

Santos

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Moomba CCS project – Strzelecki and Marabooka Toolachee monitoring and verification plan



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Abbreviations

Item	Definition
1D / 2D / 3D / 4D	One / two / three / four dimensional
ACCU	Australian carbon credit unit
AS	Australian standard
BHP	Bottom hole pressure
CCS	Carbon capture and storage
CER	Clean energy regulator
CO2	Carbon dioxide
DEM	Department for Energy and Mining
DEW	Department for Environment and Water
DHG	Down-hole gauge
DN	Nominal diameter
EPA	Environment Protection Authority
EIR	Environment impact report
FDP	Field development plan
GIS	Geographic information system
H2O	Water
H2S	Hydrogen sulphide
InSAR	Interferometric synthetic aperture radar
ISO	International Organization for Standardization
KPI	Key performance indicator
LOC	Loss of containment
M&V	Monitoring and verification
mD	Millidarcy
MD	Measured depth
MICP	Mercury injection capillary pressure
NGER	National greenhouse and energy reporting
P&A	Plugged and abandoned
PNL	Pulsed neutron log
PVT	Pressure, volume, temperature
SA	South Australia
SEO	Statement of environmental objectives
SGS	Static gradient survey
TEG	Triethylene glycol

Executive summary

The Moomba Carbon Capture and Storage (CCS) Project aims to safely store up to approximately 1.7 Mtpa CO₂ equivalent of greenhouse gas emissions. The project constructed a capture facility at the Moomba gas plant and a pipeline to transport the CO₂ to the Strzelecki and Marabooka gas fields. The first phase of the project will permanently store CO₂ in the fluvial sandstones of the Toolachee Formation and is the subject of this monitoring and verification (M&V) plan. Storage capacity for the remainder of the project will be developed progressively and will be the subject of future M&V plans.

The Toolachee Formation is part of a storage complex that includes all geological units from the regional Bulldog Shale down to the pre-Permian basement. There are multiple reservoirs and seals within the complex. The Toolachee reservoirs have been selected as the target CO₂ storage reservoirs because they have previously contained significant volumes of natural gas, with a proven primary reservoir seal provided by the extensive interbedded mudstones / siltstones of the Top Toolachee Formation and Nappamerri Group.

A detailed risk assessment shows risks associated with existing legacy wells and new wells are low, and geological risks are all rated low to very low. The role of M&V is to provide extra controls to help with managing the residual risks of CO₂ storage. The primary objective of the monitoring program is to confirm long term containment of the stored CO₂ within the storage complex.

The monitoring program will achieve this objective by:

- Accurately measuring the volume of CO₂ injected into the storage complex.
- Determining the movement and ultimate stability of the injected CO₂.
- Assessing the integrity of the storage complex and wells.
- Detecting and facilitating response to loss of containment.
- Assessing the effectiveness of risk controls that are implemented.

The M&V plan outlines the data that Santos will gather and interpret. It is divided into four elements: injection telemetry, reservoir surveillance, well integrity and environmental assurance.

The reservoir surveillance plan makes use of 12 production wells that have been repurposed as observation wells. The observation wells cover both the Toolachee storage reservoir and the first significant reservoir overlying it, the Hutton Sandstone. These wells will be used for pressure measurement and saturation logging to track the movement of the CO₂.

Well integrity will be monitored through Santos' established well integrity management system supplemented by additional proactive cased-hole logging.

The project commenced CO₂ capture and injection into the wells and reservoir for permanent storage in September 2024. Baseline monitoring is complete, and operational monitoring has commenced in accordance with the M&V plan schedule.



1 Project description

The Moomba Carbon Capture and Storage Project (referred to as “the Project”) has delivered a commercial scale CCS operation at the Moomba gas plant. Moomba is an ideal location for a CCS hub due to the presence of existing petroleum operations, well understood storage reservoirs and favourable geology. The project aims to capture and permanently store up to approximately 1.7 Mtpa CO₂ equivalent of greenhouse gas emissions over a period of up to 25 years. The CO₂ will initially be injected into depleted gas reservoirs in the Strzelecki and Marabooka fields east of Moomba.

This M&V plan exclusively covers the first phase of the project using the Strzelecki and Marabooka Toolachee storage reservoirs. Any subsequent development phase will be the subject of a separate M&V plan.

1.1 Project boundaries

A block flow diagram showing the project and system boundaries is shown in Figure 1. The Moomba gas plant has established Benfield separation trains that remove CO₂ from the natural gas. All elements downstream of the existing facilities form part of the project.

1.1.1 Capture system

The capture system is comprised of a common pipeline header connected to the vent streams of the existing separation train regeneration towers and directs the CO₂ to a new compression facility outside the Moomba gas plant.

1.1.2 Processing and compression system

Once captured, the CO₂ passes to a compressor and triethylene glycol (TEG) dehydration unit constructed adjacent to the Moomba gas plant. A Coriolis mass flow meter installed downstream of the compressor provides accurate flow measurement into the transportation system.

1.1.3 Transportation system

The CO₂ transportation system is a DN250 below ground pipeline from Moomba to Strzelecki with a mid-line riser for a take-off at Marabooka. The transportation system includes flowlines and metering / control skids at each injection well. The metering skids continuously measure the pressure, temperature and flow rate of the CO₂ stream. They also provide continuous flow and pressure control for the injection wells. The downstream edge of the transportation system is at the wing valves of the injection wells. A booster pump will likely be installed at the Marabooka riser in the future to provide sufficient injection pressure.

1.1.4 Storage system

The storage system covers all elements downstream of the injection well wing valves. It includes all wells (injection, observation and suspended) and geological structures within the storage complex. The storage complex includes the target storage reservoir (Toolachee Formation) and all geological units from the regional Bulldog Shale down to the pre-Permian basement as defined in section 3.3. The storage complex contains multiple seal / reservoir units.

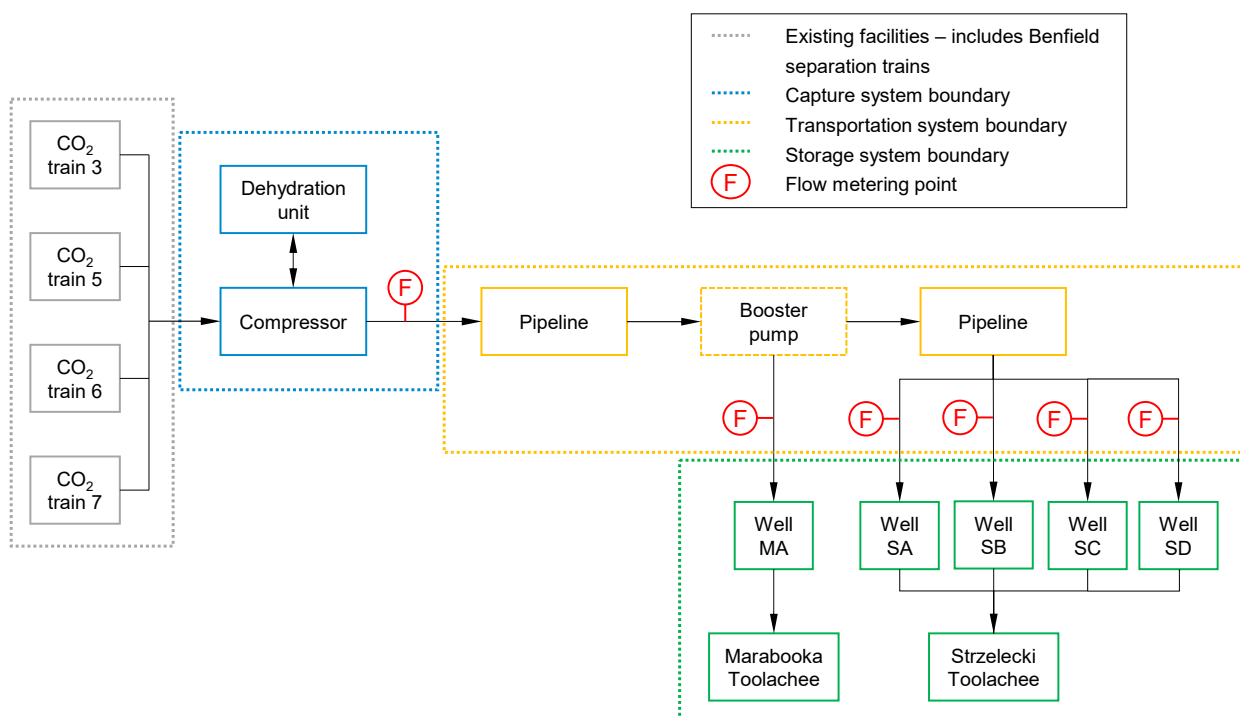


Figure 1: Project block flow diagram showing system boundaries

1.2 CO₂ stream composition

The vent stream from the Moomba Benfield units varies based on process conditions, however, long-term operational data provides good confidence on its typical composition. The vent stream is predominantly carbon dioxide and water vapour with a small carryover of other reservoir fluid components, including hydrocarbons, nitrogen and trace amounts of other substances including H₂S which are generally found naturally in, and consistent with the receiving reservoir. The capture facilities will dehydrate the vent stream, resulting in a stream of approximately 98 mole % CO₂ under typical operating conditions (Table 1). The project has been designed for a stream with a minimum CO₂ concentration of 95 mole % and other restrictions as listed in the limit operation conditions. CO₂ is required to be dehydrated for system safety and to protect downstream elements (facilities, pipeline and wells) utilising a triethylene glycol (TEG) dehydration unit, which are commonly used in gas processing globally. The TEG system operates by circulating glycol to absorb moisture from the wet CO₂ process gas. A recovery system including a high-performance filter/coalescer ensures maximum possible recovery and reuse of the glycol.

Table 1: Predominant CO₂ stream composition

Component	Typical operating conditions (mole %)	Limit operating conditions (mole %)
CO ₂	97.99	95 min
Methane	1.57	5 max
Ethane	0.13	
Propane	0.04	
Butane +	0.02	
N ₂	0.23	
H ₂ S	0.007	0.02 max
H ₂ O	0.014	0.025 max

2 M&V purpose and design

2.1 Objectives

The main purpose of monitoring and verification is to assist with managing the residual risks associated with CO₂ storage and to verify the performance of the storage complex. Santos has selected a storage complex and development strategy based on the best available data. Monitoring the actual performance of the storage complex will track and verify that management controls implemented to reduce inherent risk remain adequate.

The primary objective of the monitoring program is to confirm long term containment of the stored CO₂. Containment is defined as the injected CO₂ remaining within the storage complex – below the shallowest seal and inside the areal boundary.

The monitoring program will achieve this objective by:

- Accurately measuring the volume of CO₂ injected into the storage complex.
- Determining the movement and ultimate stability of the injected CO₂.
- Assessing the integrity of the storage complex and wells.
- Detecting and facilitating response to loss of containment.
- Assessing the effectiveness of risk controls that are implemented.

2.2 CCS project timeline

The life of a CCS project can be divided into four main stages: pre-injection, injection, closure and post-closure (Figure 2). The M&V plan is developed before the start of injection using the project risk assessment and field development plan as guides. Baseline monitoring is also conducted before the start of injection. The injection stage is the main focus of monitoring activities. The M&V plan is continually reviewed and adapted to during this stage to ensure it remains fit for purpose. A reduced monitoring scope continues beyond the end of injection to further decrease uncertainty in the ultimate behaviour of the stored CO₂. The project is decommissioned and the site closed once the residual risk is acceptably low. At this point, subject to relevant approvals, liability for the stored CO₂ transfers from the operator to the State.

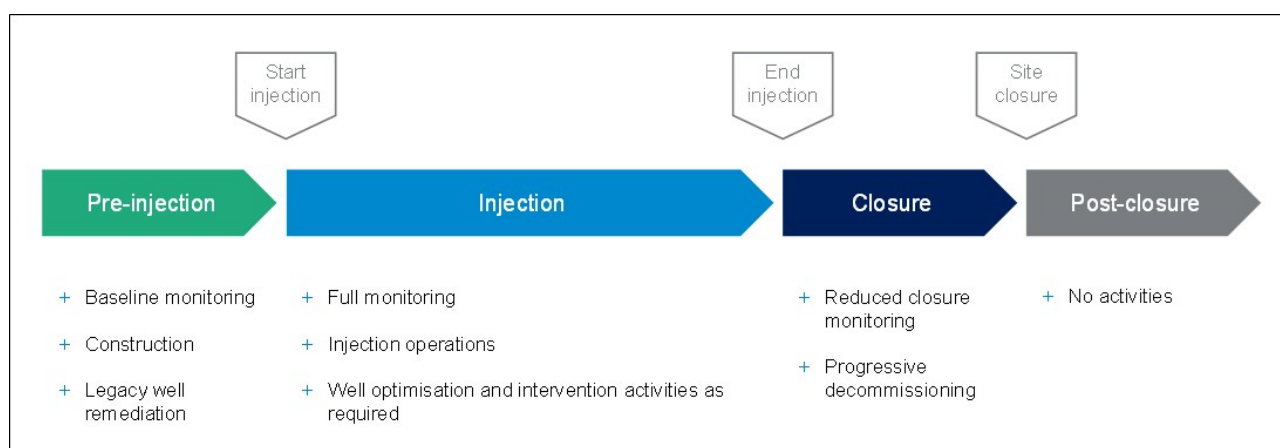


Figure 2: Moomba CCS project stages

2.3 M&V design and influences

The design principles guiding the development of the M&V plan are:

- Risk based – the plan should focus on the major project risks and provide additional controls to reduce the residual risk.
- Fit for purpose – the plan should achieve its objectives and meet all regulatory requirements in a cost-efficient manner.
- Site specific – the plan should be well suited to the characteristics and risks of the chosen storage complex.

- Continual improvement – the plan should be regularly reviewed and able to adapt to ensure it continues to meet its objectives for the life of the project.

The M&V plan meets the requirements of the *South Australia Moomba statement of environmental objectives: carbon storage* (Santos 2021), referred to as the Carbon Storage SEO. It is also heavily influenced by the *Australian Standard for geological storage of carbon dioxide* (AS ISO 27914:2019). Experience from several established CO₂ injection projects was also considered, including:

- CO₂CRC Otway International Test Centre, Victoria (depleted gas and deep saline formation)
- Gorgon, Western Australia (deep saline formation)
- In Salah, Algeria (deep saline formation)
- Quest, Canada (deep saline formation)
- Various CO₂ EOR projects, USA

The Moomba CCS Project has significant differences from other active CCS projects. The main difference is that it uses depleted gas reservoirs for CO₂ storage whereas the majority of active CCS projects use a deep saline formation. Managing the risk profile for a depleted gas reservoir is significantly different from a deep saline formation and this leads to a distinctive monitoring strategy. Furthermore, the unique geological characteristics of the Cooper Basin lead to further contrasts.

2.4 Carbon credit methodology

The regulatory requirements for generating Australian carbon credit units (ACCUs) from a CCS project are established under the *Carbon Credits (Carbon Farming Initiative) Act, 2011*, and the applicable method is the *Carbon Credits (Carbon Farming Initiative – Carbon Capture and Storage) Methodology Determination, 2021*. The Moomba CCS Project was successfully registered as an eligible offsets project with the Clean Energy Regulator (CER) in 2021.

For a CCS project to be eligible for ACCUs it must satisfy the following requirements:

- Captures, from one or more capture points, greenhouse gases that would otherwise be released into the atmosphere.
- Transports the greenhouse gases to one or more storage sites.
- Injects the greenhouse gases into a storage site, at one or more injection points, so that they are permanently stored in the storage site or any part of it.
- Could reasonably be expected to result in eligible carbon abatement.

CCS projects are credited for net abatement, which in simple terms is equal to the greenhouse gases captured minus other emissions caused directly by the project activity, examples of which include:

- Emissions required to capture, process, compress and transport the greenhouse gas stream, including Scope 2 emissions from electricity use.
- Fugitive emissions from pipelines and the underground storage site during the crediting period.
- Emissions associated with monitoring activities.

Santos has a robust method for quantifying and reporting emissions, including fugitive emissions, which adheres to the requirements of the *National Greenhouse and Energy Reporting (NGER) Scheme*. This established process forms the basis of the methodology for Santos measuring, generating and reporting ACCUs.

The M&V plan meets the requirements of the CCS Methodology Determination by demonstrating safe long-term containment of stored CO₂. It sets out all measurement and surveillance activities necessary to ensure geological storage. Other emissions caused by project activity and calculations of net abatement are not part of the M&V plan.

3 Geological storage complex

3.1 Surface location

The first phase of the Moomba CCS Project will store CO₂ in the Strzelecki and Marabooka gas fields, which is presented in Figures 3 and 4 and is referred to as the project area throughout the M&V plan. These fields are in the South Australian sector of the Cooper Basin, around 770 km north-north-east of Adelaide. They are approximately 45 km east-south-east of the Moomba gas plant, which is the source of the CO₂.

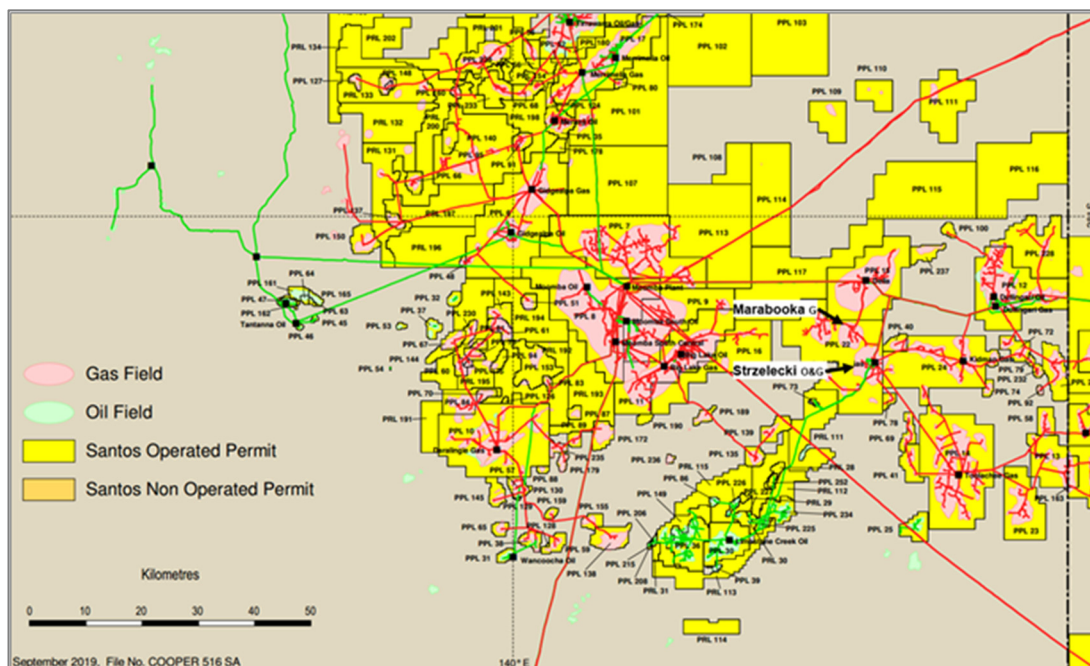


Figure 3: Cooper Basin map with storage complex location

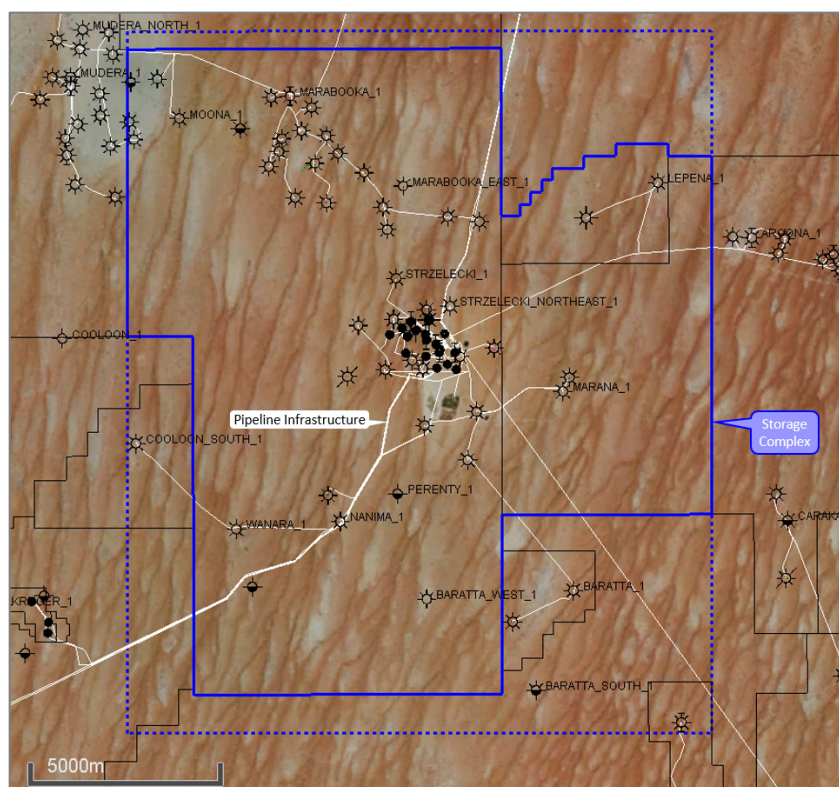


Figure 4: Surface location map showing the extent of the storage complex (solid blue polygon)

3.2 Geological description

The target storage reservoirs are within the Toolachee Formation of the Cooper Basin, in areas where hydrocarbon gas has previously been trapped. These are Permian aged, fluvial sandstones that are draped over structurally high areas like the Strzelecki and Marabooka fields at a depth between 1800 – 1950 mMD. Integral to the target storage reservoirs is the reservoir seal, provided by facies change to silt and mudstones within the Toolachee and the overlying Callamurra Member. The basin stratigraphy and type log over the Toolachee reservoirs is shown in Figure 5.

The Toolachee Formation around Strzelecki and Marabooka includes at least five fluvial sandstones, interbedded with siltstone, mudstone and coal. The formation is overlain by a conformable transition to the Callamurra Member which forms the primary seal. The sands are considered separate compartments with individual fluid contacts and limits, however, the conformable pressure behaviour suggests good communication despite the baffles present on wireline logs. The sandstones are up to 8 m thick, with porosities up to 20% (average porosity 12%) and permeability over 1,000 mD in places.

The Marabooka trap is a low relief anticline with around 30 m of relief while the Strzelecki structure is a more prominent, faulted anticline with around 110 m of relief (Figure 6, left). In Strzelecki there are a series of reverse faults from west-south-west to east-north-east across the structure and movement on these faults prior and during Toolachee deposition creates a thinning isopach over the crest of Strzelecki (Figure 6, right). These faults do not compromise the integrity of the Strzelecki trap, as shown by its ability to hold a significant gas column over tens of millions of years.

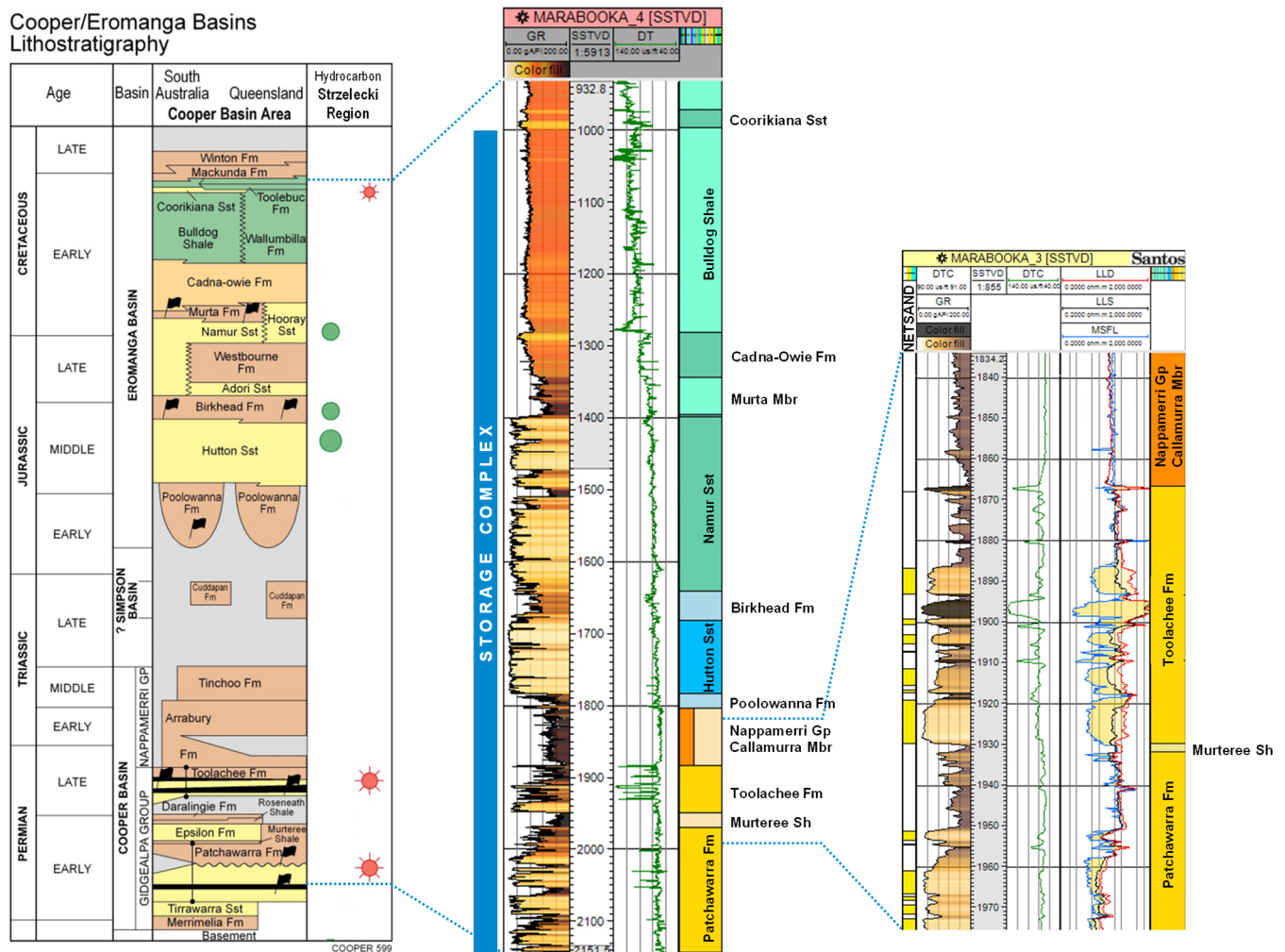


Figure 5: Local stratigraphy in the Strzelecki-Marabooka area with type log from Marabooka 3

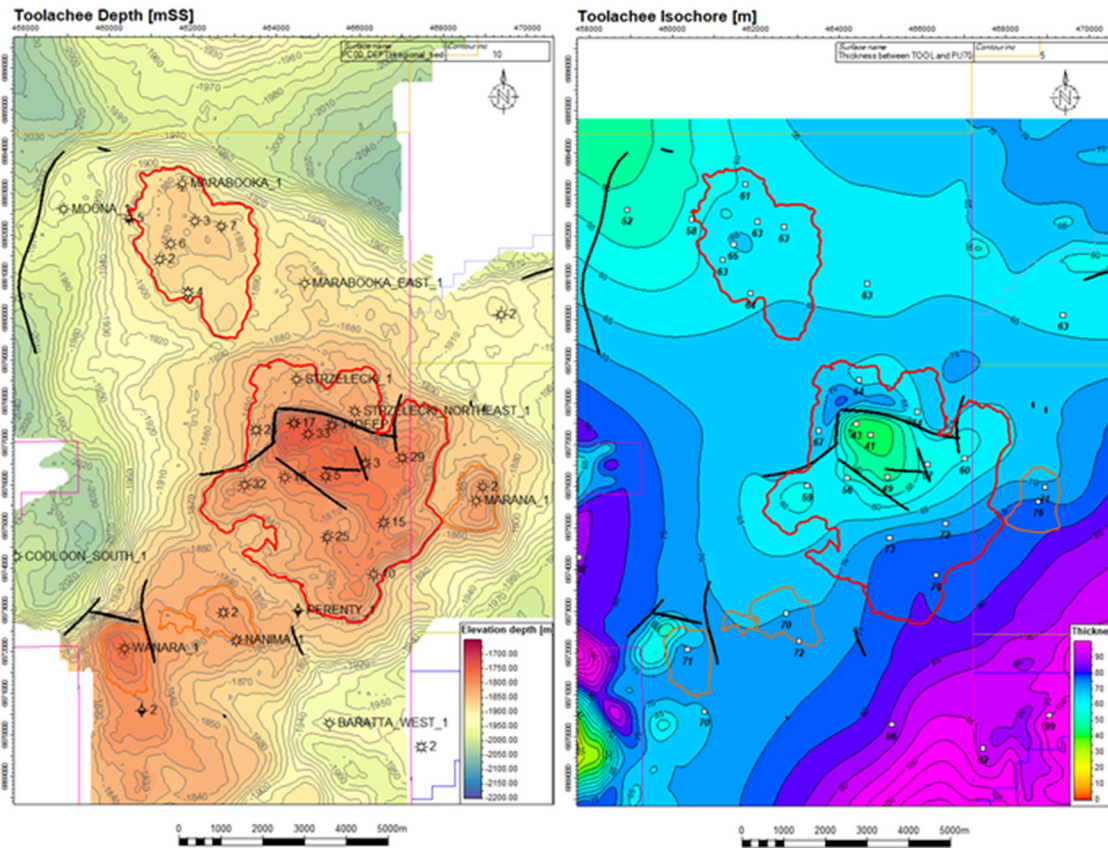


Figure 6: Toolachee depth and isochore across Strzelecki & Marabooka fields

3.3 Storage complex definition

The storage complex includes the storage reservoirs in the Toolachee as well as adjacent geological units, from the top Bulldog Shale down to the top pre-Permian basement (Table 2), a vertical extent of approximately 900m. The areal boundary of the storage complex is shown in Figure 4. An example section (Figure 7) across the storage complex shows the gas pools (red) in the Toolachee Formation that will be the target for CO₂ injection and storage along with the overlying oil / gas pools in the Hutton (green) and Namur (green/red) reservoir.

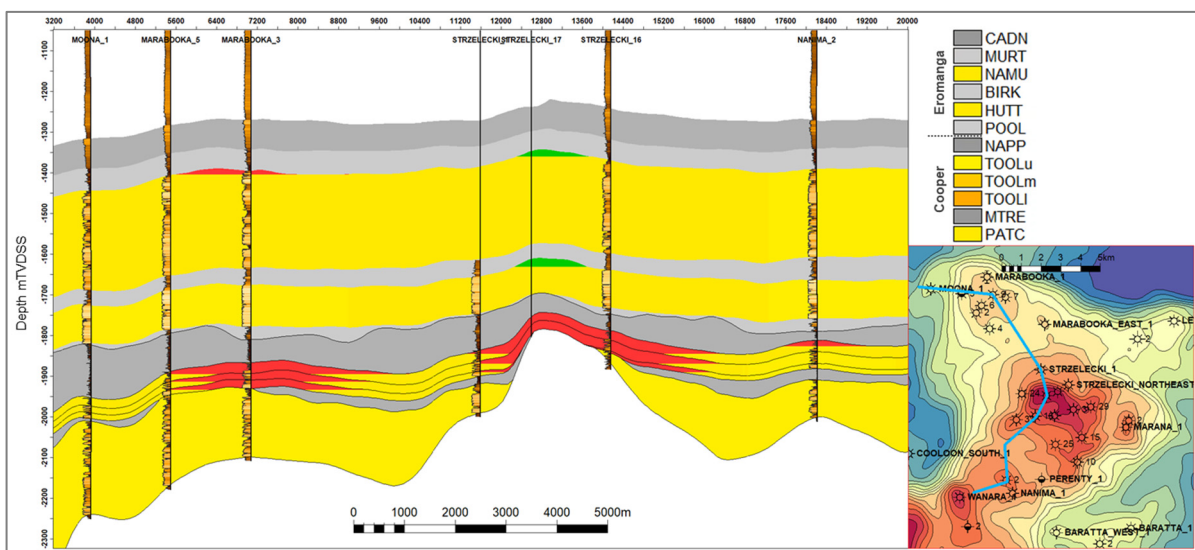


Figure 7: Cross section (path on insert map) through the storage complex, showing the Toolachee gas pools (red) that are the target for CO₂ storage and the overlying oil / gas pools (green / red)

Table 2: Stratigraphy of the storage complex

Description	Unit	Ave depth to top (m)	Ave thickness (m)	Lithology
Regional Seal	Bulldog Shale	970	270	Marine mudstone and siltstone
Permeable Interval	Cadna-Owie Formation	1215	71	Siltstone and shallow marine sandstone
Tertiary Seal	Murta Member	1330	53	Lacustrine siltstone and interbedded sandstone
Permeable Interval	McKinlay Member	1380	230	Interbedded siltstone and sandstone
Permeable Interval	Namur Sandstone	1390		Sandstone with siltstone interbeds
Secondary Seal	Birkhead Formation	1610	43	Interbedded siltstone, mudstone and sandstone
Permeable Interval	Hutton Sandstone	1655	102	Sandstone with minor siltstone interbeds
Permeable Interval	Poolowanna Formation	1745		Interbedded sandstone, siltstone and coal
Primary Seal	Nappamerri Group	1755	70	Interbedded mudstone, siltstone and sandstone
	Top Toolachee Formation	1825	10	Interbedded fluvial sandstone, siltstone and coal
Storage Reservoir	Toolachee Formation	1835	55	Interbedded fluvial sandstone, siltstone and coal
Underlying Interval	Murteree Shale	1890	18	Siltstone with minor sandstone
Underlying Interval	Patchawarra Formation	1890	80	Interbedded fluvial sandstone, siltstone and coal
Underlying Interval	Pre-Permian Basement	1890	-	Various (Warburton Basin)

The storage complex includes multiple barriers to vertical migration of CO₂. The anticlinal structures in the Toolachee Formation are also present in the overlying succession, forming traps in the Hutton Sandstone and McKinlay-Namur Sandstone. These traps were partially filled with oil and gas (Figure 7), which have been produced concurrently with gas from the Toolachee reservoirs.

3.4 Field development plan

Dynamic reservoir modelling was used to design a suitable field development plan. The model was matched to the extensive production and pressure history of the Strzelecki and Marabooka fields. The history match was good with minimal modifications, which gives confidence in the predictions of the model. The modelling workflow approach is consistent with guidelines within the *Australian Standard for geological storage of carbon dioxide* (AS ISO 27914:2019).

The field development plan requires 5 injection wells: 4 in Strzelecki and 1 in Marabooka. The wells are located centrally in both fields (Figure 9) and were perforated across all Toolachee sands. CO₂ will be injected into all Toolachee sands at Strzelecki and Marabooka. Injectors Strzelecki 34 (“SA”) and Marabooka 19 (“MA”) have been drilled as near vertical wells from separate surface pads. Injectors Strzelecki 35 (“SB”), Strzelecki 36 (“SD”) and Strzelecki 37 (“SC”) are S shaped deviated wells drilled from a common surface pad. All wells have a single completion capable of injecting up to 40 MMscf/d per well. Bottom hole injection pressure will be limited to a pressure gradient of 0.54 psi/ft to minimise the risk of geomechanical issues. This gradient is set at 80% of the low case estimate of the fracture gradient, 0.68 psi/ft, and is only 53% of the mid case estimate, 1.0 psi/ft. It is expected that this development will provide a plateau length of approximately 8 years and store approximately 250 Bscf of CO₂

(Figure 8). The uncertainty range for the plateau duration is 6-9 years. The key uncertainty controlling the plateau duration is the injection capacity of the new wells.

The CO₂ will be stored approximately within the limits of the original hydrocarbon accumulations at Strzelecki and Marabooka fields. Figure 9 shows the predicted extent of CO₂ within the storage reservoir limits from the base case reservoir model. Some spill into the Marana accumulation immediately east of Strzelecki is expected. No spill is anticipated into the Nanima and Wanara accumulations, which lie south-west of Strzelecki and on the migration path out of the greater complex.

The storage volume potential of the Hutton and McKinlay-Namur structural traps was also considered to provide some context on the risk of CO₂ migration into overlying non-target hydrocarbon reservoirs within the greater storage complex (Table 3). The combined storage potential of the Hutton and McKinlay-Namur structural traps exceeds that of the Toolachee. The Hutton and McKinlay-Namur along with associated impermeable reservoir seals which have successfully trapped hydrocarbon for millions of years present additional barriers to the vertical migration of CO₂ out of the storage complex.

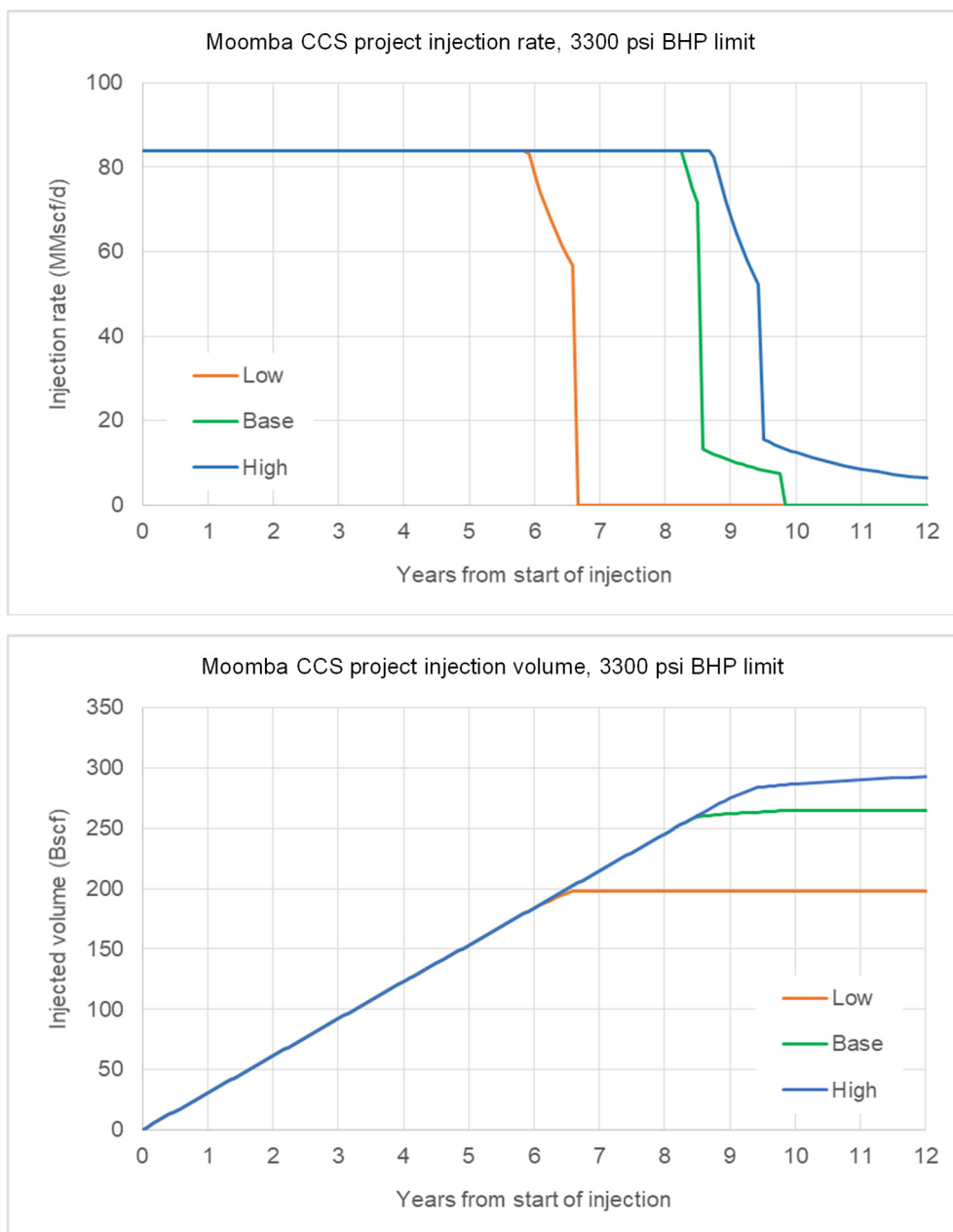


Figure 8: Low / base / high injection rate (top) and volume (bottom) profiles

Table 3: CO2 storage volume estimates on plateau (Bscf)

Reservoir	Description	P90 (Low estimate)	P50 (Best case estimate)	P10 (High estimate)
Toolachee	Primary storage reservoir	179	250	266
Hutton	Overlying hydrocarbon reservoir	88	274	588
Namur	Overlying hydrocarbon reservoir	287	387	526

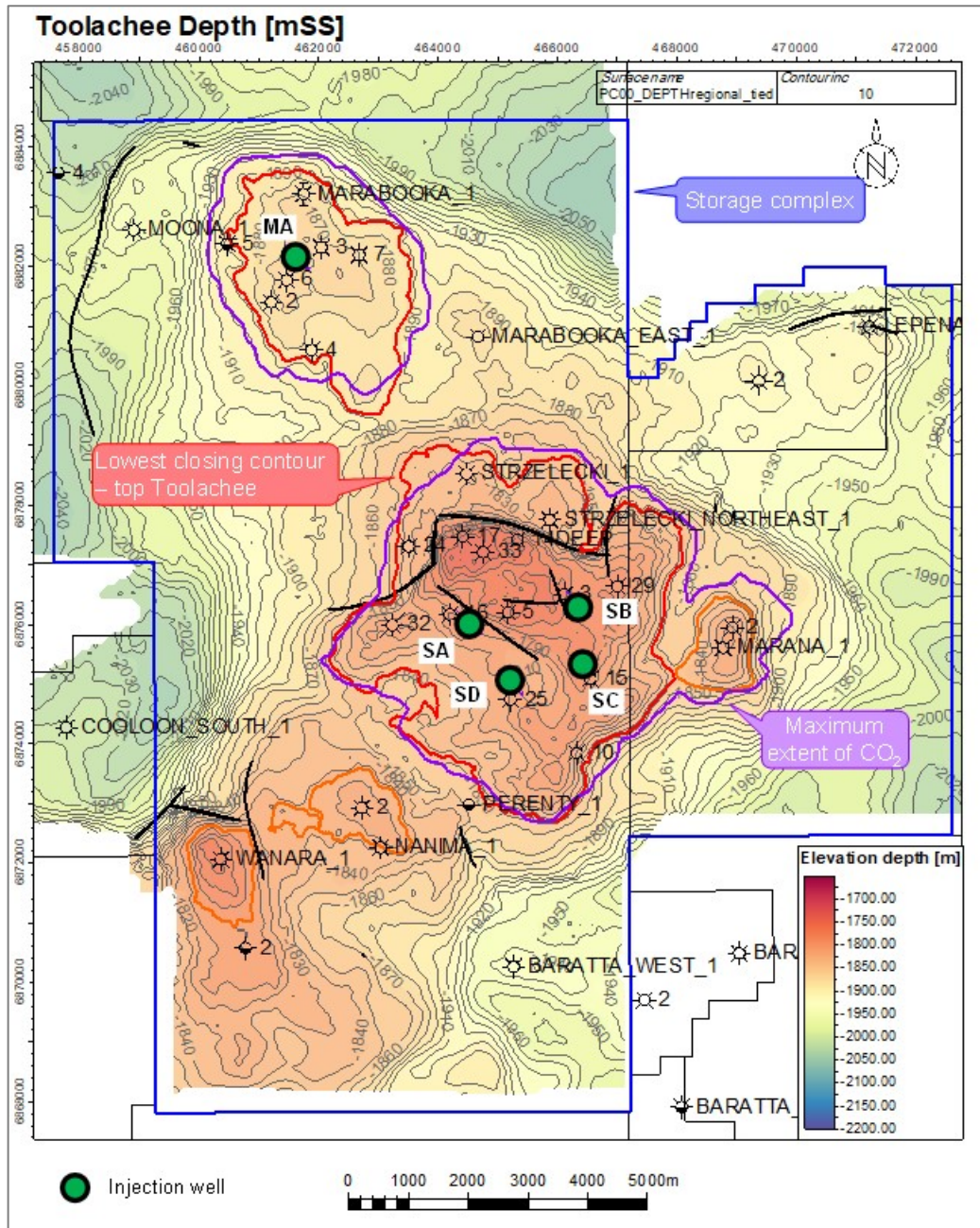


Figure 9: Strzelecki storage complex at the end of injection with predicted extent of CO2 stored in the Toolachee reservoirs shown in purple (note that this polygon is a compilation of multiple Toolachee zones and does not exactly match the top Toolachee structure)

3.5 Containment definitions

This section describes containment scenarios in the subsurface. Loss of containment at surface, although a very low risk, is addressed through the *South Australia Cooper Basin statement of environmental objectives: production and processing operations* (Santos, December 2024). Threshold levels for subsurface migration of CO₂ into non-target reservoirs, i.e. subsurface loss of containment (LOC), are defined here as required by the Carbon Storage SEO.

The storage complex includes a lateral zone beyond the maximum extent of the CO₂ plume, where CO₂ is not expected to be encountered, and a zone above the Toolachee storage reservoir containing barriers to the vertical migration of CO₂. Monitoring for CO₂ in these zones will be used to demonstrate that the CO₂ is contained and there is minimal risk of it escaping the storage complex.

Table 4 defines three monitoring trigger levels for subsurface containment scenarios:

- Green corresponds to the project proceeding as expected, all CO₂ contained within the Toolachee.
- Yellow corresponds to indications (not necessarily confirmation) of a deviation from the modelled containment scenario. In this case injected CO₂ may have migrated further than expected within the storage complex, however the evidence is not conclusive and environmental risk is low. An internal review of monitoring data and reservoir models would be triggered.
- Red corresponds to a potential deviation in containment requiring an immediate management response. Further details are provided in section 5.8.

Migration of CO₂ outside the target Toolachee storage reservoir and into overlying geological formations may still be considered permanently stored provided the CO₂ remains within those formations, which are part of the storage complex.

Table 4: Subsurface LOC triggers and monitoring indicators

Level	Vertical migration indicators	Lateral migration indicators	Indicative volume (Bscf) ^[1]
Green	No CO ₂ column at the crest of the Hutton.	CO ₂ plume in the Toolachee remains within the Strzelecki / Marana / Marabooka structures.	<1
Yellow	Indications (but not confirmation) of CO ₂ presence at the crest of the Hutton, or indications of CO ₂ migration from other verified monitoring data sources.	CO ₂ plume in the Toolachee detected at Nanima.	1-10
Red	CO ₂ column confirmed at the crest of the Hutton.	CO ₂ plume in the Toolachee detected at Wanara.	Greater than 10

¹ As per section 5.5, this is an indicative trigger volume at estimated detection limits, although smaller volumes may be detectable.

3.6 Sensitive receptors

This section defines the sensitive receptors with potentially complete exposure pathways associated with the CO₂ storage activities. Sensitive receptors were previously identified in the *South Australia Cooper Basin environmental impact report: carbon storage* (Santos 2021), referred to as the Carbon Storage EIR. According to the Santos Carbon Storage EIR, sensitive receptors are people, ecosystems, resources or other aspects of the environment or community that may be adversely affected by CO₂ storage activities, if exposed to CO₂ via exposure pathways. Potential sensitive receptors associated with the storage complex are listed in Table 5.

Table 5: Potential sensitive receptors associated with the storage complex

Location	Receptor	Comments
Surface	People	<ul style="list-style-type: none"> • People who access subsurface and low lying structures and topographic lows in the project area. • Workforce – predominately transient petroleum industry and pastoral workers. • Community – tourists traversing public roads in the project area to access conservation reserves in the region.
	Livestock	Pastoral activities in the region is predominantly beef cattle production, which may traverse topographic lows in the project area.
	Native flora and fauna	Predominately dune field with minor areas of floodplain land systems. Associated flora and fauna may be present, temporarily or permanently in topographic lows in the project area.
Subsurface	Shallow aquifers (<150m deep)	<ul style="list-style-type: none"> • Current groundwater use is limited to water for petroleum activities, road maintenance and some livestock watering. Typically accessed from a depth of 80 metres, or greater, below ground level. • Groundwater dependent ecosystems (GDEs) within the project area are low potential GDEs located in the north-west corner of the project area. These GDEs have low potential for groundwater interactions and are associated with low lying areas where water may temporarily accumulate after rainfall. These areas are considered to have potential cultural heritage values. • Springs are not located within the project area.
	Deep aquifers (>150m deep)	<ul style="list-style-type: none"> • Current groundwater use within the storage complex is limited to water for petroleum activities and road maintenance. • The nearest natural mound spring, expected to be connected to deeper aquifers, is approximately 140 km south-west at Lake Blanche. • There are no aquatic, terrestrial or subterranean GDEs expected to be associated with deeper aquifers within the project area.
	Petroleum accumulations	Producing petroleum accumulations outside the storage complex.

For there to be a risk of impact to a potential sensitive receptor there must be a complete exposure pathway. The Carbon Storage EIR identified potential exposure pathways to include:

- Well bores;
- Permeable geological structures, such as faults; and
- Diffusion through a reservoir seal.

The migration pathways are discussed further in section 4.1. The key mitigating factors identified in the Carbon Storage EIR applicable to the vertical migration of CO₂ were geological characteristics of the reservoir and storage formation as well as hydrogeological characteristics. The risk of impact to potential receptors located vertically above the storage complex can be reduced through selection of the storage complex based on the extensive geological understanding gained over 50 years of petroleum production activities in the project area.

The likelihood for surface receptors, related to the topographic lows, to be affected by CO₂ storage activities is very low. This is due to the large vertical separation and multiple geological barriers between the target storage reservoir and the ground surface.

Subsurface receptors within the overlying geological formations, such as groundwater, are more likely to be exposed to CO₂ as they are closer to the storage reservoir however the likelihood of this occurring is still considered to be low. It is noted that outside of the project area the Hutton Sandstone and Namur Formation have greater potential

value as groundwater resources and may be considered a sensitive receptor at the southern and western margins of the Cooper Basin. The Namur Formation and Hutton Sandstone are identified in the region as water resources managed under the *Far North Prescribed Wells Area Water Allocation Plan* (South Australian Arid Lands Landscape Board, 2021). Within the project area the Hutton Sandstone and Namur Formation are petroleum producing reservoirs and as such are not considered a sensitive receptor due to the petroleum hydrocarbons naturally present in the groundwater. The future use and potential environmental value of groundwater in these formations within the project area, is materially limited by the presence of free and dissolved phase petroleum hydrocarbons in the groundwater.

The geological storage complex has, over geological time, trapped petroleum hydrocarbons and prevented them from migrating laterally into the broader groundwater system. This same trapping mechanism will contain any CO₂ gas that could migrate upwards, due to buoyancy. Therefore, the likelihood of CO₂ migrating outside the geological storage complex is considered negligible.

3.7 Groundwater

Beneficial use of groundwater in the shallow and deep aquifers is limited within the project area. Potential groundwater bores in the vicinity of the project area are shown in Table 6. A site inspection was undertaken in 2023 to confirm the current use of the bores and determine suitability for baseline monitoring.

Table 6: Groundwater bores within 14 kms of injector wells

Bore name [1]	Drill hole number	Recorded depth (m) [2]	Status after site inspection
DUGGW2 (X1)	281089	17.5	Bore open standpipe – previously sampled
DUGGW5 (X4)	281082	24.2	Bore open standpipe – previously sampled
Bagundi 1	Unknown	57	Bore not able to be located
Bagundi No. 2	129853	Unknown	Bore accessed. High turbidity and limited screen depth. Not suitable for ongoing sampling
Bagundi 4 water bore	Unknown	0	Bore dry
Baratta 1	Unknown	22	Bore not located
Baratta No. 1	129775	74	Bore not located
Barrata #1 South	245642	80	Bore in use by landholder for stock watering with uncontrolled downhole access – not suitable for monitoring
Della No. 6	129823	61	Bore not located
Marabooka 1 Water Bore	129640	64	Bore in use by landholder for stock watering with uncontrolled downhole access – not suitable for monitoring
Mudera 1 Water Bore	129829	55	Bore in use for petroleum activities via airlift – not suitable for monitoring
Mudera 5 Water Bore	Unknown	56	Bore not located
Strzelecki 1 Water Bore	129597	1,841 [3]	Bore shut in and cannot be sampled.
Strzelecki 3 Water Bore	129599	61	Bore modified to enable sampling. Suitable for monitoring
Strzelecki No. 3A	129837	38	Bore not located

Bore name ^[1]	Drill hole number	Recorded depth (m) ^[2]	Status after site inspection
Strzelecki No. 3B	129623	66	Bore not located
Strzelecki No. 2	129836	85	Bore modified to enable sampling. Suitable for monitoring
Strzelecki No. 10	129710	76	Bore obstruction downhole – not suitable for sampling
Strzelecki Road bore 1	Unknown	106	Bore obstruction downhole – not suitable for sampling
Strzelecki Road	129720	106	Bore not located
Strzelecki Road No. 2	129721	91	Bore not located

¹ Bore names are not consistent between different data sources and conflict with known petroleum wells in some instances.

² Inferred maximum depth to access groundwater.

³ Current hold-up depth (HUD).

All the identified water wells are currently or have previously been associated with petroleum operations in the area, many with supporting the construction of early petroleum exploration wells. Strzelecki 1 water bore is known to have accessed water from a deep formation, the Hutton Sandstone, which forms part of the storage complex. The water bore is a converted petroleum well where the lower section of the well over the Toolachee Formation was plugged and abandoned. It is currently not used as a water source and not able to be sampled because it is shut-in.

In addition to the groundwater bores described in the table above, two oil producing wells (Strzelecki 20 and Strzelecki 27) were identified within the project area. These wells produce oil and associated water from the Hutton Sandstone and were suitable for baseline monitoring of the Hutton Sandstone reservoir immediately above the Strzelecki target injection reservoir – Refer Table 7.

Table 7: Oil wells in the vicinity of the storage complex

Oil Well name	Drill hole number	Recorded depth (m) ^[1]	Status after site inspection
Strzelecki 20	129750	1,681 ^[2]	Producing oil well that is completed in the base of the Birkhead Formation, which can be used for baseline monitoring of the Hutton Sandstone because the basal Birkhead Formation and upper Hutton Sandstone are hydraulically connected
Strzelecki 27	129905	1,725 ^[2]	Producing oil well in Hutton reservoir – can be used for baseline monitoring

¹ Inferred maximum depth.

² Current hold-up depth (HUD).

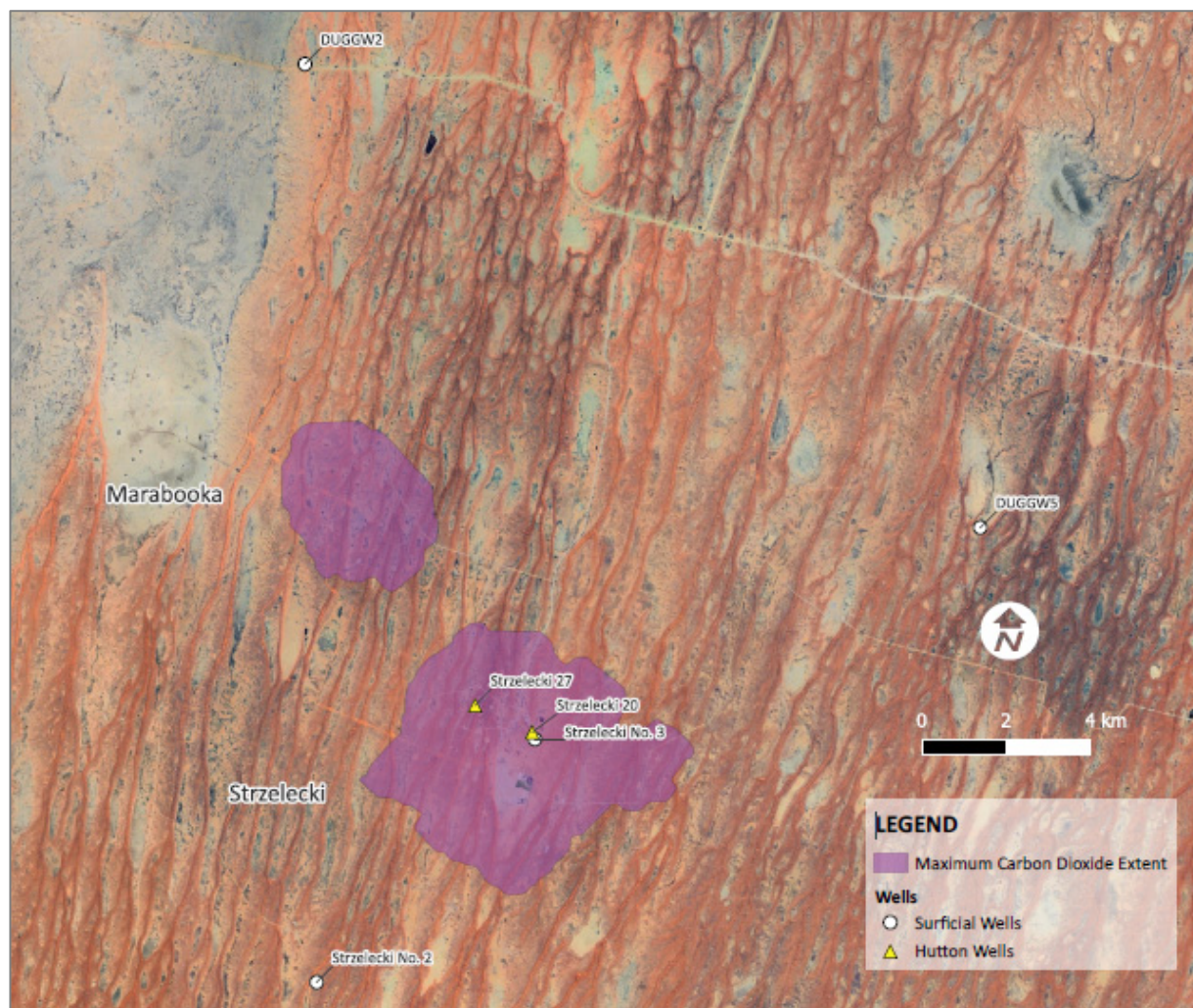


Figure 10: Map of water bores and oil wells suitable for baseline monitoring

Figure 10 shows a map of shallow groundwater water bores and oil wells suitable for baseline monitoring post site inspection in 2023, presented in lateral proximity to the CO₂ extent within the storage complex.

Two shallow surficial aquifer monitoring wells, DUGGW2 (X1) and DUGGW5 (X4), were installed as part of the Environmental Sensitivity Profile (ESP) study commissioned by Santos in 2015. Baseline data have already been collected from these bores as part of historical assessments (LBW, 2015). These historical data may be used to inform baseline groundwater conditions.

A baseline monitoring program was developed to evaluate background variability in key constituent concentrations at six locations (DUGGW2, DUGGW5, Strzelecki No. 2, Strzelecki 3 Water Bore, Strzelecki 20 and Strzelecki 27), and baseline monitoring commenced April 2023.

The two shallow ESP wells are affected by local recharge as well as atmospheric entry of oxygen. Geochemical conditions within the shallow system will be notably different from deeper systems. The remaining surficial bores intersect the deeper surficial system so will be less affected by transient processes and groundwater is likely to be at equilibrium with the formation. Temporal variance in analytical parameters is also likely to be limited in these data.

Groundwater within the Hutton reservoir is confined, artesian, and, based on the typical age of basin waters, is likely at equilibrium with aquifer materials. Therefore, temporal variability in measurements of water quality is likely to be limited.

Groundwater quality monitoring required to establish baseline geochemical conditions of the shallow groundwater and Hutton Sandstone has been completed and is discussed further in section 5.3.1.4.

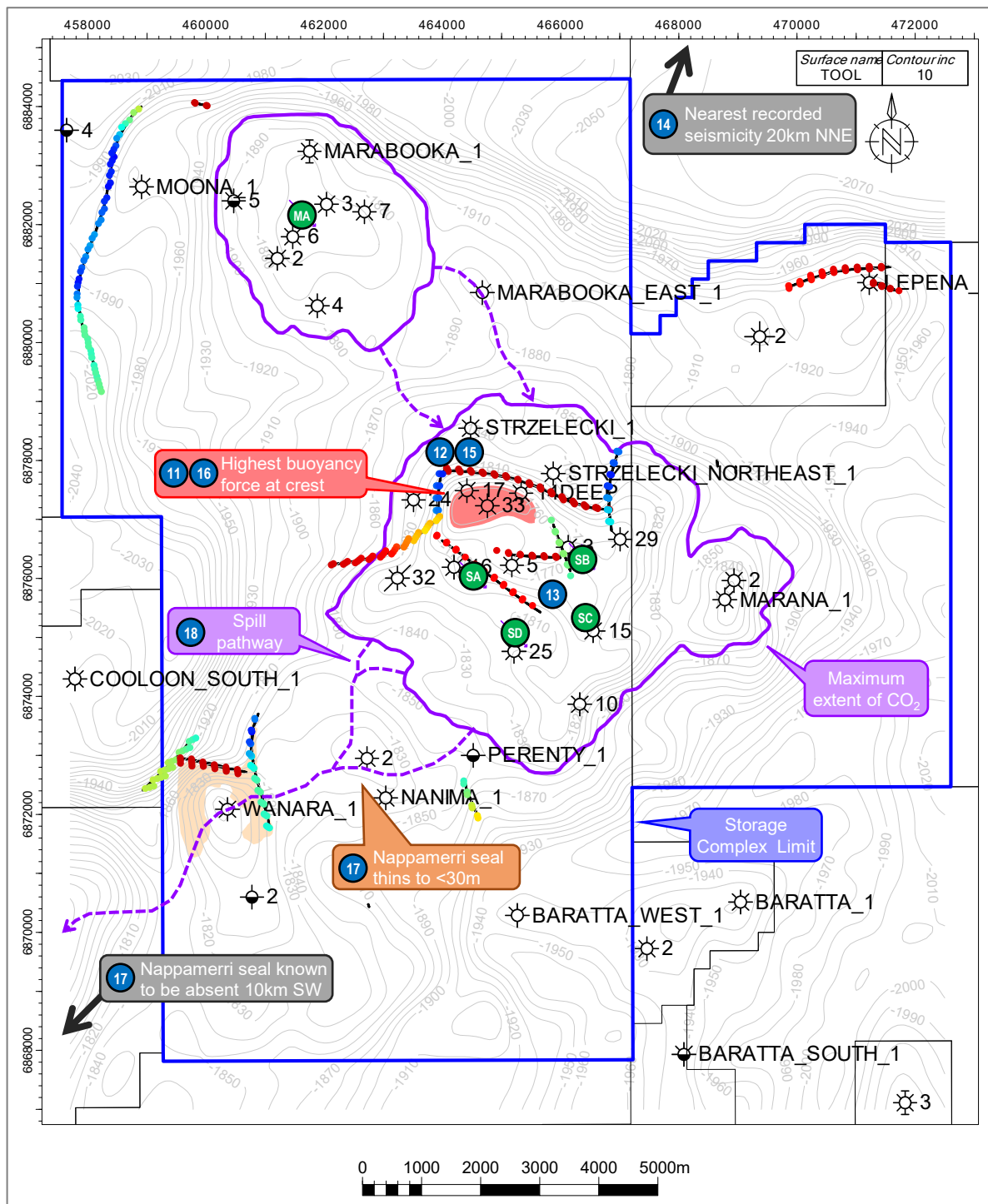
4 Containment risk assessment

This section summarises the risks associated with containment of CO₂ within the target storage reservoir. Further details are outlined in Appendix A, along with description of the controls that will be implemented. The assessment considers risks associated with proposed CO₂ storage operations. Risks associated with existing petroleum operations at the site are not considered.

4.1 Potential CO₂ migration pathways

The potential pathways by which CO₂ could migrate beyond the target storage reservoir are listed below. Pathways 1-10 relate to well integrity risks in both old and new wells, pathways 11-18 to geological risks and pathway 19 to miscellaneous. The locations where these pathways are most likely to occur are shown conceptually in Figure 11.

- (1 & 2) Poor cement isolation in an old / new well
- (3 & 4) Degradation of cement in an old / new well due to exposure to CO₂
- (5 & 6) Corrosion of the casing in an old / new well due to exposure to CO₂
- (7 & 8) Failure of the tubing or packer in an old / new well due to exposure to CO₂
- (9 & 10) Failure of a wellhead seal in an old / new well due to exposure to CO₂
- (11) Capillary leakage through seal
 - Migration would be most likely to occur at highest point on structure where the injected CO₂ column (and therefore pressure) is greatest and would occur as a result of the CO₂ column exceeding the threshold pressure of the cap rock.
- (12) Reactivated existing faults
 - If existing, sealed faults are reactivated, they could become migration pathways because of mechanical failure or geochemical reactivity. Migration would occur along faults with the most susceptible orientation, as shown in Figure 11.
- (13) Induced fracture through primary seal
 - If the primary seal rock experiences mechanical failure due to CO₂ injection, migration could occur along induced fractures, most likely in proximity to injection wells.
- (14) Natural seismicity
 - Occurrence of natural seismicity within limits of storage complex causes reactivation of faulting. Migration would occur along known/mapped faults.
- (15) Natural fracture or fault through primary seal
 - Fractures within a fault zone or juxtaposition of reservoir across a fault zone provide pathway for CO₂ through the top seal. Migration would occur along known/mapped faults with greatest throw.
- (16) Degraded primary seal due to exposure to CO₂
 - Geochemical changes to the primary seal reduce the sealing capacity. Migration would occur at highest point on structure where CO₂ column is greatest.
- (17) Stratigraphic pathway through, or absence of, Nappamerri seal
 - Base Eromanga unconformity (LU00 chronostratigraphic marker) erodes the Nappamerri Group and upper Toolachee, providing a potential juxtaposition between Toolachee reservoir and the Jurassic formations above it. Migration would occur where the seal is absent or thin.
- (18) Lateral migration outside of structural closure
 - Storage trap is limited by structural closure. Migration would occur at specific spill points.
- (19) Third party interference
 - For example, external parties breach the storage reservoir seal by drilling a well and CO₂ migrates into overlying geological complex.



No.	Risk name
1 - 10	Well Integrity
11	Capillary failure of primary seal
12	Fault reactivation
13	Induced fracture through primary seal
14	Natural seismicity
15	Natural fracture or fault through primary seal
16	Degradation of primary seal from CO ₂ exposure
17	Stratigraphic pathway through primary seal
18	Lateral migration
19	Third party interference

Fault susceptibility to reactivation

Higher Lower

Only wells and faults intersecting the Toolachee Formation are shown

Toolachee Formation depth contours in background (CI 10m)

Injection well

Risk

Figure 11: Conceptual map of potential migration paths from the target storage reservoir (Toolachee Formation)

4.2 Migration scenarios

Several hypothetical scenarios were modelled to assist with rating the containment risks, examples of which are included as Appendix A.1. These scenarios predicted how CO₂ may migrate if it escapes from the target storage reservoir, either laterally or vertically.

4.3 Controls

The project will implement controls to manage the containment risks. The controls for each risk are shown in Appendix A.2. Preventative controls mainly act to reduce the likelihood of the undesirable event. Key preventative controls are provided by well integrity remediation, site selection and reservoir management. Mitigating controls typically reduce the consequence of the undesirable event. Monitoring activities provide the key mitigating controls via detection of the undesirable event and facilitating a response in line with project guidelines.

4.4 Risk ratings

The risks identified in section 4.1 were assigned ratings following the Santos risk assessment processes. This process assesses the consequence and likelihood of each risk and assigns a rating based on the matrix shown in Appendix A.3. The assessments are based on a critical undesirable event which generates the highest rating considering the combined consequence and likelihood. In most cases, this undesirable event is cross flow from the target storage reservoir to a non-target reservoir within the overlying geological formations. The likelihood of other sensitive receptors being exposed to CO₂ is considered very low due to the large vertical separation and multiple barriers between the target storage reservoir and those receptors. Table 8 shows a summary of the residual risk ratings while Figure 12 shows the same ratings in matrix form.

Table 8: Containment residual risk ratings

Number	Risk name	Rating	Category
1	Poor cement – old well	Low	Well integrity
2	Poor cement – new well	Low	
3	Degradation of cement – old well	Low	
4	Degradation of cement – new well	Low	
5	Casing corrosion – old well	Low	
6	Casing corrosion – new well	Low	
7	Tubing / packer failure – old well	Low	
8	Tubing / packer failure – new well	Low	
9	Wellhead seal failure – old well	Very Low	
10	Wellhead seal failure – new well	Very Low	
11	Capillary failure of primary seal	Very Low	Geological
12	Fault reactivation	Low	
13	Induced fracture through primary seal	Low	
14	Natural seismicity	Very Low	
15	Natural fracture through primary seal	Very Low	
16	Degradation of primary seal from exposure to CO ₂	Low	
17	Stratigraphic pathway through primary seal	Very Low	
18	Lateral migration	Low	
19	Third party interference	Very Low	Other

A number of key risks relate to legacy well integrity, specifically poor initial cement or degradation of cement from exposure to CO₂ at old wells. With controls in place, these residual risks are assessed to be low. New wells drilled specifically for this project are considered to have low risk as they have been designed for CO₂ service.

The residual geological risks are assessed as 'Low' to 'Very Low'. This reflects the high confidence in the depleted gas reservoirs selected as the storage reservoirs. These reservoirs are generally well understood and already have extensive datasets and production history. They also have a clear history of containing hydrocarbons.

		Consequence					
		I	II	III	IV	V	VI
Likelihood	f						
	e						
	d						
	c						
	b		9, 10	5, 6, 7, 8, 18	1, 2, 3		
	a			19	4		
	aa					12, 13	
	ab					16	
	ac				11	15, 17	
	ad					14	

Risk rating	Very low	Low	Medium	High	Very high
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Figure 12: Summary of expected residual risks at start of injection

5 Monitoring plan

5.1 Monitoring elements

There are two broad objectives for monitoring. Operational monitoring is required to quantify volume of CO₂ stored in the subsurface, verify location of CO₂ within the target storage reservoir and inform ongoing storage reservoir modelling. Environmental assurance monitoring is required to demonstrate containment within the storage complex has been achieved.

Operational monitoring comprises the following elements:

- Injection telemetry – gathering surface flow, pressure and temperature data during CO₂ injection.
- Reservoir surveillance – gathering subsurface reservoir data and conducting modelling to monitor the movement of the CO₂ and confirm location of CO₂ within the storage complex.
- Well integrity – inspection of surface equipment and gathering downhole data to monitor the integrity of wells which intersect the storage complex.

Environmental assurance monitoring comprises the following additional elements:

- Monitoring of the overlying geological formations – gathering data to confirm that CO₂ has not migrated into formations above the target storage reservoir.
- Groundwater quality monitoring – in response to other monitoring data that indicates a subsurface loss of containment may have occurred.

Environmental monitoring thresholds are defined. Environmental incident reporting, and immediate investigation regarding the potential for a loss of containment will be triggered if the monitoring thresholds are detected. Operational monitoring may inform investigations and trigger environmental assurance monitoring.

5.2 Operational monitoring

5.2.1 Injection telemetry

Continuous flow metering has been installed at the Moomba CCS facility discharge and individual well injection skids (Figure 1). Coriolis mass flow meters have been selected for both applications as they provide high accuracy and are not adversely affected by the variable PVT properties of the CO₂ stream. Relative error in the mass flow rate measurement is expected to be less than 1%. Data is logged with a high frequency, typically 1 measurement per minute. Pressure and temperature are also recorded with a similar frequency at these locations and the tubing head of all injection wells.

A continuous leak detection system has been installed on the main pipeline to identify any significant failure of the pipeline. Reconciliation between the Moomba discharge and injection well flow metering allows major losses to be accounted for.

The concentration of CO₂, methane and water in the injection stream is monitored continuously at the Moomba CCS facility with online analysers. Periodic sampling and analysis of the stream by gas chromatography is undertaken to verify the analysers.

5.2.2 Reservoir surveillance

5.2.2.1 Existing data

Strzelecki and Marabooka were selected as the target storage reservoirs in part because of the good set of existing data for the fields. The area is covered by a 3D seismic survey which was acquired in 2001. Almost all wells have at least a basic suite of open-hole logs. The fields also have nearly 40 years of gas production history from the Toolachee reservoir, including production data, reservoir pressure data and other surveillance data. The existing data has provided a robust baseline to history match the models for the storage reservoir. There is also significant production history from the Hutton / Namur oil pools and the shallow Coorikiana gas pools.

5.2.2.2 Observation wells

Reservoir monitoring is primarily undertaken via observation wells. Observation wells allow for pressure monitoring, cased-hole logging to monitor CO₂ saturation and recovery of fluid samples if required. A combination of permanent downhole gauges (DHG) and static gradient surveys (SGS) is used for pressure monitoring. All injection wells have been completed with permanent downhole gauges to ensure the flowing bottom hole pressure limitation is not exceeded. Cased-hole pulsed neutron logging (PNL) is used to monitor CO₂ saturation. Saturation monitoring is primarily intended to confirm that CO₂ is not unintentionally migrating out of the storage reservoir, either laterally or vertically. Fluid sampling may be used to observe geochemical changes in the reservoir and confirm CO₂ concentrations if required.

Existing wells in the project area are conveniently located considering the structural setting. Several wells are also monobores, which gives greater flexibility for logging over shallow intervals without requiring recompletions. Figure 13 shows the proposed injection and observation well locations on the top Toolachee depth map. Toolachee observation wells broadly fall into three categories:

- Field locations that are expected to observe CO₂ arrival in the storage reservoir early in the project life. These locations can be used as controls to confirm the performance of the pulsed neutron logs.
 - Strzelecki 33
- Edge of field locations that are only expected to observe CO₂ late in the project life. These locations are near the predicted maximum extent of the CO₂ plume.
 - Marabooka 4, 5
 - Marana 2
 - Strzelecki 10, 24
 - Strzelecki Northeast 1
- Peripheral locations are not expected to observe CO₂. These locations are in small structural highs on the migration pathways out of the main structure. CO₂ that spills laterally out of closure is expected to accumulate in these locations.
 - Nanima 2
 - Wanara 1

Toolachee Depth [mSS] Surface name PCOD_DEPT

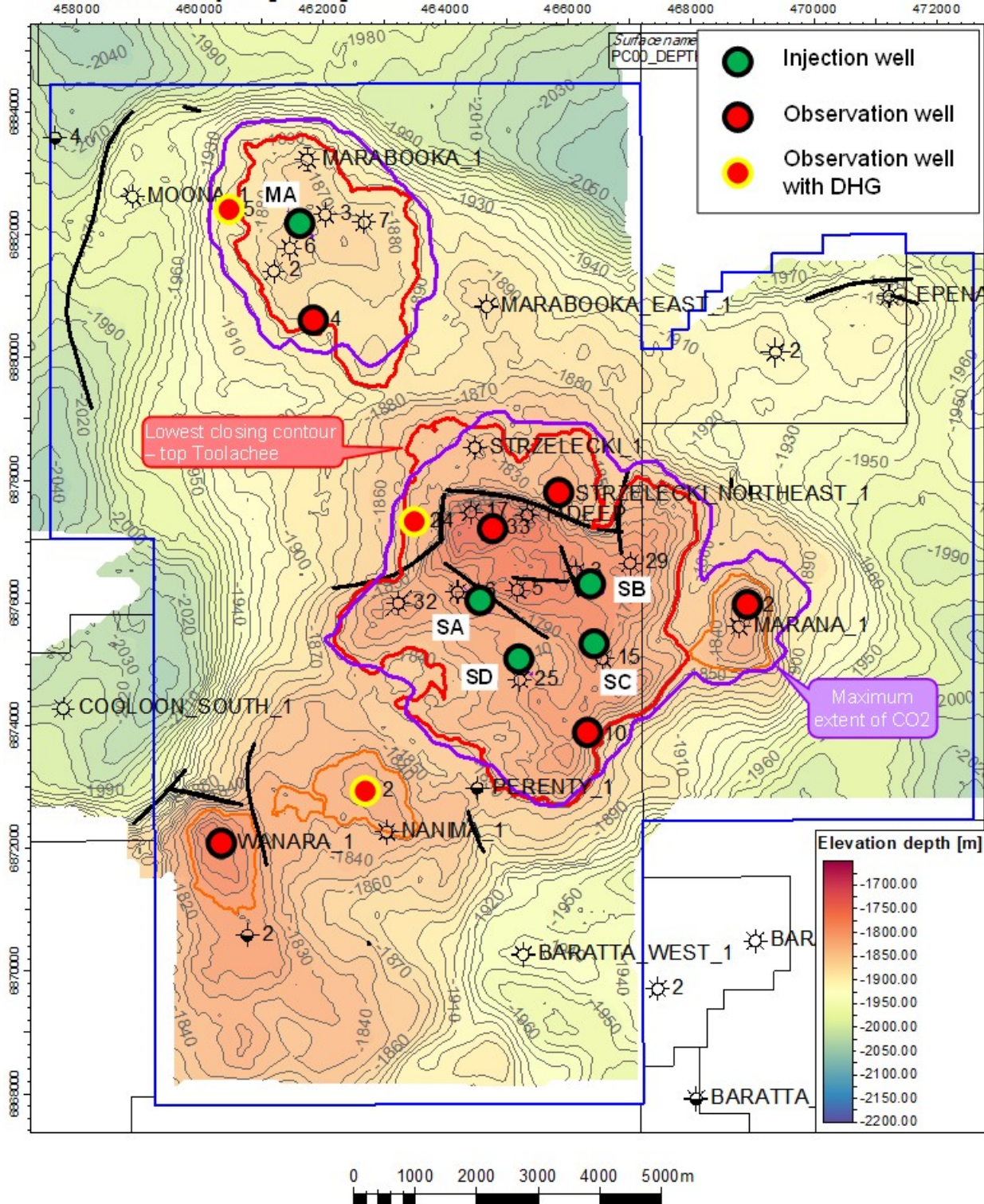


Figure 13: Injection and in-zone observation well locations on top Toolachee depth map

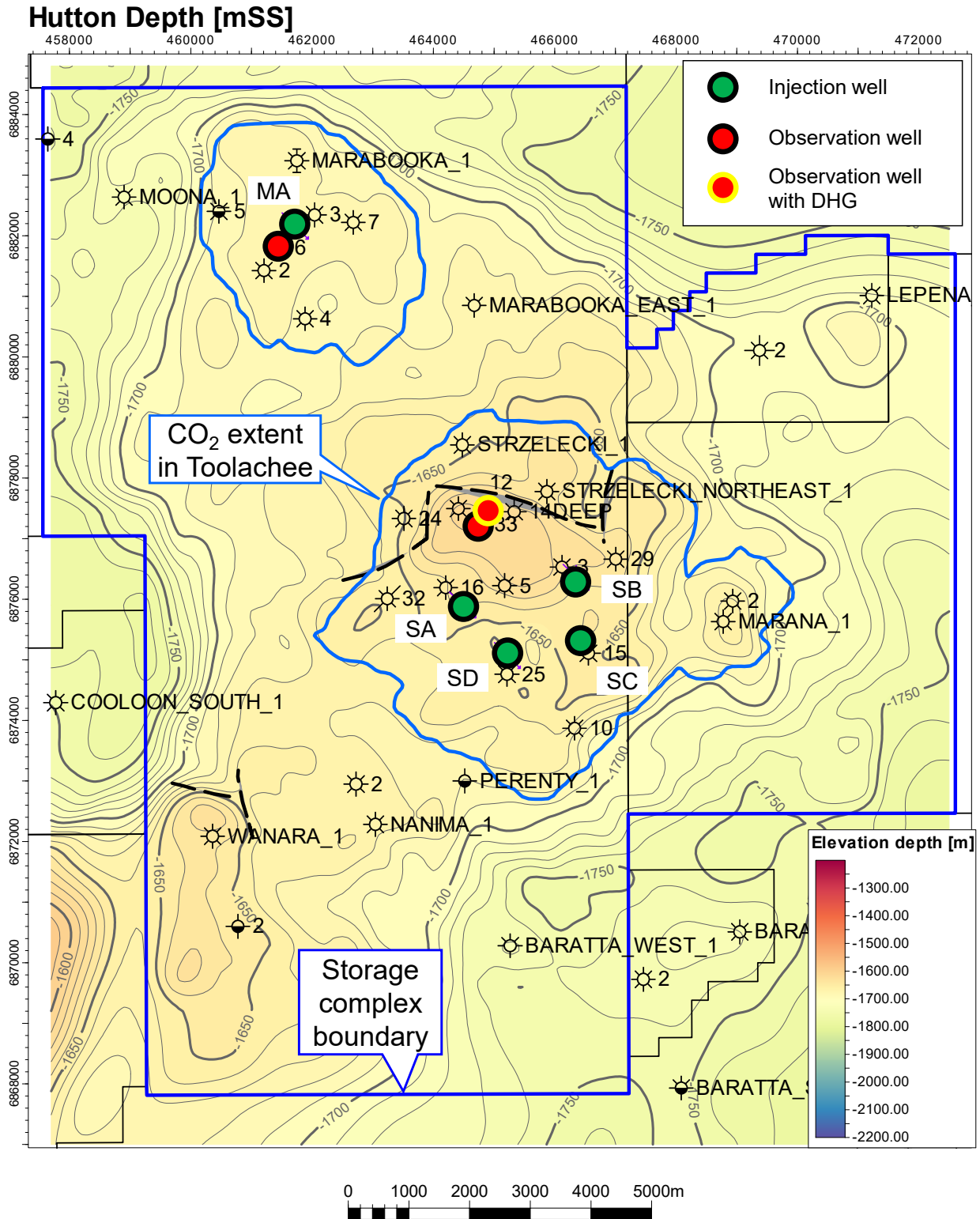


Figure 14: Injection and above-zone observation well locations on top Hutton depth map
 (Note: the faults shown only intersect the base of the Hutton)

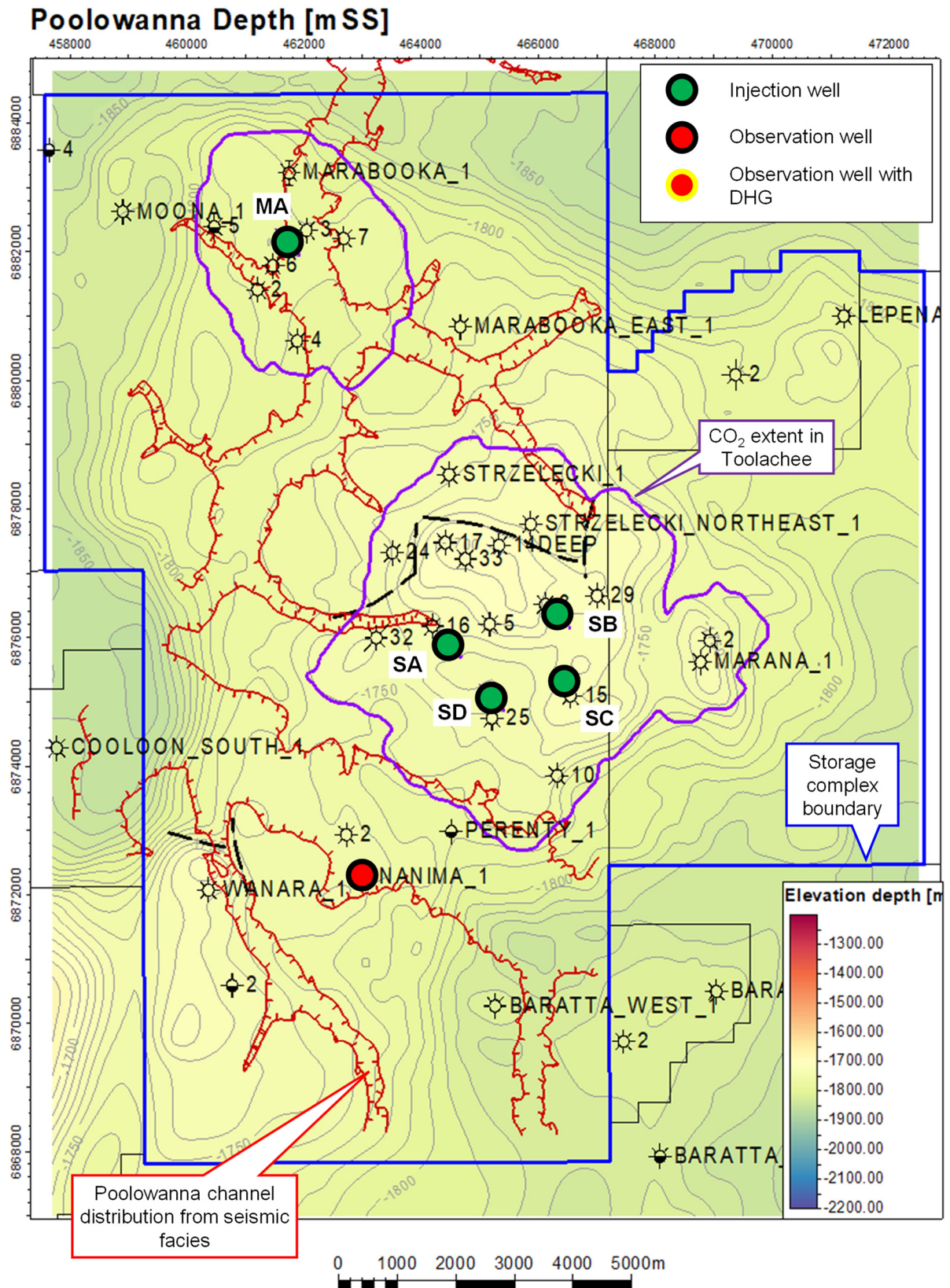


Figure 15: Injection and above-zone observation well locations in the overlying Poolowanna Formation. The Poolowanna has a mixed lithology and limited distribution bound by the base Jurassic unconformity. It has trapped gas in the Nanima Field.

5.2.2.3 Geomechanical monitoring

A mechanical earth model (MEM) has been built to understand the geomechanical behaviour of the storage complex and this will be reviewed and updated if required based on observations. The project has adopted a cautious approach to manage geomechanical risks by placing a conservative limit on the maximum injection pressure and maximum average pressure in the storage reservoir (section 3.4).

A surface geophone array will be used to continuously monitor for induced seismic activity within the storage complex. The array will be able to detect and approximately locate significant seismic events. Induced seismic events could result from fracture propagation, fault slippage, fluid movement or change in stress states as the pressure in the storage reservoir increases, however, the magnitude of any events is expected to be very low. The monitoring data will be used to calibrate geomechanical models of the storage complex and ensure no adverse impacts through ground motion to third party stakeholders and sensitive receptors. Natural seismic events will be identified primarily based the location. Based on seismic events observed by the surface geophone array during the pre-injection baseline period and supported by modelling, the detection limit and threshold for significant events has been set at Mw 1.0 and Mw 2.5, respectively.

Satellite based interferometric synthetic aperture radar (InSAR) will be used to monitor surface displacement over the storage complex. 1D geomechanical modelling predicts that the surface heave due to re-pressurising the storage reservoir is in the range of 15-100 mm. This is likely to be of similar magnitude to any surface subsidence that occurred during gas production, which had no known adverse effects.

Santos already utilises InSAR for monitoring subsidence over coal seam gas fields in eastern Queensland. Data is routinely acquired by several satellites and is readily available. InSAR baseline monitoring for the Moomba CCS project was completed prior to the start of injection. The frequency of future InSAR data acquisition and analysis is planned to be undertaken mid-project followed by a final interpretation at end of injection.

5.2.3 Well integrity monitoring and management

The integrity of existing wells poses a risk of providing unintended migration pathways for CO₂ out of the target storage reservoir. Santos has reviewed the integrity of all relevant wells within the storage complex and has remediated any wells that pose an unacceptable risk. Relevant wells include all wells in the vicinity of Strzelecki and Marabooka fields, including peripheral locations not expected to encounter CO₂ and abandoned wells. Ongoing well integrity monitoring and management will be conducted for all wells in the storage complex that are not plugged and abandoned (P&A). The monitoring will follow the established Cooper Basin well management practices which manage the risk of hydrocarbon migration from conventional oil and gas reservoirs via wells.

Well completion reports exist for all wells in the storage complex and completion records are also generally good. Initial cement evaluation logs are available for almost all relevant wells in the storage complex, and new logs were acquired in 2023 for any missing wells or to supplement existing data. All wells have recent well integrity inspections or were only drilled very recently.

Well integrity monitoring and management is described below and comprises maintenance of well integrity management plans, annulus monitoring, cement monitoring and casing/tubing monitoring.

5.2.3.1 Well integrity management plans

An individual integrity risk assessment will be maintained for each well and used to determine the frequency of monitoring. The integrity risk assessments are regularly reviewed as new data is acquired or the state of the well changes. A formal integrity management plan has been developed for each well and will be maintained throughout the project life cycle – prior to start of CO₂ injection, during and post injection.

Each well integrity plan will be reviewed annually.

5.2.3.2 Annulus monitoring

Well annulus monitoring will continue for all non-P&A wells in accordance with well integrity management plans. Annulus monitoring includes:

- Continuous remote monitoring of the production casing annulus pressure for all injection wells.
- At least one manual survey of annulus pressure every six months for all non-P&A wells within the storage complex.
- Well integrity visual inspections will be undertaken at least once every year. Inspections cover the general condition of the wellhead, surface casing and cellar.
- An unexpected increase in annulus pressure is used as a trigger for further investigation, for example gas samples may be obtained from annulus fluid returns and analysed to check for elevated CO₂ concentration.

5.2.3.3 Cement monitoring

A diligent cement evaluation interpretation has been conducted for all wells in the storage complex. Where new baseline cement evaluation logs were required, these were completed as part of the 2023 legacy well integrity program. Ongoing repeat cement evaluation logs (acoustic or ultrasonic depending on application) will be acquired at key wells, the scope and frequency of which will be determined based on each individual well integrity management plan and any observed changes. Characterising any change in cement quality over time will help to manage the risk of cement degradation.

An initial list of wells identified for cement evaluation logging appears below:

- Strzelecki 33 (2-7/8" Cr monobore) – expect to see early arrival of CO₂ at this well
- Strzelecki NE-1 (2-7/8" Cr monobore)

5.2.3.4 Casing / tubing monitoring

The risk of casing or tubing degradation due to corrosion from exposure to carbon dioxide and water is expected to be low (section 4). Downhole plugs will be used to protect legacy wells with carbon steel tubing and the injection wells will utilise corrosion resistant casing and tubing. However, it is considered prudent to monitor a sample of wells with carbon steel tubing before and during injection. Tubing evaluation logs (ultrasonic or mechanical calliper depending on application) will be run in a sample of key wells. The frequency of repeat logs will be determined by individual well integrity management plans and in response to any observed changes.

An initial list of wells identified for casing / tubing logging appears below:

- Strzelecki 10 (2-3/8" J55 tubing)
- Strzelecki 33 (2-7/8" Cr monobore)
- Injection wells

5.2.4 Operational monitoring schedule

Table 9 shows the anticipated schedule of operational monitoring activities. Baseline surveys have been successfully taken prior to the start of injection. Key monitoring locations are designated for surveys every 1-2 years during the injection period. The remaining locations will be used as required. Repeat surveys at these locations will be conducted if performance of the storage complex deviates from expectation and further information in this location would be of use. The Toolachee formation in Strzelecki 33 will be used as a control to test the performance of the pulsed neutron log. It is expected that the CO₂ front will pass this location within 3 years and logging should confirm the ability of the PNL to detect changes in saturation.

During the injection period, failed permanent downhole gauges will be replaced if sufficient data cannot be obtained from SGS or surface measurements. After the end of injection, downhole gauges will be operated as long as they are serviceable, however, failed gauges will not be replaced. Reservoir pressure will be monitored using SGS or surface measurements if all downhole gauges have failed. The frequency of reservoir surveillance activities is expected to reduce in the closure period as uncertainty and risk decrease.

Table 9: Schedule of monitoring activities

No.	Location	Type	Activity	Zone	Frequency		
					Pre-inject	Injection	Closure
1	MA	I	Downhole P/T gauge Injection telemetry	TO TO	N/A N/A	Continuous Continuous	If operating None
2	SA	I	Downhole P/T gauge Injection telemetry	TO TO	N/A N/A	Continuous Continuous	If operating None
3	SB	I	Downhole P/T gauge Injection telemetry	TO TO	N/A N/A	Continuous Continuous	If operating None
4	SC	I	Downhole P/T gauge Injection telemetry	TO TO	N/A N/A	Continuous Continuous	If operating None
5	SD	I	Downhole P/T gauge Injection telemetry	TO TO	N/A N/A	Continuous Continuous	If operating None
6	Marabooka 4	O	SGS	TO	Complete	As required	As required
7	Marabooka 5	O	Downhole P/T gauge PNL	TO TO	N/A Complete	Continuous As required	If operating As required
8	Strzelecki 10	O	SGS PNL	TO TO	Complete Complete	As required As required	As required As required
9	Strzelecki 24	O	Downhole P/T gauge PNL	TO TO	N/A N/A	Continuous As required	If operating As required
10	Strzelecki 33	O	PNL	TO	Complete	As required	As required
11	Strzelecki NE 1	O	SGS	PA	Complete	Annual	5 years
12	Marana 2	O	SGS PNL	TO TO	Complete Complete	Annual 2 years	5 years As required
13	Nanima 2	O	Downhole P/T gauge PNL	TO TO	N/A Complete	Continuous As required	If operating As required
14	Wanara 1	O	SGS PNL	TO TO	Complete Complete	Annual As required	5 years As required
15	Field	F	InSAR surface displacement study		Complete	Once	Once
16	Field	F	Induced seismicity monitoring		Complete	Continuous	Continuous
17	All wells	W	Annulus pressure monitoring		Complete	Min 6 monthly	Min 6 monthly
18	All wells	W	Well integrity inspection		Complete	Min annual	Min annual
19	Risk based, 1-3 wells	W	Cement evaluation		Complete	As required	As required
20	Risk based, 1-3 wells	W	Casing / tubing evaluation		Complete	As required	As required

Type:

- I = injection well
- O = observation well
- W = general well
- F = field wide
- G = groundwater

Zone:

- TO = Toolachee Formation
- HU = Hutton Sandstone
- PA = Patchawarra Formation
- PO = Poolowanna Formation
- SU = surficial aquifer

Certain monitoring activities have been identified in Table 9 as contingent or “as required”. These activities will be conducted if observations suggest performance of the storage complex lies outside the uncertainty range predicted by the reservoir model, as set out in Table 10. For well integrity activities, “as required” denotes activities, such as cement, casing or tubing evaluation or annulus pressure monitoring, that will be determined by each individual well integrity management plan. These plans will be adaptive over time and may be updated throughout the duration of the proposed activity.

Table 10: M&V program contingent surveillance activities

Well	Activity	Zone	Trigger
Marabooka 4	SGS	TO	SGS will be run if the performance of the reservoir is outside the uncertainty range of the reservoir modelling and further pressure data is expected to assist with history matching, e.g. if the sands at Marabooka are more disconnected than expected. Gauge failure at Marabooka 5 may be a possible but not immediate trigger for SGS at Marabooka 4.
Marabooka 5	PNL	TO	PNL will be run if the performance of the reservoir is outside the uncertainty range of the reservoir modelling and further saturation data is expected to assist with history matching, e.g. if the sands at Marabooka are more disconnected than expected.
Nanima 2	PNL	TO	PNL logging will be conducted during the injection or closure period if there is uncertainty in CO ₂ migration beyond the Strzelecki-Nanima saddle. E.g. if the Nanima 2 DHG pressure measurement is outside the uncertainty range of the reservoir modelling or if there is an unexpected pressure change indicating the CO ₂ plume is not stable during the closure period. In any event, a PNL will be acquired 4 years after first injection.
Strzelecki 24	PNL	TO	PNL will be run if the performance of the reservoir is outside the uncertainty range of the reservoir modelling and further saturation data is expected to assist with history matching. The location of Strzelecki 24 on north west flank of the Strzelecki structure will help to identify arrival of CO ₂ at the maximum fill point north of the main fault, if required.
Strzelecki 33	PNL	TO	PNL will be run if required to assist the interpretation of CO ₂ arrival at other key observation well locations. The Strzelecki 33 PNL log will act as a control or calibration reference.
Strzelecki 10	PNL	TO	PNL will be run if the performance of the reservoir is outside the uncertainty range of the reservoir modelling and further saturation data is expected to assist with history matching. The location of Strzelecki 10 on the flank of the structure will help to identify arrival of CO ₂ at the maximum fill point, if required.
Marana 2	PNL	TO	PNL will be run during the closure period if the performance of the reservoir is outside the uncertainty range of the reservoir modelling and further saturation data is expected to assist with history matching.
Wanara 1	PNL	TO	PNL will be run if CO ₂ has been observed at Nanima and there is a risk of further lateral migration.
Various	CBL	All	Cement evaluation logging will be conducted as required at higher risk wells identified by integrity risk assessment. Risk assessments will be revised on an ongoing basis and target wells may change as baseline surveys and remediation activities are completed.
Various	Csg / Tbg eval	All	Casing or tubing evaluation will be conducted as required at higher risk wells identified by integrity risk assessment. Risk assessments will be revised on an ongoing basis and target wells may change as baseline surveys and remediation activities are completed.

5.2.5 Additional monitoring activities

Additional monitoring activities may be conducted to investigate uncertainties in the reservoir models. These contingent activities may include:

- Production logging – injection zone allocation
- Temperature logging – borehole leak detection
- Noise logging – borehole leak detection
- Fluid sampling – presence of CO₂

5.3 Environmental assurance monitoring

5.3.1 Monitoring of the overlying geological formations

The objective of this program is to provide evidence that the project is not impacting environmental receptors and provide a baseline for comparison should indications of CO₂ migration outside the target storage reservoir be detected. Most environmental receptors are at the surface and are very unlikely to be exposed to CO₂. Hence the focus is on the water quality in the shallow and deep aquifers, with the main monitoring target being the Hutton Sandstone, Namur Formation and Poolowanna Formation, the first permeable formations above the target storage reservoir. This monitoring is intended to confirm the long-term containment of carbon dioxide in the storage complex. This section outlines the monitoring program for the overlying geological formations which comprises permanent down hole gauges, static gradient surveys, pulsed neutron logging and groundwater quality monitoring. The schedule of monitoring is described in Table 11.

5.3.1.1 Down hole gauges (DHG)

DHGs measure the pressure of the formation adjacent to a well that open to it. A permanent DHG will be installed to monitor the pressure at the top of the Hutton Sandstone. Accumulation of CO₂ at the crest of the Hutton Sandstone is likely to produce a pressure increase in combination with a wellbore pressure gradient that indicates the presence of gas. DHG data will be acquired continuously, for example up to once every minute.

The following location will be monitored using DHGs:

- Strzelecki 12, located near the crest of the Strzelecki Hutton Sandstone structure.

5.3.1.2 Static gradient survey (SGS)

SGSs comprise one-off measurements of downhole pressure throughout the well column. It measures the reservoir pressure and allows the detection of the wellbore pressure gradient which can be used to infer the presence of gas in the formation accessed by the monitored well. The pressure measurement is used to calibrate the reservoir model.

The following location will be monitored using SGSs:

- Nanima 1, located south west of the Strzelecki storage reservoir and near the crest of Poolowanna Formation structure.

5.3.1.3 Pulsed neutron logging (PNL)

PNL surveys enable the detection of a gas column in the formation adjacent to well, through the well casing and cement. It does not require a well to be completed and open to the target formation for monitoring. The following locations will be monitored using PNL surveys to detect whether a gas column has accumulated in the Hutton Sandstone adjacent to the well:

- Strzelecki 33, located near the crest of the Strzelecki Hutton Sandstone structure
- Marabooka 6, located near the crest of the Marabooka Hutton Sandstone structure.

5.3.1.4 Groundwater quality monitoring

Groundwater quality monitoring comprises the collection and analysis of groundwater samples to develop values that can be used to detect potential changes in groundwater quality. Baseline monitoring was undertaken prior to injection to determine baseline conditions. Baseline monitoring included monitoring of the Hutton Sandstone, the first permeable geological formation overlying the target storage reservoir. If threshold monitoring criteria indicate the

presence of CO₂ in the Hutton Sandstone (a red trigger as per Section 5.8 Environmental response plan), monitoring will commence in the Namur Formation.

The following bores and wells were monitored:

- DUGGW2 (X1), DUGGW5 (X4), Strzelecki No. 2 and Strzelecki 3 Water Bore bores that access shallow groundwater, and
- Strzelecki 20 and Strzelecki 27, wells that access the Hutton Sandstone.

Samples collected during baseline were analysed for a combination of field and laboratory parameters, using properly calibrated equipment to measure field parameters. Field parameters are listed in Table 12 and laboratory analyses are listed in Table 13. Samples were analysed by ALS Environmental Laboratory.

It should be noted that testing for boron (B), beryllium (Be), cadmium (Cd), chromium (Cr), cobalt (Co), lead (Pb), mercury (Hg), nickel (Ni), phosphorus (P), selenium (Se), and vanadium (V) are included to support groundwater geochemical modelling and align with background water quality assessments that have already been completed through previous historic sampling. These metals may not be retained after completion of the geochemical modelling.

For baseline or environmental assurance monitoring, pH, nitrate, nitrite, and ammonia will be out of hold time due to the remote nature of the site and time taken to freight samples to a laboratory. The purpose of laboratory pH measurements is to compare with field pH measurements for assessing potential analytical artefacts from precipitation-dissolution reactions within sample bottles that may occur during transit of samples to the laboratory. This step is critical for assessing false positive results. The goal of analysing for nitrogen-based parameters is to determine presence/absence as a qualitative redox indicator. The specific value of the absolute concentrations is not critical.

The establishment of baseline conditions was required to enable evaluation of potential changes in groundwater geochemistry in the shallow and deep aquifer systems in response to CCS injection activities. Wells were sampled up to eight times before the start of CCS operations to establish baseline geochemical conditions. The baseline sampling and analysis program was designed to be flexible and was intended to be adjusted following assessment of preliminary baseline data.

Following baseline sampling, a geochemical and baseline statistical assessment was completed as outlined in Appendix B. Geochemically relevant and statistically robust environmental thresholds were developed for wells in the shallow aquifer and the Hutton Sandstone. 95th percentiles were calculated for four parameters (calcium, magnesium, potassium and reactive silica) in the Hutton Sandstone and four to five parameters (calcium, magnesium, potassium, strontium and reactive silica) for each shallow aquifer bore (DUGGW2, DUGGW5 and Strzelecki No. 2).

Downhole pressure is the environmental assurance monitoring leading indicator as measured by the permanent DHG, also supported by pulsed neutron logging. If these data indicate risk of CO₂ migration into the Hutton at trigger level yellow or above, Hutton groundwater sampling and analysis will commence and be compared against baseline.

Baseline monitoring of the surficial aquifer will be ongoing throughout the injection period. This will improve the statistical quality of the baseline dataset over time. Ongoing monitoring will comprise at least annual monitoring of DUGGW2 (X1), DUGGW5 (X4), Strzelecki No. 2 and Strzelecki 3 Water Bores for the analyses listed in Table 12 and Table 13.

Table 11: Schedule of environmental assurance monitoring activities

No.	Location	Type	Activity	Zone	Frequency		
					Pre-inject	Injection	Closure
1	Marabooka 6	O	PNL	HU	Complete	2 years	5 years
2	Strzelecki 12	O	Downhole P/T gauge	HU	N/A	Continuous	If operating
3	Strzelecki 33	O	PNL	HU	Complete	2 years	5 years
4	Nanima 1	O	SGS	PO	Complete	Annual	5 years
5	DUGGW2 (X1), DUGGW5 (X4), Strzelecki No. 2 and Strzelecki 3 Water Bore bores. Strzelecki 20 and Strzelecki 27 Oil Wells.	G	Groundwater sampling	SU HU	Complete Complete	Annual As required	As required As required

Type:

- I = injection well
- O = observation well
- W = general well
- F = field wide
- G = groundwater

Zone:

- TO = Toolachee Formation
- HU = Hutton Sandstone
- PA = Patchawarra Formation
- PO = Poolowanna Formation
- SU = surficial aquifer

Table 12: Field Parameters

Field Parameter	Reporting Units	Specific Considerations
pH	Standard Units	Daily 2-point calibration
ORP	millivolts	Daily calibration
Dissolved Oxygen	mg/L	Daily calibration
Turbidity	NTU	Daily calibration

Table 13: Laboratory Analyses

Fraction	Limit of Reporting (mg/L)	Specific Analytes
Field-Filtered	1	Major cations: sodium (Na), potassium (K), magnesium (Mg), calcium (Ca).
Field-Filtered	0.005 – 0.1	Trace cations and metals: aluminium (Al), arsenic (As), boron (B), beryllium (Be), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), lead (Pb), lithium (Li), manganese (Mn), mercury (Hg), nickel (Ni), phosphorus (P), selenium (Se), silicon (Si), strontium (Sr), barium (Ba), Rubidium (Rb), thorium (Th), and uranium (U), vanadium (V) and zinc (Zn).
Field-Filtered	0.05	Reactive phosphorus (P)
Field-Filtered	0.05	Speciated iron (ferrous and ferric)
Total (unfiltered)	0.01-1	Alkalinity, sulphate (SO ₄), chloride (Cl), nitrate, nitrite, and ammonia.
Total (unfiltered)	0.1	sulphide
Total (unfiltered)	0.01	Dissolved methane
Total (unfiltered)	-	Laboratory pH

Notes:

- LOR = limit of reporting
- mg/L = milligrams per litre
- NTU = Nephelometric Turbidity unit
- ORP = oxidation-reduction potential
- * In-house technical guidance for the Natural Attenuation Indicators: Methane, Ethane, and Ethene, USEPA-Region 1, EPA New England, July 2001.

5.4 Activity schedule

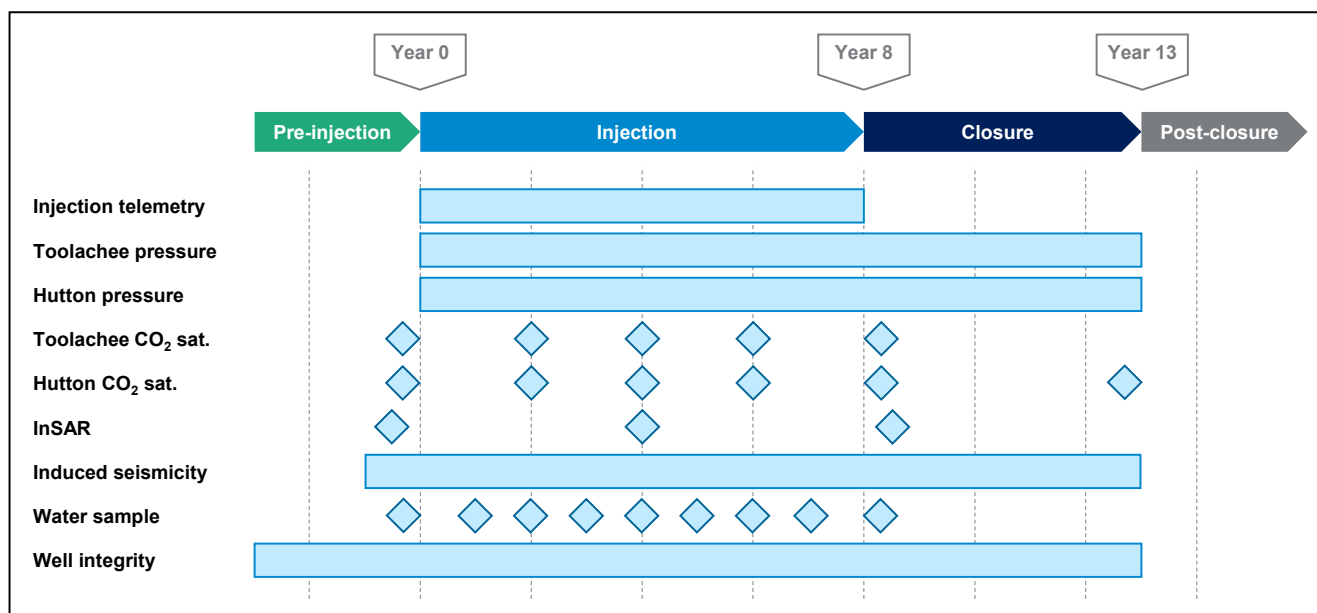


Figure 16: Schematic timeline of operational and environmental assurance monitoring activities

5.5 Detection limits

Estimated detection limits for the main monitoring techniques are listed in

Table 14. The estimates are based on dynamic modelling and operational experience. In some instances, smaller volumes may be detectable.

Table 14: Estimated detection limits for various monitoring techniques

Technique	Scenario	Order of magnitude detection limit
Gas saturation / pressure in overlying Hutton reservoir	Cross flow of CO2 from the Toolachee accumulates as a gas column at the crest of the Hutton	Volume 10 Bscf
Gas saturation / pressure in peripheral Toolachee fields	Lateral migration of CO2 out of closure	Volume 10 Bscf
Temperature / noise logging	Well integrity failure causes cross flow of CO2 from the Toolachee an overlying formation	Rate 0.1-1 MMscf/d

5.6 Verification

Monitoring activities are designed to gather data on the state of the storage complex and surrounding environment. The selected monitoring technologies provide complementary capabilities in terms of measurement sensitivity, frequency and range. Verification refers to the interpretation and integration of monitoring data to demonstrate the project objectives have been achieved. All monitoring data will require some level of interpretation and quality control. Poor quality data will be discarded or reacquired if necessary. For most parameters verification is provided by simple comparison to baseline measurements or expectations as outlined in this plan. These parameters include:

- Injection telemetry / operating envelope
- Induced seismicity
- Surface displacement
- Well integrity
- Water quality

Baseline measurements were successfully acquired prior to the start of injection. Expectations for parameters without baselines are derived from appropriate technical assessments and modelling. Expectations and tolerances to deviations from baselines may be updated over the duration of the project as understanding of the storage complex matures.

Verification of containment, particularly in the long term, requires a more complex approach incorporating dynamic reservoir modelling. Dynamic modelling integrates all relevant reservoir data into a consistent interpretation of fluid flow in the reservoir. History matching the model to the observed behaviour of the reservoir gives good confidence that the model can accurately predict the future behaviour of the reservoir within a range of uncertainty. The long production history of the Strzelecki and Marabooka Toolachee reservoirs provides a detailed starting point. Injection telemetry, reservoir pressure and saturation measurements will provide an extensive dataset from the start of CO₂ injection. Uncertainty in the model predictions will be assessed by using an automated assisted history matching workflow to develop a suite of independently matched models. This will allow probabilistic prediction of the CO₂ plume extent and movement over time. The dynamic model will be updated regularly over the life of the project to incorporate newly acquired data.

Vertical containment will be verified by demonstrating the absence of injected CO₂ in the overlying reservoirs. CO₂ presence in the overlying Hutton reservoir will be monitored using a combination of cased hole logging and pressure measurement in near-crestal observation wells. If vertical migration of CO₂ is detected, then these monitoring data will be incorporated into the dynamic model to estimate the total loss volume.

Lateral containment will be verified by demonstrating the absence of injected CO₂ on the migration pathway out of the main Strzelecki structure. Monitoring for CO₂ presence at peripheral Toolachee observation wells, Nanima 2 and Wanara 1, will be used for this purpose. The modelled extent of the CO₂ plume will also be used to assess lateral containment.

5.7 Operational response plan

In general, the following process will be used to manage deviations from expected performance, e.g. yellow or red loss of containment indicators. It is equivalent to the process that Santos uses to manage current production operations.

- Assess risk of the deviation
- Identify appropriate controls and / or gather further data
- Implement controls
- Review effectiveness of controls and confirm that the risk is as low as reasonably practical

As an example, if a loss of containment were to occur due to cement degradation in an existing well and loss of well integrity, this may result in communication between the Toolachee storage reservoir and the overlying Hutton reservoir and be detected by an accumulation of CO₂ in the Hutton, starting as a yellow loss of containment indicator. The deviation would trigger additional monitoring activities such as cased hole logs to locate the source of communication. Injection may be temporarily reduced during this time to prevent the incident escalating to the red category, depending on the risk assessment. Once identified, a workover would be undertaken to remediate or

abandon the problem well. Repeat monitoring would then be conducted to confirm that the problem has been resolved.

Should a risk of loss of containment from a geological source be identified, action will be taken to manage this risk. For example, the most likely geological loss of containment is lateral migration of CO₂ outside of the Marabooka / Strzelecki / Marana structures. This would likely be caused by preferential injection into thin, high permeability sands and could be managed by firstly adjusting the rate allocation between wells then remediating via well intervention, e.g. to shut off high permeability zones. The monitoring plan would also be expanded to track the effectiveness of these adjustments.

5.8 Environmental response plan

The following monitoring triggers will be used to determine if CO₂ has potentially migrated into geological formations overlying the target reservoir.

Table 15: Environmental LOC triggers and monitoring indicators

Trigger Level		Migration indicators	Indicative volume (Bscf) ^[1]
1	Green	No CO ₂ column at the crest of the Hutton.	<1
	Yellow	Indications (but not confirmation) of CO ₂ presence at the crest of the Hutton, or indications of CO ₂ migration from other verified monitoring data sources.	1-10
2	Red	CO ₂ column confirmed at the crest of the Hutton.	Greater than 10

¹ As per section 5.5, this is an indicative trigger volume at estimated detection limits, although smaller volumes may be detectable.

In response to environmental assurance monitoring detecting a yellow level migration indicator, Santos will:

- Verify the trigger level.
- If verified as correct, complete a notification to the Department for Energy and Mining (DEM).
- Complete an investigation to estimate the volume of CO₂ that may have migrated out of the target reservoir and implement additional monitoring in the Hutton. Review and update the project risk assessment and M&V plan, if required.
- Santos will provide details of the above, as part of the General reporting commitments defined in section 8.1.1.

In response to environmental assurance monitoring detecting a red level migration indicator, Santos will:

- Verify the trigger level.
- If verified as correct, complete any notifications, where required, under section 3 (Table 2) of the Carbon Storage SEO and / or relevant legislation (e.g. *Environmental Protection Act 1993*).
- Complete an investigation to estimate the volume of CO₂ that may have migrated out of the target reservoir, assess the potential location and extent of migration within the subsurface including the potential for migration into non-target depleted hydrocarbon reservoirs, and review and update the project risk assessment and M&V plan if required. This assessment will determine what additional monitoring and management measures are required. Examples of additional monitoring may include pulsed neutron logging, static gradient surveys, water sampling and well integrity reviews of key wells.

- If not already provided in accordance with statutory reporting requirements, Santos will provide a report of the above, including an updated version of the M&V plan if required, to DEM within 6 months of the notification.

In addition, when a red level is triggered Santos will implement steps to determine whether material change to groundwater chemistry in non-target aquifers (defined as shallow aquifers as per Table 5) has occurred. This will comprise of the following, as informed by the outcome of the investigation:

- Monitoring of the Namur Formation (non-target depleted hydrocarbon reservoir) to verify if CO₂ has not migrated outside of the Hutton Sandstone (non-target depleted hydrocarbon reservoir).
- Analysis of groundwater monitoring data in non-target aquifers (refer to section 5.3.1.4, specifically the bores that access shallow groundwater) that will determine baseline statistical parameter values (e.g. 95th percentile values) for the non-target aquifer up to the time that migration outside the target reservoir was detected.
- Monitoring of the non-target aquifer after the migration outside the target reservoir was detected, where potential material change to non-target aquifers comprises at least three consecutive monitored values at concentrations greater than the 95th percentile baseline value for indicator species that would be sensitive to change due to CO₂ migration (as a minimum, that would comprise dissolved magnesium, dissolved potassium and reactive silica). If a monitored value in a non-target aquifer is detected which is greater than the 95th percentile baseline value, the consecutive sample will be taken within one month of detection (e.g. finalisation of lab result).
- Further assessment will be undertaken to validate whether the potential change in groundwater chemistry has reduced the ability of potential groundwater users from undertaking their activities. This assessment will determine that additional monitoring and management measures are required.

6 Site closure

6.1 Closure criteria

Santos will develop a plan for closure of the storage complex during the life of the project. The plan will be finalised by agreement between Santos, DEM and the Environment Protection Authority (EPA) as the state regulators before the end of the injection period. The plan will specify the activities to be conducted during the closure period, including monitoring and decommissioning. The timing for closure of the storage complex will be based on the project demonstrating that it meets the agreed closure criteria.

Provisional closure criteria:

- The monitoring dataset is sufficient to confidently assess the future evolution of the storage complex.
- The dynamic model for the CO₂ storage complex replicates the observed performance of the storage complex within the uncertainty range.
- The residual risk of loss of CO₂ from the storage complex is low and acceptable to Santos, DEM and EPA.
- All wells and facilities are decommissioned in accordance with the relevant SEOs or are in use for other projects. At a minimum, for all wells within the CO₂ plume, the downhole section covering the storage reservoir and primary seal is appropriately abandoned.

6.2 Expected closure timing

Injection into the storage complex is expected to last between 6-9 years on plateau (Figure 8). Injection may cease at the end of the plateau or continue for up to approximately 3 years to include the small additional tail volume. The outcome depends on the performance of the storage reservoir. Current dynamic reservoir modelling indicates that site closure is likely to be possible within approximately 5 years, based on the predicted reservoir pressure response (Figure 17). The primary reservoir surveillance objective during the closure monitoring period will be to confirm that the reservoir pressure continues to behave as expected.

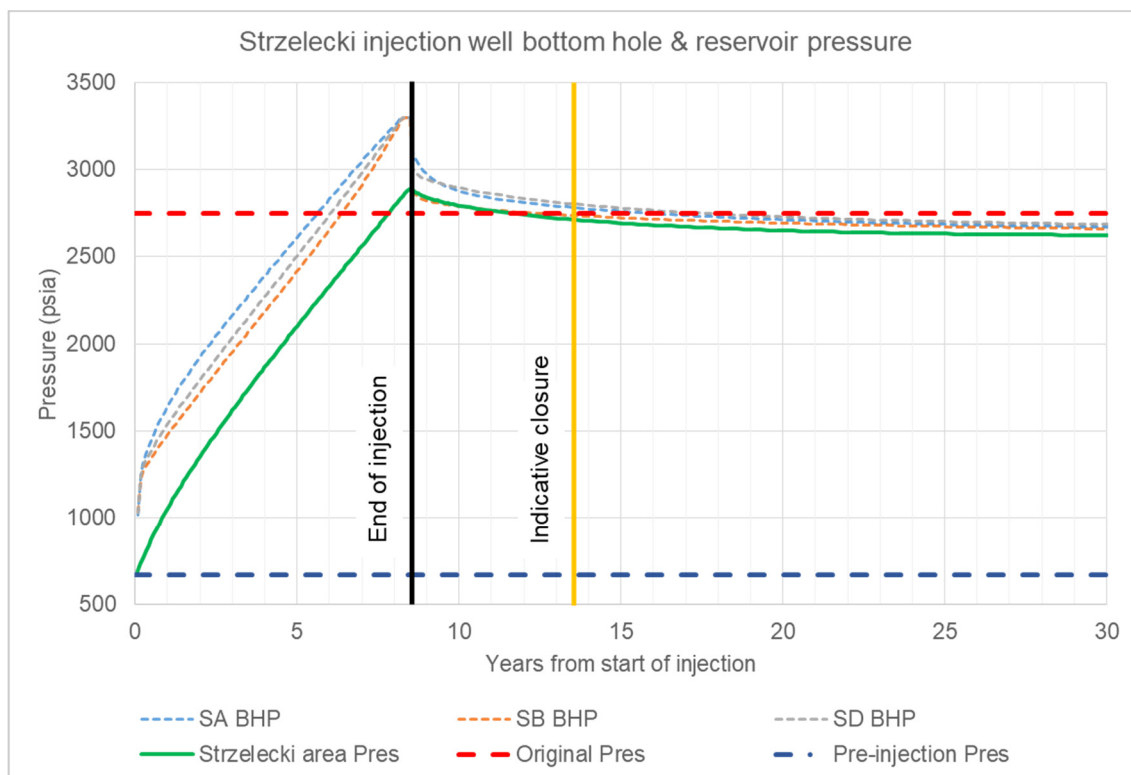


Figure 17: Base case pressure profile

6.3 Closure monitoring

Closure monitoring activities will include:

- Continued operation of serviceable permanent downhole gauges, which are likely to be sufficient to monitor reservoir pressure (items 1-5, 7, 9, 13 in Table 9, item 2 in Table 11)
- Infrequent pressure surveys in peripheral wells if required (items 12, 14 in Table 9, item 4 in Table 11)
- Lower frequency cased-hole logging across the overlying Hutton interval (items 1, 3 in Table 11)
- Well integrity monitoring until abandonment (items 17-20 in Table 9)

The reservoir models utilised during the injection phase will continue to be matched to the measured data. A final risk assessment will be undertaken to demonstrate that the long-term risk to containment of the CO₂ is as low as reasonably practical.

7 M&V performance targets

This section defines the key performance indicators (KPIs) for the M&V plan. The KPIs have been selected to clearly focus on the most important aspects of M&V plan performance. The KPIs will be reviewed over the life of the project and updated if necessary to ensure they remain relevant.

Table 16: Key performance indicators for the M&V plan

KPI number	KPI name	Definition
1	Measurement accuracy	The maximum uncertainty in total flow rate measurement is not greater than $\pm 1.5\%$.
2	Operating envelope	Operate within the composition limits (section 1.2) and injection condition limits (section 9.1) at least 99% of the time.
3	Vertical containment	CO ₂ stays contained within the target Toolachee injection reservoir. Containment threshold remains at 'green' level, as defined in section 3.5.
4	Lateral containment	CO ₂ stays contained within the target Toolachee injection reservoir. Containment threshold remains at 'green' level, as defined in section 3.5.
5	Monitoring activity schedule	Monitoring and verification activities will be at least 90% compliant with the planned activity schedule, as defined in section 5.4.

8 Reporting and review

8.1 Reporting

8.1.1 General reporting

Santos will submit an annual summary report to DEM outlining the status of the project and the activities undertaken in the past year. An interim report was submitted approximately 6 months after the start of injection. Future reports will be submitted annually. The report will include:

- Summary of major project activities and milestones
- Summary of any containment incidents
- Comparison of performance against M&V KPIs
- CO₂ injection rate and storage inventory
- Summary and interpretation of M&V activities
- Update of containment risk assessment

Santos will submit standard performance and technical reports to DEM in accordance with the *Energy Resources Act (SA)*, 2000 and the *Energy Resources Regulations (SA)*, 2013.

8.1.2 Incident reporting

The requirements for incident reporting are detailed in section 3 of the Carbon Storage SEO. Santos will report Serious Incidents or Reportable Incidents, as defined in the Carbon Storage SEO, in accordance with legislative requirements. A Serious Incident related to unintended migration of CO₂ into non-target aquifers arises when material change to groundwater chemistry in non-target aquifers has occurred as per the material change assessment defined in section 5.8, in response to a red level indicator.

8.2 Review

Santos will review the M&V plan regularly to ensure it remains fit for purpose. Any revisions to the monitoring plan will be submitted to DEM for approval. The review will focus on whether the storage complex is behaving as expected and whether any risks have changed as a result of the additional data that has been acquired. The schedule of activities will be updated to reflect these changes. It is expected that the frequency of some activities may be reduced as the understanding of the storage complex matures through the life of the project.

Reviews will be completed annually with timing aligned to the annual summary report. The frequency of future reviews may be adjusted based on the observed results.

Reviews will include independent third-party expert validation and verification.

9 Reservoir management

The objective of reservoir management is to safely optimise the performance of the storage reservoir. In practice this means ensuring stable operation of the reservoir at the required injection rate while maximising the volume of CO₂ that is stored.

9.1 Operating envelope

The injection wells will be operated within a designated envelope to ensure stable operation and containment of the CO₂. This envelope is based on results from the flow assurance study, geomechanics study and various design limitations. Table 17 lists some key constraints for the well operating envelope. The maximum volume of CO₂ that can be stored in the Strzelecki and Marabooka reservoirs is expected to be limited to approximately 250 Bscf. However, this volume limitation will be refined during detailed design and operation of the project as additional data is gathered.

Table 17: Injection well operating envelope

Parameter	Units	Minimum	Maximum
Tubing head pressure	psig	N.A.	2120
Tubing head temperature	°C	-29	65
Bottom hole pressure gradient	psi/ft	N.A.	0.54
Bottom hole temperature	°C	0	N.A.
Injection flow rate	MMscf/d	N.A.	40

9.2 Capacity management

The injection wells / reservoirs are designed to accept the full rate discharged from the Moomba CCS facilities. The distribution of flow between injection wells will be managed with a process similar to production wells. Target and maximum injection rates will be set for each well monthly in consultation between the production engineering, reservoir engineering and operations teams. The target rates will be based on achieving even fill of the storage reservoir to maximise total storage capacity. The maximum rate may be set less than the design maximum to avoid overfilling sections of the reservoir or damaging the injectors.

Injection well control skids will be provided with a combination of flow and pressure control. It is expected that the wells will typically operate in pressure control to provide back pressure to keep the pipeline in dense phase. This will allow temporary redistribution of flow if one or more wells are offline. The flow control will be used to manage the maximum injection rate.

9.3 Well interventions

It is anticipated that interventions on the injection wells may be required during the life of the project. The requirement for interventions will be determined as part of the capacity management process and is likely to be in response to underperformance of an injector or equipment failure. These activities may include but are not limited to:

- Replacement of permanent downhole gauge
- Cased hole logging
- Re-perforation
- Temporary flow back
- Tubing replacement / upsize

Interventions on injection, observation and suspended wells may also be required to maintain well integrity. This will be managed via Santos' well integrity management process.

10 References

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Appendix A Containment risk assessment details

A.1 Migration scenarios

The hypothetical scenarios considered both lateral and vertical migration of CO₂ outside of the expected storage reservoir. Figure 18 shows one scenario for lateral migration where the maximum bottom-hole pressure (BHP) constraint was lifted from the planned 3300 psia to an extreme value of 3900 psia to simulate the effect of overfilling the reservoir. Minimal difference was observed in the plume size and no migration out of structure towards the south-west spill point was predicted.

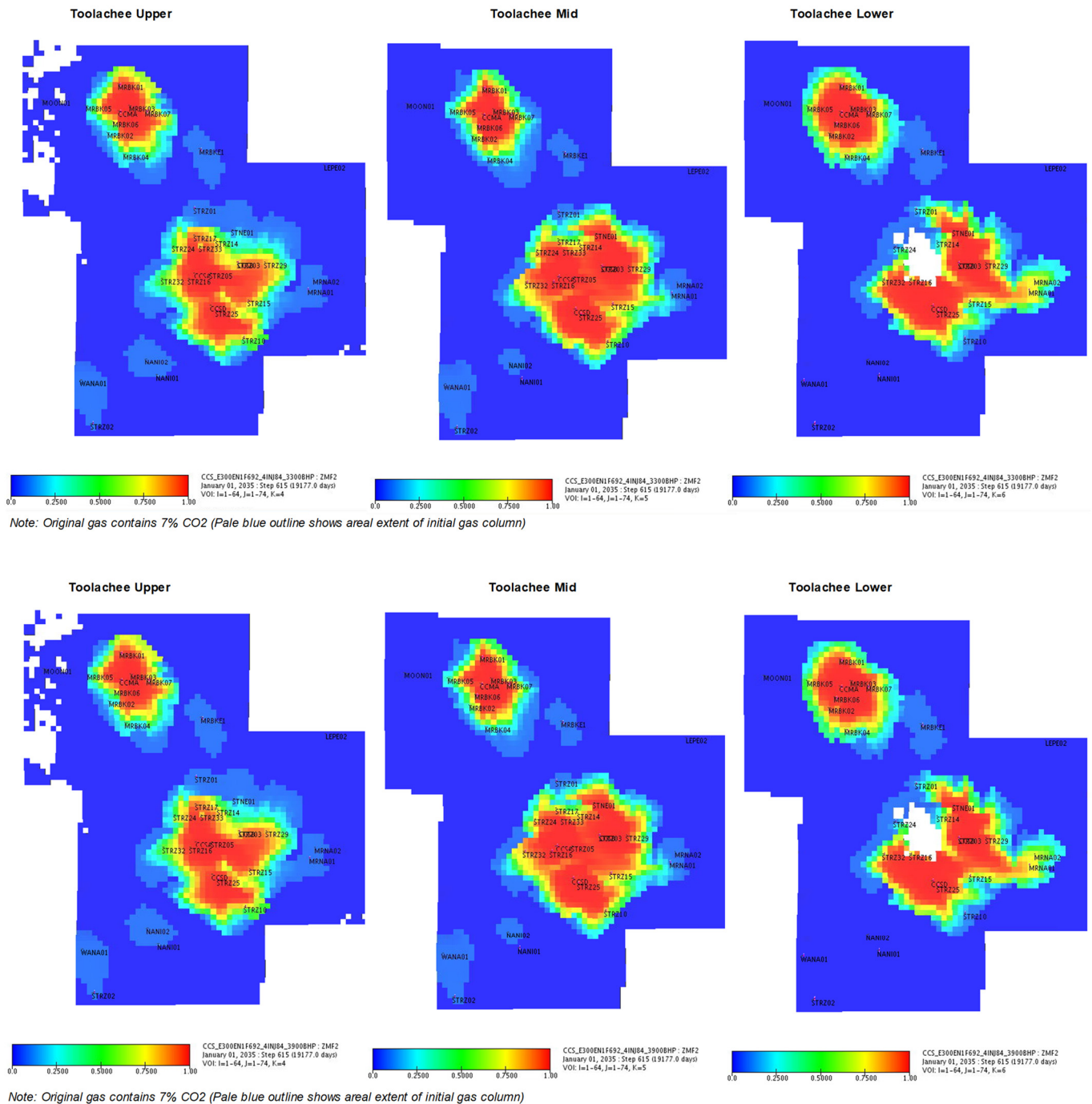


Figure 18: CO₂ extent (mole fraction) in the Toolachee reservoir in the base case (top) and with the hypothetical elevated BHP (bottom) as a containment test. The CO₂ remains contained even at the elevated pressure.

The risk of vertical migration most likely arises from failure of cement in existing wells or reactivation of a fault that intersects the primary seal. To simulate a breach through the primary seal two near crestal wells, Strzelecki 17 and Marabooka 1, were modelled to be completely open to the Hutton and Toolachee at the end of injection. This is likely to represent close to a “worst case” scenario, as a leak behind casing due to poor cement would be more restricted than a completely open well. In this scenario approximately 9 Bscf of gas cross flowed into the Hutton over a period of 50 years as the pressure equalised (Figure 19). Figure 20 and Figure 21 show that the predicted extent of this plume is small, in part because a significant fraction of the CO₂ dissolves into the water. The plume is predicted to be contained within the Hutton closure, which held a significant oil pool in the Strzelecki area.

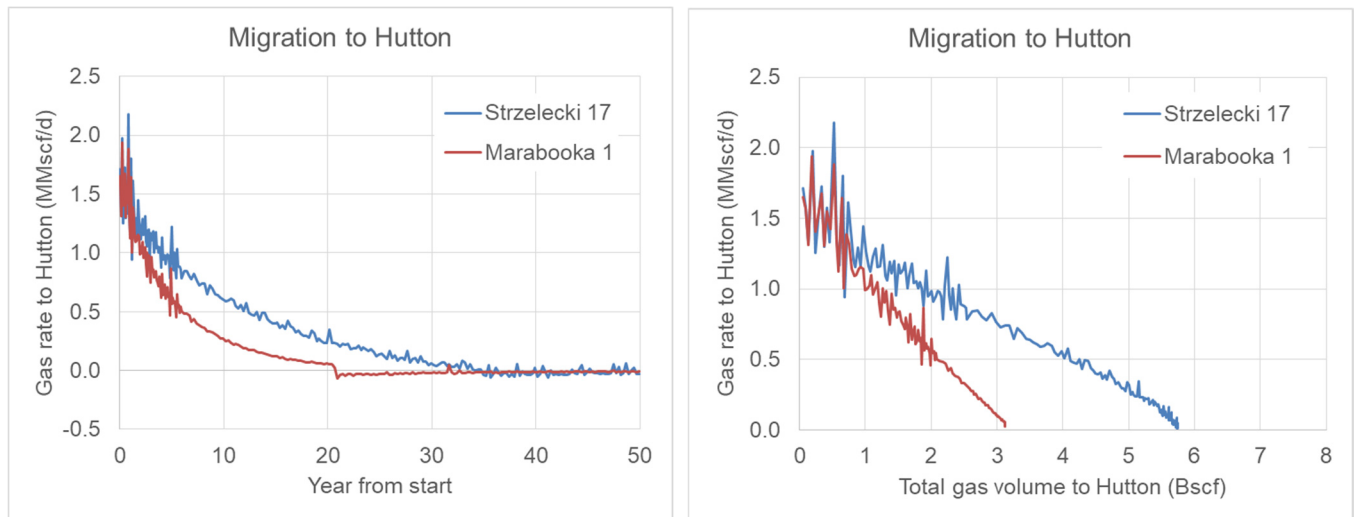


Figure 19: Modelling of hypothetical “worst case” migration from the Toolachee to Hutton in Strzelecki 17 and Marabooka 1 (note: negative rate is due to crossflow of Hutton water with dissolved CO₂ into the Toolachee)

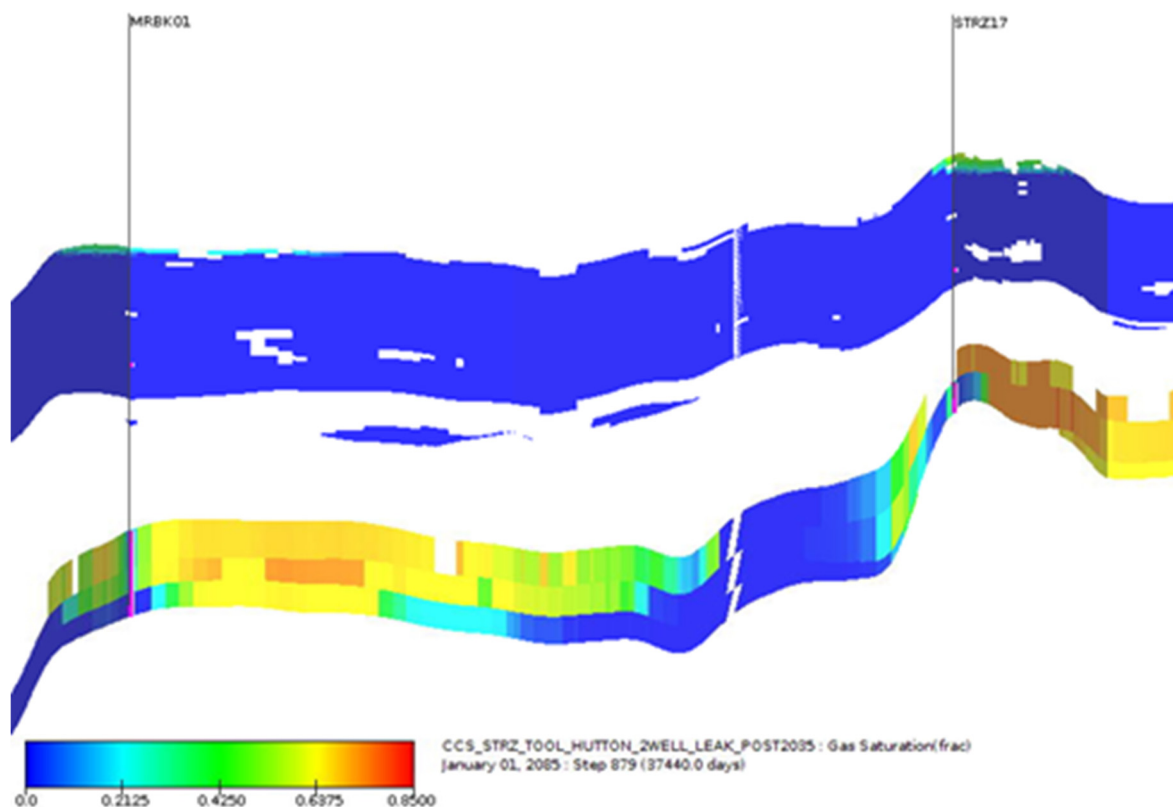
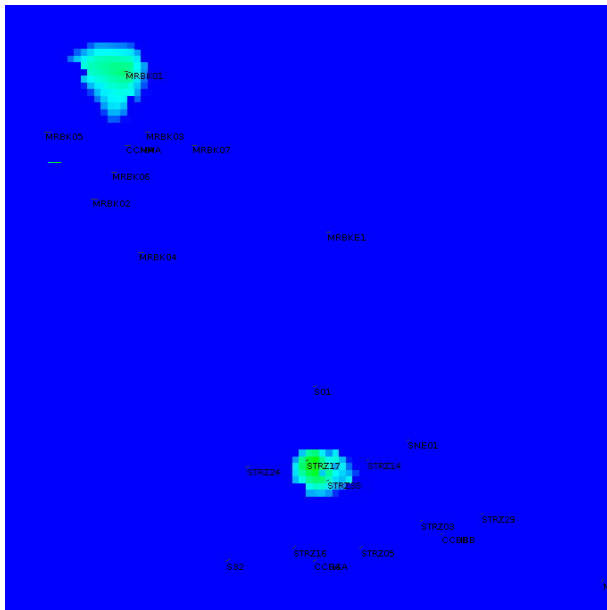
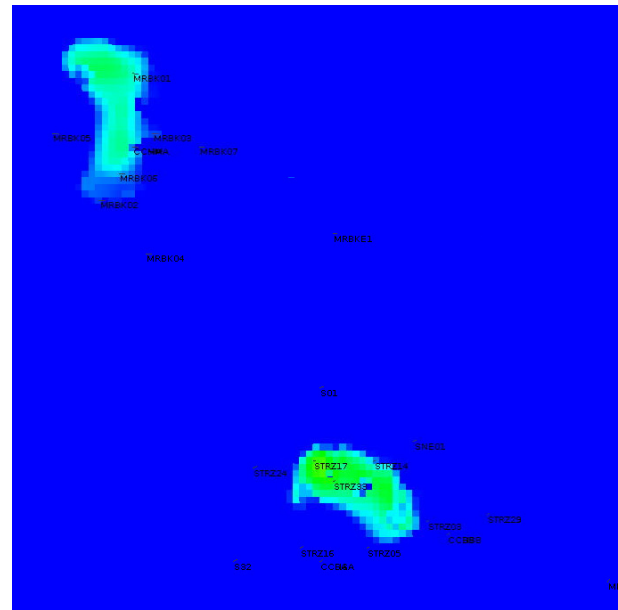


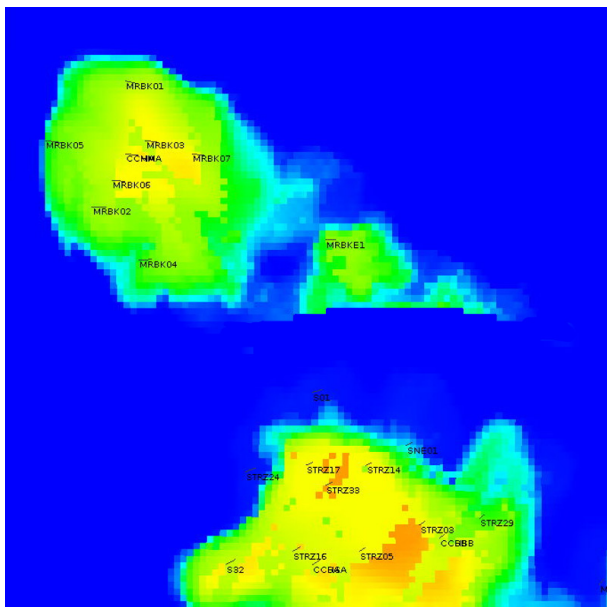
Figure 20: Cross section showing gas saturation in the Toolachee (lower interval) and Hutton (upper interval) 50 years from the start of vertical migration



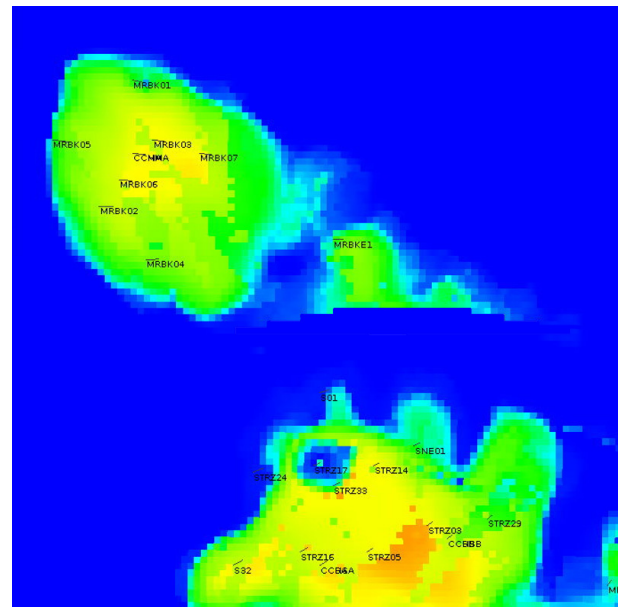
Hutton after 3 years



Hutton after 50 years



Toolachee after 3 years



Toolachee after 50 years

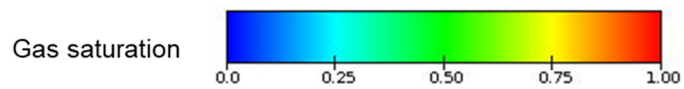


Figure 21: Gas saturation in top Hutton (top) and mid Toolachee (bottom), 3 years (left) and 50 years (right) from start of vertical migration

A.2 Detailed risk ratings

Abbreviations:

- C = consequence
- L = likelihood
- P = preventative
- M = mitigating

Risk No.	Objective	Risk Name	Risk detail	Causes	Impacts	Controls P - Preventative M - Mitigating	INHERENT			RESIDUAL		
							C	L	Risk rating	C	L	Risk rating
1	Financial / Reputation	Poor cement - old well	Migration of >1 Bscf of CO2 from storage reservoir to overlying Hutton Sandstone (yellow LOC).	No isolation over Nappamerri seal due to poor primary cement job in an old well.	Financial cost to identify and remediate problem well. Notification to regulator.	P - Well integrity review has identified wells with poor quality cement which will be remediated or abandoned prior to the start of CO2 injection. <i>This work was successfully completed in 2023.</i> M - Monitoring plan will identify migration of CO2 above the Nappamerri seal into the Hutton Sandstone.	IV	e	High	IV	b	Low
2	Financial / Reputation	Poor cement - new well	Migration of >1 Bscf of CO2 from storage reservoir to overlying Hutton Sandstone (yellow LOC).	No isolation over Nappamerri seal due to poor primary cement job in a new well (injector).	Financial cost to identify and remediate problem well. Lost revenue while well offline to remediate. Notification to regulator.	P - Well designed for CO2 service and drilled with current best practice. M - Monitoring plan will identify migration of CO2 above the Nappamerri seal into the Hutton Sandstone.	IV	d	High	IV	b	Low
3	Financial / Reputation	Degradation of cement - old well	Migration of >1 Bscf of CO2 from storage reservoir to overlying Hutton Sandstone (yellow LOC).	CO2 reacts with cement in an old well causing compromising isolation over Nappamerri seal. Likely that multiple wells would be affected.	Financial cost to identify and remediate problem wells. Notification to regulator.	P - Well integrity review has identified the type of cement used on all old wells and concluded that reactions with CO2 are likely to be limited. M - Monitoring plan will identify migration of CO2 above the Nappamerri seal into the Hutton Sandstone.	V	c	High	IV	b	Low
4	Financial / Reputation	Degradation of cement - new well	Migration of >1 Bscf of CO2 from storage reservoir to overlying Hutton Sandstone (yellow LOC).	CO2 reacts with cement in a new well (injector) causing compromising isolation over Nappamerri seal. Likely that multiple wells would be affected.	Financial cost to identify and remediate problem wells. Lost revenue while wells offline to remediate. Notification to regulator.	P - Well designed for CO2 service with CO2 resistant cement. M - Monitoring plan will identify migration of CO2 above the Nappamerri seal into the Hutton Sandstone.	V	c	High	IV	a	Low
5	Financial / Reputation	Casing corrosion - old well	Loss of well barrier.	CO2 and water corroding carbon steel casing in an old well. External corrosion near surface.	Financial cost to identify and remediate problem well or accept higher risk.	M - 2 barrier well design (corrosion resistant casing for monobores). P - A well integrity review identified wells that posed an unacceptable risk. Wells were successfully abandoned, suspended or remediated in 2023, and some wells are targeted for enhanced well integrity surveillance. M - Well integrity checks will identify casing leaks from the production casing annulus.	III	d	Medium	III	b	Low
6	Financial / Reputation	Casing corrosion - new well	Loss of well barrier in an injector which would likely need to be fixed.	CO2 and water corroding carbon steel casing in a new well (injector). External corrosion near surface.	Financial cost to identify and remediate problem well. Lost revenue while well offline to remediate.	M - 2 barrier well design. P - Well designed for CO2 service and drilled with current best practice. M - Well integrity checks will identify casing leaks from the production casing annulus.	III	c	Low	III	b	Low
7	Financial / Reputation	Tubing / packer failure - old well	Loss of well barrier.	CO2 and water corroding carbon steel tubing or causing packer seal element to fail in an old well.	Financial cost to identify and remediate problem well or accept higher risk.	M - 2 barrier well design (corrosion resistant casing for monobores). P - A well integrity review identified wells that posed an unacceptable risk. Wells were successfully re-completed, suspended or remediated in 2023, and some wells are targeted for enhanced well integrity surveillance. M - Well integrity checks will identify casing leaks from the production casing annulus.	III	d	Medium	III	b	Low
8	Financial / Reputation	Tubing / packer failure - new well	Loss of well barrier in an injector which would need to be fixed.	CO2 and water corroding carbon steel tubing or causing packer seal element to fail in a new well (injector).	Financial cost to identify and remediate problem well. Lost revenue while well offline to remediate.	M - 2 barrier well design. P - Well designed for CO2 service with corrosion resistant tubing and suitable packer. M - Well integrity checks will identify casing leaks from the production casing annulus.	III	c	Low	III	b	Low
9	Financial / Reputation	Wellhead seal failure - old well	Loss of well barrier.	CO2 causing wellhead packer seal element to fail in an old well.	Financial cost to identify and remediate problem well or accept higher risk.	M - 2 barrier well design. P - Well integrity review has identified wells with high risk tubing / packer which will be remediated, abandoned or risk assessed prior to the start of CO2 injection. M - Well integrity checks will identify wellhead seal failure.	II	d	Low	II	b	Very Low

Risk No.	Objective	Risk Name	Risk detail	Causes	Impacts	Controls P - Preventative M - Mitigating	INHERENT			RESIDUAL		
							C	L	Risk rating	C	L	Risk rating
10	Financial / Reputation	Wellhead seal failure - new well	Loss of well barrier in an injector which would need to be fixed.	CO2 causing wellhead packer seal element to fail in a new well (injector).	Financial cost to identify and remediate problem well. Lost revenue while well offline to remediate.	M - 2 barrier well design. M - Well designed for CO2 service with suitable seal elements. M - Well integrity checks will identify wellhead seal failure.	II	c	Low	II	b	Very Low
11	Financial / Reputation	Capillary failure of primary seal	Migration of >10 Bscf of CO2 from storage reservoir to overlying Hutton Sandstone (red LOC).	CO2 column buoyancy pressure exceeds capillary entry pressure of the Top Toolachee / Nappamerri seal.	Financial cost to identify problem (would likely involve well several well interventions) and additional monitoring (e.g. seismic). Significant reputational impact affecting approval of future CCS projects.	P - Site selection - Toolachee reservoir has held a gas column with a larger buoyancy pressure over geological time. P - Seal capacity tests (MICP) on Top Toolachee and Nappamerri seals have confirmed sufficient capillary threshold pressure. P - Primary seal thickness has been mapped across the area of the storage complex and is at least 40 m. A capillary leak through this thickness would likely be very slow. P - Storage capacity of Toolachee reservoir limited to original gas filled structure. M - Monitoring plan will identify migration of CO2 above the Nappamerri seal into the Hutton Sandstone.	V	a	Medium	IV	ac	Very Low
12	Financial / Reputation	Fault reactivation	Migration of >10 Bscf of CO2 from storage reservoir to overlying Hutton Sandstone (red LOC).	CO2 injection changes the stress in the storage complex causing a fault to reactivate and open to flow.	Financial cost to identify problem (would likely involve well several well interventions) and additional monitoring (e.g. seismic). Potential early closure of the storage complex. Significant reputational impact affecting approval of future CCS projects.	P - Site selection - Toolachee reservoir has held a gas column over geological time so faults must have sealed in initial stress state. P - All major faults have been identified from 3D seismic. P - Geomechanical study has considered fault reactivation and pressure will be kept below minimum threshold to reactivate a fault. M – Passive seismic geophone array will identify events associated with fault reactivation. M - Monitoring plan activities Pulsed Neutron Logging and Strzelecki 12 downhole P/T gauge (Hutton) will identify migration of CO2 above the Nappamerri seal into the Hutton Sandstone.	V	a	Medium	V	aa	Low
13	Financial / Reputation	Induced fracture through primary seal	Migration of >10 Bscf of CO2 from storage reservoir to overlying Hutton Sandstone (red LOC).	CO2 injection pressure exceeds fracture pressure causing a fracture to grow vertically through the Top Toolachee / Nappamerri seal.	Financial cost to identify problem (would likely involve well several well interventions) and additional monitoring (e.g. seismic). Potential early closure of the storage complex. Significant reputational impact affecting approval of future CCS projects.	P - Site selection - primary seal thickness has been mapped across the area of the storage complex and is at least 40 m, requiring a significant amount of energy to propagate a fracture to the Hutton Sandstone. P - Geomechanical study has considered fracture pressure and injection pressure will be kept below this threshold. P - Downhole gauges will be installed in all injectors to continuously monitor bottom hole pressure. M – Passive seismic geophone array will identify events associated with fracture growth. M - Monitoring plan activities Pulsed Neutron Logging and Strzelecki 12 downhole P/T gauge (Hutton) will identify migration of CO2 above the Nappamerri seal into the Hutton Sandstone.	V	a	Medium	V	aa	Low
14	Financial / Reputation	Natural seismicity	Migration of >10 Bscf of CO2 from storage reservoir to overlying Hutton Sandstone (red LOC).	A natural seismic event causes a breach of the storage complex.	Financial cost to identify problem (would likely involve well several well interventions) and additional monitoring (e.g. seismic). Potential early closure of the storage complex. Significant reputational impact affecting approval of future CCS projects.	P - Geomechanical study has reviewed the frequency and magnitude of natural seismic activity and assessed the site as suitable. M - Monitoring plan will identify migration of CO2 above the Nappamerri seal into the Hutton Sandstone.	V	aa	Low	V	ad	Very Low
15	Financial / Reputation	Natural fracture through primary seal	Migration of >10 Bscf of CO2 from storage reservoir to overlying Hutton Sandstone (red LOC).	Primary Top Toolachee / Nappamerri seal failure due to a fault or fracture (possibly sub-seismic resolution).	Financial cost to identify problem (would likely involve well several well interventions) and additional monitoring (e.g. seismic). Potential early closure of the storage complex. Significant reputational impact affecting approval of future CCS projects.	P - Site selection - Toolachee reservoir has held a gas column over geological time so faults must have sealed in initial stress state. P - All major faults have been identified from 3D seismic. M - Monitoring plan activities Pulsed Neutron Logging and Strzelecki 12 downhole P/T gauge (Hutton) will identify migration of CO2 above the Nappamerri seal into the Hutton Sandstone.	V	a	Medium	V	ac	Very Low

Risk No.	Objective	Risk Name	Risk detail	Causes	Impacts	Controls P - Preventative M - Mitigating	INHERENT			RESIDUAL		
							C	L	Risk rating	C	L	Risk rating
16	Financial / Reputation	Degradation of primary seal from exposure to CO2	Migration of >10 Bscf of CO2 from storage reservoir to overlying Hutton Sandstone (red LOC).	Primary Top Toolachee / Nappamerri seal failure due to partial dissolution of the seal when exposed to CO2.	Financial cost to identify problem (would likely involve well several well interventions) and additional monitoring (e.g. seismic). Potential early closure of the storage complex. Significant reputational impact affecting approval of future CCS projects.	P - Site selection - Toolachee reservoir has held a gas column over geological time with a CO2 concentration of ~10% mole. P - Geochemical study has assessed the mineralogy of the primary seal and modelled possible reactions with CO2. The seal was found to be largely unreactive. P - Primary seal thickness has been mapped across the area of the storage complex and is at least 40 m. The progress of a reaction front through this thickness and any associated leak would likely be very slow. M - Monitoring plan activities Pulsed Neutron Logging and Strzelecki 12 downhole P/T gauge (Hutton) will identify migration of CO2 above the Nappamerri seal into the Hutton Sandstone.	V	a	Medium	V	ab	Low
17	Financial / Reputation	Stratigraphic pathway through primary seal	Migration of >10 Bscf of CO2 from storage reservoir to overlying Hutton Sandstone (red LOC).	A permeable pathway exists through the primary Top Toolachee / Nappamerri seal due to erosion of the Poolowanna into the Nappamerri or at the erosional edge of the Nappamerri.	Financial cost to identify problem (would likely involve well several well interventions) and additional monitoring (e.g. seismic). Potential early closure of the storage complex. Significant reputational impact affecting approval of future CCS projects.	P - Site selection - Toolachee reservoir has held a gas column over geological time. P - Primary seal thickness has been mapped across the area of the storage complex and is at least 40 m, providing some margin against Poolowanna erosion. P - Erosional edge of the Nappamerri is mapped to be outside the storage complex. Storage capacity of Toolachee reservoir limited to original gas filled structure. M - Monitoring plan activities Pulsed Neutron Logging and Strzelecki 12 downhole P/T gauge (Hutton) will identify migration of CO2 above the Nappamerri seal into the Hutton Sandstone.	V	a	Medium	V	ac	Very Low
18	Financial / Reputation	Lateral migration	Lateral migration of >10 Bscf of CO2 outside of the Marabooka / Strzelecki / Marana structures (red LOC).	Volume of CO2 injected into the storage reservoir exceeds capacity of closure or reservoir does not fill evenly.	Financial cost to identify problem and additional monitoring. Potential reduced injection rate into storage complex. Moderate reputational impact affecting approval of future CCS projects.	P - Site selection - Toolachee reservoir has a well-established capacity from gas production history. P - Storage capacity of Toolachee reservoir limited to original gas filled structure and volume of CO2 injected will be measured. M - Monitoring plan will identify lateral migration of CO2 into adjacent structures (i.e. Marana and Nanima). P/M - Ongoing modelling and management of well injection rates.	IV	c	Medium	III	b	Low
19	Financial / Reputation	Third party interference	Migration of >1 Bscf of CO2 from storage reservoir to overlying Hutton Sandstone (yellow LOC).	Activity of a third party (e.g. drilling a well) breaches or interferes with storage complex.	Financial cost of additional monitoring. Potential early closure of the storage complex. Significant reputational impact affecting approval of future CCS projects.	P - Santos holds exclusive petroleum licenses over the storage complex. P - Toolachee reservoir will be dedicated for storage without attempting enhanced gas recovery. M - Monitoring plan will identify anomalous pressure behaviour.	III	b	Low	III	a	Very Low

A.3 Santos risk assessment matrix

Consequence		Safety	Negligible Harm + No bodily damage or minimal harm or impairment (hours to days)	Minor Harm + Short term impairment (days to weeks)	Moderate Harm + Temporary disablement or medium-term impairment (weeks to months)	Severe Harm + Long term/life altering disablement or impairment	Single Fatality OR Critical Life Threatening Injuries	Multiple Fatalities
		Environment	+ No impact to Environmental Value (EV).	+ Small-scale impact to EV(s) of conservation significance + Potential surface or groundwater impact.	+ Moderate-scale impact to EV(s) of conservation significance + Localised surface or groundwater impact.	+ Large-scale impact to EV(s) of conservation significance + Moderate-scale surface water impact; + Localised impact to groundwater with potential or known beneficial use.	+ Extensive population or community scale impact to EV(s) of conservation significance + Extensive impact to other EV(s).	+ Irreversible impact to EV(s).
		Community & Reputation	+ No actual or potential community criticism + Details remain within Santos sites and/or offices	+ Minor level local community criticism (< week) + No reputation impact	+ Local community criticism (> week) or one-day community protest + Local company reputation impacted	+ State-level community criticism or protest over multiple days/locations + State-based company reputation impacted + Very short-term share price impact (< week)	+ National community criticism or large scale protest + Company reputation and approvals impacted + Shareholder intervention or short-term share price impact (< month)	+ Sustained national community criticism or widespread protest + Industry reputation and approvals impacted + Changes at executive/board level or long-term share price impact (> month)
		Financial (A\$)	< \$100k	\$100k to \$1m	\$1m to \$10m	\$10m to \$100m	\$100m to \$500m	> \$500m
		Workforce	+ Will require some staff attention over several days. + No actual or potential impact to culture	+ Will require several days local management time. + Minor impact to employee engagement and limited staff turnover	+ Will require head office staff and take several weeks of site management time. + Moderate impact to employee engagement and staff turnover above industry average with some key roles	+ Will require several weeks of senior management time + Impact to employee engagement (< 6 months), moderate turnover of key roles and no succession	+ Will require several months of senior management time + Impact to employee engagement (< 18 months), high staff turnover and attraction issues	+ Will require more than a year of senior management involvement and operations severely disrupted + Impact to employee engagement (> 18 months), significant key role turnover and attraction issues
		Compliance	+ Non-conformance with legislation, instruments (e.g. tenure licence) or contract + No regulatory or punitive action	+ Minor breach of legislation, instruments or contract + Notification/report to; request for information by; and/or administrative/warning notice from the regulator + LOCI Tier 3 or non-hydrocarbon releases notifiable to the regulator	+ Limited number of minor breaches of legislation, instruments or contract + Statutory notice from the regulator + LOCI Tier 2 or non-hydrocarbon releases immediately reportable to the regulator	+ Systemic minor breaches (or one moderate breach) of legislation, instruments or contract + Company charged with an offence with minor penalty/fine + LOCI Tier 1 or cumulative regulator notification of non-hydrocarbon releases	+ Systemic moderate breaches (OR single material breach) of legislation, instruments or contract + Company charged with an offence with moderate penalty/fine	+ Material breaches of legislation, instruments or contract + Company or officers charged with an offence with material penalty/fine, or loss of tenure/operatorship
				I	II	III	IV	V
Likelihood	ALMOST CERTAIN (< 4 monthly) Occurs frequently	f	Low	Medium	High	Very High	Very High	Very High
	LIKELY (4 monthly - 1 yearly) Could occur within the annual plan	e	Low	Medium	High	High	Very High	Very High
	OCCASIONAL (1 - 3 yearly) Could occur within the 3-year plan	d	Low	Low	Medium	High	High	Very High
	POSSIBLE (3 - 10 yearly) Could occur within the 10-year, long term plan	c	Very Low	Low	Low	Medium	High	Very High
	UNLIKELY (10 - 30 yearly) Not expected to occur; known to have occurred elsewhere	b	Very Low	Very Low	Low	Low	Medium	High
	REMOTE (30 - 100 yearly) Requires exceptional circumstances and is unlikely even in the long term	a	Very Low	Very Low	Very Low	Low	Medium	Medium

Appendix B Groundwater monitoring to detect CO₂ migration

B.1 Geochemical assessment – carbon dioxide-induced changes in water quality

Metal concentrations in groundwater are heavily dependent on pH and redox conditions, which affect the solubility of mineral phases in the aquifer and resulting concentrations of inorganic constituents potentially detected in groundwater. Changes in inorganic analyte concentrations in groundwater are not a function of contaminant transport but rather shifts in geochemical properties of water (e.g., pH, redox) inducing dissolution of mineral phases (increasing concentrations) or precipitation of mineral phases (decreasing concentrations). Consequently, changes in analyte concentrations must be accompanied by changes in geochemical properties of water for the observed change to be attributed to the CCS activities. Several parameters including metals that are sensitive to geochemical changes will be monitored during groundwater sampling, which will be adapted as required and as new data is gathered (see section 5.3.1.4 for the proposed analysis).

There are multiple historic water analyses for the Hutton within the Strzelecki and Marabooka fields. They were collected as part of petroleum exploration and production activities. The available analyses are all basic and limited to the major dissolved ions and water properties. The historic data available for the shallow aquifer is limited.

Previous work has also explored the geochemical effects of carbon dioxide injection into relevant Australian oil reservoir lithologies using a combination of analytical, experimental, and geochemical modelling techniques (Farquhar et al., 2013; Pearce and Dawson, 2018; Pearce et al., 2019a, b, c). Analytical data indicate the Hutton Sandstone aquifer has geochemically reactive intervals containing smectite, chlorite, and carbonate minerals in addition to feldspar and lithics that could have the capacity to buffer carbon dioxide should it leak (Farquhar et al., 2013), providing a geochemical barrier for carbon dioxide leakage into the shallow groundwater aquifer.

B.2 Baseline statistical assessment

Baseline data will be analysed to develop values that can be used to detect changes from baseline conditions in monitoring data. Statistical methods are based on the *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities: Unified Guidance* (USEPA, 2009).

A limited number of key indicators of carbonic acid dissolution of host rock cement (based on prior experimental work) will be used to limit the false positive rate associated with conducting large numbers of statistical tests while maintaining the ability to detect changes associated with potential CCS releases, as recommended by USEPA (2009). Key indicators will likely include calcium, magnesium, manganese, strontium, and pH but will be determined after examining initial baseline data. Chloride will be used to normalise the concentration of each key indicator (other than pH) because it is generally conservative (concentrations are unaffected by carbon dioxide induced pH changes). This will allow for reliable comparison of indicators across wells and sampling events, improving comparability across samples and compliance with statistical assumptions.

The large number of statistical tests that will be conducted (five constituents for each well) will result in an increased likelihood that values will be falsely identified as significantly different from baseline. Therefore, when any value is flagged as significantly different than baseline, additional analyses will be conducted to determine whether differences are potentially related to CCS release or statistical false positives. These analyses will include assessment of the changes in each analysed constituent taken together and could include additional constituents as well as the key indicators. Depending on the statistical power associated with baseline results, verification sampling may also be recommended.

As baseline data are collected, the variability and comparability of constituent concentrations across wells and sampling events will be analysed. Exact analytical methods will be refined during and following collection of the planned baseline dataset. If baseline results from several wells are statistically similar, these results will be pooled to improve statistical power. The exact statistical methods will be selected based on these considerations after collection of baseline data based on the steps shown in Figure 22. Methods will include the calculation of statistical limits that monitoring data can be compared to in order to determine whether they are within the range of baseline variability.

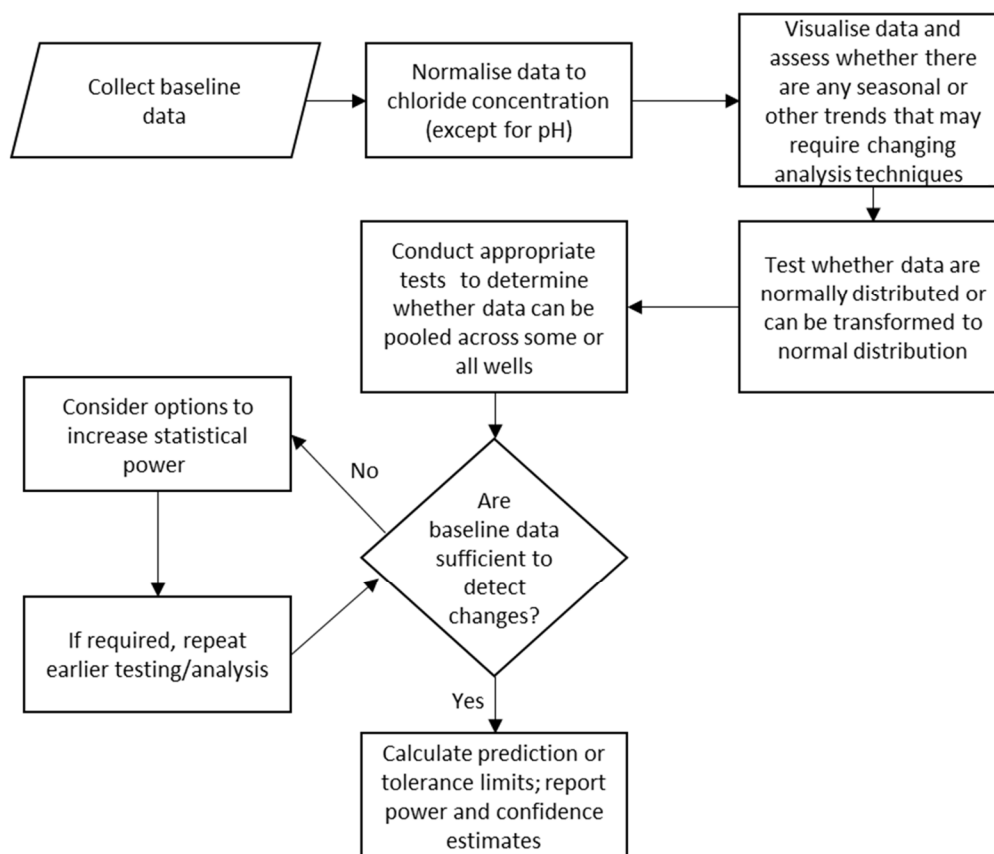


Figure 22: Baseline data analysis flowchart

B.3 Detection monitoring

If required, for example in response to other monitoring data that indicates a loss of containment may have occurred, groundwater samples may be taken to detect whether CO₂ migration can be inferred from groundwater quality data.

For each key indicator, the following process will be used to compare each round of monitoring results following a potential loss of containment event to baseline data:

- Normalise each constituent to chloride concentration (except for pH).
- Compare each constituent to the limit developed based on baseline data.

If results are not statistically significantly different from baseline data, consider whether results can be added to the baseline dataset to improve future statistical power.

If results are flagged as significantly different from baseline data, determine whether this is consistent with CCS leakage or whether this is a false positive based on additional geochemical analysis and supplemental statistical testing.

Before attributing statistical outliers to CCS leakage, alternate causes will be explored, including sampling errors, laboratory errors, natural variation, and alternate anthropogenic sources. Assessment of whether any detected changes in water quality are related to these sources will be conducted using a variety of suitable geochemical and statistical methods, including methods that rely on analysis of multiple geochemical parameters that are likely to change together in the event of any possible CCS leakage. In the event of a potential false outlier that needs to be evaluated, regulators will be consulted in determining appropriate methods based on available data.