (Co), copper (Cu), manganese (Mn), nickel (Ni) and zinc (Zn) is predicted to be similar to lead. For lead concentrations, the trigger investigation value for within the GHG plume are 2 mg/L (internal investigation) and 5 mg/L (suspend GHG stream injection, investigate and notify administering authority). Given lead's similar behaviour to other trace chemical parameters of interest, it can be used as a proxy or surrogate to other trace chemical parameters such as cadmium, cobalt, copper, manganese, nickel, and zinc. The trigger investigation values are above the maximum values in the GHG plume predicted by the RTM to minimise the likelihood of false positives, and equal to the WQO long term trigger value for Irrigation/Farm Use and the WQO short term trigger value for Irrigation/Farm Use respectively.

9.10.1.6 DATA COLLECTION AND PROGRESSIVE MODELLING UPDATES

Data will be collected and verified, and progressively input into models, including of water entitlement holders. Progressive annual updates of the hydrogeological, dynamic (plume), and geochemical models throughout the Project's operation and monitoring phases will allow for further understanding of the GHG stream injection processes and GHG plume behaviour which can be applied to larger scale GHG stream storage. All data and modelling are to be peer reviewed for accuracy.

9.10.1.7 INTERACTION WITH OTHER RESOURCE TENEMENT HOLDERS

With regard to overlapping resource tenure holders, as outlined in Chapter 4 Approvals, section 4.4.10, the *Mineral and Energy Resources (Common Provisions) Act 2014* (MERCPA) Chapters 4 and 5 do not strictly specify management of the interactions with GHG permits, but CTSCo is aware of the broad intent of MERCPA, and applies the concepts in its conduct with other resource tenement holders, including notification of activities and determining if there is potential for any interaction of activities in-field.

9.10.1.8 INTERACTION WITH WATER ENTITLEMENT HOLDERS

As outlined in Chapter 4 Approvals, section 4.4.23, for the injection of a GHG stream into the Precipice Sandstone aquifer, a water licence is required under the *Water Act 2000*, s.107 to authorise the interference with water. As per s.110 of the *Water Act 2000*, CTSCo is to make an application using *Form W2F006e Application by an entity for licence to interfere with a course of flow* (or as otherwise updated or advised) to the chief executive of the *Water Act 2000*, in a process that is separate to EIS processes. The water licence application process will be subject to a public notification process under s.112 for at least 30 business days.

Further to 9.9.6.2 above, in applying for a water entitlement under the *Water Act 2000*, an applicant is to consider the potential impacts or interactions with existing water entitlement holders, as per the *GABORA Water Management Protocol, Chapter 4 – Protection of existing licences and particular authorisations requirements on minimum separation distances*. A minimum separation distance should apply equally to both CTSCo's application for a water entitlement on existing water entitlement holders within the Precipice Sandstone aquifer, and any future water entitlement applicants into the Precipice Sandstone aquifer outside of the GHG plume or the operational lands (approximately 5 km radius from the West Moonie-1 Injection Well) to consider the minimum separation distance requirements to CTSCo's GHG plume.

Further to section 9.10.1.6, to update modelling throughout the life of the Project, data on water entitlement holders will be obtained annually from the Queensland Government data portal.

The *Water Act 2000, Chapter 3 Underground water management*, the requirements associated with Make Good Agreement do not apply to resource tenements granted under the *Greenhouse Gas Storage Act 2009*.

If a complaint or pollution incident event were raised by a water entitlement holder regarding the GHG stream affecting the quality of water taken from their bore, as outlined in sections 9.5.1, 9.6.3, 9.6.4, 9.7.6 above, in the first instance, the water would need to be sampled from the complainant's bore to characterise the carbon-13 (~$\delta^{13}C$ CO_2) isotope profile of the water. All groundwater bodies have a unique carbon-13 (~$\delta^{13}C$ CO_2) isotope profile, as does each GHG stream source. The carbon-13 (~$\delta^{13}C$ CO_2) isotope profile of water from a bore the subject of any complaint or pollution incident event would provide evidence of the source of carbon-13 (~$\delta^{13}C$ CO_2) isotope, and therefore if the GHG stream was or wasn't the source of water quality impacts.

9.10.2 Avoidance and Mitigation Measures in the Rehabilitation Phase

CTSCo is developing the Project within EPQ10 to demonstrate the feasibility of permanent geological storage of a GHG stream comprising predominately CO_2 within the Precipice Sandstone within the deepest parts of the Surat Basin. The Project findings will determine the future direction of GHG injection at EPQ10. Two options currently exist:

- Project wells and bores are plugged and abandoned following completion of the operation and monitoring phases; or
- Project wells and bores are suspended and shut-in for future development, subject to further approvals.

All Project wells and bores will be plugged and abandoned according to the *Code of Practice for the construction and abandonment of petroleum wells and associated bores in Queensland* (DNRME, 2019). However, the West Moonie Shallow Monitoring Bore will be decommissioned in accordance with the *Minimum Construction Requirements for Water Bores in Australia* (NUDLC, 2020). Subject to agreement with the landholder and obtaining relevant water entitlements under the *Water Act 2000*, the Gubberamunda Monitoring Bore will be converted to a water supply bore and handed over to the landholder. If the landholder does not agree to the handover of the Gubberamunda Monitoring Bore or a water entitlement is not granted under the *Water Act 2000*, the bore will be plugged and abandoned accordingly.

Pursuant to the GHG Act, s.31, given the temporary nature of all structures in the Transportation Facility, all structures will be removed from the area, with the operational lands rehabilitated to pasture consistent with the surrounding land use.

The hydrogeological, dynamic (plume) and geochemical models and water quality monitoring program of the Precipice Sandstone will be finalised at the closure of the Project using the most recent datasets, with findings reported to the administering authorities of EPQ10 and the EA.

Final rehabilitation will be in accordance with EPQ10 conditions, EA conditions and legislative requirements.

Further details of the rehabilitation measures to be undertaken are provided in Chapter 19 Rehabilitation.

9.11 Residual Impacts

The key to avoiding and minimising the number of residual impacts is to design, construct, operate and monitor the Project to align as closely as possible with the existing geological, hydrogeological, geochemical and environmental conditions present at the Project site.

Residual impacts are predicted to be limited and highly localised to the GHG plume:

- No impacts are predicted to the geology. Injection pressures will not cause fracturing or the reactivation of faults, and geochemical modelling predicts there will be no net change to the porosity of the Precipice Sandstone as a result of the GHG steam injection.

- The injection of the GHG stream will cause an increase in pressure within the Precipice Sandstone. The maximum predicted increase is minor at approximately 11 psi at the end of the 3-year injection period, and the pressure increase will dissipate following cessation of GHG stream injection. As there are no nearby springs or surface expression of groundwater from the Precipice Sandstone, the pressure increase is a slight positive impact of the Project, and it will offset to a very small extent the pressure decline associated with oil and water extraction from the Moonie Oil Field.
- Changes to groundwater chemistry and water quality are predicted within the GHG plume. These impacts will be highly localised to within the GHG plume, contained within approximately 1,200 m to 1,500 m diameter of the West Moonie-1 Injection Well. No changes to water quality are predicted to occur outside of the GHG plume.
- There are no predicted impacts upon groundwater dependent ecosystems or aquatic ecosystems, with further details provided in Chapter 14B Aquatic Flora and Fauna.
- There are no current groundwater entitlement holders that are predicted to be impacted by the Project.
- Future groundwater extraction from the Precipice Sandstone should be restricted from within the GHG plume, as water extraction will remove the stored GHG stream (CO_2), and not meet the purposes of *the Greenhouse Gas Storage Act 2009*.
- The application and granting of future water entitlements from the Precipice Sandstone aquifer should consider the requirements of the *GABORA Water Management Protocol, Chapter 4 – Protection of existing licences and particular authorisations* requirements on minimum separation distances, as outlined in section 9.10.1.8 above.

9.11.1 Summary of Residual Impacts with reference to the Environmental Protection Regulations 2019

Under the Environmental Protection Regulation 2019, s.35(1)(a), the administering authority must, for making an environmental management decision relating to an ERA, (other than a prescribed ERA) carry out an environmental objective assessment against the environmental objective and performance outcomes mentioned in Schedule 8, Part 3, Divisions 1 and 2. Table 9-50 and Table 9-51 present a summary of the residual impacts of relevance to the requirements of Schedule 8 and EP Regulation, s.41.

Table 9-50 Environmental Protection Regulation 2019, Schedule 8, groundwater environmental objectives and performance outcomes summary

ID	Objectives and performance outcomes	Project detail
Groundwater		
Objective	The activity will be operated in a way that protects the EVs of groundwater and any associated surface ecological systems.	The Project has been designed, constructed and will be operated in a way that protects the EVs of aquifers. The design of the Project targets the Precipice Sandstone aquifer, which is a deep, confined aquifer to avoid and minimise impacts to more frequently used overlying aquifers in the area. EVs for groundwater outside of the GHG plume are predicted to experience no impacts to water quality, or potential volumetric take under water entitlements within the Precipice Sandstone aquifer.
Performance outcomes		
1	Both of the following apply —	
(a)	there will be no direct or indirect release of contaminants to groundwater from the operation of the activity.	The Project will directly inject the GHG stream into the Precipice Sandstone aquifer as a supercritical fluid with a temperature and pressure profile similar to the existing conditions of the Precipice Sandstone aquifer. The purpose of the Project is to intentionally target a confined, deep aquifer for the purpose of GHG storage injection testing of a GHG stream to meet the purposes of the *Greenhouse Gas Storage Act 2009* that is to help reduce the impact of greenhouse gas emissions on the environment by greenhouse gas geological storage.
(b)	there will be no actual or potential adverse effect on groundwater from the operation of the activity.	The groundwater is predicted to have a negligible change in pressure due to injection of the GHG stream.

		The injection testing of the GHG stream is predicted to have a negligible impact on the groundwater uses or users of the water of the Precipice Sandstone taking or interfering with water from outside the GHG plume. The GHG plume has a predicted diameter of 1,200 m to 1,500 m centred around the West Moonie-1 Injection Well (shown in Figure 9-25). GHG storage injection testing is unlikely to result in a deterioration in the environmental values of the receiving groundwater resource, being the Precipice Sandstone aquifer outside the GHG plume, which will continue to support EVs to the same extent as the existing environment.
2	The activity will be managed to prevent or minimise adverse effects on groundwater or any associated surface ecological systems.	The Project has been designed, constructed and will be operated in a way that prevents or minimises adverse effects on groundwater and surface ecological systems. The GHG plume is predicted to experience a limited number of long-term changes to some water quality parameters within the GHG plume, as discussed in section 9.9.4. However, no changes to water quality outside of the GHG plume are predicted. No adverse effects are predicted to surface ecological systems. Multiple independent monitoring systems will be implemented for the Project to measure actual data to allow comparison with the predicted modelling outcomes. Ongoing monitoring of groundwater quality will be undertaken, and a seismic survey network used to detect GHG stream and GHG plume presence and movement. Monitoring and mitigation measures as outlined in section 9.10 will be implemented to prevent or minimise the occurrence of unexpected adverse effects on groundwater or any associated surface ecological systems. In summary, the Project will be managed to prevent or minimise adverse effects on groundwater or any associated surface ecological systems.
	Note — Some activities involving direct releases to groundwater are prohibited under section 41 of this regulation.	

Table 9-51 Environmental Protection Regulation 2019, s.41

Section 41	Activity involving direct release of waste to groundwater	Project detail
1	This section applies to the administering authority for making an environmental management decision relating to an activity that involves, or may involve, the release of waste directly to groundwater (the ***receiving groundwater***). *Example of direct release of waste to groundwater –* an activity involving the release of contaminated water to groundwater through a well, deep-well injection or a bore	The Project involves the injection of a GHG stream into the Precipice Sandstone aquifer. Hence s.41 of the EP Regulation applies.
2	The administering authority must refuse to grant the application if the authority considers:	
a	for an application other than one relating to an EA for a petroleum activity – the waste is not being, or may not be, released entirely within a confined aquifer; or	As described in section 9.7, the Precipice Sandstone aquifer is a confined aquifer, hydraulically isolated from other shallower aquifers by the lower Evergreen Formation, which provides a regionally extensive overlying aquitard at least 150 m thick. The Precipice Sandstone aquifer is also underlain by the aquitard being Moolayember Formation. From a hydrogeological basis, at the West Moonie-1 Injection Well, the Precipice Sandstone aquifer is deeply confined at an overburden depth of over 2 km, and the Precipice Sandstone remains a confined aquifer for hundreds of kilometres from the operational lands. The closest mapped outcrop of the Precipice

Section 41	Activity involving direct release of waste to groundwater	Project detail
		Sandstone is approximately 235 km north of the West Moonie-1 Injection Well. Hence, the Precipice Sandstone aquifer at the West Moonie-1 Injection Well meets the definition of a confined aquifer – as defined in EP Regulation s.41(3). The design, construction, operation and monitoring of the West Moonie-1 Injection Well will be to ensure that the GHG stream is injected into the confined Precipice Sandstone aquifer.
b	the release of the waste is affecting adversely, or may affect adversely, a surface ecological system; or	The exposure pathways assessed under section 9.9 above identified that no complete exposure pathways have been identified between the surface ecological systems and the Precipice Sandstone aquifer associated with the predicted extent of the GHG plume. In addition, the surface ecological systems are separated physically by at least six regional aquitards from the GHG storage reservoir. These aquitards act as hydraulic barriers to prevent vertical upward migration of the GHG plume. Thus, the injection testing of the GHG stream is extremely unlikely to impact on surface ecological systems.
c	the waste is likely to result in a deterioration in the environmental values of the receiving groundwater.	The EVs and WQOs of the Precipice Sandstone aquifer and overlying aquifers are defined in section 9.7.5. Some chemical parameters of the existing groundwater quality of the Precipice Sandstone are not consistent with the WQOs for the identified EVs. An assessment of the potential impacts of the Project on EVs of the Precipice Sandstone aquifer are set out in sections 9.9.4 and 9.9.7. The GHG storage injection testing will be hydraulically contained within the confined aquifer of the Precipice Sandstone. The lateral extent of the GHG plume is predicted to be approximately 1,200 m to 1,500 m in diameter centred around the West Moonie-1 Injection Well. Within the GHG plume, the water quality chemical parameters are predicted to fluctuate over time as the GHG plume reacts with the rock and formation water of the Precipice Sandstone aquifer. The predicted impacts to rock geochemistry and groundwater quality will be confined to the extent of the GHG plume with Migration Assisted Trapping (MAT) processes important to confining the flow and movement of the GHG plume. The potential impacts to groundwater chemistry and water quality are predicted to be limited to within the GHG plume. Compared to aquatic ecosystem or irrigation/farm use WQOs, some chemical parameters within the GHG plume may change to be outside the WQOs values, while some parameters will remain within the WQOs trigger values or nominated percentiles of concentration. No changes to water quality are predicted to occur beyond the GHG plume extent. Overall, the GHG storage injection testing is unlikely to result in a deterioration in the environmental values of the receiving groundwater resource, being the Precipice Sandstone aquifer, outside the GHG plume, which continues to support EVs to the same extent as the existing environment.
3	In this section – ***confined aquifer*** means an aquifer is contained entirely within impermeable strata.	

9.12 Summary of Commitments

The groundwater impact assessment has been undertaken to identify potential groundwater impacts associated with the Project with measures developed to avoid, mitigate and monitor potential GHG stream and GHG plume impacts on the groundwater environment. The following commitments are given by CTSCo:

- install and operate the 2D seismic survey network;
- drill and install the Gubberamunda Sandstone Monitoring Bore and the West Moonie Sentinel Well in 2024 within the operational lands;
- drill, construct, operate and rehabilitate wells and bores in accordance with relevant Codes of Practice, industry standards, legislation and government policies;
- apply for a water licence under the *Water Act 2000*, to authorise the interference with water;
- undertake pressure monitoring and water quality sampling of all Project wells and bores prior to the commencement of the operation phase, and continuing throughout the operation and monitoring phases, as detailed in Table 9-48;
- install, operate and maintain monitoring systems in accordance with an ITP, MVP and amended EA conditions for the life of the Project, as detailed in Table 9-49; and
- update the hydrogeological, dynamic (plume), and geochemical modelling on an annual basis. All model updates will be peer reviewed.

9.13 Proposed Amendments to Environment Authority Conditions

This section sets out the existing EA conditions relevant to groundwater, with proposed amendments shown in ***Bold, Italics***. Deletions are shown as ~~***Strikethrough, Bold, and Italics***~~.

Note that proposed amendments to condition 42 remove reference to *Chapter 7.3 of the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Managed Aquifer Recharge*, because the sources of water associated with the guideline do not apply to a GHG stream, which is predominately CO_2. However, the intent of a “water-quality impact zone” shown in Figure 7.1 of the *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Managed Aquifer Recharge* is equivalent to the GHG plume extent as shown in Figure 9-30, and the intent of a “Hydraulic impact zone” shown in Figure 7.1, is equivalent to the predicted pressure head change in the Precipice Sandstone aquifer when GHG stream injection ceases as shown in Figure 9-46.

Condition 41 Groundwater

If the holder of this environmental authority becomes aware that environmental harm is caused or threatened to be caused, as a result of injection activities, injection must cease immediately.

Condition 42

A ***GHG stream*** ~~***Water***~~ Management Plan addressing the following matters must be developed and submitted to ***the administering authority*** prior to commencement of any GHG storage exploration activities involving ~~***water***~~ ***GHG storage*** injection ***testing*** ~~***test***~~:

- Estimated volumes and rates of ~~***water***~~ ***the GHG stream*** to be ~~***produced and***~~ injected;
- A description of the physical, chemical and biological components and their concentrations of the ~~***water***~~ ***GHG stream*** to be ***injected***;
- How and where the ~~***water***~~ ***GHG stream*** will be produced, aggregated, stored and ~~***kept separate from other waters until it Is, treated to the quality of the receiving aquifer and re***~~ injected into the ~~***source***~~ aquifer;
- ~~***Where water is proposed to be treated, describe the treatment process and D***~~emonstrate that the injection fluid has inconsequential reactivity with the target formation and native groundwater it will come into contact with;
- The characteristics of the receiving environment;

- Identify the ***spatial extent of impacts to water quality and pressure due to GHG storage injection testing***;~~ ***water quality impact zone and the hydraulic impact zone***[1]***;***~~
- Identify any injection wells, all existing bores, springs, environmental assets and watercourses connected to groundwater, faults and other geologic features that ***may incur impacts to water quality and pressure due to GHG storage injection testing*** ~~***occur within the water quality impact zone and the hydraulic impact zone;***~~
- Identify the environmental values (EVs) and water quality objectives (WQOs) of the potential water quality impact~~***s zone***~~ of the target formation in accordance with the ~~***Environmental Protection (Water) Policy 1997***~~ ***Environmental Protection (Water and Wetland Biodiversity) Policy 2019*** ~~***and the Queensland Water Quality Guidelines 2006***~~;
- Assess the potential for migration of injection fluid or native groundwater out of the target formation through wells, bores, springs, connected watercourses, faults or other geologic features likely to impact on other aquifers;
- A risk assessment identifying potential hazards, their inherent risk, preventative measures for the management of potential hazards and after consideration of the preventative measures, the residual risk of the potential hazards. Potential hazards include but are not limited to:
  a) Impacts on water quality within the ~~***water quality impact zone***~~ ***GHG plume and outside the GHG plume*** within the target formation and surrounding aquifers;
  b) impact on physical integrity of the aquifer or geological formation due to reactions between injection fluid, aquifer material and native groundwater;
  c) the potential for migration of injected fluid or native groundwater out of the target formation during the injection operations;
  d) over-pressurisation of target formation and its impact on surrounding aquifers;
  e) impacts on users or resources;
  f) impacts on other aquifers of environmental, economic or social importance; and
  g) impacts on groundwater-dependent ecosystems.
- A groundwater monitoring program that is sufficient for the prediction and early detection of any detrimental impacts on the receiving environment from the injection activity. The program must include but not be limited to:
  - Operational monitoring to manage potential hazards identified in the risk assessment (including details on sampling and analysis methods (including frequency and locations) and quality assurance and control).
  - Verification to assess performance of the injection activities, preventative measures and compliance.
- Control measures that will be implemented for each ~~***water***~~ ***GHG stream*** management option (storage, treatment and reinjection) to prevent or control the release of a contaminant or waste, ***other than the GHG stream,*** to the environment;
- The indicators or other criteria against which the performance of the ***GHG stream*** ~~***water***~~ management practices will be assessed;
- Procedures that will be adopted to regularly review the monitoring program and to report to management and the administering authority should unforeseen or non-compliant monitoring results be recorded;
- Procedures that will be implemented to prevent unauthorised environmental harm from unforeseen or non-compliant monitoring results; and
- Procedures for dealing with accidents, spills, failure of containment structures, and other incidents that may arise in the course of the ~~***produced water***~~ ***GHG stream*** management practices and result in the unexpected release of contaminants or waste to the environment.

Condition 43 ~~***Water***~~ ***GHG Stream*** Injection Cessation ***and Monitoring*** Report

The holder of this environmental authority must, within 60 business days of the completion of injection ***and monitoring*** activities, submit an injection cessation ***and monitoring*** report to the administering authority that includes but is not limited to:

a) volumes of fluid injected at each well;
b) a risk assessment statement providing details on identified hazards including their inherent risk, summary of the results from the verification monitoring, preventative measures and the residual risk; and

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~~***[1] For details on defining the water quality impact zone and the hydraulic impact zone, refer to Chapter 7.3 of the Australian Guidelines for Water Recycling. Managing Health and Environmental Risks (Phase 2) Managed Aquifer Recharge.***~~

c) a monitoring report outlining the methods and results of verification monitoring undertaken to assess the performance of the injection activities and preventative measures for identified hazards.

Condition 56— Monitoring

The holder of this environmental authority must:

a) develop a monitoring program that will demonstrate compliance with the conditions of the environmental authority;
b) document monitoring and inspections carried out under the monitoring program and any actions taken; and
c) record, compile and keep for a minimum of seven (7) years all monitoring results and data.

9.14 References

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