

Environmental Assessment Report

Fracture Stimulation Operations in the Cooper Basin, South Australia, May 2014

Supplement to the Drilling and Well Operations EIR 2003

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1. Introduction

This Environmental Assessment Report (EAR) has been prepared in accordance with the *Petroleum and Geothermal Energy Act 2000* (the Act), *Petroleum and Geothermal Regulations 2013* (the Regulations) and the *Santos Statement of Environmental Objectives for Drilling and Well Operations* (SEO DWO). The intent of this document is to facilitate the regulated activity of fracture stimulation for Santos operations in the Cooper Basin.

1.1. Background

The Cooper and Eromanga Basins are located in the far northeast corner of South Australia and southwest Queensland, central Australia. Santos has been operating in the area since the 1960s, producing oil and gas from over 2700 wells. The Cooper Basin currently supplies approximately 35% of South Australia's natural gas needs, 40% of the NSW gas market and about 10% of Queensland's demand. As production from our conventional oil and gas reserves declines, the development of previously uneconomic gas reservoirs is necessary to extend the supply life of natural gas from the region. Fracture stimulation is fundamental to the development of these reservoirs. Fracturing stimulation (commonly known as 'fracing' or 'fracking') is not new to the Cooper Basin. It was first employed in the late 1960s, and has consistently been used since the early 1980s to enhance oil and gas recovery. Over 900 wells have been fracture stimulated in that time with no adverse impacts or harm to the environment.

Sustainability is an integral part of Santos' operating ethos. We are committed to responsibly managing our environmental impact, working in partnership with the communities in which we operate and reliably managing our business.

1.2. Santos Cooper Basin Operations

A proudly Australian company, Santos is a leader of the Australian natural gas industry, with more than 50 years of responsible gas exploration and production across the nation, since its establishment in Adelaide in 1954.

Oil and gas was first discovered in the South Australian Cooper Basin in the 1960s. The Cooper Basin has developed into one of Australia's major oil and gas producing provinces and the South Australian Cooper Basin currently meets over one third of the demand for domestic gas in eastern Australia, as well as producing significant quantities of crude oil and petroleum liquids for both Australian and overseas markets.

Santos currently has an interest in over 150 Petroleum Production Licences (PPLs) in the South Australia surrounding the Moomba processing facility.

1.3. Intent of Document

Santos' fracture stimulation operations are carried out in accordance with the Santos SEO DWO.

The SEO DWO is in place in accordance with requirements of Sections 99 and 100 of the Act and outlines the environmental objectives that are required to be achieved during drilling and well operations, including fracture stimulation. An accompanying Environmental Impact Report (EIR) prepared in accordance with the Regulations is also in place; the *Environmental Impact Report for Drilling and Well Operations in the Cooper Basin*, gazetted in April 2003, with an addendum in 2009 (together the EIR (2003, 2009)).

The EIR (2003, 2009) presents a description of Santos' fracture stimulation operations and details the potential environmental hazards and consequences associated with down-hole operations, along with the risk management strategies employed to prevent them.

This EAR and accompanying risk assessment (Appendix A) have been undertaken by Santos as an addition to the EIR (2003, 2009). The purpose of this document is to address fracture stimulation activities within the SEO DWO framework in further detail, ensuring these risks are managed in accordance with Objectives 1-12 of the SEO DWO.

This EAR sets out how Santos' conventional and unconventional gas fracture stimulation activities are conducted such that potential risks to the environment are minimised. It demonstrates that:

- there are no risks associated with Santos' fracture stimulation activities that are rated above risk level 2 (refer to Figure 28) and that cannot be managed to As Low As Reasonably Practical (ALARP);
- Santos' operational practices are consistent with leading industry practices;
- the level of management controls Santos employs to control the potential risks to the Cooper Basin environment associated with fracture stimulation have been and continue to be appropriate; and
- The risks associated with fracture stimulation activities are adequately managed by continued operation in accordance with the SEO DWO.

1.4. What is fracture stimulation?

Fracture stimulation has been a process used in the oil and gas industry since 1947 and the Society of Petroleum Engineers (SPE) estimates that over 2.5 million hydraulic fracture stimulation treatments have been undertaken in oil and gas wells worldwide, with over 1 million in the United States. Fracture stimulation has been successfully used on wells in the Cooper Basin for nearly 50 years without incident and is currently performed in many Basins around Australia.

Fracture stimulation is employed where gas or oil is tightly held in low permeability reservoir sands, coals and shales to enhance the permeability of the formation and to enable the hydrocarbons to flow at economic rates.

Fracture stimulation is not an explosive or high impact process. It is not part of the drilling process but is a completion technique applied after the well is drilled and the drill rig has moved to another well. Prior to the rig moving off, the well has been sealed with steel casing and cement. During the completion process, the casing is perforated and the well is stimulated via hydraulic fracturing. It is a process that results in the creation of small fractures in the rock to allow the oil and gas in the source rock to move more freely into the wellbore and enable economic hydrocarbon production. The process involves pumping water, a specific blend of chemicals and proppants such as sand or ceramic beads down a well at sufficient pressure to create fractures in the low-permeability rock. The proppant material keeps the fractures open once the pump pressure is released and improves the production of the well.

Water accounts for about 90% of the fracturing mixture and sand accounts for about 9.5%. Chemicals account for the remaining 0.5% of the mixture and assist in carrying and dispersing the sand in the low-permeability rock. The chemicals are used for different functions and are not specific to hydraulic fracturing and have many common uses such as in swimming pools, toothpaste, baked goods, ice cream, food additives, detergents, cosmetics and soap.

Environmental Assessment Report - Fracture Stimulation Operations

The design and quality of the well construction is of paramount importance in managing, and avoiding, any environmental risks associated with fracture stimulation. Santos applies best practice in its drilling techniques and related activities.

Design and construction of wells is a critical process that needs to be both well regulated and well managed to ensure that groundwater and aquifer formations are protected and so the hydrocarbons can be produced safely throughout the life of the well.

This Environmental Assessment Report was developed to assess the potential risks to the environment as a result of Santos' conventional and unconventional gas fracture stimulation operations only. Fracture stimulation associated with Santos' Cooper Basin oil operations in Eromanga Basin targets is outside of the scope of this report. An updated Environmental Assessment Report addressing oil fracture stimulation activities will be provided to DMITRE prior to any field operations being undertaken.

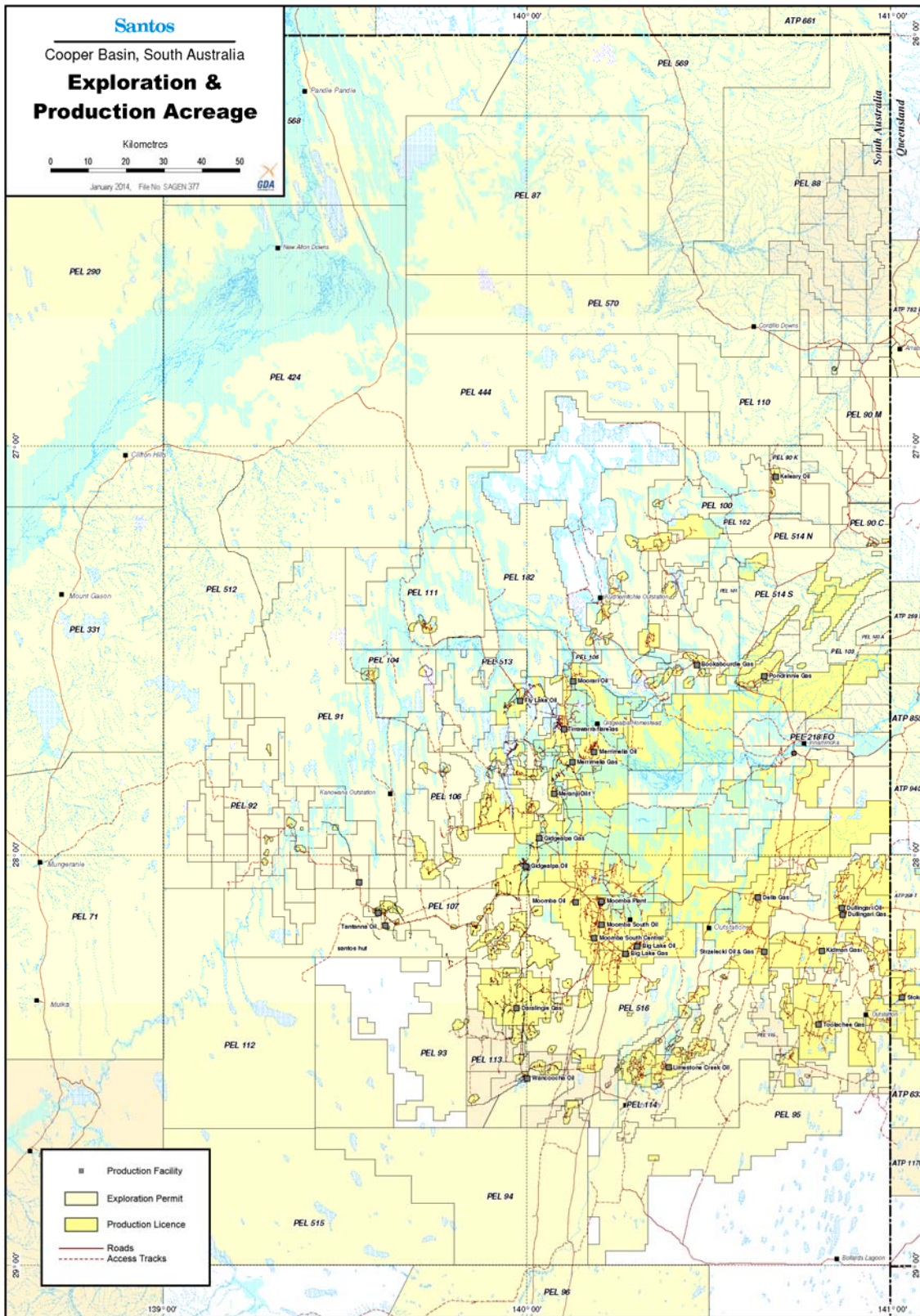


Figure 1: Exploration Permits in the Cooper and Eromanga Basins

2. Legislative Framework

This chapter outlines the legislative framework that currently applies to petroleum activities in South Australia.

2.1. Petroleum and Geothermal Energy Act 2000 and Petroleum and Geothermal Energy Regulations 2013

The Act and the Regulations form the legislation governing onshore petroleum exploration and production in South Australia. Key objectives of the legislation are to:

- Protect the natural, cultural, heritage and social aspects of the environment from risks associated with petroleum and geothermal activities governed by the Act;
- Provide for constructive consultation with stakeholders, including effective reporting of industry performance to other stakeholders; and
- Provide security of title for petroleum, geothermal energy, and other resources governed by the Act and pipeline licences.

The Act and Regulations are objective-based rather than prescriptive (McDonough 2006). An objective-based regulatory approach principally seeks to ensure that industry effectively manages its activities by complying with performance standards that are cooperatively developed by the licensee, the regulatory authority, and the community. This contrasts with prescriptive regulation where detailed management strategies for particular risks are stipulated in legislation.

Regulated resources, as defined in Part 1 of the Act, are:

- A naturally occurring underground accumulation of a regulated substance;
- A source of geothermal energy; or
- A natural reservoir.

A reference in the Act to petroleum, or another regulated substance, extends to a mixture of substances of which petroleum (or other relevant substance) is a constituent part. Regulated substances as defined in Part 1 of the Act are:

- Petroleum;
- Hydrogen sulphide;
- Nitrogen;
- Helium;
- Carbon dioxide; or
- Any substance declared by regulation to be a substance to which the Act applies.

Regulated activities, as defined in Section 10 of the Act, are:

- Exploration for petroleum or another regulated resource;
- Operations to establish the nature and extent of a discovery of petroleum or another regulated resource, and to establish the commercial feasibility of production and the appropriate production techniques;
- Production of petroleum or another regulated substance;
- Utilisation of a natural reservoir to store petroleum or another regulated substance;
- Production of geothermal energy;
- Construction of a transmission pipeline for carrying petroleum or another regulated substance; or

- Operation of a transmission pipeline for carrying petroleum or another regulated substance.

2.2. Statement of Environmental Objectives

A regulated activity can only be conducted if an approved SEO has been developed in accordance with Part 12 of the Act.

The SEO outlines the environmental objectives that the regulated activity is required to achieve and the criteria upon which the objectives are to be assessed.

The SEO is developed on the basis of information provided in an EIR. The EIR is provided by the licensee and contains an assessment of the potential impacts of an activity on the environment.

2.3. Environmental Impact Report

Once the EIR and SEO are submitted, an assessment is made by the Department of Manufacturing Innovation, Trade, Resources and Energy (DMITRE) to determine whether the activities described in the EIR are to be classified as low, medium or high impact. This in turn determines the level of consultation required prior to final approval of the SEO.

Once the approval process is complete, documentation must be entered on an Environmental Register. This public register is available on the DMITRE website and includes copies of the SEO DWO and EIR (2003, 2009) to which this EAR relates.

The activities described here do not represent new activities or a departure from those previously assessed within the EIR (2003, 2009) and approved by the Minister, and therefore the risks are also not new or of any greater consequence than those considered to be managed by the implementation of the SEO DWO or the EIR (2003, 2009).

2.4. Activity Notification

Prior to commencing a regulated activity, Section 74(3) of the Act requires that Santos provide notice of activities requiring low level surveillance at least 21 days in advance of commencement of the activities in accordance with the regulations.

3. Well Design and Best Practice

Prior to considering the practice of hydraulic fracturing to enhance conventional and unconventional gas well production as outlined in Section 4, this report addresses:

- *Comparison to International Best Practice* – the procedures employed by Santos and its contractors follow a design philosophy predicated on the guidance, specifications and recommended practices of the American Petroleum Institute (API), considered to represent International Best Practice; and
- *Well mechanical integrity and surveillance* – the procedures employed by Santos and its contractors for mechanical integrity and surveillance follow a design philosophy with International Best Practice. Practices for ensuring well mechanical integrity consist of a series of tests and a robust surveillance plan, which includes:
 - Well integrity tests including casing pressure surveys, down-hole isolation tests (where applicable), casing top-ups with inhibited fluid and casing pressure tests;
 - Operator surveillance involving quarterly casing pressure surveys and visual inspections;
 - Wellhead maintenance requiring valve function testing and maintenance; and
 - Cement integrity involving acoustic logging and casing pressure tests.

These matters are discussed in the following sub-sections.

3.1. Comparison to International Best Practice

The oil and gas industry use experienced hydraulic fracturing contractors. These contractors, along with operating companies, have developed and defined Industry Best Practice in the field of hydraulic fracturing. These practices have been adapted for applicable operations in Australia.

Industry Best Practice for fracture stimulation has been developed over 60 years of experience and technological innovation. These experiences and practices are communicated and shared via academic training, professional and trade associations, extensive literature and documents and, importantly, industry standards and recommended practices.

The Industry Best Practice Guidelines, arising from this body of knowledge, experience and leading edge research, are distilled in a series of guiding documents published by the API. Although the use of API Technical Reports (TRs) and Recommended Practices (RPs) are not legal requirements, Santos chooses to operate in accordance with API documents representing International Best Practice.

Santos uses rigorous pre-qualification criteria, including technical and operational competence requirements, in the selection of contractors for all field operations, including fracture stimulation and well construction operations.

The key guidance documents relevant to operations in the gas fields of the Cooper Basin include:

- *API Guidance Document HF1, Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines;*
- *API Guidance Document HF2, Water Management Associated with Hydraulic Fracturing;*
- *API Guidance Document HF3, Practices for Mitigating Surface Impacts Associated with Hydraulic Fracturing;*
- *API Specification 5CT/ISO 11960, Specification for Casing and Tubing;*
- *API Specification 6A/ISO 10423, Specification for Wellhead and Christmas Tree Equipment;*
- *API Specification 10A/ISO 10426-1, Specification for Cements and Materials for Well Cementing;*

- *API Recommended Practice 10B-2/ISO 10426-2, Recommended Practice for Testing Well Cements;*
- *API Recommended Practice 10B-3/ISO 10426-3, Recommended Practice on Testing of Deepwater Well Cement Formulations;*
- *API Recommended Practice 10B-4/ISO 10426-4, Recommended Practice on Preparation and Testing of Foamed Cement Slurries at Atmospheric Pressure;*
- *API Recommended Practice 10B-5/ISO 10426-5, Recommended Practice on Determination of Shrinkage and Expansion of Well Cement Formulations at Atmospheric Pressure;*
- *API Recommended Practice 10B-6/ISO 10426-6, Recommended Practice on Determining the Static Gel Strength of Cement Formulations;*
- *API Specification 10D/ISO 10427-1, Specification for Bow-Spring Casing Centralizers;*
- *API Specification 10D-2/ISO 10427-2, Recommended Practice for Centralizer Placement and Stop Collar Testing;*
- *API Recommended Practice 10F/ISO 10427-3, Recommended Practice for Performance Testing of Cementing Float Equipment;*
- *API Technical Report 10TR1, Cement Sheath Evaluation;*
- *API Technical Report 10TR2, Shrinkage and Expansion in Oil Well Cements;*
- *API Technical Report 10TR3, Temperatures for API Cement Operating Thickening Time Tests;*
- *API Technical Report 10TR4, Technical Report on Considerations Regarding Selection of Centralizers for Primary Cementing Operations;*
- *API Technical Report 10TR5, Technical Report on Methods for Testing of Solid and Rigid Centralizers;*
- *API Specification 13A /ISO 13500, Specification for Drilling Fluid Materials;*
- *API Recommended Practice 13B-1/ISO 10414-1, Recommended Practice for Field Testing Water-Based Drilling Fluids;*
- *API Recommended Practice 13B-2/ISO 10414-2, Recommended Practice for Field Testing Oil-based Drilling Fluids;*
- *API Recommended Practice 45, Recommended Practice for Analysis of Oilfield Waters;*
- *API Standard 53, Blowout Prevention Equipment Systems for Drilling Wells;*
- *API Recommended Practice 65, Cementing Shallow Water Flow Zones in Deep Water Wells*
- *API Standard 65-2 - Isolating Potential Flow Zones During Well Construction.*

3.2. Well Mechanical Integrity and Integrity Testing

The major controls in providing a high degree of protection to aquifers above and within the Cooper and Eromanga Basin are robust well design, best practice well construction standards, and scheduled integrity tests and checks throughout the lifecycle of the well i.e. from construction to production to decommissioning. Quality control procedures are implemented through material selection, sourcing process, installation and maintenance and inspections to ensure the casing and seals are adequate barriers for hydraulic isolation.

Production wells are designed to ensure full containment of hydrocarbons within its internal casing and/or completion conduit extending from the subsurface to the surface and as such, affords:

- Protection of groundwater resources and aquifer systems;
- Protection to the environment; and
- A safe working and operable environment.

Full containment is achieved by cementing in place multiple strings (typically 2-3 strings) of steel casing and installing mechanical plugs or packers after a well is drilled to depth. Best practice well design prevents

communication of aquifer systems and the cross-flow of fluids (gas, oil and water) between sedimentary layers. It is important that casing design parameters are factored in to ensure that the well's integrity is maintained during the high treatment pressures imparted during fracture stimulation. Examples of specified casing parameters include pipe weight, metallurgy, burst and yield pressures.

In addition to the subsurface well construction, the surface well head integrity is of equal importance to ensure hydrocarbon containment. A properly designed wellhead ensures that the control measures (or barriers) are in place for well production, but more critically, that the well can be secured and isolated in events such as an uncontrolled release of hydrocarbons to atmosphere. Santos has embedded Standards and Procedures (refer to Section 8) to ensure that integrity controls and measures have been performed prior to fracture stimulation. Typically, this would involve running a cement bond log to check the quality of the cement and/or pressure testing of the internal and annular spaces of the well.

The hydrocarbon reservoirs are accessed through perforations in the steel casing and cement sheaths opposite the respective reservoir zones, with the produced hydrocarbons contained within the well casing all the way to the surface. This containment and barrier philosophy along with continued zonal isolation is known as "well integrity." Should an issue with casing or cement be identified, fracture stimulation is postponed until the well is remediated. If remediation of the well is physically or economically unfeasible, the well is completed without fracture stimulation, or plugged and decommissioned to industry best practices and regulatory requirements.

Routine integrity checks are scheduled while the well is on production in accordance with the well design, well plan, and permit requirements, until such time that the well is decommissioned.

3.2.1. Drilling and Well Completion

Drilling a typical petroleum well consists of several cycles of drilling, running casing (steel casing for well construction), and cementing the casing in place to ensure isolation. In each cycle, steel casing is installed in sequentially smaller sizes inside the previous installed casing string. The last cycle of the well construction is well completion, which can include perforating (creating holes in the steel casing) and fracture stimulation or other stimulation techniques (depending on the well type and formation characteristics).

The main stages of drilling and completing a well comprise:

- Lease preparation;
- Rigging up of major drilling equipment (e.g. tanks, pumps, rig, draw works, hydraulic and power packs);
- Drilling the surface hole;
- Cementing in place the surface casing;
- Installation of the Bradenhead and Blow Out Preventer (BOP);
- Running in to continue drilling in the production hole to depth;
- Petrophysical logging of the open borehole section;
- Cementing in place the production casing;
- Securing the well and rig release;
- Cased hole logging (for well integrity);
- Installation of wellhead or Frac Tree;
- Perforation of the first zone in preparation for hydraulic fracturing;
- Fracture stimulation and initial flowback of well;
- Installation of artificial lift (if necessary);

- Installation of the final completion design;
- Installation of production well head, flowlines and telemetry;
- Well on production;
- Monitoring of well's production and integrity checks; and
- Rehabilitation of surrounding well's lease.

3.2.2. Selection and Sourcing of Casing Materials

To ensure long term casing integrity, Santos has developed detailed specifications for well casings and well completion materials. The casing materials are specifically rated to handle fracture stimulation treatments at Cooper Basin depths and pressures. Parameters such as yield and burst pressures are specified and triaxial load modelling are performed to ensure that the well's integrity is maintained during the high treatment pressures applied during fracture stimulation and for the lifecycle of the well.

All materials are inspected by Santos and the contractors prior to installation to ensure compliance with the Santos specifications. A similar process of inspections and testing are utilised throughout the drilling and casing installation program. This testing and inspection is discussed in the following sections.

3.2.3. Logging the Borehole

All of Santos gas wells are routinely logged with tools to obtain specific information on the hydrocarbon bearing reservoirs. The results of these logs are used as important indicators that aid in fracture target selection.

Open-hole Logging

Once the production hole / reservoir section is drilled to final depth, open-hole logging tools are run on wireline to obtain petrophysical information. A typical suite of electric logging tools would include the following:

- *Gamma Ray*: detects natural radiation from rock. The main isotopes of thorium, potassium, and uranium can indicate the presence of clay mineralogy.
- *Laterolog*: measures the resistivity of the fluids contained in the rock. This is used as an indication of water bearing zones. Higher resistivity values can be an indication of hydrocarbon bearing zones.
- *Spontaneous Potential (SP log)*: measures the salinity contrast between mud filtrate and formation water. This data can be used to assess permeability and potentially some information on lithology.
- *Density Tool*: measures the bulk density of the rock and indicates the presence of porosity.
- *Neutron Tool*: a source / receiver tool which measures rock porosity.
- *Caliper Tool*: measures hole diameter and can provide an indication of borehole geometry. Useful in terms of planning for casing running and cementing design.
- *Sonic Tool*: a source / receiver tool measuring the transit time of acoustic waves passing through the rock. This data can be used as an indicator of porosity but is primarily used for geomechanical calculations, including minimum horizontal stress. This is a key value required in fracture stimulation design.

Logging produces detailed information on the rock formations drilled and the water and hydrocarbons they might contain. This assists with the design and installation of casing strings to the correct depth in order to achieve the well design objectives and to properly achieve the isolation benefits of the casing and cement sheath.

Many other types of logging tools are available and may be run on a case specific basis such as cased hole evaluation logs in place of open-hole logs.

Cement Integrity (Cased-hole Logging)

After cementing the casing in place (refer to Section 3.2.4), “cased-hole” logs can be run inside the casing to validate the quality and integrity of the cement sheath bond to the casing. Typically, these logs include:

- Gamma ray (described previously).
- Casing Collar Locator (CCL; a magnetic device that detects the casing collars).
- Cement Bond Log (CBL), Radial Analysis Bond Log (RAL), Segmented Bond Tool (SBT) and Variable Density Log (VDL) that measures the acoustic properties of the cement sheath and the quality of the cement bond or seal between the casing and the formation.

The CBL-VDL or SBT is an acoustic device that can detect cemented or non-cemented casing. These acoustic devices work by transmitting a sound or vibration signal, and then recording the amplitude of the arrival signal. Casing that has no or poor quality cement surrounding it (i.e. free pipe) will have large amplitude acoustic signal because the energy remains in the pipe. Casing pipe that has a good cement sheath (fills the annular space between the casing and the formation) will have a much smaller amplitude signal since the casing is “acoustically coupled” with the cement and the formation causing the acoustic energy to be absorbed.

Santos uses experienced contractors to identify the key features of the cement operation to ensure the integrity of the cement seal for each casing pipe sheath. The cased-hole logs are also useful when the well is perforated to position the perforating guns with respect to the formations (by comparing with the gamma-ray response of the Open-hole Log and the CBL).

Santos most commonly uses the CBL-VDL or SBT cement evaluation logs to evaluate cement integrity, however other types of cement evaluation tools are available and, depending on the situation, are considered as a part of the cement evaluation program.

A key result of the cased-hole logging program is to know the exact location of the casing, casing collars, and height and quality of the cement relative to each other and relative to the subsurface formation locations. This ensures that the well drilling and construction is adequate and achieves the desired design integrity and longevity objectives. It is also used to provide information in subsequent surveys of well integrity and seals over the production life of the well. If cement is not of sufficient height or quality, fracture stimulation operations do not proceed until this is remediated. If it cannot be satisfactorily remediated, fracture stimulation operations will not proceed.

3.2.4.Casing Design

A casing completion design is prepared by the engineering team based on:

- Rock cuttings and/or borehole core retrieved from the drilling of the well hole;
- Information gained from geophysical logging of the borehole;
- The regional geological model; reservoir analysis; and
- The history of nearby wells.

Historical problems encountered in the area (lost returns, irregular hole erosion, poor hole cleaning, poor cement displacement, etc.) are considered during the design process.

These scenarios are modelled through industry-accepted software across company standard design loads for collapse, burst and tensile failures. The results of this analysis (which incorporate pressures exerted during the fracture stimulation process) direct the selection of casing grade and weight. An example of this analysis is provided as Figure 2.

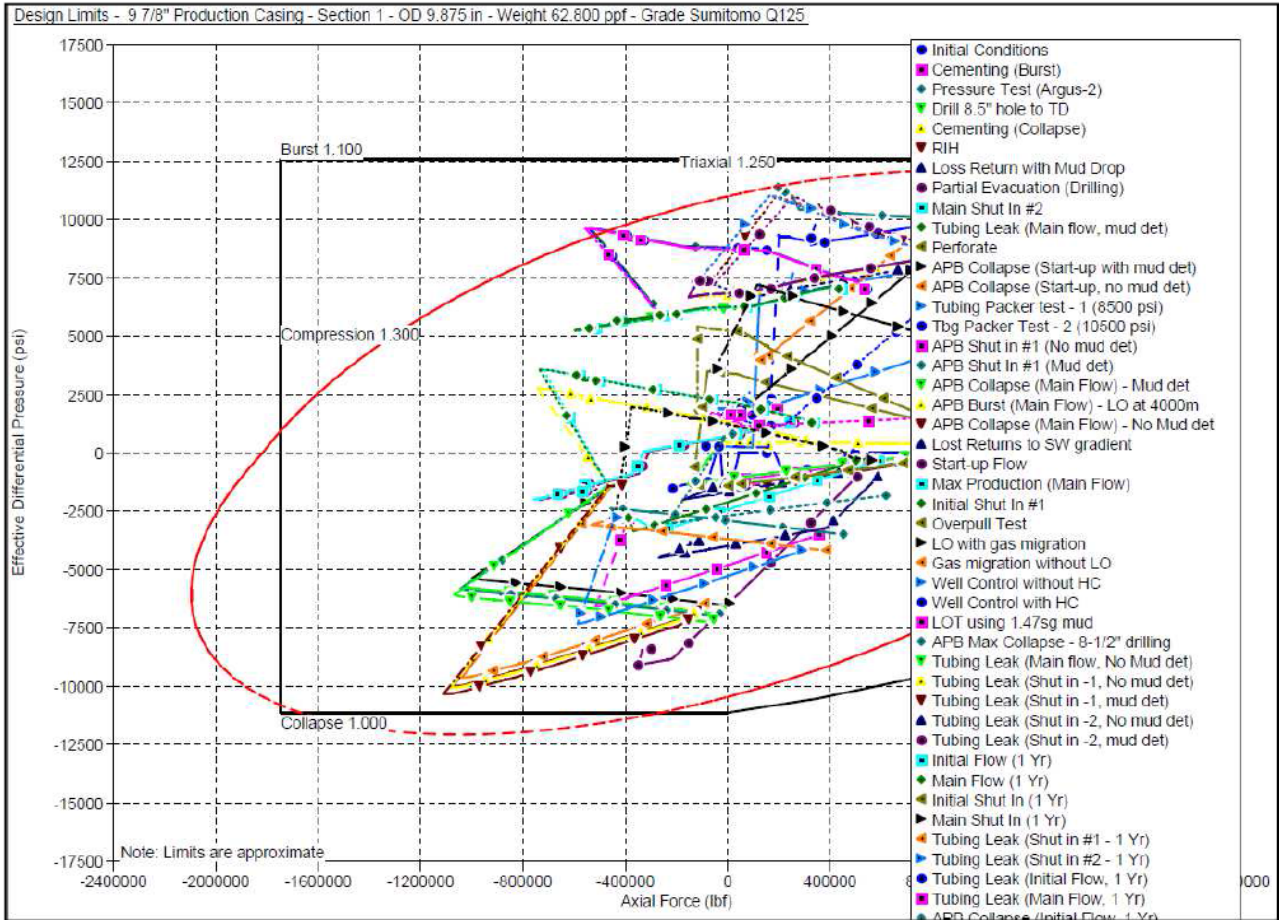


Figure 2: Casing Design Analysis

The basis of the site-specific design for the casing construction emphasises barrier performance and zonal isolation (including aquifer, low quality groundwater and poor ground isolation), as well as gas and oil production efficiency. It includes wellbore preparation, mud removal, casing pipe running (Section 3.2.5), and cement placement (Section 3.2.6) to provide barriers that prevent fluid and gas migration and well leakage. The well design process also includes contingency planning to mitigate the risk of failure due to unforeseen events.

The casing design process also accommodates analysis of those factors which determine the fracture stimulation outcomes. These include defining the optimal location and orientation of perforations such that the zone of fracture stimulation is contained entirely within the target hydrocarbon-bearing formations. The latter involves the assessment of borehole core, porosity analysis, fracture orientation and density testing, joint orientation, bedding plane analysis and stress field analysis.

3.2.5. Casing Completion

The conductor pipe is installed in the first borehole drilled. This is followed by drilling a series of sequentially deeper boreholes for installation of the various casing pipes as follows: surface casing, intermediate casing

(if necessary), and the production casing. Specific considerations for each of these casing strings are presented below. It is important to note that the shallow portions of the well have multiple concentric strings of steel casing installed.

- The *conductor casing* stabilises the surficial sediments from the drilling of subsequent drilling phases (i.e. it prevents the loose soils from caving into the borehole), and is cemented into place to ensure an appropriately robust seal (up to ground level). The conductor casing also serves to isolate the surface water table and perched aquifers, if present.
- The *surface casing* is installed to protect shallow formations (weathered or unconsolidated rock layers) and to stabilise the well from the later drilling phases of deeper sections of the borehole. This portion of the well completion can extend from 500 m to 900 m depth. This casing pipe is also cemented into place to ensure an appropriately robust seal, with cementing taking place from bottom to top to ensure an effective seal. The surface casing is designed to achieve regulatory requirements for isolating groundwater and also to contain pressures that might occur during the subsequent drilling process.
- The *intermediate casing* pipe may be installed to isolate deeper aquifer systems (if present), for example, the Wallumbilla Formation may be cased off to reduce the risk of impact to this layer. As with the shallower casing strings, this casing pipe is also cemented into place to ensure an appropriately robust seal, again with cementing taking place from bottom to top to ensure an effective seal. A formation pressure integrity test is performed immediately after drilling out of the intermediate casing.
- After the production hole is drilled and logged, the production casing pipe is lowered to the total depth of the borehole and cemented in place (total depth is typically 10 m to 20 m below the base of the lowermost hydrocarbon-bearing unit, but not penetrating the underlying aquifer systems, if present). The purpose of the production casing is to provide the final isolation between the hydrocarbon reservoirs and all other overlying formations, and for containing and pumping the various fluids used to hydraulically fracture the target zones from the surface into the producing formation without affecting the shallower layers penetrated by the well. During the operational phase of the well, its most important function is internally containing the produced hydrocarbons.
- The production casing pipe is pressure cemented, from bottom to top, to achieve robust and effective isolation of the well from the various subsurface layers (aquifers and aquitards alike).
- Prior to perforating and fracture operations, the production well casing is pressure tested. This test is conducted at a pressure that is greater than what is expected during fracturing and operations, to ensure that the casing integrity is adequate. A CBL, VDL and/or other diagnostic tools are run to establish that the cement integrity is satisfactory for the completion and operational conditions designed for the life of the well. Remedial cementing operations are implemented if there is evidence of inadequate cement integrity prior to fracture stimulation operations proceeding.

Santos is increasingly moving to *deviated* and *horizontal* production wells to reduce the oil and gas fields' footprint (pad drilling multiple deviated and/or horizontal wells from a single surface location, thereby, reducing the cumulative surface impact of the production operation). Selection and use of these techniques are currently underway.

Casing pressure tests are carried out at each stage to ensure integrity of the casing pipe for further drilling or operational conditions. These tests are conducted at pressures that will determine whether the casing integrity is adequate to meet the well design and construction objectives.

3.2.6.Cementing

Cement types, additives and mixes are high quality materials produced specifically for oil and gas operations. Materials are selected and designed to address site-specific conditions relevant to a particular well. Cement mixtures and installation techniques are employed to provide a robust seal that isolates the well from the surrounding formations, and protects the well materials from potentially corrosive groundwater or formation conditions. The cements are not typical building / construction cements, but are tailored cements designed for use in well construction and the subsurface conditions encountered.

Cement is placed using appropriate centralising equipment to completely surround the casing pipe and create a hydraulic seal against the rock face of the borehole, thereby achieving pipe integrity. Effective isolation of the well pipe from the various subsurface formations requires complete and even annular filling and tight cement interfaces between the formation and casing.

Following casing design, materials selection and cement procedures are implemented at Santos well casing completion sites, and includes:

- Computer simulation and completion planning to optimise cement placement procedures.
- Santos drilling contractors are selected based on their reputation, and their adherence to industry Best Practice methods and regulatory requirements. Importantly, as it relates to cementing, contractors are also required to use established, effective drilling practices to achieve a uniform, stable well borehole with the desired hole geometry. They must ensure that their cementing equipment provides adequate mixing, blending, and pumping of the cement in the field. Further to this, they are required to satisfy Santos Health Safety and Environment (HSE) requirements with regard to their personnel and equipment.
- Santos drilling contractors must ensure that the drilling fluid selection is appropriate for the designed well and the geologic conditions likely to be encountered..
- Site drilling and cementing equipment are selected to adequately achieve the well design that will meet the well design objective and ensure effective isolation.
- Santos drilling contractors are required to employ casing pipe centralisers to centre the casing pipe within the borehole and provide for good mud removal and cement placement, especially in critical areas, such as hydrocarbon-bearing zones, and aquifers.
- Santos cementing contractors must use appropriate cement testing procedures to ensure cement slurry quality and designs are adequate. These include implementation of appropriate cement slurry quality controls, with testing to measure the following parameters depending on site-specific geological and groundwater quality conditions:
 - Slurry density;
 - Thickening time;
 - Fluid loss control;
 - Free fluid;
 - Compressive strength development;
 - Fluid compatibility (cement, mix fluid, mud);
 - Sedimentation control;
 - Expansion or shrinkage characteristics of the set cement;
 - Static gel strength development;
 - Mechanical properties (e.g. Young's Modulus, Poisson's Ratio, elastic / compressibility characteristics); and

- Cement design may include placement in two stages, using a “lead” cement of lower density and a “tail” cement of higher density and compressive strength.

Appropriate setting times are adhered to ensure that the cement seals are optimal prior to further drilling, hydraulic fracturing and/or operational testing. The cement is tested using specific Quality Assessment and Quality Control (QA / QC) procedures such as circulation testing and logging as described in Section 3.2.3.

3.2.7. Well Completion Design

The final well completion (Figure 3) is not typically run until after fracture stimulation, although there are situations where it is run before the well is stimulated. Completions design is the process of running in a separate piece of corrosion-resistant pipe or conduit in the already cased well. The pipe is secured with mechanical packers above the producing zones and is usually performed with a separate Completions / Workover Rig. The purpose of the final completion string is to allow the hydrocarbons to produce from it. A three casing string design is illustrated in Figure 4.

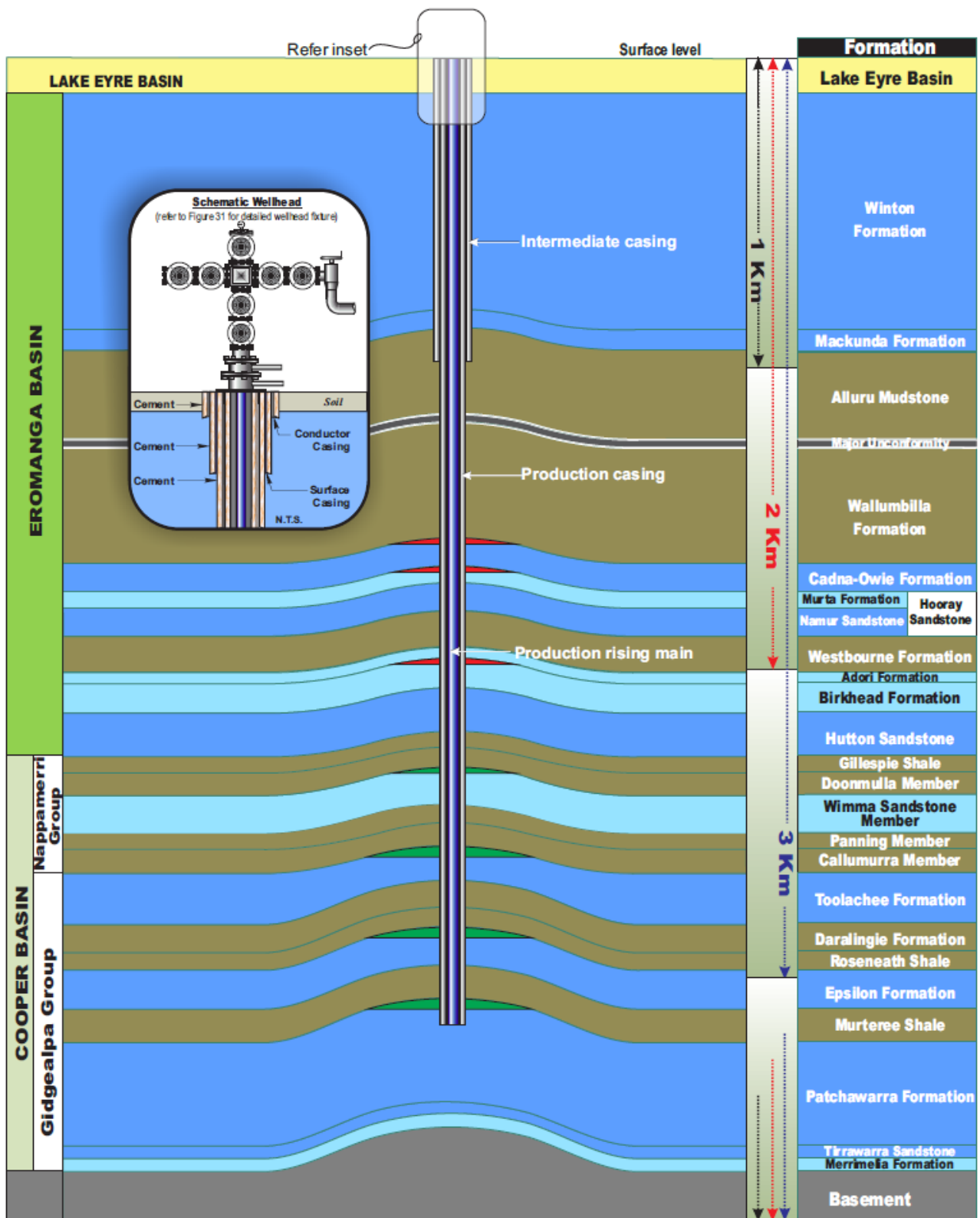


Figure 3: Conceptual Conventional or Unconventional or Gas Well Construction Detail

4. Description of the Fracture Stimulation Process

4.1. Introduction

This section describes the process of hydraulically fracturing conventional and unconventional oil or gas well, including:

- Description of hydrocarbon reservoir formations in the study area;
- Purpose of the fracture stimulation process;
- Fracture stimulation treatment design considerations;
- Fracture stimulation process description;
- Infrastructure and equipment used;
- Stages of fracture stimulation
- Fracture stimulation water use; and
- Other components of fracture stimulation operations.

4.2. Description of Hydrocarbon Reservoir Formations in the Study Area

4.2.1. Sources of natural gas

Natural gas is found in sedimentary basins, in a number of geological settings and within various rock types. All natural gas, whether it is described as conventional or unconventional, is composed predominantly of methane (CH₄), with varying, usually minor, quantities of other hydrocarbons and inert compounds (N₂, CO₂ etc.). The descriptor of conventional versus unconventional refers to the rocks or formations that the gas is trapped in and the methods required to extract it commercially.

4.2.2. Conventional gas

Conventional gas is trapped in porous and permeable reservoir rocks, such as sandstones, in favourable geological structures or traps and within sedimentary basins. To date, most of the gas that has been produced, globally and in Australia, has been conventional gas. Conventional gas will flow naturally at economic rates from wells drilled into the gas bearing formations.

4.2.3. Unconventional Gas

Unconventional gas is found in reservoirs that require specialised extraction technology such as dewatering or fracture stimulation to extract the gas from the formation at economic rates.

Tight gas

Tight gas is not dissimilar to conventional gas, in terms of geological setting, except that the reservoir rock has a low permeability, meaning that it is more difficult to extract the gas than is the case for conventional, higher permeability sands. To extract the gas economically, the permeability has to be enhanced through hydraulic fracture stimulation. Tight gas has been produced in Australia in the Cooper Basin for over 30 years through the use of hydraulic fracture stimulation.

Shale

Shale gas occurs in very fine-grained, low permeability organic-rich sediments usually in deeper parts of basins. It is therefore necessary to create permeability to allow the gas to flow from the rock. This is typically

done by combination of horizontal wells (wells with long horizontal or lateral sections giving them greater contact with the reservoir rock) and hydraulic fracture stimulation.

Shale and tight gas resources are typically between two and four kilometres below the ground and separated from near-surface freshwater aquifers by at least a kilometre of impermeable rock.

4.2.4. Conventional Gas Production

Conventional gas is produced predominantly from stacked sands of the Toolachee and Patchawarra Formations (Gidgealpa Group), which lie within the Cooper Basin (refer to Figure 5). The fluvial sandstone reservoirs are separated by shales and coals, which act as intra-formational seals. Minor gas production also occurs from other sediments within the Gidgealpa Group (e.g. the Epsilon Formation) from various localised sediments within the overlying Nappamerri Group (also part of the Cooper Basin), and from the Hutton Sandstone (within the Eromanga Basin). Generally, however, the Nappamerri Group shales act as a regional top-seal for gas.

Gas is predominantly stored as free gas within pore spaces in the sandstone reservoirs. Much of the porosity found in sandstone reservoirs is preserved primary intergranular porosity. The sandstone reservoirs often have low permeabilities (usually of the order of 1 to 10 milliDarcies, equivalent to a hydraulic conductivity range of 10^{-2} to 10^{-3} m/d), such that fracture stimulation is essential in order to achieve economic flow-rates and production volumes. Under the natural confining pressure of a typical reservoir, the gas exists in a near liquid state.

When a conventional gas well is completed with its final production string, pressure drawdown (i.e. differential pressure between the reservoir and wellbore) is created by opening up the well to the gathering system. Gas is then able to flow by virtue of the conductive path to the well via the formations permeability. In general, most gas reservoirs naturally deplete through a gas expansion drive mechanism. In contrast to the drive mechanisms associated with oil reservoirs and unconventional coal bed methane reservoirs, the drive mechanism in conventional gas reservoirs are such that gas will move from high pressure in the reservoir to low pressure at surface without the aid of mechanical lifting devices.

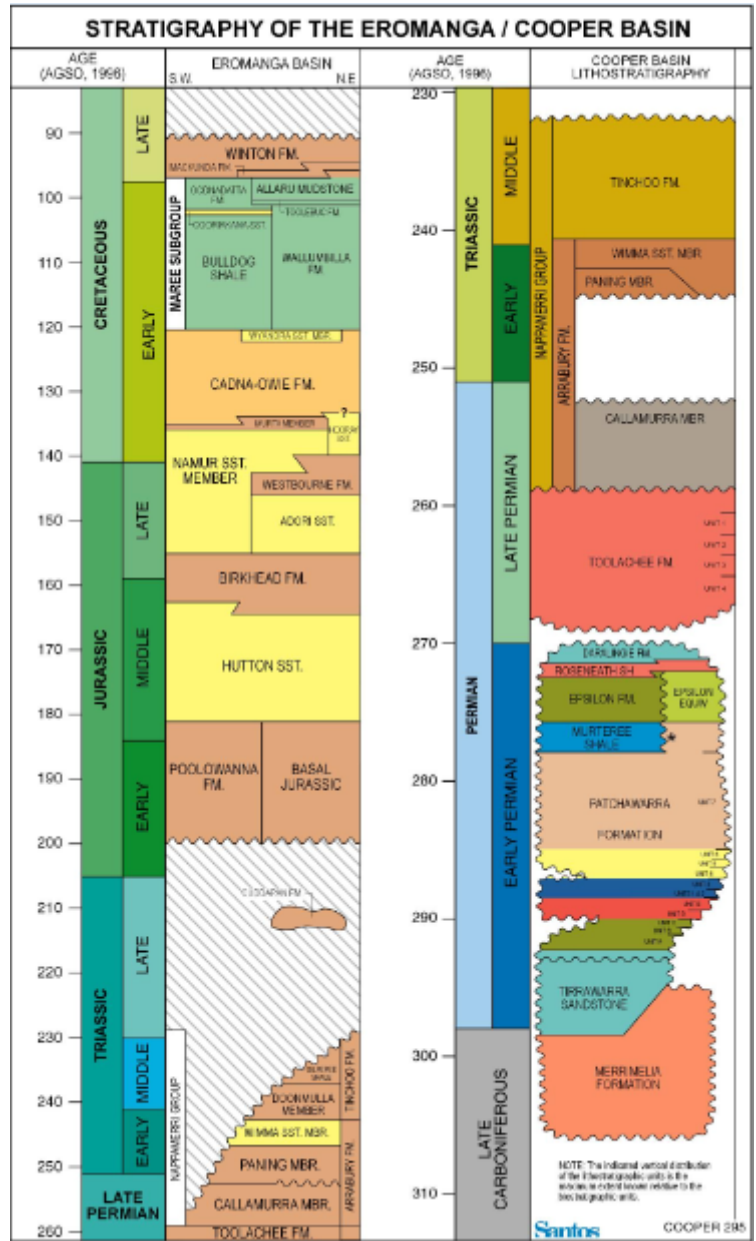


Figure 5: Cooper Basin Stratigraphy

4.2.5. Unconventional Gas Production

Unconventional gas plays in the Cooper Basin are comprised of Shales, Deep Permian Coals or Tight Sandstones which are largely characterised as self-contained systems (providing the full petroleum system of source, seal, reservoir and trap), with the presence of gas not influenced by any such structural (anticlinal) setting. It is important to note that because the unconventional reservoirs lie within the same stratigraphy as that of the conventional reservoirs, the hydrocarbon produced is the same as that of a conventional gas well. A distinguishing feature of unconventional resources is their very low permeabilities, ranging from ultra-tight sub-micro (10^{-6} D) to nanodarcy (10^{-9} D) permeability.

Unconventional gas plays often exist as large, continuous and predictable accumulations such as the Roseneath, Epsilon and Murteree (REM) package in the Moomba / Big Lake Area. They may also exist in

either normally-pressured or over-pressured deep trough areas of the Cooper Basin, such as in the Nappamerri Trough.

The key enabler for the commercialisation of unconventional gas formations is fracture stimulation.

4.3. Purpose of the Fracture Stimulation Process

Fracture stimulation is employed in the petroleum industry to improve the production efficiency of many gas and oil producing wells. This is achieved by creating an area of increased conductivity or flow path within the reservoir. This increased reservoir contact, through a highly permeable fracture, creates an efficient pathway for the flow of gas and oil. In the majority of cases, the low permeability nature of the hydrocarbon bearing reservoirs are too tight to produce from at economic rates and, without this increased flow potential, many of the gas wells within the Cooper Basin could not sustain economic flow rates.

Hydraulic fracturing is not an explosive or high impact process. It is not part of the drilling process but is a completion technique applied after the well is drilled and the drill rig has moved to another well. It is a process technology that results in the creation of fractures in the rock to allow the oil and gas in the rock to move more freely into the wellbore and enable economic production of them. It involves pumping water, a specific blend of chemicals and proppants such as sand or ceramic beads down a well at sufficient pressure to create fractures in the low-permeability rock. The proppant material keeps the fractures open against earth stresses once the pump pressure is released and serves to improve the production of the well.

Water accounts for about 90% of the fracturing mixture, sand/proppant for about 9.5% and chemicals for the remaining 0.5%. The fracturing fluid assists in carrying and dispersing the sand/proppant in the low-permeability rock. The chemicals used are not specific to hydraulic fracturing and have many common uses such as in swimming pools, toothpaste, baked goods, ice cream, food additives, detergents, cosmetics and soap. The chemicals are subject to full disclosure requirements. They are used to augment the following functions:

- Viscosity – Gelling agents (natural plant based) are added to the water to provide viscosity to enable the proppant material to be transported down the well and into the created fractures.
- Friction Reduction - to reduce the force required to pump the fluid, friction reducers are added, making the fluid more slippery and easier to pump at high pressures and at rates required to create the fracture network.
- Biocide – biocides or disinfectants are added to ensure that there are no microbes or organisms present in the water that will destroy the gelling agents and to ensure they will not enter and contaminate the reservoir.
- Scale and Corrosion – scale and corrosion inhibitors are added to prevent deposition of mineral scales and to prevent corrosion of the steel casing or tubing.
- Surface tension – surfactants or surface tension modifiers are added to assist the back flow of fluids from the formation.

As part of the process, the sand/proppant material remains in the low-permeability rock while much of the fracturing fluid is recovered to surface prior to hydrocarbons flowing into the well.

In some instances chemical or radioactive tracers will be used to provide information on fracture growth and/or which fractures are contributing to oil and gas production. Tracers are used in a wide variety of applications including medical and industrial and are used to “tag” injected fluids, solids, or slurries.

Santos has decades of experience using this technology in the Cooper Basin in both South Australia and South-West Queensland, with the first fracture stimulation treatment in 1969.

The design and quality of the well construction is of paramount importance in managing, and avoiding, any environmental risks associated with hydraulic fracturing. Santos applies best practice in our drilling techniques and activities.

Production wells may be subject to multiple fracturing events during the completion process. In order to produce from the reservoirs intersected by a well, Santos uses methods to selectively isolate and individually fracture each hydrocarbon-bearing zone. As a result, a typical gas well will have more than one fracture treatment. The current average number of treatments is approximately six treatments per well. Unconventional fracture stimulation utilises essentially the same process and techniques employed in conventional fracture stimulation with the main differences being:

- *Job size* - shales, coals and tight sandstones often require to 2-3 times the size of a typical conventional well in order to obtain effective stimulated rock volume;
- *Job type* - unconventional jobs are often “slickwater” or “hybrid style” treatments which uses less chemical additives than a conventional gas or oil treatment; and
- *Horsepower requirements* - unconventional jobs particularly in the Nappamerri Trough area, are subject to higher pore pressure, geomechanical stresses and geothermal conditions than conventional wells and therefore require up to two times as many pumping units in order to place effective fracturing treatments per stage.

The subsequent Sections describe fracture design and the fracturing process, with a dedicated section on unconventional fracture treatments (Section 4.7.13).

4.4. Fracture Stimulation Design Considerations

As discussed in detail in Section 3.2.2 through to Section 3.2.6, drilling, open-hole and cased hole logging of the reservoir section provides information useful in the hydraulic fracture design process. Data is acquired providing information on reservoir parameters, as well as lithology variations and stress contrast from layer to layer. This data is processed using an industry-accredited stimulation software to develop an optimal design.

The basis of well specific design is to produce hydrocarbon from the reservoirs through an optimal number of fracture stages, fracture length, fracture conductivity, and fracture height within the targeted reservoir formation. A number of considerations influence the final design for each fracture design:

- Depth and thickness of the target zone;
- Lithology of target and bounding layers;
- Minimum horizontal stress across all layers (target and bounding);
- Thickness of the ‘seals’ (aquifer layers) above and below the target reservoir formation;
- Porosity and permeability;
- Pore fluid saturations (percentage of pore volume occupied by each fluid e.g. oil, gas or water);
- Pore fluid properties (e.g. density, water salinity);
- Well performance data, including flow rates, formation pressure and produced fluid properties;
- Formation boundaries (as identified from seismic data);
- Bulk density, elastic properties and compressibility;
- Bedding planes, jointing and mineralisation;
- Natural fracture networks;
- Thickness of underlying formations and rock strength; and

- Stress field analysis to determine the maximum principle stress direction and the minimum principle stress direction.

The completion design process accommodates detailed analysis of these parameters to specify a fracture stimulation design that provides containment within the target formation. The fracture stimulation design models can model the fracture geometry; including fracture length and fracture height based on the geomechanical rock properties input into the model. The models do not predict the fracture orientation; however, Santos holds regional stress information that is used to predict the fracture orientation across the Basins. Further, there is an increased use of micro-seismic sensing and other diagnostic techniques to monitor fracture orientation within the industry. Santos has experience with these technologies and may consider additional projects in the future.

Fracture stimulation treatments are designed to provide an optimal geometry within the formation of interest. A complete layer description, including lithology, stress contrasts between layers, and reservoir parameters is input into the fracturing simulator. Various pumping schedules are input to evaluate the simulated fracture geometry. Economics are also optimised by designing a treatment to maintain the fracture height within the target formation and therefore gas producers are incentivised to achieve this through detailed design.

At the local scale, the regional stress field (magnitude and orientation) will be affected by discontinuities in the rock mass such as faults. The magnitude of horizontal stress will also be influenced by the geotechnical properties of the layered sedimentary rocks. The stiffer, more brittle rock layers, such as sandstone, have a low apparent fracture toughness (i.e. requires relatively little energy to fracture) compared to shale, which is considered ductile (high apparent fracture toughness) and requires relatively large quantities of energy to fracture. Sandstones are porous and permeable in nature and have a significantly higher permeability compared with the overlying shale.

Fracture stimulation is initiated with hydraulic pressure applied to the rock through perforations. With continued fluid injection, the fracture will propagate in the direction of maximum horizontal stress. The fracture will be limited in height by higher stress boundaries encountered due to a rock formation property change. Fracture height growth is also limited by fluid volumes pumped.

Conventional fracture stimulations in Cooper Basin gas targets are typically medium scale treatments, designed to achieve fracture heights in the order of 100 m. As discussed in Section 7.2.3, the conventional Cooper Basin targets have numerous barriers to fracture height growth out of formation, including multiple shales above the target sands and the very thick Nappamerri Group siltstones, which are 100 to 500 m thick and provide an additional 'safety barrier'.

Unconventional fracture stimulations are typically larger scale treatments and are pumped with higher pressures and volumes of fluid at a greater rate. They are designed to stimulate a larger volume of rock than a conventional stimulation target. As discussed in Section 7.2.3, the sealing Nappamerri Group rocks have their thickest development (up to 500 m) over the unconventional targets (in the Nappamerri Trough) and provide an effective barrier to fracture propagation between the unconventional targets and deep GAB aquifers..

Detailed studies by Fisher and Warpinski (2012) have reviewed height growth data from key unconventional (shale) plays in the US including the Barnett, Marcellus and Woodford shales, which indicated that maximum height growth can sometimes exceed 300 m when contained within a relatively homogeneous layer. However, Cooper Basin stimulation treatments are limited by the heterogeneous nature of the deeper

Permian formations and therefore height growth in excess of 300m is not expected to occur, based on the layered geological environment and other geomechanical parameters of the rock.

Studies by Cooke (2013) also demonstrate that the vertical separation between the deeper Permian gas formations and the deep Greater Artesian Basin aquifers is approximately 600 metres. The shallowest unconventional Permian gas formations (such as the Toolachee) are in the order of 400 m below the deep Great Artesian Basin Aquifers. Surface groundwater is typically within the top 200 metres, which is in excess of 1500 metres separation from the Permian gas formations. This is represented in the montage shown in Figure 6.

Limitations on fracture height growth in unconventional Cooper Basin targets were also reviewed in Beach Energy’s *Environmental Impact Report 2012* with the level of risk posed by fracture propagation into overlying aquifers assessed as low (Beach Energy 2012).

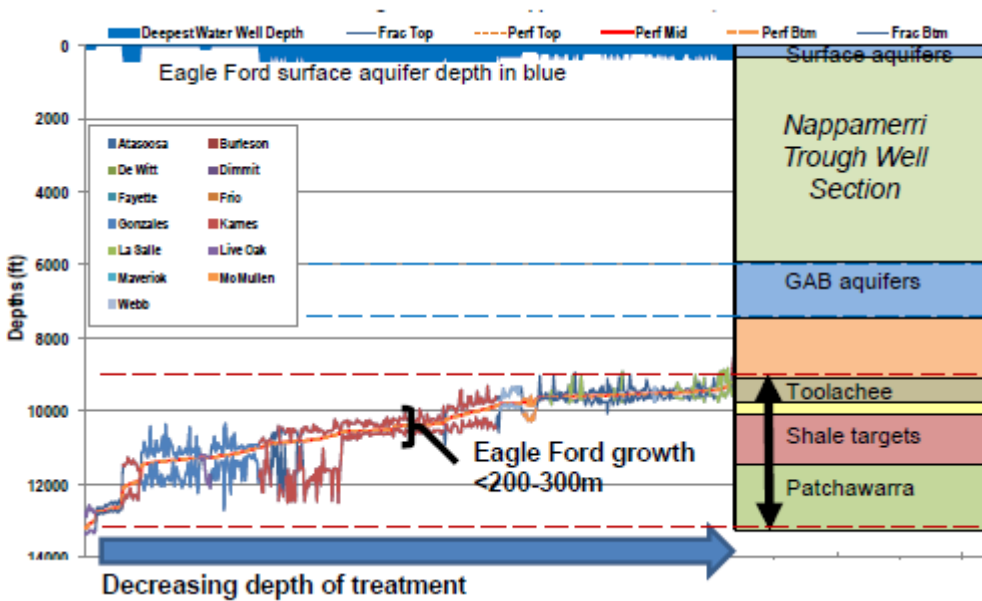


Figure 6: Typical fracture height growth measured during shale gas stimulation in the Eagle Ford (USA) with Cooper Basin well section superimposed (Source: Fisher & Warpinski, 2012; Beach Energy 2012)

4.5. Fracture Stimulation Process Description

Fracture stimulation uses specially designed fluids, primarily consisting of water and sand or ceramic proppant, mixed on the surface. The fluids are injected into the well and through the perforations into the reservoir formation to create the fracture. A typical wellhead used to inject into and control the well, during fracturing operations, is illustrated in Figure 8.

As discussed above, the fracture stimulation process occurs under high hydraulic pressures in order to physically fracture the reservoir rock. The hydraulic fracturing fluids are injected through perforations (10 to 20 mm diameter holes created with jet perforating) in the well casing pipe. The fracture fluids are injected from the surface via the wellhead or frac tree (Figure 7 and Figure 8). A simplified schematic of the created fracture geometry is indicated in Figure 9. A fracture stimulated in deep reservoirs, similar to the Cooper Basin, will propagate laterally from the well in a vertical plane, based on the in-situ stresses. Common dimensional terminology for hydraulic fractures includes fracture half length (x_f) and fracture height (h_f) and propped width (w_f).

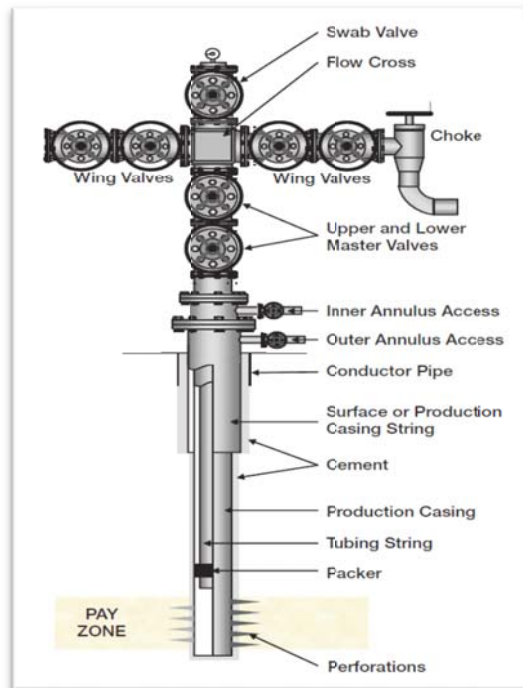


Figure 7: Typical Fracture Stimulation Wellhead Fixture (Source: Economides and Martin, 2007)

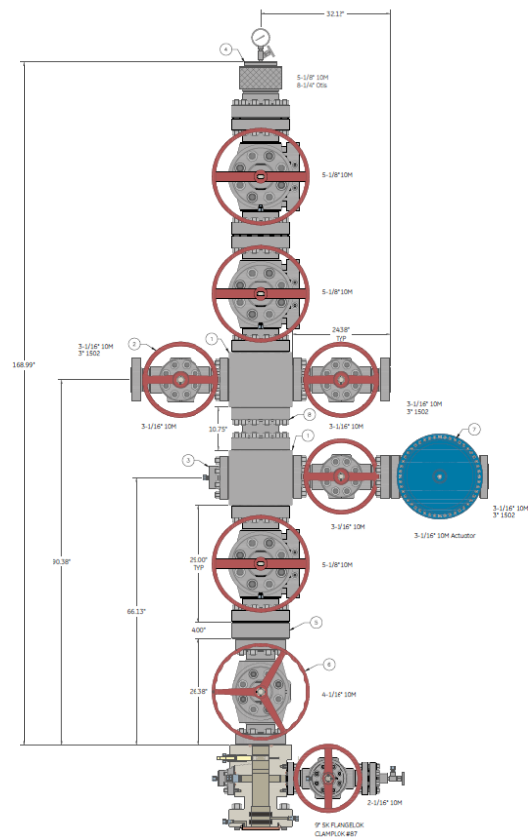


Figure 8: Typical Frac Tree used on Santos Fracture Stimulation Operations (source: GE, 2013)

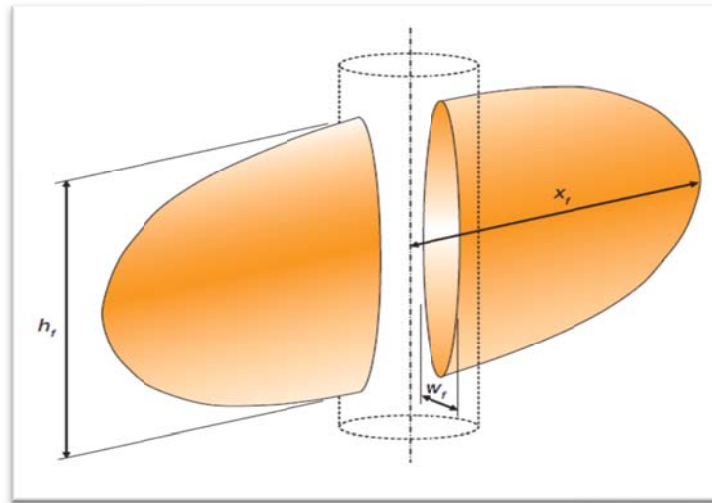


Figure 9: Conceptualised Shape of Fracture Stimulation Zone of Influence (source: Economides and Martin, 2007)

The intent of fracture stimulation is to place a highly conductive channel into the reservoir to increase the flow capacity. Typically used in low permeability reservoirs that cannot sustain economic production, it can be analogous to increasing the effective wellbore radius. This increase in flow area will increase the production rates and, in some cases, can contact additional reserves. A number of steps make up the fracture stimulation process:

1. Perforate the interval to be fracture stimulated. The perforations are through jet perforating or abrasive jetting with coiled tubing and sand to jet holes through the casing and cement.
2. Pre-frac injection test to validate and update the design; includes shut-down and decline to evaluate near wellbore entry friction, fracture gradient, fluid leakoff, and minimum horizontal stress. This stage is not always included.
3. Main fracture treatment; consisting of pad volume, slurry stages with increasing proppant concentrations, and flush stage to displace last slurry stage to the perforations. On occasion a pre-pad stage including weak hydrochloric acid to assist with remediating near wellbore entry friction may be pumped ahead of the pad stage.
4. Prepare to mechanically isolate the fracture stage completed, if part of a multi-stage well completion.
5. Perforate the next stage to be fracture stimulated and repeat the process in 2 to 4 above until final stage is completed.
6. Remove all mechanical isolation devices.
7. Flowback well to clean up injected fluids and monitor hydrocarbon production.

The following sections describe some of the specialised equipment required for fracture stimulation and a further description on some of the various stages of the treatment.

4.6. Infrastructure and Equipment Used

Santos uses two methods to pump and isolate fracture stages within multiple target gas wells in the Cooper Basin. The first method, “plug and perf”, uses wireline conveyed jet perforating across each reservoir target. Sands are fracture stimulated sequentially, one at a time, from the bottom of the well upwards. Between each pumping sequence a mechanical bridge plug is set above the sand completed, in order to isolate that sand, while fracturing the next sand above.

Another technique is to use coiled tubing assisted annular fracturing which can be used to provide a conduit for “pin-point fracturing”. Coiled tubing is run into the well to the deepest target. The bottom-hole assembly incorporates a jetting assembly which allows for low concentration sand slurry to be pumped into the coil and exit this assembly with high velocity. The jet created, along with the abrasive properties, will cut holes or slots into the casing and cement. These provide access to the reservoir similar to what jet perforating accomplishes. The fracture stimulation treatment is then pumped into the coiled tubing / casing annulus to initiate and propagate the fracture. The other function of the coiled tubing is to include a packer as part of the bottom-hole assembly that can be used to isolate the fractured formation, while fracturing the next formation / target above.

Descriptions of other equipment required for fracture stimulation is provided below:

- *‘Clean Fluids’ Pit / Turkeys Nest or Above Ground Storage Tanks* (Figure 10) – on site, a pre-dug synthetic lined pit (Turkey's Nest) or constructed above ground water storage tank provides temporary clean water storage for use in the hydraulic fracturing process. Source water is generally trucked from a nearby production facility. Small dosages of biocide are added to control algal growth particularly under warm and stagnant conditions. Often in smaller fracture treatments, the volume of source water is small enough that the use of turkey's nests is not required and the source water is stored and treated in tanks instead. Following completion of works, temporary water storage infrastructure is either backfilled or removed from site.



Figure 10: Above Ground Storage Tanks, Cowralli Multi-well pad, Cooper Basin 2013

- *Sand Trailer Unit* – a large, multi-compartment trailer that holds proppant (sand or ceramic material) required for the treatment (Figure 11). When proppant is required, a conveyor system distributes proppant from the compartments to the down-hole blender.



Figure 11: Sand Trailer Unit (Halliburton, 2012)

- *Blender Units* (Figure 12 and Figure 13) – In general, two different blending units are used: A pre-gel blender; and a down-hole blender. The pre-gel blender combines the source water with additives required for the base stimulation fluid (also known as “linear gel”) and proportions of required additives to provide the final fracturing fluid. The down-hole blender unit then proportions proppant to the fracturing fluid to provide the proppant concentrations specified in the fracture design. The final fracturing fluid, without proppant, is referred to as the “clean fluid”. The final fracturing fluid, with proppant added, is referred to as “slurry”. Most of the fracturing fluids used within the Cooper Basin for the main fracturing treatment are cross-linked fluids to assist with fracture geometry and proppant transport. In small fracture jobs, the linear gel may be “batched mixed” in tanks and negates the use of the pre-gel blender, thus reducing the overall equipment footprint on site. Chemicals are precisely measured, controlled and recorded by the blender throughout the fracture stimulation treatment.



Figure 12: Blender Unit (Halliburton, 2012)



Figure 13: Blender Unit, (Halliburton, 2012)

- **High Pressure Pumps** (Figure 14) – reciprocating triplex or quintaplex pumps that receive low pressure fracturing fluid from the down-hole blender and inject these fluids at sufficiently high pressure into the well during the fracturing process. Multiple units may be used on single fracture stimulation treatments.



Figure 14: High Pressure Pump, (Halliburton, 2012)

- **Control or Data Acquisition Unit** (Figure 15) – telemetry from all units are connected to a central control room during the fracturing treatment. Treatment parameter data, including surface and bottom-hole pressure, pumping rate, chemical rate and fluid density, are monitored, recorded and plotted. Treatment supervisors monitor and control the treatment to ensure that the treatment is pumped according to design. Satellite communication facilities allow further oversight by technical experts around the world.



Figure 15: Control Unit (Halliburton, 2012)

- ‘Coil Tubing’ Unit (Figure 16) – a Coiled Tubing Unit (CTU) has many uses within Santos operations but is not always required as part of a fracture stimulation operation. On some occasions the fracture treatments are placed using coiled tubing assisted annular fracturing, as opposed to “perf and plug” completions. The coiled tubing can be used in place of wireline jet perforating by jetting holes through the casing and cement using abrasive jetting. Once the perforations are jetted, the coiled tubing is left inside the well and the fracturing treatment is pumped down the coiled tubing / casing annulus. Part of the coiled tubing bottom-hole assembly allows a mechanical barrier to be set which protects a fractured interval below, while pumping a fracture treatment in a subsequent target above. Following a treatment, the coiled tubing is pulled up to the next interval and the abrasive jetting procedure is repeated.



Figure 16: Coil Tubing Unit, (Halliburton, 2012)

- Lined Tank / Flare Pit – A higher walled (thicker) poly lined flare pit is constructed as part of lease preparation or as an above ground tank (Figure 10). This pit / tank is used to receive produced fluids

during stimulation operations and during the initial clean-up phase after the fracturing operation. Pits are lined with UV stabilised synthetic liners to prevent any seepage to ground. Typically, after the initial clean-up phase the produced fluids are diverted to a separator to separate the various phases and capture any hydrocarbons into tanks. The ability to unload the stimulation fluid immediately after it has undergone treatment is considered one of the most crucial stages because poor or delayed clean-up may hinder the well's ability to produce at economic rates.

4.7. Stages of Fracture Stimulation

4.7.1. Fracture Stimulation Event Design

Fracture stimulation events are individually designed in detail as part of the well completions design process described in Section 4.5. The design input parameters are described in that section.

Key to a successful and contained fracture stimulation event is the inclusion of detailed fracture modelling and fracture monitoring by Santos Fracture Stimulation Engineers and its contractor of each targeted reservoir zone using computer modelling methods, calibrated by historical data.

Design outcomes include:

- Equipment requirements based on expected treating pressures and pump rate;
- Fracturing fluid type and volumes required;
- Volumes of water required on location to be available for designed treatment;
- Proppant types and volumes required;
- Simulated fracture geometry and expected treating pressure;
- Fluid pumping schedule describing stage volumes, rates, and proppant concentration;
- Shut-down and flowback procedures; and
- Site preparations and logistics for material supply and accessory equipment required.

4.7.2. Stage Perforation / Jetting

To provide communication between the wellbore and the reservoir, perforations are required. In wireline deployed perforation, these are created using charges. Alternatively, perforations are created using a CTU, where low concentrations of an abrasive sand slurry are used to create holes of much lower shot density.

The length of the perforated interval is determined by the thickness of the sand layer to be fractured. A typical perforated interval across a given sand layer is 3 m in length; however, this interval can vary between 0.3 m to 6 m or more. The perforations within the interval are placed at varying shot densities, or shots per metre. Typical perforation or shot densities are 9 shots per metre (spm) to 20 spm. The perforation diameter will vary based on the method of perforating, as well as other variables, but typical dimensions are 10 mm to 25 mm in diameter.

The preference for deploying one method over another depends on several factors, the main ones being: resource availability; number of zones to be fractured in the well; efficiency and cost.

4.7.3. Pre-Treatment

In some formations, the initial breakdown can create significant Near Well Bore Pressure (NWBP) drops. This can be calculated from Minifrac results (Section 4.7.4) and can be caused by a variety of downhole conditions. NWBP can cause difficulties in placing designed proppant volumes/concentrations. This NWBP loss needs to be remediated in some cases prior to pumping the main treatment. One method is to use a

small volume of dilute hydrochloric acid (15% wt/wt HCl acid) as a pre-flush to the main treatment. Any acid soluble materials, in the near wellbore area, are removed and an improved connection between the wellbore and the reservoir is created. It is noted however, that acid pre-treatments are not routinely required and many fracture treatments are performed without pre-treatment. If fracture stimulation is undertaken in deep gas reservoirs, a dilute acid is commonly used as a pre-fracturing treatment. This is primarily to reduce friction pressure for future pumping operations by improving access through the perforations to the reservoir. It is carried out after completion of the well casing and perforations, but prior to fracturing.

4.7.4.Minifrac

A Minifrac is a small volume injection of fluid (such as friction reduced water or linear gel) into the perforated or jetted holes for the purpose of ascertaining design related parameters such as NWBP, fracture gradient, treatment rate, treatment pressures and fluid leakoff signatures. These parameters can influence a design change in the main treatment and in cases where high NWBP is encountered, warrant an acid pre-treatment or other mitigation activity.

4.7.5.Corrosion Inhibitor

Some chemicals are corrosive to metals and the corrosion rate increases with higher temperatures. On any chemical treatment, a corrosion inhibitor is added to protect against any corrosion of the casing during the pumping operation. This ensures that the well integrity is maintained by applying a protective coating on the surface of the casing. The concentration of the corrosion inhibitor is based on lab testing with the same material at down-hole temperature conditions for a given period of time. Typical corrosion inhibitor concentrations used are 2% by volume or 20 L inhibitor per 1 m³ of chemical blend.

4.7.6.Pad Volume Injection

The fracture stimulation process is initiated by pumping a designed volume of the fracturing fluid without proppant, referred to as the “pad”. The purpose of the pad volume is to create the fracture area required to receive the designed proppant volume.

The pad fluid is carefully prepared using the equipment described in Section 4.6. Prior to pumping into the well, the base gel is prepared and tested using specific QA / QC procedures. The main polymer used for Cooper Basin hydraulic fracturing is a guar derivative which is combined with recycled PFW in the pre-gel blender, providing the base gel viscosity. The guar gum and associated ingredients comprise approximately 0.050% by volume of the pad volume. Programmed and automated control systems are used to maintain the fluid properties during the pumping of the treatment. Fluid sampling and testing occurs during the treatment to ensure that the fluid maintains the desired properties.

The gel (illustrated in Figure 17 and Figure 18) is allowed to hydrate in a baffled tank, referred to as the Hydration Unit, for several minutes prior to being pumped to the down-hole blender. The base gel viscosity of the fluid is typically in the region of 30 to 40 centipoise (cp), depending on the specific fluid designed.



Figure 17: Example of a typical slurry gum constituent, Guar Gum – illustrating its native form, seed form, splits and powder

** Note: Guar gum is a vegetable product which is ground into a powder and used to create a viscous liquid for hydraulic fracturing. Source: Economides and Martin, 2007



Figure 18: Example of Typical Stages of Gum (Guar) Cross-linking to Achieve 300 cp (Source Economides and Martin, 2007)

The pump rate or rate of injection on a fracturing treatment is based on the design factors discussed in Section 3.2 and will vary depending on the reservoir. Typical Cooper Basin injection rates range from 15 bbl/min (2.4 m³/min) to 80 bbl/min (12.7 m³/min). Surface treating pressures can range from 5,000 psi (35,000 kPa) to 14,000 psi (96,500 kPa).

At the initial stage of injection, the pressure will increase until the formation fractures. This is evident by a drop in the injection pressure and signals that the fracture has been initiated. Pumping of the pad volume will continue at the designed rate, in order to promote the designed fracture geometry. Once the pad volume is pumped, the injection of the slurry stages begins without interruption to the treatment.

4.7.7. Slurry Volume Injection

Once the pad volume is pumped, and without shutting down the pumps, the proppant is added to the down-hole blender and proportioned into the fracturing fluid. The concentration of proppant increases through each stage as designed within the fracture simulator. The fracturing fluid with proppant is referred to as “slurry.

Additives including cross-linkers, buffers, breakers, and surfactants are added to the slurry at the down-hole blender to provide a suitable fluid for transporting proppant into the created fracture. The viscosity of the cross-linked fluid will vary with time and temperature but typical designs will provide a fluid with viscosities in the several hundreds of centipoise. This viscosity is required to propagate the fracture and to transport proppant well into the created fracture.

Breaker compounds are added at progressively increasing concentrations throughout the pad and slurry stages. The breaker comprises an oxidizing compound or enzyme that breaks the crosslink sites, as well as the long chain polymers. The end result is a fluid with significantly lower viscosity that can be easily flowed back from the fracture to assist with clean-up. The “break time” is designed to coincide with the known pump time at reservoir conditions plus some additional time to ensure the treatment is pumped to completion. This enables the fluid to be more easily recovered from the formation.

Proppant addition begins at low concentrations and is staged up to the final designed concentration which is specific to the formation being fracture stimulated. Typical proppant concentrations will range from 0.5 lb/gal (60 kg/m³) to 8 lb/gal (1000 kg/m³).

Proppants used in fracture stimulation range from graded quartz sand to higher strength ceramic proppants (refer Figure 19 and Figure 20). The strength of this inert material varies, with ceramic being much stronger than quartz sand. Ceramic proppant is most often used in the Cooper Basin due to the high effective geological stresses. Proppant grain size varies and is also chosen based on the required parameters for the specific fracture design. Each size and type of proppant has a number of attributes that must be met for consistency with API quality specifications.

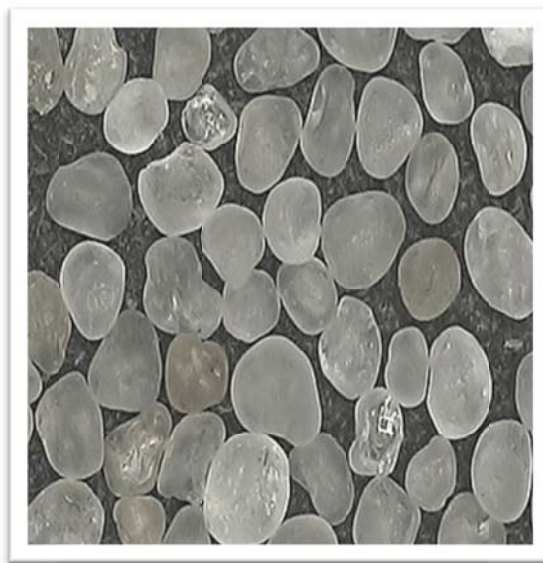


Figure 19: Typical 20-40 Grade Sand used in Fracture Stimulation (Source Economides and Martin, 2007.)



Figure 20: Typical Sand - Guar Gum fluid mix (Source Economides and Martin, 2007)

Once the final slurry stage is pumped on surface, the final flush stage is pumped. The flush stage is a friction reduced fluid (non cross-linked) that is used simply to displace the last stage of slurry down to the perforations. This leaves the wellbore volume free of any proppant and has proppant placed within the fracture. Once this flush or displacement volume has been pumped, the high pressure pumps are shutdown and the main fracturing treatment is considered complete.

The duration of the fracturing treatment is dependent on the specified volumes to be pumped and the rate at which the treatment is pumped, but is typically around 1 hour.

The above procedure is carried out for each target zone in the reservoir formations. In the case of gas reservoirs, the number of sands or fracture stages can range from 1 stage to 10 or more stages in a single well, depending on the stacked reservoirs contacted during the drill.

A typical conventional Cooper Basin fracturing treatment may use from 0.15 ML to 0.38 ML of water for the main fracturing treatment. The required volume is dependent on the size of the treatment required for the particular formation to be stimulated. The volume of proppant required may range from 18 tonnes to 90 tonnes and again, is dependent on the specific formations being stimulated.

4.7.8. Flush Volume

As discussed above, a flush stage or displacement stage is pumped at the end of the treatment to ensure that the proppant is within the fracture and not within the wellbore. On occasion, proppant placement is restricted due to near wellbore width restrictions. If this restriction completely blocks the entry of proppant, the pressure rises quickly and terminates the treatment. This termination is referred to as a “screenout” and requires proppant to be removed from the wellbore to enable production of the well.

4.7.9. Flowback

The fluid used to create the fracture and place the proppant will restrict the ability of the well to produce hydrocarbons. As previously mentioned, the use of breakers and reservoir temperature will assist with viscosity reduction. With the fluid viscosity reduced to near water (1 cp), the well is flowed back to recover injected fluids.

Following completion of the fracture stimulation process, a considerable volume of the injected fracture fluids are recovered upon flowback of the injected fluid. Studies performed by the USEPA (2004) indicated that approximately 60% of the fracture fluids are recovered in the first three weeks, and total recovery was estimated to be from 68% to 82%.

Once pumped into the well, the injected fluids undertake a change in chemical properties and as a result become more benign. Chemicals returning to surface from a well following a stimulation treatment are typically a fraction (usually 20% or less for chemicals and about 40% for polymers) of what was initially pumped (King 2012, Friedman 1986, Howard 2009). Compounds such as polymers decompose rapidly at temperature, biocides are spent on organic demand and degrade, surfactants are adsorbed on rock surfaces and scale inhibitors precipitate and are returned at 10 to 15 ppm (parts per million or milligrams per litre) over periods of up to several months (King 2012).

Hydrochloric acid, which is used in the initial fluid injection phase, is spent within a short distance of the entry point into the formation and no live acid is returned to the surface. Corrosion inhibitor is used as an additive to the acid (hydrochloric acid) only and is adsorbed onto the steel casing and then onto the formation. Approximately 5 to 10% of the total volume of corrosion inhibitor injected returns to the surface (King 2012) in the produced fluids. Many of the compounds such as acids, corrosion inhibitors or biocides used in the stimulation process that are identified as potentially hazardous on their MSDS, are effectively neutralised during and/or directly following treatment and/or are present at significantly reduced concentrations in the produced fluids.

Light condensate, including naturally occurring hydrocarbon compounds such as TPH, PAHs and BTEX, may be associated with gas and present in recovered fluids. Produced fluids are directed into lined pits (e.g. lined with UV stabilised HDPE or equivalent) or tanks and, if required, separators are used to separate water, condensate, and gas for separate handling. The fluids are removed by a licensed waste transporter and taken to a nearby facility for discharge into produced formation water pond systems. Potential environmental risks are assessed regularly and managed through containment and/or monitoring. Fluid management ponds are constructed in accordance with the standards of the time of installation and new ponds are constructed to meet the South Australia Environment Protection Authority Waste Water Lagoon Guidelines.

Santos utilises industry best practice in managing surface handling of fluids and is constantly introducing new technologies for surface handling of fluids and disposal. Santos is undertaking stage-wise improvements towards eventual replacement of lined flare pits to tanks. An example of this includes a trial of specially designed flowback tanks and pit-less flowback operations.

4.7.10. Fracture Stimulation Treatment Monitoring

As described in Section 4.4, the fracture for reservoir layers are modelled using an industry leading hydraulic fracture simulator. Based on the final pumping schedule from the optimised design, a predicted fracture geometry and expected pressures are available.

During the treatment key parameters such as surface, bottom-hole and annular treatment pressures, proppant concentrations, volume of injected fluid and fluid additives are monitored (Figure 21). The modelled pressures are compared with the actual pressures. The overall pressure response can provide useful information in evaluating the achieved fracture growth and containment. The mechanical properties of the interbedded sandstones, shales and coals mean that horizontal propagation of the fracture network dominates. Post-treatment parameters are used with the fracture model, following the treatment, to achieve

a history match and predict the actual fracture geometry. This is used to refine and improve subsequent designs as part of the continuous improvement process.

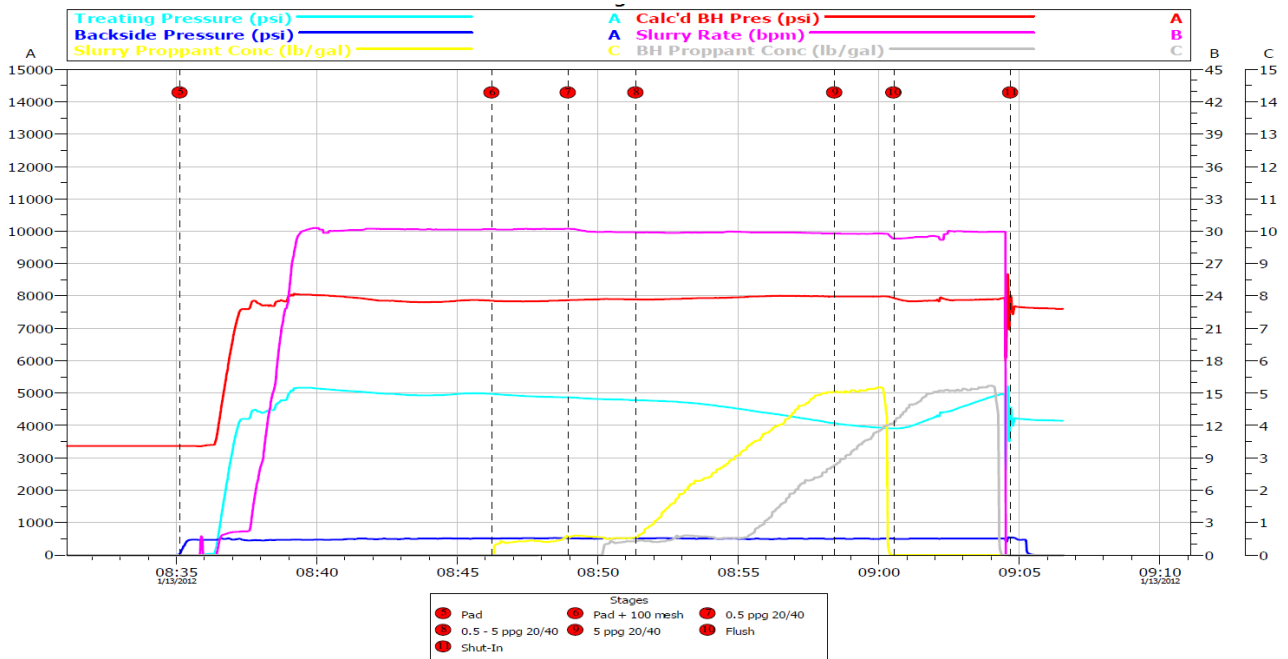


Figure 21 Typical Real Time Fracture Job Plot, Santos 2012.

Computer assisted live monitoring allows for potential problems (surface or down-hole) to be identified and corrected quickly. In the event that a problem develops on the surface (e.g. leak in line, pumps shut down), the use of live monitoring as a control measure for early detection can prevent the problem from escalating. An example of live monitoring applied to down-hole conditions is if pressure communication is seen between the annulus of the well and inside of the well, the well's integrity may have been breached and the treatment is stopped immediately.

In South Australia, Santos has trialled the use of advanced fracture monitoring techniques such as microseismic monitoring, which can be used to evaluate fracture azimuth, fracture height and fracture half length. This additional information can be used to further calibrate the fracturing model predictions.

Microseismic monitoring involves the use of a string of sensitive receivers (“geophones”) at the surface or within one or more nearby wells to detect and locate in 3D space the releases of energy associated with the propagation of the stimulated fractures. Figure 22 shows an example of a side-view of the locatable microseismic events that were detected during the multi-stage fracture stimulation of Cowralli-10 (in South Australia), with the positions of the events colour-coded by fracture stage. The viewpoint for the figure is at approximately the same depth as the upper fracture stages (shown in red, mid-blue and grey), and shows that the fracture propagation is predominantly horizontal, and that coals are effective in confining the vertical propagation. All locatable microseismic events for each fracture stage were contained within the formation being stimulated. Figure 23 shows a map view of the locatable microseismic events; these are shown in red, and the ellipses around each well show the expected (modelled) fracture-extents. The modelling and field results show good agreement, however in practice horizontal fracture propagation does not extend as far from the stimulation initiation point location as the modelling predicts. Whilst providing a good mechanism for model calibration, microseismic techniques and tiltmeters are limited by infield requirements such as the presence of at least one pre-existing nearby well (within approximately 500 - 700 m) for monitoring, and cost.

The use of tiltmeters to evaluate fracture growth direction (and potentially height) is being considered for selected unconventional stimulation treatments, the results of which may provide an additional tool for model calibration.

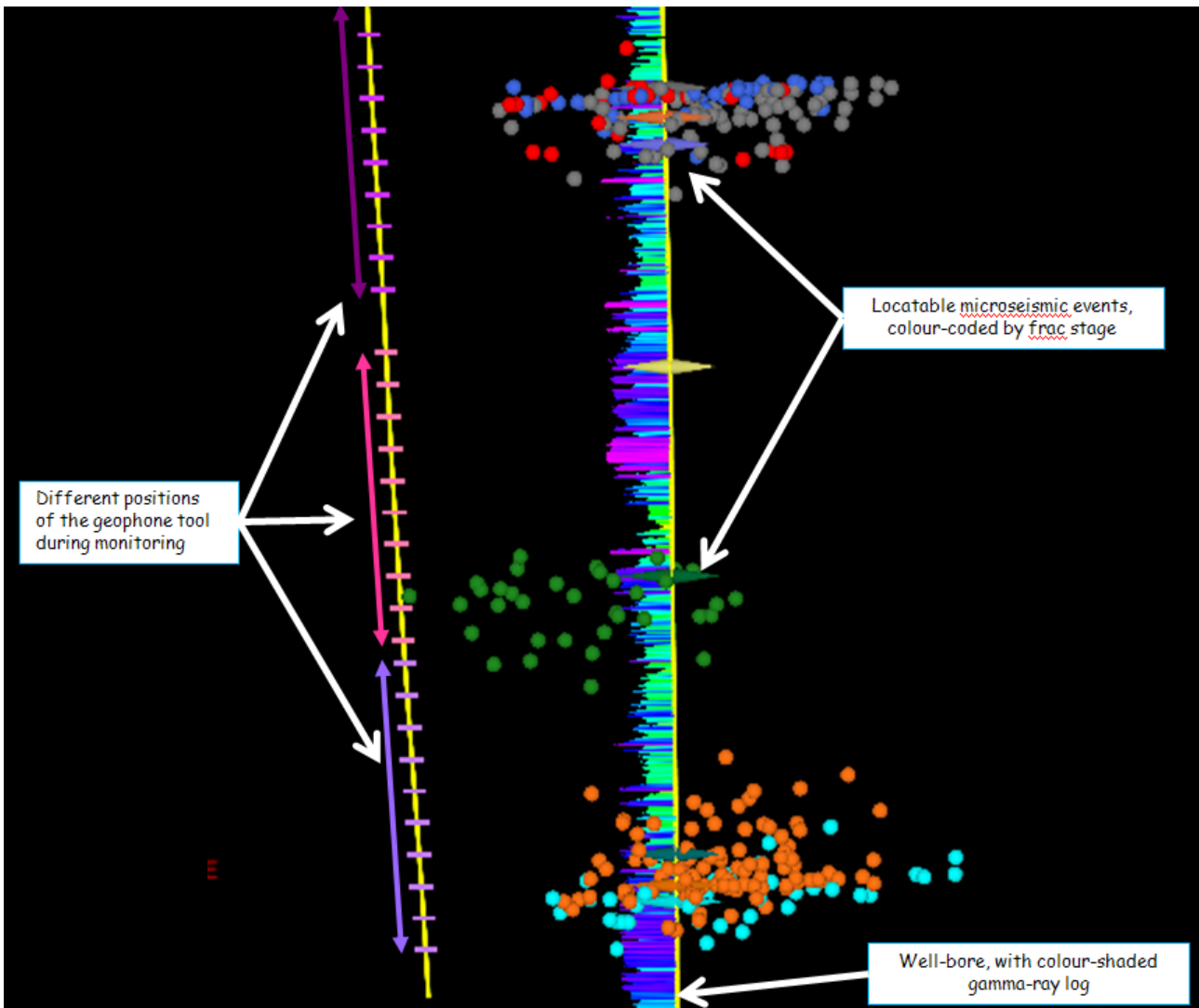


Figure 22: Lateral View of the Locatable Microseismic Events during Monitoring of Multi-Stage Fracture Stimulation of Cowralli-10 (Santos 2009)

4.7.11. Timing of Fracture Stimulation Process

Fracture treatment of an unconventional gas well typically takes up to 7-10 days to complete depending on the number of stages. The fracturing of a deep gas well with multiple stages can require anywhere from five to ten days to complete the fracture stimulation operation. The flowback period may extend from three to ten days depending on the reservoir and clean up profile.

At the end of the clean up phase, completions engineers install the production tubing and associated completion equipment such as packers, nipple profiles, tubing hanger, and the production tree.

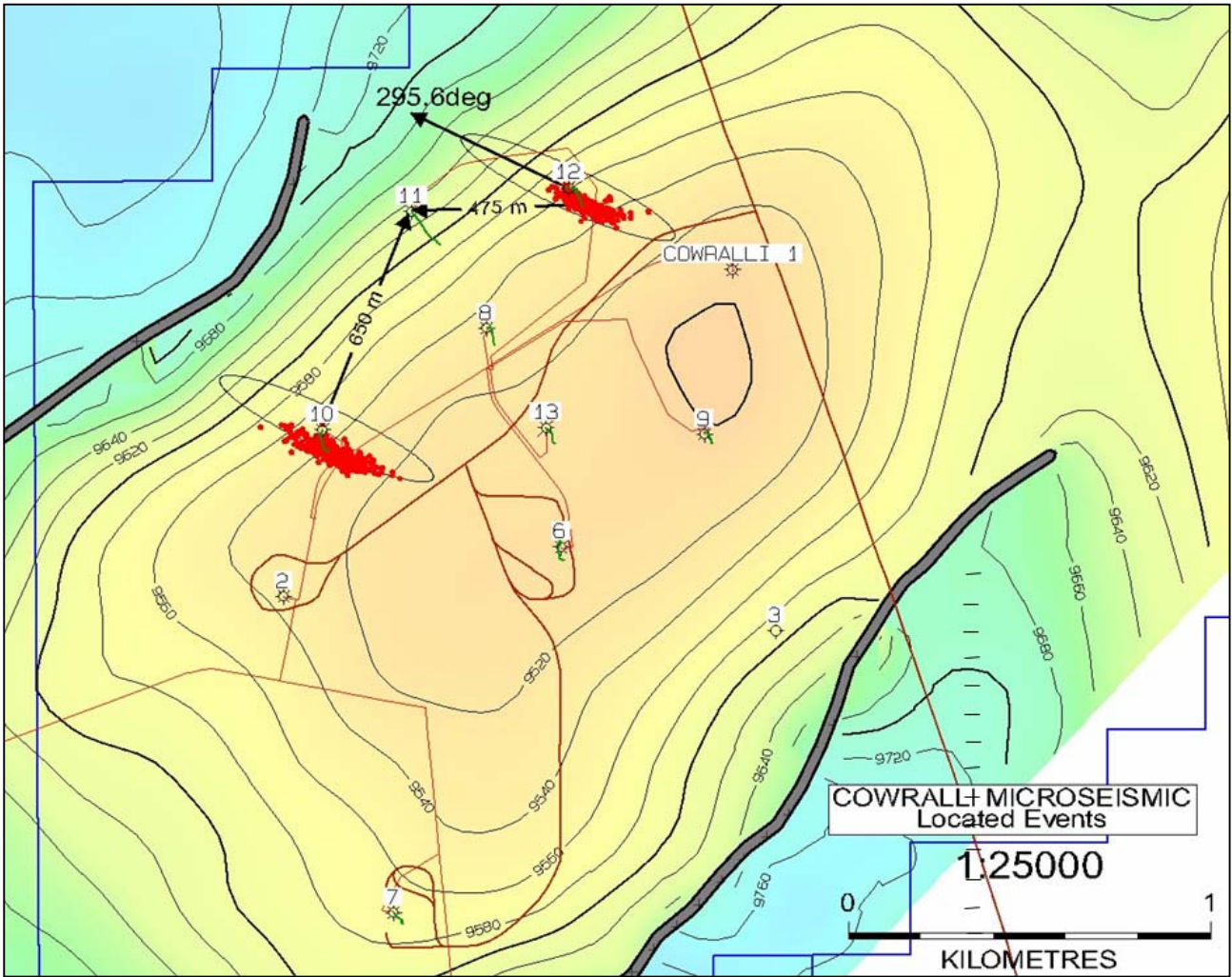


Figure 23: Map View of the Locatable Microseismic Events During Monitoring of Multi-stage Fracture Stimulation of Cowralli-10 and Cowralli-12 (Santos, 2009).

4.7.12. Chemical Constituents in Fracture Stimulation Fluid Systems

Santos’ use of chemicals is kept to the lowest level possible. We also work with our fracture stimulation contractors to ensure usage of most environmentally friendly chemicals and lowest possible concentration of chemical components in our fracture stimulation operations. Santos safely manages the use of chemicals and fuels, and contains recovered stimulation fluids to minimise the environmental footprint of stimulation activities. Most of the chemicals used in fracture fluids are found within products that are used in the home or in industry. Additives that may be hazardous in concentrated forms are diluted by water when used in the fracturing process and are therefore present in relatively low concentrations. Even in low concentrations Santos handles these additives with care to avoid any potential for impacts on human health or the environment.

With Santos’ operational controls and management, the overall or residual risk to the environment associated with the chemicals used in fracture stimulation is low.

In 2012 Santos engaged Golder Associates to undertake a toxicological risk assessment of fracture stimulation fluids used for Santos’ southwest Queensland operations. The assessment included a detailed

evaluation of potential ecological and human health risks associated with exposure to produced fluids. The report found that the only cause of toxicological exposure arising from fracture stimulation fluids would be by submersion of a person or animal. Santos ensures that this risk is always mitigated by adequate fencing and other protections (e.g. signage, inductions) around flowback/disposal ponds.

A list of the individual fracture stimulation fluid chemicals considered in the Fracture Risk Assessment for Santos operations in southwest Queensland (eastern Cooper Basin) and their respective Chemical Abstracts Service Registry Numbers (CAS RN) are provided in Appendix C. This list is similar to, but will inevitably vary from other published sources of fracture stimulation fluid compositions, as the specific fracture stimulation fluid mixtures are proprietary products of the fracture stimulation contractors and their product suppliers. The principal provider of fracturing services to Santos in the Cooper Basin is Halliburton, a world leader in use of fracturing technology.

The chemical constituents used by Halliburton were reviewed by Golder in 2012 and do not contain benzene, toluene, ethylbenzene, xylenes (BTEX) or polycyclic aromatic hydrocarbons (PAHs).

As discussed in Section 4.3, water accounts for about 90% of the fracturing mixture, sand/proppant for about 9.5% and chemicals for the remaining 0.5%. The chemicals are used for different functions are not specific to hydraulic fracturing and have many common uses such as in swimming pools, toothpaste, baked goods, ice cream, food additives, detergents, cosmetics and soap. The chemicals used to augment the following functions:

- Viscosity – Gelling agents (natural plant based) are added to the water to provide viscosity to enable the proppant material to be transported down the well and into the created fractures.
- Friction Reduction - to reduce the force required to pump the fluid, friction reducers are added, making the fluid more slippery and easier to pump at high pressures and at rates required to create the fracture network.
- Biocide – biocides or disinfectants are added to ensure that there are no microbes or organisms present in the water that will destroy the gelling agents and to ensure they will not enter and contaminate the reservoir.
- Scale and Corrosion – scale and corrosion inhibitors are added to prevent deposition of mineral scales and to prevent corrosion of the steel casing or tubing.
- Surface tension – surfactants or surface tension modifiers are added to assist the back flow of fluids from the formation.

A list of typical Fracture Stimulation Chemicals can be found in Appendix C, and a mass balance analysis is included in Appendix D.

Other chemicals that may be used in association with fracture stimulation activates include radioactive and or chemical tracers. Radioactive tracers (proppant beads impregnated with isotopes) if used, are generally retained in the formation along with the remainder of the proppant. They have a short half-life and rapidly degrade. Very little is returned to surface and if so, would be at very low concentration and would not be in solution (it would settle out into the lined pit with any proppant flushed from the well). Santos would monitor flowback where radioactive tracers are used to ensure that radiation levels are well below any levels of concern.

Chemical tracers, if used, are non-hazardous and are injected in very low concentrations (around 750 parts per billion in each stage). In flowback they are expected to be less than 250 parts per billion in total within the flowback fluid.

Where radioactive and/or chemical tracers are applied, they are deployed using a closed loop injection skid up gradient of the blender unit.

4.7.13. Unconventional Gas Well Fracture Stimulation

Fracture stimulation processes used for conventional and unconventional treatments are largely the same. Differences between unconventional and conventional treatments include size, job type and horsepower requirements.

Due to the ultra low permeability of many of the unconventional plays, complex large fractures are required to achieve commercial flowrates. The treatment sizes are larger for unconventional resources mainly because the formation target is often very low permeability and several times thicker than thinly laminated conventional sandstones. The REM shale in particular, can be up to 250 m thick, requiring between two to three times the clean gel volume (make up water) compared to a conventional job in order to create effective stimulated contact area.

The type of fracturing treatment may be different to that of a conventional gas well treatment. Conventional style fracturing relies on the thickening of cross-linked gels to transport sand (proppant) into the wellbore to enable the forming of a conductive fracture pack connecting the reservoir fluid to the wellbore. Unconventional style fracturing may rely on high rate, low viscosity linear gel sweeps to transport small amounts of low density proppant away from the wellbore creating a complex fracture network and thus allowing gas to flow into the wellbore. In this case, the proppant concentrations are much lower than a conventional treatment because the fracture width created from the pad does not allow a large volume of proppant to be placed. This style of fracturing is known as “slickwater fracturing” which is a common technique that has been used for fracturing shale wells in North America. In some cases, where surface treating pressures allow, a small volume of cross linked gel is tailed in to allow for a continuous ramp in proppant to be placed at the end of a treatment. This style of fracturing is known as “Hybrid” fracturing which is used in deep coals and tight sandstones.

The Nappamerri Trough area presents challenging geomechanical stress, geothermal and overpressured conditions not encountered anywhere else in the Cooper Basin. The depth and deposition of a typical unconventional sandstone target (e.g Toolachee Tight Sand) is approximately 500 to 625 m deeper than that encountered in a Moomba conventional gas well. In order to prepare the well for fracturing under these high stresses, high pressure and temperature conditions, careful drilling and completion considerations are required. A typical Santos unconventional well would comprise of a surface, intermediate and production casing with higher density and heavy walled steel deployed over the fracture targets. This design would allow higher fracturing treating pressures to be reached without risking the integrity of the wellbore. Two fracture spreads with increased number of pumping units are often deployed for unconventional fracturing to enable high rate transport of the fluid and proppant for a slickwater or hybrid fracture stimulation design.

4.8. Fracture Stimulation Water Use

The amount of water used in fracture stimulation operations in the Cooper Basin is dependent on the type of stimulation undertaken. Conventional stimulation operations use a comparably small volume of water and make up the majority of projects executed in the Cooper Basin. These projects comprise 71% of the total

water used for fracture stimulation. Unconventional stimulation operations are less frequent and use a larger volume of water per stage. In 2013 a total of 60 ML of water was used for fracture stimulation operations, 14 ML of which was consumed by unconventional stimulation operations. In 2014, Santos estimates that a total of 120 ML of water will be utilised, of which 29% will be used by unconventional operations. Table 1, presented below provides a summary of 2013 forecast Santos Cooper Basin Water Requirements for 2014 to 2017.

Table 1: Forecast Water Use for 2014 Categorised by Fracture Stimulation Job Type

Conventional Gas	2014	2015	2016	2017
Number of wells planned	52	62	66	65
Total frac water req p/well (m3)	1610	1610	1610	1610
Annual frac water req. (ML)	83.7	99.8	106.3	104.7
Unconventional Gas				
Number of wells planned	6	7	14	34
Total frac water req p/well (m3)	5724	5724	5724	5724
Annual frac water req. (ML)	34.3	40.1	80.1	194.6

The majority of water sourced for Santos' Cooper Basin fracture stimulation operations is from oil and gas satellite ponds or Produced Formation Water (PFW). Where satellite pond water is not available, water can be trucked in or piped depending on distance from the source and any infrastructure already in place.

In limited cases where PFW is not available, groundwater bores may be used, such as on projects in more remote areas of the Cooper Basin. It is noted however that typically, water bores are not able to supply water at the rate or quality required for fracture stimulation activities and are not Santos' preferred source. The drilling of water wells and extraction of groundwater in the region (which is within the Far North Prescribed Wells Area) is regulated under the *Natural Resources Management Act 2004*. A licence is generally required to use groundwater, however some existing blanket authorisations apply for taking of groundwater for drilling, constructing or testing petroleum exploration wells. A well construction permit from the Department for Environment, Water and Natural Resources (DEWNR) is required for any water well drilled. Santos will liaise with DEWNR to ensure that appropriate authorisations are in place for drilling and extraction of groundwater. Water use for fracture stimulation will be in accordance with the Far North Prescribed Wells Area Water Allocation Plan.

4.8.1. Conventional Gas

Conventional gas fracture stimulations can use between 200 kL and 500 kL per stage and an average of 1.6 ML of water per well. Target horizon selection is dependent on the location of the gas field and other considerations such as the reservoir parameters dictate the design of the stimulation and/or whether fracture stimulation is actually required. As a result, each well can have a different number of stages as well as a target specific stimulation design.

4.8.2. Unconventional / Tight Gas

Unconventional fracture stimulations can use between 400 and 1200 kL per stage and an average of 2-3 ML of water per well. The water use is dependent on the number of stages in the well, size of the target formation, reservoir parameters and the spacing between stages.

4.9. Other Components of Fracture Stimulation Operations

Other elements associated with fracture stimulation activities such as well lease preparation, drilling, casing, well operation and monitoring, well decommissioning, well lease restoration and camps are not within scope of this EAR and are relevantly addressed within the Santos Cooper Basin DWO EIR (2003, 2009) and the Santos SEO DWO 2009.

4.9.1. Waste Management

Santos follows best practice with respect to waste management activities, including waste generation, transport, storage, handling and disposal, in order to minimise potential impact on the environment. Operations and activities are conducted in a manner that uses resources efficiently in order to reduce the risk of environmental harm associated with the disposal of wastes by reducing waste generation and increasing reuse and recycling.

Santos' Cooper Basin waste management is governed by the waste hierarchy: avoid, reduce, reuse, recycle, recover, treat, dispose.

Typical waste streams generated as part of fracture stimulation operations include:

- Produced fracture stimulation fluids
- Fracture stimulation flowback solids/proppant
- Sewage and grey water;
- Putrescibles;
- Plastic, glass, cans, cardboard, paper;
- Oily wastes;
- Industrial Bulky Containers (IBC);
- 200 L drums;
- Scrap metal;
- Chemical wastes;
- Timber pallets; and
- Tyres.

Other waste streams generated as part of the fracture stimulation operations such as sewage and gray water are covered under the EIR DWO 2003 (Section 4.5.4).

Produced fluids are managed in produced formation water pond systems where environmental risks are assessed regularly and managed through containment and/or monitoring. Solids/proppant are managed at temporary and/or licensed landfarms.

A Fracture Stimulation Waste Management Plan has been developed for Santos' Cooper Basin operations (an example is provided as Appendix B).

5. Location

5.1. Cooper Basin

The Cooper Basin covers a total area of 130,000 km² of which approximately 50,000 km² lies within north-east South Australia (refer to Figure 1) and can generally be described as arid with a uniform climate. The Cooper Basin contains a wide diversity of land systems that are defined by geological, geomorphological and hydrological influences.

This section provides an outline for the operations area of regional climatic conditions, biophysical environments and social environments, including indigenous heritage and land use.

5.2. Geology and Hydrogeology

The Eromanga and Cooper basins are located in central and eastern Australia. The saucer-shaped Eromanga Basin extends over one million square kilometres in Queensland, New South Wales, South Australia, and the south-east of the Northern Territory (refer to Figure 24).

The Eromanga Basin is overlain by the Lake Eyre Basin, a succession of Tertiary and Quaternary age sediments occurring extensively throughout central Australia. In the north east of South Australia, the Lake Eyre Basin consists of the sediments described in the preceding sections on floodplains, wetlands, tablelands, gibbers, salt pans. At depth, units include the Yandruwantha Sand (medium to coarse grained sand), the Namba Formation (deltaic and lacustrine clay, silt and sand), and the Eyre Formation (sandstone and shale). The thickness of Lake Eyre Basin sediments in the Moomba area is generally in the range 200m to 300m (Drexel and Preiss 1995).

Eromanga Basin sediments were deposited during the Jurassic-Cretaceous period, and reach a maximum thickness of between 1200 m and 2700 m over the Cooper Basin (Gallagher and Lambeck 1989). These sediments were deposited under fluvial, lacustrine and (later) shallow-marine conditions, and are broadly continuous across the basin (Vine, 1976) (refer to Figure 5). These sediments are gently folded in some areas and contain a succession of aerially-extensive sandstone formations that serve as oil reservoirs and regional aquifers. The Eromanga Basin is the largest of the group of basins that constitute the Great Artesian Basin (GAB). The Eromanga Basin is the only part of the GAB that lies within South Australia, the other components being in Queensland and in part in New South Wales.

Beneath, and entirely covered by the Eromanga Basin, is the Permian – Triassic Cooper Basin, limited in its distribution by bounding faults and pinch-out edges. The Cooper Basin extends over a much smaller area than the Eromanga and covers a smaller area of about 153,000 km² in northeast South Australia and southwest Queensland (Stanmore, 1989). Total Cooper Basin sediment accumulations exceed 1500m in places and are characterized by fluvial, deltaic and swamp deposits that include some coal measures (Thornton, 1979). These sediments contain petroleum reservoirs (mainly gas) and limited aquifers. The South Australian end of the Cooper basin includes several north-east to south-west-trending depocentres, including the Patchawarra and Nappamerri troughs. In the deepest and most central portion of the Cooper Basin (the Nappamerri Trough), high pressure gas cells with reservoir pressures in excess of 7000 psi are present.

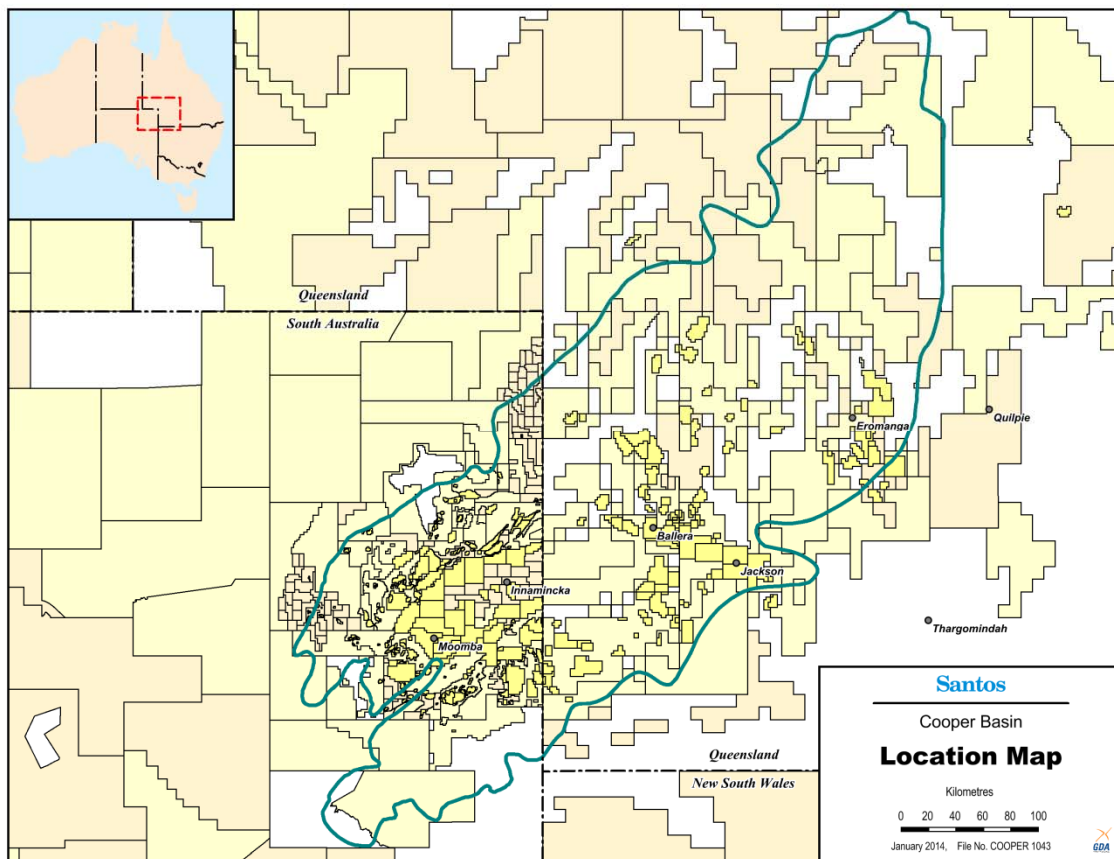


Figure 24 Cooper Basin Location Map

The tectonic history of the Cooper and Eromanga basins is complex and has been characterised by several periods of rift-related subsidence and compressional uplift and erosion. This history has resulted in the Cooper Basin being subdivided into a number of large scale sub-troughs separated by fault bounded ridges. The historical evolution of the Cooper and Eromanga basins is discussed by Kuang (1985), Finlayson et al. (1988), Gallagher (1988), Hunt et al. (1989) and Stanmore (1989). The groundwater flow in the region is described in terms of the Great Artesian Basin (GAB) (Habermehl 1980). From 10 to 5 million years ago a phase of structuring in the Eromanga uplifted the margins of the Basin (particularly in the east), raising the ground surface to a slightly higher level than the present -day elevation and instigated the groundwater flow pattern within the GAB (Great Artesian Basin) which is described in detail by Habermehl (1980, 1986).

Geothermal gradients in the Cooper and Eromanga range from 30°C/km on the margins to 60°C/km in the Nappamerri Trough, some of the highest recorded gradients worldwide in hydrocarbon-bearing basins. Here temperatures in the basal Cooper sediments reach approximately 250°C.

The Cooper and Eromanga basins are currently subject to a regionally compressive stress regime. Motion along fault bounded basement blocks result in strong local stress variations. Evidence from well bore geomechanics shows that conditions for movement on faults are present and that the structural evolution of the area is ongoing. The relative stress magnitudes and orientations that make up the stress regime are an important consideration in fracture stimulation as they define the direction of fracture propagation and its vertical extent.

With respect to hydrogeology, the rock column of the Eromanga and Cooper basins can be broadly subdivided into aquifers and confining beds (aquitards and seals). Aquifers are porous and permeable units that are able to store and transmit water and are generally analogous to the petroleum reservoirs in that they have storage capacity for fluids as well as permeability which enables the passage of fluids through them. In several instances, porous-permeable units are both aquifers and petroleum reservoirs.

Confining beds (aquitards) are units that impede the movement of water, and in general have low hydraulic conductivities or permeability. Aquitards can have such a low conductivity that no fluid permeates them under the pressure conditions inherent in that part of the basin. Seals are proven by their ability to trap and hold gas under pressure.

The reservoir pressure of an aquifer can be described as a pressure or a hydraulic head. In general, the hydraulic head drives the flow of water from one part of an aquifer to another, (i.e. from high to low). The head distribution can be used to create a potentiometric surface map that links locations of equal head potential by the construction of equipotential contours. Flow paths are constructed orthogonal to these contours to show the direction of lateral groundwater flow. Differences in head potential between aquifers occur when a confining layer is present and flow in each aquifer occurs independent of the other. In this situation, the head difference will drive water through the confining bed until equilibrium is established. The volume of water moving through a confining bed is generally very small compared with the lateral flow in the aquifers. The rate of movement through the confining bed depends on its thickness, its vertical hydraulic conductivity (related to lithology) and the head difference. Flow through confining beds can also occur along faults.

If the hydraulic head is the same in two aquifers separated by a confining bed, the mixing of fluids between aquifers will not occur even if the aquitard is breached by a fault or well bore.

In general terms, aquifers and aquitards have been assigned in terms of formations, the basic rock unit used to describe a stratigraphic succession. In more detail, many formations contain both aquifers and aquitards. For example, the Cadna-owie Formation has been described as one of the main aquifers of the GAB. However, the bottom three quarters of the Cadna-owie Formation is siltstone and shale and acts as an aquitard while the upper quarter of the unit is a sandstone that may act as an aquifer where it is not cemented or too silty. Large parts of the Poolowanna, Birkhead, Murta and Westbourne formations, plus almost the entire Wallumbilla Formation and the Bulldog Shale, Allaru, Toolebuc and Oodnadatta formations are aquitards within the Eromanga Basin. Within the Cooper Basin, trapping of gas shows most of the aquitards to be seals. The entire Murteree Shale and Roseneath Shale are seals. The Patchawarra, Epsilon and Toolachee formations are composed of sandstone-shale-coal cycles each of which contains a potential aquifer / reservoir and a seal or aquitard. The formations as a whole act as seals. The Nappamerri Formation, which overlies the coal measures, is a regional seal to the gas sands of the Cooper Basin, except around the eastern southern and western margins of the Cooper where it has been eroded. As a seal, it prevents the vertical movement of gas and oil, diverting the hydrocarbons laterally until they reach the eroded edge of the Nappamerri, where the hydrocarbons can resume their vertical movement.

There is little information on the hydraulic properties of these aquitards. However, the hydraulic conductivities of these beds have been estimated by numerical model calibration to be about 10^{-4} m/day (Audibert, 1976). Despite these low hydraulic conductivities, the aquitards have enabled hydraulic communication between aquifers over 'geologic time' such that most are in hydraulic equilibrium and have the same hydraulic head. In addition, many aquitards have been breached naturally, either by

erosion or by faulting. Where this occurs, large scale mixing of the aquifers has taken place and hydraulic equilibrium has or is being reached.

Aquifers include the Eyre Formation of the Lake Eyre Basin, some parts of the Winton, Coorikiana, Cadnaowie, Murta, Birkhead formations, and large parts of the Mackunda, Namur, Adori, Hutton, Poolowanna and Cuddapan formations, and all of the Eromanga Basin. In the Cooper Basin, parts of the Nappamerri Group, Toolachee, Daralingie, Epsilon, Patchawarra and Merrimelia formations, and all of the Tirrawarra Sandstone, may act as aquifers. Hydraulic conductivities measured within aquifers range between 0.1 and 10 m/day (Audibert, 1976). Observed porosity values within the sandstone aquifers are about 0.3 m/day (Senior and Habermehl, 1980).

Table 2 contains a summary of the pressure, permeability and salinity characteristics of these aquifers and regional geological cross sections are shown in Figure 24 and 25.

Based on the geological data available, the aquifers can be grouped into six largely regional hydrogeological cells, labelled from the top down as follows:-

1. The Meteoric Recharge Zone (the top water table or unconfined aquifer);
2. The Eyre Formation, which in places overlaps and is coincident with the surface Meteoric Recharge zone;
3. Parts of the Winton and most of the Mackunda Formations (non-flowing, uppermost GAB aquifer system (K aquifer of Habermehl, 1980);
4. Coorikiana Sandstone (non-flowing aquifer restricted to the western parts of the Eromanga Basin);
5. Uppermost part of the Cadnaowie Formation, parts of the Murta Formation, a large part of the Namur Sandstone, parts of the Westbourne and Birkhead formations and most of Hutton Sandstone and Poolowanna Formations – all within the GAB and collectively called the J Sands by Habermehl (1986);
6. The Cooper Basin (normal pressure) (largely the shallower parts of the Basin and around its margins; and
7. The Cooper Basin (abnormal pressure) (largely the deeper, hotter parts of the Basin such as the deep Nappamerri Trough.

Whilst the data available strongly supports this interpretation, it is recognised that in some areas the data to prove the regional interpretation is unavailable. Where this occurs, the well data can provide an adequate delineation of the cells within a well bore.

The distribution of these cells across the Cooper and Eromanga Basins show how in several areas the aquifer / reservoirs of the basins are in direct communication. However, all cells do not necessarily exist in all parts of the Basin. Towards the margins of the Cooper Basin and along some intra-basin highs, the GAB and Cooper Basin cells are in connection and the Cooper Basin (abnormal pressure) does not exist. Also, the Coorikiana Sandstone is only known from the southern and western Eromanga Basin.

The rocks of the Eromanga and Cooper Basins can be characterized into a third group, the unconventional resources (summarised in Table 3). These are rocks that may contain oil or gas but stored either in microporosity or adsorbed onto the surface of organic matter that makes up part of the rock framework. Rocks in this group include shales, siltstones and mudstones (commonly grouped as shales), coals and very tight sandstones. Shales and coals are known as the source of hydrocarbons in the Cooper Basin. Low concentrations of organic matter in the shales, and high concentrations in the coals, is partially converted to

hydrocarbon fluids by heating associated with burial. In conventional reservoirs, the hydrocarbon moves away from the source rock (migrates) through a permeable conduit to collect in a porous and permeable reservoir rock. In some situations, particularly where the rocks have been deeply buried, hydrocarbon is unable to migrate and remains in or close to where it was generated, often with an increase in pressure. The gas phase can become continuous through the rock, as it is immobile. Water can still be present in the rock but the combination of a gas and fluid phase reduces the permeability of both phases; the water blocks gas movement and gas blocks water movement. Sandstones that behave as conventional reservoirs in the shallower parts of the Cooper Basin, move into the unconventional tight gas category as they become more deeply buried where compaction and heat act to close up the pores, thereby limiting fluid conductivity.

In the Cooper Basin, gas is the main unconventional target. Under “normal” conditions, the gas stored in these rocks is immobile and the rocks fall into the aquitard or seal category. Gas flow and recovery can only be achieved by intense fracture stimulation where a network of fractures is induced through the rock.

Geochemical correlation between source rocks and petroleum reservoirs has been inconclusive and has led some investigators to question whether Eromanga hydrocarbons were sourced by either Eromanga or Cooper sediments (Heath et al., 1989). Most of the oil pools in the Eromanga Basin are located over and adjacent to the margins of the Permian-Triassic Cooper Basin (Heath et al., 1989).

Stratigraphically, the Eromanga fields are characterised by vertically stacked pools, with the largest accumulation of oil usually located just below the deepest, most competent seal. Heath et al. (1989) used these and other factors to argue that much of the oil and gas in the Eromanga Basin was actually sourced from the underlying Cooper rocks. The fact that oil pools stack vertically within an anticline demonstrates that the seals between the sands are imperfect and that fluids can migrate vertically. In this situation the mudstones are best described as aquitards, where flow is impeded but not prevented.

In the Cooper Basin, the location of oil and gas fields is closely related to the distribution of maturity in the source rocks; most gas fields are located in or near the ‘hot’ Nappamerri Trough, whereas the ‘cooler’ Patchawarra Trough is home to many of the oil fields in the Cooper reservoir rocks (Kanstler et. al. 1983; Hunt et. al. 1989).

The distribution of hydrocarbons and hydrogeological cells in a well bore can guide the effective management of the impact of drilling and production on the hydrocarbon and water resources of the region.

Table 2: Summary of Salinity, Pressure and Permeability Characteristics

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Reservoir / Aquifer	Use	Extent	Salinity	Pressure System (6)	Permeability
Eyre Formation	Limited use for petroleum exploration (rig water)	Basin wide	(2) Unclear, probably high(>9000 ppm)	Uppermost aquifer. Unknown, probably less than GAB	High
Winton Formation (multiple sands and aquitards)		Basin wide, but sands may be of limited extent	As above	As above	High
Macunda Formation		Basin wide	(2) Unclear, probably high (>9000 ppm)	Uppermost GAB aquifer. Known to be less than GAB (Della 20 evidence)	High
Coorikiana Sandstone	Potential reservoir	Restricted to more marginal southern and central areas of Basin	(2) Unclear, probably high (>9000 ppm) dataset, may be high or low	Aquifer between Bulldog Shale and Oodnadatta Formation. One data point apparently less than GAB. Not in communication with GAB in Cooper area	Generally low but local areas up to moderate
Cadna-owie Formation (aquifer at top of formation)	Known aquifer in uppermost part of formation only	Basin-wide	Limited data – possibly 2000 – 5000 ppm	Part of Main GAB system, on a common water pressure system	Often low, locally high
Murta Formation (multiple sands and aquitards)	Known reservoir	Basin wide, but sands may be limited in extent	(3) Limited data (3000-4000 ppm) for Murta sands	Part of main GAB aquifer (Algebuckina Sandstone equivalent). Data pressures variable and source not verifiable, may be problem with mixing McKinlay Member data.	High - up to multiple darcy
Namur Sandstone (includes McKinlay member of Murta Fm)	Known aquifer and reservoir	Basin wide	(4) 300-4000 ppm	Part of main GAB aquifer (Algebuckina Sandstone equivalent). May have local depleted zones	High - up to multiple darcy

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Reservoir / Aquifer	Use	Extent	Salinity	Pressure System (6)	Permeability
Adori Sandstone	Known aquifer and reservoir	Restricted to northern part of basin	(4) 300-4000 ppm	Part of main GAB aquifer (Algebuckina Sandstone equivalent). May have local depleted zones	High - up to multiple darcy
Birkhead Formation (multiple sands)	Known reservoir	Basin wide but sands separated by aquitards	(4) 300-4000 ppm	Part of GAB. May have local depleted zones	Highly variable
Hutton Sandstone	Known aquifer and reservoir	Basin wide	(4) 300-4000 ppm	Part of main GAB aquifer (Algebuckina Sandstone equivalent). May have local depleted zones	High - up to multiple darcy
Poolowanna Formation	Known reservoir	Basin wide	3000-4000 ppm in Cooper Basin area, but in excess of 9000 ppm in northern areas	Unclear if part of GAB. May have local depleted zones.	High - up to multiple darcy
Cuddapan Formation	Known reservoir	Patchawarra Trough only	Unknown	?	High - up to multiple darcy
Nappamerri Group (multiple sands and seals)	Known reservoir	Basin wide, but sands of local extent. Degree of interconnection across basin unclear	(5) 3000-7000 ppm. Local variations appear to depend on connection with GAB	May be same or greater or less than GAB. May have local depleted zones	Highly variable
Toolachee Formation (multiple sands and seals)	Known reservoir	Basin wide, but sands of local extent. Complex interconnections across basin.	1500 to 15,000 ppm apparently depending on connection with GAB. Data set combined with Daralingie.	Potential for very high pressures in centre of basin. May be same or greater or less than GAB. May have local depleted zones. Can prove connection with GAB in Munkarie Brumby area.	Highly variable

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Reservoir / Aquifer	Use	Extent	Salinity	Pressure System (6)	Permeability
Daralingie Formation (multiple sands and seals)	Known reservoir	As above	Data combined with Toolachee.	Potential for very high pressures in centre of basin. May be same or greater or less than GAB. May have local depleted zones.	Highly variable
Epsilon Formation (multiple sands and seals)	Known reservoir	As above	Limited dataset, 2000 to 10,000 ppm apparently depending on connection with GAB.	As above	Highly variable
Patchawarra Formation (multiple sands and seals)	Known reservoir	As above	2000 to 18,000 ppm. Low salinities in Weena / Tinga Tingana Trough	As above	Highly variable
Tirrawarra / Merrimelia Formation	Known reservoir	Basin wide except for south east and around local highs	Limited dataset for Tirrawarra 5000 to 17,000 ppm no data for Merrimelia	As above	Highly variable
Pre Permian Basement	Known reservoir	Basin wide	Unknown	Potential for very high pressures in centre of basin. May be same or greater or less than GAB	Highly variable, may include natural fractures

Table 3: Summary of Current and Potential Unconventional Resources

Basin	Formation	Unconventional target	Comments
Eromanga	Winton	Coal (shale)	Possible future targets – no current activity
	Toolebuc	Shale	Possible future target
Cooper	Toolachee	Coal	Thick extensive coals may become targets
		Shale	
		Tight sand	
	Daralingie	Coal	
		Shale	
		Tight sand	
Roseneath	Shale	Current target	
Epsilon	Coal	Grouped lithologies are current target	
	Shale		
	Tight sand		
Murteree	Shale	Current target	
Patchawarra	Coal	Grouped lithologies are current target Tight sands are borderline conventional-unconventional	
	Shale		
	Tight sand		

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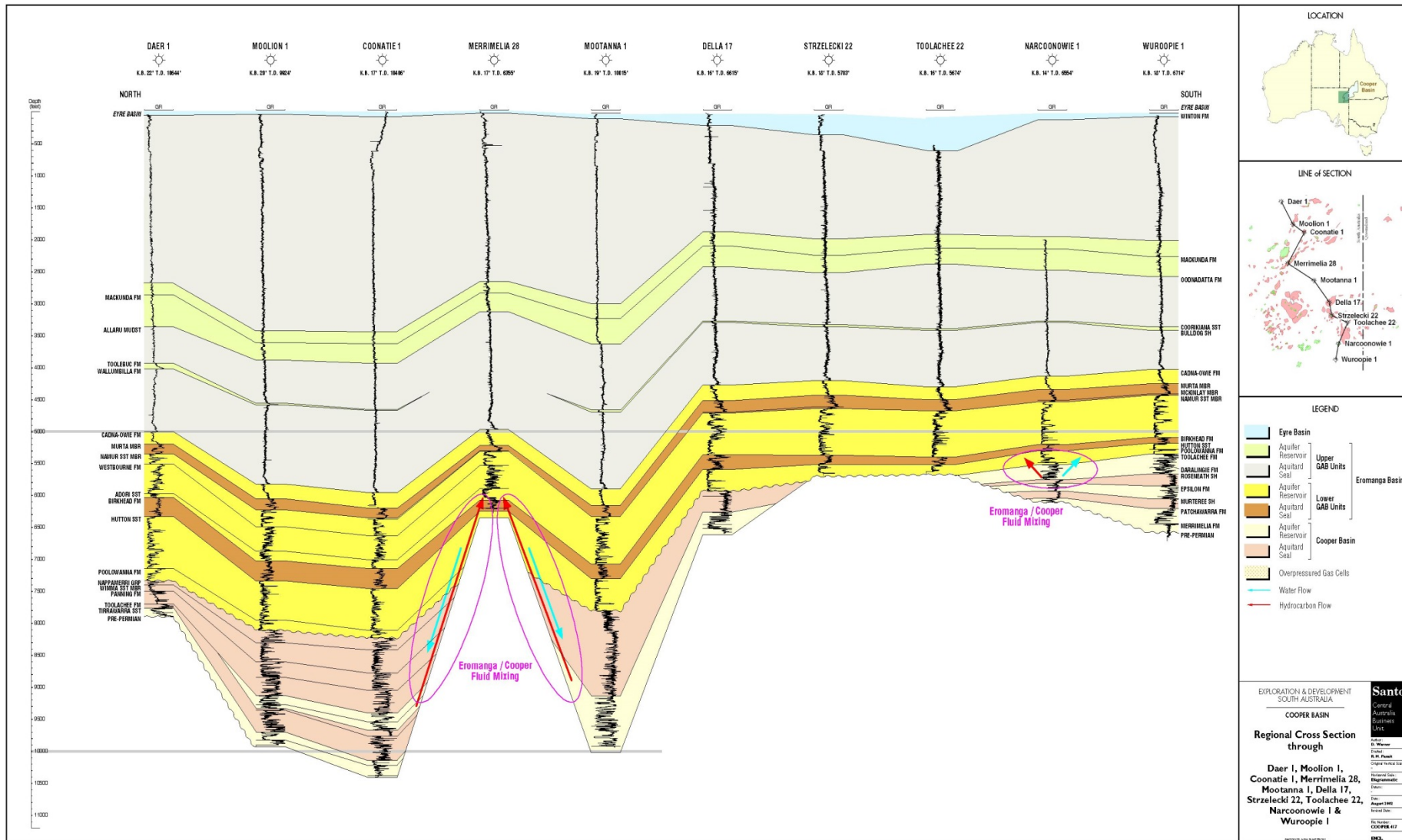


Figure 24: Regional Geological Cross-sections of the Cooper Eromanga Basin Area (a)

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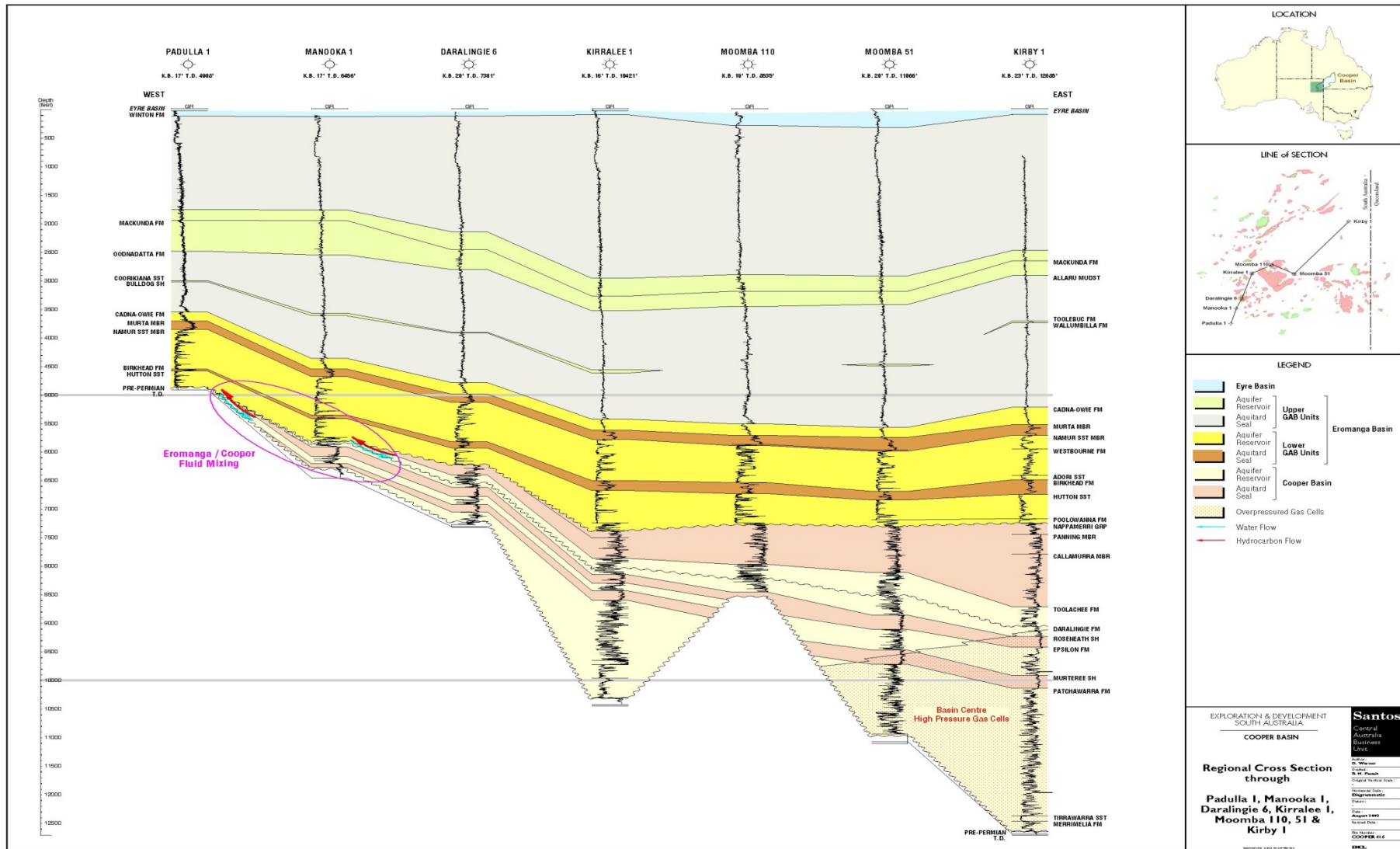


Figure 25: Regional Geological Cross-sections of the Cooper Eromanga Basin Area (b)

6. Environment

6.1. Biophysical Environment

The six major land systems contained within the Cooper Basin licence areas are:

- Dunefields;
- Floodplains;
- Gibber plains;
- Wetlands;
- Salt lakes; and
- Tablelands.

The sensitivity of each system to disturbance depends upon its basic characteristics: geology, landform, soils, hydrology, flora and fauna. Each land system has been discussed with respect to these characteristics.

6.1.1. Dunefields

The dunefields of the Tirari and Strzelecki deserts dominate the SACBJV' licence areas. These dunefields mainly occur in the far north-west, south-west and south-east regions of the Cooper Basin licence areas (Figure 26).

Geology, Soils and Landform

The development of the dunefields commenced approximately 18,000 years ago when a combination of low lake levels and extremely dry windy conditions created large, mobile dunes of lakebed and floodplain material (Twidale and Wopfner 1990). The process of dune development and migration continues today with sediment from river channels, floodplains and salt lakes being transported by the wind and shaped into dunes.

The Cooper Basin dunefields are characterised by parallel dunes of red, yellow or white aeolian sands of the Simpson Sand (Drexel and Preiss 1995), dominated by single crested linear sand ridges. Dunes are separated by flat interdune corridors (swales), which usually consist of claypans (Twidale and Wopfner 1990, Santos 1997). Dunes range in height from 5 m to 35 m and trend approximately northeast (Twidale and Wopfner 1990). Sand cover rarely exceeds 30 m and a stony base is usually exposed in interdune areas. Sand dunes have the potential to be affected by wind erosion as a result of disturbances brought about by production activities. In sandy desert areas, the potential for wind erosion to effect soils disturbed by operations (particularly earthworks) poses a significant environmental hazard. Red dunes are generally considered to be more susceptible to wind erosion than grey / brown sand dunes.

Water erosion is less likely on dunes as rainfall generally infiltrates rapidly into the sands before creating enough force to cause surface erosion. However, where there is a fairly high proportion of clay in the sand, as for example at the base (or toe) of a dune, rilling and sheet erosion can occur (Santos 1997).

In those parts of the basin where salt lakes and distributary channels occur in interdune corridors, the soils between dunes are dominantly grey and brown clays. Elsewhere, the common interdune soils are solonised brown soils, calcareous red earths and earthy sands (Wright et al. 1990).

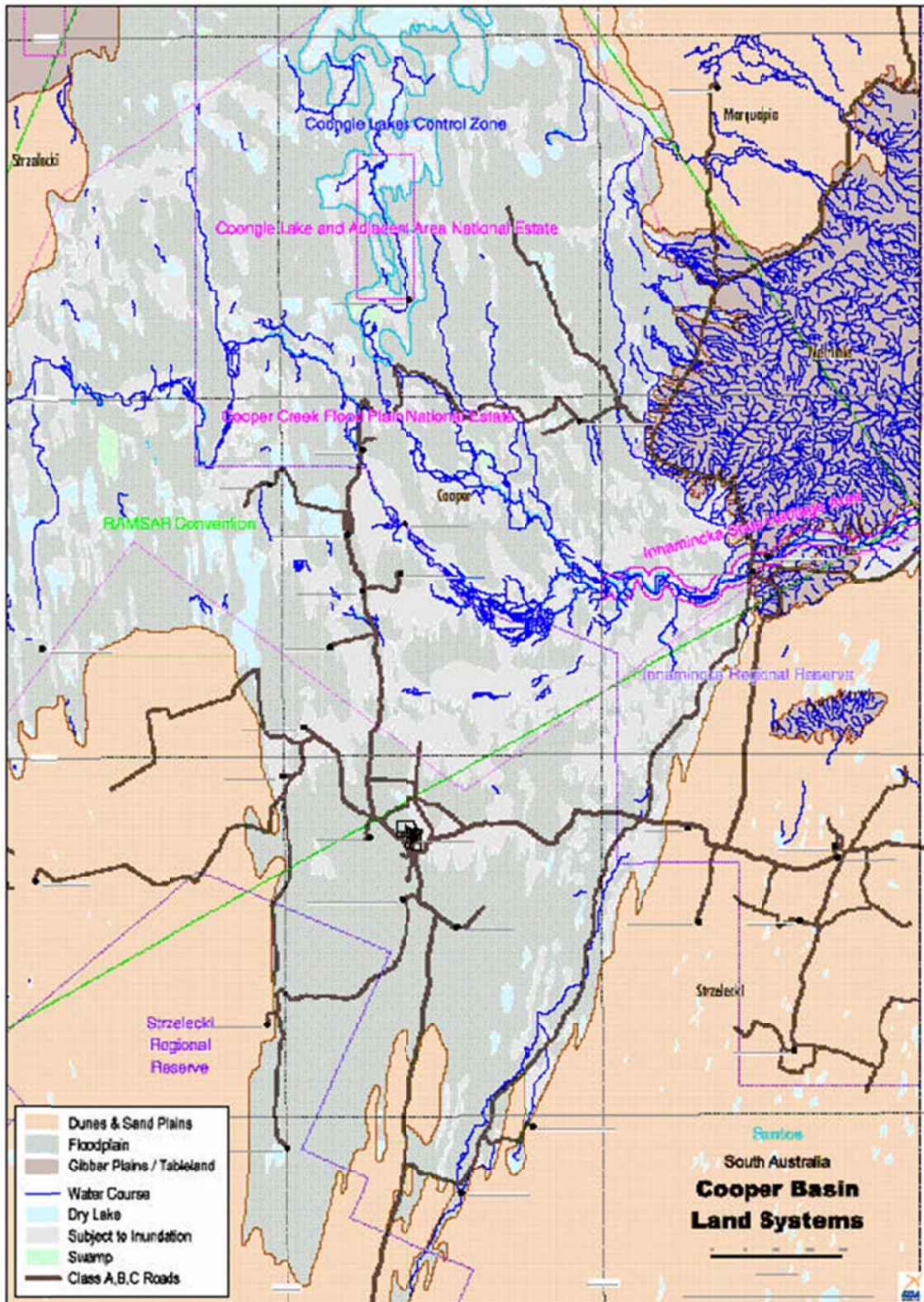


Figure 26: Cooper Basin Land Systems

Hydrology

The dunefields are extremely arid and lack any permanent surface water. Good quality groundwater can be found at shallow depths in dunefield areas adjacent to major watercourses (for example the Strzelecki and Cooper creeks). This water is non-artesian and contained within unconfined aquifers that are primarily recharged from surface stream flows.

Flora

Vegetation types alternate between the upper slopes and crests of dunes and interdune areas. Dune crests are often sparsely vegetated (depending on seasonal conditions) with tussock grassland species (for example canegrass), needlebush, herbs and ephemeral forbs (Santos 1997). Dune flanks are characterised by:

- Tussock grasses in the Tirari desert;
- Lobed spinifex grassland in the Strzelecki Desert;
- Shrubland consisting of sandhill wattle in dunefield areas; and
- Shrubland species such as whitewood and narrow-leafed hopbush more commonly in the Strzelecki Desert dunefields.

Vegetation in interdune areas depends largely on dune spacing. Narrowly spaced areas contain similar vegetation to dune flanks. Widely spaced dune areas, where gibber or floodplain soils are exposed, may contain low shrubland of Saltbush or Bluebush (Santos 1997). In general, interdune vegetation may consist of hummock grassland, chenopod shrubland, open shrubland or low open woodland.

Fauna

Despite the lack of free-water, dunefields provide important habitat for a range of wildlife including a variety of small mammals, reptiles and birds. Thirteen species of mammals, including exotic species, have been recorded in the dunefields in north-east South Australia. Common wildlife species include the Fattailed Dunnart, Striped-faced Dunnart, White-winged Wren, White-backed Swallow, Richards's Pipit and the Brown Falcon. Common reptiles include Geckos, Skinks, Dragons, Blind snakes, Elapid snakes and Pythons (Tyler *et al.* 1990). The Dusky Hopping-mouse is a nationally vulnerable species (EPBC Act) and occurs primarily in sand dunes along Strzelecki Creek in the vicinity of Lake Blanche (Morton *et al.* 1995). The entire known range of the Eyrean Grasswren is circumscribed by the limits of the Simpson, Tirari and Strzelecki deserts. The species habitat requirements are tied to Sandhill Canegrass, which it uses for food, shelter and nesting (Reid *et al.* 1990).

6.1.2.Floodplains

The Cooper Creek Floodplain is a major feature of the South Australian section of the Cooper Basin. It covers the central third of the Basin and includes the Coongie Lakes System to the north and the Strzelecki Creek floodplain that feeds Lake Blanche in the south (refer Figure 26). The Cooper Creek Floodplain occurs in close association with the dunefields of the Basin.

Geology, Soils and Landform

The Cooper Creek and Strzelecki Creek Floodplains consist of intricately braided channels, swamps and extensive outwash plains. Floodplain topography is relatively flat and consists of an extensive and extremely variable system of rivers and creeks (Blackley *et al.* 1996). Soils are characterised by deep, grey, self-

mulching clays which are derived from fluvial mudstone and siltstone, and occasional fluvial sand and conglomerates in river and creek beds.

Geological units include undifferentiated fluvial and lacustrine sands of the Eurinilla Formation, clays and fine sands of the Tingana Clay, clays of the Milyera Formation and fluvial sands of the Yandruwantha Sand (Drexel and Preiss 1995).

Hydrology

The floodplains of the Cooper Basin are primarily associated with the Cooper Creek drainage system. The Cooper Creek originates in the moister catchments of south-west Queensland and channels water through the basin to Lake Eyre.

Cooper Creek still has the hydrologic character of an unregulated arid zone river with an extremely variable flow regime. The Cooper flows every year, although several months often pass without flow (Puckridge *et al.* 1999). Annual flow volumes for the Cooper Creek are presented in Figure 27 and are based on readings from the Cullyamurra gauging station near Innamincka (approximately 140 km upstream from Coongie Lakes). Puckridge *et al.* (1999) have developed nine flood classes for the lower Cooper Basin floodplain based on the 25 year Cullyamurra record. Table 4 provides expected frequencies and volumes for each of these flood classes. The predicted extent of flooding for each class is based on satellite imagery of previous flood events in the Cooper Basin region (Puckridge *et al.* 1999).

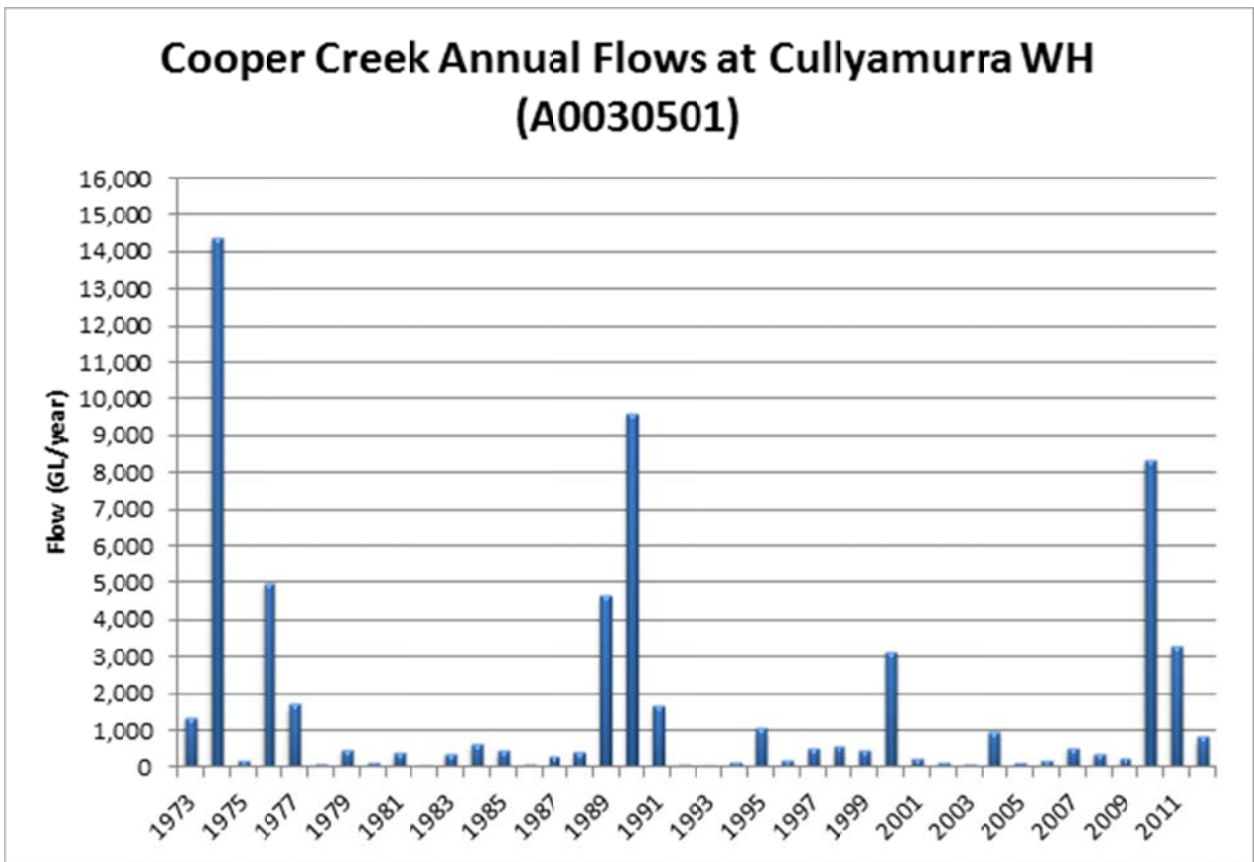


Figure 27: Annual Flow Volumes of Cooper Creek, Cullyamurra Gauge Station 1973 – 2012

Table 4: Cooper Creek Flood Classes, Volumes and Frequency

Flood Class	Daily Flow Volume (MI/day)	Total Volume (MI)	Frequency	Comment
1	600 - 1,200	14,000 - 40,000	Annual	Since 1973 there have been Class 1 floods, or larger, every year. Water flows into the north-west branch of Cooper Creek.
2	1,200 - 2,500	40,000 - 130,000	1-2 years	Most water flows into the north-west branch, but a proportion flows into the main branch of Cooper Creek.
3	2,500 - 5,400	130,000 - 220,000	1-2 years	Significant part of flows into the main branch as far as Embarka Swamp.
4	5,400 - 18,000	220,000 - 400,000	2 years	Significant flow enters the main branch, to the lower main branch and the lower Cooper Creek.
5	18,000 - 40,000	400,000 - 1,400,000	2-5 years	Significant flow occurs out of Coongie Lakes into the lower Cooper Creek as far as Lake Hope.
6	40,000 - 100,000	1,400,000 - 2,400,000	5 years	Results in flows into Wilpinnie Creek. Flow into this area can disrupt gasfield installations.
7	100,000 - 180,000	2,400,000 - 4,500,000	10 years	Results in flows into Strzelecki Creek but not as far as Lake Blanche. Flows occur along the lower Cooper Creek.
8	180,000 - 450,000	4,500,000 - 10,750,000	20 years	Flow into Lake Eyre North and fill Lake Blanche. Class 8 flood was the largest flood in 1990.
9	> 450,000	> 10,750,000	100 years	A Class 9 flood occurred in 1974, but no satellite images are available to determine flood extent.

Upper catchments of the Cooper Creek provide virtually all flows to the South Australian section of the Cooper Basin floodplain, as local rainfall makes only a small contribution to the hydrology of the region (Puckridge *et al.* 1999). Data from the Cullyamurra gauging station therefore provides flow data that is representative of total flows in the lower Cooper Creek Floodplain. Eighty-seven percent of flow at Cullyamurra is from the upstream catchment of the Cooper Creek.

Flora

Woodland, often with a tall shrub layer, is characteristic of the major intermittent watercourses in the Cooper Basin. Woodlands of River Red Gum, Coolibah, Gidgee and Bean Tree Fringe floodplains, channels and semi-permanent waterholes (Santos 1997). Groundcover on floodplains has a high ephemeral component, with very rapid growth after flooding. In frequently flooded areas, open Coolibah woodland with a shrub or ephemeral understorey is common. Further out onto floodplains, tall shrubland consists of Broughton Willow or Prickly Wattle. Old Man Saltbush and scattered Coolibah may be considered the main cover of tributary streams. Shrubland of lignum, Old Man Saltbush or Queensland Bluebush may also extend into the Coolibah woodlands, but tends to be characteristic of outer floodplains (Santos 1997).

Fauna

Within the arid zone, the most vital and important environmental areas are those connected with sites of permanent water. They provide permanent habitat for a variety of flora and fauna, and are especially important as a refuge during drought conditions. For example, the Cooper drainage system is thought to be an important refuge for the long-haired rat during particularly dry conditions (Morton *et al.* 1995, Kemper 1990). Generally, watercourse habitat supports more mammal species than other habitat types in the Basin. Thirty-five species of native mammal have been recorded from the floodplain areas of the greater north-east region of South Australia. Notable species in South Australia include Forrest's mouse and the yellow-bellied sheath-tailed bat (Kemper 1990).

Birdlife along major watercourses is prolific, especially in river red gum woodlands of the upper Cooper to which the barking owl and endemic Mallee ringneck are restricted. Floodplains support a highly significant population of raptors. Breeding densities, calculated along Strzelecki Creek, are among the highest in the world. Especially significant is the occurrence of the Grey Falcon, Black-breasted Buzzard and Letter Winged Kite. Aside from the terrestrial avifauna, floodplain areas also support varied and abundant waterbird populations. The Cooper Creek Floodplain and associated wetlands are a preferred breeding area for the Freckled Duck, Black-tailed Native-hen, and red-necked avocet, all of which are Australian endemics (Reid *et al.* 1990). The Cooper Creek wetlands support the richest amphibian fauna within the South Australian Cooper Basin. However, less than 3% of the known frog fauna of Australia occurs in the region (Brandle and Hutchinson 1997).

6.1.3. Wetlands

Despite its aridity, the Cooper Basin contains an array of wetlands. The Coongie Lakes and the Strzelecki wetland systems are included in the Directory of Nationally Important Wetlands. The Coongie Lake system is also listed under the Ramsar Convention as a wetland of international importance to waterfowl (Morton *et al.* 1995, Blackley *et al.* 1996) and falls under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The intent of the EPBC Act is to maintain the ecological character of a wetland and the *Australian Department of the Environment - Significant Impact Guidelines 1.1 2013* seeks to prevent actions that could have a significant impact on a Ramsar wetland including:

- Areas being destroyed or substantially modified;
- A substantial and measureable change in the hydrological regime of the wetland;
- The habitat or lifecycle of native species dependent upon the wetland being seriously affected;
- A substantial and measureable change in the water quality of the wetland; and
- An invasive species that is harmful to the ecological character of the wetland being established.

Sections 7.3 and 7.4 provide details on the lease site selection and the internal approvals process which will effectively minimise impacts associated with gas operations in areas of environmental significance.

Geology, Soils and Landform

Wetlands in the South Australian section of the Basin most commonly occur within floodplain and dunefield land systems. These include ephemeral shallow lakes, waterholes, swamps, flooded woodlands and grasslands, deep permanent channel reaches and samphire claypans. Soils generally consist of deep, cracking clays and occasional siliceous sands and conglomerates.

Geological units include undifferentiated fluvial and lacustrine sands of the Eurinilla Formation, clays and fine sands of the Tingana Clay, clays of the Milyera Formation and fluvial sands of the Yandruwantha Sand (Drexel and Preiss 1995).

Hydrology

Wetlands may be perennial or ephemeral and are considered to contain water more often, or be subjected to more frequent inundation, than surrounding areas of Floodplain (Santos 1997).

The Cooper Creek intermittently discharges into a vast area of swamps, lakes and overflows (Morton *et al.* 1995). Most wetlands in the Basin receive flows from this system which carries floodwaters throughout the Basin and occasionally, during major flooding events, to Lake Eyre. Wetlands are also filled intermittently by heavy rainfall. Flooding is considered to be the most crucial factor in the recharge of many wetlands in the basin area.

Flora

The presence of water in an otherwise arid environment has allowed the development of a diversity of plant habitats and communities (Reid *et al.* 1990). The close association between floodplains and wetlands results in similar flora being present in both systems. Woodlands of River Red Gum, Coolibah, Gidgee and Bean Tree often border the margins of wetland areas. The aquatic environment consists of several macrophyte species including *Ludwigia peploides*, *Azolla filiculoides* and *Myriophyllum verrucosum* (Blackley *et al.* 1996).

Fauna

The wetlands associated with the north-west branch of the Cooper Creek, including Coongie Lakes, are recognised as a region of exceptional ecological value. The aquatic invertebrate fauna is abundant and diverse and includes an array of insects, crustaceans and gastropods (Reid and Puckridge 1990). Aquatic vertebrates include the water rat and Cooper Creek short-necked tortoise.

The fish community of the north west Cooper Creek system is one of the most significant in South Australia as it is close to its original composition, with only two exotic species present (Reid and Puckridge 1990).

The Coongie Lakes system supports enormous numbers and diversity of water birds. These wetlands have been recognised as internationally significant under the Ramsar Convention, providing a feeding, resting and breeding site for large numbers of migratory and nomadic birds. The lakes also support a great variety of aquatic fauna, including desert rainbow fish, shrimp, the Cooper Creek tortoise and a diverse frog population.

6.1.4.Salt Lakes

The basin is dotted with numerous salinas, or salt lakes and salt pans, of varying sizes (referred to as dry lakes in Figure 26). In these lakes, excess evaporation in interior basins leads to the concentration of soluble salts as a surface crust. The salts themselves are derived from the weathering of rock and are transported to the lakes via the movement of surface water (e.g. rivers and streams). The larger salt lakes in the licence area include Lake Blanche, Lake Hope, Lake Gregory, Lake Etamunbane and Lake Uloowaranie (Santos 1997).

Geology, Soils and Landform

Salt lakes usually have a low topography and dry surface covered with a gypsum (salt) crust. Lunettes are found along parts of the eastern shores of lakes. Little is known about the physical attributes of many salt lakes.

Hydrology

Salt lakes are predominantly dry, but are occasionally filled by floodwaters from the major river systems. During flooding, water may remain fresh and can support abundant fish populations. Lakes become increasingly saline as they dry. The frequency of flooding and inundation is highly variable.

Flora

Although the surface of salt lakes is devoid of vegetation, the immediate surrounds are usually fringed with samphire and occasional nitre bush shrubland. Samphire eventually grades to low open chenopod shrubland in the outer surrounds (Reid *et al.* 1990).

Fauna

Dry salt lakes form a harsh environment with a complete absence of surface water and extremes in daily temperature. Consequently, they support relatively few fauna. Salt lakes are particularly depauperate with regard to bird species. Salt Lakes in the region constitute highly ephemeral aquatic habitat for birds and, as such, no species is restricted to salt lakes alone (Reid *et al.* 1990). Surrounding chenopod shrublands support common species such as the Orange Chat and Richard's Pipit. While birds are almost entirely absent from the lakebed when dry, during flooding fish populations can flourish and consequently a variety of waterbirds (such as pelicans, terns and cormorants) can be found.

6.1.5.Tablelands

Tableland areas are commonly known as dissected residuals or breakaways. They are characterised by a silcrete surface that has been eroded to form low but steep escarpments, mesas, buttes and extensive gibber covered footslopes (Santos 1997). Tableland areas in the Cooper Basin include Wadi Wadi or Innamincka Dome, Mount Kingsmill and Kertietia Hill (refer Figure 26).

Geology, Soils and Landform

Uplift in the Lake Eyre Basin has led to erosion and dissection of the silcrete surface and formation of low steep escarpments, small mesas and extensive gibber covered footslopes. Tableland areas generally have moderately deep clay rich soils of aeolian origin, and a fine crystalline gypsum-rich horizon.

Geological units present in tableland areas include gibber surfaces, which consist of "recent deposits of silcrete pebbles on sandy soils, gypsiferous soils or Callabonna Clay", plus Tertiary age fluvial sands and

shales of the Eyre Formation and Cretaceous age Winton Formation (Drexel and Preiss 1995). The Eyre Formation is generally silicified, as are portions of the Winton Formation.

Hydrology

Permanent surface water is scarce in elevated areas of tablelands. Minor drainage channels occur in lowland plains and can contain permanent waterholes. Temporary surface water can also be found lying in pools after rain in lowland plain areas.

Flora

Landforms that dominate the tablelands support a variety of low open woodlands, shrublands and low open Chenopod shrublands (Santos 1997b). Areas of relatively high relief support low Acacia woodlands, and occasionally on calcareous soils an uncommon Eucalyptus socialis Mallee formation (Brandle 1997). The most heavily wooded areas occur along drainage lines with river red gums and Coolibah fringing more permanent waterholes.

6.1.6. Gibber Plains

Throughout SACBJV licence areas, there are vast expanses of flat to gently undulating gibber covered plains and downs such as the Sturt Stony Desert and the Innamincka or Wadi Wadi Dome (Santos 1997) (refer Figure 26).

Geology, Soils and Landform

Gibber Plains are extremely flat to undulating plains that were formed during the breakdown and gradual recession of former tablelands. Soils typically consist of red and brown clays that are mantled by stone or gibber (Brandle 1994 -1997). As stated above, gibbers are recent deposits of silcrete pebbles on sandy soils, gypsiferous soils or Callabonna Clay. Gibbers form a stable pavement that protects underlying soil from erosion. Gibber Plains commonly contain gilgai or low surface relief structures.

While Gibber Plains are generally considered to be a stable environment, disturbance or removal of the surface layer of stones (gibbers) and the exposure of clay soils, can result in significant erosion by either wind or water. Even in gently sloping areas, water can gather enough force to cause erosion gullies in exposed soils (Santos 1997). The erosive potential of these soils is clearly evident in areas where grading or removal of gibber has resulted in severe erosion and long-term scarring on the landscape. For example, creation of windrows during seismic activities can remove the protective layer of gibber and result in gully and sheet erosion.

Hydrology

Permanent surface water sources are generally lacking, but temporary pools of water often form after rain in low depressions or gilgai. Minor drainage channels occur throughout lowland plain areas.

Flora

There is an immense range of vegetation throughout gibber country. On the southern and south western margins, relatively dense low open shrubland of Bladder Saltbush, Low Bluebush and Cotton Bush are common. Further north, much of the area is naturally bare, but Mitchell grass tussock grasslands become more frequent. In other gibber areas, the main cover may be short-lived Copperburrs and ephemeral grasses. There is still further variation caused by hills and drop-offs where small trees or tall shrubs, particularly Emu Bushes, may form a tall open shrubland.

Fauna

Gibber Plains have a poor fauna assemblage compared to other land systems in the region. Only a minority of the bird assemblage of the South Australian Cooper Basin is considered to be resident (Brandle and Reid 1997). Gibber areas are an important habitat for a number of bird species including the chestnut-breasted white face, the inland dotterel and the gibber chat. The chestnut-breasted whiteface is unusual amongst birds in being endemic to the gibber plain area (Reid *et al.* 1990).

Common mammal species include the stripe-faced dunnart, fat-tailed dunnart, dingo and Forrest's mouse. Less common species include the fawn hopping mouse and Gile's planigale. Gile's planigale is common in habitats with cracking clay soils. The kowari is endemic to the stony deserts and considered vulnerable to extinction. It appears to be restricted to the north-east region of South Australia (Brandle 1997a).

6.2. Social Environment

6.2.1. Land Use and Tenure

The primary land uses in the basin are pastoral, oil and gas exploration and production, conservation and tourism (MSCB 1997). Sixty percent of the region is used for pastoral production and the majority of the remainder falls within Regional Reserves.

Pastoral Land Use

The main pastoral enterprise in the region is beef cattle production on native pasture. Pastoral properties located within the Cooper Basin operational areas are:

- Merty Merty;
- Gidgealpa;
- Cordillo Downs;
- Innamincka;
- Clifton Hills;
- Mungeranie;
- Bollards Lagoon; and
- Mulka.

Operators within the South Australian Cooper Basin carry out their activities on four properties that have either obtained a level of certification or are in the process of conversion to NASAA Organic Beef Export (OBE). These include Bollards Lagoon, Merty Merty, Mungeranie and Cordillo Downs. The OBE Guidelines identify the maximum levels of chemicals (including metals and hydrocarbons) allowable in soil, consistent with allowing organic certification for beef exports.

In addition landholders are certified under the Cattle Care Quality Assurance System. Cattle Care is an initiative of the Cattle Council of Australia and places emphasis on minimising the risk of chemical contamination, bruising and hide damage and ensuring that herds are effectively managed and improved. In particular, the contamination of property and livestock by organochlorines and other persistent chemicals must be minimised, and contaminated cattle identified.

6.2.2. Conservation

The region contains some of South Australia's largest conservation reserves dedicated under the *National Parks and Wildlife Act 1972*. The main reserves are Innamincka Regional Reserve and Strzelecki Regional

Reserve and Coongie Lakes National Park. Regional Reserves are areas proclaimed for the purpose of conserving wildlife, natural or historical features while allowing responsible use of the area's natural resources. As such, oil and gas production and processing can occur within Regional Reserve areas.

Together, the Innamincka and Strzelecki Regional Reserves account for just over two million hectares of land within the Cooper Basin region. In 1987, part of the Cooper Creek System was proclaimed as the Coongie Lakes Wetland of International Importance under the Ramsar Convention. The Ramsar wetland is defined by Lake Moorayeppe to the north, the Queensland border at the crossing of Cooper Creek to the east, and a point south-west of Lake Hope. It is estimated that the Coongie Lakes Wetlands Ramsar area covers 30% of the known oil and gas resources within the South Australian portion of the Cooper Basin (DEHAA 1999).

Oil and Gas Production

While the supporting infrastructure extends throughout much of the central and north-east portion of the Cooper Basin in South Australia, the land used for gas production is small.

Santos is the predominant petroleum company in the area, operating a total of 24 gas and oil satellites across the Cooper Basin, the Moomba petroleum processing plant in South Australia and associated infrastructure (Figure 1).

6.2.3. Socio-economic

The present population of the Cooper Basin region comprises a small number of residents working in the pastoral industry and over 1000 petroleum industry workers, largely based at Moomba. Between 40,000 and 50,000 tourists have been estimated to visit the region annually. The Strzelecki Track, Innamincka Regional Reserve and Coongie Lakes wetlands are major tourist attractions in the region.

Infrastructure in the region is minimal. Unsealed roads service the district, with the Strzelecki and Birdsville tracks being the major routes through the region. Moomba and Innamincka are the main population centres.

Santos contributes significant investment in the Cooper Basin region, including maintenance and upgrades of roads and facilities. The Cooper Basin operations currently contribute over \$50 million in royalties to South Australia each year.

6.3. Heritage

The Cooper Basin area has broad indigenous cultural and European historical significance. There are a range of current land use types throughout the area including conservation, tourism, oil and gas production and pastoral activities. While the regional population has decreased with time, tourist numbers are consistent. The region remains generally undeveloped in terms of infrastructure and roads.

6.3.1. Aboriginal Cultural Heritage

The north-east desert region historically sustained a significant Aboriginal population, particularly in the area surrounding Cooper Creek and its many channels (Santos 1998b).

Santos has two primary Aboriginal stakeholders in the South Australian Cooper Basin, the Dieri and Yandruwandha / Yawarrawarrka native title groups. The Dieri are recognised as native title holders for an area of Santos operations that includes the Tirrawarra and Charo fields. The Yandruwandha / Yawarrawarrka are pursuing a consent determination over a native title claim area that

incorporates the Dulingarri, Moomba (South and East) and Limestone Creek fields and most of the Nappa Merrie Trough Unitisation Zone.

Sites of Aboriginal heritage can still be identified throughout the region and include features of spiritual importance and archaeological sites: for example middens, artefact scatters, rock engravings, arrangement sites, burial sites and quarries (Blackley *et al.* 1996) (are summarised in Table 5).

Table 5: Land Types and Aboriginal Artefacts

Land Types	Artefacts and Sites	Location of Sites
Sand Dunes	Burial sites: common	Often in eroding sand dunes
	Shell middens: common	Near sources of permanent water such as Cooper Creek and Coongie Lakes
Floodplains	Burial sites	Isolated dunes and sandy rises
	Camp sites	Isolated dunes and sandy rises
	Shell middens	Near lakes and rivers
	Rock art	Near lakes and rivers
	Tree scars: rare	Along rivers and creeks
	Stone artefact scatters	Near lakes and rivers
Gibber Plains	Cleared pathways	Near stone arrangements
	Stone tool quarries	Mesa caps
	Stone arrangements	Gibber country

Sand dunes often contain the largest and most important archaeological sites within the Cooper Basin region. For example, stones found on sand dunes may be representative of sites of Aboriginal cultural significance. Burial sites are also relatively common and are often found in eroding sand dunes. Shell middens are another common feature, particularly near sources of permanent water such as Cooper Creek and Coongie Lakes.

Clay covered floodplains contain small numbers of sites of Aboriginal heritage. Campsites and burial sites are often found on sandy rises and isolated dunes in floodplains, while stone artefact scatters, shell middens and rock art are found near lakes and rivers (particularly Cooper Creek). Although relatively uncommon, scar trees can be found along creeks and rivers. Boomerang scars can also be found on trees of various types, including Acacias and Eucalypts.

Large numbers of sites of Aboriginal heritage are found in the pebble-covered gibber country. The dense bands of stone that cap mesas were often extensively quarried for making stone tools. Stone arrangements can be recognised from the combination of regular patterns of larger rocks in lines, circles and cairns. Cleared pathways near these stone arrangements are also common.

The Cooper Creek region has been proclaimed a State Heritage Reserve because of its association with Aboriginal and European history as well as its environmental significance. The area encompasses Innamincka and a one kilometre strip either side of Cooper Creek, totalling 120 km². There are a number of

sites of Aboriginal heritage including relics, campsites, quarries and engravings with several unique designs located around Cullyamurra waterhole.

6.3.2. Non-Aboriginal Heritage

Europeans commenced exploration of the region during the 1840s. Pastoral development rapidly followed exploration and by the mid-1880s all available pastoral leases in the region had been taken up.

Rapid pastoral expansion was due in part to the presence of Afghan cameliers who are thought to have advanced the opening up and development of the region by fifty to sixty years. Afghan cameliers first arrived in the north-east desert region in the 1860s. They were employed on survey expeditions into the arid interior and transported supplies from the railhead to remote settler areas. From 1884, Marree was the hub of a vast pack-camel transportation network.

There are numerous historical sites scattered throughout the region, many of which are listed on the National Heritage Register. Most sites are associated with exploration and the expansion of pastoralism throughout the north-east deserts.

Historical sites in the far north-east of South Australia listed on the National Heritage Register as registered or indicative are:

- Blanchewater Homestead on the Strzelecki Track;
- Wills Monument and Blazed Tree;
- Burke's Memorial;
- Grays Tree;
- Horse Capstan Pump and Well;
- Tinga Tingana Homestead Ruin;
- Cordillo Downs Homestead and Woolshed;
- Australian Inland Mission Nursing Home (former); and
- Cadelga Outstation Ruin.

6.4. Stakeholder consultation

Santos recognises the importance of working with its stakeholders in the Cooper Basin. Santos has been operating in the region for over 40 years and has throughout that period consulted with relevant stakeholders. We have a long history of mutually beneficial relationships with pastoral stakeholders in the Cooper Basin and also continually engage with traditional owner groups.

Section 6 of the EIR (2003, 2009) demonstrates that key stakeholders are aware of and understand the relevant issues associated with South Australia Cooper Basin operators' drilling and well operations in the Cooper Basin.

7. Risk Assessment

This EAR and accompanying risk assessment (Appendix A) have been undertaken by Santos as an addition to the EIR (2003, 2009). The purpose of this document is to address fracture stimulation activities within the SEO DWO framework in further detail, ensuring these risks are appropriately managed in accordance with Objectives 1-12 of the SEO DWO.

This EAR sets out how Santos' conventional and unconventional gas fracture stimulation activities are conducted such that potential risks to the environment are minimised. It demonstrates that:

- There are no risks associated with Santos' fracture stimulation activities that are rated above risk level 2 (refer to Figure 28) and cannot be managed to As Low As Reasonably Practical (ALARP);
- Santos' operational practices are consistent with leading industry practices;
- The level of management controls Santos employs to control the potential risks to the Cooper Basin environment associated with fracture stimulation have been and continue to be appropriate; and
- The risks associated with fracture stimulation activities are adequately managed by continued operation in accordance with the SEO DWO.

Santos' fracture stimulation operations are undertaken in accordance with Environment, Health and Safety Hazard Standards, industry standards and legislative and regulatory requirements to meet the objectives set out in the SEO DWO. The controls and procedures employed to manage the potential hazards associated with fracture stimulation affects the overall risk profile of our business such that operations do not pose an unacceptable risk to the environment.

Santos has developed an Environment, Health and Safety Management System (EHSMS) to provide a company-wide approach to effectively manage Environment, Health and Safety (EHS) risks and to allow for continual EHS improvement. EHSMS Standard 09 (EHSMS09) provides the framework under which Santos identifies and eliminates, or puts in place appropriate controls, in order to reduce potential harm to people and the environment.

This standard outlines the requirements to:

- Identify EHS hazards, assess their risk and control them to As Low As Reasonably Practicable (ALARP);
- Identify significant EHS hazards and document how they are being managed to as low as reasonably practicable;
- Have a system to escalate EHS significant hazards to management for approval of continued operation and for management to sign off on EHS significant hazards, controls and how critical controls will be checked; and
- Meet legislative requirements that require certain EHS hazards and risks to be managed.

The potential for risk to the environment as a result of Santos' operations is evaluated based on six levels of environmental consequence and six levels of likelihood. The levels of consequence are used to describe the severity and or impact to ecosystems, plants and animals with conservation value and land / water / air ranging from localised and short term environmental of community impact – readily dealt with (negligible) to regional and long term impact on an area of significant environmental value (critical) and the levels of likelihood ranging from remote to almost certain are used to predict the probability of a hazard occurring. Figure 28 presents the operational matrix Santos uses to evaluate risk.

OPERATIONAL RISK MATRIX

CONSEQUENCE		PEOPLE P	Minor injury - first aid treatment or no effect. Process Safety Exception	Injury requiring medical treatment with no lost time. LOCI Tier 2 OR any loss of primary containment irrespective of the quantity	Medium term reversible disability to one or more persons. Significant medical treatment, disabling or lost time injury. LOCI Tier 1	Extensive injuries OR irreversible disability OR multiple lost time injuries. High Impact Process Safety incident	Single fatality and/or severe irreversible disability to multiple people	Multiple fatalities or significant irreversible disability to 10's of people
		ENVIRONMENT E	Localised and short term environmental or community impact - readily dealt with	Localised and short term impact to an area, plants or animals of environmental value. Readily treated.	Localised and medium term impact to areas, plants or animals of significant environmental value. Remediation may be difficult or expensive.	Extensive and medium-term impact to an area, plants or animals of recognised environmental value. Remediation possible but may be difficult or expensive.	Destruction of an important population of plants or animals or of an area of significant environmental value. Complete remediation not practical or possible.	Regional and long term impact on an area of significant environmental value. Destruction of an important population of plants and animals with recognised conservation value. Complete remediation impossible.
FINANCIAL A		< AUD 30K IMPACT	AUD 30K-300K IMPACT	AUD 300K-3M IMPACT	AUD 3-30 M IMPACT	AUD 30-300M IMPACT	> AUD 300M IMPACT	
REPUTATION R		Kept on site. No media or community interest	Local media coverage. One or two community complaints.	State media coverage. Interest by regulator.	State media coverage over several days. Involvement by regulator and shareholders.	National media coverage over several days. Shareholders and Board exercise control. Potential for class action.	Prominent international media coverage over several days. Long term affect on share price. Leads to changes at executive level management.	
LEGAL L		Minor legal issues, non-compliances and breaches with regulation.	Breach of regulation with investigation or report to authority with possible prosecution and fine.	Major breach of regulation with punitive fine. Involvement of senior management.	Litigation or prosecution costing >\$1M. Investigation by regulatory body. Litigation involving weeks of senior management time.	Major litigation or prosecution with damages or fines of >\$10m+ plus significant costs.	Public inquiry taking up resources and executive time. Major litigation or prosecution with damages/fines of >\$100m+ plus significant costs. Custodial sentence for a manager.	
LIKELIHOOD	INCIDENT	THREAT	I	II	III	IV	V	VI
	Has occurred three times or more during the last year	ALMOST CERTAIN Occurs in almost all circumstances OR could occur within days to weeks	f 2	3	4	5	5	5
	Has occurred at least once in the last year	LIKELY Occurs in most circumstances OR could occur within weeks to months	e 2	3	4	4	5	5
	Has occurred once in 3 years	OCCASIONAL Has occurred before in Santos OR could occur within months to years	d 2	2	3	4	4	5
	Has occurred once in 10 years	POSSIBLE Has occurred before in the industry OR could occur within the next few years	c 1	2	2	3	4	5
	Has occurred once in 30 years	UNLIKELY Has occurred elsewhere OR could occur within decades	b 1	1	2	2	3	4
Has occurred once in 100 years	REMOTE Requires exceptional circumstances and is unlikely even in the long term OR only occurs as a "100 year event"	a 1	1	1	2	3	3	
RISK LEVEL	MITIGATION / INVESTIGATION FOCUS (ADD ADDITIONAL BUSINESS UNIT SPECIFIC REQUIREMENTS WHERE REQUIRED)			GOVERNANCE MECHANISM (ADD ADDITIONAL BUSINESS UNIT SPECIFIC REQUIREMENTS)		AUTHORITY FOR ACCEPTANCE OF PLAN TO ACHIEVE ALARP	AUTHORITY FOR ACCEPTANCE OF RESIDUAL RISK AT ALARP	
5	<ul style="list-style-type: none"> - Intolerable risk level - Following verification of the residual risk at level 5, activity must stop - Activity cannot recommence until controls implemented to reduce residual risk to level 4 or lower - Dedicated multi-disciplinary incident investigation team - Management involvement in the investigation 			<ul style="list-style-type: none"> - Top Level Operations Governance or EHS Forum/Committee - Sponsorship of incident investigation at Level 2 or 3 Manager level 		Level 3 Manager (e.g. General Manager, Country President) Normally within 1 month	Intolerable Risk Level	
4	<ul style="list-style-type: none"> - Assess risk to determine if ALARP - If ALARP, activities related to maintenance of controls/barriers prioritised & managed - If not ALARP, improve existing controls and/or implement new controls - Dedicated multi-disciplinary incident investigation team 			<ul style="list-style-type: none"> - Value Stream level performance reviews or applicable EHS Forums - Sponsorship of incident investigation at level 3 Manager level 		Level 3 Manager (e.g. General Manager, Country President) Normally within 1 month	Level 3 Manager (e.g. General Manager, Country President) Normally within 1 month	
3	<ul style="list-style-type: none"> - Assess risk to determine if ALARP - If ALARP, activities related to maintenance of controls/barriers prioritised & managed - If not ALARP, improve existing controls and/or implement new controls - Full incident investigation 			<ul style="list-style-type: none"> - Asset level performance reviews or applicable EHS forums - Sponsorship of incident investigation at Level 4 Manager Level 		Level 4 Manager (e.g. Asset or Functional Manager) Normally within 3 months	Level 4 Manager (e.g. Asset or Functional Manager) Normally within 3 months	
2	<ul style="list-style-type: none"> - Assess risk to determine if ALARP - If ALARP, activities related to maintenance of controls/barriers prioritised & managed - If not ALARP, improve existing controls and/or implement new controls - Incident investigations using simple tools 			<ul style="list-style-type: none"> - Site level performance review or applicable EHS forums - Sponsorship for incident investigation at Level 5 Manager/Supervisor level 		Level 5 Manager (e.g. Area Manager, Team Leader, Superintendent or equivalent)	Level 5 Manager (e.g. Area Manager, Team Leader, Superintendent or equivalent)	
1	<ul style="list-style-type: none"> - Managed as stipulated by the related work processes - No incident investigation required 			<ul style="list-style-type: none"> - Periodic reviews to identify patterns and underlying threats 		Deemed ALARP	Deemed ALARP	

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Date of last revision: 02-Jul-2013

Figure 28: Operational Risk Matrix

7.1. Geology

As part of the Santos activity notification process a geological risk assessment of the proposed fracture stimulation operation is undertaken. The assessment considers data collected in the field such as formation depth and formation separation, well construction, fracture stimulation design and clean-up and flowback.

7.2. Aquifers

7.2.1. Leakage to Aquifers due to loss of well integrity

Objective 6 of the SEO DWO is to minimise loss of aquifer pressure and avoid aquifer contamination. Leakage to, and/or depressurization of, aquifers due to loss of well integrity is assessed as a remote likelihood due to our stringent management controls.

As described in Section 3.2, the design and execution process followed by Santos throughout the well construction phase ensures casing strings are designed using the relevant load cases and casing design software, and are installed in line with current Industry Best Practice. As a result, casing integrity during any fracture stimulation operation will be maintained through the monitoring of treating pressures and ensuring that maximum surface pressures are within the limitations of the casing itself. Surface casing is monitored throughout the construction phase and protected through use of a Pressure Relief Valve (PSV). Use of the PSV further ensures that any potential problems with the production casing integrity are known and mitigated before a critical breach of the casing system through to the surface casing can occur.

the production phase of the well, the following controls are used:

- Aquifers are isolated behind multiple casing strings which are cemented in place;
- Cement in the production hole is placed to isolate aquifers;
- Casing strings are designed by an appropriately qualified and competent engineer and reviewed by a senior engineer and/or external consultant (where required);
- Metallurgy of casing string designed to withstand wellbore fluid and gas composition;
- Cased hole cement bond logs maintained to confirm quality and bond of cement job;
- Well Integrity Management System and testing procedures in place to ensure well integrity throughout the life of well (as per Section 3.2);
- New casing and wellhead installed on every new drill;
- Regular well head inspection and checks by production operator throughout the life of well.

Implementation of the above control mechanisms during the fracture stimulation and production operation phases of a well ensure that casing integrity is maintained and that leakage to aquifers due to loss of well integrity is considered a remote likelihood at an overall risk ranking of 1 (the lowest ranking). Section 3.2 of this document and Section 4.3 of the EIR Drilling and well Operations 2003 provides additional information on Santos' well integrity management and testing procedures.

The management strategies and control measures described above ensure that leakage to and/or loss of aquifer pressure and subsequent aquifer contamination does not occur and complies with Objective 6 of the SEO DWO.

7.2.2. Fracture Propagation into Overlying Great Artesian Basin Aquifers

Ensuring fracture stimulation operations of gas targets do not result in propagation into Great Artesian Basin (GAB) aquifers is a priority for Santos operations. Accessing these aquifers could result in:

- Potential contamination of the aquifers with stimulation fluids; and
- Excessive water production resulting in an uneconomic well if it cannot be shut in.

To ensure that propagation does not occur, Santos assesses the risk of accessing any water bearing zones during the well project scoping phase. If a fracture stimulation target is deemed to have an unacceptable risk of accessing a high water bearing zone or a GAB aquifer, the fracture stimulation stage will not be pursued.

Section 4.4 provides detail of the control procedures in place that manage the remote likelihood of fracture propagation into overlying aquifers.

Prior to any stimulation activities being undertaken, modelling works (for every location) to predict the extent and impact of fracture propagation are undertaken. The model is built using reservoir data collected in the field including, but not limited to, geological and/or hydrogeological logs, formation pressures and ductility, matrix porosity, hydraulic conductivity, fracture frequency and ratios of anisotropy. Model outputs include fracture network geometry, pressure gradients, estimates for fluid and proppant requirements as well as predicted return rates. The intent of the modelling is to maximise the economic return of the target gas horizon by minimising impacts to overlying and underlying formations and limiting the volume of PFW produced.

Water production rates throughout the flowback and production phase of a well are monitored to ensure that water production from each zone is within the expected range of deliverability. In conjunction with the above operational controls and procedures, Santos has a high level of confidence that it understands the vertical and lateral extent of fracture stimulation treatments.

The management strategies and control measures described above ensure that leakage to and/or loss of aquifer pressure and subsequent aquifer contamination is managed in accordance with Objective 6 of the SEO DWO

7.2.3. Leakage to GAB Aquifers Through Geologic Media

Potential leakage of fracture fluids, formation water and hydrocarbons into aquifers of the Great Artesian Basin (GAB) or reverse flow from the aquifer into a pressure-depleted reservoir, should be considered in two situations:-

- Conventional Cooper Basin stimulations (medium scale); and
- Unconventional Cooper Basin stimulations (medium to large scale).

Fracture height growth into the GAB aquifers is not considered to be a credible risk.

The extent of the fracture network produced by fracture stimulation depends on a number of factors:-

1. Brittleness, elasticity and strength of the target formation;
2. Proximity from the stimulation initiation point to the boundary of the target formation being stimulated and the rock properties of the adjacent formations;
3. The stress regime in the vicinity of the wellbore being stimulated at the level of the operation;
4. The properties of the fluid being used for the stimulation; and
5. The volume, rate and pressure of the pumped fluids.

The rock properties in formations in the Cooper Basin are known from such measurements as Young's Modulus (stiffness of elastic material), Poissons Ratio (change in shape in response to an applied force) and rock strength testing done on core samples and from the response to previous fracture stimulations. Modelling to predict the type and extent of the proposed fracture network is done prior to fracture

stimulations using known values for each of the properties 1-5 above. In some instances the models are calibrated in certain wells by microseismic monitoring that determines the vertical and lateral extent of the fracture propagation by “listening” to the rocks as they crack at the leading edge of the propagating fractures. Feedback on the pressure profile throughout the stimulation event and post-stimulation flow-back adds to the knowledge of effectiveness of the stimulation exercise. The result of each stimulation event is predicted in terms of its extent to be confined within the targeted Permian reservoirs with a high degree of confidence.

Conventional Cooper Basin Stimulations

The objective of fracture stimulating in conventional Cooper Basin gas targets is to improve conductivity along reservoir sands that have low permeability and occurs at the pore and depositional scale of a unit. Reservoir sands in the Toolachee, Daralingie, Epsilon, and Patchawarra formations are relatively thin (1-10 metres) bound above and below by low to very low permeability coals, shales and siltstones, often from 2 – 30 metres thick. The Tirrawarra Sandstone is a single sand unit with a highly variable thickness averaging around 70 metres (Hill and Gravestock in Drexel and Preiss, 1995). The Murteree Shale (around 70 m thick) and the Roseneath Shale (up to 100m thick) separate the Patchawarra from the Epsilon formation and the Epsilon from the Daralingie or Toolachee formations where the shales are present and not removed by erosion within the depositional succession.

The whole of the gas-bearing coal measure succession (Toolachee to Patchawarra inclusive) is capped over the majority of the Cooper Basin by the shales and siltstone seals of the Nappamerri Group (100 – 500 metres thick). The Nappamerri seal has been removed by erosion during the late Triassic around the eastern, western and south-western margins of the Cooper Basin. Only where the Nappamerri seal has been completely eroded do the reservoir sands of the Cooper Basin sit in contact with the overlying units of the Eromanga Basin wherein lie the GAB aquifers.

Excessive fracture height growth outside the targeted formation is of remote likelihood due to the changes in geomechanical properties, which will limit vertical fracture propagation. As there are multiple sands in each formation, each separated by shale and in many cases, coal, should a fracture network break through one barrier above or below, there are numerous additional barriers to prevent a fracture breaking out of the target formation. The Murteree Shale provides an impenetrable barrier above the Patchawarra Formation, as does the Roseneath Shale to stimulations in the Epsilon Formation. The very thick Nappamerri Group siltstones provide a safety barrier over much of the Cooper Basin, except around the margins where it has been eroded. In these areas, gas has already escaped into the Eromanga Basin where an aquitard prohibits further upward migration.

Prior to any stimulation activities being undertaken in the field, modelling works/risk assessment (for every location) to predict the extent and impact of fracture propagation are undertaken. The model is built using data collected in the field including geological and/or petrophysical logs, formation pressures, geomechanical properties, matrix porosity, hydraulic conductivity, fracture frequency and ratios of anisotropy. Model outputs include pressure gradients, extent of fracture network propagation, proppant concentration (lb/ft^2), estimates for fluid and proppant requirements as well as predicted return rates. The intent of the modelling is to optimise the return of the target gas horizon by minimising impacts to overlying and underlying formations and limiting the volume of produced formation water.

Unconventional Cooper Stimulations

Fracture stimulation into unconventional resource zones can be done at a different scale and with a different purpose to treatments in conventional reservoirs. An unconventional stimulation aims to provide a fracture

network into rock that would normally be unproductive where gas is locked in until fractured. The rocks are usually harder as these resources are deeply buried and of very low permeability. This means the treatment is completed by pumping at higher pressures with greater volumes of fracture fluid and at a greater rate, to stimulate a larger volume of rock than a conventional stimulation target.

In the Cooper Basin, the current unconventional targets are often found in the deeper areas of the Basin including the Nappamerri Trough. Similar to conventional stimulation, numerous intraformational seals make the likelihood of vertical fracture growth into a GAB aquifer remote.

The sealing Nappamerri Group rocks have their thickest development (up to 500 metres) in the Nappamerri Trough over the top of the unconventional targets. The biggest fracture stimulation jobs are protected by the thickest seals. Consequently the likelihood of leakage through geological media in either unconventional or conventional fracture stimulations is remote with a risk level of 1.

The management strategies and control measures described above ensure that leakage to and/or loss of aquifer pressure and subsequent aquifer contamination does not occur in accordance with Objective 6 of the SEO DWO.

7.2.4.Lateral Migration of Injected Fluids

Lateral migration of injected fluids away from the fracture treatment initiation point cannot occur. Once the fracture stimulation treatment has been completed, the well is flowed back creating a pressure differential and a flowpath from the end of the fracture treatment point back towards the wellbore. This pressure differential continues into the production phase of the well where the production of reservoir fluids will increase the pressure differential and ensure migration of fracture stimulation fluids is unlikely. Further to this, the formations selected for fracture stimulation are low permeability formations in which it is unlikely that any migration of fracture stimulation fluids is able to occur.

The management strategies and control measures described above ensure that leakage to and/or loss of aquifer pressure and subsequent aquifer contamination does not occur in accordance with Objective 6 of the SEO DWO.

7.2.5.Fracture Propagation between Isolated Zones

Fracture propagation between isolated zones may occur in some circumstances where fracture stimulation targets are in close proximity. This will not have a significant impact as cross flow will be negligible between zones of comparable composition which are the secondary target of the fracture stimulation.

The Permian formations are separated by thick shales which act as aquitards and restrict fracture height growth minimising the potential of connection of isolated zones. Further to this, once the fracture stimulation is complete, flowback and production will deplete the target formation creating a differential pressure and flow path toward the target formation. As a result, any cross flow between these formations will cause a flow of stimulation fluid back towards the target formation and minimise retained stimulation fluids in neighbouring Permian Formations.

Water zones isolated within the formations are identified by Santos and if any risk of fracture propagation into these zones is present these fracture targets will be avoided. As a result, propagation into neighbouring zones will be designed to only access neighbouring / secondary target gas formations and any resultant cross flow, although minimal, will be of equivalent composition. This is considered a very low risk for Santos' fracture stimulation operations.

The management strategies and control measures described above ensure that leakage to and/or loss of aquifer pressure and subsequent aquifer contamination does not occur and meets Objective 6 of the SEO DWO.

7.2.6. Groundwater Impacts due to Water Use

The majority of water sourced for Santos fracture stimulation activities is recycled formation water from satellite evaporation ponds.

To prevent the loss of water stored on site to seepage Turkey's Nest are constructed with a HDPE, stabilized UV synthetic liner.

The water source for fracture stimulation operations is considered as part of the project initiation phase and in some cases such as the Cowralli Simultaneous Operations (SIMOPS) project oil satellite water (Gidgealpa Oil Satellite) will be piped from the closest suitable water source to the operation site. However, where distances exceed ~15 to 20 km water, will be trucked to the operational site.

Where pond water of suitable quality is not available, groundwater will be used to generate fracture stimulation fluid. Extraction of groundwater is undertaken within the framework of the *Natural Resources Management Act 2004* and in accordance with the DEWNR water well construction permits and licence conditions. It is noted that groundwater extraction for fracture stimulation operations is not common practice and to date fracture stimulation operations requiring bore water for fluid generation has been limited to the Darmody #1 bore located in the Bookabourdie field. Darmody #1 is a Santos owned bore, is 210 m deep and is classified as sub-artesian. There are no other registered bores within a 5 km radius of the Darmody #1 bore and therefore the risk to other potential users is negligible.

In the event that there is no suitable satellite pond water and/or existing bore water available for fracture stimulation activities, a new groundwater extraction bore may be required. The installation and construction of new groundwater extraction bores will be undertaken in accordance with the *Far North Prescribed Wells Area Water Allocation Plan (FNPWA WAP)* and DEWNR by a licensed Class 3 Waterbore driller. Prior to any drilling works, a search of government registered bores within a 5 km vicinity of the proposed location will be undertaken. Where registered bores are identified within this area, consultation with the well owner will be undertaken to ensure that the potential for impacts due to drawdown are managed.

Where proposed groundwater bores are in an area adjacent to, and/or in the vicinity of, a surface water system that is dependent on base flow, an impact assessment will be undertaken and the bore moved to an alternative location where required.

Santos' groundwater consumption for fracture stimulation operations is not considered a risk. Implementation of numerous control systems including preferentially using oil and gas satellite pond water, lining of well site Turkey's Nests and compliance with relevant licence conditions ensures that the risk to other groundwater users is negligible.

The management strategies and control measures described above ensure that potential for leakage to and/or loss of aquifer pressure and subsequent aquifer contamination is managed in accordance with Objective 6 of the SEO DWO.

7.3. Soil and Shallow Groundwater

Objective 2 of the SEO DWO is to minimise disturbance and avoid contamination to soils. Objective 4 is to minimise disturbance to drainage patterns and avoid contamination of surface water and shallow

groundwater resources. Objective 11 seeks to optimise (in order of most to least preferable) waste avoidance, reduction, reuse, recycling, treatment and disposal.

Impacts to soil and shallow groundwater are generally associated with spills and leaks of fuel, chemicals and/or other fluids including PFW, brackish or saline water and fracture stimulation fluids.

To minimise impacts to soil and shallow groundwater the storage and handling of fuel and chemicals is undertaken in accordance with Santos Standard ESHS08 *Chemical Management and Dangerous Goods* and relevant standards and guidelines (e.g. EPA bunding guidelines and AS 1940) and meets Objectives 2 and 4 of the SEO DWO. This includes but is not limited to fuels and chemicals being stored with appropriate secondary containment such as double skinned tanks (fuel storage) and 110% bunding capacity for chemicals. Training of appropriate personnel in emergency spill response procedures, the use of spill kits, chemical and dangerous goods handling including re-fuelling and cleanup procedures is a requisite for working on Santos sites. In the event of a spill, contaminated material is cleaned up as soon as practicable and transported to an appropriate facility for disposal / treatment. Where soil hydrocarbon staining remains, the material may be treated in-situ using a product to facilitate biological breakdown of the remnant hydrocarbons.

Generation, storage and disposal of waste associated with fracture stimulation operations are undertaken in accordance with Santos Standard EHS04 *Waste* and relevant legislation and guidelines. Waste streams generated as a result of fracture stimulation activities include:

- Produced fracture stimulation fluids
- Fracture stimulation solids/proppant
- IBCs
- Wooden pallets
- Bulky bags
- Paper
- Putrescibles

The largest waste streams generated as a result of fracture stimulation activities are produced fluids and solids/proppant. Produced fluids are flowed back to a lined pit (UV stabilised HDPE or equivalent) or tank and then transported to a nearby facility for disposal or treatment in lined pond systems. Santos is currently evaluating options for the classification and treatment of produced fluids in accordance with SA EPA guidelines. Solids and proppant are treated at landfarms. Waste material is transported to approved waste management facilities by licensed waste management contractors.

Waste is management in accordance with EHS04 and meets Objective 11 of the SEO DWO.

Storage of water used for fracture stimulation activities is contained in above ground tanks and/or in temporary pits lined with UV stabilised polyethylene to prevent salinisation of soils and/or shallow groundwater. Temporary tanks are installed in accordance with manufacturer specifications and pits are constructed in accordance with Santos Standard EHS02 *Underground Storage Tanks and Bunds* which includes use of appropriate liners (HDPE or equivalent) and above ground earthen bunds. During operations, tanks and ponds are inspected daily (as a minimum) for potential breaches or leaks and repair works are undertaken when and where required. A minimum of 300 mm freeboard in tanks and pits is maintained to prevent overflow associated with flooding or surface water ingress and where practicable chemical utilisation is minimised. Where possible, alternative, lower toxicity chemicals will be used to achieve

the same outcomes as the use of higher toxicity chemicals. Fluid storage in accordance with EHS02 and meets Objective 2 and 4 of the SEO DWO.

Routine inspection of flowback lines, connections, high pressure equipment and trip systems is undertaken to prevent operations above design limits and emergency shutdown systems are installed on all equipment to prevent uncontrolled releases of flowback water, fuel and/or other chemicals. The design, inspection and shutdown procedures associated with the operation of fracture stimulation equipment (i.e. high pressure equipment) reduces the risk of soil and shallow groundwater contamination from fracture stimulation fluids by minimising the volume of fluids released.

In the event of an uncontrolled release emergency response procedures will be employed and operations shut down to allow for cleanup and remedial works. Remedial works may include:

- Vacuum removal of surficial chemicals or fuel;
- Installation of a collection or drainage trench(es);
- Pumping of produced fluids to alternative storage (i.e. above ground tank, tanker);
- Installation of fencing around impacted areas; and
- Other works upon consultation with DMITRE and the Environment Protection Authority.

Fencing around lined Turkey's Nests is installed during lease construction works to prevent stock and wildlife access and fencing around flowback pits is installed post operations. Flowback pits are partially fenced during fracture stimulation operations, however increased site activity acts as a deterrent to stock and wildlife. Immediately following cessation of flowback operations, fencing is completed around flowback pits and installed in accordance with Santos operational standards.

The phreatic water table across much of the Cooper Basin is greater than 15 m below ground level (m bgl), is brackish to saline (5,000 – 30,000 mg/L Total Dissolved Solids (TDS)), low yielding and has limited beneficial re-use. The rate of infiltration of surface spilt contaminants or leakage from ponds is likely to be low based on the presence of low permeability clay lenses, low rainfall and high rates of evaporation. The impact to soil and shallow groundwater as a result of pond seepage is likely to be confined to a localised area with limited consequences to other potential users. In the event of a pond failure, impacts could affect a larger area but with similar consequences to pond seepage. Given the control measures in place to manage potential risks such as pond construction, lining, operation and monitoring, the residual risk to soil and shallow groundwater ranges from level 1 to 2 which is considered to be low. Fluid storage is in accordance with EHS02 and meets Objective 2 and 4 of the SEO DWO.

Objective 2 of the SEO DWO is to minimise disturbance and avoid contamination to soils. Objective 4 is to minimise disturbance to drainage patterns and avoid contamination of surface water and shallow groundwater resources and Objective 7 of is to minimise disturbance to native vegetation and native fauna. Impacts to soil associated with land disturbance such as lease and road builds are managed in accordance with Santos Standard EHS01 *Biodiversity and Land Disturbance*. It is considered that some important environmental values could be in close proximity to Santos fracturing activities. Therefore, prior to greenfield disturbance, or subsequent re-disturbance, a Santos Environmental Adviser and/or an external ecologist inspects the site for potential environmental impact. The assessment, and any recommendations for mitigation, is managed via the Santos Environmental Approval Request Tracking Form (EART). Approval conditions are in accordance with Santos Standard EHS06 *Environmental Impact Assessment and Approvals*, the SEO DWO and other relevant regulatory requirements must be accepted by the relevant project proponent prior to any physical works occurring.

Further to this, Santos is in the process of implementing an Environmental Sensitivity Profile (ESP) tool which identifies the environmental value(s) within the Cooper Basin and creates profiles of environmental sensitivity for specific areas based on these values. These are defined on a sensitivity rating scale of one through five and enable the user to understand the sensitivity of the receiving environments of its operations in the Cooper Basin. Areas of sensitivity are defined by geographic location and identified spatially within a hierarchical layer over the Cooper Basin operational areas.

The development and implementation of the ESP model is being undertaken to align with the objectives of the Queensland *Environmental Protection Act 1994* and the South Australian *Act* and the SEO DWO, with the intention of providing a risk based approach to assessing the impact of Santos activities on the environment in line with State and Commonwealth legislative requirements.

Land disturbance is conducted in accordance with EHS02 and meets Objective 2, 4 and 7 of the SEO DWO.

The management strategies and control measures described above ensure that impacts to soil and shallow groundwater do not occur in accordance with Objective 2, 4 and 7 of the SEO DWO.

7.4. Surface Water

Objective 4 of the SEO DWO is to minimise disturbance to drainage patterns and avoid contamination of surface water and shallow groundwater resources. Like soil and shallow groundwater, impacts to surface water are generally associated with spills and leaks of fuel, chemicals and/or other fluids such as PFW, saline water and fracture stimulation fluids.

As per Section 7.3, the storage, handling and disposal of fuels, chemicals and wastes generated as part of fracture stimulation operations is undertaken in accordance with Santos Standards EHS04 *Waste* and ESHS08 *Contaminated Sites* and relevant standards and guidelines (e.g. EPA bunding guidelines and AS 1940). This includes the use of secondary containment, training personnel in emergency spill response and chemical and dangerous goods handling and the use of spill kits. Waste management is undertaken by a licensed contractor with disposal to approved facilities.

Some undiluted chemicals used in the fracture stimulation process may be toxic to aquatic organisms and therefore the following controls are employed:

- Closed loop blending system maintained in accordance with manufacturer specifications;
- Construction of 350 m³ (average) capacity lined flowback pits to limit the volume of fluid stored on site;
- Construction of earthen bunds around flowback pits to prevent surface water ingress;
- Lining of flowback pits with an appropriately UV rated HDPE (or equivalent) liner;
- Maintaining minimum pond / pit freeboard;
- Routine inspection and repairs as required;
- All high pressure equipment rated to manufactures specifications;
- Emergency shutdown systems;
- Where possible alternate lower toxicity chemicals used;
- Lease location assessment to minimise potential impacts to drainage patterns and surface water contamination;
- Ecological assessment on new proposed lease locations;
- No operations during times of inundation at the site;
- No operations proximal to main surface water channels and/or permanent water holes;
- Where possible leases constructed on high ground;

- In low lying areas leases are not to be built up significantly (e.g. 300 mm);
- Monitoring of weather conditions and Cooper Creek gauging stations during periods of high rainfall for preparation of shutdown due to inundation/flooding; and
- Removal of fluids from pits/tanks where floodwater pose a site inundation risk.

As discussed in Section 7.3, prior to any new disturbance or subsequent re-disturbance an environmental assessment is undertaken and recommendations made based on field observations. Approval to undertake site works cannot progress until the project has accepted site specific environmental conditions. Conditions may include no works being undertaken during periods of rainfall / inundation and/or use of above ground fluid storage tanks only.

Where flood waters pose a risk to fracture stimulation operations, produced fluids can be removed from pits to reduce the volume of fluid stored on site, and mitigate the potential for flowback fluid release to the environment. Fluids can be transferred to sites that are not subject to flood risk including satellite facilities, alternative flowback pits or above ground tanks.

The controls employed to mitigate the likelihood of impacts to surface water associated with fracture stimulation activities provides confidence that the risk of a release is minor in accordance with Objective 4 of the SEO DWO.

7.4.1.Coongie Lakes Ramsar Wetland

The Coongie Lakes Ramsar Wetland (Section 6.1.3) covers approximately 1.9 million hectares of the Cooper Basin Floodplain and comprises a series of perennial and/or ephemeral freshwater wetlands, lakes, interdunal corridors, channels floodplains and swamps with limited connection to the Cooper Creek system. It also covers extensive areas of dunefield with no hydrological connection to Cooper Creek and Coongie Lakes. Hundreds of oil and gas wells currently operate within the designated Ramsar area.

All new and/or re-disturbances are subject to an environmental assessment which is undertaken in accordance with Santos Standard EHS06 Environmental Impact Assessment and Approvals, the SEO DWO and the recommendations made based on field observations.

As detailed in Sections 7.3 and 7.4, Santos has control measure in place to minimise potential impacts to soil and surface water systems from fracture stimulation activities. In addition, Santos does not undertake drilling or fracture stimulation activities within one kilometre of the Coongie Lakes National Park.

The control measures employed by Santos to manage potential risks to surface water systems, and specifically Wetlands of International Importance, provides confidence that fracture stimulation operations are appropriately managed in accordance with Objectives 4 and 7 of the SEO DWO. Where EPBC is triggered Santos will comply with all legal requirements including those under EPBC as they arise.

7.5. Stock / Wildlife and Vegetation

Objective 3 of the SEO is to avoid the introduction or spread of pest plants and animals and implement control measures as necessary, Objective 7 is to minimise disturbance to native vegetation and native fauna, Objective 9 is to maintain and enhance partnerships with the Cooper Basin Community and Objective 12 is to remediate and rehabilitate operational areas to agreed standards.

Impacts to stock, wildlife and vegetation are primarily due to the following:

- Spills and leaks from the storage and handling of fuels, chemicals or produced fluids;
- Interaction with fluid storage ponds;

- Use of roads and movement of vehicles and machinery;
- Activity outside of designated areas; and
- Waste storage and transport.

Stock and wildlife access to fuel, chemicals and flowback fluid storage areas presents a potential hazard which is managed by Santos Environmental Hazard Standards EHS01 *Biodiversity and Land Disturbance*, EHS04 *Waste*, EHS06 *Environmental Impact Assessment and Approvals* and Health and Safety Hazard Standard HSHS08 *Chemical Management and Dangerous Goods* and EHS09 *Pest Plants and Animals*. Controls include:

- Ecological assessment of new proposed lease sites to evaluate sensitivity, including habitat assessment;
- Storage of fuels and chemicals in designated areas;
- Scheduled (and/or upon request) removal of waste from operational sites;
- Immediate clean-up of any fuel or chemical spills;
- Pit construction including steep sided edges to prohibit vegetation growth and/or creation of beaches which could attract birdlife;
- Installation of stock proof fencing following cessation of flowback operations; and
- Regular and ongoing inspections (by site operators) to ensure fence integrity.

Where appropriate controls are not in place and/or where controls have failed, an incident report will be entered into the Santos incident management system (IMS) and actions assigned to rectify and/or circumvent reoccurrence.

The presence of fluid storage pits with steep plastic lined banks has the potential to trap stock or wildlife. Installation of stock proof fencing limits accessibility by fauna.

Temporary fluid storage pits and ponds have the potential to attract bird life. To reduce this potential, lined pits and ponds are constructed with steep sides to mitigate the creation of beaches and vegetation growth and therefore reduce the frequency of bird visitation. In the event that bird visitation and/or mortality increases at a specific location, implementation of additional measure such as flagging or gas guns could be employed to discourage visitation.

Material Safety Data Sheets (MSDS) for fracture stimulation injection fluids indicate that the concentrations of chemicals of greatest concern to fauna such as biocides, is expected to be below levels that pose a significant risk to birds coming into contact with fracture stimulation fluids in the temporary ponds.

Toxicological assessment of fracture stimulation fluids used in Santos' southwest Queensland operations (Golder Associates, 2012) found that flowback water at surface presents some inherent risk. However, with Santos' operational controls and management, the overall or residual risk to the environment associated with the chemicals used in fracture stimulation is low. Therefore the presence of temporary pits and ponds is not expected to have a significant impact on birds and/or other fauna species.

As discussed in Sections 7.3 and 7.4, a release of fracture stimulation produced fluids to the environment is unlikely but if it occurred could impact native vegetation if present at a spill site. To reduce the likelihood of a release and therefore potential impacts to native flora, operational controls such as an ecological sensitivity assessment (at each new lease site) and standard pit construction and monitoring procedures are employed. In the event of a pre-stimulation pond breach, brackish or saline water may temporarily impact vegetation outside of the cleared lease area however this impact would be negligible.

Fracture stimulation produced fluids comprise degraded stimulation fluids and PFW. In the event of a release of produced fluids beyond the extent of a cleared lease area, impacts to flora would be temporary and are unlikely to pose an ongoing risk to the health of native vegetation. Impacts to native fauna or stock may need to be considered where produced fluids enter a feed area and management may include installation of cattle proof fencing or drainage channels to divert fluids away from specific areas.

Rehabilitation of impacted areas would be undertaken in accordance with Objective 12 of the Santos SEO DWO, 2009 and EHS01 and may include ongoing monitoring.

Increased vehicle trafficking associated with fracture stimulation operations has the potential to impact stock, wildlife and vegetation. Vehicle collisions with stock and wildlife are the primary risk associated with fauna and Santos employs the following controls (Standard HSHS02 *Land Transportation*) to reduce the likelihood:

- No off-road or off-lease driving except with prior approval;
- Adherence to specified speed limits;
- In Vehicle Monitoring (IVMS) of speed, route and harsh braking;
- Minimising night-time driving to the greatest extent practicable; and
- Driver education programs.

Off-road or off-lease driving is prohibited to all Santos personnel and contractors without appropriate prior approval. The risk to vegetation associated with driving outside of cleared areas includes destruction of rare or endangered species and associated habitat and degradation of important flora communities. Where areas of sensitive vegetation are identified they will be flagged off and signposted with restricted access.

The introduction or spread of pest plants or animals is also minimised by the restriction of activities and vehicle movements to existing, defined well leases and access tracks.

Windblown litter and scavenger access has the potential to impact stock, wildlife and vegetation. Waste management through the use of secure storage and transport of waste reduces the potential for impacts by reducing the level of access.

The residual risk to stock, wildlife and vegetation associated with Santos Cooper Basin fracture stimulation activities is negligible and is managed through the use of operational controls and procedures in accordance with Objective 3, 7, 10 and 12 of the SEO DWO. Prior to any new lease disturbance, an ecological assessment is undertaken to evaluate the sensitivity of a proposed location. The results of the assessment are used to inform the internal approvals process from which a set of site specific conditions is generated. The objective of these conditions is to provide a set of guidelines for lease construction and operation and to minimise the likelihood of impacts to the environment outside of the area cleared for operation.

7.6. Noise and Air Emissions

Objective 8 of the SEO is to minimise air pollution and greenhouse gas emissions, Objective 9 is to maintain and enhance partnerships with the Cooper Basin community, and Objective 10 is to avoid or minimise disturbance to stakeholders and/or associated infrastructure.

Potential impacts associated with noise and air emissions include:

- Disturbance to native fauna;
- Disturbance to the local community;
- Reduction in local air quality; and

- Generation of greenhouse gases.

Landowners will be notified of proposed operations and consultation process initiated to ensure appropriate procedures in place to mitigate any impacts. Noise and air emissions from the well sites during fracture stimulation will be localised and short term and are not likely to have a significant noise or air quality impact. The sites are not located in close proximity to residences (e.g. station homesteads or Innamincka).

Well flowback will be diverted to a separator as soon as practicable to minimise the cold venting of gas and commence flaring. Flaring during production testing will be undertaken in accordance with APPEA Guideline 6 (2011), Emissions are reported annually in accordance with the National Pollution Inventory.

Santos manages noise in accordance with EHS12 *Noise Emissions* has undertaken noise assessments for EHS purposes and implemented controls accordingly to manage the noise exposure of personnel on site. Relevant PPE will be utilised as required. Noise assessments are available for personnel on site and displayed.

The level of risk associated with noise and air emissions is deemed low and the control measures employed by Santos to manage potential risks are in accordance with Objective 8, 9 and 10 of the SEO DWO.

7.7. Radioactivity

Objective 1 of the SEO is to minimise risks to the safety of the public and other third parties, Objective 4 of the SEO is to minimise disturbance to drainage patterns and avoid contamination of surface waters and shallow groundwater resources and Objective 6 is to minimise loss of aquifer pressure and avoid aquifer contamination.

The potential for exposure to radioactivity resulting from Naturally Occurring Radioactive Materials (NORM) that are brought to the surface has been considered and is assessed as a low risk.

Based on historical Cooper Basin operations, levels of radioactivity associated with NORM in flowback of fracture stimulation fluids are not expected to be significant and are expected to be well below any levels of concern. NORM are usually only a potential issue when they are concentrated (e.g. by the formation of mineral scales or sludges over time in tanks, piping and facilities).

Flowback pits are lined to prevent soil and shallow groundwater contamination, and monitoring of NORM at operational sites to confirm that levels are within acceptable limits.

In the unlikely event that high levels of NORM are experienced it will be immediately reported to the Contractor and Santos Management and appropriate mitigation actions taken. Any radioactive source will be stored and handled accordingly, and appropriate labelling of materials and signage will be in place.

The control measures employed by Santos to manage potential risks associated with NORM provides confidence that fracture stimulation operations are in accordance with Objectives 1, 4 and 6 of the SEO DWO and do not pose an unacceptable risk to the environment.

7.8. Seismicity

Objective 4 of the SEO is to minimise disturbance to drainage patterns and avoid contamination of surface waters and shallow groundwater resources and Objective 6 is to minimise loss of aquifer pressure and avoid aquifer contamination.

The induction of seismic events (i.e. micro-earthquakes) as a result of fracture stimulation is sometimes perceived as a potential issue. Fracture stimulation of Permian conventional and unconventional gas targets in the Cooper Basin does not pose a safety or environmental risk.

Fracture stimulation has been carried out in the Cooper Basin for over 40 years without any issues related to seismicity. Throughout Santos' activity, numerous seismic monitoring techniques have been employed, including microseismic (Moomba 191 and Cowralli Campaign) and surface monitoring across the 2013 Cowralli Pad Project. Monitoring during fracture stimulations operations reported very minor microseismic responses, and were not deemed to pose any risk to the seismicity of the region.

Microseismic monitoring will continue for the evaluation of fracture stimulation geometry on selected wells which will also provide ongoing confirmation that the operation will not create any significant seismic events.

Modelling of proposed fracture stimulation treatments provides additional confidence that any potential impacts to the environment are managed in accordance with Objectives 4 and 6 of the SEO.

7.9. Public Safety

Objective 1 of the SEO is to minimise risks to the safety of the public and other third parties.

Potential sources of risk to the public and other third parties principally arise from unauthorised access resulting in exposure to site hazards and the use of roads and movement of vehicles and heavy machinery.

Fracture stimulation operations are undertaken at established well leases where public access is restricted. Most sites in the Cooper Basin are relatively remote from public roads and have little or no public access. Measures such as signage and fencing will be in place to warn of hazards at the site and restrict access into the site. Potentially hazardous areas such as sumps and lined pits will be securely fenced with warning signs in place.

Fracture stimulation operations can result in short term and localised increase in vehicle traffic. The existing road network in the Cooper Basin is already heavily used by the oil and gas industry and the incremental increase is not considered to be significant. As discussed in Section 7.5, Santos employs controls (outlined in Standard HSHS02 *Land Transportation*) to manage the risks of road use, including adherence to specified speed limits, In Vehicle Monitoring (IVMS) of speed, route and harsh braking, minimising night-time driving and driver education programs.

The management strategies and control measures ensure that the risks to the safety of the public and other third parties are managed in accordance with Objective 1 of the SEO.

7.10. Cultural Heritage

Objective 5 of the SEO is to avoid disturbance to sites of cultural and heritage significance. Fracture stimulation operations are undertaken on a prepared well lease, within an area that has been subject to cultural heritage clearance. Off-lease activity is strictly controlled, and measures such as signage or fencing are installed if required to delineate any restricted areas or sites of cultural heritage significance.

Consequently, the potential for impacts to cultural heritage is low and managed in accordance with Objective 5 of the SEO.

7.11. Risk Assessment Summary and Cumulative Impacts

The level of risk associated with fracturing operations is dependent on the likelihood and consequence of environmental harm. The purpose of this environmental risk assessment is to identify and separate the minor acceptable risks from the major risks and to provide a framework or strategy to manage the risks. The risk assessment has been undertaken in accordance with Santos Standard EHSMS09 *Managing EHS Risk* and aims to identify potential hazards and implement appropriate controls to reduce potential harm to people and the environment. The standard outlines the requirements to:

- Identify EHS hazards, assess their risk and control them to as low as reasonably practicable;
- Identify significant EHS hazards and document how they are being managed to as low as reasonably practicable;
- Have a system to escalate EHS significant hazards to management for approval of continued operation and for management to sign off on EHS significant hazards, controls and how critical controls will be checked; and
- Meet legislative requirements that require certain EHS hazards and risks to be managed.

Six levels of environmental consequence are used to describe the severity and or impact to ecosystems, plants and animals with conservation value and land / water / air ranging from localised and short term environmental or community impact – readily dealt with (negligible) to regional and long term impact on an area of significant environmental value (critical) and 6 levels of likelihood ranging from remote to almost certain are used to predict the probability of a hazard occurring.

The control measures employed by Santos to manage potential impacts to the environment and meet the objectives of the SEO DWO mean that for fracture stimulation activities the maximum residual risk is 2 which is considered low. Therefore the cumulative effects of Cooper Basin operations are also considered low and any impacts would be isolated, temporary in nature and affect only a small portion of the greater Cooper Basin region.

A summary table is presented in Appendix A and is based on the assumption that control measures described in Section 7 of this report are in place.

8. Environmental Management

The Santos Environment, Health and Safety Management System (EHSMS) has been developed by Santos to provide a company-wide approach to effectively manage Environment, Health and Safety (EHS) risks and to allow for continual EHS improvement. An EHS Committee has been established in order to ensure an established protocol in relation to EHS is maintained. The EHSMS is readily available to employees and contractors via the Santos intranet 'The Well'.

The EHSMS Framework provides structured, comprehensive and efficient EHS practices for Santos' activities and operations and is compliant with both *AS 4801:2000 Occupational Health and Safety Management Systems – Specification with Guidance for Use* and *AS/NZS ISO 14001:2004 Environmental Management Systems – Specification with Guidance for Use*.

The Framework of the EHSMS is multi-layered and comprises policies, standards, processes and procedures with Management and EHS Standards forming the key components of the Framework (Figure 29). The upper layer of the framework comprises the overarching EHSMS policies which outline Santos' direction and objectives in relation to the EHS and demonstrates the commitment Santos has made to continual improvement in respect of EHS performance. These policies include:

- Health and Safety Policy;
- Environmental Policy; and
- Climate Change Policy.

The Santos Environmental Policy, which applies to all Santos operations within Australia, is provided in Appendix D.

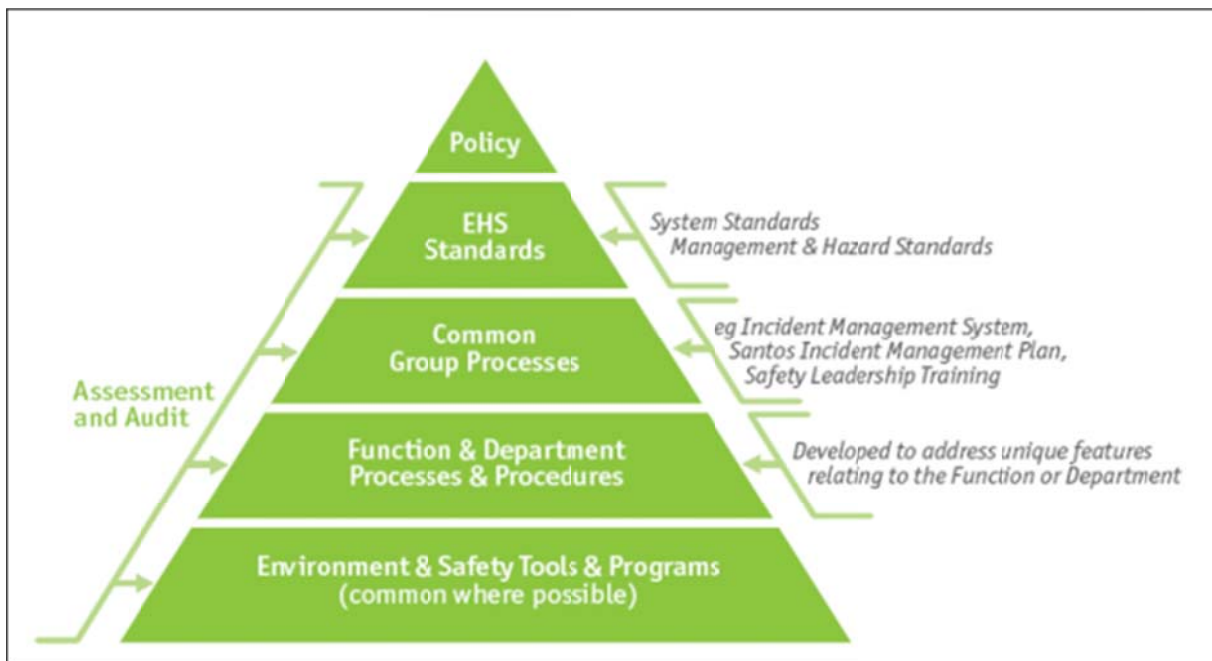


Figure 29: Santos EHSMS Framework

8.1. Management Standards

Management Standards have been developed as part of the EHSMS. These Standards define the requirements necessary to ensure that environmental, health and safety risk is systematically managed. These Standards include, but are not limited to:

- EHSMS02 – Legal Obligations and Targets;
- EHSMS04 – EHS Improvement Plans;
- EHSMS05 – EHS Responsibility and Accountability;
- EHSMS06 – Training and Competency;
- EHSMS09 – Managing EHS Risk;
- EHSMS09.2 – Hazard Studies;
- EHSMS10 – Contractor and Supplier EHS Management;
- EHSMS11 – Operations Integrity;
- EHSMS12 – Management of Change;
- EHSMS13 – Emergency Preparedness;
- EHSMS14 – Monitoring, Measurement and Reporting;
- EHSMS15 – Incident Investigation and Response;
- EHSMS 15.2 – Environmental Incident Response; and
- EHSMS 16 – EHS Audit and Inspection

8.2. Hazard Standards

8.1.1 Environment

Environmental Hazard Standards detail the controls required to manage the risks of specific hazards to acceptable levels and apply to all Santos operations. The Standards contain specific requirements for planning and undertaking activities and include checklists and references to internal and external approvals, controls and auditing guidelines. Environmental Hazard Standards developed under the EHSMS include:

- EHS01 – Biodiversity and Land Disturbance;
- EHS02 – Underground Storage Tanks and Bunds;
- EHS03 – Produced Water Management;
- EHS04 – Waste;
- EHS05 – Air Emissions;
- EHS06 – Environmental Impact Assessment and Approvals
- EHS07 – Energy Efficiency;
- EHS08 – Contaminated Sites;
- EHS09 – Pest Plants and Animals;
- EHS10 – Water Resources;
- EHS11 – Cultural Heritage; and
- EHS12 – Noise Emissions.

8.1.2 Health and Safety

The Health and Safety Standard has been developed to manage hazards and risks associated with all of Santos operations. The intent of the standard is to prevent injury or illness to all employees, contractors, customers and the public who may be affected by Santos work activities. Health and Safety Hazard Standards developed under the EHSMS include:

- HSHS02 – Land Transportation;
- HSHS08 – Chemical Management and Dangerous Goods;
- HSHS09 – Radiation; and
- HSHS12 – Occupational Noise.

8.3. Statement of Environmental Objectives

The intent of the SEO DWO is to outline the environmental objectives to be achieved as part of Santos' everyday operations and the criteria against which the objectives are assessed. The SEO is subject to Part 12 of the *Environment Protection of the Act*, the objective of which is to manage and reduce environmental harm as far as reasonably practicable, eliminate significant long term environmental damage and ensure that land adversely affected is properly rehabilitated.

The SEO DWO describes twelve objectives designed to minimise environmental damage involved in exploration for, or the recovery or commercial utilisation of petroleum and other resources and from activities involved in drilling and well operations.

These twelve objectives for drilling and well operations are:

1. Minimise risks to the safety of the public and other third parties.
2. Minimise disturbance and avoid contamination to soil.
3. Avoid the introduction or spread of pest plants and animals and implement control measures as necessary.
4. Minimise disturbance to drainage patterns and avoid contamination of surface waters and shallow groundwater resources.
5. Avoid disturbance to sites of cultural and heritage significance.
6. Minimise loss of aquifer pressure and avoid aquifer contamination.
7. Minimise disturbance to native vegetation and native fauna.
8. Minimise air pollution and greenhouse gas emissions.
9. Maintain and enhance partnerships with the Cooper Basin community.
10. Avoid or minimise disturbance to stakeholders and/or associated infrastructure.
11. Optimise (in order of most to least preferable) waste avoidance, reduction, reuse, recycling treatment and disposal.
12. Remediate and rehabilitate operational areas to agreed standards.

8.4. Job Safety Analysis and Permit to Work

Job Hazard Analysis (JHA) is a practical risk assessment tool used by workers to identify and document hazards associated with a job / task and what will be done to control the risks associated with the hazards.

Santos and its contractors perform a JHA before conducting a job/task if:

- The job / task is not a routine low-risk job / task; and
- There is not a documented risk assessment for the job / task that:
 - Identifies reasonably foreseeable EHS hazards; and
 - Details required control measures including who is responsible for each control measure; and
 - Includes a process to ensure that the information in the documented risk assessment is clearly communicated and understood by all those undertaking the job/task; or
- There are other material risks that may present when the work is conducted (e.g. other work being conducted in close proximity (simultaneous operations), that would not be covered in an existing documented risk assessment for the job / task.

Santos and its contractors utilise the multi-purpose industry accepted Wellsite Permit to Work (WPTW) system. WPTW is a safe work planning and control system for the review and authorisation of work on Australian and other onshore Wellsites. The WPTW System applies to drilling, completions, work over or other well intervention activities such as fracture stimulation.

The WPTW system is used in conjunction with applicable regulatory requirements, good industry practice and project specific documentation, and forms part of the Santos and Contractor Environmental Health and Safety Management Systems. Work assessed with anything other than a low risk, and/or work that is not regularly performed, must be undertaken with a WPTW in place.

8.5. Training

Prior to the start of field operations all field personnel are required to undertake an Environmental Health and Safety (EHS) induction specific to the work site, to ensure they understand their role with regard to protecting their safety, and safety of others, and with regard to protecting the environment.

A record of induction and attendees will be maintained.

Appropriately trained personnel will be on site during operations, with lease access further restricted to only necessary personnel during pressure pumping activities.

A copy of the contractors training matrix will be maintained and available on site and the contractor will be in position to verify competency of personnel as requested.

8.6. Emergency Preparedness

Santos utilises the Wellsite Emergency Response Plan to provide Santos and Contractor personnel with guidance for responding to an emergency at or near a wellsite. The Wellsite Emergency Response Plan is an Emergency Response Plan for all Santos onshore wellsites and related activities within the Cooper Basin and Central Australia.

The plan provides an overview of:

- How to prepare for and respond to an emergency at a wellsite or while moving between wellsites;
- The basic guidelines for an emergency response; and

- The interface with other Santos emergency and incident plans.

Santos and Contractor personnel are required to undertake emergency response drills to practice and prepare for potential incidents on site.

8.7. Incident Response and Management

Santos has adopted a two-tiered approach to EHS incident investigation, based on actual and potential consequence of an incident. Incidents with lower actual or potential consequence may require a minor investigation; and incidents with higher actual or potential consequence may require a major investigation.

The main aim of investigating incidents is to:

- Identify the cause and prevent similar incidents in the future;
- Identify any new hazards;
- Identify and choose appropriate hazard management controls;
- To inform the work group of causes and what remedial action has been undertaken; and
- To comply with legislation.

Incidents (including near misses) with higher potential consequence should be subject to major investigation, using a process such as TapRoot®, ICAM or DEM. Incidents with lower potential shall be subject to a minor investigation, to capture basic information for trending and determine whether risk controls should be revised.

The system also provides a mechanism for recording 'reportable' incidents, as defined under the Act and associated regulations.

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List of Abbreviations

ALARP	As Low as Reasonably Practicable
API	American Petroleum Institute
APPEA	Australian Petroleum Production & Exploration Association
BTEX	benzene, toluene, ethylbenzene, xylenes
cp	centipoise
CAS RN	Chemical Abstracts Service Registry Numbers
CBL	Cement Bond Log
CCL	Casing Collar Locator
CTU	Coiled Tubing Unit
DMITRE	Department for Manufacturing, Innovation, Trade, Resources and Energy
EAR	Environmental Assessment Report
EART	Environmental Approval Request Tracking Form
EIR	Environmental Impact Report
EIR DWO	Environmental Impact Report for Drilling and Well Operations in the Cooper Basin
EHS	Environmental Hazard Standards
EHSMS	Environmental Health and Safety Management Standard
EPBC	Environment Protection and Biodiversity Conservation
ERP	Emergency Response Plan
ESP	Environmental Sensitivity Profile
IBC	Industrial Bulky Containers
GAB	Great Artesian Basin
HDPE	High-density polyethylene
HSHS	Health and Safety Hazard Standards
IVMS	In Vehicle Monitoring
JHA	Job Hazard Analysis
MSDS	Material Safety Data Sheets
NWBP	Near Well Bore Pressure
PAHs	Polycyclic Aromatic Hydrocarbons
PELs	Petroleum Exploration Licenses
PFW	Produced Formation Water
PPE	Personnel Protective Equipment

Environmental Assessment Report - Fracture Stimulation Operations

PPLs	Petroleum Production Licences
PSV	Pressure Relief Valve
QA / QC	Quality Assessment and Quality Control
RAL	Radial Analysis Bond Log
REM	Roseneath, Epsilon and Murteree
RPs	Recommended Practices
SACBJV	South Australian Cooper Basin Joint Venture
SBT	Segmented Bond Tool
SEO	Statement of Environmental Objectives
SEO DWO	Santos Statement of Environmental Objectives for Drilling and Well Operations
SIMOPS	Simultaneous Operations
TDS	Total Dissolved Solids
TPH	Total Petroleum Hydrocarbons
TRs	Technical Reports
UV	Ultra Violet
VDL	Variable Density Log
WPTW	Wellsite Permit to Work

APPENDIX A – RISK ASSESSMENT TABLE

Identification				SEO DWO	Control Strategy	Assessment		
Activity	Risk Issue	Causes	Impact	Relevant SEO Objective Number	Existing Controls	Risk		
						Consequence	Likelihood	Risk Rating
Fracture Stimulation	Aquifer Contamination / Leakage to Aquifers	Loss of Well Integrity	Contamination of aquifers - impact to environmental receptors	Objective 4 Objective 6	<ul style="list-style-type: none"> - Aquifers isolated behind casing string(s) cemented in place - Casing string and cement slurry designed by qualified & competent engineers & confirmed by senior engineers or external consultants where necessary - Cased hole cement bond logs to confirm quality of cement job in the production casing string - New casing and wellhead installed on every new drill - Well integrity management system & checks to confirm well integrity through well life - Production operator checks during well life - Real time pressure monitoring and installation of pressure relief valve during fracture treatment to ensure surface casing integrity 	III	Remote	1
Fracture Stimulation	Contamination of overlying GAB aquifers	Leakage through geologic media	Contamination of aquifers - impact to environmental or human health receptors	Objective 4 Objective 6	<ul style="list-style-type: none"> - Minimal connecting faulting noted on seismic acquired throughout the basin - Low permeability of the Nappamerri group siltstone, resulting in poor hydraulic conductivity into the GAB - Pressure differential between GAB aquifers and Upper Permian reservoirs, indicating no communication - Modelled stimulation treatments demonstrate containment of height growth within acceptable limits between gas targets and any GAB aquifers - Real time pressure monitoring during fracture treatment to identify containment 	III	Remote	1
Fracture Stimulation	Aquifer Contamination / Leakage to aquifers	Lateral migration of injected fluids	Contamination of aquifers - impact to environmental or human health receptors	Objective 4 Objective 6	<ul style="list-style-type: none"> - When in production the pressure gradient underground will result in fluids moving towards the well being produced, rather than migrating upwards or laterally away from the fracture stimulation network. - Fracture stimulation targets have very low permeability reducing likelihood of migration fracture stimulation fluids away from the fracture network - Modelling of all proposed fracture stimulation treatments to estimate fracture propagation - Fracture stimulation treatments are flowed back as soon as practicable to recover treatment fluids. 	III	Remote	1
Fracture Stimulation	Loss of aquifer pressure	Increased water usage	Drawdown of artesian or sub-artesian aquifer	Objective 6	<ul style="list-style-type: none"> - Satellite ponds as primary fracture stimulation water source - Compliance with water licence and allocations where applicable - Lining of all storage ponds to reduce the potential for loss of water due to seepage - Exclusive utilisation of existing Santos groundwater bores where applicable - Installation of any new water bores will be in accordance with all government regulations and licencing conditions - Consultation with other groundwater users/bore owners 	II	Remote	1
Fracture Stimulation	Loss of aquifer pressure and associated impacts to groundwater	Increased water usage	Depletion of water resources resulting in shortage for other users, impacts to groundwater dependant ecosystems	Objective 4 Objective 6 Objective 9	<ul style="list-style-type: none"> - Satellite ponds as primary fracture stimulation water source - Compliance with water licence and allocations where applicable - Lining of all temporary storage ponds to reduce the potential for loss of water due to seepage - Minimise use of groundwater - Exclusive utilisation of existing Santos groundwater bores where applicable - Installation of any new water bores will be in accordance with all government regulations and licencing conditions - Consultation with other groundwater users/bore owners - Impact assesement where proposed groundwater bores are in the vacinity of surface water systems that are baseflow dependant. 	III	Remote	1
Fracture Stimulation	Impact to soil & shallow groundwater	Loss of containment, spills from hazardous materials storage and handling areas	Soil and shallow groundwater contamination, access to contaminants by stock and wildlife and impacts to flora	Objective 2 Objective 3 Objective 4 Objective 7	<ul style="list-style-type: none"> - Chemical storage and handling in line with Santos HSHS08 - Emergency spill response procedures and kits in place - Trained personnel for handling of chemicals and materials including re-fuelling and clean-up procedures - Appropriate use of bunding and secondary containment - Appropriate storage of materials for disposal to a licenced waste facility - Lined ponds/pits 	III	Unlikely	2

Identification				SEO DWO	Control Strategy	Assessment		
Activity	Risk Issue	Causes	Impact	Relevant SEO Objective Number	Existing Controls	Risk		
						Consequence	Likelihood	Risk Rating
Fracture Stimulation	Impact to soil & shallow groundwater	Loss of containment of flowback fluids	Soil and shallow groundwater contamination, access to contaminants by stock and wildlife and impacts to flora	Objective 2 Objective 4 Objective 7	<ul style="list-style-type: none"> - Flowback fluids stored in designated lined pits/ tanks - Quality control of flowback pit construction including above ground earthen bunds to prevent surface water ingress - Use of appropriate liners and tanks, maintain minimum pond freeboard - Regular inspection of pit walls and repairs undertaken when and where required - Routine inspection of flowback lines - High pressure equipment rated and trip systems in place to prevent operations above design limits - Emergency shutdown systems in place - Spills and leaks cleaned up and remediated - Fencing installed to prevent stock and wildlife access - Chemical utilisation minimised to achieved required outcome - Alternative most environmentally friendly chemicals employed to achieve required outcome. 	II	Unlikely	1
Fracture Stimulation	Impact to soil & shallow groundwater	Loss of containment of saline or brackish stimulation fluid makeup water	Soil and shallow groundwater contamination, access to saline or brackish water by stock and wildlife and impacts to flora	Objective 2 Objective 4 Objective 7	<ul style="list-style-type: none"> - Makeup water stored in designated lined pits - Quality control of pit construction including above ground earthen bunds to prevent surface water ingress - Use of appropriate liners - Maintain minimum pond freeboard - Regular inspection of pit walls and repairs undertaken when and where required 	I	Possible	1
Fracture Stimulation	Spills and storage of waste materials	Spill and storage of waste materials prior to transport to a licenced waste management facility	Localised contamination of surface water, soil and/or shallow groundwater, impacts to vegetation and/or habitat, attraction of scavenger animals and stock/wildlife, litter and loss of visual amenity	Objective 2 Objective 3 Objective 4 Objective 7	<ul style="list-style-type: none"> - Storage pits are lined with an appropriate liner (e.g. UV stablized polyethylene) - Application of the waste hierarchy system (avoid, reduce, reuse, recycle, treat, dispose, waste removed from site and transported to a licenced waste management facility - High standard of site housekeeping, appropriate use of designated bins (e.g.covered skips) - Licenced waste management contractor - Wastes handled in accordance with Santos EHSMS and relevant legislation 	II	Unlikely	1
Fracture Stimulation	Impact to Coongie Lakes Ramsar Wetland	Loss of containment of flowback fluids	Contamination of soil, surface water and shallow groundwater	Objective 3	<ul style="list-style-type: none"> - Flowback fluids stored in designated lined pits or tanks - Fluid blowdown line from a separator - Quality control of flowback pit construction including above ground earthen bunds to prevent surface water ingress - Use of appropriate liners (e.g. UV stablized polyethylene) - Maintain minimum pond freeboard - Regular inspection of pit walls and repairs undertaken when and where required - Routine inspection of flowback lines - High pressure equipment rated and trip systems in place to prevent operations above design limits - Emergency shutdown systems in place - Emergency spill response plans in place - Spills and leaks cleaned up and remediated - Fencing installed to prevent stock and wildlife access - Chemical utilisation minimised to achieved required outcome - Most environmentally friendly chemicals utilised to achieve required outcome - Lease location selected to minimise potential impacts to drainage patterns flora and fauna and surface water contamination - No operations within 1 km of Coongie Lakes National Park - No fracture stimulation operations during times of inundation at the site - No operations proximal to main surface water channels and/or permanent water holes - Where possible leases to be constructed on high ground - In low lying areas leases are not to be built up significantly (e.g. 300mm) - Monitoring weather conditions for preparation of shutdown due to flooding/inundation - Removal of fluids from pits/tanks where floodwaters pose a site inundation risk 	III	Unlikely	2

Identification				SEO DWO	Control Strategy	Assessment		
Activity	Risk Issue	Causes	Impact	Relevant SEO Objective Number	Existing Controls	Risk		
						Consequence	Likelihood	Risk Rating
Fracture Stimulation	Impact to Coongie Lakes Ramsar Wetland	Lease location, off-lease or off-road driving	disturbance to surface drainage patterns	Objective 4	<ul style="list-style-type: none"> - Lease location selected to minimise impacts to surface drainage patterns - Where possible leases to be constructed on high ground - In low lying areas leases are not to be significantly built up (e.g. 300mm) - Ecological assessment of all new lease sites - No off road or off lease driving 	II	Unlikely	1
Fracture Stimulation	Impact to Stock/wildlife	Lease location, fauna access to lease storage pits	Loss of habitat, injury or death of stock/wildlife	Objective 2 Objective 3 Objective 4 Objective 7	<ul style="list-style-type: none"> - Ecological assessment of all new proposed lease sites to evaluate sensitivity - Storage pits securely fenced to prohibit stock/wildlife access - Pits constructed with steep edges and lined with an appropriate synthetic liner to prohibit vegetation growth and/or creation of beaches - Monitoring of lease and ponds for trapped or stranded stock or wildlife - Pits are temporary and will rehabilitated following well completion works - Use of biodegradable chemicals where possible 	I	Possible	1
Fracture Stimulation	Impact to vegetation	Lease location, loss of containment (spills) off-road/off-lease driving	Impacts to Santos Priority 1 & 2 flora species, spread of pest weeds	Objective 2 Objective 3 Objective 4 Objective 7	<ul style="list-style-type: none"> - Ecological assessment of new proposed lease sites to evaluate flora sensitivity and site appropriately - Pits constructed with steep edges and lined with an appropriate synthetic liner to prohibit vegetation growth - Rehabilitation of lease sites following well completion works to facilitate vegetation re-growth - Use of biodegradable chemicals where possible - No off-lease or off-road driving 	II	Occasional	2
Fracture Stimulation	Public, personnel and 3rd party health and safety	Unauthorised access to operational and non operational lease sites, road hazards and vehicle movement	Injury or danger to the health of the public, personnel and/or 3rd parties	Objective 1	<ul style="list-style-type: none"> - Road speed restrictions and appropriate signage where appropriate - Use of In Vehicle Monitoring System (IVMS) to track speed, route and harsh breaking - Use of roughometer and scheduled road maintenance program - Dust control measures (i.e. road watering) when appropriate - Discourage night-time driving - Driver education programs including four wheel driving - Authorised access only to Santos operational sites - Appropriate signage to warn of access restrictions - Emergency response plans in place and drills conducted - Ponds securely fenced 	III	Remote	1
Fracture Stimulation	Impacts to sites of cultural heritage	Off-lease or off road driving, unauthorised access to sites of cultural significance, ground disturbance prior cultural heritage clearance	Impact to preservation of sites of cultural heritage	Objective 5	<ul style="list-style-type: none"> - All new disturbance are assessed for sites of cultural heritage - No off-lease or off-road driving - Appropriate signage and/or fencing around sensitive sites 	III	Unlikely	2
Fracture Stimulation	Noise Emissions	Noise emissions from fracture stimulation activities	Disturbance to fauna and or nearby communities	Objective 8 Objective 9 Objective 10	<ul style="list-style-type: none"> - Remote location of well sites - Landowners notified of proposed operations and consultation process initiated to ensure appropriate procedures in place to mitigate impacts - Operations not to be undertaken proximal to the township of Innamincka or pastoral homesteads - Equipment operated and maintained in line with manufacturer specifications 	II	Unlikely	1

Identification				SEO DWO	Control Strategy	Assessment		
Activity	Risk Issue	Causes	Impact	Relevant SEO Objective Number	Existing Controls	Risk		
						Consequence	Likelihood	Risk Rating
Fracture Stimulation	Air Emissions	Air emissions from fracture stimulation activities	Generation of greenhouse gas emissions, reduction in air quality	Objective 8 Objective 9 Objective 10	<ul style="list-style-type: none"> - Remote location of well sites - Landowners notified of proposed operations and consultation process initiated to ensure appropriate procedures in place to mitigate impacts - Operations not to be undertaken proximal to the township of Innamincka or pastoral homesteads - Equipment operated and maintained in line with manufacturer specifications - Well flowback diverted to three phase separator to minimise impacts associated with raw gas released to atmosphere - Flaring during production testing undertaken in accordance with APPEA Guideline 6 (2011) - Monitoring of well parameters during testing to evaluate the potential for fugitive emissions at the well head - Emissions reported annually in accordance with the National Pollution Inventory 	II	Unlikely	1
Fracture Stimulation	Radioactivity	Naturally occurring radioactive materials (NORM) in flowback fluids and/or radioactive traces	Contamination of surface water, soil and or shallow groundwater	Objective 2 Objective 4 Objective 6	<ul style="list-style-type: none"> - Flowback pits are lined to prevent soil and shallow groundwater contamination - Monitoring in accordance with the HSHS09 radiation at operational sites to confirm that levels are acceptable 	I	Remote	1
Fracture Stimulation	Seismicity	Fracture stimulation operations	Ground disturbance, contamination of surface water, soil and or shallow groundwater, contamination of aquifers	Objective 6	<ul style="list-style-type: none"> - Santos' history of fracture stimulation in the Cooper Basin does not show any evidence of induced seismicity as a result of fracture stimulation operations - Fracture stimulation modelling undertaken on all fracture stimulation treatments - No transfer of reverberations to surface due to fracture stimulation activities 	III	Remote	1

APPENDIX B – EXAMPLE WASTE MANAGEMENT PLAN



**COWRALLI MULTI WELL PAD WASTE & RECYCLING
MANAGEMENT PLAN**

COOPER BASIN SIMULTANEOUS OPERATIONS

Waste & Recycling Management Plan

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1 PURPOSE & SCOPE

The purpose of this Waste & Recycling Management Plan is to document how waste & recycling will be managed on the Cowralli MWP SIMOPS site.

The Plan is only concerned with managing waste & recycling within the Cowralli MWP SIMOPS site. It is intended the Plan will be used as a guide and reference document by the SIMOPS integration Lead (SIL) and the SIMOPS Co-ordinator to manage the sites waste & recycling.

2 OPERATIONAL BACKGROUND

2.1 Cowralli SIMOPS Site Location & Layout

The Cowralli field is located approximately 40 km north west of Moomba in the Cooper Basin. The Cowralli SIMOPS site is located in between Cowralli # 4 and # 7 on a new road alignment linking the Kanowana and Jack Lake roads.

The site's main access is via a southern entry and consists of two 8 well pads with a central laydown yard located in between.

Please refer to the map attached below for further details.

2.2 Cowralli SIMOPS Environment & Hazards

16 gas wells will be developed at the Cowralli Multi Well Pad. Work activities will be compressed into a smaller *per well* pad footprint compared to what has historically been used in the Cooper Basin. Additionally, simultaneous operations (SIMOPS) will be undertaken on site which will further add work intensity and complexity on site during well development. Together, these factors increase the potential on-site risk to environment and safety.

With the increased SIMOPS and development activity at the Cowralli pad, the volume and frequency at which waste is generated will be much higher than that at single well operations. Therefore, in order to adequately manage waste streams and volume generated at the Cowralli Pad this Waste & Recycling Management Plan has been developed.

3 WASTE & RECYCLING MANAGEMENT

3.1 Reuse, Recycling and General Waste

Santos' environmental vision is to lighten the footprint of our activities and the management strategy for waste associated with this is avoid, reduce, reuse, recycle, and then dispose.

In accordance with Santos' vision, wastes including IBCs, plastic drums and wooden pallets will be reused wherever possible and where this is not an option will be sent to Adelaide for recycle.

All IBCs and plastic drums will be sent to Adelaide for re-use or recycle. Where IBCs and plastic drums are in good condition they can be reused and Santos will receive a partial refund. Where IBCs are in poor condition they will be sent for recycle and Santos will be charged a receiving fee. Photos 1 and 2 presented below provide examples of good and poor IBC condition.



Photo 1. Example of IBC in good condition. Photo 2. Example of IBC in poor condition

Similar to IBCs and plastic drums, wooden pallets will be sent to Adelaide for reuse/recycle. The better the condition of the pallets the greater the likelihood the pallets can be reused. Photo 3 presented below provides example of wooden pallets in good condition.



Photo 3. Example of wooden pallets in good condition.

In general, re-use of 1m³ bulker bags is limited to on-site operations for containment of other waste products and/or packaging. Therefore, wherever possible empty bulker bags should be used to contain and compact other non-recyclable waste products and/or packaging.

All recyclable cardboard, bottles, cans and food containers should be segregated according to Veolia colour coded recycle bins and transported to the Moomba Waste Management Facility (WMF) for processing.

General and putrescible waste such as non-recyclable packaging and food scraps should be placed in the appropriate bin for transport to the Moomba waste management facility for disposal.

To maximize opportunities for re-use and recycle the following management strategy should be employed:

- Ensure all waste is segregated in accordance with bin compartments.
- Do not mix waste streams.
- Ensure appropriate PPE is used when handling containers.
- SIL to co-ordinate suitable schedule for bin rotation (bin drop-off and pickup) with Veolia.
- SIL to co-ordinate suitable pickup times with Veolia.

3.2 IBC (tote) Waste & Recycling Management

3.2.1 Volumes & Assumptions

The waste containers are classified according to the chemicals they contain and include dangerous and non-dangerous goods. In accordance with their classification, empty containers should be stored with like packing group (II or III).

3.2.2 IBC Waste & Recycling Plan

- Ensure all chemical containers are empty (must ensure minimal chemical residue is left in containers) and maintained in good condition.
- Empty containers need to be stored in their separate **Packing Groups (II or III)** in readiness for Toll pickup and loading.
- SIL to co-ordinate suitable pickup times for empty chemical containers with Toll
- SIL to notify Veolia of impending Toll delivery schedule.
- Ensure appropriate PPE is used when handling DG containers.
- When loading empty DG chemical containers ensure that like packing groups are loaded with like packing groups i.e. ensure that only one DG packing group is loaded per trailer
- Only single layer loads are permitted for DG containers.
- Ensure 80% gate coverage on DG loads.

3.3 Pallet Waste & Recycling Management

3.3.1 Volumes & Assumptions

- Approx. 150 x proppant pallets will be generated each day, based on 6 zones / day.
- Approx. 360 x pallets (in good condition) can be loaded on each trailer, therefore 720 x pallets per road train.
- Therefore, expected requirement is 1 x road train every 5 days.

3.3.2 Pallet Waste & Recycling Plan

- Ensure hard wood and soft wood pallets are stored separately.
- Ensure appropriate PPE is used when handling wooden pallets.

3.4 Bulker (Proppant) Bag Waste & Recycling Management

3.4.1 Volumes & Assumptions

- Approx. 150 x proppant bags will be generated each day, based on 6 zones / day.
- Approx. 10 x bags can be stuffed into 1 x bag (11 bags total per stuffed "bale").
- Approx. 72 bales (792 bags) can be loaded onto 1 x trailer.
- Therefore, expected requirement is 1 x trailer every 5 days, or 1 x road train every 10 days.

3.4.2 Proppant Bag Waste & Recycling Plan

- Ensure bulker bags are stored separately.
- Stuff 10 x empty bags into another bulker bag (approx. 10 x bags can be stuffed into 1 bag - 11 bags total per stuffed "bale").
- SIL to co-ordinate suitable pickup times for bulker bags with Toll.
- SIL to notify Veolia of impending Toll delivery schedule.

3.5 General Recycling and Putrescible Waste Management

3.5.1 Volumes & Assumptions

- Generated as part of day to day site operations

3.5.2 General Recycling and Putrescible Waste Plan

- Ensure waste is segregated in accordance with Veolia colour coded bins.
- SIL to co-ordinate suitable schedule for bin rotation (bin drop-off and pickup) with Veolia.
- SIL to co-ordinate suitable pickup times with Veolia.

4 RESPONSIBILITIES & CONTACT DETAILS

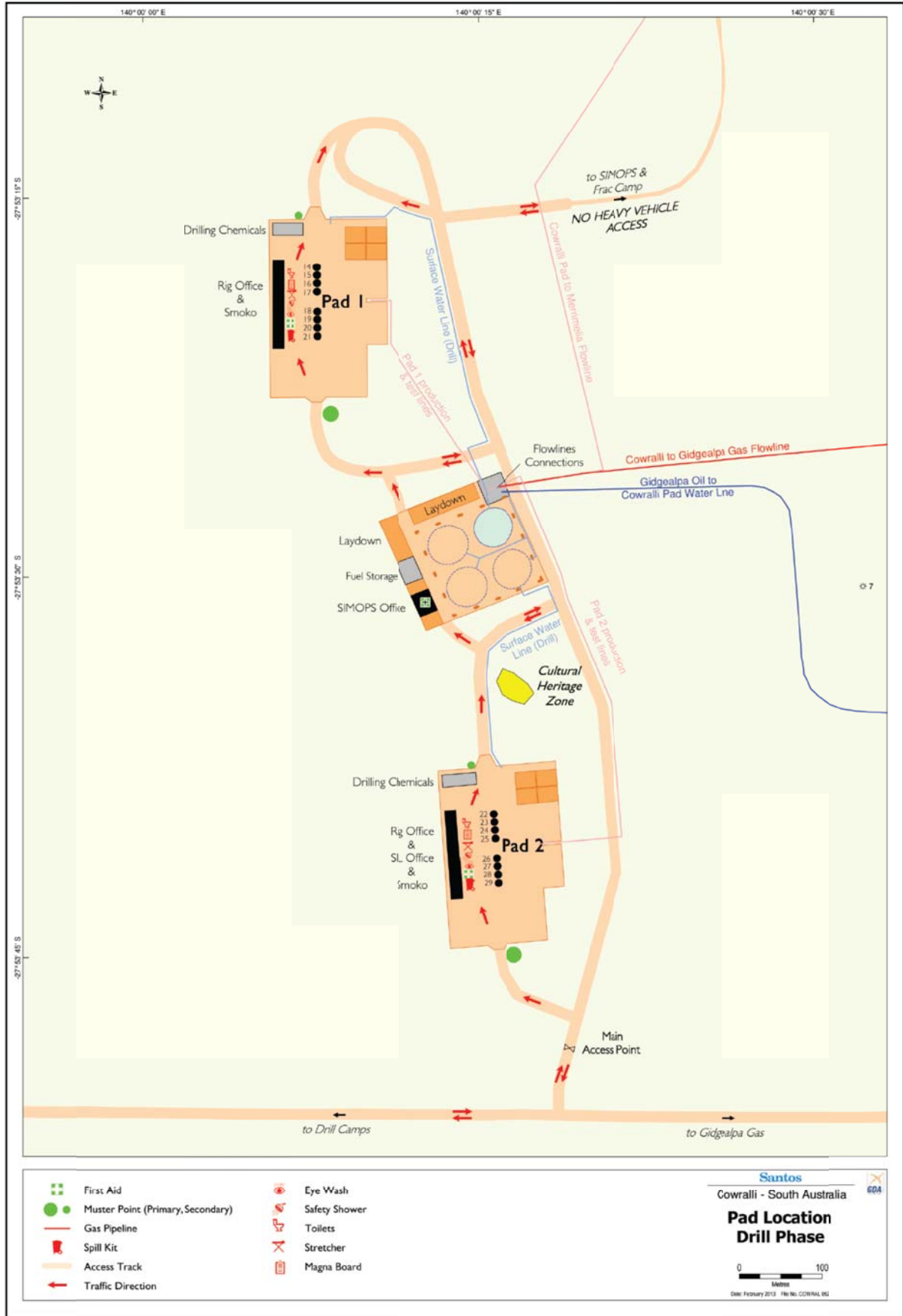
Company	Contact Name	Position	Email	Phone

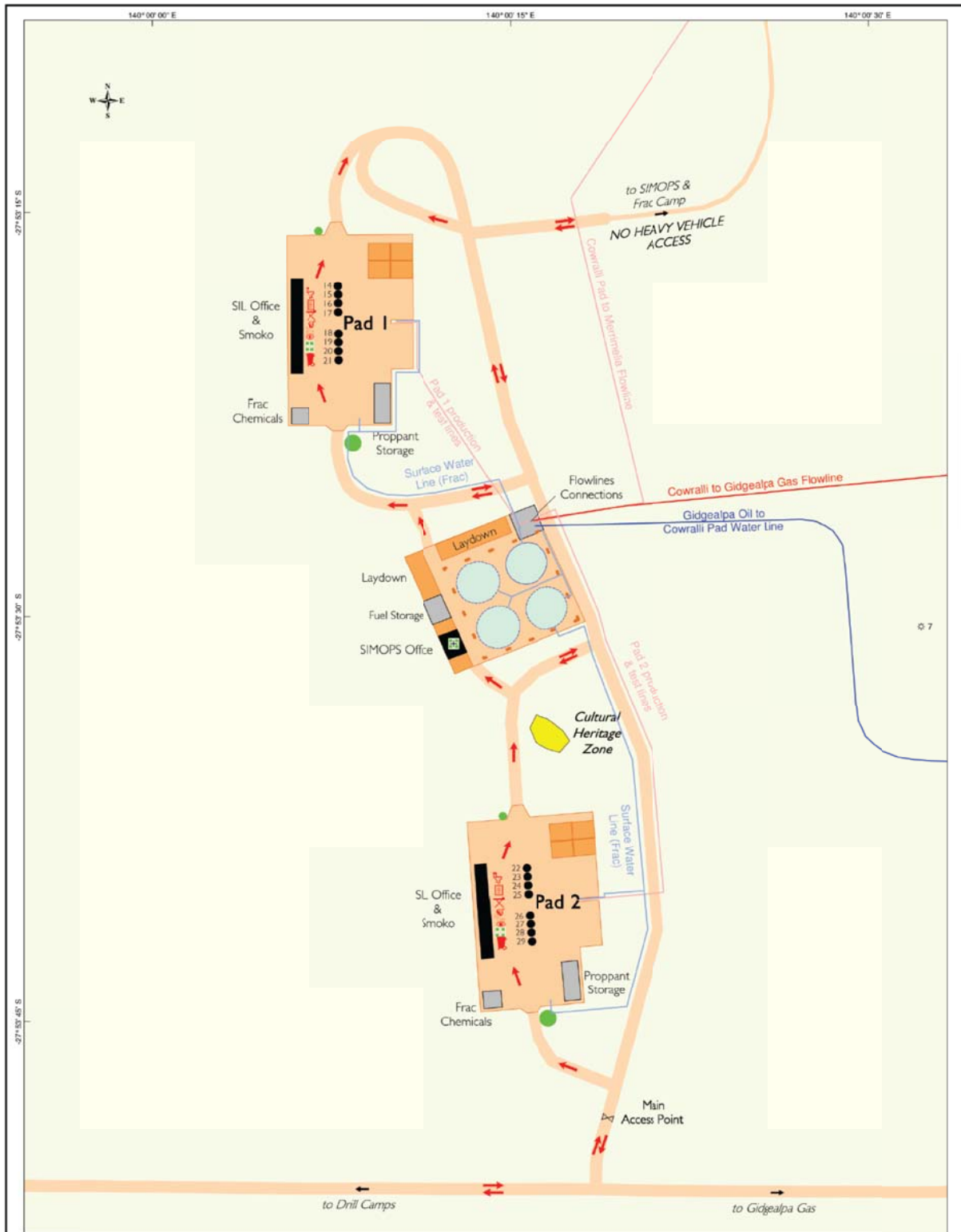
5 AUTHORITY & RESPONSIBILITY

The SIL will have ultimate control of the execution of this Waste & Recycling Management Plan. The SIL may alter the operation of the plan as required to manage the safe and efficient operation of the site.

The SIMOPS Co-ordinator will support the SIL in managing site waste & recycling.

6 COWRALLI SIMOPS LOCAITON FIGURES



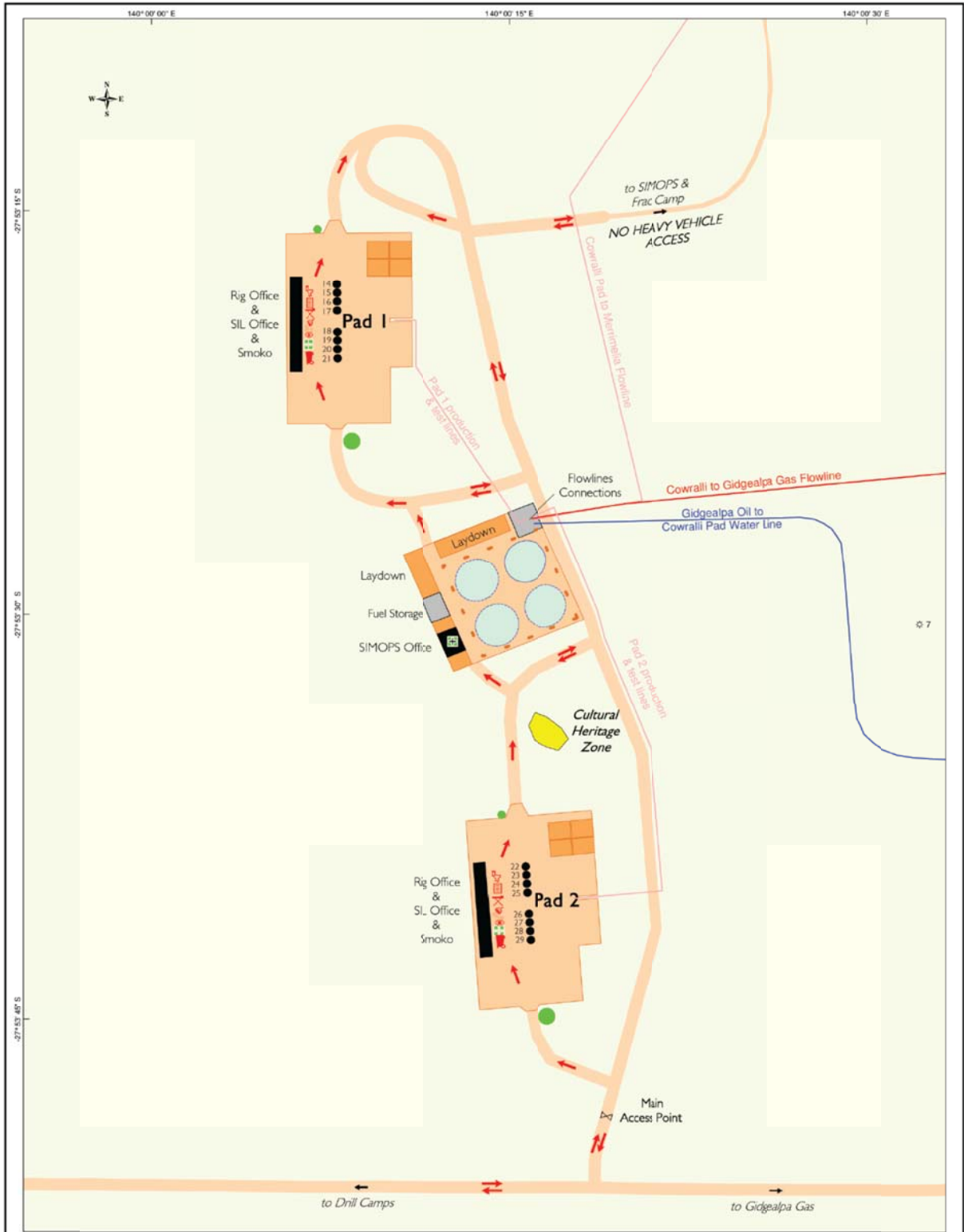


- | | |
|-----------------------------------|---------------|
| First Aid | Eye Wash |
| Muster Point (Primary, Secondary) | Safety Shower |
| Gas Pipeline | Toilets |
| Spill Kit | Stretcher |
| Access Track | Magna Board |
| Traffic Direction | |

Santos
 Cowralli - South Australia
 GDA

Pad Location
Frac Phase

0 100
 Metres
Date: February 2013 File No: COWRAL_GSA



- | | |
|-----------------------------------|---------------|
| First Aid | Eye Wash |
| Muster Point (Primary, Secondary) | Safety Shower |
| Gas Pipeline | Toilets |
| Spill Kit | Stretcher |
| Access Track | Magna Board |
| Traffic Direction | |

Santos
 Cowralli - South Australia
Pad Location Completions Phase
 GDA

0 100
 Metres
 Date: February 2013 File No: COWRAL0510

APPENDIX C –LIST OF TYPICAL CHEMICALS USED IN FRACTURE STIMULATION

Typical Chemicals used in Fracture Stimulation

Chemical Name	CAS RN	Common Use
Organic		
2-Bromo-2-nitro-1,3-propanediol	52-51-7	preservative agent, antibacterial soap, skin cleansing wipes, hand wash and body shampoo and microbial treatment in water systems
Acetic Acid	64-19-7	Additive in the food industry, processed fruit, cheese meat and poultry, descaling agent
Food Red 10	3734-67-6	Food dye
Red No. 2	915-67-3	Dye
Violet 12	6625-46-3	Air freshener, commercial pH indicator solution
Citric Acid	77-92-9	Food agent for sour taste, fruit juice, dishwasher cleaner, all-purpose cleaner, hand soap
Ethylene Glycol Monobutyl Ether	111-76-2	Cleaning products, cosmetics, liquid soaps, paint removal gel, citrus household cleaner, sterilising wipes, commercial lubricating oil
Glycerine	56-81-5	Solvent, sweetner, filler in food, laundry stain remover, antimicrobial soap, toothpaste, lipstick
Glyoxal	107-22-2	Cross linker in the paper and textile industries
Isopropanol	67-63-0	Solvent, medical grade disinfectant, tape head cleaner, hops extract used for beer, air freshener
Methanol	67-56-1	Windscreen washer fluid, wastewater treatment, alternative fuel blends, liquid hand soap, furniture finisher, windscreen washer concentrate, hops extract
Xanthan Gum	11138-66-2	Thickening agent in salad dressings, sauces, ice-creams
Quaternary Amine	- *	Disinfectants, surfactants, fabric softeners, antistatic agents, and wood preservation
Alcohols, C12-16, ethoxylated	68551-12-2	Laundry detergents, surface cleaners, cosmetics and for use in agriculture, textiles and paint, car wash liquid, air freshener
Polyacrylate	- *	Absorbent material in nappies, laundry detergent, glass cleaning solution, dishwashing detergent, children's bath water additive
Quaternary amine	- *	Disinfectants, surfactants, fabric softeners, antistatic agents, and wood preservation, industrial and commercial water acidity neutralising solution
Alcohol (1)	- *	Scouring agent for textiles, commercial defoamer
Amine	- *	Disinfectants, surfactants, fabric softeners, antistatic agents, and wood preservation, commercial bathroom cleaner, medical rinsing solution, photography print ink
Polyacrylamide copolymer	- *	Soil conditioner in the horticulture and agriculture industries, flocculator in potable water treatment, mulch binder, dust control agent
Terpene	- *	Natural agricultural pesticides, laundry soap, furniture oil, grease stripper, paint, ink, gum removal
Ether Compound	- *	Air freshener, food flavouring agents
Oxyalkylated polymer	- *	Demulsifiers, flotation agents
Phenolic compound	- *	Plastic and textile generation, detergents
Glycol compound	- *	foods, cosmetics, and oral hygiene products as a solvent, preservative, and moisture-retaining agent
Hydroxypropyl guar	39421-75-5	Thickener in cosmetics, baked goods, ice cream, toothpaste, and sauces, fabric softener, hair straightening aid, shampoo, body lotion, shaving cream
Benzaldehyde	100-52-7	Almond flavouring in food
Cinnamaldehyde	104-55-2	Food flavour, herbicide, cancer treatment, antimicrobial
Diethylene glycol	111-46-6	Moisture retainer in tobacco, cork, ink glue, cosmetics. Used in brake fluids.
Alkyl phenol alkyoxylates	- *	Metal soldering flux, commercial and industrial cleaners and degreasers
Glycol ether	- *	Pharmaceuticals, sunscreens, cosmetics, inks, dyes, water based paints, degreasers, cleaners, aerosol paints and adhesives
Choline chloride	67-48-1	Feed additive for chickens
Ethylene glycol	107-21-1	Antifreeze, household cleaners, deicing, caulk

Environmental Assessment Report - Fracture Stimulation Operations

Chemical Name	CAS RN	Common Use
Acrylonitrile	107-13-1	Plastic manufacture
Alcohols, C6-C12, Ethoxylated propoxylated	68937-66-6	Household and industrial and institutional cleaners, paints and coatings, pulp and paper, textile processing
Alcohols, C10-C16, Ethoxylated propoxylated	69227-22-1	Household and industrial and institutional cleaners, paints and coatings, pulp and paper, textile processing
Polyethylene glycol	25322-68-3	Laxatives, medications
Inorganic		
Ammonium Sulfate	7783-20-2	Soil fertiliser
Chlorous Acid, Sodium Salt	7758-19-2	Bleaching and stripping of textiles, pulp, and paper
Crystalline Silica, Quartz	14808-60-7	Sand and gravel, cat litter, tile mortar, arts and crafts ceramic glaze
Disodium Octaborate Tetrahydrate	12008-41-2	Antiseptic, insecticide, flame retardant
Hydrochloric Acid	7647-01-0	leather processing, purification of common salt, household cleaning
Potassium carbonate	584-08-7	Soap, glass, china, food additive
Silica Gel	112926-00-8	Mouthwash, toothpaste, powdered sugars
Sodium Carbonate	497-19-8	Laundry detergent, dishwashing liquid, toothpaste, pool pH additive
Sodium Chloride	7647-14-5	Food grade salt, laundry detergent, aquarium fish medication, ice melting product
Sodium Hydroxide	1310-73-2	Laundry detergent, toothpaste, cocoa, milk products, chocolate
Sodium Hypochlorite	7681-52-9	Household bleach, disinfectant, water treatment, endodontics, eczema treatment
Sodium Iodide	7681-82-5	Light bulbs, infant food
Sodium Persulfate	7775-27-1	Bleach, metal etching, soil conditioner, detergent
Sodium Sulfate	7757-82-6	Dishwasher detergent, laundry detergent, liquid hand soap, toothpaste
Aluminium oxide	1344-28-1	Paint, pigment, plastic filler, water/gas purification,
Aluminium silicate	1302-76-7	Blanket felt, paper or boards
Crystalline silica, cristobalite	14464-46-1	Glass, optical fibres for telecommunications
Iron oxide	1309-37-1	Pigments in paint, coatings, coloured concretes
Silica dioxide	112926-00-8	Cement, glass, optical fibres for telecommunications, porcelain, earthenware
Titanium dioxide	13463-67-7	Sunscreen, food colouring, paint pigments
Borate salts	- *	Agricultural plant food, fertiliser, industrial glass manufacturing additive
Almandite and pyrope garnet	1302-62-1	Gemstone, grit blasting
EDTA / Copper chelate	- *	Fertilisers, water softeners, shampoos, food preservatives
Sodium bisulfite	7631-90-5	Food preservative, swimming pool chemical

Note: "- *" = chemical not disclosed for reasons of confidentiality

APPENDIX D – FRACTURE FLUID MASS BALANCE CALCULATION

Fracture Stimulation Fluid Mass Balance Calculation

The purpose of a mass balance is to estimate the concentrations and absolute masses of chemicals that we be reacted, returned to the surface or left in the target gas producing formations subsequent to hydraulic fracturing.

A quantitative mass balance assessment of fracture stimulation fluid components was undertaken by Golder Associates on behalf of Santos based on chemical data provided by Halliburton. Four ‘fluid systems’ were assessed. For each mixture, Halliburton provided details regarding the products in the mixture, and a complete inventory (including mass fraction) of the individual chemicals in the fluid mixtures. The composition of the fracture stimulation fluids and calculated total mass and injected concentrations of the individual chemicals are summarised in further detail in the table below. The fluid compositions in Table D-1 were divided into chemical additives, proppants, water in additives, and makeup water.

In addition to the four fluid systems disclosed by the stimulation service provider, a total of seven “optional” additives, comprising 22 individual chemicals (not including water), were presented. Eight additional chemicals were later disclosed. The optional additives were indicated as potential supplements to, or alternatives for, the additives presented for two of the four fluid systems (HyborH and Omegafrac). A comparison of the additive masses indicated that replacement of the primary additives by the optional additives would result in a similar overall fluid chemical mass. However because the individual chemical constituents are not linked to the additives in the fluid disclosure, it was not possible to determine which chemicals in the fluid system would be replaced by the optional additives / chemicals. Accordingly, the table below includes the individual masses of the optional chemicals expected in a 50,000 gallon mixture of HyborH; however the overall mass balance for HyborH is based on the primary additives / chemicals only.

Mass and mass fraction calculations were based on information provided by the stimulation service provider in their “Stimulation Fluid Disclosure” (note that mass and volumes were provided in imperial units and were converted to SI units). The table below presents the estimated mass of additives, proppant and water included in the stimulation fluid systems *per stimulation event* for both the oil and gas wells. The stimulation service provider noted that typically only one stimulation event is conducted on oil production wells, whereas up to six stimulation events may be conducted on conventional gas production wells.

Table D-1: Estimated Component Mass per Stimulation Event in Typical Stimulation Fluid Systems

Fluid System	HyborH	Omegafrac	Friction Reduced Water	High Temp. Acid Spearhead*
Typical fluid Volume	50,000 gal (~190,000 L)	15,000 gal (~57,000 L)	20,000 gal (~76,000 L)	500 gal (~1,900 L)
Mass of Stimulation Fluid Components (kg)				
Additives	2,212	1,323	142	421
Proppant	49,895	18,144	0	0
Water in additives	1,705	504	113	722
Makeup water	189,148	56,744	75,659	832
Proportion of Stimulation Fluid Components by Mass (%)				
Additives	0.9%	1.7%	0.2%	21.3%
Proppant	20.5%	23.7%	-	-
Water in additives	0.7%	0.7%	0.1%	36.6%
Makeup water	77.9%	73.9%	99.7%	42.1%

Note: ¹ Fluid volume per stimulation event, as indicated in the stimulation service provider's fluid disclosure.

The additives in typical stimulation fluid mixtures comprise approximately 0.2 to 1.7 wt% of the injected mixture for the primary fluid systems (HyborH and Omegafrac) and the friction reduced water typically used for flushing during the stimulation process. The relative percentage of additives is higher in the acid spearhead mixture as this is a concentrated acid, however is used in smaller total volumes when required.

If either HyborH or Omegafrac are used to perform up to six stimulation stages within a single gas production well, then the total mass of additives injected for the well (excluding proppant) would range from approximately 8,000 kg to 13,000 kg.

Following completion of the fracture stimulation process, a considerable volume of the injected fracture fluids are recovered upon flowback of the injected fluid. Studies performed by the USEPA (2004) indicated that approximately 60% of the fracture fluids are recovered in the first three weeks, and total recovery was estimated to be from 68% to 82%. If it is conservatively assumed that 40% of the fracture stimulation fluid volume remains in the formation (this being the “worst case”) this would correspond to 530 to 885 kg per stimulation event, or 3,180 kg to 5,309 kg per production well where up to six stimulation stages are performed (excluding proppant).

APPENDIX E – SANTOS ENVIRONMENTAL POLICY

Environmental Policy



Our Environmental Vision:

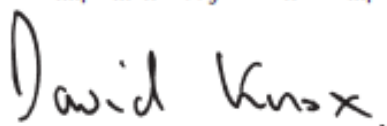
"We will lighten the footprint of our activities"

At Santos we are adopting the principles of sustainable development. We recognise our responsibility to meet community expectations and we are committed to the continuous improvement of our environmental performance. We believe that environmental stewardship is both a management obligation and the responsibility of every employee.

To achieve this we will:

- Maintain and continuously improve the Environment, Health and Safety Management System (EHSMS) across the organisation.
- Ensure that all employees and contractors receive appropriate training to fulfil their individual EHSMS and environmental responsibilities.
- Proactively pursue the identification of all hazards and eliminate or, if not possible, manage the risk to as low as reasonably practicable.
- Establish annual environmental objectives and targets and implement programs to achieve them.
- As a minimum comply with relevant legal and other requirements.
- Ensure that we have the resources and skills necessary to achieve our environmental commitments.
- Incorporate environmental performance in the annual appraisal of employees and contractors and recognise accordingly.
- Implement strategies to minimise pollution, manage waste effectively, use water and energy efficiently and address relevant cultural heritage and biodiversity issues.
- Formally monitor, audit, review and report annually on our environmental performance and EHSMS requirements against defined objectives.
- Require that companies providing contract services to Santos manage their environmental performance in line with this Policy.
- Steward the environmental performance of Joint Venture activities operated by others.

As Chief Executive Officer and Managing Director, I am committed to working with Santos personnel to ensure that this policy is communicated, understood, accepted and successfully implemented by all Santos employees and contractors.



David Knox
Chief Executive Officer and Managing Director

Revision 2