Appendix E: Stimulation Risk Assessment - Santos Southwest Queensland Tenements (SRA)

Report

Stimulation Risk Assessment - Santos Southwest Queensland Tenements

Site Setting and Stimulation Process

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Distribution List

Golder Associates - 1 electronic copy

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Executive Summary

Introduction

Santos Ltd (Santos) engaged Golder Associates Pty Ltd (Golder) to prepare a desktop risk assessment of stimulation (previously referred to as hydraulic fracturing) activities for conventional oil and gas production in their Southwest Queensland (SWQ) tenements. This Stimulation Risk Assessment (SRA) is undertaken to meet Department of Environment and Science (DES; formerly Department of Environment and Heritage Protection (DEHP)) Environmental Authority (EA) consent conditions.

This version of the SRA report updates a 2012 version of the report (127666004-011-R-Rev0, December 2012). Updated content includes reference to the updated Environmental Authority (EA) Blueprint conditions (updated December 2019), updated tenements (as of January 2020), historical well stimulation events and potential dates for future stimulation events. Background information, such as the geological setting, hydrogeology, environmental values and stimulation process, etc has largely not changed in this version of the SRA.

This desktop SRA is presented in two report volumes, as follows:

- Volume One (this report) discusses the environmental and geological settings within which Santos' stimulation activities take place and the general techniques for the drilling, completion and stimulation of wells. The report also discusses why stimulation is essential in SWQ and outlines Santos' current forward programme for fracture-stimulation, although it should be noted that for a variety of reasons (including but not limited to future production performance and / or access-related issues such as the flooding of the Cooper Creek system), the forward programme is frequently reviewed and is subject to change.
- Volume Two relates specifically to the stimulation fluids proposed to be used by *Stimulation Service Providers*[1] on Santos wells in the SWQ conventional oil and gas fields. The report considers the ecological and human health toxicity of the chemical constituents in the stimulation fluids and includes an exposure pathway assessment and risk characterisation based on a review of complete exposure pathways and controls to mitigate exposure.

In the future, specific data relating to the stimulation fluids used by other Stimulation Service Providers may be submitted as a subsequent Volume Two of this report, to allow Department of Environment and Science (DES) approval for fracture-stimulation operations by these contractors.

Golder previously prepared an Underground Water Impact Report (UWIR) for the SWQ conventional oil and gas operations, which was prepared for Santos in accordance with the requirements of the Water Act 2000 (Golder, 2012a; updated January 2020). This SRA report considers the geological and hydrogeological conceptual model developed in the UWIR, any updates to the UWIR (January 2020), additional information provided by Santos, and the requirements of DES to provide a formal risk assessment of stimulation activities in the SWQ Project Areas.

Comparison of Conventional Oil and Gas Operations to Coal Seam Gas (CSG) Operations

There are key differences between CSG and conventional oil and gas production, both in the geographic and geological setting of the resource and the methodology for accessing the resource, that have a substantial bearing on the risk profile presented by stimulation activities. These include:

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[1] At the time of reporting (January 2020) 31 Haliburton products only were in use in SWQ hydraulic fracturing operations. No Schlumburger fracturing products were in use.

- Santos' conventional oil and gas operations in SWQ are located in an arid, sparsely populated area of central Australia. Whilst groundwater is an important water supply to support the rural land uses, the extent of water supply development is limited (commensurate with the small population base).
- In Santos' SWQ operations, the hydrocarbon reservoirs generally occur in anticlines capped with thick, laterally-extensive, low permeability formations that isolate the reservoirs from overlying water-bearing formations.
- The oil and gas reservoirs in the SWQ study area are very deep, of the order of 1500 to 3000 m below ground level, which provides hundreds to over a thousand metres vertical separation between the formations in which stimulation activities are proposed and the shallow groundwater resources. There is also no requirement to remove formation water in order to facilitate gas flow, with the possible exception of well blow downs on a case by case frequency.

Environmental Setting

Santos operates conventional gas and oil fields across petroleum tenements within an approximately 30,000 km^2 portion of SWQ. The terrain in the study area is generally characterised by low undulating topography (hills and ridges) between the drainage channel systems of the Cooper Creek. The area is sparsely developed, and generally comprises rural communities and homesteads that are largely engaged in pastoralism.

The stratigraphy primarily comprises the Eromanga and underlying Cooper Basins, where the oil and gas reservoirs are respectively located. These Basins contain the proposed target formations for stimulation activities. A detailed description of key geological and hydrogeological features is provided in the text, including geological models for the study area, identification of the target hydrocarbon-bearing sandstone formations (oil in the Eromanga Basin formations at depths ranging from 700 to 1,200 m below ground level (mbgl); and gas in the Cooper Basin formations at depths of 1,500 to greater than 2,000 mbgl), their hydraulic characteristics, adjacent aquifers and aquitards, structural features including faults and fracture characteristics (and their potential to behave as barriers or conduits), regional and local seismicity characteristics, aquifer environmental values and the location of groundwater users.

In terms of the environmental setting, this document has provided specific information that addresses the requirements anticipated of the EA conditions regarding stimulation that will apply to new areas proposed for development.

These specific inclusions are located within the logical flow of the description of the existing environment in the SWQ study area.

Key Environmental Values

Based on an understanding of the environmental setting, this risk assessment considered the following key environmental values:

Groundwater Environmental Values:

- Town water supply;
- Stock and domestic water supply;
- Sandstone aquifers of the GAB; and
- Groundwater Dependant Ecosystems (GDEs).

Surface Water Environmental Values:

- Protection of aquatic ecosystems;
- Recreation and aesthetics: primary recreation with direct contact, and visual appreciation with no contact; and
- Cultural and spiritual values.

Terrestrial Environmental Values:

- Protection of flora and fauna, particularly small mammals, reptiles and birds.

The report considers the applicable environmental values in the context of the proposed stimulation activities within the study area.

Stimulation Process Description Summary

With regard to the process of stimulation, the requirements of the EA approval conditions are considered within the stimulation description as they are proposed to be employed in the SWQ study area, with the specific information included as follows:

- Practices and procedures to ensure that the stimulation activities are designed to be contained within the target gas producing formation;
- Details of where, when and how often stimulation is to be undertaken on the tenures covered by this environmental authority;
- A description of Santos' well mechanical integrity testing program;
- Process control and assessment techniques to be applied for determining extent of stimulation activity(ies) (e.g. microseismic measurements, modelling etc); and
- A process description of the stimulation activity to be applied, including equipment and a comparison to best international practice.

Conclusions

Based on the available geological information for the study area, the following key points are noted:

- The DEHP database[2] and the interim results of the WBBA program (WBBA 2012; UWIR 2020) indicate that groundwater supply development in the vicinity of Santos' tenements is limited to the Glendower and Winton Formations, and to a lesser extent the Hooray Sandstone. The minimum vertical offset between the Glendowner and Winton Formations and the shallowest hydrocarbon reservoirs (oil reservoirs of the Cadna-Owie Formation) is 400 to 800 m, which includes the low permeability formations of the Wallumbilla Formation and Allaru Mudstone, which form a thick, competent and regionally extensive seal between the Cadna-Owie Formation and the shallower aquifers. The vertical offset to gas reservoirs is much greater (1,000 m to 1,800 m).
- Within formations that host both aquifers and hydrocarbon reservoirs (e.g. Hooray Sandstone), the water-bearing zones are separated from hydrocarbon reservoirs by intra-formational seals. However, there is not enough information available to discretise the internal stratigraphy of these formations. Where petroleum activities (including stimulation) occur within a formation that hosts both aquifers and hydrocarbon reservoirs, the lateral distance of the water supply bores accessing the aquifer to Santos' tenements was considered.
- Based on information from 2012, and information provided by Santos (January 2020), the closest functioning beneficial use bore to the Santos tenements targeting the Hooray Sandstone in the DEHP database records is the Coothero Bore, which is located at least 25 km from the closest tenement

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[2] DEHP database accessed in 2012

proposed for stimulation and more than 80 km from the closest tenement with activities proposed at a similar depth. The Coothero Bore is monitored by Santos as part of the UWIR monitoring program.

Based on the available site setting information for the study area, the following key points are noted:

- Cooper Creek is largely influenced by surface water flows and evaporation, with negligible contribution from groundwater. Waterholes and billabongs occur throughout the Cooper Creek floodplain and channel complex, some of which coincide directly with Santos tenements. Cooper Creek resides within the Channel Country Strategic Environmental Area under the Regional Planning Interests Act.
- Three of the identified wetlands (Cooper Creek – Wilson River Junction, Bulloo Lake and Cooper Creek Swamps – Nappa Merrie) are within the boundaries of Santos' tenements. It should be noted that stimulation activities may be completed within any tenement boundary over the life of the Project.
- The Cooper Creek catchment and downstream Lake Eyre are popular recreational fishing destinations. Popular fishing spots include Bulloo River at Thargomindah, Wilson River at Nockatunga and Cooper Creek flows (episodically).

Based on the stimulation process information provided by Santos, the following key points are noted:

- Buffers are assigned during establishment of well leases between petroleum operations and potential "environmentally sensitive areas" identified though database review and site-specific ecological assessment where warranted.
- 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.
- 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 robust surveillance plan.
- OH&S procedures are implemented during stimulation operations to prevent workers from direct contact with chemicals during spills and when handling flowback water or sediments. Golder understands that there has not been a recordable spill since stimulation commenced in 1987.
- Santos operational procedures monitor fracture/stimulation design to stay within the target formation.
- Santos implement spill containment procedures during operations to prevent migration of and exposure to chemicals.

Hence, the combination of the remote project location, sparse local population density (and limited water supply development), different production methods and the substantial vertical separation of oil and gas reservoirs from primary groundwater supply aquifers results in an inherently low risk profile with regard to stimulation activities. In addition, Santos procedures and operational controls are design to mitigate residual risk.

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1.0 INTRODUCTION

1.1 Preamble

Santos Ltd (Santos) is a holder of numerous existing Environmental Authorities (EAs) for activities and operations throughout Southwest Queensland (SWQ), collectively referred to as “SWQ”. To meet EA consent conditions, a formal risk assessment of stimulation activities is required and subsequently, Golder Associates Pty Ltd (Golder) has been engaged by Santos to prepare this Stimulation Risk Assessment (SRA).

This version of the SRA updates a 2012 version (127666004-011-R-Rev0, December 2012 previously referred to as a Hydraulic Fracturing Risk Assessment (HFRA)). Updated content includes reference to the updated Environment Authority (EA) Blueprint conditions (updated December 2019), updated tenements (as of January 2020), historical well stimulation events and potential future stimulation dates. Background information, such as the geological setting, hydrogeology, environmental values and stimulation process, etc has not changed in this version of the SRA.

This desktop SRA is presented in two volumes, as follows:

- Volume One discusses the environmental and geological settings within which Santos’ stimulation operations take place and the general techniques for the drilling, completion and stimulation of wells. The report also discusses why stimulation is essential in SWQ and outlines Santos’ current forward programme for fracture-stimulation, although it should be noted that for a variety of reasons (including but not limited to future production performance and / or access-related issues such as the flooding of the Cooper Creek system), the forward programme is frequently reviewed and is subject to change.
- Volume Two relates specifically to the stimulation fluids proposed to be used by *Stimulation Service Providers*[3] on Santos wells in the SWQ conventional oil and gas fields. The report considers the ecological and human health toxicity of the chemical constituents in the stimulation fluids and includes an exposure pathway assessment and risk characterisation based on a review of complete exposure pathways and controls to mitigate exposure.

In the future, specific data relating to the stimulation fluids used by other Stimulation Service Providers may be submitted as a subsequent Volume Two of this report, to allow DES approval for fracture-stimulation operations by these contractors.

Golder previously prepared an Underground Water Impact Report (UWIR) for the SWQ conventional oil and gas operations, which was prepared for Santos in accordance with the requirements of the Water Act 2000 (Golder, 2012a; updated January 2020). The current report considered the geological and hydrogeological conceptual model developed in the UWIR, any updates to the UWIR (January 2020), additional information provided by Santos, and the requirements of DES to provide a formal risk assessment of stimulation activities for the future development of the SWQ Project Areas.

1.2 Limitations

Your attention is drawn to the document - “Limitations”, which is included in APPENDIX A of this report. The statements presented in this document are intended to advise you of what your realistic expectations of this report should be. The document is not intended to reduce the level of responsibility accepted by Golder, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

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[3] At the time of reporting (January 2020) 31 Haliburton products only were in use in SWQ hydraulic fracturing operations. No Schlumberger fracturing products were in use.

1.3 Santos SWQ Project – Overview

Santos currently operates a significant number of conventional gas and oil fields within SWQ (Figure 1). The area covered by the petroleum tenements within which these fields encompass is approximately 30,000 km^2 of largely semi-arid agricultural land and was first developed for petroleum operations in the early 1970's. Within the Cooper-Eromanga Basin as a whole (including that part which lies in South Australia), Santos operates approximately 114 gas fields and 87 oil fields, the majority of which are currently in production (Figure 2).

- *Conventional oil* is produced from the formations of the Eromanga Basin (a sub-basin within the Great Artesian Basin (GAB)). The oil is present in discontinuous oil reservoirs within interbedded sandstones beds or larger sandstone formations. There are several types of oil reservoirs resulting from the process of "trapping" of the oil (Section 2.4.3.4).
- *Conventional gas production* is undertaken from porous sandstone formations and as such does not require the depressurisation of the target beds (with respect to groundwater). Some water is produced as a by-product however the volumes are limited (refer to the UWIR (2020) for detailed discussion). The conventional gas production is typically associated with the deeply-buried formations of the Cooper Basin (separate from and underlying the GAB). Very limited volumes of gas have also been produced from within the Eromanga Basin Production Areas.

For the purposes of this assessment, the term "*study area*" refers to the area applicable to this assessment: all SWQ tenements operated by S*antos* and the land immediately surrounding the Santos tenement boundaries (Figure 2).

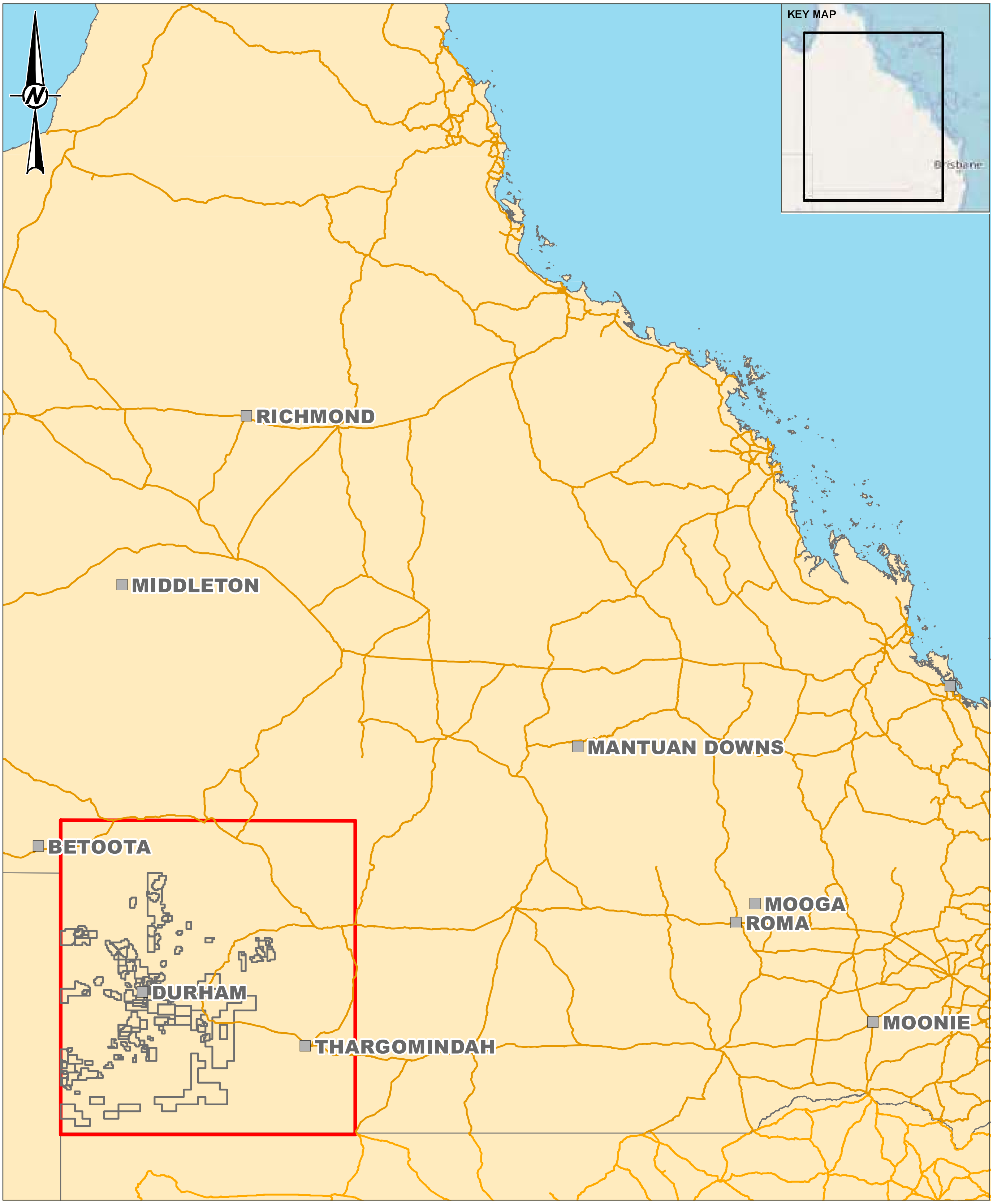
1.3.1 Proposed Stimulation Operations

The use of stimulation is essential in order to achieve economically-viable flow-rates and recoverable volumes from the majority of the production wells that are drilled in SWQ.

Between March 2013 and May 2019, 101 oil and gas wells underwent stimulation activities with another 67 oil and gas wells potentially undergoing stimulation activities between 2020 and 2022.

It should be noted that for a variety of reasons (including but not limited to future production performance and / or access-related issues such as the flooding of the Cooper Creek system), the forward drilling and stimulation programme is frequently reviewed and is subject to change.

The oil and gas production field and lease areas are further discussed in Section 1.5.



LEGEND

■ Town/Locality

— Highway/Major Road

▭ Santos Tenements

🟥 Study Area

NOTE(S)

REFERENCE(S)

1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019

CLIENT
SANTOS

PROJECT
HYDRAULIC FRACTURING RISK ASSESSMENT – SANTOS SOUTHWEST QUEENSLAND TENEMENTS

TITLE
SANTOS SWQ STUDY AREA

CONSULTANT

GOLDER

DD-MM-YYYY	19-03-2020
DESIGNED	KB
PREPARED	KB
REVIEWED	CB
APPROVED	CB

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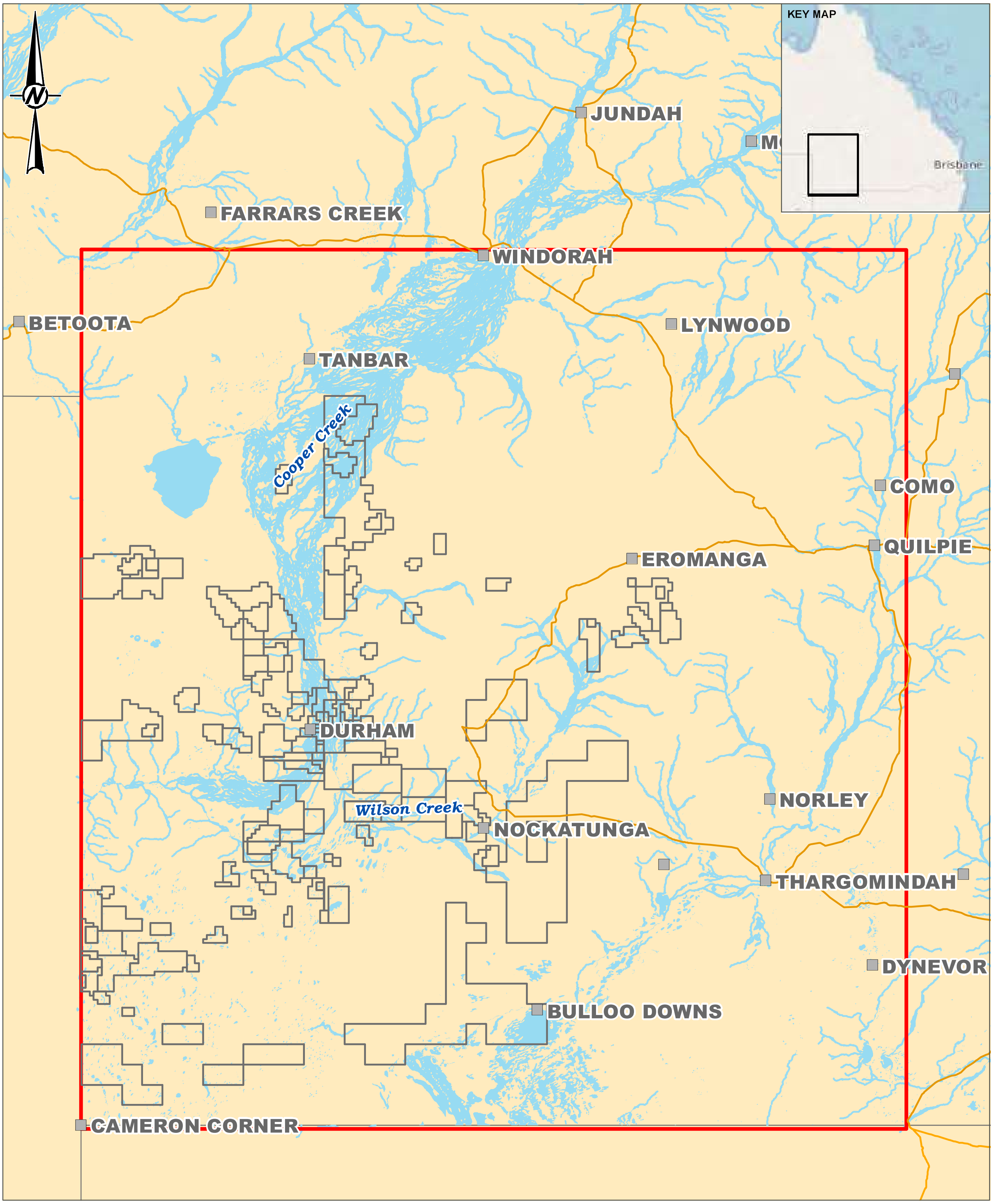

LEGEND

■ Town/Locality

— Highway/Major Road

— River/Creek

☐ Santos Tenements

🟥 Study Area

0 KILOMETERS 100

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NOTE(S)

REFERENCE(S)

1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019

CLIENT
SANTOS

PROJECT
HYDRAULIC FRACTURING RISK ASSESSMENT – SANTOS SOUTHWEST QUEENSLAND TENEMENTS

TITLE
OIL AND GAS FIELDS FOR THE SWQ PROJECT

CONSULTANT
GOLDER

DD-MM-YYYY	19-03-2020
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1.3.2 EA Conditions

The Environmental Authority (EA) approval requirements for the Santos' SWQ operations necessitate the collection and provision of information on stimulation. Detailed regulatory requirements contained in these approvals and the sections of this risk assessment where the conditions are met are provided in Table 1. Conditions related to stimulation risk assessments can vary between Santos SWQ EAs and can also vary to those included within DES' Streamlined model conditions for petroleum activities Guideline (ESR/2016/1989).

Table 1: Summary of Consent Conditions*

Condition		Report Volume	Report Section
(a)	a process description of the **stimulation** activity to be applied, including equipment	One	3.3
(b)	provide details of where, when and how often **stimulation** is to be undertaken on the tenures covered by this environmental authority	One	3.4.1
(c)	a geological model of the field to be stimulated including geological names, descriptions and depths of the target gas producing formation(s)	One	2.4 and 2.5
(d)	naturally occurring geological faults	One	2.4.3.5 and 2.4.5
(e)	seismic history of the region (e.g. earth tremors, earthquakes)	One	2.4.5
(f)	proximity of overlying and underlying aquifers	One	2.6
(g)	description of the depths that aquifers with environmental values occur, both above and below the target formation	One	2.6
(h)	identification and proximity of **landholders' active groundwater bores** in the area where **stimulation** activities are to be carried out	One	2.5.7
(i)	the environmental values of groundwater in the area	One	2.6
(j)	an assessment of the appropriate **limits of reporting** for all water quality indicators relevant to **stimulation** monitoring in order to accurately assess the risks to environmental values of groundwater	Refer Stimulation Impact Monitoring Program	-
(k)	description of overlying and underlying formations in respect of porosity, permeability, hydraulic conductivity, faulting and fracture propensity	One	2.4.4 and 2.5.5
(l)	consideration of barriers or known direct connections between the target formation and the overlying and underlying aquifers	One	2.5.2.3, 3.3.4 and 3.3.7
(m)	a description of the well mechanical integrity testing program	One	3.2.2

Condition	Report Volume	Report Section
(n) process control and assessment techniques to be applied for determining extent of **stimulation** activities (e.g. microseismic measurements, modelling etc.)	One	3.3.4 and 3.3.7
(o) practices and procedures to ensure that the **stimulation** activities are designed to be contained within the target formation	One	3.3.4 and 3.3.7
(p) groundwater transmissivity, flow rate, hydraulic conductivity and direction(s) of flow	One	2.5.3, 2.5.4 and 2.5.5
(q) a description of the chemicals used in **stimulation** activities (including estimated total mass, estimated composition, chemical abstract service numbers and properties), their mixtures and the resultant compounds that are formed after **stimulation**	Two	3.0
(r) a mass balance estimating the concentrations and absolute masses of chemicals that will be reacted, returned to the surface or left in the target formation subsequent to **stimulation**	Two	3.2
(s) an environmental hazard assessment of the chemicals used including their mixtures and the resultant chemicals that are formed after **stimulation** including: (i). toxicological and ecotoxicological information of chemical compounds used (ii). information on the persistence and bioaccumulation potential of the chemical compounds used (iii). identification of the chemicals of potential concern in stimulation fluids derived from the risk assessment	Two	4.0, 5.0, 6.0 and 7.3.2
(t) an environmental hazard assessment of the chemicals used including mixtures and the resultant chemicals that are formed after stimulation	Two	4.0, 5.0, 6.0 and 7.3.2
(u) identification and an environmental hazard assessment of using radioactive tracer beads in **stimulation** activities where such beads have been used or are proposed to be used	One	3.3.7.10
(v) an environmental hazard assessment of leaving chemical compounds in **stimulation fluids** in the target formation for extended periods subsequent to **stimulation**	Two	
(w) human health exposure pathways to operators and the regional population	Two	6.0
(x) risk characterisation of environmental impacts based on the environmental hazard assessment	Two	7.0
(y) potential impacts to landholder bores as a result of **stimulation** activities	Two	2.2.3.1

Condition		Report Volume	Report Section
(z)	an assessment of cumulative impacts, spatially and temporally of the **stimulation** activities to be carried out on the tenures covered by this environmental authority	Two	7.5
(aa)	potential environmental or health impacts which may result from **stimulation** activities including but not limited to water quality, air quality (including suppression of dust and other airborne contaminants), noise and vibration	One and Two	1.3 (Report Version One) 4.0, 5.0, 6.0 and 7.3.2 (Report Version 2)

*Consent conditions from Schedule K (Well Construction, Maintenance and Stimulation), subsection K6, 21 December 2019

1.4 Risk Assessment Process

Risk assessment provides a systematic framework for characterising the nature and magnitude of risks from stressors (in this case, stimulation chemicals). Risk assessment is an important tool for decision-making. Australian risk assessment guidance has been used in the preparation of this report, namely draft guidance for ecological risk assessment provided by the Environment Protection Authority (EPA) Victoria (Gibson *et al.*, 1997) and enHealth-Environmental Health Risk Assessment, "Guidelines for Assessing Human Health Risks from Environmental Hazards", June 2004 (enHealth, 2004).

The scope of the qualitative risk assessment comprises of:

- **Issue Identification** (Volume One) - A description of the current environmental setting (including a description of potential receiving environments and the various factors which act upon them, including climatic influences), detailed geological and hydrogeological information, gas well integrity and a description of the stimulation process including an identification of the constituents of the stimulation fluid(s);
- **Exposure Assessment** (Volume Two) **–** The exposure assessment comprises an evaluation of surface and subsurface exposure pathway assessment;
- **Hazard Assessment** (Volume Two) **–** An evaluation of the environmental hazard of relevant chemical additives in the stimulation fluid based on aquatic toxicity, environmental persistence and bioaccumulation. The environmental hazard assessment provides a relative ranking of the chemical additives and those chemicals considered to represent a high hazard are identified as chemicals of potential concern (COPC) for further assessment. An evaluation of terrestrial and human health toxicity will also be presented;
- **Risk Characterisation** (Volume Two) **–** A qualitative evaluation of environmental and human health risk associated with the stimulation activities based on the identification of complete exposure pathways and hazard identification.

The evaluation of exposure pathways includes both *subsurface* and *surface* processes. The principles for ecological and human health risk assessment consist of the following steps: issue identification, hazard (or toxicity) assessment, exposure assessment, and risk characterisation. Human health risk assessment is limited to assessment of effects on one receptor: *humans*. Ecological risk assessment is concerned with assessment of effects on the ecosystem (populations and communities) and therefore is not limited to one receptor. The guidance framework for ecological risk assessment in Australia is the "Guideline on Ecological Risk Assessment" (NEPM, Schedule B(5), 1999; updated 2013) which refers to draft guidance prepared by EPA Victoria (Gibson *et al.*, 1997). These guidance documents focus on risks to terrestrial environments although the overall approach for assessment or risk is the same. The risk assessment was undertaken in general accordance with these guidelines and national guidelines for risk assessment recommended by enHealth (enHealth-Environmental Health Risk Assessment, “Guidelines for Assessing Human Health Risks from Environmental Hazards”, June 2012).

If, in the future, conditions, stimulation methodologies and/or regulatory requirements change, and/or additional exposure pathways to additional receiving environments are identified, further evaluation of the associated risks *may* be warranted.

1.5 Study Area

Santos’ Production Licences in SWQ cover an area of over 17,000 km^2. The development of petroleum fields in SWQ started in the early 1970s. Santos currently produces conventional gas and oil from approximately 212 gas wells from 53 fields and 250 oil wells from 47 fields in SWQ.

The land is generally characterised by low undulating topography (hills, ridges and valleys) between the various fluvial systems (e.g. the Cooper Creek). The areas occupied by these creek systems are regionally referred to as “Channel Country” and consist of a system of braided or anastomosing channels and associated inter-channel areas and floodplains. Surrounding the floodplains are gravel plains, dunefields and low ranges. The area is sparsely developed, and generally comprises rural communities and homesteads that are largely engaged in pastoralism.

The Cooper Basin underlies, but is considered to be geologically separate from, the Eromanga Basin, which is the largest sub-basin within the Great Artesian Basin (GAB). Some of the sedimentary formations associated with the GAB are recognised as regionally significant aquifers (Figure 3). There are no outcrops of the GAB formations within the study area, which is overlain by quaternary alluvium. With a couple of localised exceptions, conventional gas is produced from formations within the Cooper Basin, at depths exceeding 2000 m, while oil is mainly produced from formations within the Eromanga Basin at depths of approximately 700 to 1,200 m below ground level.

Santos activities are described in the SWQ *Project Areas* Environmental Management Plans (Santos, 2014). The summary information on activities and infrastructure reported below has been extracted from these environmental management plans.

As a summary, the SWQ study area includes a combination of gas and oil production, associated transport, storage and processing infrastructure and ongoing exploratory, appraisal and development drilling. The operations are grouped in “processing satellites” or centres where Santos has developed all the facilities necessary to the operations of the fields. Santos has developed the following infrastructure within the Cooper-Eromanga Basin as a whole (including that part which lies in South Australia):

- Approximately 29 Oil and Gas Processing Satellites, the main ones for SWQ are discussed in Section 1.5.1; and
- Approximately 212 producing gas wells and 250 producing oil wells in SWQ.

1.5.1 Oil and Gas Occurrences and Production

A consequence of the geological setting of the Cooper and Eromanga Basins is the location of *gas* fields within the centre of the basin system (Figure 2) and the *oil* fields mainly around the edges of the study area (mainly in the centre and the east of Santos tenements in SWQ).

The petroleum fields proposed for production, the corresponding lease areas and infrastructures are discussed in the following sections.

1.5.1.1 Target Gas Formations

Gas is primarily extracted from the formations of the Cooper Basin. The geology of the Cooper Basin is presented in Section 2.4.3.1. The main consequence of the geological setting is the very deep location of the target gas reservoirs at depths of 2,000 m or more. The gas fields are located in the centre of Santos tenements in SWQ and in SA (Figure 2).

The primary gas reservoirs (discussed in Section 2.4.3.4) targeted for stimulation are sandstones within:

- The Paning and Doonmulla Members (Nappamerri Group);
- The Toolachee Formation (Gidgealpa Group);
- The Epsilon Formation (Gidgealpa Group); and
- The Patchawarra Formation (Gidgealpa Group).

These reservoirs are stacked porous sandstones, separated by coals and / or finer-grained siltstones mudstones (refer to detailed stratigraphy in Section 2.5.2). These impermeable layers are typically referred to as the seal or cap rock beds where they are located immediately above the reservoirs. The sandstone reservoirs often have low porosities and permeabilities (usually of the order of 1-10 milliDarcies), such that fracture-stimulation is essential in order to achieve economic flow-rates and production volumes.

In addition, other sediments may become targets for stimulation if encountered in future wells.

Operation of tenements is likely to change in the future and assessment of additional tenements will be considered prior to stimulation being undertaken following due consultation with DES and the Department of Natural Resources, Mines and Energy (DNRME).

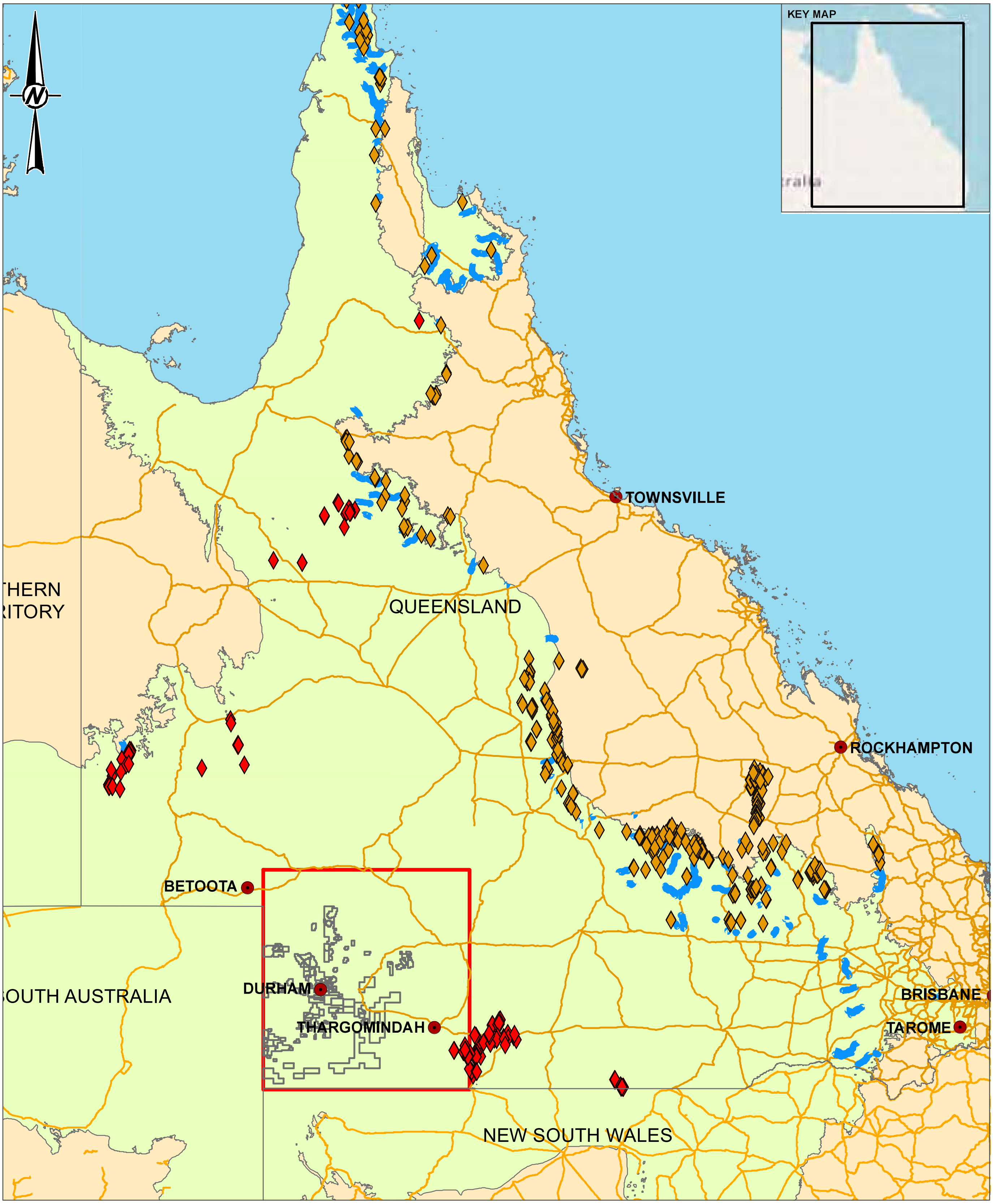
1.5.1.2 Target Oil Formations

Oil is produced from sediments within the formations of the Eromanga Basin (part of the Great Artesian Basin), at depth of approximately 700 to 1,200 m below ground level. There are 227producing oil wells within Santos tenements in SWQ.

The oil reservoirs (discussed in Section 2.4.3.4) targeted for stimulation are:

- The Murta Formation (Upper Hooray Sandstone). Oil reservoirs are abundant in the Murta Formation (interbedded mudstones, siltstones and fine grained sandstones);
- The Birkhead Formation, comprising interbedded siltstone, mudstone and fine sandstone. Oil reservoirs are present mostly in the Lower Birkhead unit, scattered oil reservoirs also occur in the Middle Birkhead unit; and
- The Wyandra Sandstone Member (upper unit of the Cadna-Owie Formation), oil occurrence is less frequent.

Operation of tenements is likely to change in the future and assessment of additional tenements will be considered prior to stimulation being undertaken following due consultation with DES and DNRME.



LEGEND

- ● Town
- ♦ GAB ROP Discharge Spring
- ♦ GAB ROP Recharge Spring
- ▬ GAB ROP Water Course Spring
- ― Highway/Major Road
- ☐ Santos Tenements
- 🟥 Study Area

0 KILOMETERS 250

1:10,000,000 GCS GDA 1994

NOTE(S)

REFERENCE(S)

1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019
3. GAB BOUNDARY, SOURCED FROM HTTPS://DATA.GOV.AU, SOURCED 18.12.2019

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PROJECT
HYDRAULIC FRACTURING RISK ASSESSMENT – SANTOS SOUTHWEST QUEENSLAND TENEMENTS

TITLE
LOCATION OF THE GREAT ARTESIAN BASIN

CONSULTANT

GOLDER

DD-MM-YYYY	19-03-2020
DESIGNED	KB
PREPARED	KB
REVIEWED	CB
APPROVED	CB

PROJECT NO.	CONTROL	REV.	FIGURE
127666004	011-R	2	3

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1.6 Comparison of Conventional Oil and Gas Operations to Coal Seam Gas Operations

HFRA (now referred to as SRA) reports have previously been prepared to address stimulation activities related to Santos' coal seam gas (CSG) developments as part of the Gladstone Liquefied Natural Gas (GLNG) Project. There are key differences between CSG and conventional oil and gas production, both in the geological setting of the resource and the methodology for access, that have a substantial bearing on the risk profile presented by stimulation activities.

Santos' conventional oil and gas operations in SWQ are located in an arid, sparsely populated area of central Australia. Whilst groundwater is an important water supply to support the rural land uses, the extent of water supply development of the productive aquifers is limited (commensurate with the low population base) and is almost entirely within the upper sedimentary formations of the Eromanga Basin. The lateral equivalents of the GAB aquifers in Eastern Queensland that support substantial beneficial uses have little or no water supply development in in the study area.

The nature of the hydrocarbon resources in SWQ is also fundamentally different from CSG targets. Conventional oil and gas reservoirs are formed when hydrocarbons in a porous (typically sandstone) formation are "trapped" and accumulate as a result of encountering a low permeability sedimentary or structural "seal". In Santos' SWQ operations, the hydrocarbon reservoirs generally occur in anticlines capped with thick, laterally-extensive, low permeability formations that isolate the reservoirs from overlying water-bearing formations. The nature of the geological and hydrogeological setting provides for substantial separation of fracturing and production activities from the shallower groundwater resources that support the majority of water supply development in the region. There is also no requirement to remove formation water in order to facilitate gas flow, with the possible exception of well blow downs on a case by case frequency. In addition, the oil and gas reservoirs in the SWQ study area are very deep, in the order of 1500 to 3000 m bgl, which provides hundreds to over a thousand metres vertical separation between the formations in which stimulation activities are proposed and the shallow aquifers that provide the majority of private groundwater supply.

Hence, the combination of the remote project location, sparse local population density (and limited water supply development), different production methods and the substantial vertical separation of oil and gas reservoirs from primary groundwater supply aquifers results in an inherently low risk profile with regard to stimulation activities.

2.0 SITE SETTING AND ISSUE IDENTIFICATION

The description of the site setting, and issue identification is covered under the following headings:

- Description of the climate in SWQ;
- Description of the topography;
- Description of the hydrology;
- Description of the continental geological setting and basin stress regime;
- Description of the regional geology and stratigraphy of the GAB;
- Description of the local geology and oil and gas field models;
- Seismic history of the region;
- Description of the GAB hydrogeological setting and hydrostratigraphy;
- Description of the hydrogeological context of oil and gas production;
- Groundwater quality and use in the study area;
- Environmental values of groundwater and surface water in the study area, which comprise the potential receptors considered in the exposure analysis for stimulation activities; and
- Proximity of overlying and underlying aquifers to the target oil or gas formations, and proximity of surface operations to sensitive receptors.

2.1 Climate

The Cooper Basin of SWQ is an isolated arid to semi-arid region of central Australia where the average rainfall is low (<300 mm per year) and is significantly exceeded by the pan evaporation potential (approximately 3,000 mm per year). The seasons are generally characterised by hot summers with significant thunderstorm activity and mild dry winters. December to February are the wettest and hottest months where temperatures generally exceed 35°C. The Bureau of Meteorology (BOM) provides monthly average data for temperature and rainfall for anywhere in Australia. For a more detailed description please refer to http://www.bom.gov.au/.

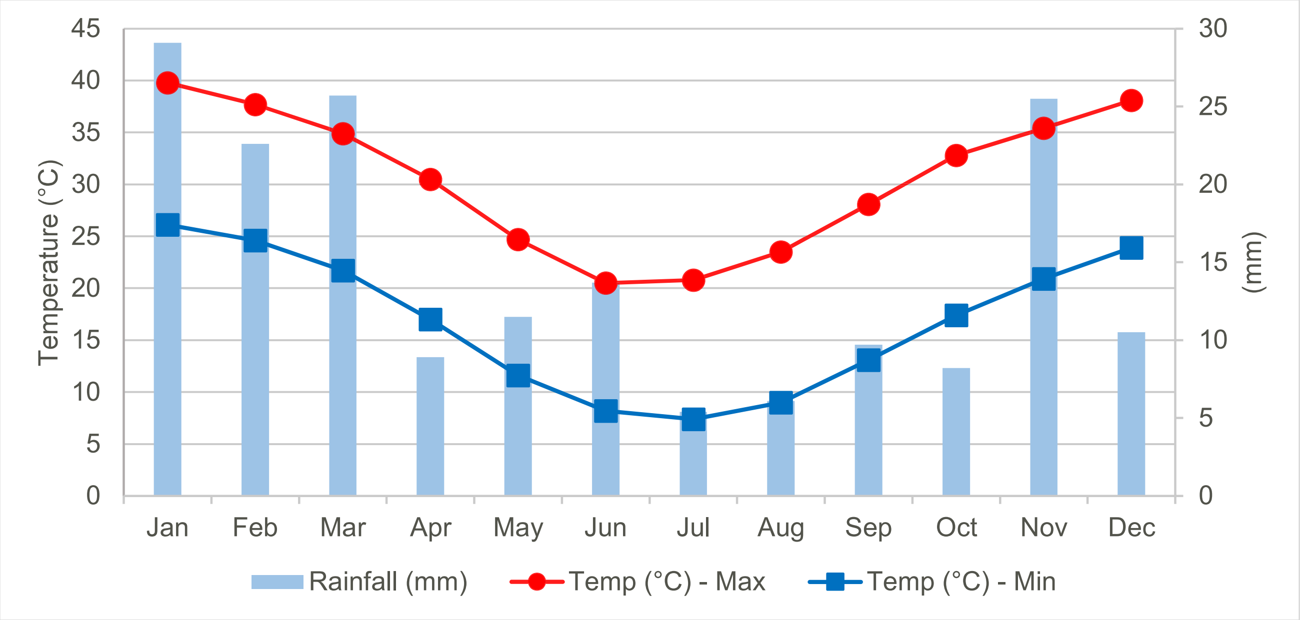
Table 2 and Figure 4 present the average minimum and maximum monthly temperatures and average monthly total rainfall from Ballera Gas Field, the closest BOM facility to Durham (approximately 16 km to the west). These data are averages for number of years. Annual average values are presented for temperature while average annual total amount of rainfall are presented in the same table. Maximum values are in red and minimum values in blue. No data on evaporation for the Ballera Gas Field site was available. However, data for evaporation was available for Windorah Evaporation Station located approximately 220 km to the north of Durham. Evaporation for Windorah ranged from 3.7 mm daily evaporation in June to 12.4 mm daily evaporation in December (data collected from 1969 to 2019). It should be noted that for this location the mean rainfall was higher than for Ballera and ranged from 10.0 mm mean monthly rainfall in August to 48.3 mm mean monthly rainfall in February approximately double that seen for Ballera in the same months.

Table 2: Mean Climate Characteristics within the Cooper Basin Operations Area – Ballera Gas Field

Mean	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Temp (°C) - Max	39.8	37.7	34.9	30.5	24.7	20.5	20.8	23.5	28.1	32.8	35.4	38.1	30.6	2002-2019
Temp (°C) - Min	26.1	24.6	21.7	17.0	11.6	8.2	7.4	9.0	13.1	17.4	20.9	23.9	16.7	2002-2019
Rainfall (mm)	29.1	22.6	25.7	8.9	11.5	13.7	5.4	6.1	9.7	8.2	25.5	10.5	181.8	2000-2019

* Estimated from the average *daily* pan evaporation as reported by BOM.

Figure 4: Rainfall and Temperature Diagram - Monthly Averages from 1931-2012 for Ballera Gas Field



Source: BOM, 2012

2.2 Topography

The study area is situated across a large, relatively flat drainage area of the Cooper Creek river system referred to as the ‘Channel Country’ of far south-western Queensland (extending into South Australia).

The topography of the study area comprises low undulating hills and ridges between the drainage channel systems. The Channel Country is characterised by extensive alluvial plains with braided channel networks of the Diamantina and Coopers Plains. Surrounding the floodplains are gravel or gibber plains, dune fields and low ranges. The low resistant hills and tablelands present in the study area are remnants of the flat-lying Cretaceous (65 to 140 million years ago) sediments.

The drainage system of the study area is dominated by the Cooper Creek Basin and is discussed further in Section 2.3.

2.3 Surface Water

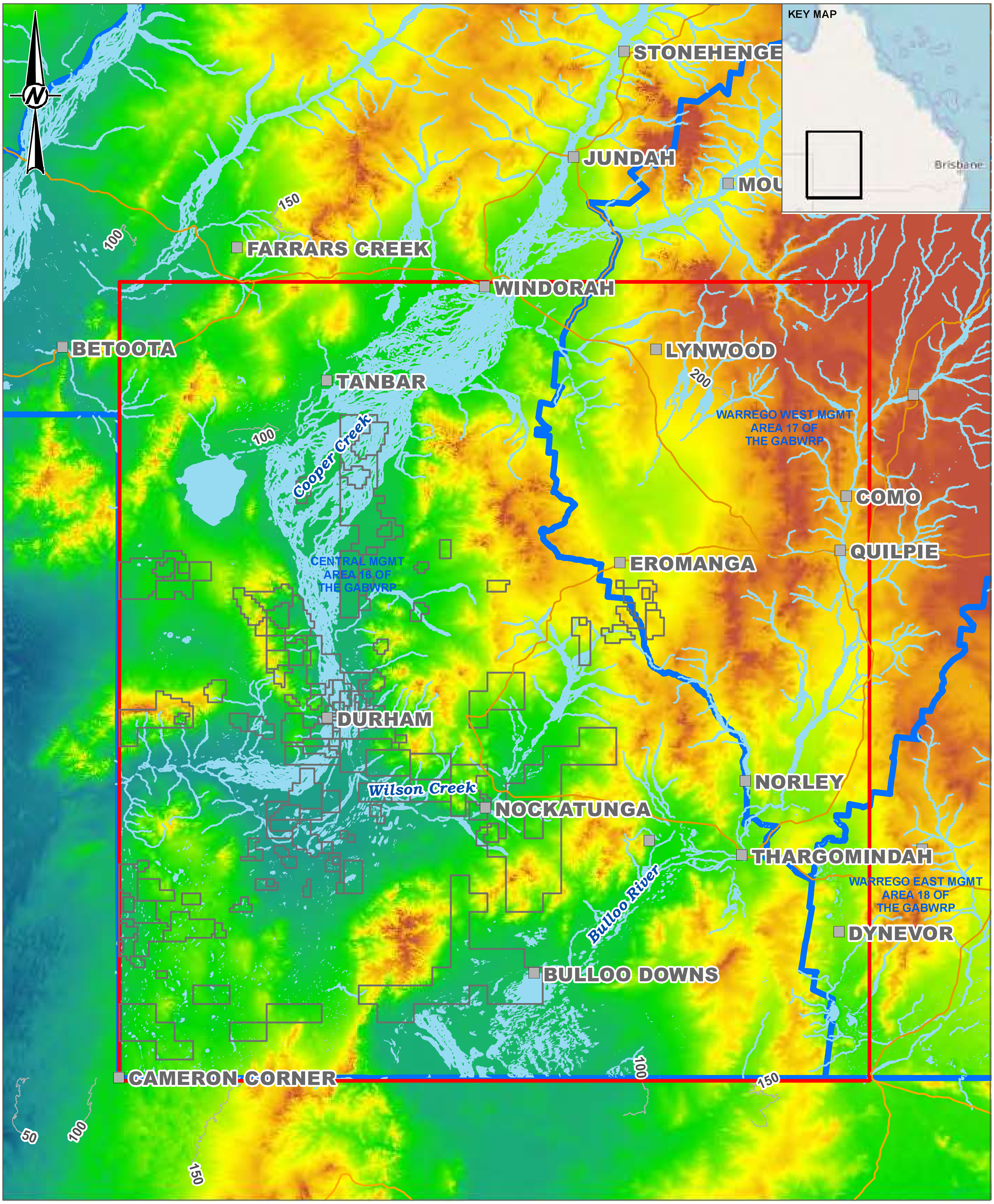
The surface water drainage system within the study area (Figure 5) is dominated by Cooper Creek Basin, which drains southwest towards Lake Eyre. This Basin comprises almost a quarter of the overall Lake Eyre Basin catchment. During periods of monsoonal rainfall in its headwaters, the flat topography and drainage channel system forms a large floodplain. The surface water flow bottlenecks where Cooper Creek crosses the Queensland-South Australia border.

Cooper Creek is an internal (i.e. no outlet to the ocean) ephemeral river of 1,500 km in length and covering a catchment area of 306,000 km^2. Water flows vary greatly over time and are predominantly controlled by the occurrence of monsoonal rains in the headwaters of the Cooper Creek drainage system (Kotwicki and Allen, 1998).

Generally, Cooper Creek stream flows are confined to the main channels, but every three to four years flows are sufficient to inundate parts of the Cooper Creek floodplain, via a network of tributary channels. The cyclic nature of flows in Cooper Creek has been reported to correlate with La Nina events, which result in monsoon rains penetrating further into inland Australia (Kotwicki and Allen, 1998). During extended periods of no flow, the Cooper Creek drainage contracts to a series of disconnected, semi-permanent waterholes that form in deeper portions of the river channels, which provide drought refuges for a variety of flora and fauna. Two minor flood events were observed in 2019 and the latest large flood event was observed in early to mid 2010 (Figure 6).

Within the study area (largely confined to the Cooper Creek catchment basin), there are also intermittent surface water flows following storm events that cause ponding of surface water on interdune clay pans, predominantly in the dunefield regions and other areas.

There are only a handful of major water storages in the Cooper Creek Basin, with no in-stream dams. There are a number of small weirs for stock and domestic purposes, and a limited number of larger weirs that are mainly used for town water supply including at the northern margin of the study area at Wombunderry. Waterholes are the biggest storages in the basin with some entitlements to divert water to off-stream storages for domestic use. There is no supplemented water supply scheme in the Cooper Creek Basin.



LEGEND

- ■ Town/Locality
- — Highway/Major Road
- — River/Creek
- ▭ Groundwater Management Area
- ▭ Santos Tenements
- 🟥 Study Area

Elevation
High : 475
Low : 0

0 KILOMETERS 100
1:2,750,000 GCS GDA 1994

NOTE(S)

REFERENCE(S)
1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019
3. SRTM - NGA AND NASA

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PROJECT
HYDRAULIC FRACTURING RISK ASSESSMENT – SANTOS SOUTHWEST QUEENSLAND TENEMENTS

TITLE
TOPOGRAPHY AND DRAINAGE OF THE STUDY AREA

CONSULTANT
GOLDER

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PREPARED	KB
REVIEWED	CB
APPROVED	CB

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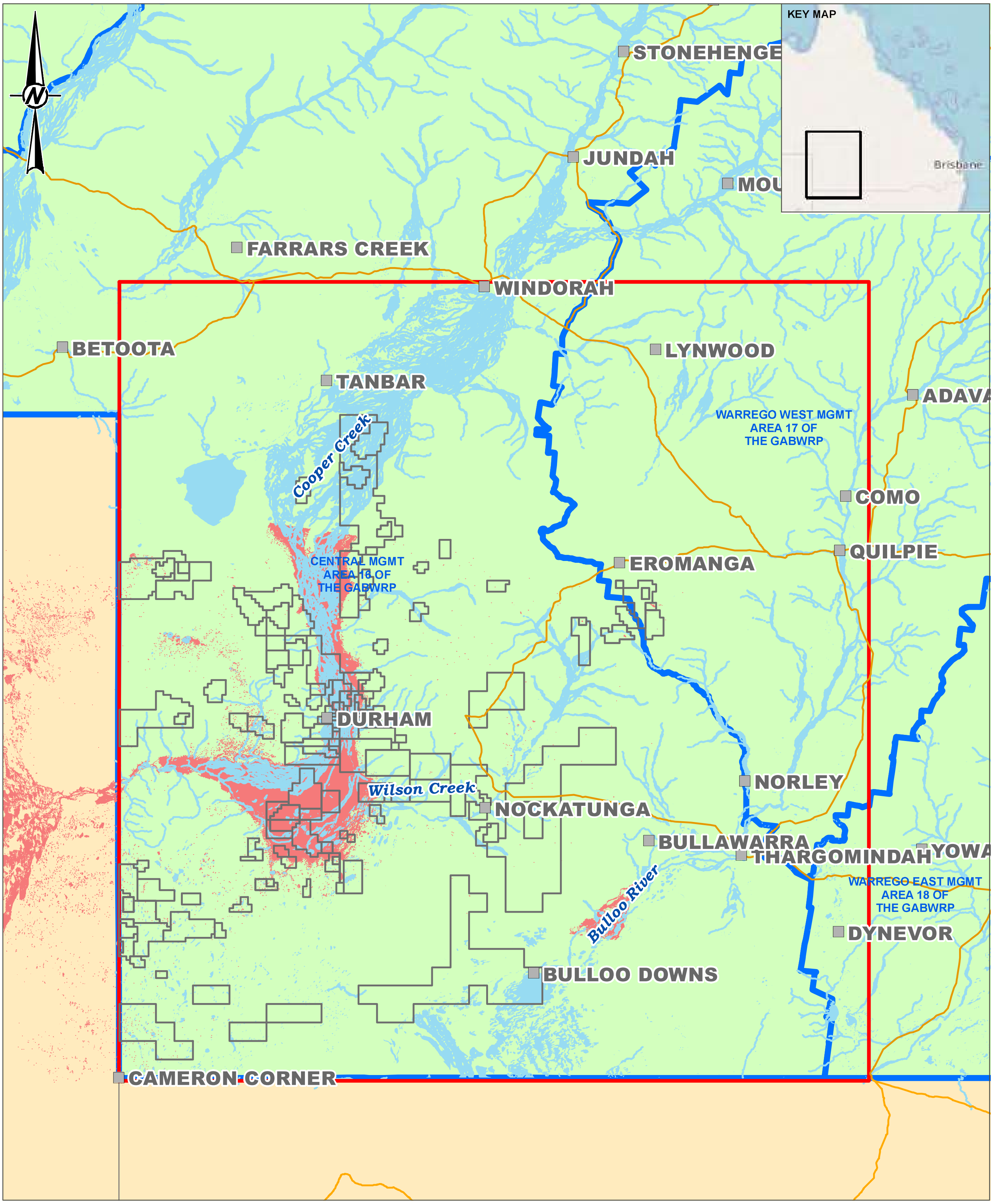

LEGEND

■ Town/Locality	☐ Santos Tenements
Highway/Major Road	🟥 Study Area
River/Creek	
🟥 Flood Area 2010 Extent	
🟩 Groundwater Management Area	

0 KILOMETERS 100

1:2,750,000 GCS GDA 1994

NOTE(S)

REFERENCE(S)
1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019
3. FLOOD EXTENTS PROVIDED BY SANTOS, 2011

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PROJECT
HYDRAULIC FRACTURING RISK ASSESSMENT – SANTOS SOUTHWEST QUEENSLAND TENEMENTS

TITLE
STUDY AREA DURING A FLOOD EVENT (2010)

CONSULTANT

GOLDER

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APPROVED	CB

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2.4 Geological Setting

2.4.1 Continental Setting

The study area is located in the south-western portion of the Great Artesian Basin (GAB). The GAB is a hydrogeological basin that underlies approximately one fifth of the Australian continental area and extends beneath a large portion of Queensland, South Australia, New South Wales and the Northern Territory; stretching between the Great Dividing Range to the Lake Eyre depression (Figure 3). The GAB consists of three large sedimentary basins (the Eromanga, Carpinteria and Surat Basins), comprising layered sedimentary sequences up to 3,000 m thick in the deepest portions of the basin. The sub-basins of the GAB unconformably overlay a number of older depositional basins including the Cooper Basin in SWQ (Figure 7).

It has been an historical convention in Queensland's groundwater management framework to include the upper sedimentary sequences of certain older basins underlying the GAB (specifically, the Bowen, Galilee and Cooper Basins) in the broader definition of the GAB groundwater resource. Whilst this convention was adopted for administrative convenience, in a strict geological sense these basins are considered to be distinct and separate from the sub-basins of the GAB.

2.4.2 Regional Geological Setting

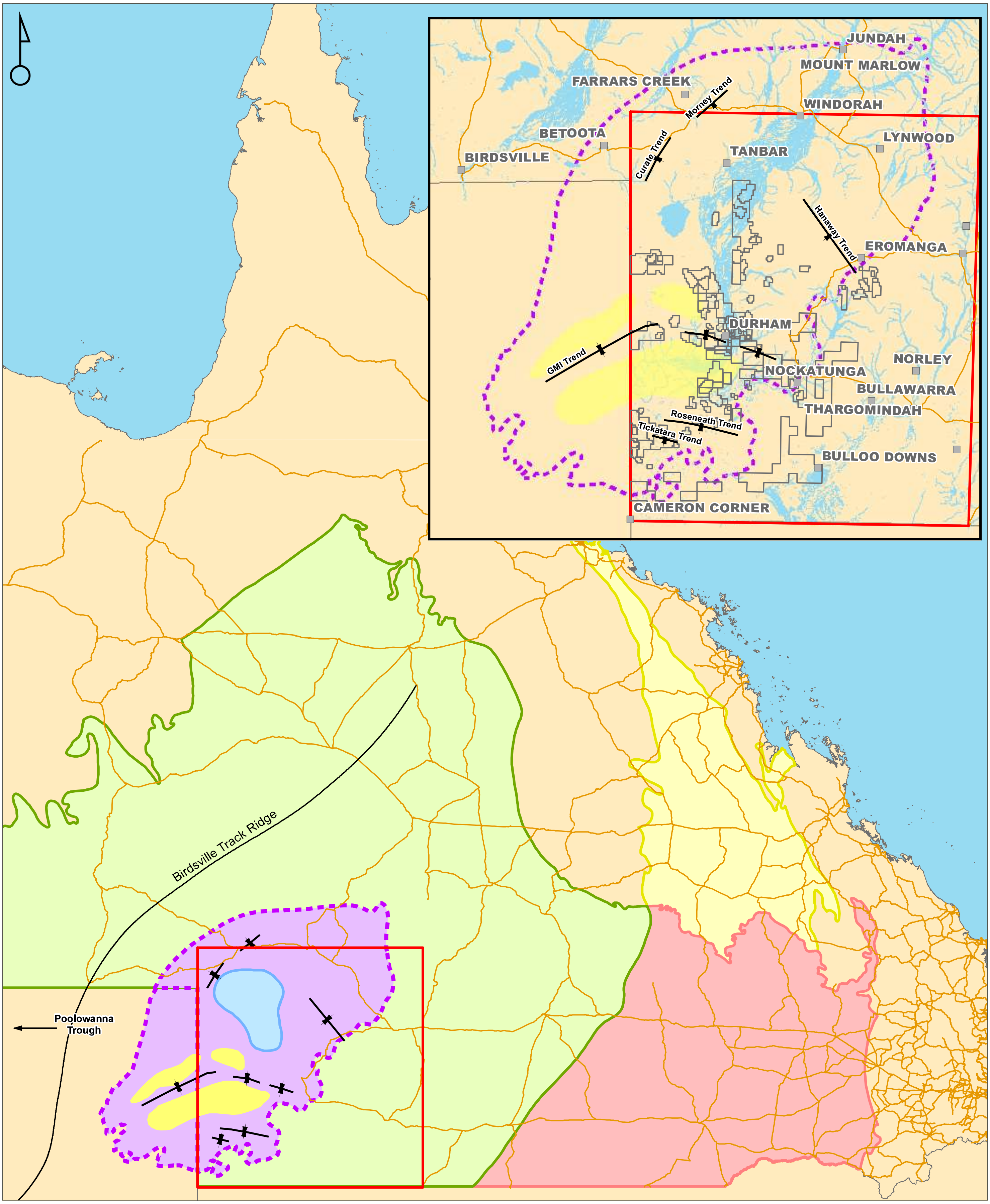
The study area is situated over portions of the Eromanga and Cooper Basins in SWQ. The geology within the study area includes a late Carboniferous to Triassic age sequence of interbedded sandstones, coals and siltstones associated with the Cooper Basin, which is unconformably overlain by the Jurassic to Cretaceous sedimentary deposits of the Eromanga Basin (Figure 7).

The Eromanga Basin is the largest of the main sub-basins of the GAB. It contains two major centres of basin subsidence: the Central Eromanga depositional centre and the Poolowanna Trough separated by the Birdsville Track Ridge (Figure 7).

The Cooper Basin is entirely buried below the Eromanga Basin and they are vertically separated by a major unnamed unconformity. Although considered structurally separate sedimentary depositional centres, they are stratigraphically and, to a very limited extent, hydraulically connected. Formations of the Cooper Basin and the GAB have varying nomenclature in stratigraphic successions from one area to another. Habermehl (1986) and others have tried to provide basin-wide correlations between nomenclatures for the GAB. This section adopts the geological nomenclature defined for SWQ by Draper (2002). Reference to "equivalent naming" is required in order to link with the nomenclature used in the QLD GAB regulation.

At the surface, the regional geological maps indicate a predominance of consolidated sediments of the Glendower Formation (Tertiary) or Winton Formation (Cretaceous) on the higher ground structures and also Quaternary alluvial deposits (Figure 8 and Figure 9) associated with the Cooper Creek flood plains. The Quaternary surface sedimentation of the Cooper Creek catchment was described by Nanson et al. (2008) as comprising extensive late Quaternary fluvial and aeolian deposits, overlain by thick floodplain and channel mud deposits.

The general stratigraphic sequence for the study area is presented in Table 3.



LEGEND

- ■ Town/Locality
- — Birdsville Ridge (Approximate Location)
- — Highway/Major Road
- ✚ Structural Trend
- 🟨 Geological/Structural Trough
- 🟪 Cooper Basin
- 🟦 Barrolka Trough
- 🟨 Bowen Basin
- 🟩 Eromanga Basin
- 🟥 Surat Basin
- ☐ Santos Tenements
- 🟥 Study Area

0 KILOMETERS 400

1:6,000,000 GCS GDA 1994

NOTE(S)

REFERENCE(S)
1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019
3. STRUCTURAL GEOLOGY OF GAB, DERM
4. STRUCTURAL ELEMENTS OF THE COOPER AND EROMANGA BASINS DIGITISED FROM LOWE YOUNG ET AL 1997

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PROJECT
HYDRAULIC FRACTURING RISK ASSESSMENT – SANTOS SOUTHWEST QUEENSLAND TENEMENTS

TITLE
GAB STRUCTURAL GEOLOGY OF THE STUDY AREA

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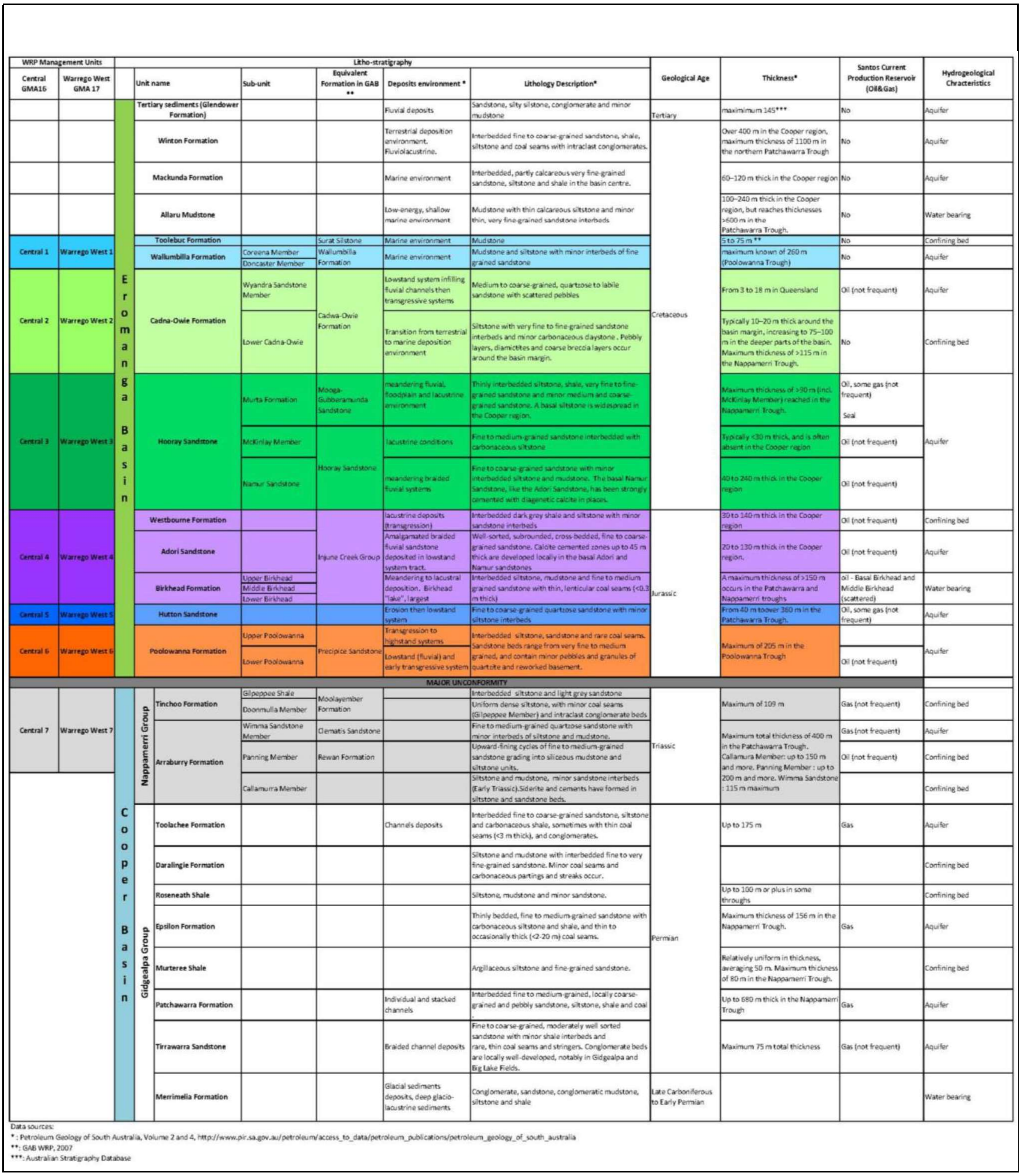
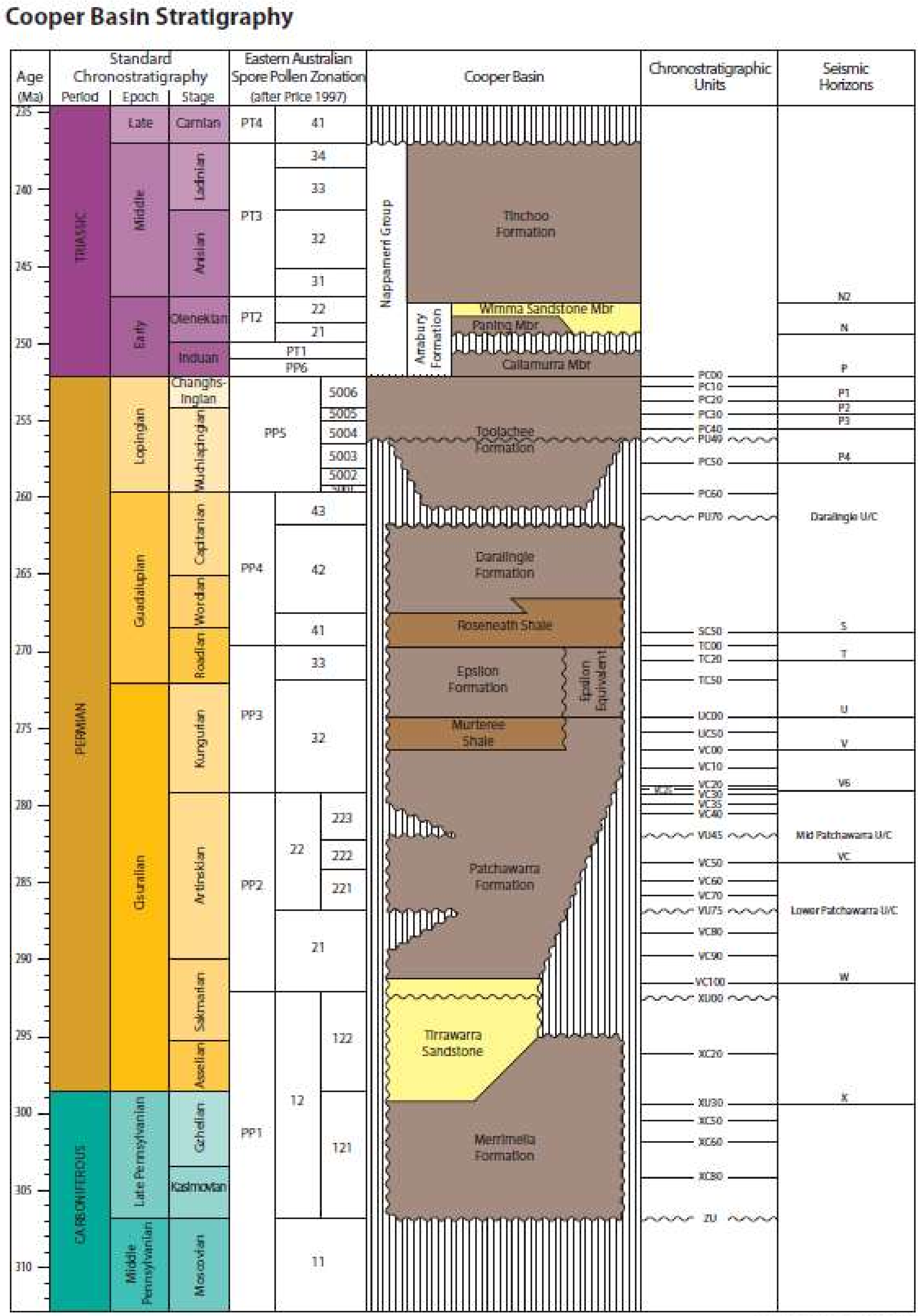
Table 3: Stratigraphic Sequence for the Study Area



WRP Management Units		Litho-stratigraphy							Geological Age	Thickness*	Santos Current Production Reservoir (Oil&Gas)	Hydrogeological Chracteristics
Central GMA16	Warrego West GMA 17			Unit name	Sub-unit	Equivalent Formation in GAB **	Deposits environment *	Lithology Description*				
		Eromanga Basin		Tertiary sediments (Glendower Formation)			Fluvial deposits	Sandstone, silty silstone, conglomerate and minor mudstone	Tertiary	maximimum 145***	No	Aquifer
				Winton Formation			Terrestrial deposition environment. Fluviolacustrine.	Interbedded fine to coarse-grained sandstone, shale, siltstone and coal seams with intraclast conglomerates.	Cretaceous	Over 400 m in the Cooper region, maximum thickness of 1100 m in the northern Patchawarra Trough	No	Aquifer
				Mackunda Formation			Marine environment	Interbedded, partly calcareous very fine-grained sandstone, siltstone and shale in the basin centre.		60–120 m thick in the Cooper region	No	Aquifer
				Allaru Mudstone			Low-energy, shallow marine environment	Mudstone with thin calcareous siltstone and minor thin, very fine-grained sandstone interbeds		100–240 m thick in the Cooper region, but reaches thicknesses >600 m in the Patchawarra Trough.	No	Water bearing
Central 1	Warrego West 1			Toolebuc Formation		Surat Silstone	Marine environment	Mudstone		5 to 75 m **	No	Confining bed
				Wallumbilla Formation	Coreena Member	Wallumbilla Formation	Marine environment	Mudstone and siltstone with minor interbeds of fine grained sandstone		maximum known of 260 m (Poolowanna Trough)	No	Aquifer
					Doncaster Member							
Central 2	Warrego West 2			Cadna-Owie Formation	Wyandra Sandstone Member	Cadwa-Owie Formation	Lowstand system infilling fluvial channels then transgressive systems	Medium to coarse-grained, quartzose to labile sandstone with scattered pebbles		From 3 to 18 m in Queensland	Oil (not frequent)	Aquifer
					Lower Cadna-Owie		Transition from terrestrial to marine deposition environment	Siltstone with very fine to fine-grained sandstone interbeds and minor carbonaceous claystone . Pebbly layers, diamictites and coarse breccia layers occur around the basin margin.		Typically 10–20 m thick around the basin margin, increasing to 75–100 m in the deeper parts of the basin. Maximum thickness of >115 m in the Nappamerri Trough.	No	Confining bed
Central 3	Warrego West 3			Hooray Sandstone	Murta Formation	Mooga-Gubberamunda Sandstone	meandering fluvial, floodplain and lacustrine environment	Thinly interbedded siltstone, shale, very fine to fine-grained sandstone and minor medium and coarse-grained sandstone. A basal siltstone is widespread in the Cooper region.		Maximum thickness of >90 m (incl. McKinlay Member) reached in the Nappamerri Trough.	Oil, some gas (not frequent) Seal	Aquifer
					McKinlay Member	Hooray Sandstone	lacustrine conditions	Fine to medium-grained sandstone interbedded with carbonaceous siltstone		Typically <30 m thick, and is often absent in the Cooper region	Oil (not frequent)	
					Namur Sandstone		meandering braided fluvial systems	Fine to coarse-grained sandstone with minor interbedded siltstone and mudstone. The basal Namur Sandstone, like the Adori Sandstone, has been strongly cemented with diagenetic calcite in places.		40 to 240 m thick in the Cooper region	Oil (not frequent)	
Central 4	Warrego West 4			Westbourne Formation		Injune Creek Group	lacustrine deposits (transgression)	Interbedded dark grey shale and siltstone with minor sandstone interbeds	Jurassic	30 to 140 m thick in the Cooper region	Oil (not frequent)	Confining bed
				Adori Sandstone			Amalgamated braided fluvial sandstone deposited in lowstand system tract.	Well-sorted, subrounded, cross-bedded, fine to coarse-grained sandstone. Calcite cemented zones up to 45 m thick are developed locally in the basal Adori and Namur sandstones		20 to 130 m thick in the Cooper region.	Oil (not frequent)	Aquifer
				Birkhead Formation	Upper Birkhead		Meandering to lacustral deposition. Birkhead "lake", largest	Interbedded siltstone, mudstone and fine to medium grained sandstone with thin, lenticular coal seams (<0.3 m thick)		A maximum thickness of >150 m occurs in the Patchawarra and Nappamerri troughs	oil - Basal Birkhead and Middle Birkhead (scattered)	Water bearing
					Middle Birkhead							
					Lower Birkhead							
Central 5	Warrego West 5			Hutton Sandstone			Erosion then lowstand system	Fine to coarse-grained quartzose sandstone with minor siltstone interbeds		From 40 m toover 360 m in the Patchawarra Trough.	Oil, some gas (not frequent)	Aquifer
Central 6	Warrego West 6			Poolowanna Formation	Upper Poolowanna	Precipice Sandstone	Transgression to highstand systems	Interbedded siltstone, sandstone and rare coal seams. Sandstone beds range from very fine to medium grained, and contain minor pebbles and granules of quartzite and reworked basement.		Maximum of 205 m in the Poolowanna Trough		Aquifer
					Lower Poolowanna		Lowstand (fluvial) and early transgressive system				Oil (not frequent)	
MAJOR UNCONFORMITY												
Central 7	Warrego West 7	Cooper Basin	Nappamerri Group	Tinchoo Formation	Gilpeppee Shale	Moolayember Formation		Interbedded siltstone and light grey sandstone	Triassic	Maximum of 109 m	Gas (not frequent)	Confining bed
					Doonmulla Member			Uniform dense siltstone, with minor coal seams (Gilpeppee Member) and intraclast conglomerate beds				
				Arraburry Formation	Wimma Sandstone Member	Clematis Sandstone		Fine to medium-grained quartzose sandstone with minor interbeds of siltstone and mudstone.		Maximum total thickness of 400 m in the Patchawarra Trough. Callamura Member: up to 150 m and more. Panning Member : up to 200 m and more. Wimma Sandstone : 115 m maximum	Gas (not frequent)	Aquifer
					Panning Member	Rewan Formation		Upward-fining cycles of fine to medium-grained sandstone grading into siliceous mudstone and siltstone units.			Oil (not frequent)	Confining bed
					Callamurra Member			Siltstone and mudstone, minor sandstone interbeds (Early Triassic).Siderite and cements have formed in siltstone and sandstone beds.				Confining bed
			Gidgealpa Group	Toolachee Formation			Channels deposits	Interbedded fine to coarse-grained sandstone, siltstone and carbonaceous shale, sometimes with thin coal seams (<3 m thick), and conglomerates.	Permian	Up to 175 m	Gas	Aquifer
				Daralingie Formation				Siltstone and mudstone with interbedded fine to very fine-grained sandstone. Minor coal seams and carbonaceous partings and streaks occur.				Confining bed
				Roseneath Shale				Siltstone, mudstone and minor sandstone.		Up to 100 m or plus in some throughs		Confining bed
				Epsilon Formation				Thinly bedded, fine to medium-grained sandstone with carbonaceous siltstone and shale, and thin to occasionally thick (<2-20 m) coal seams.		Maximum thickness of 156 m in the Nappamerri Trough.	Gas	Aquifer
				Murteree Shale				Argillaceous siltstone and fine-grained sandstone.		Relatively uniform in thickness, averaging 50 m. Maximum thickness of 80 m in the Nappamerri Trough.		Confining bed
				Patchawarra Formation			Individual and stacked channels	Interbedded fine to medium-grained, locally coarse-grained and pebbly sandstone, siltstone, shale and coal		Up to 680 m thick in the Nappamerri Trough	Gas	Aquifer
				Tirrawarra Sandstone			Braided channel deposits	Fine to coarse-grained, moderately well sorted sandstone with minor shale interbeds and rare, thin coal seams and stringers. Conglomerate beds are locally well-developed, notably in Gidgealpa and Big Lake Fields.		Maximum 75 m total thickness	Gas (not frequent)	Aquifer
				Merrimelia Formation			Glacial sediments deposits, deep glacio-lacustrine sediments	Conglomerate, sandstone, conglomeratic mudstone, siltstone and shale	Late Carboniferous to Early Permian			Water bearing

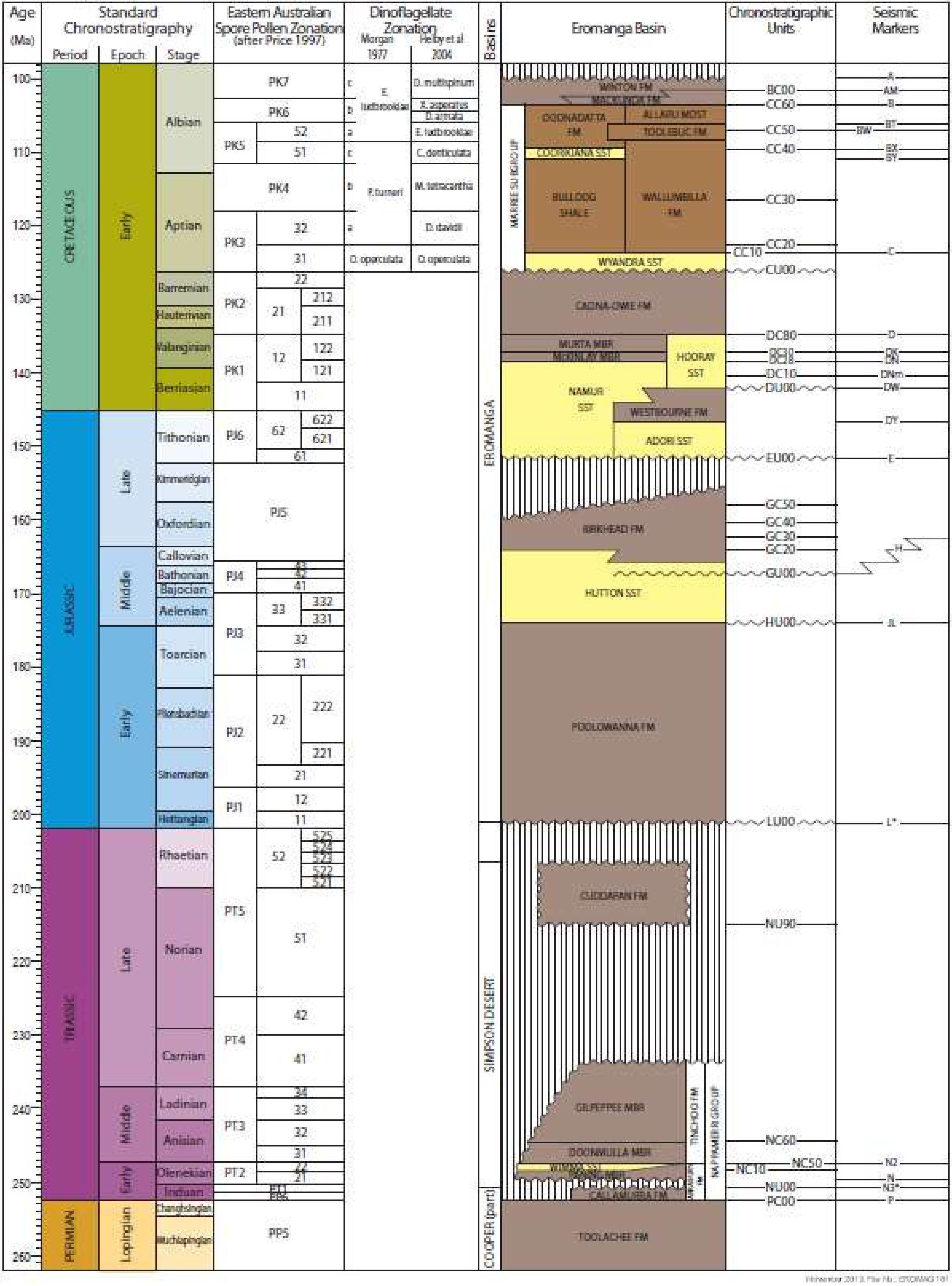
Data sources:
*: Petroleum Geology of South Australia, Volume 2 and 4, http://www.pir.sa.gov.au/petroleum/access_to_data/petroleum_publications/petroleum_geology_of_south_australia
**: GAB WRP, 2007
***: Australian Stratigraphy Database

Figure 8: Chronology and Stratigraphy of the Cooper and Eromanga Basins (Queensland and South Australia)

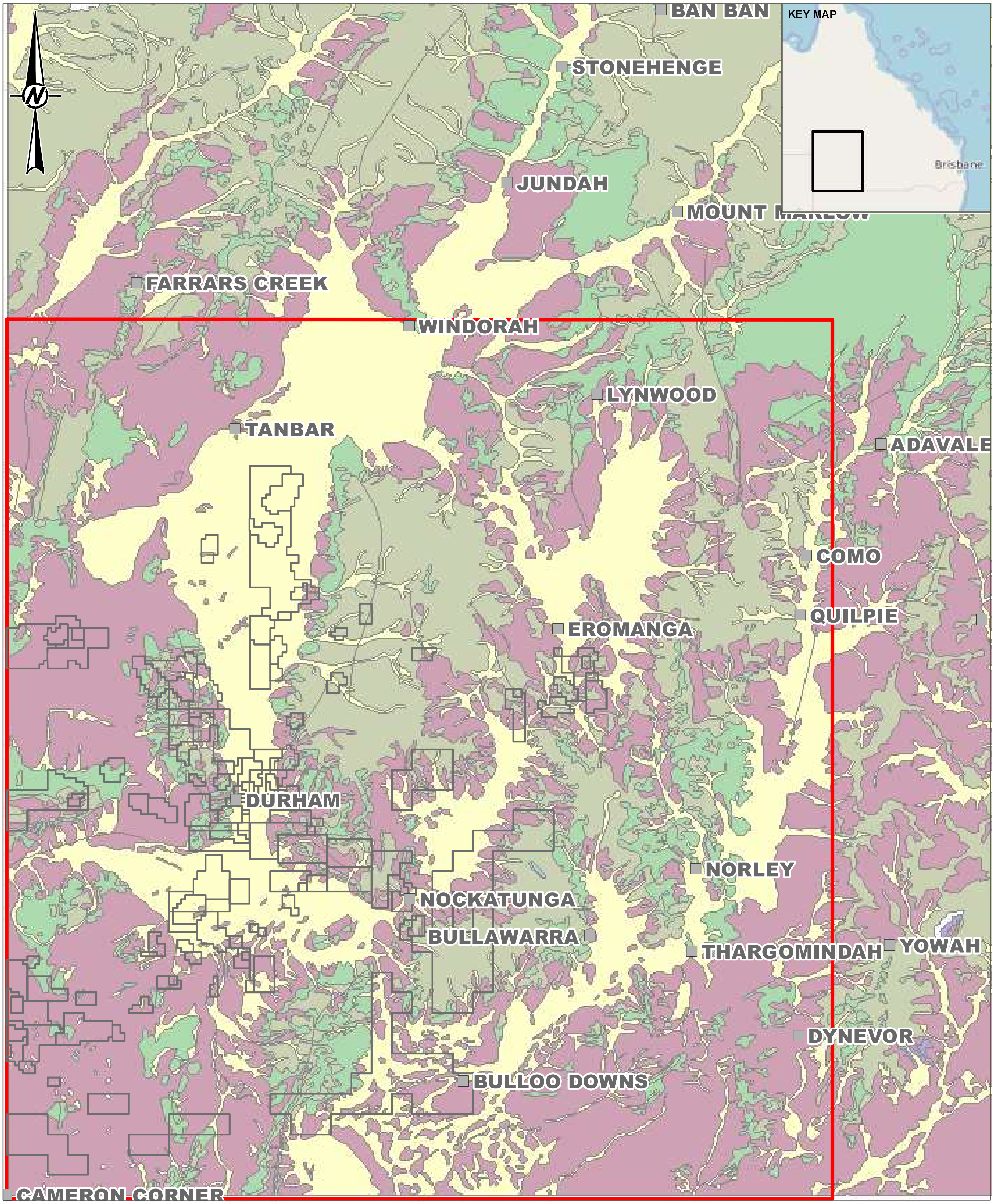


September 2016, File No.: COOPER 1025

Eromanga Basin Stratigraphy



Source: Draper, 2002



LEGEND

■	Town/Locality
🟨	Qa-CER
🟪	Q-CER
🟩	Glendower Formation
▨	Winton Formation
🟦	Mackunda Formation
🟪	Doncaster Member
☐	Santos Tenements
🟥	Study Area

0 KILOMETERS 100

1:2,500,000 GCS GDA 1994

NOTE(S)

REFERENCE(S)

1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019
3. GEOLOGY SOURCED DEPARTMENT OF MINES AND ENERGY, QLD GOVERNMENT, 2007

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TITLE
SURFACE GEOLOGY

CONSULTANT

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2.4.3 Local Geological Setting and Petroleum Field Models

The following sections provide a summary of the Cooper Basin and Eromanga Basin geological settings. An overview of the stratigraphy and lithology for the study area is provided in Table 3. Figure 8 provides information on the continuity of the deposition process, and the discontinuities or major unconformities present in the stratigraphic sequence.

2.4.3.1 Cooper Basin Geological Setting and Model

The Cooper Basin comprises a thick late Carboniferous to middle or late Triassic non-marine sedimentary stratigraphic succession within a broad basin shaped setting in the interior of central Australia.

Structurally, the Cooper Basin is one of a number of remnant late Carboniferous to early Permian depositional centres which lay in the Australian interior of the Gondwana Supercontinent. The Cooper Basin differs from the smaller depositional centres by containing an additional sequence that ranges in age from late Permian to middle Triassic and spans the Permo-Triassic boundary without a break in deposition. It also differs as being the only such basin with major oil and gas production (Petroleum Geology of South Australia, Volume 4 - Cooper Basin, PIRSA, 1998). Three major troughs (Patchawarra, Nappamerri and Tanapperra) are identified within the basin, each separated by structurally high ridges.

The Cooper Basin depositional episode was terminated by a period of gentle regional compressional deformation resulting in landmass uplift and sustained erosion within the basin. Sedimentary basin development re-initiated subsequently with the formation of the Eromanga Basin (Section 2.4.3.2) during the Early Jurassic to Late Cretaceous times.

The Cooper Basin contains a succession of fluvio-lacustrine sandstone, shales and coals to a thickness of up to 1,800 m to the south and thinner in the north (up to 600 m thick). The target gas formations in the Cooper Basin lie at depths of 1,500 mbgl to greater than 2,000 mbgl.

The Cooper Basin is subdivided in two major geological groups: the late Carboniferous and Permian Gidgealpa Group and the Triassic Nappamerri Group. The earliest sediments within the Cooper Basin were of glacial origin. The subsequent formations generally consist of interbedded sandstone, coal and shale formations. The Tirrawarra Sandstone represents low sinuosity fluvial to glacial outwash deposits overlain by peat swamp, floodplain and high sinuosity fluvial facies of the Patchawarra Formation. Two lacustrine shale units (Murteree and Roseneath Shales) with intervening fluvio-deltaic sediments (Epsilon and Daralingie Formations) were deposited during a phase of continued subsidence. Early Permian uplift led to erosion of the Daralingie Formation and underlying units from basement highs (SA DPI, 1998).

The upper sequence of the Cooper Basin, the Gilpeppee Member of the Tinchoo Formation is dominated by siltstones and shales. Draper (2002) has mapped the thickness of shales of the Tinchoo Formation in SWQ. The mudstone (both shale and siltstone) thickness ranges from 80 to 160 m in the centre of the Cooper Basin with a maximum thickness of 182 m.

The Tirrawarra Sandstone, Patchawarra Formation, Epsilon Formation and Toolachee Formation (Table 3) are the main gas producers of the Cooper Basin. Minor gas reservoirs are also present in the Tirrawarra Sandstone, the Wimma Sandstone Member of the Arraburry Formation and the Tinchoo Formation. Some oil reservoirs are present in the Panning Member of the Arraburry Formation.

Geological contour maps illustrating the top and thickness of the following formations can be found in APPENDIX B (sourced from UWIR Report, Golder, 2012a). These maps include:

- Depth to the Toolachee Formation
- Depth to the Patchawarra Formation

- Thickness of the Patchawarra Formation
- Thickness of the Toolachee Formation
- Thickness of the shale within the Nappamerri Group.

2.4.3.2 Eromanga Basin Geological Setting and Model

The Jurassic to Cretaceous Eromanga Basin unconformably overlies the older Carboniferous to Permian Cooper Basin. The sedimentary sequences of the Eromanga Basin reach a thickness of up to 2,500 m and were deposited during a period of subsidence subsequent to that of the Cooper Basin. There are two main sub-basin centres in the Eromanga Basin: the *Central Eromanga Depositional centre* and the *Poolowanna Trough* to the west separated by the Birdsville Track Ridge (Figure 7). The top of the Eromanga Basin is also delimited by an unconformity.

The study area for this project is located in the *Central Eromanga Basin*.

The deposits of the Eromanga Basin follow three episodes (and three different origins) of deposition:

- Lower non-marine sediments from early Jurassic to Mid-Cretaceous corresponding to the Poolowanna Formation to the Cadna-Owie Formation. During that period the largest transgression over the Eromanga Basin was the “Birkhead Lake” transgression;
- Marine sediments from mid-cretaceous to late Cretaceous corresponding to the Wallumbilla Formation to the Mackunda Formation; and
- Upper non marine sediments (fluviolacustrine) of the Winton Formation.

The formations of the Eromanga Basin are a succession of well-defined sandstones, siltstones and mudstones with interbedded minor sandstones and occasional coal seams, as shown in Table 3. The formations of the Eromanga Basin often have an equivalent throughout the GAB. The nomenclature adopted in this section is the SWQ nomenclature as illustrated in Figure 8.

The target oil formations of the Eromanga Basin lie at depths ranging from 700 to 1,200 mbgl.

Geological contour maps for the following formations can be found in APPENDIX B (sourced from UWIR Report, Golder, 2012a):

- Depth to the Winton Formation;
- Depth to the Cadna-Owie Formation;
- Depth to the Hooray Sandstone;
- Depth to the Hutton Formation;
- Depth to the Poolowanna Formation;
- Thickness of the Cadna-Owie Formation ;
- Thickness of the Hooray Sandstone;
- Thickness of the Hutton Sandstone; and
- Thickness of the Poolowanna Formation.

2.4.3.3 Conceptual Geological Cross Sections

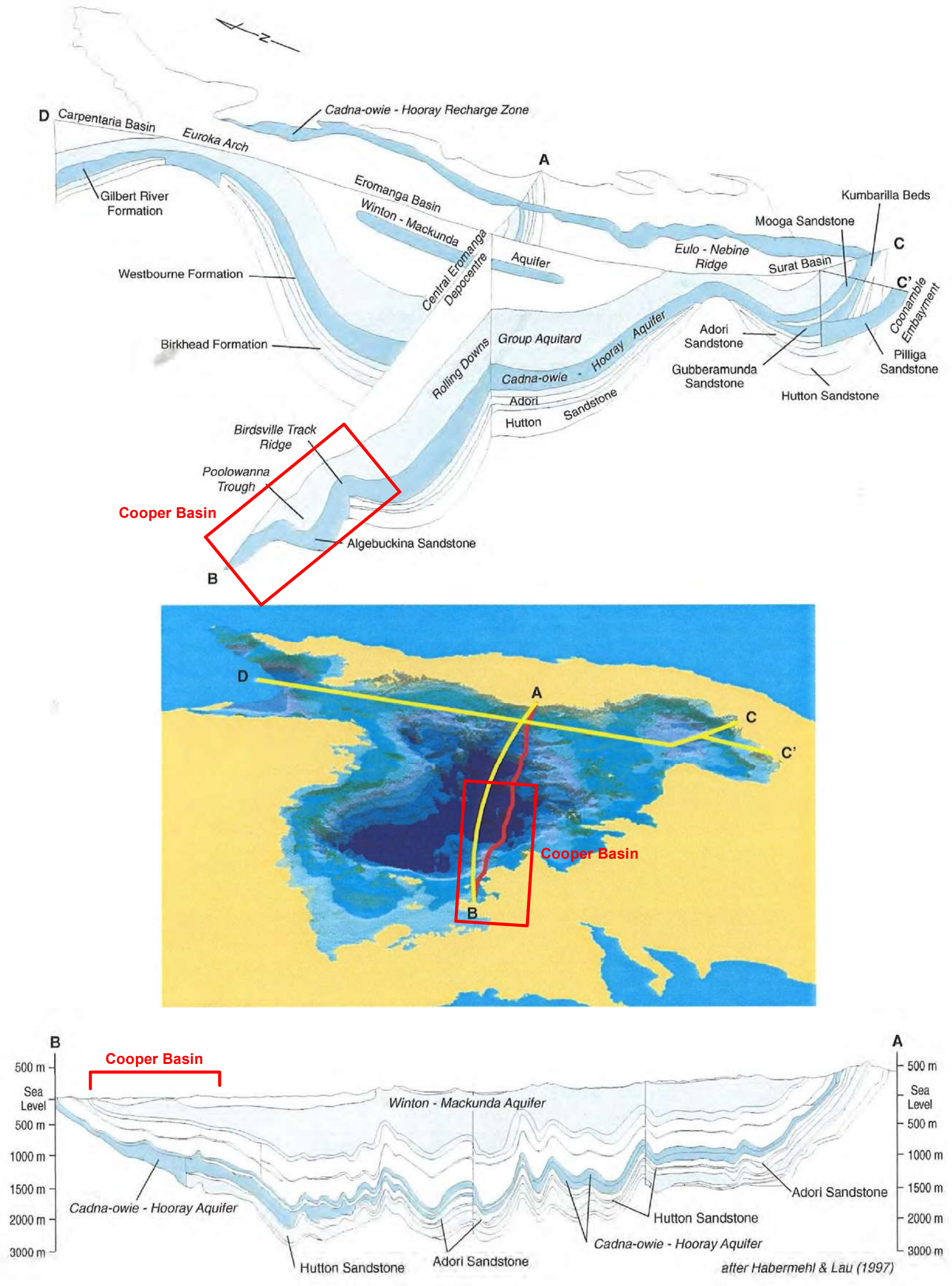
A schematic geological cross-section across the Eromanga Basin is presented in Figure 10. The “A-B” section cuts across the main depositional centre of the basin in SWQ. This corresponds to the general location of the study area. As displayed, the upper formations of the Eromanga Basin (from Cadna-Owie and Hooray Sandstone and younger) are continuous across the Basin. Older formations are restricted to areas within sub-basins (these formations or their equivalent may be present in several basins).

Abbreviations commonly used by Santos as stratigraphy markers or reservoir markers and used in some of the geological figures are summarised in Table 4.

Table 4: Geological Abbreviations for Stratigraphical Markers

Name of Marker	Definition
'C' Horizon	Top Cadna-Owie
'E' Horizon	Top Birkhead Formation
'H' Horizon	Top Hutton Sandstone
'L*' Horizon	Basal Eromanga Unconformity
'PC00' Horizon	Top Toolachee Formation (chrono-marker)
'PU70' Horizon	Basal Toolachee Formation (chrono-marker and un-named Unconformity)
'VC00' Horizon	Top Patchawarra Formation (chrono-marker)
'VC50' Horizon	Lower Patchawarra Formation (chrono-marker)
'VCxx' - Horizon	Chrono-stratigraphic marker within the Patchawarra Formation
'ZU00' Horizon	Top Pre-Permian (Basement)

A geological conceptual cross section across both the Cooper and Eromanga Basins has been generated in a SW to NE axis across the study area passing through the Barrolka fields (Barrolka Trough). The conceptual geological cross-section is presented in Figure 11.



SWQ HYDRAULIC FRACTURING
RISK ASSESSMENT

SANTOS

GEOLOGICAL SCHEMATIC CROSS SECTION ACROSS THE GAB EROMANGA BASIN

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DATE:	19/12/2012
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FIGURE 10

COPYRIGHT

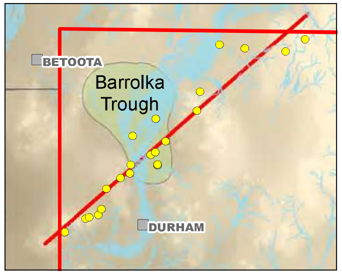
1. Figure taken from Hydrochemistry and Implied Hydrodynamics of the Cadna-Owie-Hooray Aquifer Great Artesian Basin – BRS, 2000
2. Golder Associates 2012a Cooper Basin UWIR Report

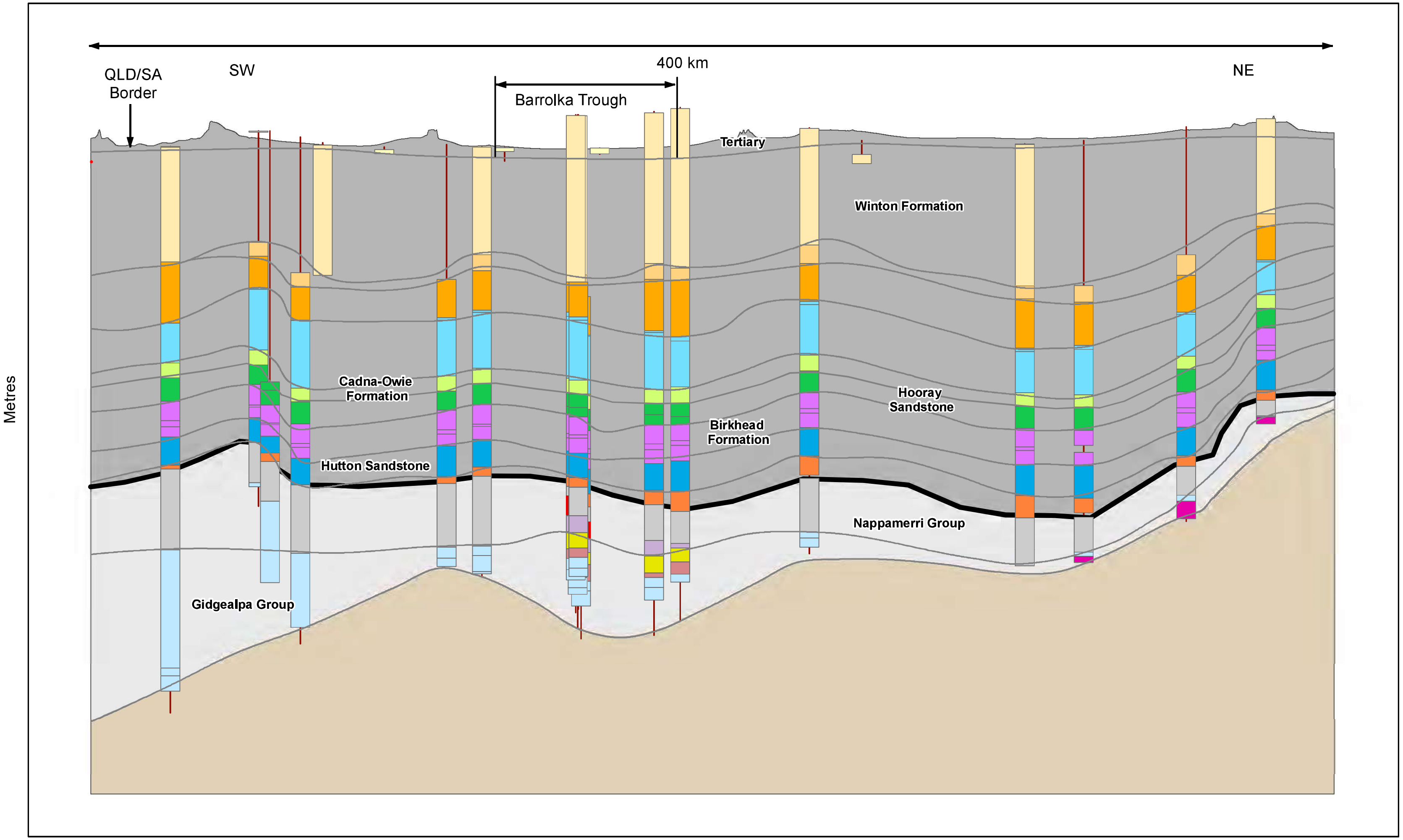
GOLDER

SWQ HYDRAULIC FRACTURING RISK ASSESSMENT

SANTOS

GEOLOGICAL CONCEPTUAL CROSS SECTION ACROSS THE STUDY AREA





LEGEND

Litho-stratigraphy		Unit name	Sub-unit
		Tertiary sediments	
Eromanga Basin		Winton Formation	
		Mackunda Formation	
		Allaru Mudstone	
		Toolebuc Formation	
		Wallumbilla Formation	Coreena Member Doncaster Member
		Cadna-Owie Formation	Wyandra Sandstone member Lower Cadna-Owie
		Hooray Sandstone	Murta Formation McKinlay Member Namur Sandstone
		Westbourne Formation	
		Adori Sandstone	
		Birkhead Formation	Upper Birkhead Middle Birkhead Lower Birkhead
		Hutton Sandstone	
		Poolowanna Formation	Upper Poolowanna Lower Poolowanna
Cooper Basin	Nappamerri Group	Tinchoo Formation	Gilpepee Shale Doonmulla Member
		Arraburry Formation	Wimma Sandstone Member Panning Member Callamurra Member
	Gidgealpa Group	Toolachee Formation	
		Daralingie Formation	
		Roseneath Shale	
		Epsilon Formation	
		Murteree Shale	
		Patchawarra Formation	
		Tirrawarra Sandstone	
		Merrimelia Formation	

▭	Study Area
—	Geological Contact
━	Major Unconformity
▨	Eromanga Basin
▨	Cooper Basin
▨	Basement

0 10 20 40 60 Kilometres

Vertical Exaggeration 1:50

PROJECT: **127666004**
DATE: **19/12/2012**
DRAWN: **FA**
CHECKED: **RS**

FIGURE 11

GOLDER

2.4.3.4 Primary Oil and Gas Producing Reservoirs

Oil and gas production in the study area targets sandstone reservoirs in both the Cooper and Eromanga Basins. Conventional gas reservoirs are predominantly present within the Cooper Basin sequence, whereas oil reservoirs present in the Eromanga Basin. The production of oil or gas is related to its deposition (sedimentological and lithological), hydrocarbon maturation (i.e. paleontological and age related) and charge.

Several types of reservoirs can form depending on the “trapping” mechanism for the hydrocarbons (Figure 12). The trapping mechanisms prevent further migration, and result in accumulation, of the hydrocarbon fluids in the sandstone reservoir. The hydrocarbon reservoir trapping mechanisms relevant to the Cooper and Eromanga Basins are shown in Figure 13.

Figure 12: Hydrocarbon ‘Traps’ Geological Settings

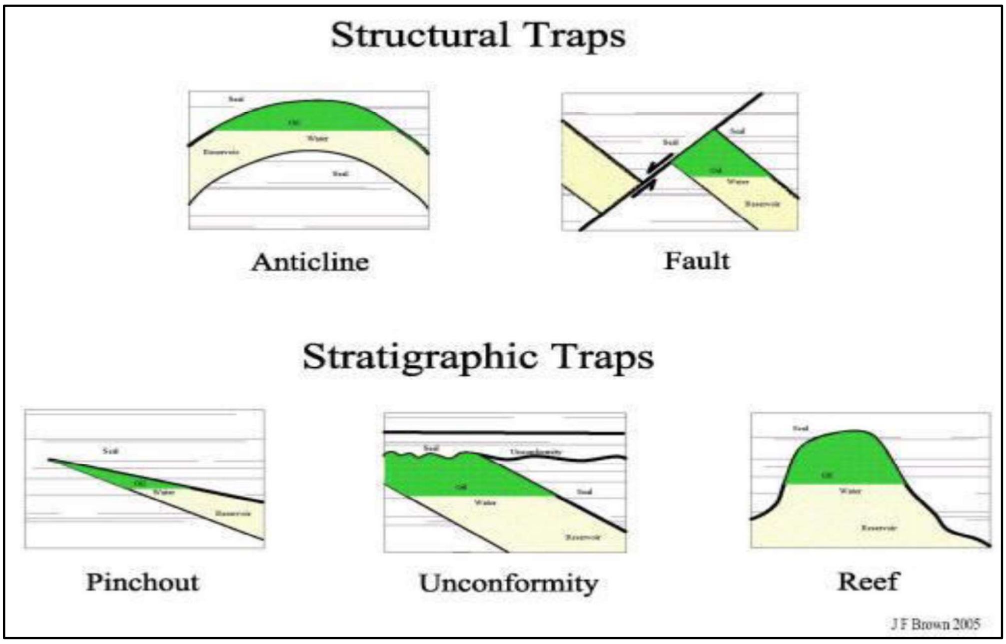
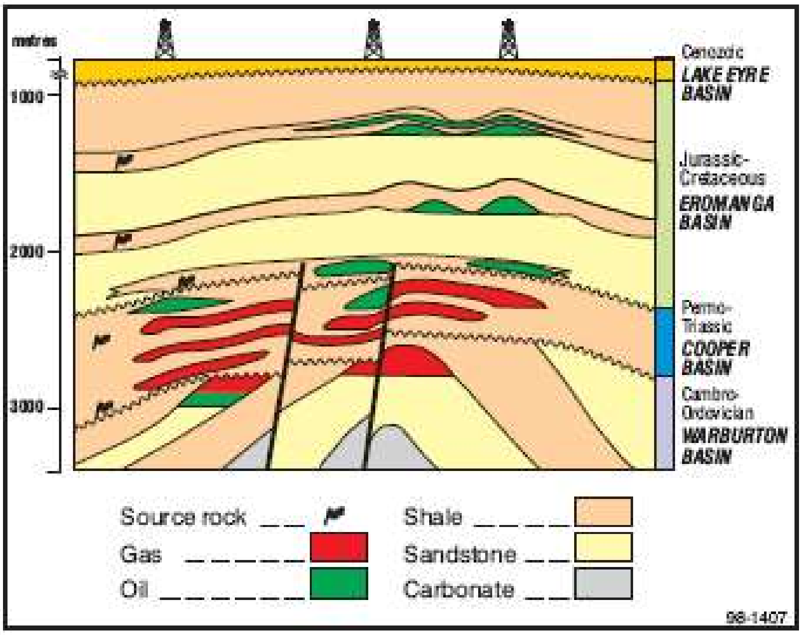


Figure 13: Petroleum Reservoirs Trapping Mechanisms of the Cooper and Eromanga Basins



Source: SA DPI, 1998

Cooper Basin

Anticlinal and faulted anticlinal traps have been identified as proven exploration targets in the Cooper Basin. The reservoir formations are capped by a series of fine-grained, laterally extensive seals. The predominantly fine-grained formations of the Nappamerri Group act as a regional seal to the Cooper Basin, providing several hundred metres of vertical separation between the primary gas reservoirs of the Cooper Basin and the overlying Eromanga Basin. Deeper in the basin, the Roseneath Shale acts as a regional top seal for the reservoir sands in the Epsilon Formation and the Murteree Shale seals hydrocarbon reservoirs in the Patchawarra Formation. These formations also provide effective barriers to prevent vertical migration of stimulation fluids during fracture stimulation treatments of Cooper Basin reservoir formations.

The reservoir formations of interest for Santos in the Cooper Basin (from deepest) include:

- The *Tirrawarra Sandstone* comprises fine to coarse-grained and pebbly sandstone with locally common interbeds of conglomerate and minor interbeds of carbonaceous siltstone, shale and coal. The Tirrawarra Sandstone is 30 to 40 m thick on average in the study area.
- The *Patchawarra Formation* comprises predominantly sandstone beds interbedded with siltstone, shale and coals. The Patchawarra Formation is thickest (up to 680 m) in the Nappamerri Trough, with an estimated maximum thickness of 550 m in the study area (Figure 7).
- The *Epsilon Formation* comprises a series of sandstones, siltstones and shales with minor coals. The maximum reported formation thickness (156 m) occurs in the Nappamerri Trough, however in the study area, the thickness typically ranges from 30 to 40 m.
- The *Toolachee Formation* consists of sandstones, siltstones and shale with thin coal seams and some conglomerates. In the study area the thickness is typically of the order of 25 to 50 m (Draper, 2002).
- Minor oil and gas reservoirs occur in sand units of the Nappamerri Group, but due to its predominantly fine-grained texture (mudstone and shale) it acts as a thick, regional seal to the reservoirs of the Cooper Basin (PIRSA, 1998).

Stimulation events related to gas production in the study area from 2012 to 2016 are planned for the deeper Patchawarra Formation, the Toolachee Formation, and to a lesser extent in formations within the Nappamerri Group.

Eromanga Basin

Trapping mechanisms in the Eromanga Basin are predominantly structural with a stratigraphic component (e.g. Hutton–Birkhead transition, Poolowanna facies, McKinlay Member and Murta Formation). Seals consist of intraformational siltstones and shales of the Poolowanna, Birkhead and Murta Formations. Where these units are absent, potential seals higher in the sequence include the Bulldog Shale and Wallumbilla Formation (SA DPI, 1998).

The reservoir formations of interest for Santos in the Eromanga Basin are (from deepest):

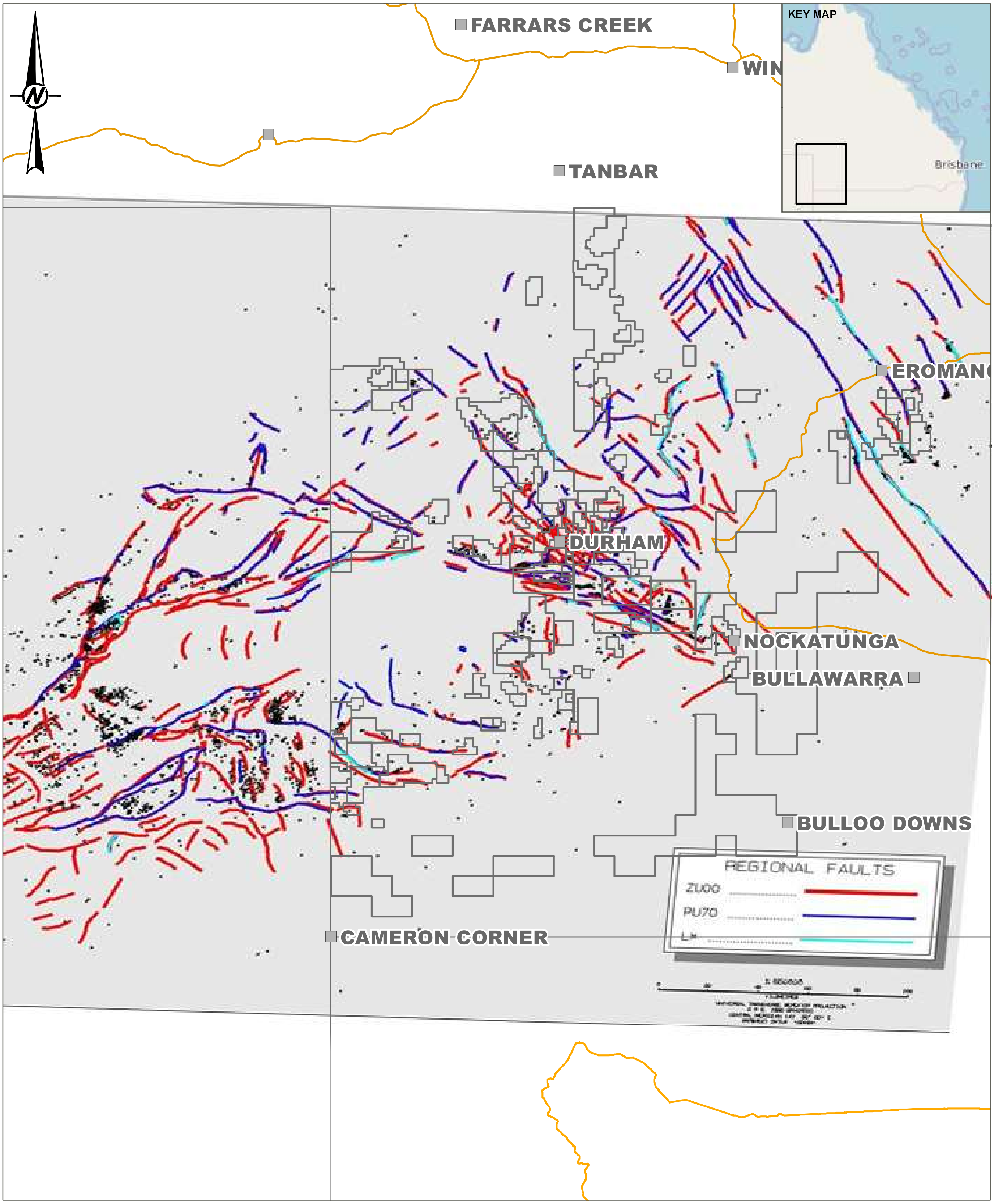
- The *Hutton* and *Poolowanna Formations* are major sandstone formations of the GAB. In the study area, the Hutton Formation is typically 90 to 210 m thick, and the Poolowanna Formation is up to 165 m thick;
- The *Westbourne Formation, Adori Sandstone* and *Birkhead Formation*: This group is dominated by shale and mudstone beds with thicknesses up to 140 m for the Westbourne Formation and 110 m for the Birkhead Formation in the study area. Interbedded sandstone layers within the Birkhead Formation comprise the primary oil targets. The Adori Sandstone contains the main sandstone beds of the group and is up to 55 m thick in the study area, and is reported to have a thick calcite-cemented zones (up to 45 m) developed in the base of the unit; and
- The *Cadna-Owie* and *Hooray Formations* consist of permeable sand units interbedded with siltstone, mudstone and shale that form intra-formational seals for hydrocarbon reservoirs. The basal unit of the Hooray Sandstone (the Namur Sandstone) is also strongly cemented.

2.4.3.5 Faults and Other Geological Controls

The structural framework of the Cooper Basin, particularly with regard to faulting is complex in the study area. Santos has undertaken an exercise of mapping (Figure 14; Santos, 2004) to simplify the tectonic features within the basins. The primary purpose of the mapping undertaken by Santos was to identify potential fault conduits (likely to enhance vertical migration of petroleum fluids), fault baffles (likely to prevent lateral migration of petroleum fluid) and identify potential gas targets.

Over the study area, the major episodic faults occurred in the top pre-Permian (basement), the basal Toolachee Formation and the basal Eromanga unconformity. The top pre-Permian faults provide the basin's overall fabric, whereas the younger faults from the basal Toolachee Formation and basal Eromanga unconformity are generally reactivated Permian faults.

In the Eromanga Basin formations, very few regional faults are observed as very little fault movement occurred during deposition of Eromanga Basin sediments. Major faulting events and structural uplifts have occurred within the eastern part of the Eromanga Basin; however, they did not structurally affect the part of the Eromanga Basin covered by Santos' SWQ tenements. Subsidence and compaction dominate the structural geology (PIRSA, 2006).



LEGEND

■ Town/Locality

Highway/Major Road

Basal Toolachee Formation (PU70 Horizon)

▭ Santos Tenements

Top Pre-Permian (ZU00 Horizon)

Basal Eromanga Unconformity

0 KILOMETERS 100

1:2,500,000 GCS GDA 1994

NOTE(S)

REFERENCE(S)

1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019
3. FAULTS MAP SUPPLIED BY SANTOS (2004)

CLIENT
SANTOS

PROJECT
HYDRAULIC FRACTURING RISK ASSESSMENT – SANTOS SOUTHWEST QUEENSLAND TENEMENTS

TITLE
SURFACE GEOLOGY

CONSULTANT

GOLDER

DD-MM-YYYY	19-03-2020
DESIGNED	KB
PREPARED	KB
REVIEWED	CB
APPROVED	CB

PROJECT NO.	CONTROL	REV.	FIGURE
127666004	011-R	2	**14**

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2.4.4 Stress Field Setting

2.4.4.1 Regional Setting

The origin and nature of near surface stress in Australia has been discussed in a number of publications, for example, Brown and Windsor (1990) and Enever and Lee (2000). The total stress at a point in the Earth's crust (including Australia) is generally considered to be made up of the following components:

- Gravity due to the weight of overburden. Gravity also contributes to the horizontal stress due to Poisson's effect;
- Tectonic component, which could be an active or a remnant tectonic stress, from movement of the earth's plates, and generally impacts the horizontal stress field; and
- Thermal and physio-chemical effects.

Analysis of stress in the SWQ study area has been undertaken through in-house services (discussed further under Section 2.4.5.3). The results of these studies are consistent with stress magnitude and orientation produced by broader plate tectonics as indicated on the publicly available Australasian Stress Map (Australasian Stress Map web site, University of Adelaide, Hillis et al., 1999; Hillis and Reynolds, 2003; and Reynolds et al., 2006).

Excerpts of the stress map are presented in Figure 15 and Figure 16 (from the web site, 2012) and illustrate the tectonic contribution to the regional stress field within continental Australia. Australia lies within the Indo-Australian tectonic plate and undergoes an absolute movement of approximately 7 cm per year to N-NNE. This is reflected in the N-NNE stress direction observed in SE Queensland (e.g. Bowen Basin, Figure 15). *However*, the Australian intra-plate stress field is highly variable and the maximum stress orientation at Cooper Basin, SWQ, is W-E and approximately perpendicular to the N-NE direction of the Indo-Australian plate. The stress field in Cooper basin appears to mark the apex of a horseshoe-shaped rotation in maximum horizontal stress direction across central eastern Australia (Reynolds, 2005). This is consistent with the project area that was mapped by Santos in 2004, which is discussed further in Section 2.4.5.2.

The minor horizontal stress will be approximately normal (90°) to this, i.e. N-S. The horizontal in situ stress is low but can be high and anisotropic and can *exceed* the vertical stress is some parts of the basin (Reynolds et al, 2006). The latter is an important consideration when stimulation pressures are calculated when designing and implementing a fracture event such that it is confidently contained entirely within the reservoir formations (Sections 3.2 and 3.3.5).

2.4.4.2 Basin Stress Regime

The primary stresses within the Cooper-Eromanga basin are vertical overburden stress σv, maximum horizontal stress σH, and minimum horizontal stress σh. The stress regime within the basins are characterised on the assumption that σv is a principal stress and therefore, σH and σh are also principal stresses, where σh is the least principal stress. This assumption is considered valid given the relatively flat topography across the basin.

The maximum horizontal stresses, σH, in the basin generally follow an east to west orientation, at approximately 101˚, as indicated by stress data from borehole breakout testing (Hills et al, 1998; Reynolds et al, 2004). The east-west trending nature of σH predominates in the Nappamerri trough, however, regional variations across the basin have been observed. In the Patchawarra Trough σH is oriented southeast to north-west; north-east of Gidgealpa σH was oriented west-northwest to east-southeast. This clockwise rotation of σH from the Nappamerri Trough to the Patchawarra Trough is accepted to be part of the larger stress rotation observed across the Australian continent. The orientation of σH does not exhibit significant variation with depth. (Reynolds et al, 2004).

The vertical overburden stress, σ_v is governed by overlying rock mass and the stress gradient does not exhibit significant variation with depth. The σ_v stress gradient is approx. 20.3 MPa/km at 1,000 m depth and approaches approximately 22.6 MPa/km at 3,000 m depth.

The magnitude of σ_h varies significantly across the basin; the σ_h stress gradient ranges from 13.6 MPa/km to 22.6 MPa/km across the basin, with σ_h approaching σ_v in some local areas (Reynolds et al, 2004). σ_h decreases with depth up to approximately 1 km below the surface and then stabilises. At 1 km to 4 km depth σh is between 0.6 σv to 0.7 σv, with σ_h generally approaching the higher end of this range (Hillis et al, 1998). At lower depths σ_h approaches, and may exceed, σ_v, resulting in σ_v becoming the minimum principal stress. (Reynolds et al, 2004).

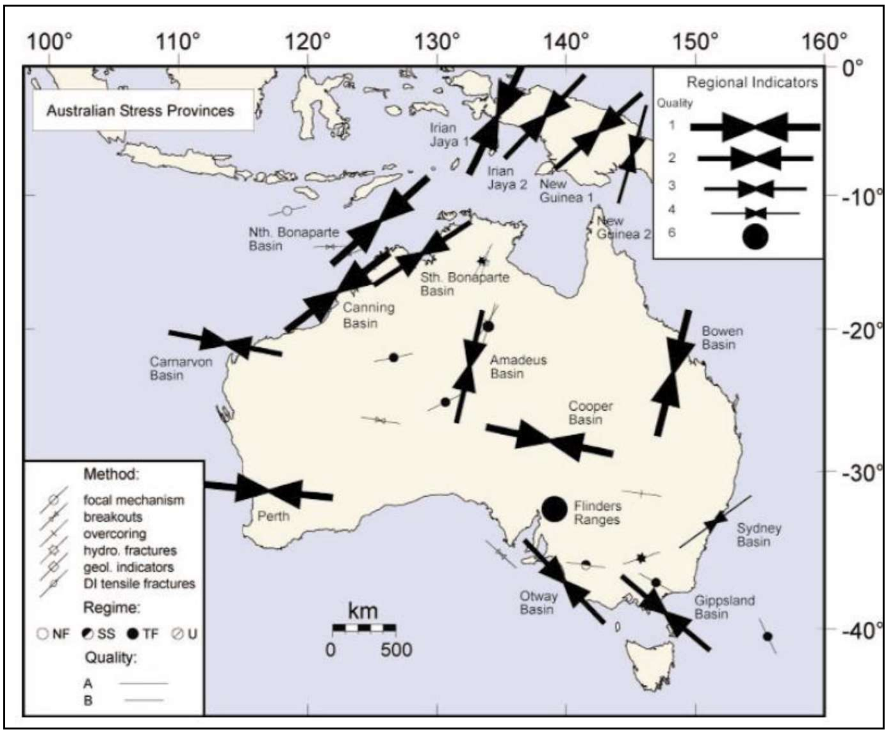
2.4.4.3 Stress Assumptions and Principal Stresses – General Faulting Regime

On the basis that σ_h is the minimum principal stress, the Cooper-Eromanga basin stress regime is primarily associated with strike-slip faulting ($\sigma_H > \sigma v > \sigma_h$), normal faulting ($\sigma_v > \sigma_H > \sigma_h$), and transitional strike-slip/reverse faulting ($\sigma_H > \sigma_h \approx \sigma_v$) at depth, where $\sigma_h \approx \sigma_v$. Reverse faulting ($\sigma_H > \sigma_h > \sigma_v$) is not associated with the stress regime in the basin however, at lower depths where $\sigma_h > \sigma_v$ may occur some reverse faulting may exist. (Reynolds et al, 2004).

2.4.4.4 Hydrostatic Stress

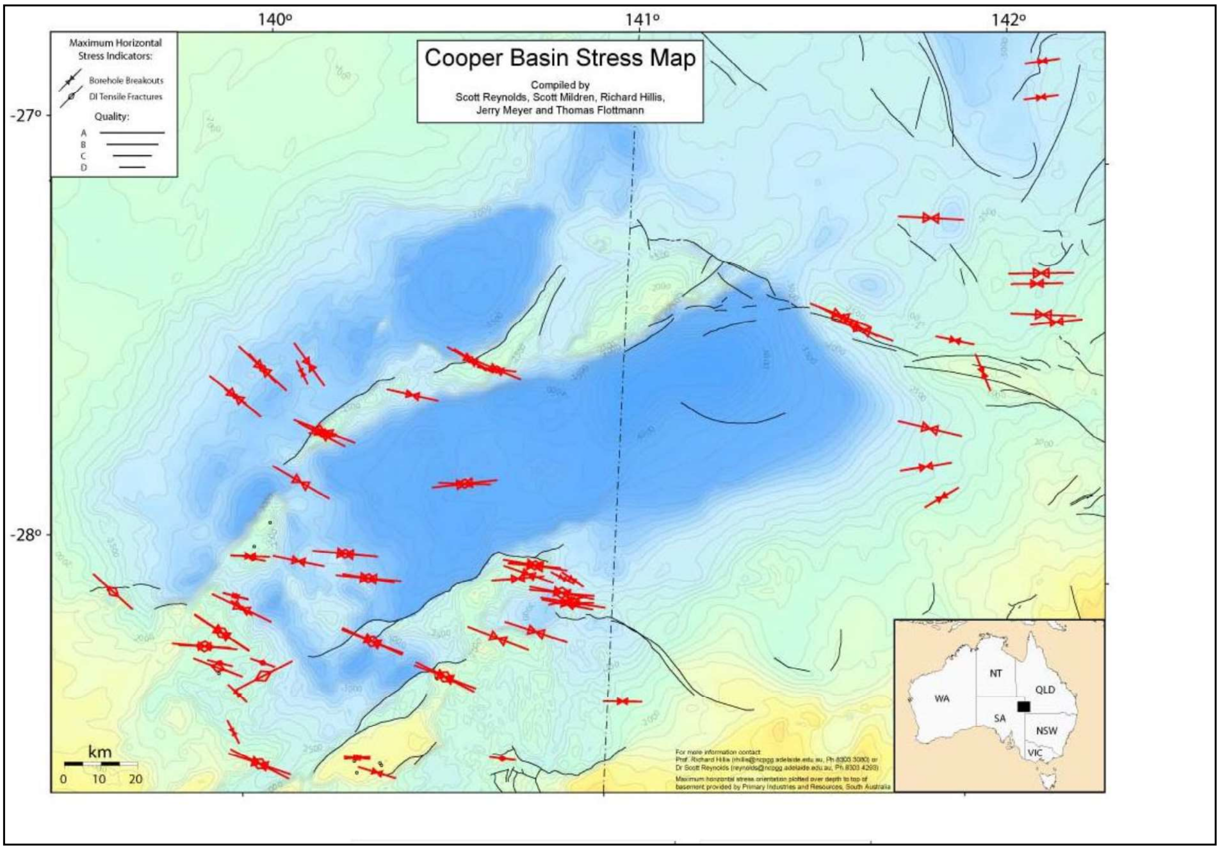
Pore pressures within the basin are generally hydrostatic. Overpressures are thought to occur in deeper shalier strata within the basin and have been observed in the Nappamerri Trough from depths of 2.7 km (Hillis et al, 1998). Local under-pressures have also been observed and are attributed to production within the basin (Reynolds et al, 2004). This is of particular importance when considering the impact of depressurising formations during oil and gas production. The implication is that impact translation though the depositional sequences are minimised or negated completely.

Figure 15: Continental Geomechanical Setting – Mean Stress Orientation within Australian Stress Provinces



Source: Hillis and Reynolds, 2003

Figure 16: Primary Stress Field Distribution for SWQ Queensland (Reynolds et.al, 2006)



2.4.5 Seismic History of the Project Region

2.4.5.1 Vulnerability

The continent of Australia does not demonstrate significant seismic activity, particularly compared to the western US, Japan, and New Zealand. Australia is on the Indo-Australian plate, relatively far from the plate boundaries, reducing the amount of seismic activity affecting the continent. Earthquakes in Australia are generally caused from the release of built-up stress in the interior of the Indo-Australian plate, which is being pushed north (NNE) and is colliding with the Eurasian, Philippine, and Pacific plates. Geosciences Australia (2012) reported that:

- On average 200 earthquakes of magnitude 3.0 or more occur in Australia each year;
- Earthquakes above magnitude 5.5 occur on average every two years; and
- About every five years there is a significant earthquake of magnitude 6.0 or more.

Santos' SWQ tenements are in one of the least seismically active areas on the Australian continent. The closest seismic activity area is the Adelaide region, SA, some 250 km southwest of Cameron's Corner. While more frequent and larger in magnitude earthquakes occur in the Adelaide area, very little impact is experienced within the SWQ tenement area. A study performed in the 1990's found that there is a 90% chance that the *unitless peak ground acceleration* (a term used in civil engineering to estimate forces on structures) will not exceed 0.05 in any 50-year period for this area. This indicates that regardless of the epicentre of any possible earthquake, little ground movement will occur in this region.

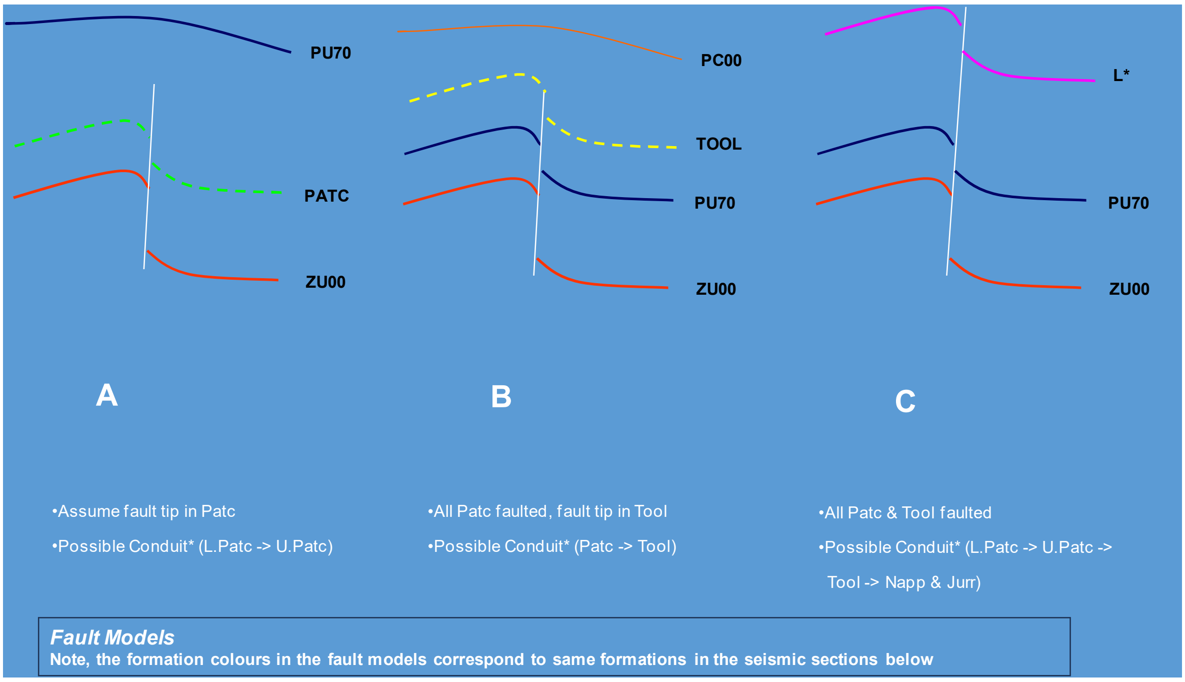
2.4.5.2 Local Historical Faults and Potential Seismic Activity

The Santos fault model is shown in Figure 17 (refer to Table 4 for stratigraphical marker abbreviations). This cross section illustrates the major fault and fold structures affecting the Cooper and Eromanga Basin sequences. Of particular note is the deep-seated nature of the basement structures, particularly faulting. The major episodic faults occurred in the top pre-Permian (basement), the basal Toolachee Formation and the basal Eromanga unconformity. These generally do not penetrate beyond the Eromanga Basin stratigraphy. The structures are predominantly compressional, and do not have large fault-throws within the Cooper Basin stratigraphy and negligible throws in the Eromanga Basin stratigraphy.

The episodic faults in the Santos fault model (Figure 17 (refer to Table 4 for stratigraphical marker abbreviations)) provide the basin's overall fabric. The basal Toolachee Formation (PU70) and basal Eromanga unconformity (L*) are generally affected by reactivated Top Pre-Permian (Basement; Zu00) faults. Figure 17 shows the Toolachee formation may be more elastic and does not fracture due to folding. The fault does not extend up through the Eromanga unconformity into the Eromanga Basin.

The episodic faults presented in Figure 17 provide the basin's overall fabric. The basal Toolachee Formation (PU70) and basal Eromanga unconformity (L*) are generally affected by reactivated Top Pre-Permian (Basement; Zu00) faults. Figure 17 shows the Toolachee formation may be more elastic and does not fracture due to folding. The fault does not extend up through the Eromanga unconformity into the Eromanga Basin.

Figure 17: N-S Seismic Section for SWQ Project Area Showing Fault Models



- Assume fault tip in Patc
- Possible Conduit* (L.Patc -> U.Patc)

- All Patc faulted, fault tip in Tool
- Possible Conduit* (Patc -> Tool)

- All Patc & Tool faulted
- Possible Conduit* (L.Patc -> U.Patc -> Tool -> Napp & Jurr)

Fault Models
Note, the formation colours in the fault models correspond to same formations in the seismic sections below

2.4.5.3 Active Seismic Area and Faults

While no major currently or potentially active faults exist near the study area, there was possibly a minor fault within a former tenement area. The potential minor fault is 5 to 10 km and is considerably smaller in size than the majority of faults mapped within Australia (Geosciences Australia, 2012). The fault is located within a former tenement (ATP 766P, current in December 2012, but no longer a Santos tenement) at approximately latitude and longitude 26.4°S 143.1°E (the north-eastern most tenements in the study area). As of January 2020, the closest oil and gas fields to the minor fault were located at 50 to 60 km from the fault zone, and it was therefore considered highly unlikely that the fault zone would be influenced by stimulation activities proposed for the fields. No significant seismic activity has occurred in the vicinity of this possible fault (ATP 766P; Figure 18) during the period 1950-2020.

2.4.5.4 Seismic History of the Cooper Basin Area

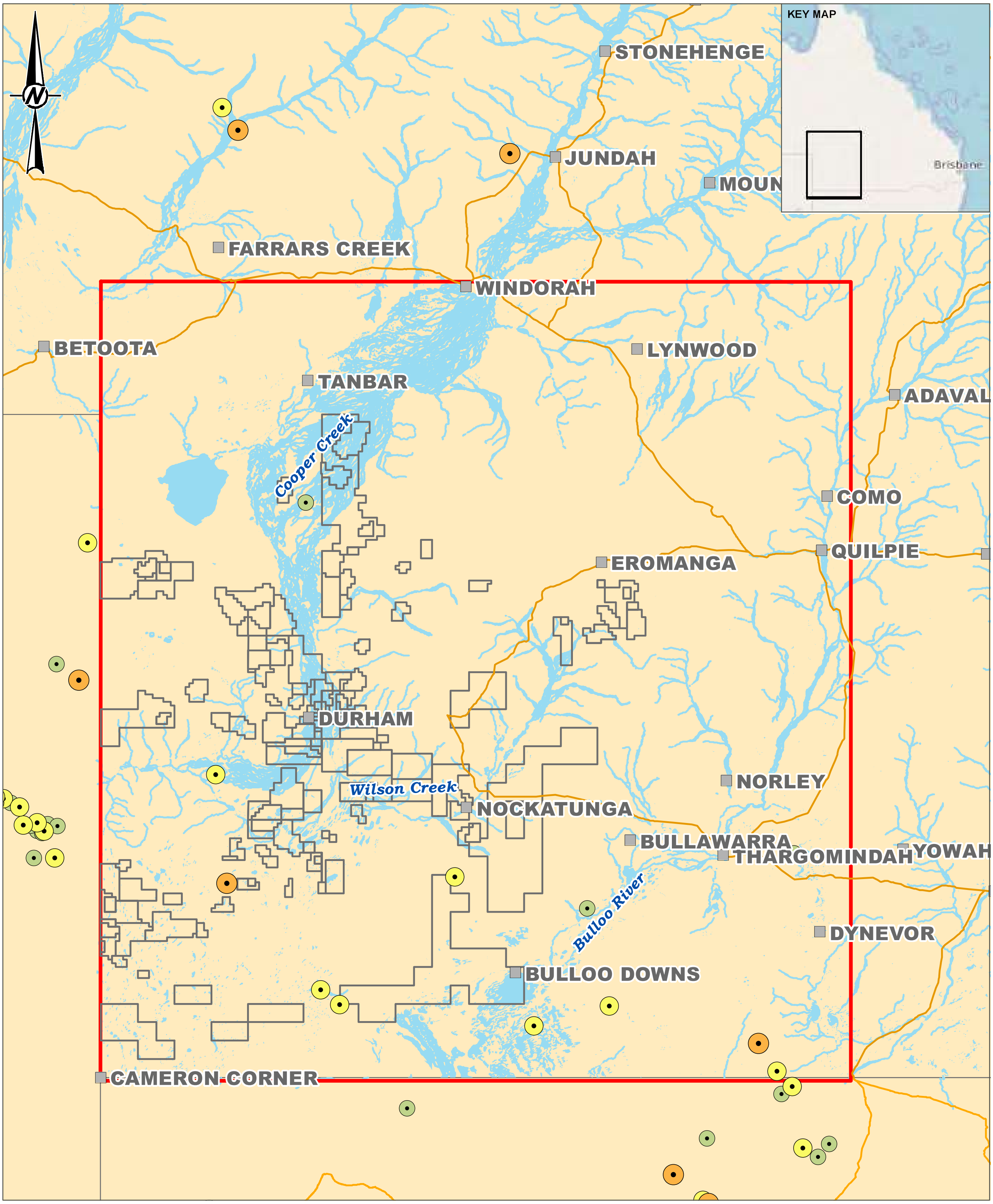
This region has experienced intermittent earthquakes of low to moderate magnitude since 1950 in the study area (Table 5). The location of the epicentre of these earthquakes is presented on Figure 18.

The majority of the earthquakes that have occurred since 1950 were approximately 8 to 11 km below the surface, with magnitudes ranging between 2.3 and 4.7 on the Richter scale. The earthquakes were generally located towards the south and western end of the study area.

Table 5: Earthquake Locations and Depths in the Study Area From 1950 - 2012

Magnitude	UTC	Latitude	Longitude	Depth (km)*
4.7	28/12/1961	-28.12	141.57	10
3.8	30/03/1963	-27.2	140.9	10
4	31/03/1963	-27.2	140.9	10
3.1	30/01/1985	-26.58	140.94	0
4	23/05/1989	-28.843	143.978	5
3.3	8/08/1989	-27.63	141.52	10
3.4	4/06/1996	-28.972	144.063	0
3.2	30/07/1997	-28.093	142.604	11
3.3	21/02/1999	-28.767	142.962	0
2.7	26/09/1999	-27.985	144.141	0
3.2	3/08/2000	-28.676	143.302	0
3.3	27/02/2001	-28.67	142.082	0
3.2	9/03/2001	-28.604	141.995	8
2.4	23/04/2001	-28.234	143.205	8
2.3	23/09/2002	-26.397	141.928	10

* Where depth is poorly constrained by available seismic data, a default depth of 0 or 10 km may be selected depending on the local earthquake activity in the area (Reference: Geoscience Australia www.ga.gov.au).



LEGEND

■ Town/Locality	Epicentre - Magnitude Range	● 4-4.9	
Highway/Major Road	● <1	● 5-5.9	
River/Creek	● 1-1.9	● 6-6.7	
▭ Santos Tenements	● 2-2.9		
▭ Study Area	● 3-3.9		

0 KILOMETERS 100

1:2,750,000 GCS GDA 1994

NOTE(S)

REFERENCE(S)

1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019

CLIENT
SANTOS

PROJECT
HYDRAULIC FRACTURING RISK ASSESSMENT – SANTOS SOUTHWEST QUEENSLAND TENEMENTS

TITLE
EPICENTRE AND MAGNITUDE OF EARTHQUAKES IN THE STUDY AREA

CONSULTANT

GOLDER

DD-MM-YYYY	19-03-2020
DESIGNED	KB
PREPARED	KB
REVIEWED	CB
APPROVED	CB

PROJECT NO.	CONTROL	REV.	FIGURE
127666004	011-R	2	18

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2.5 Hydrogeology and the Groundwater Resource

2.5.1 Introduction and Setting

The Cooper and Eromanga Basins are two chronologically successive stacked basins, with the Cooper overlying the Eromanga. Based on strict geological interpretation, the Cooper Basin is considered to be distinct and separate from the GAB, however it has been an historical convention in Queensland to include the upper sedimentary units of the Cooper Basin in the administration of GAB groundwater resources (GAB Resource Operating Plan (ROP), DERM 2007: GAB Water Resources Plan (WRP), DERM 2006). The Eromanga Basin is the largest of the three major sedimentary basins comprising the GAB and covers the whole of the Cooper Basin. The connection between the two basins is geologically marked by a major unconformity.

Both the Cooper Basin and Eromanga Basin are multi-layered systems comprising alternating layers of sandstone, shale, mudstone and siltstone formations (Section 0). The sandstone formations of the Eromanga Basin correspond to water bearing formations and aquifer formations; they support a range of beneficial uses such as potable water and stock and domestic supply. In other areas of the Basin (remote from Santos' tenements), they also supply groundwater to springs.

The siltstone, shale and mudstone formations are low permeability rocks and act as aquitards separating aquifer formations (and also as seals for hydrocarbon reservoirs). In the study area, a number of thick, competent and laterally extensive fine-grained formations are present within both the Cooper and Eromanga Basins that are important in providing vertical separation of water and hydrocarbon-bearing formations. Minor sandstone units occasionally occur as interbedded layers within predominantly fine-grained formations and may be capable of providing limited groundwater supply (e.g. <5 L/s), however in the study area water supply development preferentially targets the upper formations of the Eromanga Basin (e.g. the Winton and Glendower Formations).

For management purposes, the GAB has been subdivided into 25 Groundwater Management Areas (GMA) as defined in the *GAB Hydrogeological Framework for the GAB WRP Area* (DERM, 2005); the GMAs relevant to the study area are presented in Figure 19. GMAs are subdivided into groundwater management units (GMU), as represented in Table 3, comprising one or more geological formations with similar hydrogeological properties.

2.5.2 Hydrostratigraphy

As previously described, the formations of the Cooper and Eromanga Basin within the study area comprise a stacked sedimentary sequence of sandstone formations that act as aquifers and hydrocarbon reservoirs, interbedded with fine-grained formations that act as competent and laterally extensive aquitards and seals for hydrocarbon traps. The main aquifer and aquitard units are presented in Table 6. The main aquifer groupings, in terms of production of groundwater, include:

- The aquifers of the Quaternary sediments and Tertiary formations (potential water supply for agricultural and potable water);
- The GAB aquifers of the Eromanga Basin (possible water supply for agricultural and potable water, and produced formation water); and
- The older and deeper aquifers of the Cooper Basin (produced formation water).

The Quaternary and Tertiary deposits are preferentially developed as groundwater resources because they are shallow, accessible and able to yield productive quantities of groundwater to support beneficial uses relevant to the study area (principally, domestic supply and stock watering). In contrast, groundwater resources associated with the deeper aquifers of the Eromanga Basin have had limited development. The deep aquifers of the Cooper Basin are only accessed during the production of gas.

A summary of the groundwater resources within the study area is presented in the following section. A more detailed discussion of the groundwater resources is contained in the UWIR (Golder 2020).

Table 6: Hydrostratigraphy of the Study Area

GMA Unit			Unit name	Sub-unit	Equivalent Formation other parts of the GAB
	Eromanga Basin		**Glendower Formation**		
			Winton Formation		
			Mackunda Formation		
			Alluru Mudstone		
Central 1 - Warrego West 1			**Toolebuc Formation**		Surat Siltstone
			Wallumbilla Formation	Coreena Member	Wallumbilla Formation
				Doncaster Member	
Central 2 - Warrego West 2			**Cadna-Owie Formation**	Wyandra Sandstone Member	Cadna-Owie Formation, Bungil formation, Gilbert River Formation
				Lower Cadna-Owie	
Central 3 - Warrego West 3			**Hooray Sandstone**	Murta Formation	Hooray Sandstone, Mooga Sandstone, Orally Formation and Gubberamunda Sandstone
				Namur Sandstone	
Central 4 - Warrego West 4			**Westbourne Formation**		Injune Creek Group
			Adori Sandstone		
			Birkhead Formation	Upper Birkhead	
				Middle Birkhead	
				Lower Birkhead	
Central 5 - Warrego West 5			**Hutton Sandstone**		
Central 6 - Warrego West 6			**Poolowanna Formation**	Upper Poolowanna	Precipice Sandstone
				Lower Poolowanna	
MAJOR UNCONFORMITY					
Central 7 - Warrego West 7	Cooper Basin	Nappamerri Group	**Tinchoo Formation**	Gilpeppee Member	Moolayember Formation
				Doonmulla Member	
			Arraburry Formation	Wimma Sandstone Member	Clematis Sandstone
				Panning Member	Rewan Formation
				Callamurra Member	

GMA Unit		Unit name		Sub-unit	Equivalent Formation other parts of the GAB
		Gidgealpa Group	**Toolachee Formation**		
			Daralingie Formation[1]		
			Roseneath Shale		
			Epsilon Formation		
			Murteree Shale		
			Patchawarra Formation		
			Tirrawarra Sandstone		
			Merrimelia Formation		
▨		Aquifer			
🟦		Water Bearing in part			
▩		Confining Bed			

[1] The Daralingie Formation is considered to be water bearing in some areas of the Cooper Basin but has been classified as a confining bed within this study area.

Source: DERM, 2005

2.5.2.1 Eromanga Basin

The main GAB aquifers in the study area occur within the Eromanga Basin stratigraphy, and include the Winton Formation, Cadna-Owie Formation, Hooray Sandstone, Hutton Sandstone and Poolowanna Formation (Precipice Sandstone equivalent).

Hydrogeological contour maps are provided (where data was available) in APPENDIX C for the following hydrostratigraphic units. Note that the Quaternary and Tertiary sediment aquifers and the Winton Formation are not administered under the GAB ROP (DERM 2007).

Poolowanna Formation (Central 6 - Warrego West 6)

Also referred to as the Basal Jurassic Formation (older name in the nomenclature), the Poolowanna Formation is the equivalent of the Precipice Sandstone (in SE QLD). No further information is available.

Hutton Sandstone (Central 5 - Warrego West 5)

The Hutton Sandstone is a significant GAB aquifer however its depth in the study area (approximately 2,000 mbgl; refer to Figure 11) has precluded access for water supply development. Based on limited available data, the groundwater flow is expected to be to the southwest (i.e. consistent with the regional flow direction of the major GAB formations).

The water quality of the Hutton Sandstone in the study area cannot be commented upon as produced water quality data was not readily available, and no data was available in the DEHP database.

Westbourne Formation, Adori Sandstone and Birkhead Formation (Central 4 - Warrego West 4)

The Westbourne Formation is considered to be a confining layer of relatively homogeneous characteristics (lacustrine deposits associated with a large transgression). However, in the southeast section of the study area, it is possible that a number of private bores are completed in the Westbourne Formation, possibly accessing minor sandstone beds within the formation.

The Adori Sandstone is considered to be an aquifer (at least in part) in the study area, however insufficient information is available to characterise it further. The basal portion of the Adori Sandstone is noted as having a thick calcite cemented zone up to 45 m thick.

The Birkhead formation comprises a succession of non-continuous confining beds and water bearing sandstone units.

Water quality data for these formations are not available in the DEHP database and were not available in regard to Santos produced water extracted from this formation. Data collected during a Water Bore Baseline Assessment (WBBA) of the study area is limited and not conclusive.

Hooray Sandstone (Central 3 - Warrego West 3)

The Hooray Sandstone is a significant unit in GAB. In the study area it is considered to be a major aquifer. Oil reservoirs and minor gas reservoirs are also contained with this unit. Two sub-units are identified in the Hooray Sandstone:

- The Murta Formation (equivalent formations in other GAB basins include the Mooga and Gubberamunda Sandstones). In the study area it is considered to be a confining bed, the main confining unit being a siltstone bed located at the base of the Murta Formation and found widespread over the Cooper region. Minor oil and gas reservoirs are noted to be present as fine-grained sandstone units capped by intra-formational siltstone and shale seals.
- The Namur Sandstone consists predominantly of fine to coarse grained sand with minor fine-grained interbeds, and is the major water bearing unit of the Hooray Sandstone. Oil can also be present in this unit.

The water quality in the Hooray Sandstone is generally fresh to slightly brackish with electrical conductivity (EC) values (DEHP database) ranging from 675 to 3,930 µS/cm (or approximately 470 to 2,750 mg/L) with a median value of approximately 1,000 µS/cm (approximately 700 mg/L). This water quality is suitable for potable water supply, and the few available long-term records (i.e. 40 year monitoring period) indicate that water quality has remained consistent over time.

A number of bores within the Hooray Sandstone may be artesian. Groundwater bores for that unit seem to be concentrated to the southeast of the study area (APPENDIX C). No reliable water level and salinity data are available for this formation in the vicinity of Santos' tenements.

According to the available data the groundwater flow direction is towards the southeast (APPENDIX C).

The Hooray Sandstone is considered to yield productive quantities of groundwater, and a town water supply bore is potentially completed with the Hooray Sandstone (to be confirmed as part of continuing field works for the WBBA).

Cadna-Owie Formation (Central 2 - Warrego West 2)

The Cadna-Owie Formation is considered to be a major aquifer of the GAB, and in the study area comprises two sub-units: the upper the Wyandra Sandstone and the Lower Cadna-Owie. The Wyandra Sandstone is considered to be an aquifer however its thickness is limited in SWQ. The Lower Cadna-Owie comprises siltstone and very fine-grained sandstone and is considered to be an aquitard.

The few data points available in the DEHP groundwater database indicate fresh to slightly brackish water quality with the Wyandra Sandstone. Insufficient water level information is available to describe water flows and water levels.

Habermehl (1986 and 1997) defines this unit as non-artesian; however, the DEHP groundwater database does identify artesian bores in the Cadna-Owie Formation.

Winton Formation (Central 1 - Warrego West 1)

According to the DEHP database, the Winton Formation is a significant aquifer for the local community that supplies a number of stock and domestic bores. The depth and thickness of the Winton Formation are illustrated in the maps of APPENDIX B. The top of the Winton Formation is approximately 50 mbgl and thickness can reach up to 970 m.

Santos' geology team however dispute the role of the Winton Formation as a significant aquifer in SWQ and consider it to be water bearing at best. Although the Winton Formation is a significant aquifer in a large area of Queensland, the quality of the Winton Formation as an aquifer appears to diminish westward from central to southwest Queensland and into South Australia (Pers. Comm. N. Lemon, Santos, November 2011). The top and bottom of the Winton are so poorly defined in the subsurface that it is difficult to confirm whether water production currently assigned to the Winton Formation is coming from the overlying Tertiary (Eyre Formation in South Australia) or underlying Mackunda Formation. This situation is supported in SA by the findings of Gravestock and al. (1995).

The Winton Formation directly underlies the Tertiary sediments; some degree of hydraulic connectivity is expected however no data is available to confirm this.

The water quality in the Winton Formation is fresh to brackish with EC values ranging from 900 to 13,000 µS/cm (approximately 630 to 9,100 mg/L). Groundwater flow in this aquifer is generally to the southwest (APPENDIX C).

Quaternary and Tertiary Alluvium

Quaternary and Tertiary alluvial deposits cover a large proportion of the study area. They are often associated with the very flat structures of the flood plains and are absent where the Winton Formation outcrops.

Cendon et al. (2010) have described the groundwater resources associated with Quaternary sediments of the Cooper Creek basin as comprising predominantly saline water (reported total dissolved solids (TDS) values up to 38,000 mg/L) that occurs within fluvial and aeolian sand deposits that are extensively overlain by thick, low permeability mud deposits. The surficial fine-grained deposits limit recharge to the sand units, even below the waterholes that are present in the main creek channels during extended periods of low (or no) stream flow. Episodic flood events are thought to occasionally scour through the low permeability deposits within major creek channels and provide temporary recharge to the underlying sand beds, resulting in discrete and discontinuous freshwater lenses in the otherwise saline groundwater environment.

Evaluation of water level and water quality data (including major and minor ion chemistry and stable isotope analysis) suggests that the surface water features in the study area do not receive shallow groundwater recharge (Hamilton et al., 2005; Bunn et al., 2006; Costelloe et al., 2007, Cendon et al., 2010). However, they may receive seepage through their basal mud layers to provide limited recharge to the underlying saline groundwater system. The lack of connectivity between surface water systems and shallow groundwater is an important consideration with respect to exposure pathway analysis (as is discussed in corresponding hydraulic stimulation service provider reports).

The Glendower Formation is the main Tertiary formation within the study area. The Glendower Formation consists of consolidated sediments comprising sandstones, sandy siltstones and minor conglomerate and mudstones (Australian Stratigraphic Database, Geosciences Australia). The Australian Stratigraphic Database identifies the Whitula Formation as overlying the Glendower Formation; however, the significance of the Whitula Formation in the study area is unknown.

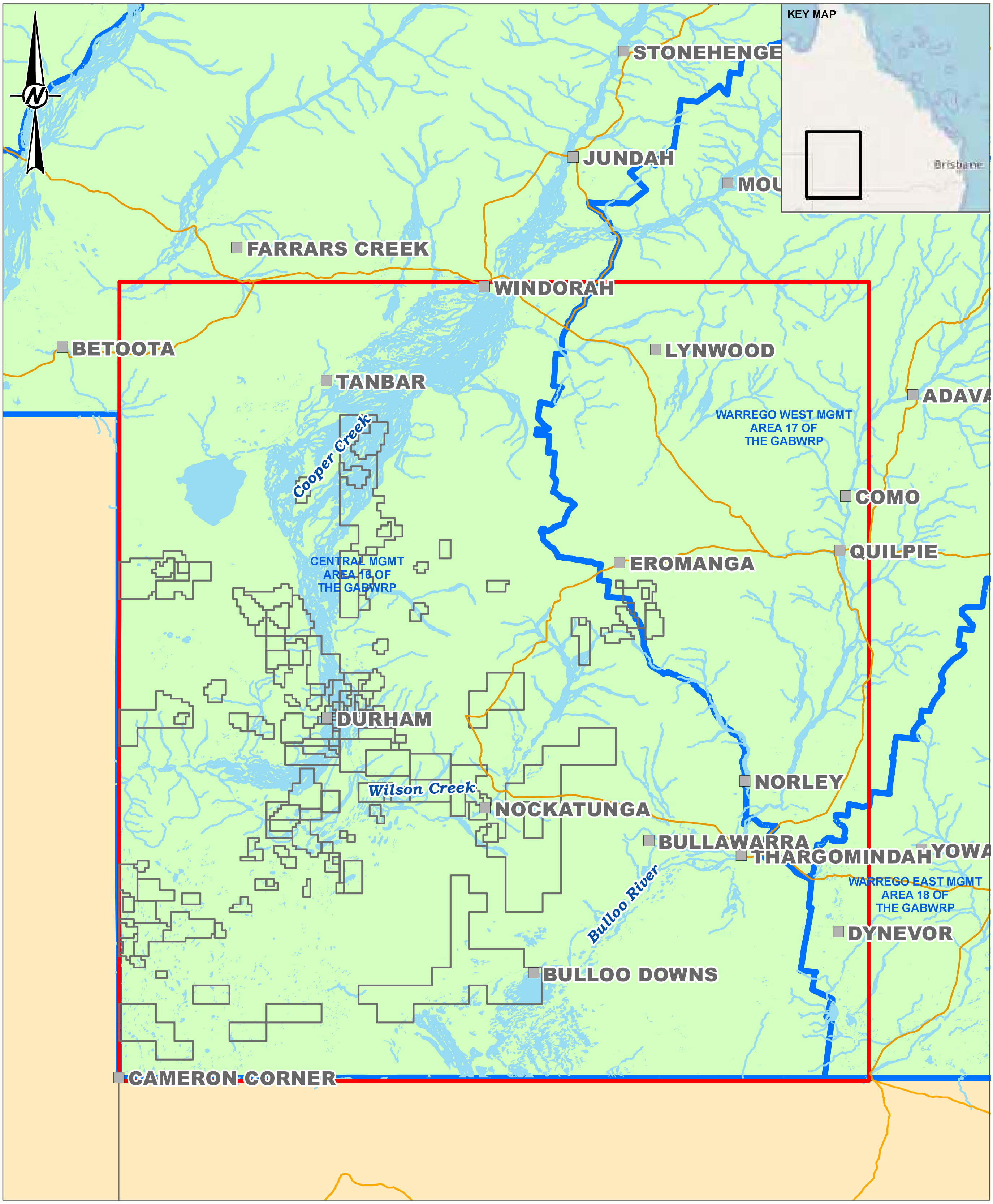
Groundwater flow in these formations follows topography in the study area and is influenced by outcrop areas of the underlying Winton Formation. As illustrated on the hydrogeological map (APPENDIX C), the hydraulic gradient is very small.

The quality of the Tertiary aquifers is brackish, with EC values ranging from 3,000 to 7,000 µS/cm (approximately 2,100 to 4,900 mg/L).

2.5.2.2 Cooper Basin

The upper formations of the Cooper Basin are included in the administration of GAB groundwater resources under QLD regulations. This includes the Panning and Wimma Sandstone Members of the Arraburry Formation, and the underlying Toolachee formation.

Insufficient information is available to provide a detailed description of the hydrostratigraphy of the Cooper Basin formations.



LEGEND

■	Town/Locality
—	Highway/Major Road
—	River/Creek
🟩	Groundwater Management Area
☐	Santos Tenements
🟥	Study Area

0 KILOMETERS 100

1:2,750,000 GCS GDA 1994

NOTE(S)

REFERENCE(S)

1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019
3. GROUNDWATER MANAGEMENT AREA SOURCED DEPARTMENT OF NATURAL RESOURCES & WATER, QLD GOVERNMENT, 2008

CLIENT
SANTOS

PROJECT
HYDRAULIC FRACTURING RISK ASSESSMENT – SANTOS SOUTHWEST QUEENSLAND TENEMENTS

TITLE
GROUNDWATER MANAGEMENT AREAS FOR THE STUDY AREA

CONSULTANT

GOLDER

DD-MM-YYYY	19-03-2020
DESIGNED	KB
PREPARED	KB
REVIEWED	CB
APPROVED	CB

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2.5.2.3 Observed Reservoir Pressure Data

The hydrostatic pressure of water-bearing stratum is measured during drilling activities by:

- Drill stem test (DST);
- Repeat formation tester (RFT); or
- Formation micro tester (FMT).

Pressure testing is undertaken to assess the likely thickness of the oil or gas column found at any particular depth interval. This is calculated by comparing the pressure in the hydrocarbon-bearing zone with the expected water pressure as predicted by the water pressure-depth line (Figure 20).

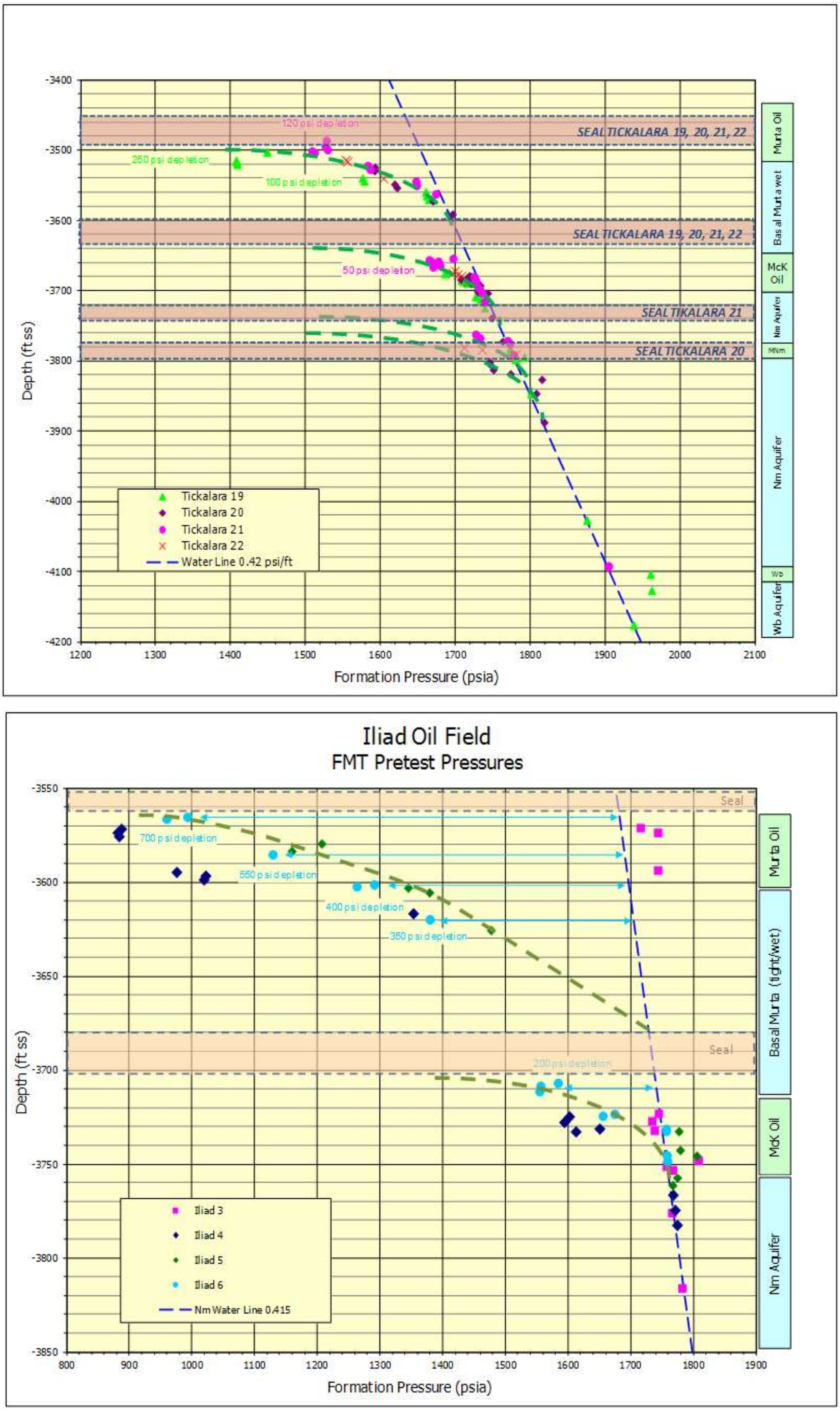
Models for predicting the influence of gas and oil, and associated water production at depth require input data on the pressure transmissibility of the strata that separates the target formations (referred to as seals). In the case of SWQ:

- Seals between the Glendower and Winton aquifers; and
- Seals between the Murta, Namur (Hooray) and Hutton Sandstone, from which oil is produced.

Numerous Santos wells have undergone pressure measurements in the Cadna-Owie Formation to establish water pressure-depth lines and this data can be re-assessed to see if depletion from underlying hydrocarbon production zones has influenced the aquifers utilised for water supply. If no depletion is observed in the Cadna-Owie Formation, then this provides evidence of the integrity of the cap rock separating the Cadna-Owie Formation from the underlying hydrocarbon reservoirs.

Figure 20 demonstrates how formation pressures are depleted below the predicted water pressure line (the blue dashed line increases in pressure with increasing depth) and are confined within each target formation (yellow layers) by the presence of an overlying aquitard (seal bed, orange layers). This data demonstrates the competence of the confining units in isolating hydrocarbon reservoirs from overlying and underlying aquifers.

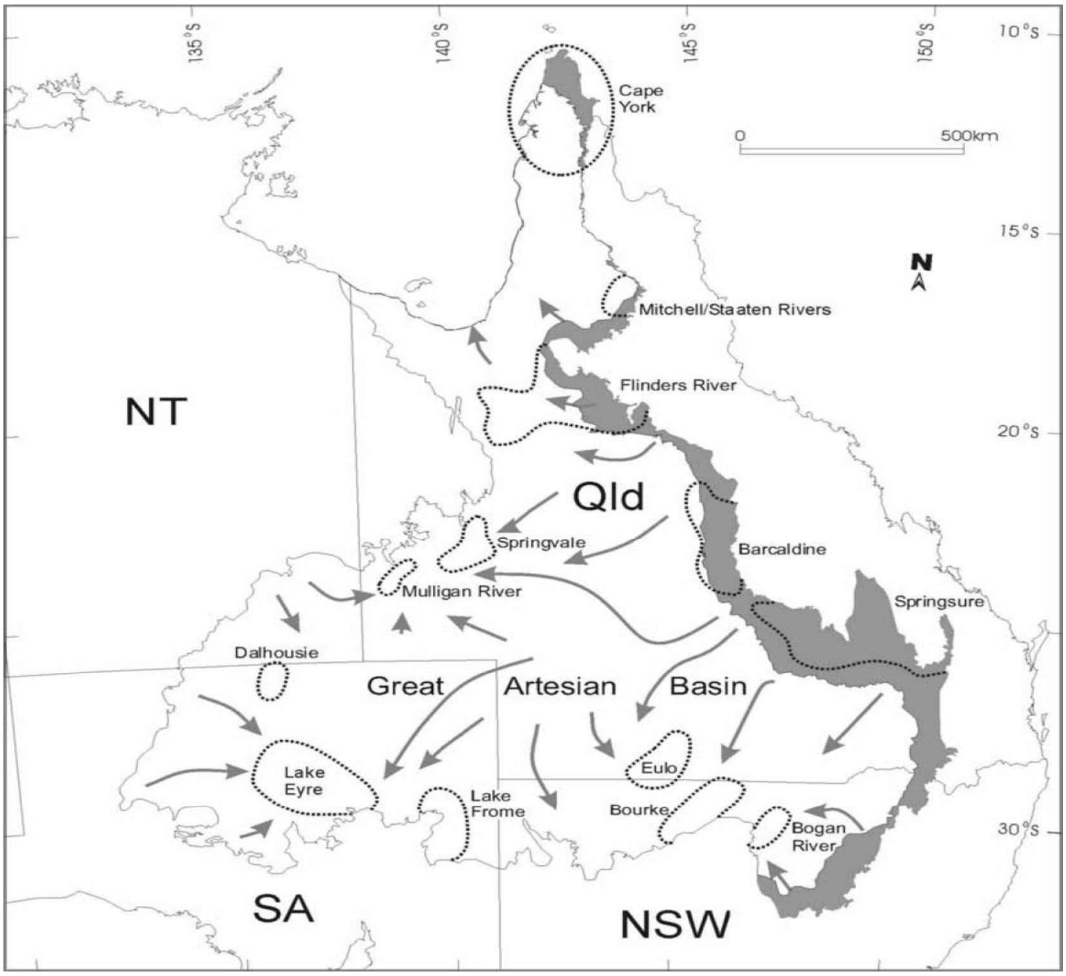
Figure 20: Observed Tickalara (top) and Iliad Field Pressure with Depth Plots



2.5.3 Groundwater Flow

In general, groundwater flow through the majority of the deeper units of the Eromanga Basin is to the south to southwest. This is consistent with the direction of flow in the major GAB units (Figure 21; BRS, 2000). Potentiometric surface contours for select Eromanga Basin aquifers are presented in APPENDIX C (sourced from the UWIR (Golder, 2012a) based on information available for the study area in the DEHP database). This data supports a southward flow direction but exhibits a high degree of variability which is attributable to the limited data available from the database. Shallower groundwater flow in the Tertiary Formation appears to be influenced by surface topography. The shaded patterns in Figure 21 broadly represent the recharge area; arrows represent modelled flow lines after Welsh (2000). Dashed lines represent spring clusters updated from Habermehl.

Figure 21: Map of GAB Extent, Regional Flow Paths, Recharge Beds, and Spring Clusters



Source: After Habermehl and Lau (1997)

Structural Influence on Groundwater Flow

Section 2.4.4 presents a summary of the tectonic setting and basin stress regime within the Cooper-Eromanga Basins. The stress regime is primarily associated with strike-slip faulting, normal faulting, and transitional strike-slip/reverse faulting at depth. When taking the observed (and sustained) overpressures into account, this stress regime is predominantly more conducive to tight compressive (non-tensional) fault creation, and as such largely self-sealing fault systems. This would infer the faults are not likely to form conduits for groundwater (or gas or oil) flow. This is supported by pressure profiles and sustained overpressures, such as presented in Figure 20.

2.5.4 Recharge/Discharge

The upper GAB aquifers are recharged by infiltration (rainfall), and leakage from streams into outcropping sandstone formations, mainly on the eastern margins of the GAB along the western slopes of the Great Dividing Range. Regional groundwater flow is from the topographically higher recharge areas around the basin margins towards the lowest parts of the basin in the southwest (Figure 21).

Outcropping areas of the major GAB units, which are considered as the recharge areas for the GAB, do not occur within 300 km of the study area.

Discharge areas in the GAB typically manifest as springs, supplied by leakage to alluvial aquifers (Tertiary-Recent), and discharge to inland lakes and water supply bores. In the study area there are no identified GDEs (Section 2.6.2.4); the only discharge of water is through water supply bores or as a by-product during oil and gas production.

2.5.5 Aquifer and Aquitard Hydraulic Properties

A review of hydraulic parameters was undertaken for the strata in the vicinity of the study area. The hydraulic parameters characterising the formations are presented in Table 7. The data presented in the table are based on field measurements and available published values.

Table 7: Hydraulic Parameters

Basin	Formation	Hydraulic Conductivity (m/d)		Porosity (fraction)
		Min	Max	
Eromanga Basin	Quaternary and Tertiary Alluvium	-	-	-
	Winton Formation	-	-	-
	Mackunda Formation Alluru Mudstone Toolebuc Formation Wallumbilla Formation	-	-	-
	Cadna-Owie Formation	-	-	-
	Hooray Sandstone	4.3x10^{-4}	4.3x10^{-1}	-
	Westbourne Formation, Adori Sandstone and Birkhead Formation	8.0x10^{-7} [2]	2.5x10^{-4} [2]	0.2 [2]
	Hutton Sandstone	3.5x10^{-1}	9.8x10^{-3}	
	Poolowanna Formation	1x10^{-7} [2]	3.7x10^{-3} [2]	0.18 [2]
Cooper Basin	Tinchoo / Arrabury Formations			
	Toolachee Formation	2.0x10^{-3} [1]	4.3x10^{-3}	0.15 0.08 to 0.12[3]
	Daralingie, Roseneath Shale, Epsilon and Murteree Shale Formations	-	-	-
	Patchawarra Formation	3.3x10^{-4} [1]	3.5x10^{-3} [1]	0.13 0.08 to 0.12[3]

[1] Gov. of South Australia, Primary Industries and Resources, SA. Petroleum and Geothermal in South Australia – Cooper Basin, 2009.
[2] Alexander, E.M., Reservoirs and Seals of the Eromanga Basin (undated).
[3] Recent information provided by Santos (Santos, 2011a).

Note that insufficient data is available to provide transmissivity, which is a function of the thickness of an aquifer (T = Kb).

2.5.6 Groundwater Quality

Groundwater quality data was reported in a metadata table from the UWIR (Golder, 2012a; 2020). The metadata table includes both automated database enquiries and manually interpreted data for target formations using the available depth and construction information. Water quality data extracted from the DEHP database included a total of 772 samples collected from 437 groundwater bores located within the study area. However, only 494 of the samples collected were considered suitable for interpretive use, based on cation-anion balance, and could be assigned to a particular aquifer formation.

Groundwater quality data in the study area was available for the aquifers associated to the following formations[4]:

- Tertiary sediments (10 samples):
- Glendower Formation (31 samples):
- Winton Formation (160 samples):
- Mackunda Formation (16 samples):
- Alluru Mudstone (7 samples):
- Wallumbilla Formation (97 samples)[5];
- Cadna-Owie Formation (20 samples);
- Hooray Sandstone (147 samples);
- Adori Sandstone (1 sample); and
- Hutton Sandstone (5 samples).

Groundwater pH values in the study area ranged from 6.2 to 9.9. The slightly acidic pH (6.2) was associated with groundwater from the *Winton Formation* aquifer. The most alkaline sample was collected from the *Wallumbilla Formation.* For the majority of samples, the pH ranged between 7.5 and 8.5.

Total hardness was calculated from the chemical composition and refers to the sum of calcium and magnesium (expressed in mg/L of CaCO3). Approximately 49% of samples represent soft groundwater, 16% moderately hard, and approximately 15% of groundwater samples would cause scaling.

2.5.6.1 Water Types of the Study Area Formations

A piper diagram of all groundwater samples within the study area is presented as Figure 22, and piper diagrams for individual formations are presented in Figure 23. The red line represents conservative (non-reactive) mixing of fresh water and sea water. The position of the markers away from the conservative mixing line is an indication of a geochemical reaction. As presented in Figure 22 and Figure 23 the dominant ions are sodium, bicarbonate and chloride, and water types are either sodium-bicarbonate or sodium-bicarbonate-chloride types. Groundwater from the Winton Formation, Wallumbilla Formation, Hooray Sandstone and Tertiary Sediments/Glendower Formation appear to have higher proportion of sodium and magnesium.

2.5.6.2 Total Dissolved Solids

Based on TDS concentrations the majority of the groundwater samples (87%) are slightly brackish (TDS <3,000 mg/L). The rest of the samples from Winton Formation, Wallumbilla Formation, Glendower Formation

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[4] Data current as of December 2012

[5] The Alluru Mudstone and Wallumbilla Formation are considered to be confining beds in the study area. Interpretation of water quality and completion formation is based on the target formation interpretations in the DEHP database. It is possible that samples may have been mis-identified.

and Hutton Sandstone are classified as brackish with TDS concentrations in the range of 3,000 to 10,000 mg/L. The most saline sample was collected from the *Winton Formation* aquifer.

A measure of salinity and sodium hazard is presented in a Wilcox plot in Figure 24. Both salinity hazard (C) and sodium hazard (S) are each divided into four classes based on EC values and sodium absorption ratio (SAR): S1 or C1 indicates low sodicity or salinity (respectively) and S4 or C4 indicates high results. Figure 22 indicates that groundwater from the study area plot within a wide range of both sodium and salinity hazard classes. The groundwater from all of the formations from SWQ aquifers fall into high sodicity (S2-S4) and very high salinity classes (C4).

Figure 22: Piper Diagram

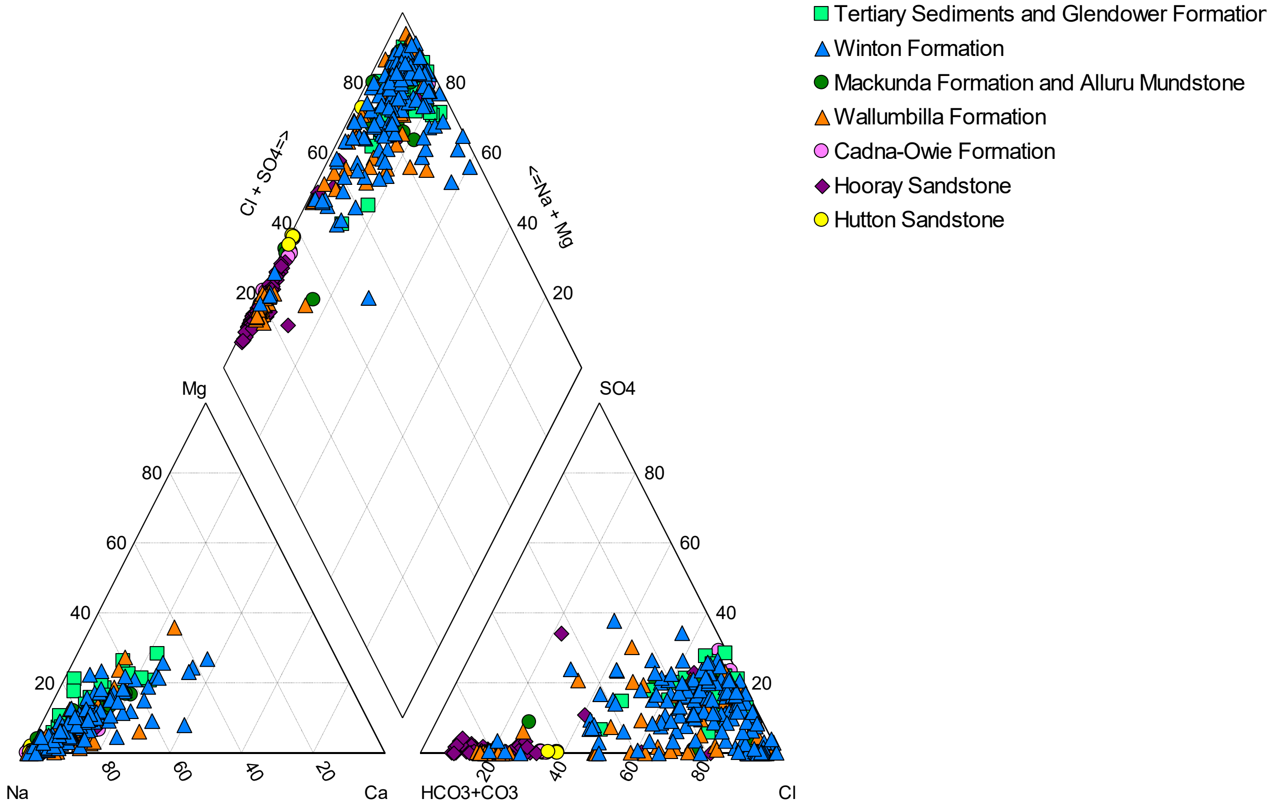
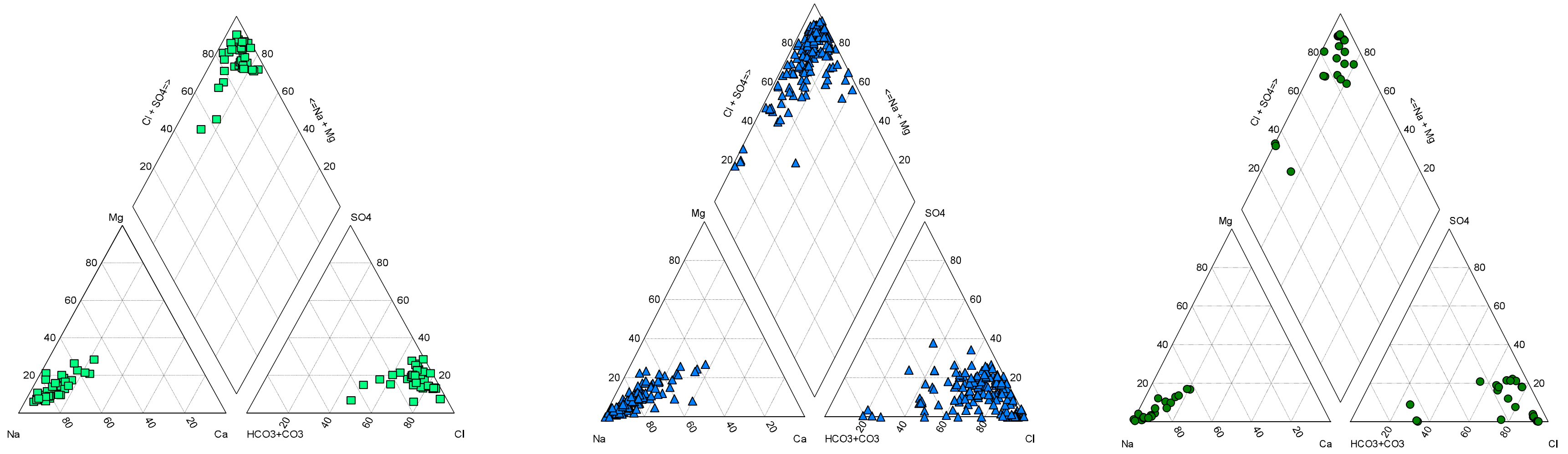


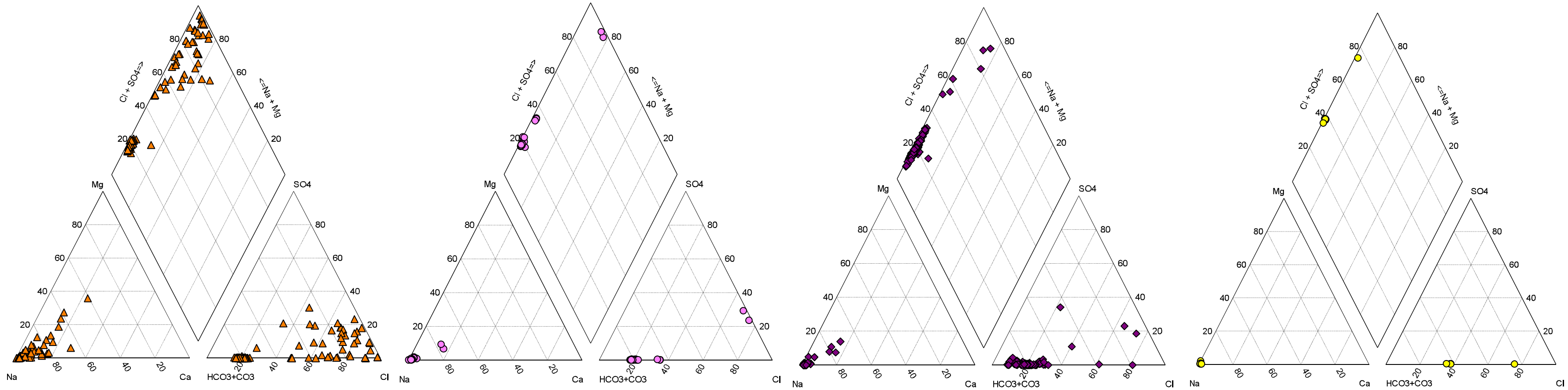
Figure 23: Piper Diagrams of Individual Formations



Tertiary Sediments and Glendower Formation

Winton Formation

Mackunda Formation and Alluru Mudstone



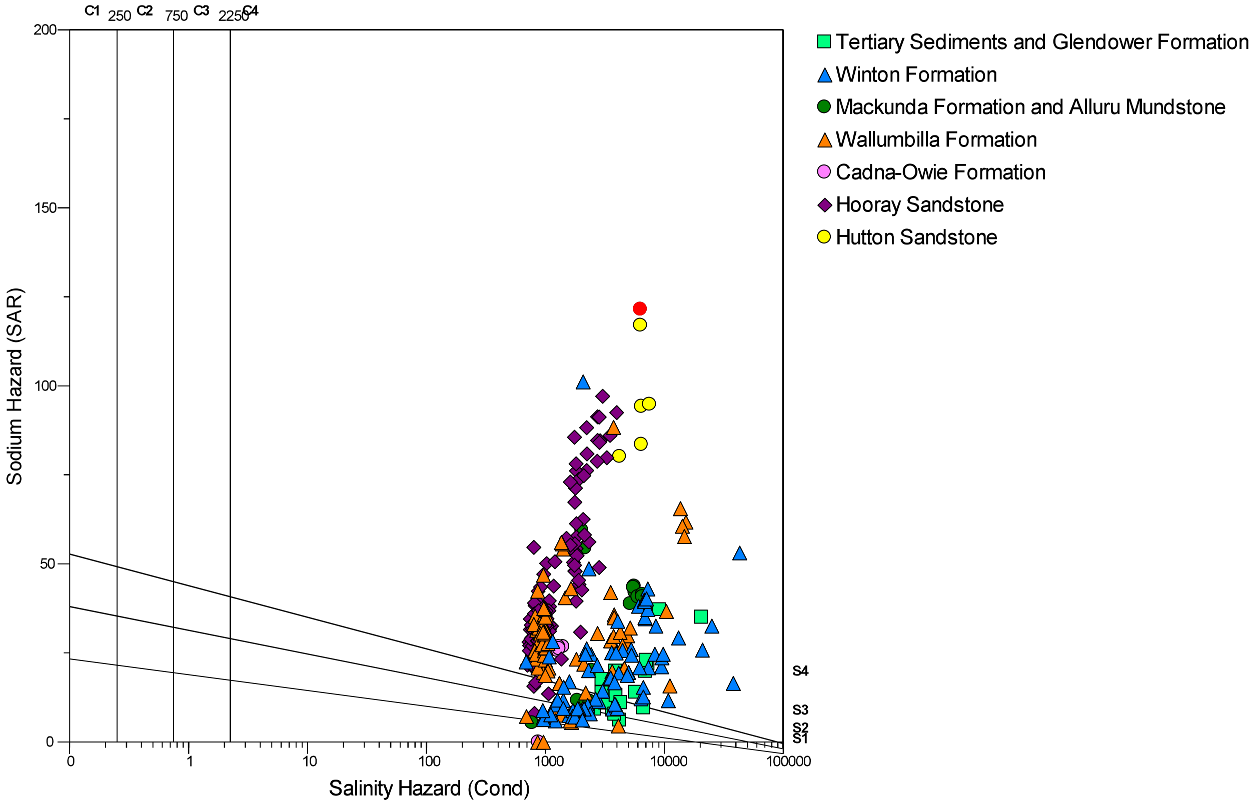
Wallumbilla Formation

Cadna-Owie Formation

Hooray Sandstone

Hutton Sandston

Figure 24: Wilcox Plot Showing Salinity and Sodicity Hazard Classes



2.5.7 Groundwater Use (Excluding Produced Water)

Groundwater use is largely for stock and domestic purposes, with some town and camp water supply also sourced from groundwater (Figure 25).

There are no large groundwater users albeit for municipal supply in the study area, based on the available data in the DEHP Water Entitlements System (WES) database (previously WERD database). The bores for municipal supply licensed in the WES database are for Eromanga and Thargomindah.

There are 99 existing water production bores known to Santos within the Project Area. Of these, 55 are currently operated by Santos (SWQ EMP 2014).

Groundwater is primarily sourced from the Tertiary formations and the upper GAB formations of the Eromanga Basin. Figure 26 illustrates the distribution of groundwater sources for registered water supply bores within the study area[6]. The geographical distribution of private bores and Santos bores is presented in Figure 27.

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[6] Data current as of December 2012

Figure 25: Groundwater Use within the Santos Study Area

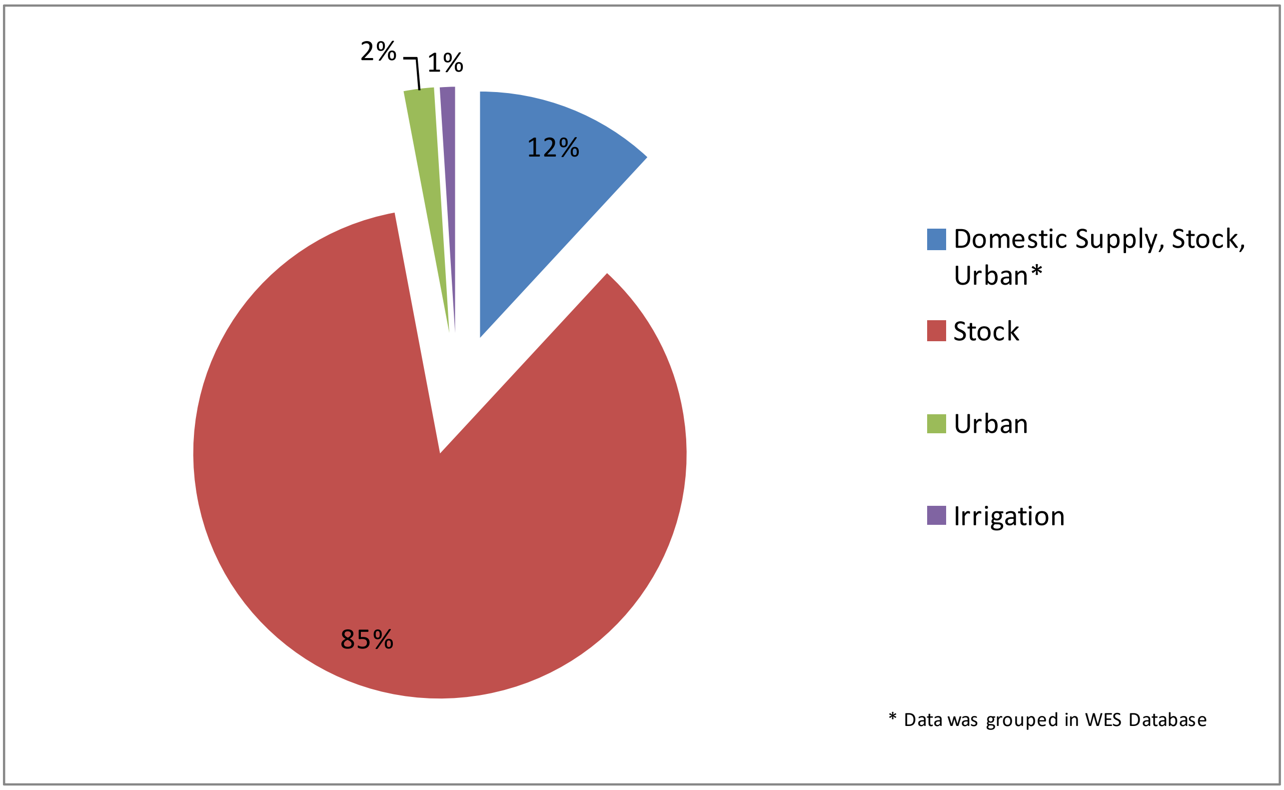
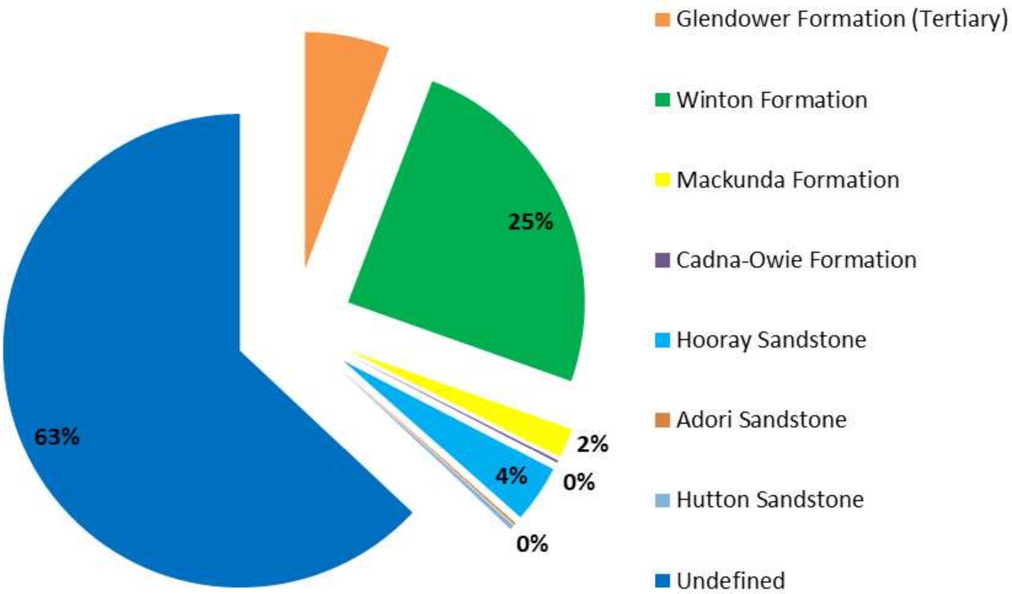


Figure 26: Target Groundwater Sources for Groundwater Usage in the Study Area



Note: Figure 26 was prepared using the data from the DERM groundwater database (Golder, 2020). A total of 138 bores have information on pump type or are indicated as artesian and have been assumed to be used for groundwater supply. Of these 138 licensed bores in the study area, 63% are assigned to the Hooray Sandstone aquifer.

Most private properties are expected to have access to their own water supply through stock and domestic entitlements as part of the basic landholder rights to access water. Groundwater use is limited to domestic consumption and cattle farming (not including industrial cattle operations). There is no volumetric groundwater entitlement associated to these licences however it is commonly assumed that those bores extract a maximum of 5 ML/year.

As of January 2020 (UWIR, 2020), the total volumetric water entitlements in the study area is 2,390 ML/yr for urban and town supply from seven bores; however, four of these licensed bores (totalling 900 ML) were listed as “Lapsed/Never Constructed” and/or expired. The total nominal allowance for stock and domestic bores is 635 ML/yr for 127 bores. The total extraction volume for the 135 licensed bores listed in the DEHP database is therefore 2,125 ML/yr (excluding lapsed/non-constructed bores entitlements).

Santos water production associated with oil and gas production (Golder, 2012a) is mostly from the Hutton Sandstone (82% of average annual production), the Birkhead Formation (7.8%) and the oil reservoirs of the Hooray Sandstone (8.6%).

2.5.8 Regional Bore Inventory

In parallel with the UWIR (Golder, 2012a) Santos engaged Golder to undertake a Water Bore Baseline Assessment (WBBA) in SWQ (Golder, 2012b; reference no. 117666006-019-R-Rev0). The purpose of the WBBA was to verify the existence and operation of water supply bores in the study area, and where possible to collect water extraction, level and quality data. In 2012, Santos identified 242 water bores within the study area which required assessment according to the following criteria:

- *Priority 1*: within leased areas and inside a 2 km radius of a production bore;
- *Priority 2*: within leased areas and outside a 2 km radius of a production bore;
- *Priority 3*: outside of the established leased areas but within Santos tenement boundaries.

The WBBA works undertaken were generally consistent with the DEHP requirements outlined in the *Baseline Assessment Guideline* (2011) (now DES Baseline Assessment Guidelines Version 3.02, effective 5th July 2017), and condition J13 of the draft CSG model conditions for Level 1 EAs, and included assessment of the following information:

- Capacity, quality, and water level of existing bores in the vicinity of oil and gas production areas;
- Details on bore construction, where available;
- Type of infrastructure used to pump water from the bore;
- Identifying bores with potential for inclusion in a regional groundwater monitoring network; and
- Providing an opportunity for bore owners to have direct communication with a field scientist and Santos Land Access Staff (LAS) and for developing positive relationships with these groundwater users.

As of December 2012, 89 bores were located within leased areas (*Priority 1* and *2* bores). Of these, only eight active water supply bores were confirmed within Santos tenements. Details are presented in Table 8 and Figure 27. Refer to the WBBA (Golder 2012b) for a detailed description of field observations.

Table 8: Summary of WBBA Priority 1 and 2 Bores Observed to be Used by Third Parties (Assumed Private Landowners)

Santos Priority	Bore Name	DEHP RN	Santos' Permit	Measured Water Depth (m btoc)	Bore Depth (mbgl) (source: DEHP database)	Target Aquifer (source: DEHP database)*
1	Palara Bore	6057	PL 59	-	243.80	(no data)
1	Mt Margaret No 14	9096	PL 170	-	129.60	Winton Formation
1	Walla Wallan Bore 5	6373	PL 295	15.40	156.70	(no data)
2	Mt Margaret No 20	10565	PL 295	-	89.00	(no data)
2	Cherry Cherry Bore	6369	PL 39	-	285.40	(no data)
2	Tarbat Job No 1947	12036	PL 295	30.40	209.80	Winton Formation
2	Grahams Bore	14955	PL 110	-	94.80	Glendower Formation
-	Moon Road Field Bore	0**	ATP 259P (now referred to as ATP 1189)	-	-	-

Notes:
* Data extracted from the DEHP database (bore depth and target aquifer) is considered to be indicative only, as the original data source is unknown and was not confirmed with field measurements.
** Bore not observed in database records. Referred to as "Moon Field Road Bore" in WBBA.

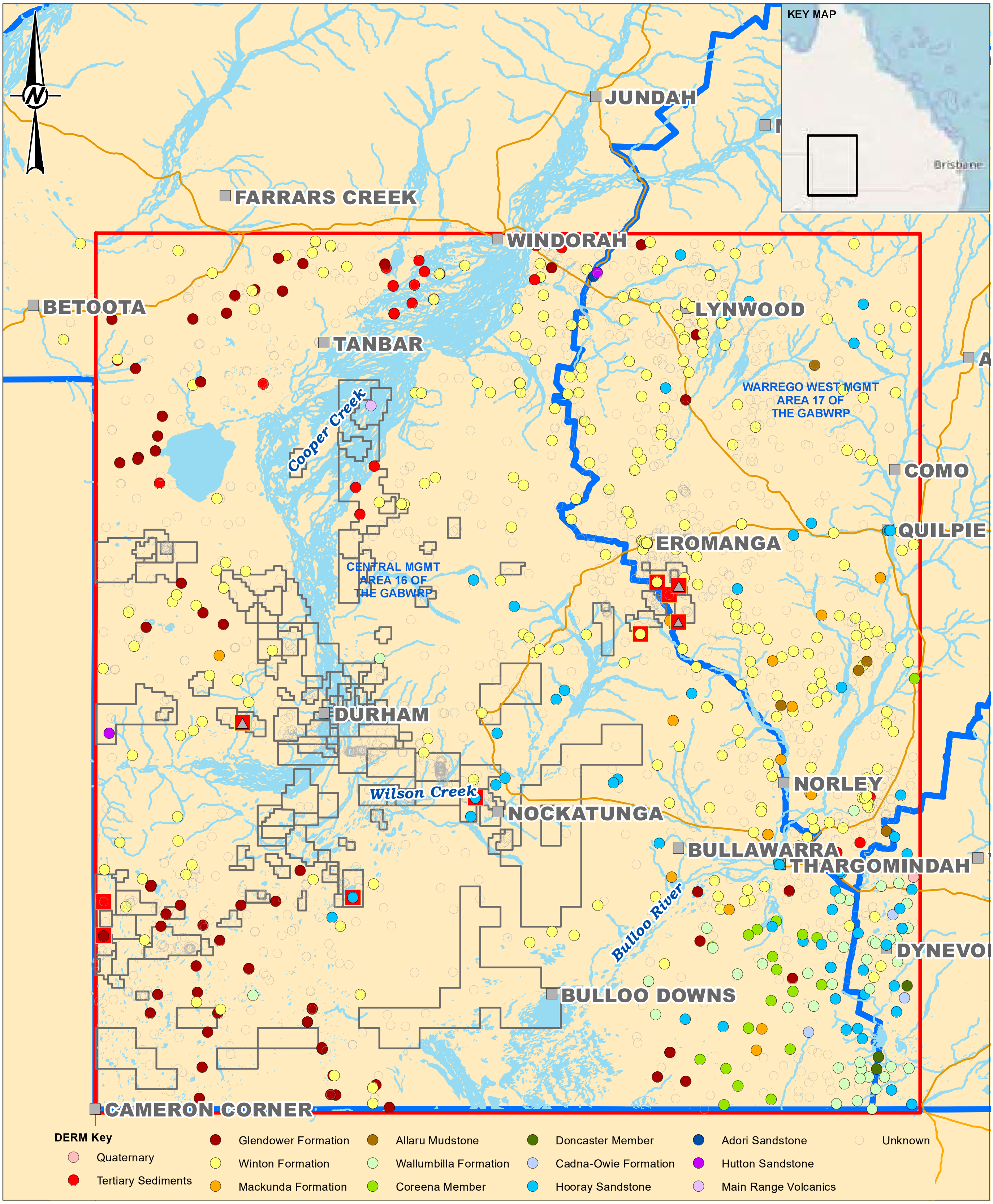
Significant data gaps have been identified between the DEHP database (used in preparing the UWIR), Santos records and the actual existence of bores (Refer to Section 4.8 of the WBBA). Active bores were also observed not to have corresponding DEHP registration numbers. In general, reliable historic and bore construction records were limited and records indicating the aquifer in which bores are screened were not available.

The Golder UWIR indicates that oil and gas production may produce groundwater drawdown in some locations within the study area. Two bores highlighted in the UWIR as being within potential impact zones (in addition to the eight identified private bores) were identified within the affected areas:

- **5032: Whim Well**
  Coordinate location visited in 2012; however, the bore was not observed and the DEHP records could not be verified. In 2016, the bore was located by Santos and was found to be non-operational (A. Stannard, pers. comm.).
- **5033: Coothero Water Bore**
  This bore is monitored by Santos as part of the UWIR Monitoring program (UWR 2020). It is located outside of the established leased areas but within Santos tenement boundaries (i.e., *Priority 3;* location shown on Figure 27*)*. This bore targets the Hooray Sandstone at 1,415 m depth, which is vertically within several hundred metres of hydrocarbon reservoirs in which hydraulic stimulation may occur. Bore uses may include road maintenance and stock watering (based on observations at the site). This bore was investigated by DES and found not to be an authorized bore (does not have a license that permits the

owner to extract groundwater). It therefore does not qualify for protection and management in accordance with s363 of the Water Act (as advised by DEHP on 29 July 2014) (UWIR 2020). Water level measurements between 1988 and 2009 show a 40 m decline in this well, potentially as a result of water extraction due to oil and gas field activities, this however has not been confirmed and could be a result of climatic factors (long-term drought cycles) (UWIR 2020).

The locations of the eight identified private bores and the additional identified bores (Whim Well and Coothero Bore)are shown within the Santos tenements on Figure 27. The locations of these bores in proximity to the stimulation activities are discussed further in Section 3.5.



LEGEND

Santos Bores

- ▲ Unknown
- 🟥 WBBA Bores
- ■ Town/Locality
- Highway/Major Road
- River/Creek
- Groundwater Management Area
- Santos Tenements
- Study Area

0 KILOMETERS 100

1:2,500,000 GCS GDA 1994

NOTE(S)

REFERENCE(S)

1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019
3. GROUNDWATER MANAGEMENT AREA SOURCED DEPARTMENT OF NATURAL RESOURCES & WATER, QLD GOVERNMENT, 2008

CLIENT
SANTOS

PROJECT
HYDRAULIC FRACTURING RISK ASSESSMENT – SANTOS SOUTHWEST QUEENSLAND TENEMENTS

TITLE
GEOGRAPHICAL DISTRIBUTION OF GROUNDWATER USE

CONSULTANT

GOLDER

DD-MM-YYYY	19-03-2020
DESIGNED	KB
PREPARED	KB
REVIEWED	CB
APPROVED	CB

PROJECT NO.	CONTROL	REV.	FIGURE
127666004	011-R	2	27

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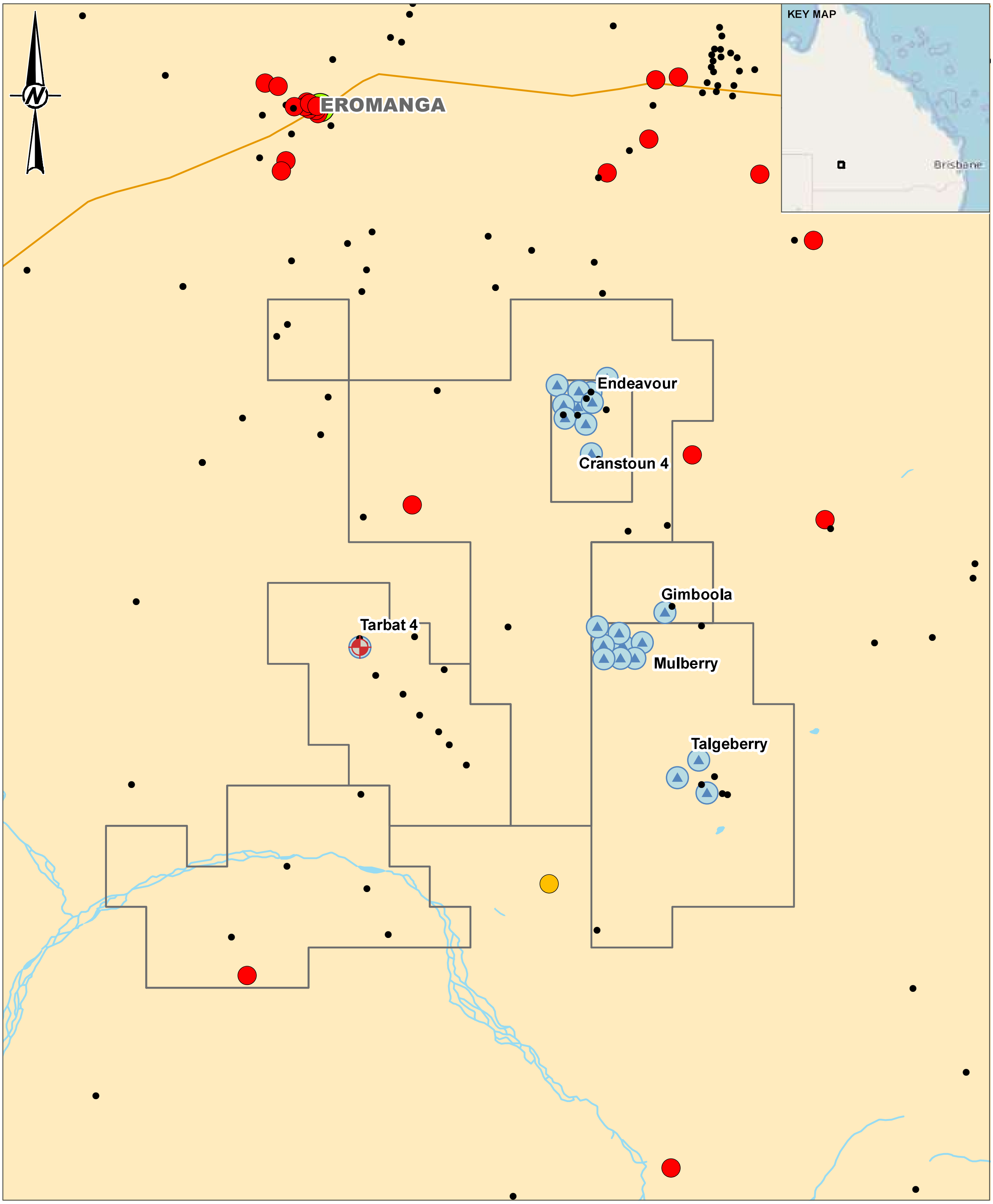

LEGEND

Private Bores - Target Aquifer

- 🟢 Hooray Sandstone
- 🔴 Winton Formation
- 🟠 Mackunda Formation
- ● Unknown
- ⊕ Water Source Well
- ▲ Water Injection Wells
- ■ Town/Locality
- — Highway/Major Road
- — River/Creek
- ☐ Santos Tenements
- 🟥 Study Area

0 KILOMETERS 10

1:250,000 GCS GDA 1994

REFERENCE(S)

1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019
3. GROUNDWATER MANAGEMENT AREA SOURCED DEPARTMENT OF NATURAL RESOURCES & WATER, QLD GOVERNMENT, 2008

CLIENT
SANTOS

PROJECT
HYDRAULIC FRACTURING RISK ASSESSMENT – SANTOS SOUTHWEST QUEENSLAND TENEMENTS

TITLE
WATER FLOODING ACTIVITIES

CONSULTANT

GOLDER

DD-MM-YYYY	19-03-2020
DESIGNED	KB
PREPARED	KB
REVIEWED	CB
APPROVED	CB

PROJECT NO.	CONTROL	REV.	FIGURE
127666004	011-R	2	28

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2.6 Environmental Values in the Study Area

2.6.1 Introduction

For the purpose of this study, environmental values (EVs) relate to surface water or groundwater resources within the study area and are defined as “those qualities of the waterway that make it suitable to support particular aquatic ecosystems or human use” (*Environmental Protection (Water) Policy, 2009*, referred to as EPP Water, 2009). The EPP 2009 provides guidelines on determining the environmental value that should be considered for a particular project site or area, which follow the framework set out in *Appendix H* of the *Queensland Water Quality Guidelines 2006* (QWQG 2006).

Terrestrial environmental values of the study area, defined as the terrestrial ecosystems (flora and fauna) present within the study area, have also been considered, with information obtained from the Department of Environment and Energy (DoEE) formerly the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) Interim Biogeographic Regionalisation of Australia (IBRA), and the Environment Protection and Biodiversity Protection (EPBC) Act Protected Matters Search Tool.

With the exception of updated tenements, this section of the SRA is largely unchanged from the Rev0 (December 2012) version of this report.

2.6.2 Environmental Values of Groundwater

The EVs relevant to groundwater resources in the study area include:

- Town water supply;
- Stock and domestic water supply;
- Sandstone aquifers of the GAB; and
- Groundwater Dependant Ecosystems (GDEs).

2.6.2.1 Town Water Supply

Groundwater is a common potable water source for many inland arid to semi-arid areas of Australia, especially where productive, good quality aquifers are present at reasonably shallow depths. Use of groundwater in the region is further encouraged by the low average rainfall, which is significantly exceeded by the pan evaporation potential (Section 2.1).

Municipal water supply accounts for most of the larger licensed groundwater allocations across the study area. Municipal water supply bores identified in the WES database are licensed to extract from the Hooray Sandstone.

2.6.2.2 Stock and Domestic Water Supply

Groundwater is an important resource for stock and domestic water supply for many inland areas of Australia, especially where productive, good quality aquifers are present at reasonably shallow depths.

Groundwater supply development by the local communities predominantly targets the Glendower and Winton Formations (according to the DEHP database), and to a lesser extent the deeper formations of the Eromanga Basin. The WBBA undertaken by Golder (2012b; 2020) identified eight private water supply bores in use from a total list of 242 *Priority 1* and *2* bores within the Santos tenements (Section 2.5.8).

Groundwater for stock and domestic supply is considered to be an important environmental value in the study area.

2.6.2.3 Sandstone Aquifers of the Great Artesian Basin

The main GAB aquifers present within the study area (Section 2.5.2.1) are the Winton Formation, Cadna-Owie Formation, Hooray Sandstone, Hutton Sandstone and Poolowanna Formation (Precipice Sandstone equivalent). The sandstone formations of the Cooper Basin are not considered by the regulator to fall within the definition of "*sandstone aquifers of the GAB*".

In the study area, only the upper aquifers within the stratigraphic sequence are of interest to the local community (Section 2.5.7). The deeper aquifers are not economically viable for use as domestic supply due to the drilling costs to access them. As such, the Hutton and Poolowanna Sandstone aquifers are not used by the community with the possible exception of a couple of oil and gas exploration bores converted to private bores.

Any activity interfering with recharge to the aquifer may impact on the greater GAB. However, outcropping areas considered as the recharge regions of the major GAB units do not occur within 300 km of the study area.

2.6.2.4 Groundwater Dependant Ecosystems

GDEs can be defined as those ecosystems whose ecological processes and biodiversity are wholly or partially reliant on groundwater. There is currently no national GDE database, however, the *Environmental Water Requirements of Groundwater Dependent Ecosystems* report prepared by Sinclair Knight Merz Pty Ltd (SKM; 2001) provides an overview of key threatened GDEs in Australia and the framework for assessing environmental water provisions for GDEs. The extent of GDE dependency on groundwater can range from being marginally or episodically dependent to being entirely dependent on groundwater.

Examples of GDEs include:

- Springs and associated aquatic ecosystems in spring pools;
- Aquatic ecosystems in rivers and streams that receive groundwater baseflow;
- Terrestrial vegetation supported by shallow groundwater;
- Wetlands, which are often established in areas of groundwater discharge; and
- Aquifers and caves, where stygofauna (groundwater-inhabiting organisms) reside.

The potential presence of GDEs in the study area was assessed from literature sources (DERM, 2005 and 2007; Fensham and Fairfax, 2005) and public databases (e.g. Queensland wetlands project, Queensland spring database, EPBC Act Protected Matters database). The results of the GDE evaluation in the study area are presented in Figure 29 and are summarised below:

- No discharge springs (according to the GAB registers) are located within the vicinity of proposed stimulation activities. The nearest GAB discharge spring is located 95 km southeast of Santos tenements, and 150 km east of the nearest tenement proposed for stimulation (Figure 29);
- No GAB recharge springs, or watercourse springs have been registered within the study area;
- The *Cooper Creek Basin Wild River Area Summary: Natural Values Assessment* (DERM, 2010) concludes that "the persistence of waterholes in the Cooper Creek is largely influenced by surface water flows and evaporation, with little inputs from groundwater". This is supported by published peer-reviewed research into the surface water – groundwater connectivity of Cooper Creek waterholes, as discussed in Section 2.3 and 2.5.2.1. As a consequence, the Cooper Creek drainage system, including the associated watercourses and waterholes, is *not* classified as a GDE;
- Within the study area, one listed wetland of international significance and 11 wetlands of national significance were identified (Table 10). The Ramsar-listed Currawinya Lakes is located in the south-eastern corner of the study area, more than 170 km from the closest Santos lease and is not considered further in this report. Of the nationally important wetlands, three are located (partially) within Santos

tenement boundaries, two are within 25 km of a Santos tenement boundary, and the rest are 40 km or more from tenement boundaries. Similar to the discussion of the groundwater dependency of waterholes above, it is considered that the wetlands in this region are likely to be sustained by episodic flood events or surface water from the semi-permanent waterholes, as the relatively deep and saline water table aquifer characteristic of the study area is unlikely to sustain the wetlands. Further discussion of the wetlands is provided in Section 2.6.3.1; and

- Nearby national parks include the Lake Bindegolly National Park, west of the town of Thargomindah and the large Innamincka Recreation Reserve in SA, which do not have registered GDEs.

In summary, according to the GDE databases and literature referenced above, the only registered GDEs within the study area are discharge springs located more than 95 km from Santos tenements. These have not been considered further in this report.

2.6.2.5 Proximity of Oil and Gas Targets to Overlying and Underlying Aquifers

The key aquifers identified in the study area are considered to be the following: the Tirrawarra Formation, Patchawarra Formation, Epsilon Formation, Toolachee Formation and Wimma Sandstone of the Cooper Basin; and the Poolowanna Formation (Precipice Sandstone equivalent), Hutton Sandstone, Hooray Sandstone, Cadna-Owie Formation, Winton Formation in the Eromanga Basin (refer to Section 2.5.2).

The general ranges of stratigraphic thickness that separate the aquifers from the nearest hydrocarbon reservoirs are also presented in Table 9.

The average offset between the base of the Hutton Sandstone and the top of the Permian gas reservoirs is between 200 to 300 m, with most of the intervening stratigraphy consisting of very low permeability mudstones and shales. For economic reasons landholder bores will generally access the shallowest beneficial use aquifer, typically being the Glendower and Winton Formations in the study area. The vertical offset between these aquifers and the top of the gas-bearing Permian interval is of the order of 1,400 m to 1,800 m for the Glendower Formation and between 1,000 m to 1,500 m for the Winton Formation.

Across the study area, the typical depth range between the Glendower Formation and the Cadna-Owie Formation in which the shallowest oil reservoirs are present is of the order of 500 m to 1,400 m, and between 400 m to 800 m for the Winton Formation.

Table 9: Stratigraphic Thickness between Hydrocarbon-Bearing Formations and Aquifers

Basin	Stratigraphic Unit	Relative to Nearest Potential Oil/Gas Target Formation	Vertical Distance
Eromanga	*Winton Formation (GAB)*	Wyandra Oil (Upper Cadna-Owie)	400 – 800 m
	Cadna-Owie Formation (GAB)		0 – 90* m
	Hooray Sandstone (GAB)	Murta Oil (Upper Hooray)	0 – 85* m
	Hutton Sandstone (GAB)	Middle Birkhead Oil (Birkhead Formation)	40 - 80 m
	Poolowanna Formation (GAB)		140 – 220 m
		Wimma Gas (Nappamerri Grp)	140 – 200 m
Cooper	*Wimma Sandstone (GAB)*		0 – 115* m
	Toolachee Formation (CB)	Toolachee Gas (Gidgealpa Group)	0 – 190* m
	Epsilon Formation (CB)		<180**

Basin	Stratigraphic Unit	Relative to Nearest Potential Oil/Gas Target Formation	Vertical Distance
		Patchawarra Gas (Gidgealpa Group)	<50**
	Patchawarra formation (CB)		0 – 150 *
	Tirrawarra Formation(CB)		0 - 40 m

GAB = Great Artesian Basin (Eromanga Sub-basin, Triassic-Cretaceous), CB = Cooper Basin (Permian-Triassic),
* maximum thickness of unit (where the nearest gas or oil unit is a sub-unit of the aquifer).
** Maximum (uncertain due to lack of information)

In Table 9, where aquifer formations also contain hydrocarbon reservoirs the vertical range between the aquifer and reservoir formation is indicated as zero up to the maximum thickness of the formation. The water-bearing zones are separated from hydrocarbon reservoirs by intra-formational seals; however, there is not enough information available to discretise the internal stratigraphy of these formations. Where petroleum activities (including stimulation) occur within a formation that hosts both aquifers and hydrocarbon reservoirs, the lateral distance of the water supply bores accessing the aquifer to Santos' tenements was considered.

According to the DEHP database and the interim results of the WBBA program, groundwater supply development in the vicinity of Santos' tenements is limited to the Glendower and Winton Formations, and to a lesser extent the Hooray Sandstone. The minimum vertical offset between these aquifers and the shallowest hydrocarbon reservoirs (oil reservoirs of the Cadna-Owie Formation) is 400 to 800 m, which includes the low permeability formations of the Wallumbilla Formation and Allaru Mudstone, which form a thick, competent and regionally extensive seal between the Cadna-Owie Formation and the shallower aquifers.

The closest beneficial use bore to the Santos tenements targeting the Hooray Sandstone in the DEHP database records is the Coothero Bore, which has a DEHP database recorded depth of 1,165 m, is at least 25 km from the closest tenement proposed for hydraulic stimulation and more than 80 km from the closest tenement with activities proposed at a similar depth (i.e. oil production from the Hooray Sandstone). Santos monitors the Coothero Bore as part of the UWIR monitoring program.

2.6.3 Environmental Values of Surface Water

Specific EVs for the watercourses within the study area are not defined within the EPP (Water) 2009 and there are no detailed local plans relating to environmental values for the catchments.

Based on the land uses present within the catchment area the EVs which would apply to watercourses within the Cooper Creek Catchment are:

- Protection of aquatic ecosystems;
- Recreation and aesthetics: primary recreation with direct contact, and visual appreciation with no contact; and
- Cultural and spiritual values.

The Santos EMPs (March 2014) discuss the cultural and spiritual values of the study area. These are summarised in the UWIR (Golder 2020). The EMPs identify ten sites of Aboriginal cultural heritage significance related to surface water within or in close proximity to the study area. These are presented in the UWIR (2020) and are listed in the Register of the National Estate (RNE) and or the Queensland Heritage Register.

2.6.3.1 Aquatic Ecosystems

The EVs associated with aquatic ecosystems comprise two inter-related aspects:

- The intrinsic value of aquatic ecosystems, habitat and wildlife in waterways and riparian areas – for example, biodiversity, ecological interactions, plants, animals, key species (such as waterfowl or frogs) and their habitat, food and potable water; and
- Waterways that include perennial and intermittent surface waters, groundwater, tidal and non-tidal waters, lakes, storages, reservoirs, dams, wetlands, swamps, marshes, lagoons, canals, natural and artificial channels and the bed and banks of waterways.

As discussed in Section 2.3, water flows in the Cooper Creek vary greatly over time. The Cooper Creek drainage channel system is predominantly ephemeral. Every three to four years a major flood event occurs (Figure 6) and during extended periods of no flow, the Cooper contracts to a series of semi-permanent waterholes, which provide drought refuges for a variety of flora and fauna.

The Cooper Creek Basin is the largest catchment in the Lake Eyre region. This area resides within the Channel Country Strategic Environmental Area and may include threatened plants, birds and marine and estuarine species. Hence, the aquatic ecosystems associated with the waterholes and billabongs that form between flood events are considered to be of high ecological value.

2.6.3.1.1 Wetlands

For the purpose of this study, wetlands are defined as areas of permanent or periodic/intermittent inundation, with water that is static or flowing fresh, brackish or salt (Wetlandinfo, 2012). Wetlands must have one or more of the following attributes:

- at least periodically, the land supports plants or animals that are adapted to and dependent on living in wet conditions for at least part of their life cycle; or
- the substratum is predominantly undrained soils that are saturated, flooded or ponded long enough to develop anaerobic conditions in the upper layers; or
- the substratum is not soil and is saturated with water or covered by water at some time.

The Queensland Wetland Program identifies eleven wetlands of ecological importance and one Ramsar Wetland (Commonwealth of Australia, 2010) within the study area. These wetlands and their proximity to Santos' tenements are summarised in Table 10.

Table 10: Identified Wetlands of National and International Significance in the Study Area

Wetland Name	Reference Number	Area (ha)	Approximate Distance to Santos SWQ Tenement
International Importance [1]			
Currawinya Lakes[1]	43	151,300	130 km E of ATP 1063P
National Importance [2]			
Cooper Creek – Wilson River Junction	QLD027	63,925	Within ATP 1189, PL25 PL133, PL150, PL177, PL208, PL1051 and PL1060
Bulloo Lake	QLD024	83,227	Within ATP 1063P
Cooper Creek Swamps – Nappa Merrie	QLD026	106,311	Within ATP 1189, PL131 and PL146
Lake Yamma Yamma	QLD037	86,548	17 km NE of ATP752 and 25 km W of PL38
Lake Bullawarra	QLD031	1,287	50 km E of ATP765

Wetland Name	Reference Number	Area (ha)	Approximate Distance to Santos SWQ Tenement
Nooyeah Downs Swamps Aggregation	QLD041	6,241	40 km E of ATP765
Lake Cuddapan	QLD033	1,704	61 km NW of ATP1189
Cooper Creek Overflow Swamps – Windorah	QLD025	124,853	20 km N of ATP1189
Lakes Bindegolly and Toomaroo	QLD125	9,677	113 km E of ATP765
Quilpie (Bulloo River FP) water holes	QLD167	30	87 km NE of PL295
Mitchell Swamp	QLD170	500	140 km NE of PL295

1. List of Wetlands of International Importance of the Ramsar Convention
2. A Directory of Nationally Important Wetlands in Australia (Environment Australia, 2001)

2.6.3.1.2 Ecological Investigation of the Study Area

The unpredictable flow regime and spatially complex environment has created a distinctive ecology, with the Cooper Creek Catchment (Section 2.3) providing important habitats for a range of species, especially in times of flood.

Most species of aquatic fauna are well adapted to the extreme flood-drought regime prevailing in the region. Life cycles are completed rapidly during favourable conditions, and temperature, salinity and oxygen tolerances are often high. Several species are highly dependent upon the refuge habitat provided by permanent waterholes for survival during the long droughts that regularly occur in the region.

A brief overview of the biology of the study area, as evidenced from the field surveys undertaken to better understand the implications of the Commonwealth EPBC Act 1999 (Carpenter and Armstrong, 2001 and 2002; Santos 2003), is summarised below:

- Aquatic Flora: No rare or threatened species of aquatic flora have been recorded from the waterways in the oil and gas fields;
- Aquatic Macroinvertebrate Communities: Several species of crustaceans inhabit the creeks and waterholes of the Cooper Basin. They are dependent upon permanent water for survival, and generally retreat to permanent waterholes during droughts. Some species, however, can survive for prolonged periods, buried in the dry bed of creeks and waterholes. Species include freshwater crabs, the common yabby, shield shrimps, freshwater shrimps and freshwater mussel;
- Fish Communities: Most of the fish species within the study area can tolerate a large range of water quality conditions. Golden perch, mosquito fish, western carp-gudgeon and central Australian catfish are tolerant species that can live in water characterized by low DO levels, high salinity and relatively high turbidity;
- Waterfowl: Sixteen species of waterbird were surveyed near water holes along the flood plain. These include the pink eared duck, glossy ibis and brolga. Brolga is a large silvery-grey waterbird with a red face and nape and is listed as vulnerable. It inhabits shallow lakes, swamps, wet grasslands and dry land adjacent to these areas.

2.6.3.2 Recreational Values

The Cooper Creek Catchment is a popular recreational fishing destination. Fishing for golden perch and catching common yabby are popular within the study area in:

- the waterholes of the Bulloo River at Thargomindah;
- the Wilson River at Nockatunga; and
- Cooper Creek, in the channel country (Bulloo Shire Council, 2012).

The portion of the Cooper Creek system in South Australia, downstream of Cooper Basin, is a popular destination for tourists from all over the world. With only a few permanent waterholes in South Australia section of the Cooper Creek system, fish must survive droughts by colonising as many temporary waterholes as possible during the Cooper Creek catchment flood events (Section 2.3).

2.6.3.3 Proximity of Santos Tenements to Surface Water with Environmental Values

The proximity of Santos tenements and proposed petroleum activities to surface water EVs are described below:

- *Aquatic Ecosystems* **–** The proximity of aquatic ecosystems to Santos' tenements are described in detail in Section 2.6.3.1 and illustrated in Figure 29. Cooper Creek, is largely influenced by surface water flows and evaporation, with negligible contribution from groundwater. Waterholes and billabongs occur throughout the Cooper Creek floodplain and channel complex, some of which coincide directly with Santos tenements;
- *Wetlands* **–** As indicated in Table 10 reveals that three of the identified wetlands (Cooper Creek **–** Wilson River Junction, Bulloo Lake and Cooper Creek Swamps **–** Nappa Merri) are within boundaries of Santos' tenements. It should be noted that stimulation activities may be completed within any tenement boundary over the life of the Project;
- *Recreational Values* **–** The Cooper Creek catchment and downstream Lake Eyre are popular recreational fishing destinations. The proximity to popular fishing spots from Santos activities are listed below:
  - Bulloo River at Thargomindah is 55 km from the Santos tenement boundaries, and 90 km to the closest active lease area; and
  - Cooper Creek flows (episodically) through some of the western tenements.

These wetlands, waterholes and rivers with ecological and recreational values are identified and spatially managed in a DEHP GIS database of Environmentally Sensitive Areas (ESAs), a copy of which was provided to Santos for all of their tenements. The ESAs form a routine part of the constraints analysis in the planning of all Santos well leases and associated disturbance proposals in SWQ. Prior to any greenfield disturbance, or subsequent re-disturbance, a Santos Environmental Advisor or external ecologist inspects the site for potential environmental impact. The resultant assessment, and any recommendations for mitigation, is managed via the Santos *Environmental Approval Request Tracking Form* (EART). Approval conditions must be accepted by the relevant project proponent prior to any physical works occurring.

2.6.4 Terrestrial Environmental Values

For the purpose of this assessment, terrestrial environmental values are considered to comprise the native flora and fauna of the study area. Based on information obtained from the SEWPaC (now referred to as DoEE) IBRA (online at: http://www.environment.gov.au/parks/nrs/science/bioregion-framework/ibra/index.html), three biogeographical regions cover the study area, as follows:

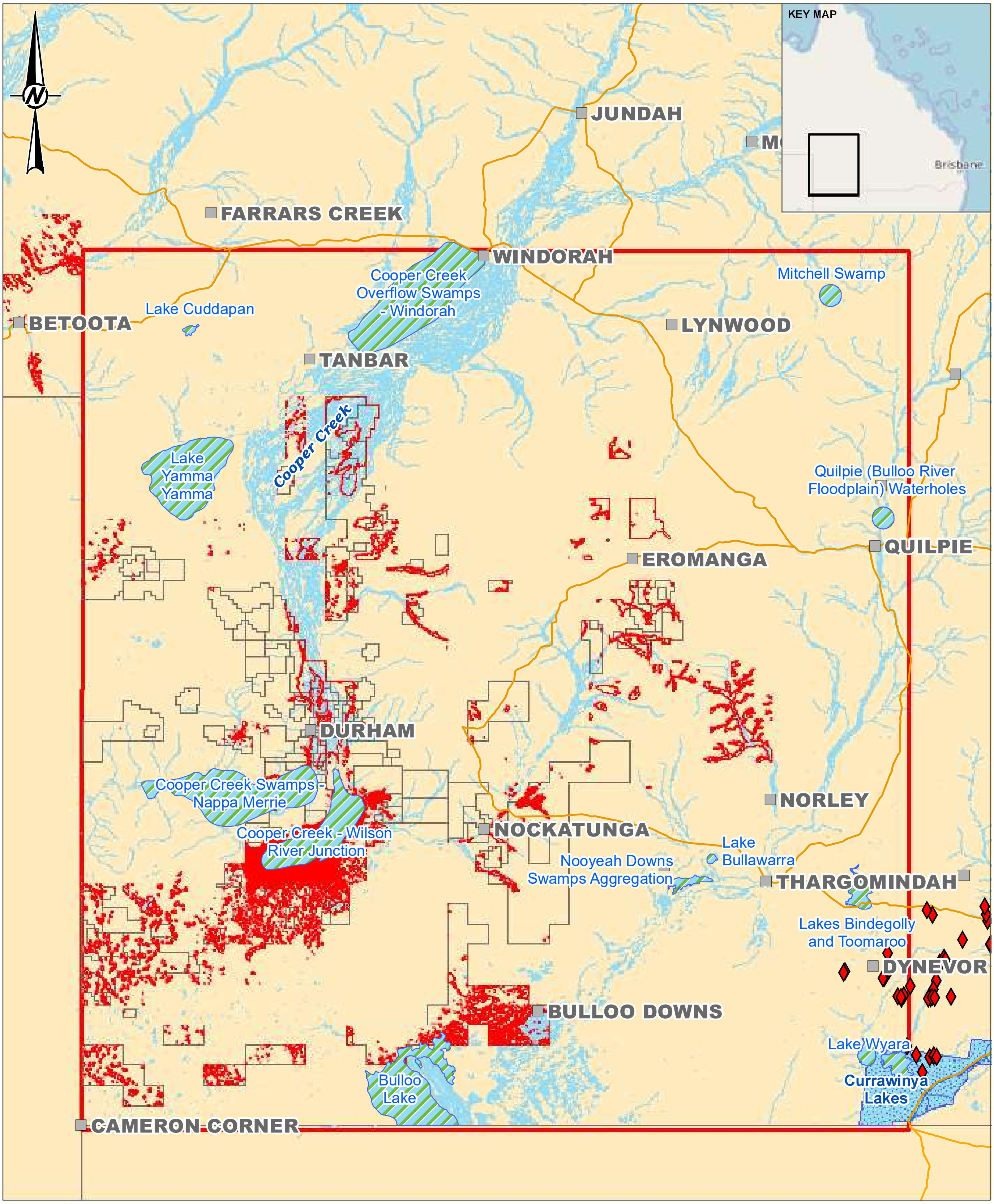
- Channel Country, which covers the central portion of the study area and is characterised by vast braided, flood and alluvial plains surrounded by gibber plains, dunefields and low ranges. Native vegetation is predominantly Mitchell grass, gidgee and spinifex, and various weeds are known to exist in the area. The region is predominantly used for stock grazing (approximately 91%) and is home to several invasive animals. Native species are abundant and include red, eastern, and western grey kangaroos, with various marsupials and reptiles adapted to the variable ecosystems ;
- Mulga Lands, which covers the eastern portion of the study area and is characterised by flat to undulating plains with outcrops of low ranges and tablelands. The dominant native vegetation types are mulga and eucalypt woodland, with some weed species well established particularly where grazing occurs. The region is predominantly used for stock grazing (approximately 94%) and is home to several invasive animals, but also supports an assemblance of diverse native species; and

- Simpson Strzelecki Dunfields, which covers the southwest corner of the study area and comprises long parallel sand dunes, fringing dunefields, extensive sand plains, ephemeral watercourses and saltpans. Vegetation is predominantly spinifex hummock grasslands with sparse acacia shrublands and some narrow river red gum and coolibah riverine woodlands. The region is partially used for stock grazing (approximately 49%) and is home to several invasive animals, as well as highly adapted native species.

A study area specific report generated from the interactive EPBC Act Protected Matters Search Tool (http://www.environment.gov.au/epbc/pmst/index.html, assessed 2012) indicated matters of national environmental significance, as follows:

- Threatened species including 5 birds, 1 fish, 6 small and medium sized mammals, 1 reptile and 8 plants;
- Migratory species including 3 marine birds, 2 terrestrial birds and 6 wetland birds;
- Listed species including 9 birds;
- Indicative and registered indigenous and historic areas;
- Reserves and wetlands; and
- Invasive plant and animals.

It is considered that some of these terrestrial environmental values could be in close proximity to Santos stimulation activities. Consistent with before mentioned procedures, prior to greenfield disturbance, or subsequent re-disturbance, a Santos Environmental Advisor or external ecologist inspects the site for potential environmental impact. The resultant assessment, and any recommendations for mitigation, is managed via the Santos Environmental Approval Request Tracking Form (EART). Approval conditions must be accepted by the relevant project proponent prior to any physical works occurring.



LEGEND

♦ GAB ROP Discharge Spring

♦ GAB ROP Recharge Spring

■ Town/Locality

— Highway/Major Road

— River/Creek

▨ Nationally Important Wetland

▨ Ramsar Site

☐ Constraint Areas

🟥 ESA (Primary)

🟥 ESA (Secondary)

☐ Santos Tenements

☐ Study Area

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1:2,500,000 GCS GDA 1994

REFERENCE(S)

1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019

CLIENT
SANTOS

PROJECT
HYDRAULIC FRACTURING RISK ASSESSMENT – SANTOS SOUTHWEST QUEENSLAND TENEMENTS

TITLE
ENVIRONMENTALLY SENSITIVE AREAS IN TENEMENTS WITHIN THE SANTOS STUDY AREA

CONSULTANT

GOLDER

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DESIGNED	KB
PREPARED	KB
REVIEWED	CB
APPROVED	CB

PROJECT NO.	CONTROL	REV.	FIGURE
127666004	011-R	2	29

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3.0 STIMULATION PROCESS

3.1 Introduction

The description of the stimulation process is covered under the following headings:

- Description of the oil-bearing units and the oil they contain;
- Description of the gas-bearing units and the gas they contain;
- Purpose of the stimulation process;
- Description of the stimulation process;
- How is stimulation carried out;
- Infrastructure and equipment used;
- Stages of stimulation;
- Assessment techniques for determining extent of stimulation activities;
- Practices and procedures used to ensure fracture remains in target zone;
- Program for wells to be stimulated;
- Frequency of stimulation;
- Distribution of wells stimulated to date and to be stimulated;
- Location of landholders' active bores; and
- Chemical constituents in acid and stimulation package.

3.2 Well Design and Stimulation - General Considerations

Prior to considering the practice of stimulation to enhance conventional oil and gas well production, two important matters require addressing in accordance with the requirements anticipated of the EA conditions that will apply to new areas proposed for production, namely:

- 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;
- *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 robust surveillance plan, which includes;
    - *Well integrity checks including casing pressure surveys, downhole isolation checks (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.*
    - *Cement integrity involving acoustic logging and casing pressure tests.*

3.2.1 Comparison to International Best Practice

Within Australia and the world, the oil and gas industry is reliant on a number of experienced stimulation contractors.

These contractors, along with operating companies, have developed and defined industry best practices in the field of stimulation. These practices have been transferred to applicable operations in Australia.

These practices have been developed over 60 years using 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 guidance documents published by the API. It should be noted that API Technical Reports (TRs) and Recommended Practices (RPs) are not legal requirements and the use of these documents is voluntary. The key guidance documents relevant to the contractor's operations in the SWQ oil and 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 Recommended Practice 53, *Blowout Prevention Equipment Systems for Drilling Operations*
- API Recommended Practice 65, *Cementing Shallow Water Flow Zones in Deep Water Wells*
- API Recommended Practice 65-2, *Isolating Potential Flow Zones During Well Construction*
- API Recommended Practice 90, *Annular Casing Pressure Management for Offshore Wells*

The stimulation contractors operating in Australia and used by Santos currently follow the intent and detail of these guidance documents as they apply to the site-specific conditions for each hydrocarbon bearing field. In conjunction with these activities, other stimulation technologies are also being used, such as use of pneumatic techniques (gases, such as CO_2) to fracture the sandstone hydrocarbon reservoirs. The process of researching alternate methods is an ongoing process, and descriptions and results of trialled alternative methods will be provided as the findings become available and are considered field-ready.

3.2.2 Well Mechanical Integrity and Integrity Testing

3.2.2.1 Background

One of the major controls in providing a high degree of protection to the Cooper and Eromanga aquifers is through robust well design, well construction, and scheduled integrity checks throughout the lifecycle of the well i.e. from production to abandonment. Quality control procedures are implemented through the material selection, sourcing process, installation as well as maintenance and checks to ensure the casing and seals are adequate barriers for hydraulic isolation.

A properly designed production well provides full containment of hydrocarbons within its internal casing and/or completion conduit from the subsurface to the surface and affords:

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

Full containment is achieved by cementing in place multiple strings of steel casing and installing mechanical plugs or packers after a well is drilled to depth. The primarily objective of the well design is to prevent communication with aquifer systems and cross flow of fluids (gas, oil and water) between sedimentary layers. Of particular note is that important casing design parameters are factored 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 (EHSMS 11.5, AIMS and PESP 9.1, Santos 2009) to ensure that integrity controls and measures have been performed prior to 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 sides 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 oil and gas contained within the well casing all the way to the surface. This *containment* and barrier philosophy along with continued zonal isolation is what is meant by the term “well integrity.” Should an issue with casing 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 abandoned to regulatory specifications.

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 abandoned.

NOTE: The discussion of well integrity has been drawn from discussions and information provided by Santos and supplemented by information directly sourced from API HF1 (API, 2009). The reader is urged to consult this document for a detailed description of the well completion process.

3.2.2.2 Drilling and Well Completion

Drilling a typical oil or gas 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 stimulation or other 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 Preventor (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 stimulation;
- 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.

3.2.2.3 Selection and Sourcing of Casing Materials

To ensure long term casing integrity, Santos has developed detailed specifications for all well casings and well completion materials. The casing materials are specifically rated to handle stimulation treatments at Permian depths and pressures. Parameters such as yield and burst pressures are specified and triaxial load modelling are sometimes 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 sections below.

3.2.2.4 Logging the Borehole

All of Santos oil and 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*: a receiver tool that detects natural radiation from rock. The main isotopes of thorium, potassium, and uranium can indicate the presence of clay mineralogy;
- *Laterolog*: tools which measure 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;
- *Calliper Tool*: measures hole diameter and can provide an indication of borehole geometry. Useful in terms of planning for casing running and cementing design; and
- *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 hydraulic fracture stimulation design.

Logging produces detailed information on the rock formations drilled and the water and hydrocarbons they might contain. This assists with 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 3.2.2.5), “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 the following:

- gamma ray (described previously);
- casing collar locator (CCL; a magnetic device that detects the casing collars); and
- cement bond log (CBL), 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 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 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 production well.

3.2.2.5 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. A typical casing design is illustrated in Figure 30.

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 3.2.2.6), and cement placement (Section 3.2.2.7) 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 stimulation outcomes. These include defining the optimal location and orientation of perforations such that the zone of 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.

3.2.2.6 Casing Completion

The first borehole drilled is for installing the conductor pipe (Figure 30). 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 action of subsequent drilling phases (prevents the loose soils from caving into the borehole) and is cemented into place to ensure an appropriately robust seal (up to ground level). Is also serves to isolate the surface water table and perched aquifers, if present;
- The *surface casing* is typically installed to protect the 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 30 m to 60 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 all 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, *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 stimulate the target zones from the surface into the producing formation without affecting the shallower layers penetrated by the well. It also houses the downhole production pumping equipment (oil wells) when the well becomes operational. During the operational phase of the well, its most important function is internally containing the hydrocarbons produced from the oil and gas units.

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 stimulation operations, the production well casing is pressure tested. This test should be conducted at a pressure that is greater than what is expected during stimulating 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 wells life (see Section 3.2.2). Remedial cementing operations are implemented if there is evidence of inadequate cement integrity: and
- Santos is increasingly moving to *deviated* and potentially *horizontal* production wells to reduce the oil and gas fields' footprint (multiple horizontal wells from a single surface location, thereby, reducing the cumulative surface impact of the production operation). Selection and use of these techniques are in its infancy and trials 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.

3.2.2.7 Cementing

Cement types, additives and mixes are higher 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 aggressive 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 to 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 with the formation and casing.

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

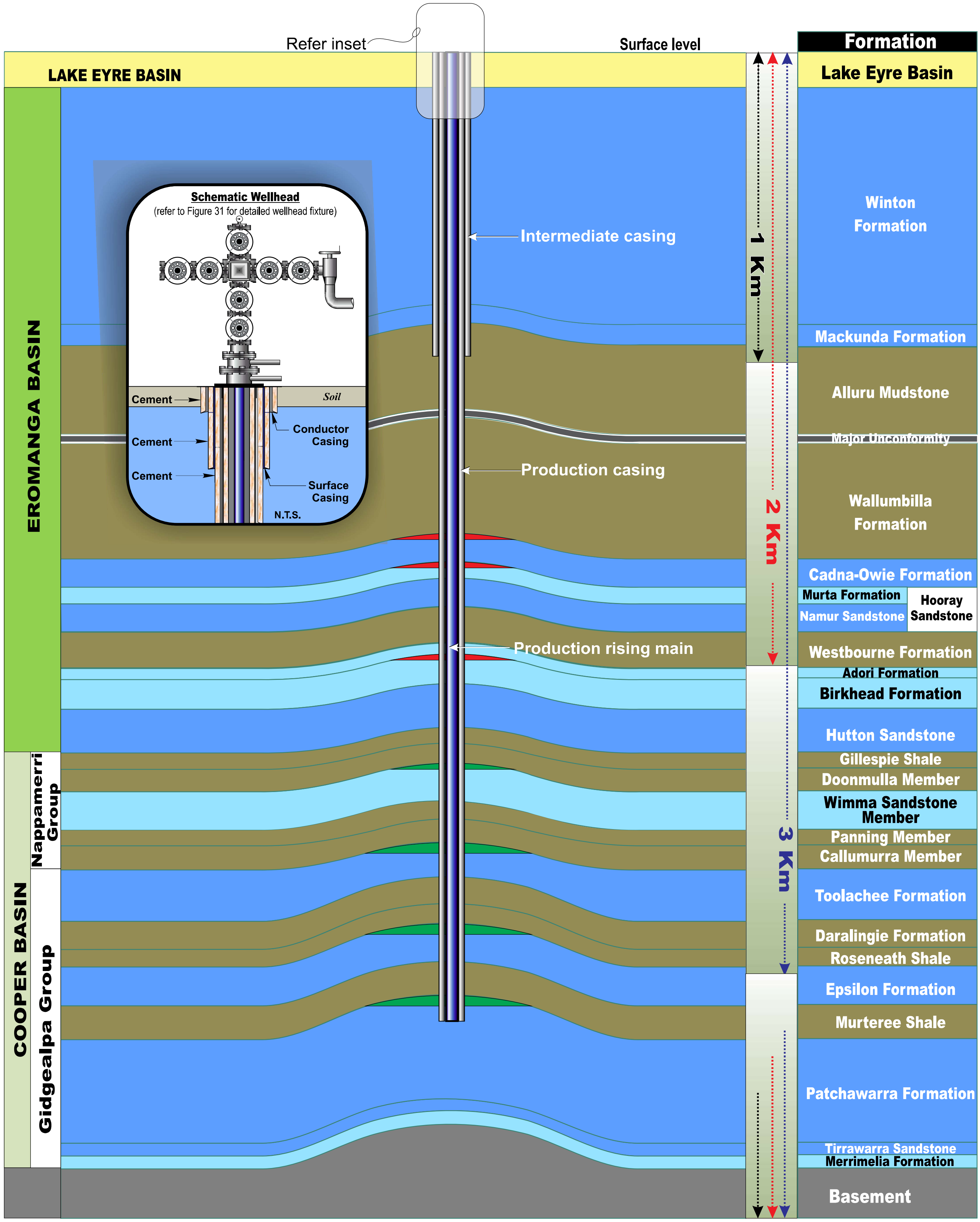
- Computer simulation and completion planning is carried out to optimise cement placement procedures;
- Santos drilling contractors are selected based on their reputation, and their adherence to industry best practice methods and regulatory requirements. Importantly, as it affects cementing, they are required to use established, effective drilling practices to achieve a uniform, stable well borehole with the desired hole geometry. Additionally, they are required to satisfy Santos health-safety-environmental (HSE) requirements with regard to their personnel and equipment. They are required to ensure that their cementing equipment provides adequate mixing, blending, and pumping of the cement in the field;
- Santos drilling contractors are required to ensure that the drilling fluid selection is appropriate for the designed well and the geologic conditions likely to be encountered, and present a low risk to the environment;
- 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 help 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 groundwater aquifers;
- Santos cementing contractors are required to 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, stimulation 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 outlined in Section 3.2.2.4.

3.2.2.8 Well Completion Design

The final well completion 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 of a separate piece of pipe or conduit in the already cased well. This pipe is secured with mechanical packers above the producing zones and is usually performed with a separate Completions/ Work Over Rig. The purpose of the final completion string is to allow the hydrocarbons to produce from it, but on a well integrity perspective, it acts as the secondary barrier control such that if the primary barrier (being the casing) fails, there is not an uncontrolled release of hydrocarbon to surface.



Key

- 🟦 Aquifer
- 🟦 Water Bearing
- 🟫 Confining Bed
- 🟩 Gas Accumulation
- 🟥 Oil Accumulation

Source: Stratigraphy and scale based on DMITRE, 2012. Road map for unconventional Gas Projects in South Australia. Energy Resources Division, April 2012.

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PROJECT SWQ HYDRAULIC FRACTURING RISK ASSESSMENT

DRAWN HC DATE 16.11.2012

CHECKED RS DATE 19.12.2012

TITLE CONCEPTUAL CONVENTIONAL OIL OR GAS WELL CONSTRUCTION DETAIL

SCALE VERTICAL SCALE: AS SHOWN
HORIZONTAL SCALE: N.T.S.
A3

PROJECT No.	DOC No.	DOC TYPE	FIGURE No.	REV No.	
127666004	011	R	F030	0	FIGURE 30

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3.3 Description of the Stimulation Process

3.3.1 Introduction

This section describes the process of hydraulically fracturing/stimulating a conventional oil or gas well, including:

- Description of the reservoir formations and the hydrocarbons they contain;
- Purpose of the stimulation process;
- Description of the stimulation process;
- Infrastructure and equipment used;
- Stages of stimulation;
- Assessment techniques for determining extent of stimulation activities;
- Practices and Procedures used to ensure fracture remains in target zone;
- Program for wells to be stimulated;
- Frequency of stimulation;
- Distribution of wells stimulated to date and to be stimulated; and
- Chemical constituents in stimulation fluid systems.

3.3.2 Description of Hydrocarbon Reservoir Formations in the Study Area

3.3.2.1 Conventional Gas

Conventional gas is mostly methane and is produced predominantly from stacked sands of the Toolachee and Patchawarra Formations (Gidgealpa Group), which lie within the Cooper Basin. The fluvial sandstone reservoirs are separated by shales and coals, which act as intra-formational seals (refer to detailed stratigraphy in Section 2.4). 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.

The 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.

A key element that distinguishes conventional gas production from CSG production is that conventional sandstone reservoirs do not require the depressurisation of the target beds (with respect to groundwater). 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 formation’s 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.

3.3.2.2 Conventional Oil

The conventional oil reservoirs in the study area are associated with sandstone formations of the Eromanga Basin. The oil is present in discontinuous oil reservoirs within interbedded sandstones beds or larger sandstone formations (in the sandstone units of the Cadna-Owie, Hooray Sandstone and Birkhead formations); with reservoirs typically comprising structural and sedimentary traps (Section 2.4.3.4).

The sandstone reservoirs are generally interbedded with shales, mudstones, siltstones and coals, which act as intra-formational seals. The primary oil reservoir formations are separated by low permeability formations comprising shale-mudstones-siltstones-sandstone assemblages of the Eromanga Basin, themselves situated at depth within a thick sequence of highly variable sedimentary rock types (Table 3).

The porosity found in oil sandstone reservoirs is preserved primary intergranular porosity. Water and oil commonly occur together, having a film of water separating the pore boundaries from the oil. Oil reservoirs that lack a film of connate water at pore boundaries can occur but are rare.

Oil production wells generally do not free flow, so gas lift is typically used to aid oil or condensate production. The produced water is separated from the oil and treated and is typically used in water flooding activities to restore and maintain reservoir pressure and enhance production (Figure 28; Golder, 2012a).

3.3.3 Purpose of the Stimulation Process

Hydraulic 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 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.

Santos include conventional fracture stimulation as part of the final completion process. Once the production casing is cemented, cement evaluation has occurred, and a frac tree is installed at the surface; the stimulation operation can begin. Perforations are placed across the required interval of the reservoir formation and the surface fracturing equipment is rigged up and tied-in to the well.

Production wells may be subject to multiple stimulation events during the completion process. In order to produce from all of the reservoirs intersected by a well, Santos uses methods to selectively isolate and individually stimulate each hydrocarbon-bearing zone. As a result, a typical gas well will have more than one stimulation treatment and the current average is about six treatments per well. The typical Santos oil well will rarely have more than one stimulation treatment due to the limited number of oil reservoirs and the fact that oil-bearing formations are not as dependent on stimulation to be commercially viable.

The subsequent sections describe stimulation design and the stimulation process.

3.3.4 Stimulation Treatment Design Considerations

As discussed in detail in Section 3.2, drilling, open hole and cased hole logging of the reservoir section provides information useful in the stimulation design process. Data is acquired providing information on reservoir parameters, as well as lithology variations and stress contrast from layer to layer. All of this data is used within an industry accredited stimulation software to develop an optimal design.

The basis of well specific design is to exploit the reservoirs through an optimal number of stimulation 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’ (aquitard 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;
- 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 stimulation design that provides containment within the target formation. The 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 has regional stress information that is used to predict the fracture orientation across the basins. There is an increased use of micro-seismic sensing within the industry to monitor fracture orientation. Santos has experience with this technology and may consider additional projects in the future.

Stimulation fractures 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 optimised by designing a treatment that maintains the fracture height within the target formation. Fracture propagation into non-reservoir units will result in sub-optimal economics. Growth into non-reservoir units can have two outcomes: Firstly, the fluids and proppant are wasted and the hydrocarbon production may be reduced due to poor placement of proppant; secondly, there is a risk of fracturing into a water bearing interval which could lower production due to liquid loading. This would lead to an expensive workover to shut off the water production.

As discussed in Section 2.4.4, 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.

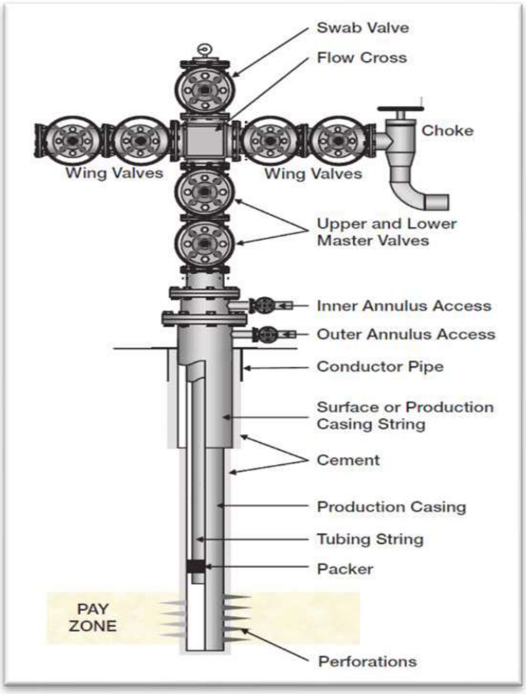
Stimulation is initiated with hydraulic pressure applied to the rock, through the perforations, such that the rock fails in tension against the minimum horizontal stress. With continued fluid injection, the fracture will continue to propagate in the direction of maximum horizontal stress. The fracture will also grow in height until a higher stress boundary is encountered. This stress contrast will prevent the fracture height growth to continue until the pressure in the fracture exceeds the barrier stress. Bottom hole fracturing pressures, at the depth of Cooper Basin reservoirs, can be of the order of 50 MPa to 80 MPa depending on depth of the reservoir rock being fractured/stimulated and its geomechanical properties. Fractures within the basin, at the depths of the reservoir sands, are expected to be near vertical and orientated parallel to the major horizontal in-situ stress direction. Fracture height growth is likely to truncate along a low shear strength plane such as the top of the sedimentary layer. Alternatively, if a fracture propagates from a brittle (sandstone) layer into a formation that is ductile (shale often exhibits plastic properties), extra energy would be required to continue the fracture propagation. Consequently, contrasts in apparent fracture toughness form effective fracture height barriers.

In multi-target production wells, casing isolations are used to isolate the fracture pressures to the targeted reservoir rock and to limit the potential for fracturing of sequences above and below the target intervals. Two techniques are commonly used by Santos within the Cooper Basin. The first technique referred to as “plug and perf”, uses composite bridge plugs to mechanically isolate stages prior to perforating the next sand above. The second technique uses coiled tubing with the ability to mechanically isolate a stage below and jet perforate the next stage above, prior to fracturing.

3.3.5 Stimulation Process Description

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 (‘pay zone’ in Figure 31), to create the hydraulic fracture. A typical well head used to inject into and control the well, during fracturing operations, is illustrated in Figure 31.

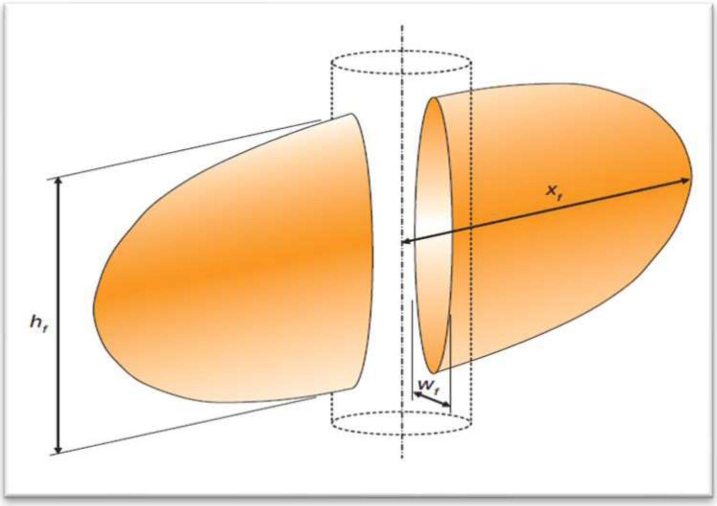
Figure 31: Typical Stimulation Wellhead Fixture



Source: Economides and Martin, 2007

As discussed above, the stimulation process occurs under high hydraulic pressures in order to physically fracture the reservoir rock. The stimulation fluids are injected through perforations (10 to 20 mm diameter holes created with jet perforating) in the well casing pipe. The stimulation fluids are injected from the surface via the wellhead or frac tree (Figure 31). A simplified schematic of the created fracture geometry is indicated in Figure 32. A hydraulic fracture 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 32: Conceptualised Shape of Stimulation Zone of Influence



Source: Economides and Martin, 2007

The intent of 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 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 with 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 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; and
6) Flowback well to clean up injected fluids and monitor hydrocarbon production.

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

3.3.6 Infrastructure and Equipment Used

Within SWQ stimulation is used on both oil and gas reservoirs. For the most part the process is the same. The differences may involve slight fluid formulation changes due to temperature variations with depth and some variation on the equipment used. Smaller oil reservoir stimulation treatments usually use less pumping horsepower and less stimulation fluid and proppant, and therefore require a smaller set-up than gas reservoir treatments (refer to .

Figure 33 and APPENDIX D for a typical equipment set up). Deeper gas reservoirs usually require variations in the fracturing fluid due to higher bottom-hole temperatures and higher in-situ stresses. The higher stresses mean that higher horsepower is usually required.

Santos uses two methods to pump and isolate fracture stages within multiple target gas wells within the Cooper Basin. The first method, referred to as “plug and perf”, uses wireline-conveyed jet perforating across each reservoir target. Sands are 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 to isolate the 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 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.

Figure 33 and APPENDIX D indicates the coiled tubing equipment, which may or may not be required on the actual treatment. Some further descriptions of equipment are provided below:

- **‘Clean Fluids’ Pit or Turkeys nest –** on site, a pre-dug lined pit (turkey's nest) provides temporary clean water storage for use in the stimulation process. Source water is generally trucked from a nearby water supply bore or recycled water 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 (e.g. oil wells), 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.
- **Sand Trailer Unit –** a large, multi-compartment trailer that holds proppant (sand or ceramic material) required for the treatment. When proppant is required, a conveyor system distributes proppant from the compartments to the downhole blender.
- **Blender Units –** In general, two different blending units are use: A pre-gel blender; and a downhole blender. The pre-gel blender combines the source water with additives required for the base stimulation fluid (also known as “linear gel”) and proportions all required additives to provide the final stimulation fluid. The downhole blender unit then proportions proppant to the stimulation fluid to provide the proppant concentrations specified in the fracture design. The final stimulation fluid, without proppant, is referred to as the “clean fluid”. The final stimulation fluid, with proppant added, is referred to as “slurry”. Most of the stimulation fluids used within the Cooper Basin for the main stimulation treatment are cross-linked fluids to assist with fracture geometry and proppant transport. In small stimulation jobs for oil wells, the linear gel is "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 stimulation treatment.
- **Hydration Units –** The hydration unit is generally situated between the pre-gel and downhole blenders and serves to prepare the linear gel for crosslinking. Water from the pond or tank is pumped to the hydration unit where a polymer, such as guar gum, is proportioned into the water. A sufficient residence time is available for the polymer to hydrate and provide sufficient viscosity for the fluid designed. The final result is the base gel, or linear gel, for the final stimulation fluid.
- **High Pressure Pumps –** reciprocating triplex or quintaplex pumps that receive low pressure stimulation fluid from the downhole blender and inject these fluids at sufficiently high pressure into the well during the stimulation process.
- **Control or Data Acquisition Unit –** telemetry from all units are connected to a central control room during the stimulation treatment. Treatment parameter data, including surface and bottom-hole pressure, pumping rate, chemical rate and fluid density, are monitored, recorded and plotted. Treatment supervisors and a Santos representative monitor and control the treatment to ensure that the treatment is pumped according to design.
- **‘Coil Tubing’ Unit –** a Coiled Tubing unit (CTU) has many uses within Santos operations but is not always required as part of a stimulation operation. On some occasions the stimulation 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 stimulation 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 stimulation 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.

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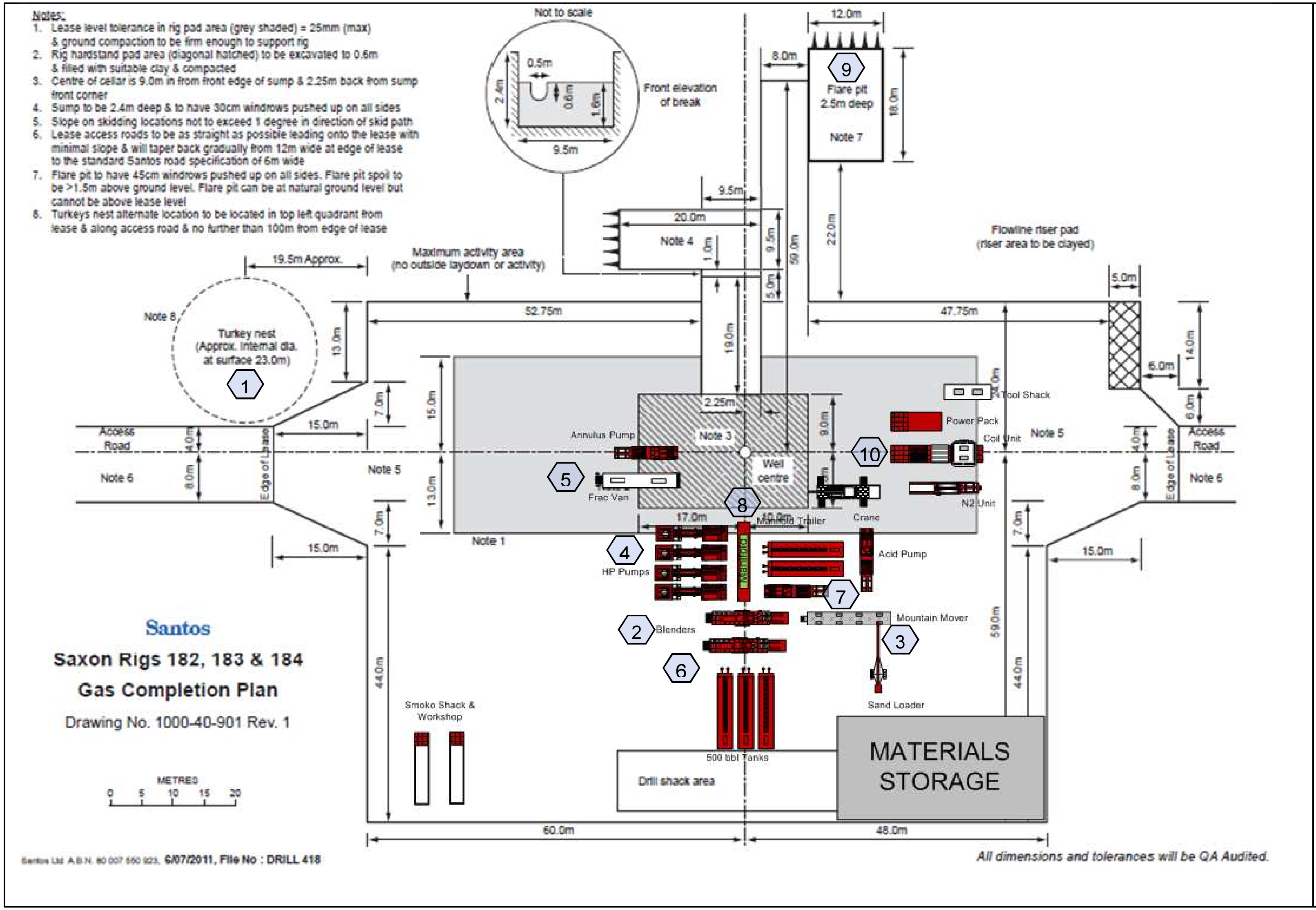
Figure 33: Diagrammatic Layout of a Typical Stimulation Operation on a Conventional Oil or Gas Well Lease (Saxon Rigs 182, 183 and 184)*



Notes:

1. Lease level tolerance in rig pad area (grey shaded) = 25mm (max) & ground compaction to be firm enough to support rig
2. Rig hardstand pad area (diagonal hatched) to be excavated to 0.6m & filled with suitable clay & compacted
3. Centre of cellar is 9.0m in from front edge of sump & 2.25m back from sump front corner
4. Sump to be 2.4m deep & to have 30cm windrows pushed up on all sides
5. Slope on skidding locations not to exceed 1 degree in direction of skid path
6. Lease access roads to be as straight as possible leading onto the lease with minimal slope & will taper back gradually from 12m wide at edge of lease to the standard Santos road specification of 6m wide
7. Flare pit to have 45cm windrows pushed up on all sides. Flare pit spoil to be >1.5m above ground level. Flare pit can be at natural ground level but cannot be above lease level
8. Turkeys nest alternate location to be located in top left quadrant from lease & along access road & no further than 100m from edge of lease

Santos

Saxon Rigs 182, 183 & 184

Gas Completion Plan

Drawing No. 1000-40-901 Rev. 1

Santos Ltd A.B.N. 80 007 550 923, 6/07/2011, File No : DRILL 418

All dimensions and tolerances will be QA Audited.

1) ‘Clean Fluids’ Pit or Turkeys nest
2) Blender Units *(one hydration blender and one down-hole blender)*
3) Proppant Storage Unit
4) High Pressure Pumps
5) Control or Data Acquisition Unit
6) Frac Tanks for water storage
7) Additional Pump Unit
8) Manifold Trailer
9) Lined Flare Pit or ‘Return Fluids’ Pit
10) Coiled Tubing equipment and associated equipment (if required: power pack, N_2 Unit, coil unit, crane, acid pump)

*Note: This figure shows a deep gas well set up for Coiled Tubing Assisted Annular Stimulation. Conventional oil or gas rig set up is similar (lacks items 10 above).

3.3.7 Stages of Stimulation

3.3.7.1 Stimulation Event Design

Stimulation events are individually designed in detail as part of the well completions design process described in Section 3.2. The design input parameters are described in that section.

Key to a successful and contained 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.

Design outcomes include:

- Equipment requirements based on expected treating pressures and pump rates;
- Stimulation fluid type and volumes required;
- Volumes of water required on location to be available for designed treatment;
- Proppant types and volumes required;
- Simulated hydraulic 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.

3.3.7.2 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 stimulated. 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 meter (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 stimulated in the well; efficiency and cost.

3.3.7.3 Pre-Treatment

In some formations, the initial breakdown can create significant near wellbore pressure (NWBP) drop and can be calculated from Minifrac results (Section 3.3.7.4). This can be caused by various conditions but can result in difficulties placing the proppant volumes and concentrations designed for. 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. Typical volumes of acid ahead of the main treatment are of the order of 1,000 to 1,500 L of acid. Any acid soluble materials, in the near wellbore area, are removed and an improved connection between the wellbore and the reservoir is created. However, acid pre-treatments are not routinely required, and many stimulation treatments are performed without pre-treatment. If stimulation is undertaken in deep gas reservoirs, a dilute acid is commonly used as a pre-stimulation 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 ‘well screen’ perforations, but prior to stimulation.

3.3.7.4 Minifrac

A Minifrac is a small volume injection of clean 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, frac 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.

3.3.7.5 Corrosion Inhibitor

Weak acids are corrosive to metals and the corrosion rate increases with higher temperatures. On any acid 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 downhole temperature conditions for a given period of time. Typical corrosion inhibitor concentrations used are 2% by volume or 20 L inhibitor per m^3 of acid blend.

The acid is mixed into a surface tank prior to pumping. The mixing procedure is controlled while mixing all the chemicals from bunded containers. The order of mixing is to add the fresh water to the tank, add the additives including the corrosion inhibitor and then the concentrated acid (32% hydrochloric acid, HCl). The total blend will be the required volume of acid at a concentration of 15% HCl. This acid blend is pumped directly into the well using a single high pressure pump.

3.3.7.6 Pad Volume Injection

The stimulation process is initiated by pumping a designed volume of the stimulation fluid without proppant, referred to as the “pad”. This fluid is carefully prepared using the equipment described in Section 3.3.6. 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 stimulation is a guar derivative (Figure 34) which is combined with bore water in the pre-gel blender, providing the base gel viscosity. Programmed and automated control systems are used to maintain the fluid properties during the pumping of the treatment. Fluid sampling occurs during the treatment to ensure that the fluid maintains the desired properties.

The purpose of the pad volume is to create the fracture area required to receive the designed proppant volume. Once the pad volume is pumped, and without shutting down the pumps, the proppant is added to the downhole blender and proportioned into the stimulation fluid. The concentration of proppant increases through each stage as designed within the stimulation simulator. The stimulation fluid with proppant is referred to as “slurry” and the proppant concentration is measured up to the maximum designed concentration in kg/m^3.

The pad fluid comprises a mix of water (typically 99.5% by volume) and is usually comprised of groundwater obtained from nearby water bores or formation water. A mix of water and guar gum, together with a number of additives such as crosslinkers, buffers, and breakers, make up the crosslinked stimulation fluid.

Figure 34: Example of a Typical Slurry Gum Constituent: Guar Gum

Illustrated in 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 stimulation. Source: Economides and Martin, 2007

The gum (Figure 35) is allowed to hydrate in a baffled tank, referred to as the Hydration Unit, for several minutes prior to being pumped to the downhole 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.

Subsequently, additives including cross-linkers, buffers, breakers, and surfactants are added at the downhole blender to provide a suitable fluid for transporting proppant into the hydraulic fracture.

At this point, the guar gum and associated ingredients comprise approximately 0.050% by volume of the pad volume. The viscosity of the crosslinked fluid will vary with time and temperature, but typical designs will provide a fluid with viscosities in the several hundreds of centipoise (Figure 35). This viscosity is required to propagate the fracture and to transport proppant well into the created fracture. Following the treatment, this fluid viscosity will break back to close to water viscosity due to added breakers and the bottom hole temperature.

Figure 35: 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 stimulation treatment is based on the design factors discussed in Section 3.2.2 and will vary depending on the reservoir. Typical Cooper Basin injection rates range from 15 bbl/min (2.4 m^3/min) to 35 bbl/min (5.6 m^3/min). Surface treating pressures can range from 5,000 psi (35,000 kPa) to 11,000 psi (76,000 kPa).

At the initial stage of injection, the pressure will increase until a breakdown of the formation occurs. This is evident by a drop in the injection pressure and signals that the stimulation 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.

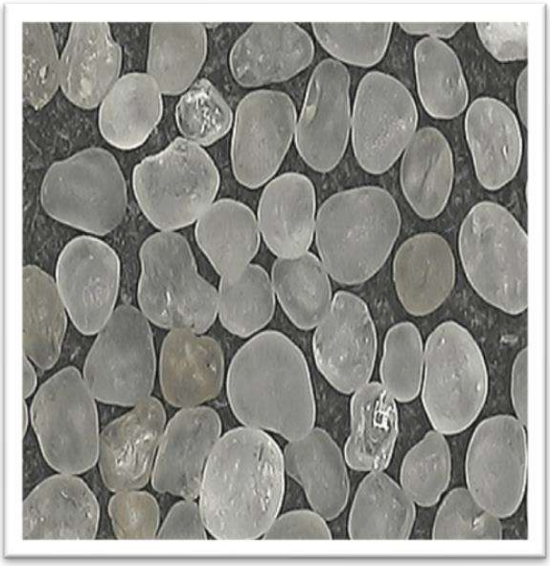
3.3.7.7 Slurry Volume Injection

Following the injection of the pad volume, the proppant stages are pumped according to the design. 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/m^3) to 8 lb/gal (1000 kg/m^3).

Proppants used in stimulation range from graded quartz sand to higher strength ceramic proppants (refer to Figure 36 and Figure 37). The strength of these materials increases based on the material, with ceramic being much stronger than quartz sand. Ceramic proppant is most often used in the Cooper Basin due to the high effective closure stresses. Proppant grain size varies and is also chosen based on the required conductivity for the specific fracture design. Each size and type of proppant has a number of specifications that must be met for consistency with API conditions.

Figure 36: (Left) Typical 20-40 Grade Sand used in Stimulation

Figure 37: (Right) 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 linear gel fluid (non-crosslinked) and 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 all proppant placed within the fracture. It is just as important not to over displace the proppant away from the wellbore. Once this flush or displacement volume has been pumped, the high pressure pumps are shut down and the main stimulation treatment is considered complete.

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 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. An unbroken fluid will restrict the ability for the fracture to clean up and hydrocarbon production will be impaired.

The duration of the stimulation treatment is dependent on the specified volumes to be pumped and the rate at which the treatment is pumped.

The above procedure is carried out for each target zone (pay zone) in the reservoir formations. In the case of Santos’ oil reservoirs, this typically equates to one target zone per well. In the case of gas reservoirs, the number of sands or fracture stages can range from 1 stage to 10 stages in a single well, depending on the reservoirs contacted during the drill.

A typical Cooper Basin stimulation treatment may use from 40,000 gallons (150 m^3) to 100,000 gallons (400 m^3) of water for the main stimulation treatment. The required volume is dependent on the size of the treatment required for the particular formation to be stimulated. The amounts of proppant required typically range from 40,000 lb (18 tonne) to 200,000 lb (90 tonne) and, again, is dependent on the specific formations being stimulated.

3.3.7.8 Flush Volume

As discussed above, a flush stage or displacement stage is pumped at the end of the treatment to ensure that all of 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 the wellbore to be cleaned out to enable production of the well.

3.3.7.9 Flowback

The fluid used to create the fracture and place the proppant will restrict the ability of the well to clean up and produce hydrocarbons. As 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 allowed to flowback to reduce the amount of leak off into the formation. Often recovered fluid volumes are in the range of 30% to 60% of the total volume pumped. This is usually enough to allow the well to flow on its own energy or with assistance from artificial lift.

Light condensate entrained in the flowback fluid is often removed with a vacuum truck and taken to a nearby oil facility. The clean-up of conventional oil zones is often bypassed due to the fact that artificial lift systems are installed as part of the final completions program. These lift systems include typical installation beam pumps which can lift both the oil and fluid out of the well.

Flowback fluids are removed from site and transported to and disposed to a dedicated flowback fluid pond located in Naccowlah.

After the well has been equipped with all the required completion and gathering equipment, the well is put on production. Production continues for the life of the well, with produced water (groundwater, condensation and frac fluid) over that period ranging less than 1 ML up to 30 ML for gas wells, increasing to a maximum of approximately 340 ML for oil wells. This flow is likely to flush all the available (mobile) components of the original stimulation fluid which may remain in the formation *after* flowback.

3.3.7.10 Stimulation Treatment Monitoring

As described in Section 3.3.4, the stimulation for each reservoir layer is modelled using an industry accepted stimulation simulator. Based on the final pumping schedule from the optimized 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 live from the Frac Van as well as at Santos' offices. The modelled pressures are compared with the actual pressures. The overall pressure response can provide useful information in evaluating the fracture growth and containment. A contained fracture will exhibit a pressure profile different from an uncontained fracture. The mechanical properties of the interbedded sandstones, shales coals mean that horizontal propagation of the fracture network dominates. Treatment parameters are used with the stimulation model, following the treatment, to achieve a history match and predict the actual fracture geometry.

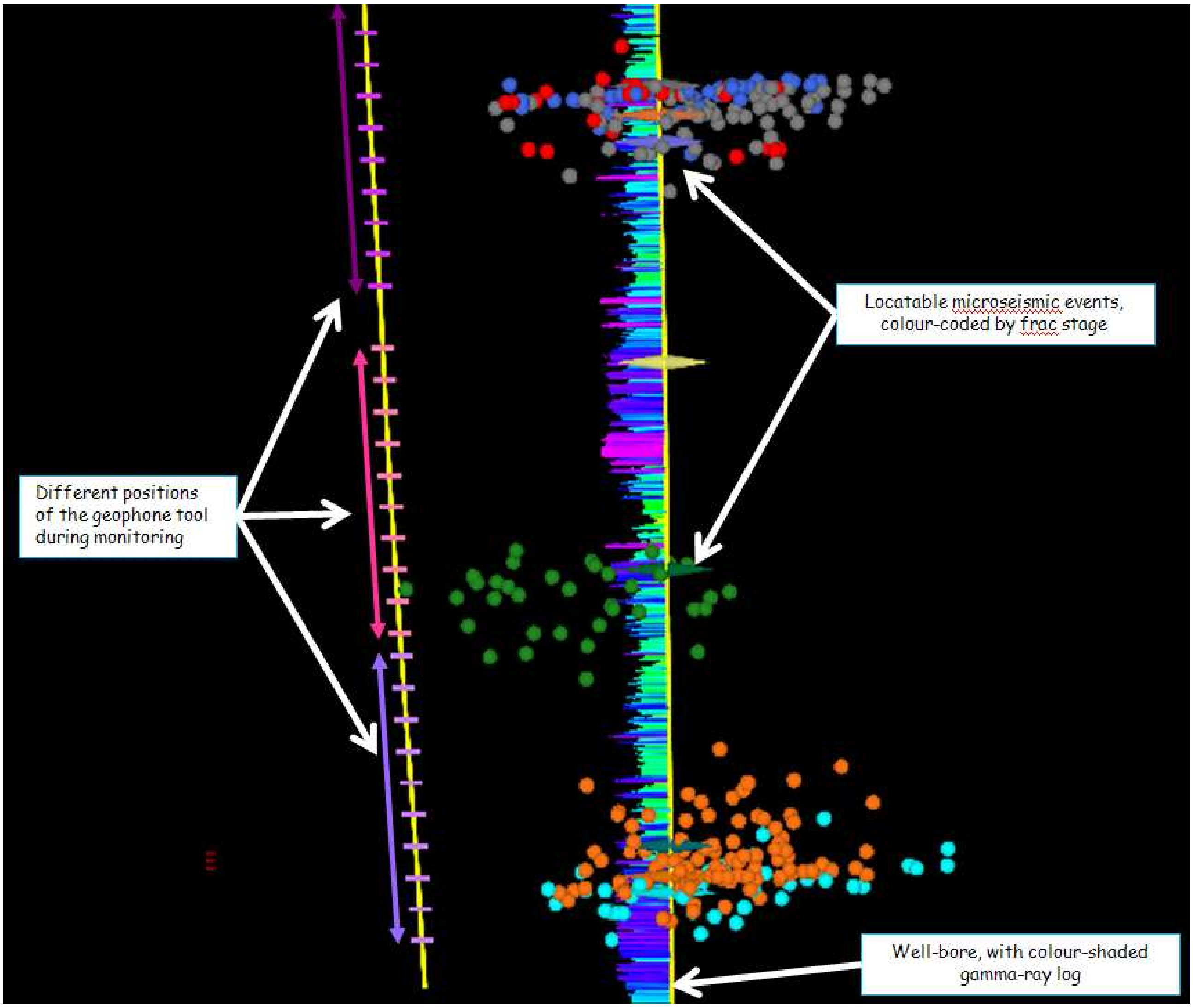
Live monitoring allows for potential problems (surface or downhole) to be identified and corrected quickly. In the event that a problem develops on the surface (e.g. leak in line, pumps shut down), the use of live monitoring as a control measure for early detection can prevent the problem from escalating. An example of live monitoring applied to downhole 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.

Santos has trialled in South Australia the use of advanced monitoring techniques such as micro-seismic monitoring, which can be used to evaluate fracture azimuth and fracture half length. This additional information can be used to further calibrate the stimulation model predictions. The additional cost of this technology precludes the use on every treatment and will be evaluated as the technology is better understood.

Microseismic monitoring involves the use of a string of sensitive receivers (“geophones”) in one or more nearby wells to detect and locate in 3D space the releases of energy associated with the propagation of the hydraulically-induced fractures. Figure 38 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 frac stage. The viewpoint for the figure is at approximately the same depth as the upper frac stages (shown in red, mid-blue and grey), and it can be seen that the fracture propagation is predominantly horizontal, with the coals being effective at confining the vertical propagation of the fractures. All of the locatable microseismic events for each frac stage were contained within the formation that was being stimulated. Figure 39 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 actual results show good agreement, although in practice the fractures seem to have propagated horizontally slightly less far than expected. The technique has limitations, in that it requires at least one pre-existing nearby well (within approximately 500 - 700 m) to use for the monitoring, and it is also expensive, meaning that the use of the technique is necessarily selective.

The use of radioactive tracers (as impregnated beads) involves incorporating a different short half-life radioactive isotope into the proppant slurry for each stage, and then monitoring for the distribution of each of these isotopes along the wellbore after the stimulation treatment. However, there are presently no plans to use radioactive materials in SWQ, should this alter Santos will comply with all applicable legislative requirements concerning their use, storage and disposal.

Figure 38: Lateral View of the Locatable Microseismic Events during Monitoring of Multi-Stage Fracture Stimulation of Cowralli-10 (SA)

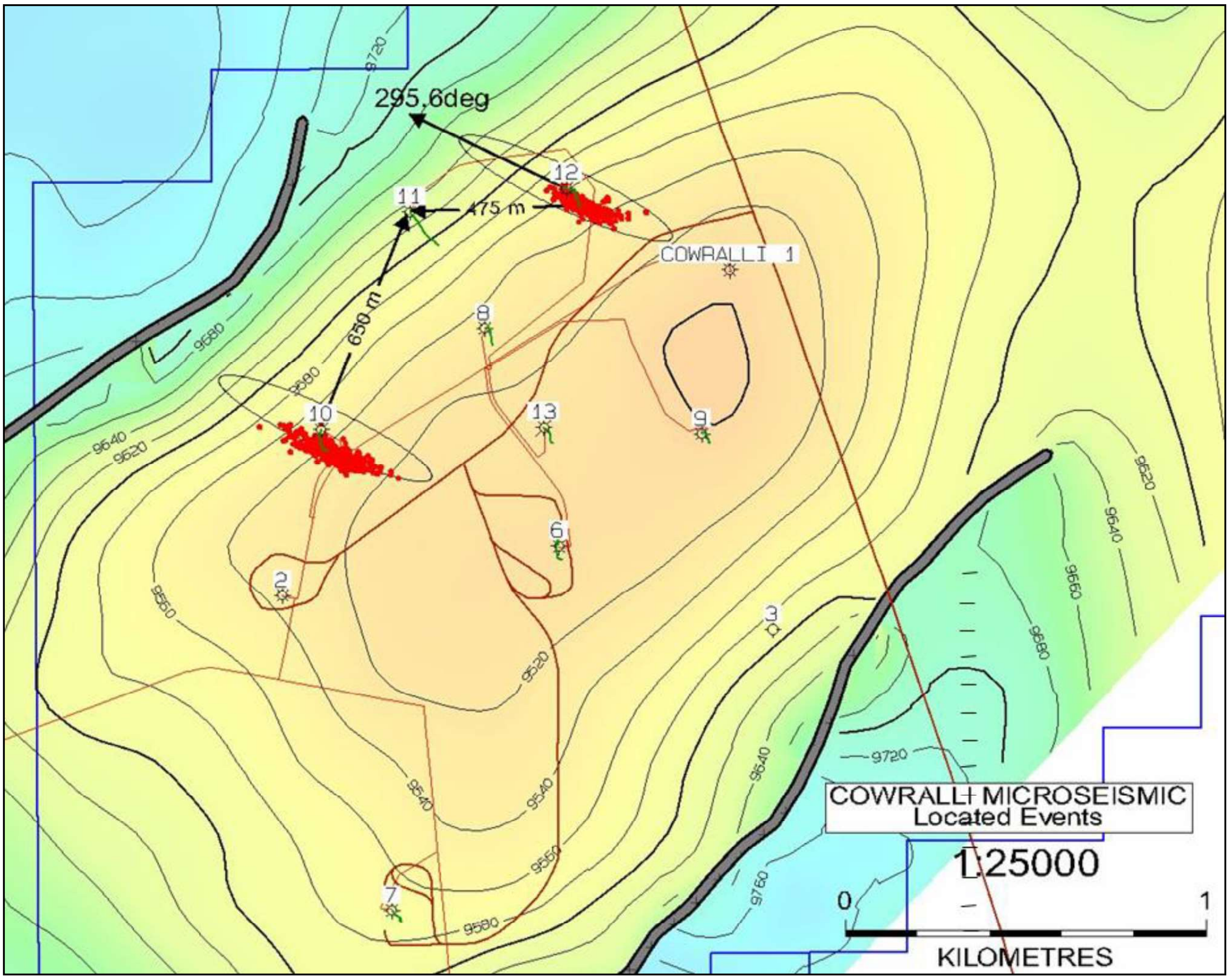


Locatable microseismic events, colour-coded by frac stage

Different positions of the geophone tool during monitoring

Well-bore, with colour-shaded gamma-ray log

Figure 39: Map View of the Locatable Microseismic Events During Monitoring of Multi-stage Fracture Stimulation of Cowralli-10 and Cowralli-12 (SA)



3.3.7.11 *Timing of Stimulation Process*

The stimulation of a typical conventional oil well takes two to three days to complete a treatment. The stimulation of a deep gas well with multiple stages can require anywhere from five to ten days to complete the stimulation operation. The flowback period can extend from three to ten days depending on the reservoir and clean up profile.

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

3.4 Program for Wells to be Stimulated

3.4.1 Frequency of Stimulation

Selected wells will be stimulated prior to being brought into production, involving the various tasks described previously. At the time of writing, Santos has indicated that approximately 67 wells are proposed for stimulation in SWQ. The potential wells scheduled for stimulation are expected to occur over the period 2020 to 2022. However, the program of wells is *indicative* only and prone to change.

During the life of the well, the formation may be re-stimulated at a later date, which would essentially be a repeat of the initial stimulation process.

3.4.2 Distribution of Completed and Scheduled Stimulation Locations

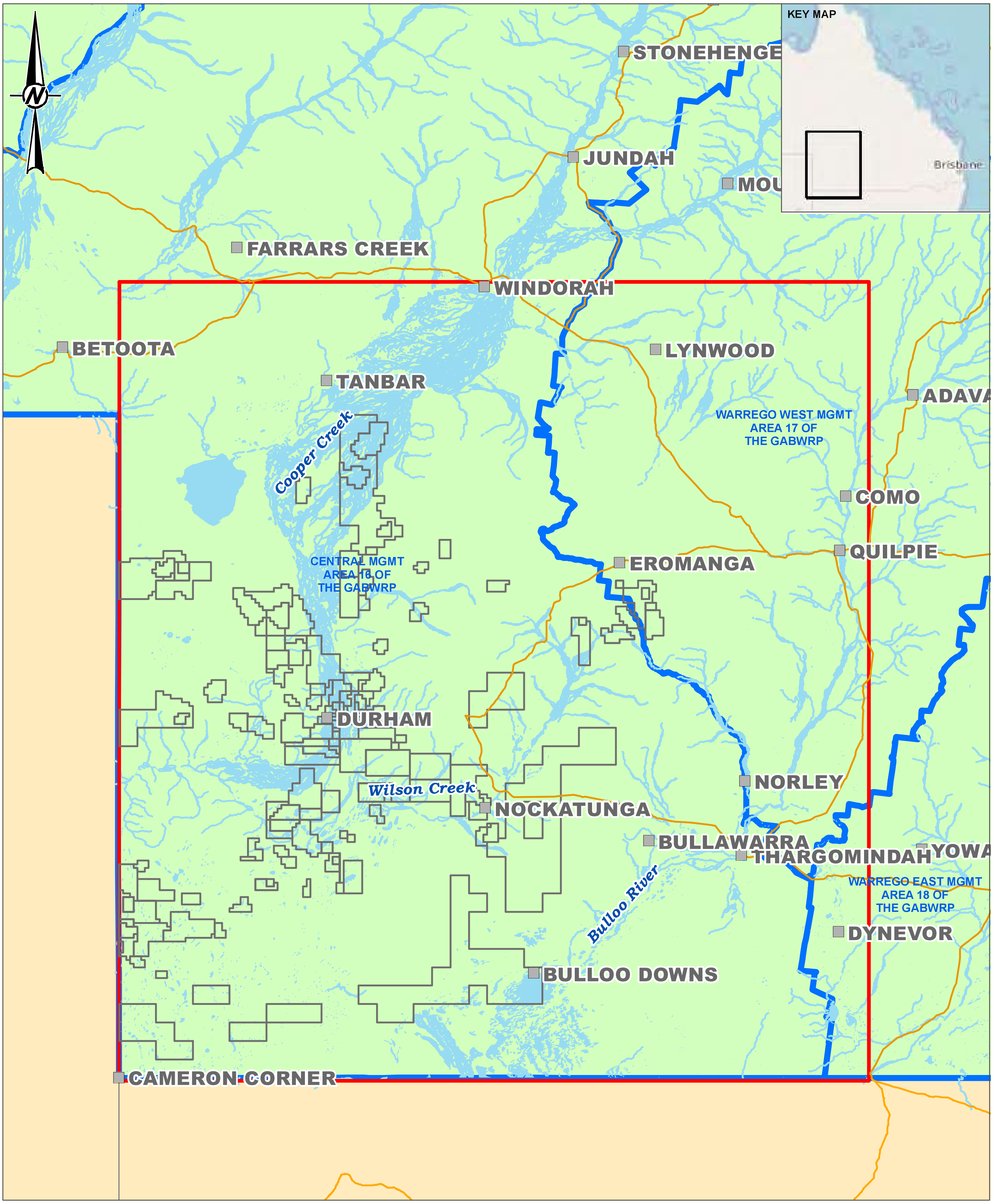
Oil and gas wells that have been stimulated to date are listed in Figure 40 and presented in APPENDIX E. Since 1987, a total of 376 wells have been stimulated in SWQ. Golder understands that have been no recorded incidents associated with these activities. Indicative wells that are scheduled for fracturing until 2022 are presented in APPENDIX F.

According to information provided by Santos, the well spacing varies between the oil and gas well heads, from 400 m in the oil fields, up to tens of kilometres in the gas fields. Santos is moving toward “Pad” wells, where multiple deviated wells emanate from a single wellsite. Proposed deviated gas wells for the Santos project are listed in APPENDIX E and include “DEV” in the well name. These are generally shown as clusters within tenements (e.g. Baryulah Gas, PL131).

It should be noted that for a variety of reasons (including but not limited to future production performance and access-related issues such as the flooding of the Cooper Creek system), the geographic distribution of the forward fracturing programme is frequently reviewed and is subject to change, although the overall number of fracture stimulations is likely to remain similar to that outlined here.

Queensland legislation regarding notice of intent and reporting of activities allows for flexibility to change the program of wells to be fractured. According to the Petroleum and Gas regulations, 2004 (PGGD-03, s35, and subsections s35A and S46A) the holder of a petroleum tenure must lodge a notice prior to activity commencement with the (now) Department of Natural Resources and Mines and Energy (DNRME, formerly Department of Natural Resources and Mines), followed by a notice of completion after activities have ended. These notices must be distributed to the landholder and land occupier. A detailed stimulation activities completion report must then be lodged no later than two months after activities have been carried out including a stimulation fluid statement and if any material environmental harm has occurred (relevant to the definitions of the EPA 1994).

Santos proposes to copy DES on the notification of stimulation operations on the same timescales as required by the above DNRME legislation. Adjustments to the locations or schedule of future stimulation activities will be managed in the context of the outcomes of this risk assessment.



LEGEND

● Historical Stimulation Locations

■ Town/Locality

— Highway/Major Road

— River/Creek

▭ Groundwater Management Area

☐ Santos Tenements

🟥 Study Area

0 KILOMETERS 100

1:2,750,000 GCS GDA 1994

NOTE(S)

REFERENCE(S)

1. BASE INFORMATION COPYRIGHT MAPINFO AUSTRALIA PTY LTD
2. ATP/PL TENURE SUPPLIED BY SANTOS, NOVEMBER 2019
3. GROUNDWATER MANAGEMENT AREA SOURCED DEPARTMENT OF NATURAL RESOURCES & WATER, QLD GOVERNMENT 2008

CLIENT

SANTOS

PROJECT

HYDRAULIC FRACTURING RISK ASSESSMENT – SANTOS SOUTHWEST QUEENSLAND TENEMENTS

TITLE

HISTORICAL HYDRAULIC FRACTURING LOCATIONS IN SW QLD

CONSULTANT

GOLDER

DD-MM-YYYY	19-03-2020
DESIGNED	KB
PREPARED	KB
REVIEWED	CB
APPROVED	CB

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3.5 Location of Landholders Active Bores

The locations of licensed water bores relative to the Santos tenement boundaries are discussed in Section 2.5.8 and are presented in Figure 40. The results of the WBBA completed (as of December 2012 (updated 2020), Section 2.5.8) identified eight active private bores and one additional bore being within potential impact zones. The vertical proximity of the target petroleum formations to aquifers utilised for private or commercial/industrial water supply is discussed in Section 2.6.

The proximity of the identified water supply bores to the proposed stimulation locations is presented in APPENDIX F and the distances are listed in Table 11 (refer to Sections 0 and 2.6.2 for the stratigraphic thickness ranges separating hydrocarbon-bearing formations from aquifers).

The active landholder bores in the oil fields in the east of the project range from approximately 3 to 10 km from the closest proposed oil well. The upper-most formation proposed for stimulation is the Wyandra Sandstone (Upper Cadna-Owie). The closest bore, Mt Margaret No 14, targets the shallower Winton formation for stock purposes. At this location the vertical separation between the Winton Formation and the Wyandra Sandstone is at least 750 m, including the low permeability mudstones of the Wallumbilla and Toolebuc Formation and the Allaru Mudstone (Section 0).

The active landholder bores within, or near, the gas fields in the west of the project range from approximately 25 to 90 km from the closest proposed stimulation location. The upper-most target proposed for stimulation are formations within the Nappamerri Group. The closest bore was the Whim Well however this well is not in operation. The Coothero Bore which targets the Hooray Sandstone for stock water is the closest operational bore. The Coothero Bore and is located more approximately 44 km from the closest proposed location for gas production, and more than 80 km from the closest location proposed for oil production from the Hooray Sandstone. The Coothero Bore is monitored by Santos as part of the UWIR monitoring program.

Table 11: Distance of Active Landholder Bores in the Study Area to the Closest Proposed Stimulation Location

Bore Name	DEHP RN	Distance	Target Aquifer
Mt Margaret No 14	9096	3 km	Winton Formation
Walla Wallan Bore 5	6373	5 km	(no data)
Mt Margaret No 20	10565	3 km	(no data)
Cherry Cherry Bore	6369	10 km	(no data)
Tarbat Job No 1947	12036	8 km	Winton Formation
Palara Bore	6057	12 km	(no data)
Grahams Bore	14955	87 km	Glendower Formation
Moon Road Field Bore	0**	81 km	-**
Coothero Bore*	23569	44 km	Hooray Sandstone

* Potentially within the impact zone as described in Section 2.5.8

** Bore not observed in database records. Referred to as "Moon Field Road Bore" in WBBA.

4.0 CONCLUSIONS

4.1 Environmental Setting

Santos operates conventional gas and oil fields across petroleum tenements within an approximately 30,000 km^2 portion of Southwest Queensland. The operations are divided into three sub-areas of interest: *Western, Central* and *Eastern Project Areas*. At the time of preparation of this report the three project areas were no longer in effect, with the project area (Figure 1) now referred to as "SWQ". The terrain in the study area is generally characterised by low undulating topography (hills and ridges) between the drainage channel systems of the Cooper Creek. The area is sparsely developed, and generally comprises rural communities and homesteads that are largely engaged in pastoralism.

It is within the stratigraphy that comprises the Eromanga Basin and the underlying Cooper Basin that oil and gas reservoirs are located which contain the proposed target formations for hydraulic fracturing. A detailed description of key geological and hydrogeological features is provided in the text, including geological models for the study area, target hydrocarbon-bearing sandstone formations (oil in the Eromanga Basin formations at depths ranging from 700 to 1,200 m below ground level (mbgl); and gas in the Cooper Basin formations at depths of 1,500 to greater than 2,000 mbgl), their hydraulic characteristics, adjacent aquifers and aquitards, structural features including faults and fracture characteristics (and their potential to behave as barriers or conduits), regional and local seismicity characteristics, aquifer environmental values and the location of groundwater users.

In terms of the environmental setting, this stimulation risk assessment (SRA) document has provided specific information which addresses the requirements anticipated of the EA conditions regarding stimulation that will apply to new areas proposed for production.

This version of the SRA updates a 2012 version (127666004-011-R-Rev0, December 2012). Updated content includes reference to the updated Environment Authority (EA) Blueprint conditions (December, 2019), updated tenements (as of January 2020), historical well stimulation events and potential future stimulation dates. Background information, such as the geological setting, hydrogeology, environmental values and stimulation process, etc has not changed in this version of the HFRA.

Specific inclusions addressing consent conditions are located within the logical flow of the description of the existing environment in the Santos SWQ petroleum field areas, with the specific information located as follows:

- a geological model of the field to be stimulated including geological names, descriptions and depths of the target producing reservoir(s) (Sections 2.4 and 0);
- naturally occurring geological faults (Sections 2.4.3.5 and 2.4.5);
- seismic history of the region (e.g. earth tremors, earthquakes) (Section 2.4.5);
- proximity of overlying and underlying aquifers (Section 2.6);
- description of the depths that aquifers with environmental value(s) occur, both above and below the target producing reservoir (Section 2.6);
- description of overlying and underlying formations in respect of porosity, permeability, hydraulic conductivity, faulting and fracture propensity (Sections 2.4.4 and 2.5.5);
- consideration of barriers or known direct connections between the target producing formation and the overlying and underlying aquifers (Section 0);
- the environmental values of groundwater in the area (Section 2.6);
- locations of landholders' active groundwater bores (Section 2.5.7); and
- groundwater transmissivity**,** flow rate, hydraulic conductivity and direction(s) of flow (Sections 2.5.3, 2.5.4 and 2.5.5);

Based on understanding of the environmental setting, this qualitative risk assessment considered the key environmental values as follows:

Groundwater environmental values:

- Town water supply;
- Stock and domestic water supply;
- Sandstone aquifers of the GAB; and
- Groundwater Dependant Ecosystems (GDEs).

Surface water environmental values:

- Protection of aquatic ecosystems;
- Recreation and aesthetics: primary recreation with direct contact, and visual appreciation with no contact; and
- Cultural and spiritual values.

Terrestrial environmental values:

- Protection of flora and fauna, particularly small mammals, reptiles and birds.

The report considered the applicable environmental values in the context of the proposed fracturing activities within the study area.

4.2 Stimulation Process Description

A detailed description of the stimulation process was provided in Section 3.0; with an emphasis on the safeguards inherent in the planning and implementation of fracturing events to ensure that the stimulation fluid and proppant are delivered (and maintained) within the target formation. The specific information required in the EA consent conditions can be found in the following sections:

- practices and procedures to ensure that the stimulation activity(ies) is designed to be contained within the target gas producing formation (Sections 3.3.4 and 3.3.7);
- provide details of where, when and how often stimulation is to be undertaken on the tenures covered by this environmental authority (Section 3.4);
- a description of the well mechanical integrity testing program (Section 3.2.2);
- process control and assessment techniques to be applied for determining extent of stimulation activity(ies) (e.g. microseismic measurements, radioactive tracers, modelling etc.) (Sections 3.3.4 and 3.3.7); and
- a process description of the stimulation activity to be applied, including equipment and a comparison to best international practice (Sections 3.2.1 and 3.3).

4.3 Summary

Based on the available geological information for the study area, the following key points are noted:

- The DEHP database and the interim results of the WBBA program indicate that groundwater supply development in the vicinity of Santos' tenements is limited to the Glendower and Winton Formations, and to a lesser extent the Hooray Sandstone. The minimum vertical offset between the Glendowner and Winton Formations and the shallowest hydrocarbon reservoirs (oil reservoirs of the Cadna-Owie Formation) is 400 to 800 m, which includes the low permeability formations of the Wallumbilla Formation and Allaru Mudstone, which form a thick, competent and regionally extensive seal between the Cadna-Owie Formation and the shallower aquifers. The vertical offset to gas reservious is much greater (1,000 m to 1,800 m).

- Within formations that host both aquifers and hydrocarbon reservoirs (e.g. Hooray Sandstone), the water-bearing zones are separated from hydrocarbon reservoirs by intra-formational seals. However, there is not enough information available to discretise the internal stratigraphy of these formations. Where petroleum activities (including fracturing) occur within a formation that hosts both aquifers and hydrocarbon reservoirs, the lateral distance of the water supply bores accessing the aquifer to Santos' tenements was considered.
- The closest beneficial use bore to the Santos tenements targeting the Hooray Sandstone in the DEHP database records is the Coothero Bore, is at least 25 km from the closest tenement proposed for stimulation and more than 80 km from the closest tenement with activities proposed at a similar.

Based on the available site setting information for the study area, the following key points are noted:

- Cooper Creek is largely influenced by surface water flows and evaporation, with negligible contribution from groundwater. Waterholes and billabongs occur throughout the Cooper Creek floodplain and channel complex, some of which coincide directly with Santos tenements.
- Three of the identified wetlands (Cooper Creek – Wilson River Junction, Bulloo Lake and Cooper Creek Swamps – Nappa Merri) are within boundaries of Santos' tenements. It should be noted that hydraulic fracturing activities may be completed within any tenement boundary over the life of the Project.
- The Cooper Creek catchment and downstream Lake Eyre are popular recreational fishing destinations. Popular fishing spots include Bulloo River at Thargomindah, Wilson River at Nockatunga and Cooper Creek flows (episodically).

Based on the provided Santos stimulation process information, the following key points are noted:

- Buffers to are assigned during establishment of well leases between petroleum operations and potential "environmentally sensitive areas" identified though database review and site-specific ecological assessment where warranted.
- 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.
- 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 robust surveillance plan.
- OH&S procedures are implemented during stimulation operations to prevent workers from direct contact with chemicals during spills and when handling flowback water or sediments. Golder understands that there has not been a recordable spill since hydraulic fracturing commenced in 1987.
- Santos operational procedures monitor fracture design to stay within the target formation.
- Santos implement spill containment procedures during operations to prevent migration of and exposure to chemicals.

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Signature Page

Golder Associates Pty Ltd

APPENDIX A

Limitations

The document ("Report") to which this page is attached and which this page forms a part of, has been issued by Golder Associates Pty Ltd ("Golder") subject to the important limitations and other qualifications set out below.

This Report constitutes or is part of services ("Services") provided by Golder to its client ("Client") under and subject to a contract between Golder and its Client ("Contract"). The contents of this page are not intended to and do not alter Golder's obligations (including any limits on those obligations) to its Client under the Contract.

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This Report has been prepared in the context of the circumstances and purposes referred to in, or derived from, the Contract and Golder accepts no responsibility for use of the Report, in whole or in part, in any other context or circumstance or for any other purpose.

The scope of Golder's Services and the period of time they relate to are determined by the Contract and are subject to restrictions and limitations set out in the Contract. If a service or other work is not expressly referred to in this Report, do not assume that it has been provided or performed. If a matter is not addressed in this Report, do not assume that any determination has been made by Golder in regards to it.

At any location relevant to the Services conditions may exist which were not detected by Golder, in particular due to the specific scope of the investigation Golder has been engaged to undertake. Conditions can only be verified at the exact location of any tests undertaken. Variations in conditions may occur between tested locations and there may be conditions which have not been revealed by the investigation and which have not therefore been taken into account in this Report.

Golder accepts no responsibility for and makes no representation as to the accuracy or completeness of the information provided to it by or on behalf of the Client or sourced from any third party. Golder has assumed that such information is correct unless otherwise stated and no responsibility is accepted by Golder for incomplete or inaccurate data supplied by its Client or any other person for whom Golder is not responsible. Golder has not taken account of matters that may have existed when the Report was prepared but which were only later disclosed to Golder.

Having regard to the matters referred to in the previous paragraphs on this page in particular, carrying out the Services has allowed Golder to form no more than an opinion as to the actual conditions at any relevant location. That opinion is necessarily constrained by the extent of the information collected by Golder or otherwise made available to Golder. Further, the passage of time may affect the accuracy, applicability or usefulness of the opinions, assessments or other information in this Report. This Report is based upon the information and other circumstances that existed and were known to Golder when the Services were performed and this Report was prepared. Golder has not considered the effect of any possible future developments including physical changes to any relevant location or changes to any laws or regulations relevant to such location.

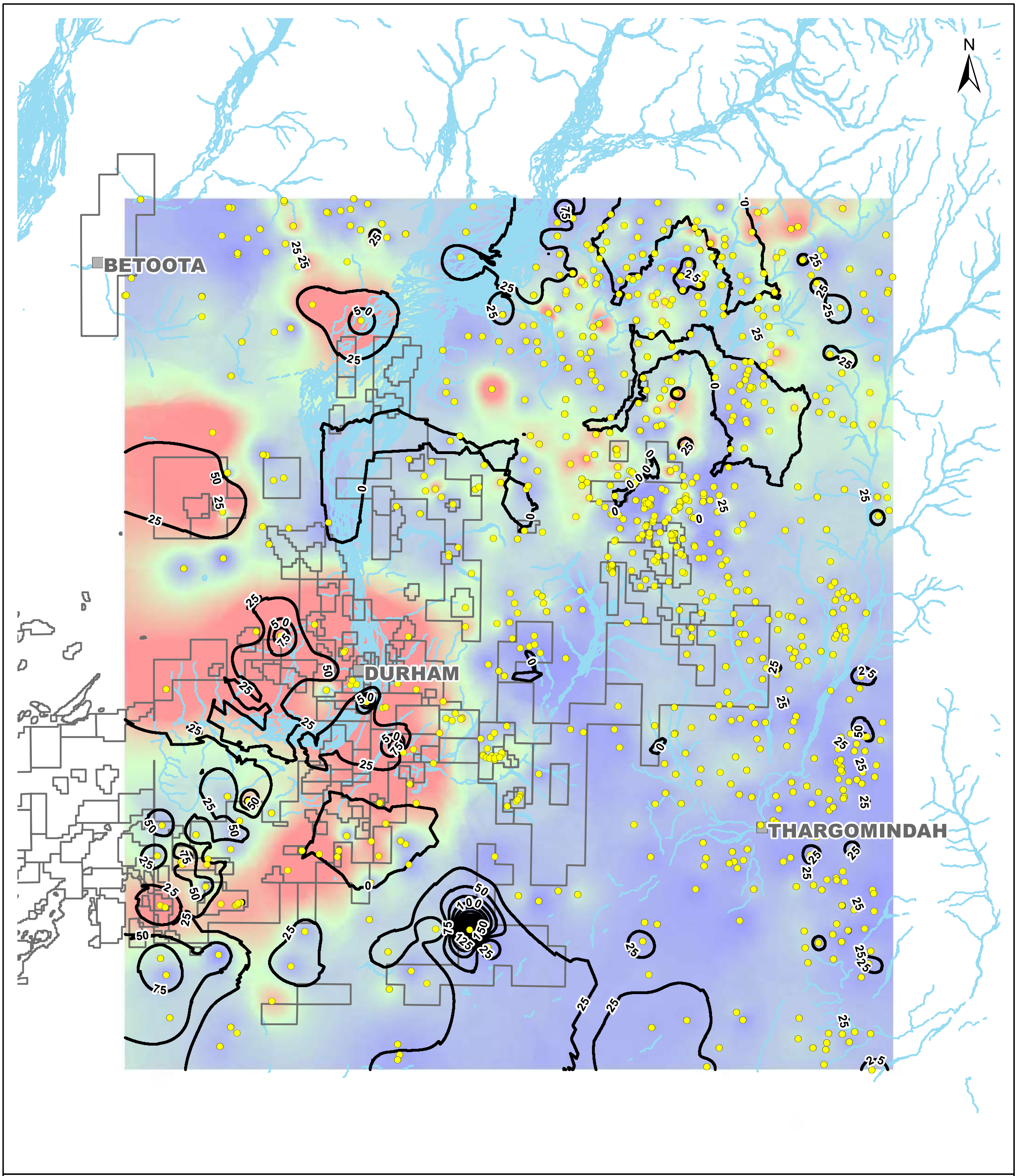
Where permitted by the Contract, Golder may have retained subconsultants affiliated with Golder to provide some or all of the Services. However, it is Golder which remains solely responsible for the Services and there is no legal recourse against any of Golder's affiliated companies or the employees, officers or directors of any of them.

By date, or revision, the Report supersedes any prior report or other document issued by Golder dealing with any matter that is addressed in the Report.

Any uncertainty as to the extent to which this Report can be used or relied upon in any respect should be referred to Golder for clarification

APPENDIX B

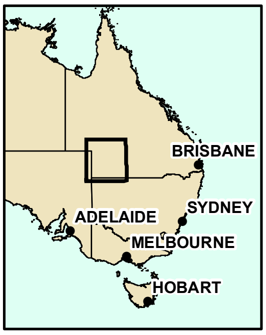
Geological Contour Plans



SWQ HYDRAULIC FRACTURING RISK ASSESSMENT

SANTOS

GEOLOGICAL CONTOUR MAP: WINTON FORMATION



LEGEND

- ● Geology Data Point
- ■ Town/Locality
- — Depth to Winton Formation (m)
- — River/Creek
- ☐ Santos Operated Permits

Thickness of Winton Formation (m)

High : 970

Low : 1

0 5 10 20 30 40 50 Kilometres

SCALE (at A3) **1:2,500,000**

Coordinate System: GCS GDA 1994

PROJECT:	**127666004**
DATE:	**27/09/2012**
DRAWN:	**FA**
CHECKED:	**RS**

APPENDIX C1

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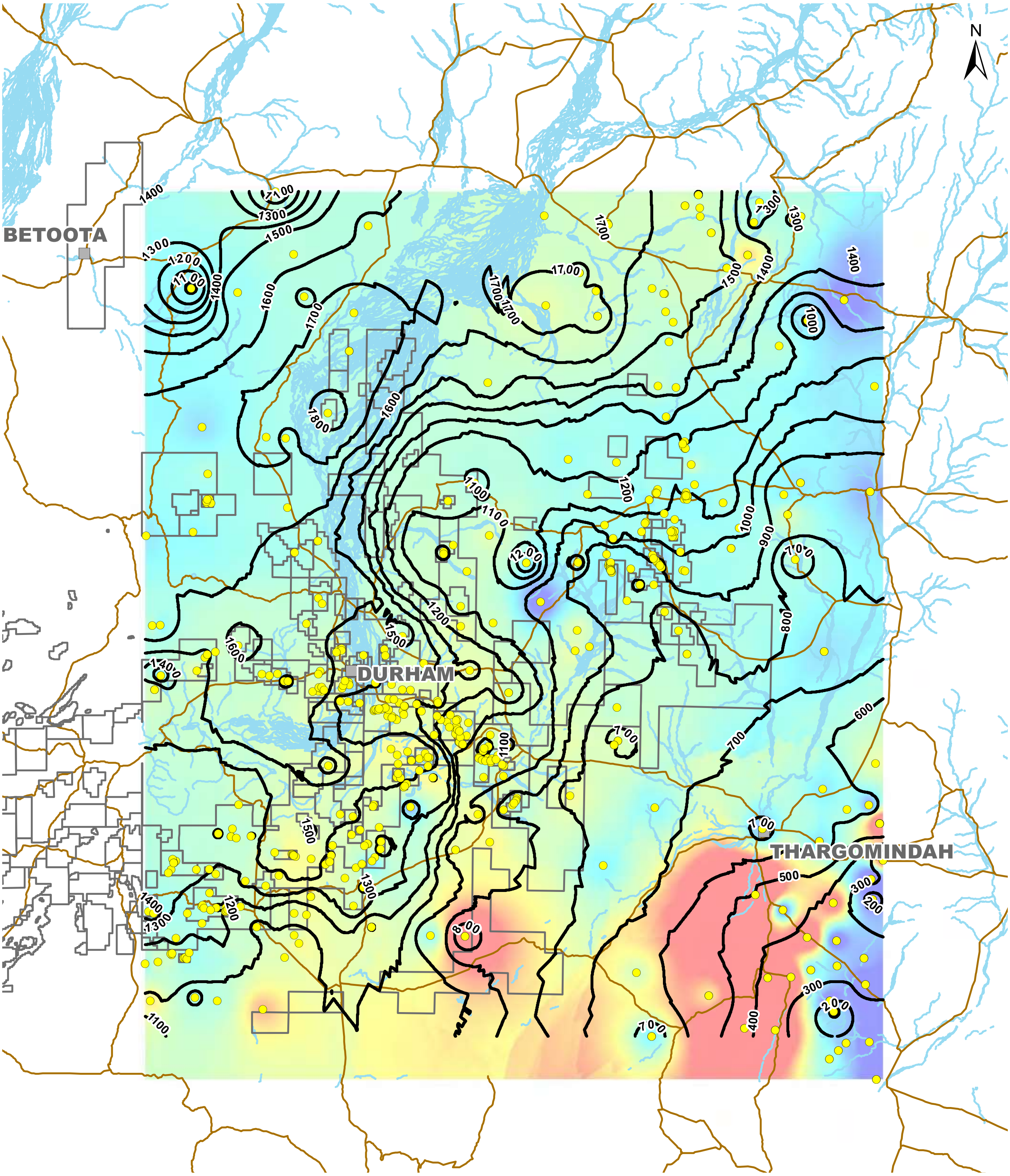
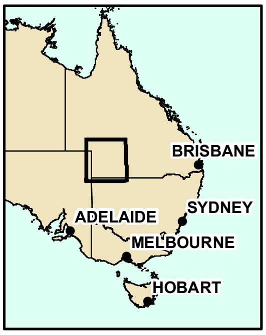


SWQ HYDRAULIC FRACTURING
RISK ASSESSMENT

SANTOS

GEOLOGICAL CONTOUR MAP: HOORAY FORMATION



LEGEND

- ● Geology Data Point
- ■ Town/Locality
- — Depth to Hooray Sandstone (m)
- — Highway / Major Road
- — River/Creek
- ☐ Santos Operated Permits

Thickness of Hooray Sandstone (m)

High : 595

Low : 1.8

0 5 10 20 30 40 50 Kilometres

SCALE (at A3) **1:2,500,000**

Coordinate System: GCS GDA 1994

PROJECT: **127666004**
DATE: **27/09/2012**
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APPENDIX C2

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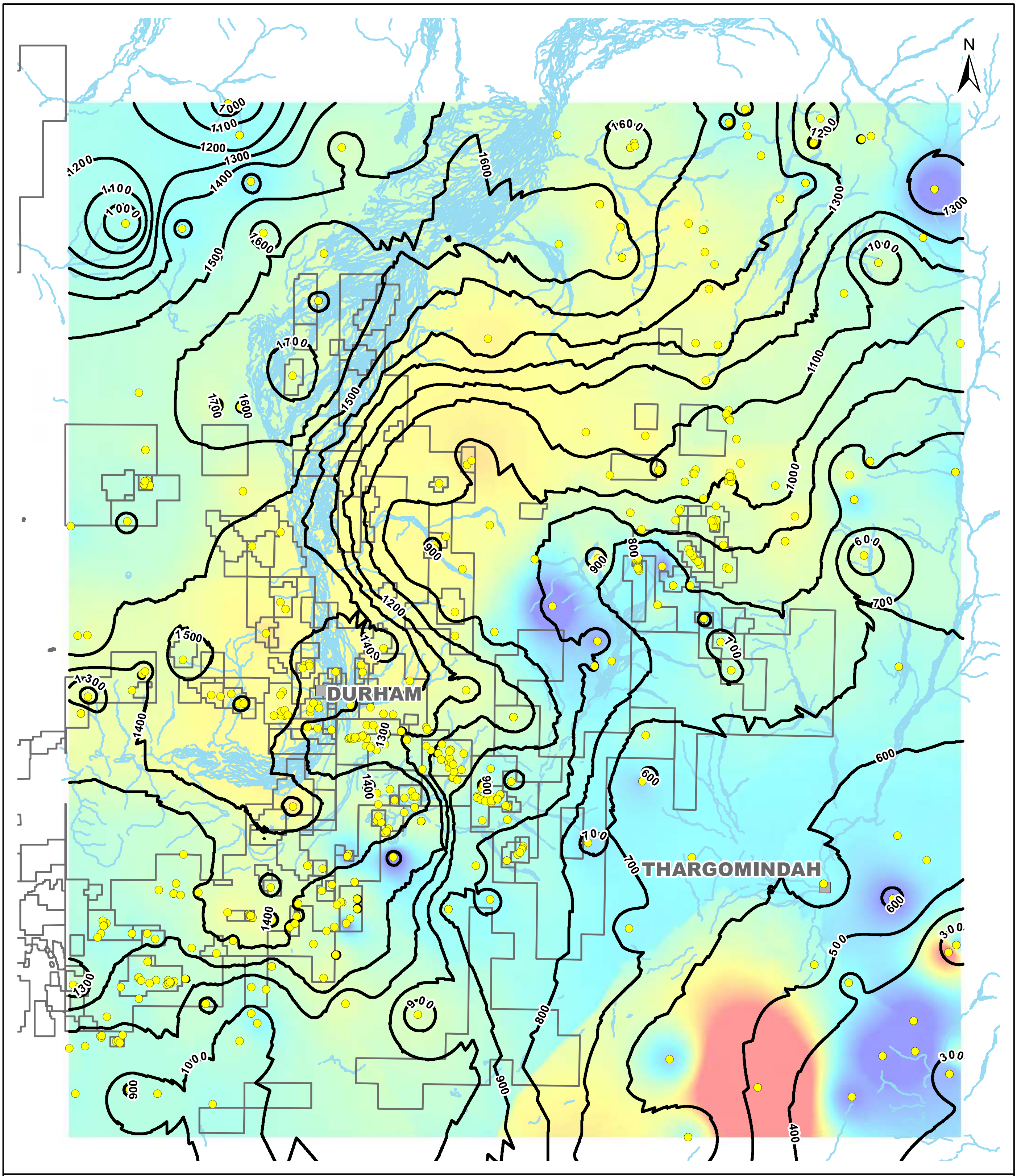
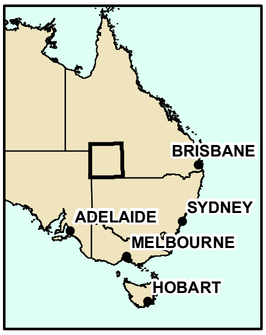


SWQ HYDRAULIC FRACTURING
RISK ASSESSMENT

SANTOS

GEOLOGICAL CONTOUR MAP: CADNA OWIE FORMATION



LEGEND

●	Geology Data Point
■	Town/Locality
—	Depth to Cadna Owie (m)
—	River/Creek
☐	Santos Operated Permits

Thickness of Cadna Owie Formation (m)

High : 390

Low : 18

0 5 10 20 30 40 50 Kilometres

SCALE (at A3) **1:2,000,000**

Coordinate System: GCS GDA 1994

PROJECT:	**127666004**
DATE:	**27/09/2012**
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CHECKED:	**RS**

APPENDIX C3

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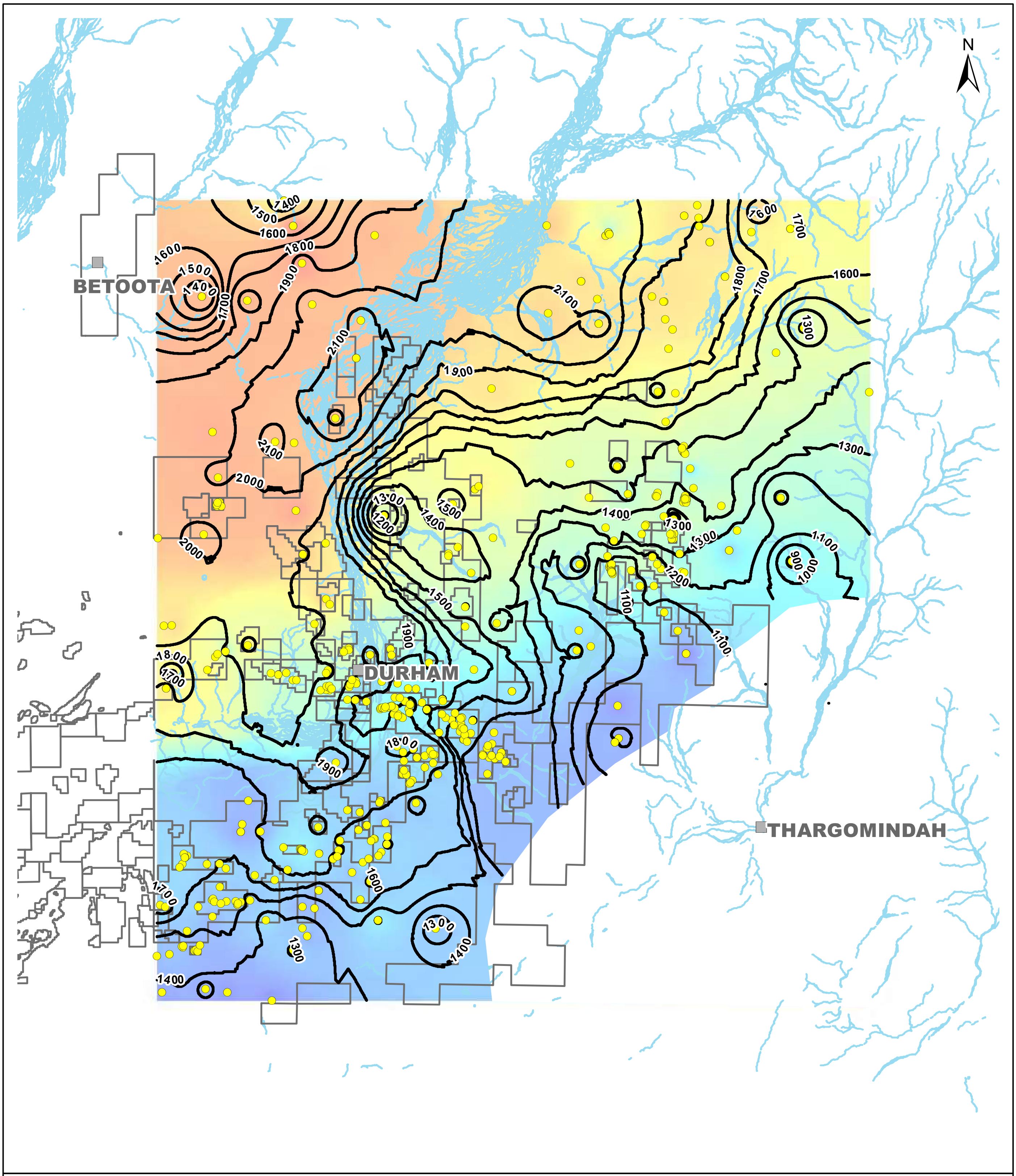

SWQ HYDRAULIC FRACTURING RISK ASSESSMENT

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GEOLOGICAL CONTOUR MAP: HUTTON SANDSTONE

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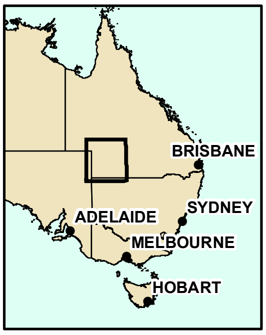

LEGEND

●	Geology Data Point
■	Town/Locality
—	Depth to Hutton Sandstone (m)
—	River/Creek
☐	Santos Operated Permits

Thickness of Hutton Sandstone (m)

High : 241

Low : 2.

DRAFT

0 5 10 20 30 40 50 Kilometres

SCALE (at A3) **1:2,500,000**

Coordinate System: GCS GDA 1994

PROJECT: **127666004**
DATE: **27/09/2012**
DRAWN: **FA**
CHECKED: **RS**

APPENDIX C4

GOLDER

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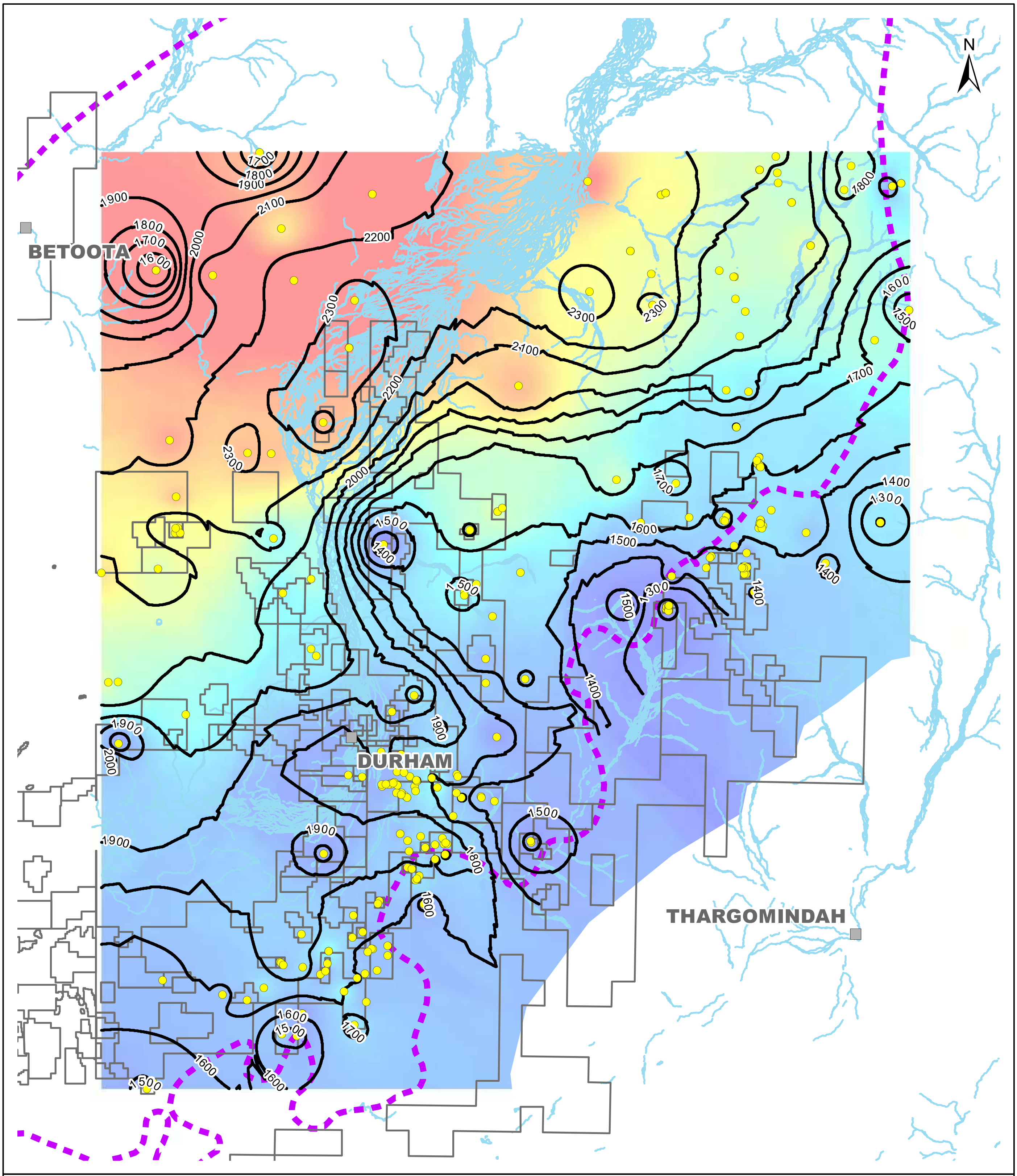

SWQ HYDRAULIC FRACTURING
RISK ASSESSMENT

SANTOS

GEOLOGICAL CONTOUR MAP: POOLOWANNA FORMATION

LEGEND

● Geological Data Point

■ Town/Locality

— Depth to Poolowanna Formation (m)

— River/Creek

☐ Santos Operated Permits

▭ Cooper Basin

Thickness of Poolowanna Formation (m)

170

3

0 5 10 20 30 40 50 Kilometres

SCALE (at A3) **1:2,000,000**

Coordinate System: GCS GDA 1994

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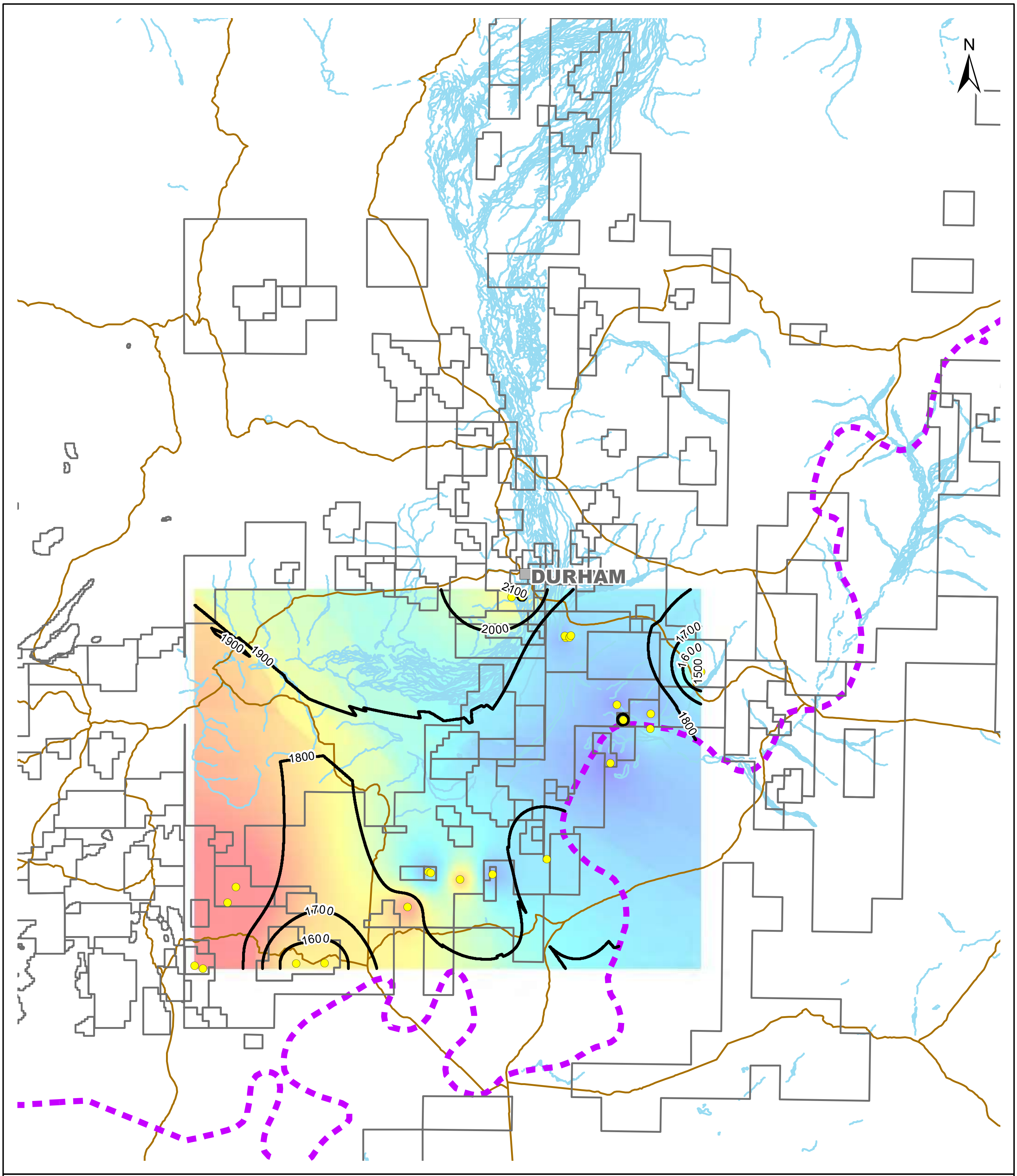

SWQ HYDRAULIC FRACTURING
RISK ASSESSMENT

SANTOS

GEOLOGICAL CONTOUR MAP: TOOLACHEE FORMATION

LEGEND

- ● Geology Data Point
- ■ Town/Locality
- — Depth to Toolachee Formation (m)
- — Highway / Major Road
- — River/Creek
- ☐ Santos Operated Permits
- ┅ Cooper Basin

Thickness of Toolachee Formation (m)

160

7

0 5 10 20 30 40 50 Kilometres

SCALE (at A3) **1:1,500,000**

Coordinate System: GCS GDA 1994

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APPENDIX C6

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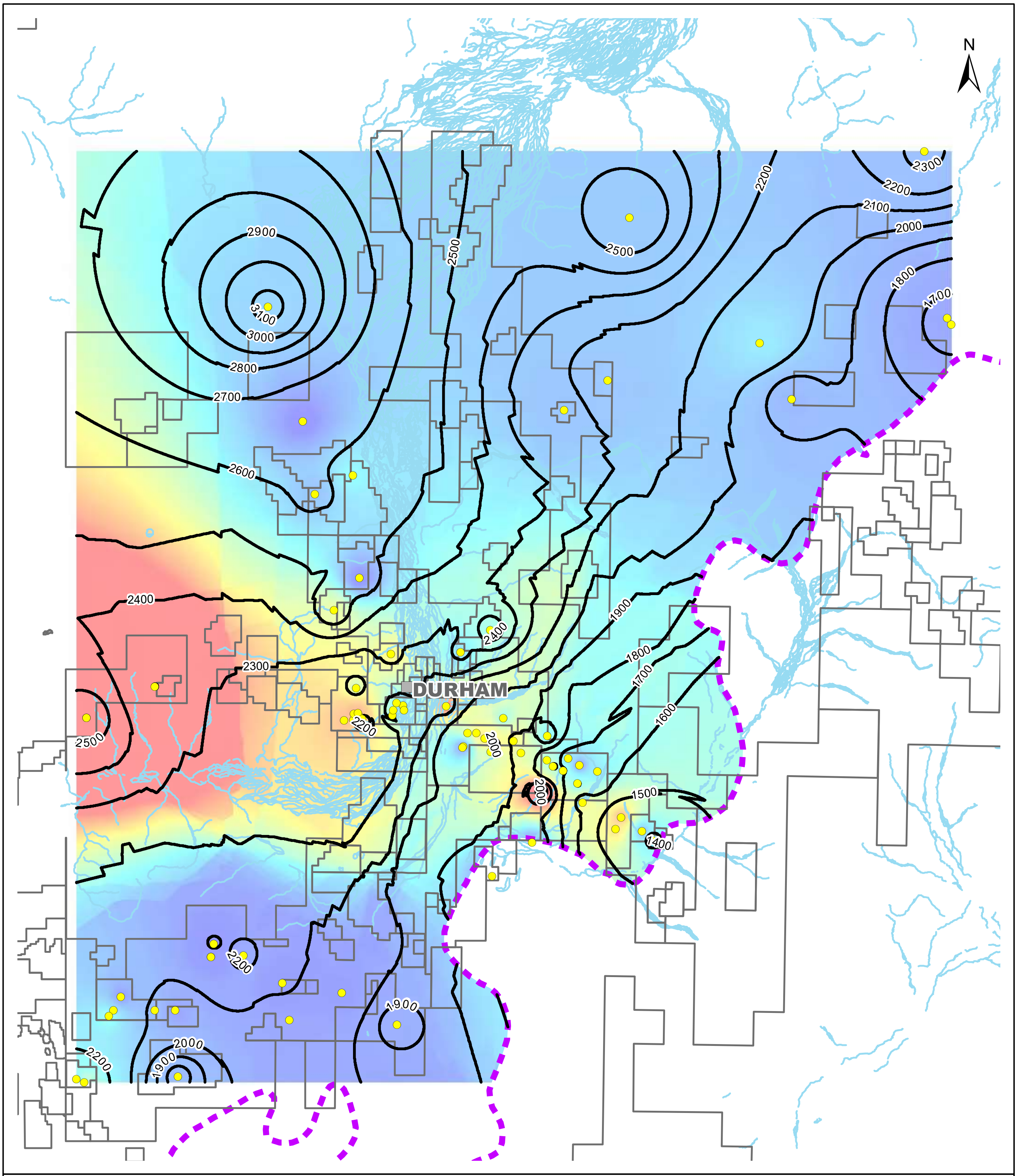

SWQ HYDRAULIC FRACTURING RISK
ASSESSMENT

SANTOS

GEOLOGICAL CONTOUR MAP: PATCHAWARRA FORMATION

LEGEND

- ● Geology Data Point
- ■ Town/Locality
- — Depth to Patchawarra Formation (m)
- — River/Creek
- ☐ Santos Operated Permits
- ▭ Cooper Basin

Thickness of Patchawarra Formation (m)

745

Low : 7.5

0 5 10 20 30 40 50 Kilometres

SCALE (at A3) **1:1,500,000**

Coordinate System: GCS GDA 1994

PROJECT:	**127666004**
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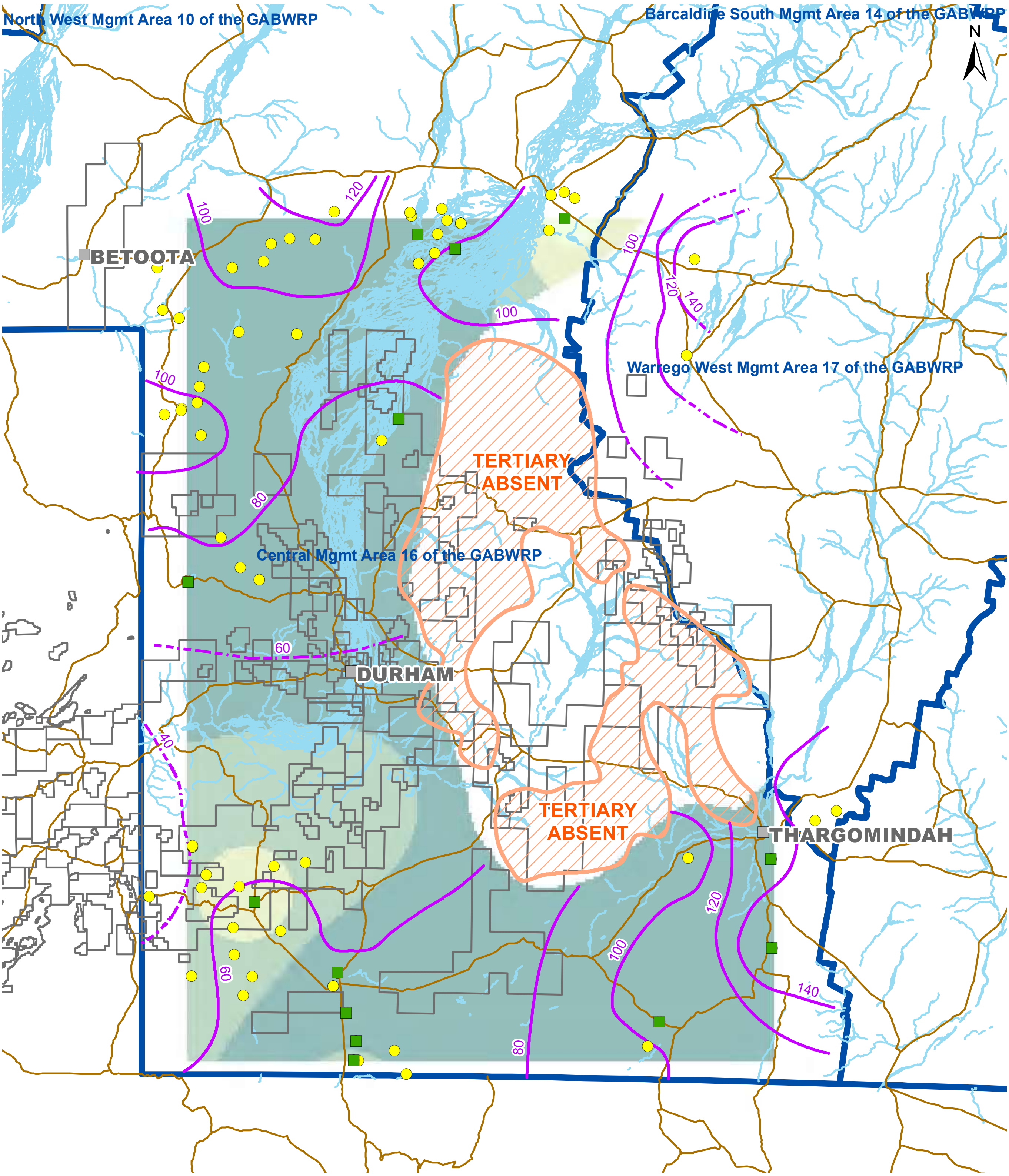
APPENDIX C

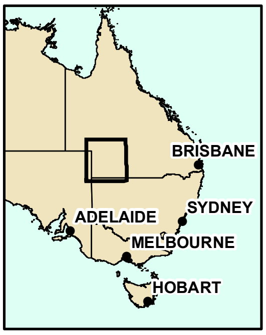
Hydrogeological Contour Plans



SWQ HYDRAULIC FRACTURING RISK ASSESSMENT

SANTOS

HYDROGEOLOGICAL MAP: TERTIARY FORMATION



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LEGEND

- ■ Town/Locality
- 🟩 Water Level and Electrical Conductivity Data Point
- ● Water Level Data Point
- Piezometric Isoline (mAHD) 20 m Interval
- Inferred Piezometric Isoline (mAHD) 20 m Interval
- Highway / Major Road
- River/Creek
- ☐ Santos Operated Permits
- ☐ Groundwater Management Area

Electrical Conductivity (µS/cm)

- ▨ 0 - 3000
- ▨ 3,000 - 4,500
- ▨ 4,500 - 6,000
- ▨ 6,000 - 7,500
- ▨ 7,500 - 9000

0 5 10 20 30 40 50 Kilometres

SCALE (at A3) **1:2,500,000**

Coordinate System: GCS GDA 1994

PROJECT: **127666004**
DATE: **27/09/2012**
DRAWN: **FA**
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APPENDIX D1

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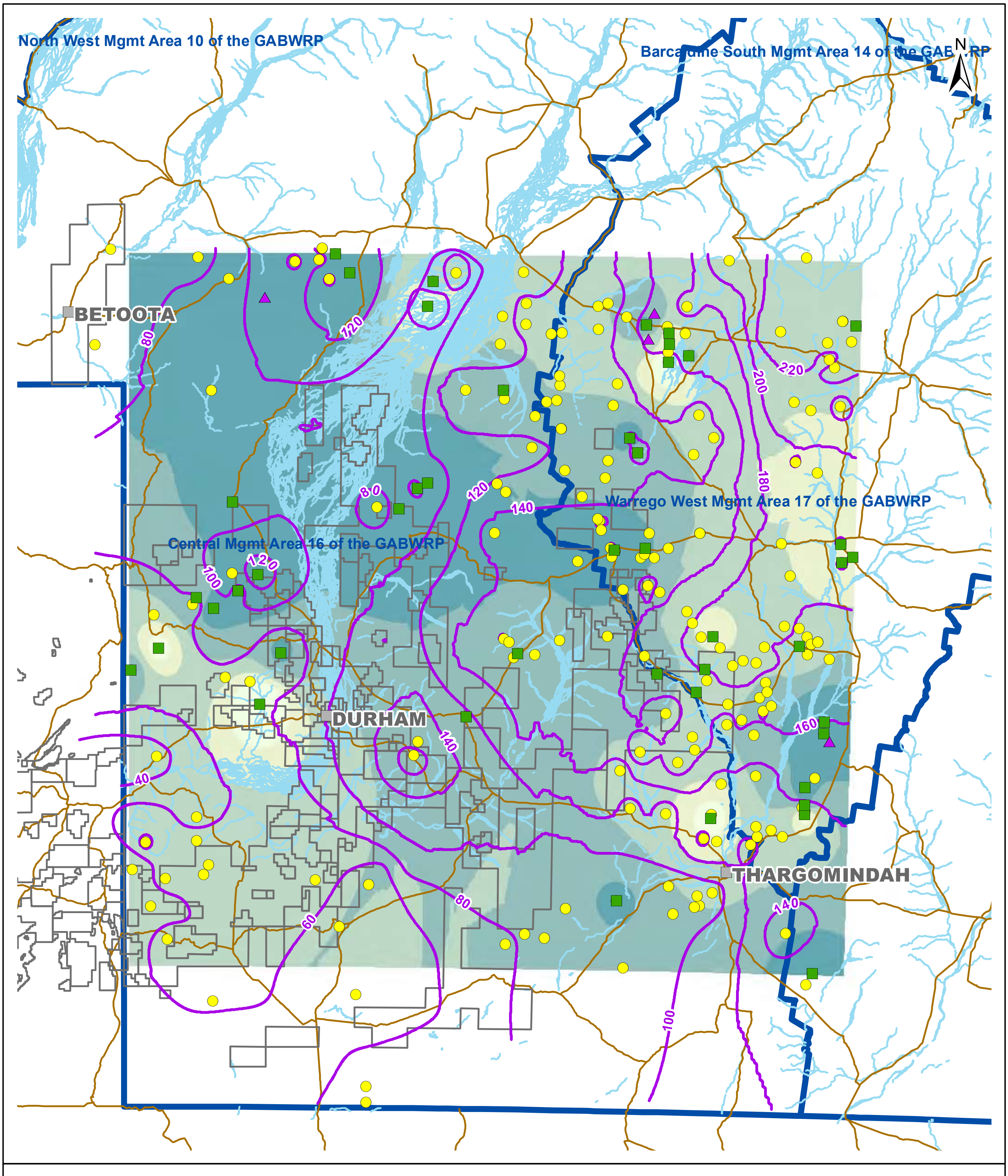
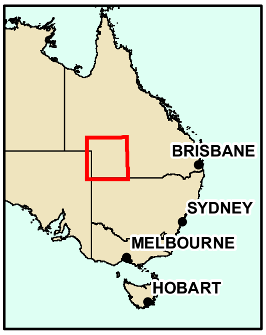


SWQ HYDRAULIC FRACTURING RISK ASSESSMENT

SANTOS

HYDROGEOLOGICAL MAP: WINTON FORMATION



LEGEND

- ■ Town/Locality
- 🟩 Water Level and Electrical Conductivity Data Point
- ▲ Electrical Conductivity Data Point
- ● Water Level Data Point
- ━ Inferred Piezometric Isoline (m AHD) 20 m interval
- ━ River/Creek
- ━ Highway / Major Road
- ☐ Santos Operated Permits
- ▭ Groundwater Management Area

Electrical Conductivity (µS/cm)

- ▨ 0 - 3,000
- ▨ 3,000 - 4,500
- ▨ 4,500 - 6,000
- ▨ 6,000 - 7,500
- ▨ 7,500 - 15000

0 5 10 20 30 40 50 Kilometres

SCALE (at A3) **1:2,500,000**

Coordinate System: GCS GDA 1994

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APPENDIX D2

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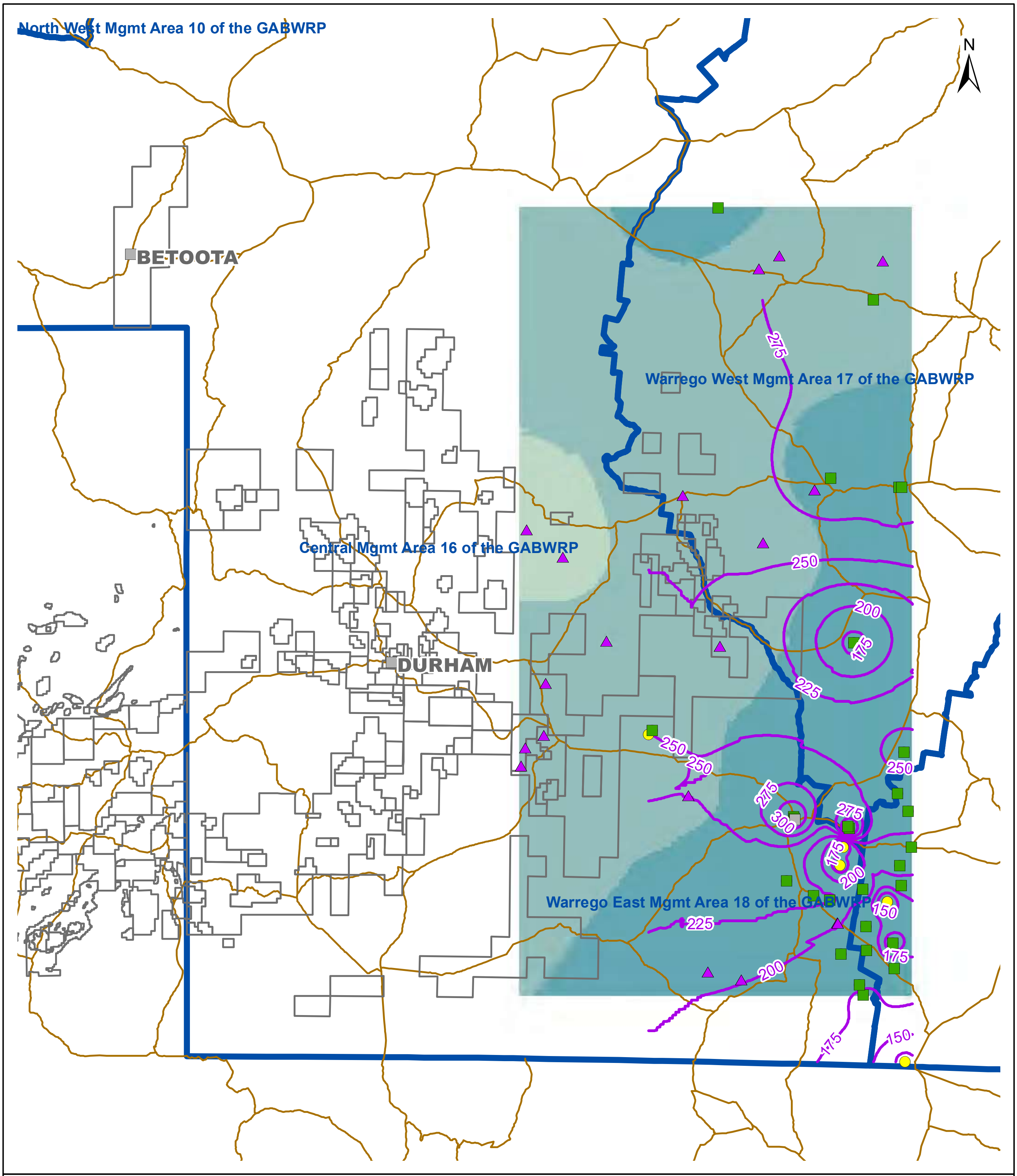
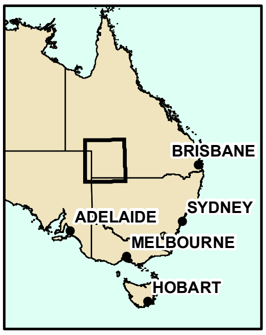


SWQ HYDRAULIC FRACTURING
RISK ASSESSMENT

SANTOS

HYDROGEOLOGICAL MAP: HOORAY SANDSTONE



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LEGEND

■	Town/Locality
🟩	Water Level and Electrical Conductivity Data Point
▲	Electrical Conductivity Data Point
●	Water Level Data Point
—	Inferred Piezometric Isoline (metres AHD - Interval 25 metres)
—	Highway / Major Road
☐	Santos Operated Permits
▭	Groundwater Management Area

Electrical Conductivity (µS/cm)

▨	0 - 1,500
▨	1,500 - 3,000
▨	3,000 - 4,500

0 5 10 20 30 40 50 Kilometres

SCALE (at A3) **1:2,500,000**

Coordinate System: GCS GDA 1994

PROJECT: **127666004**
DATE: **27/09/2012**
DRAWN: **FA**
CHECKED: **RS**

APPENDIX D3

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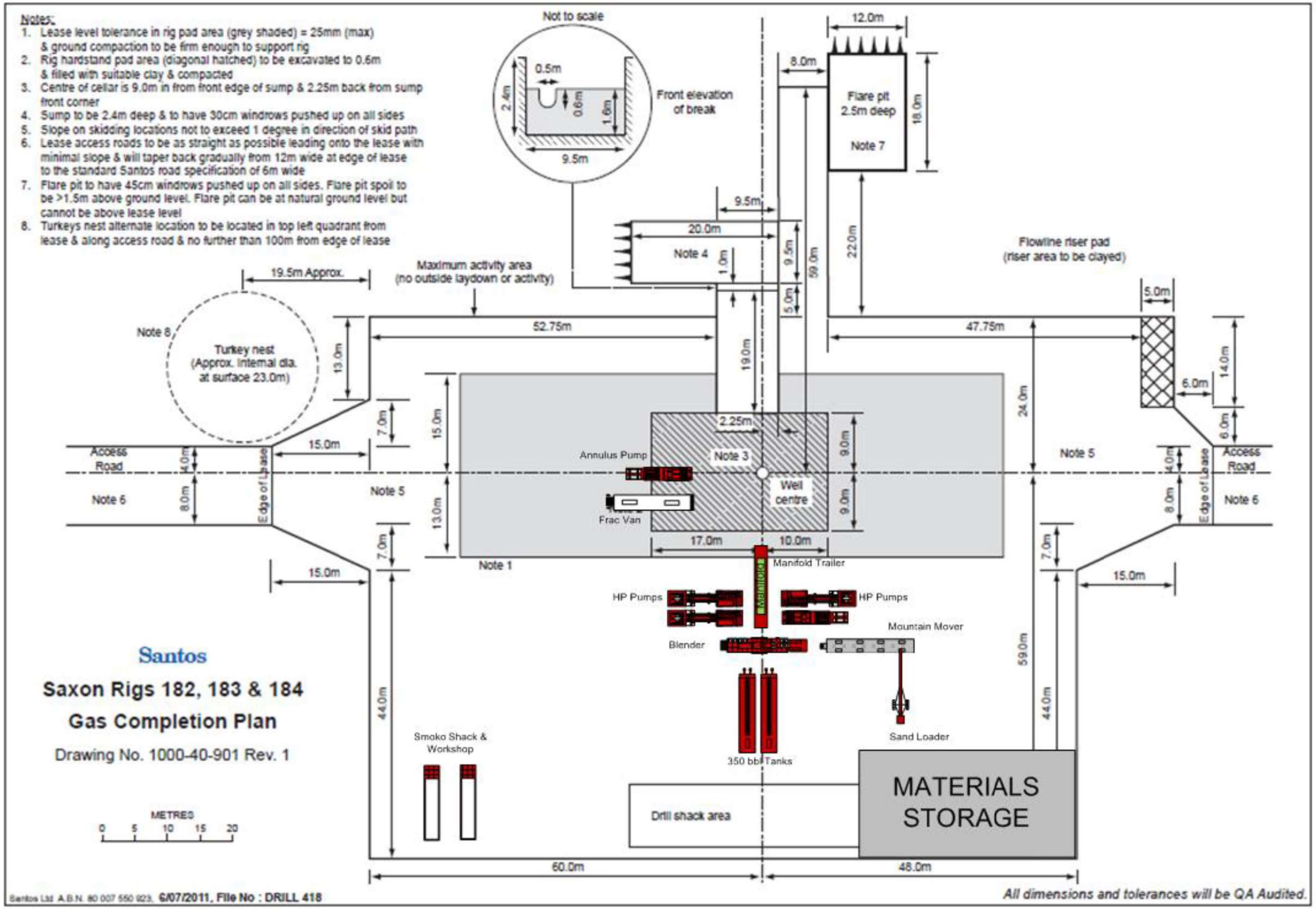
APPENDIX D

Santos Hydraulic Stimulation - Schematic Well Lease Setup

Figure D1: Conventional Oil Well Lease Set-up (Batch Mixing)



Notes:

1. Lease level tolerance in rig pad area (grey shaded) = 25mm (max) & ground compaction to be firm enough to support rig
2. Rig hardstand pad area (diagonal hatched) to be excavated to 0.6m & filled with suitable clay & compacted
3. Centre of cellar is 9.0m in from front edge of sump & 2.25m back from sump front corner
4. Sump to be 2.4m deep & to have 30cm windrows pushed up on all sides
5. Slope on skidding locations not to exceed 1 degree in direction of skid path
6. Lease access roads to be as straight as possible leading onto the lease with minimal slope & will taper back gradually from 12m wide at edge of lease to the standard Santos road specification of 6m wide
7. Flare pit to have 45cm windrows pushed up on all sides. Flare pit spoil to be >1.5m above ground level. Flare pit can be at natural ground level but cannot be above lease level
8. Turkeys nest alternate location to be located in top left quadrant from lease & along access road & no further than 100m from edge of lease

Santos

Saxon Rigs 182, 183 & 184

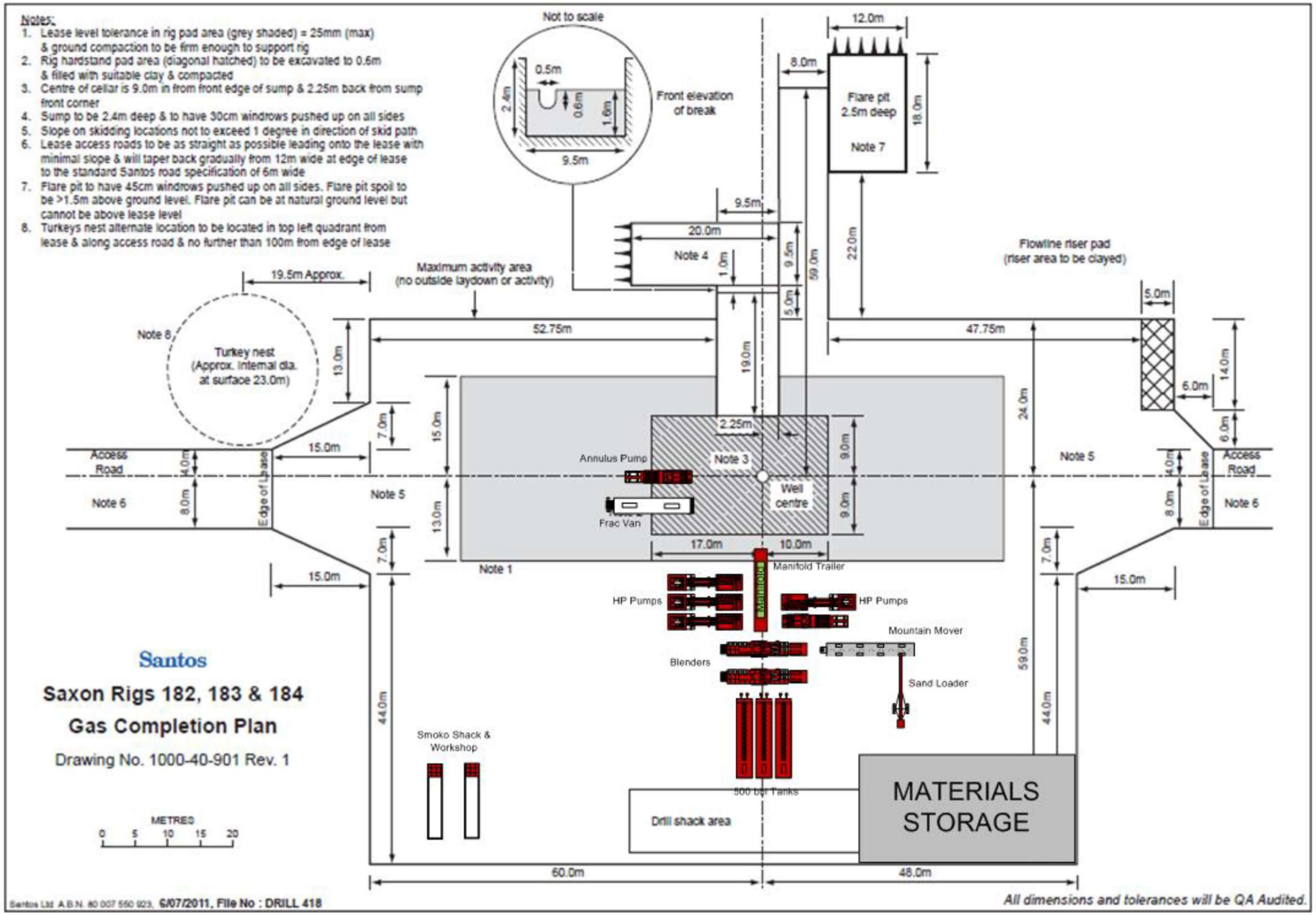
Gas Completion Plan

Drawing No. 1000-40-901 Rev. 1

Santos Ltd A.B.N. 80 007 550 923, 6/07/2011, File No : DRILL 418

All dimensions and tolerances will be QA Audited.

Figure D2: Conventional Gas Well Lease Set Up



Notes:

1. Lease level tolerance in rig pad area (grey shaded) = 25mm (max) & ground compaction to be firm enough to support rig
2. Rig hardstand pad area (diagonal hatched) to be excavated to 0.6m & filled with suitable clay & compacted
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4. Sump to be 2.4m deep & to have 30cm windrows pushed up on all sides
5. Slope on skidding locations not to exceed 1 degree in direction of skid path
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7. Flare pit to have 45cm windrows pushed up on all sides. Flare pit spoil to be >1.5m above ground level. Flare pit can be at natural ground level but cannot be above lease level
8. Turkeys nest alternate location to be located in top left quadrant from lease & along access road & no further than 100m from edge of lease

Santos

Saxon Rigs 182, 183 & 184

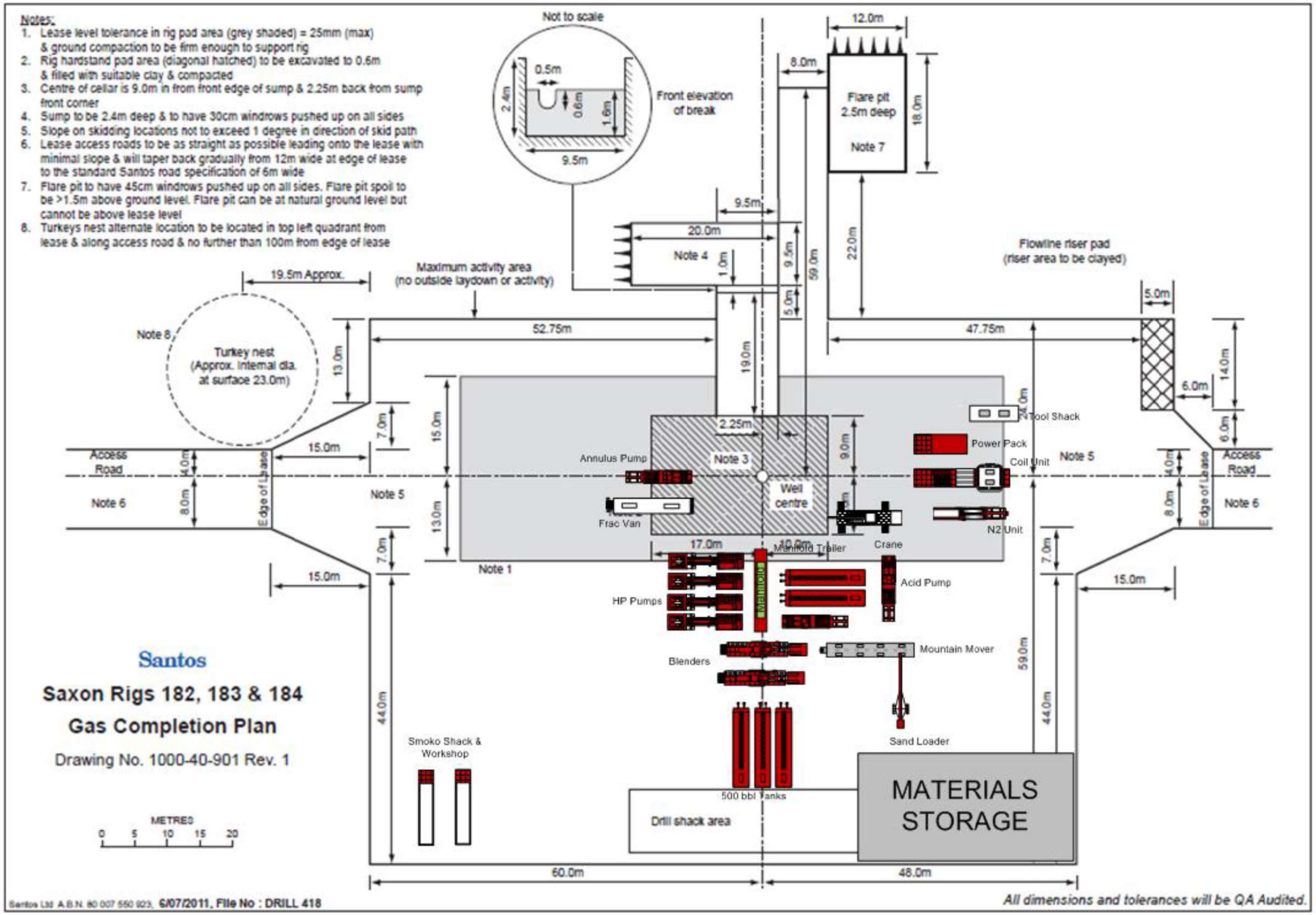
Gas Completion Plan

Drawing No. 1000-40-901 Rev. 1

Santos Ltd A.B.N. 80 007 550 923, 6/07/2011, File No : DRILL 418

All dimensions and tolerances will be QA Audited.

Figure D3: Deep Gas Well Lease Set Up (Coil Tubing Assisted Stimulation)



Notes:

1. Lease level tolerance in rig pad area (grey shaded) = 25mm (max) & ground compaction to be firm enough to support rig
2. Rig hardstand pad area (diagonal hatched) to be excavated to 0.6m & filled with suitable clay & compacted
3. Centre of cellar is 9.0m in from front edge of sump & 2.25m back from sump front corner
4. Sump to be 2.4m deep & to have 30cm windrows pushed up on all sides
5. Slope on skidding locations not to exceed 1 degree in direction of skid path
6. Lease access roads to be as straight as possible leading onto the lease with minimal slope & will taper back gradually from 12m wide at edge of lease to the standard Santos road specification of 6m wide
7. Flare pit to have 45cm windrows pushed up on all sides. Flare pit spoil to be >1.5m above ground level. Flare pit can be at natural ground level but cannot be above lease level
8. Turkeys nest alternate location to be located in top left quadrant from lease & along access road & no further than 100m from edge of lease

Santos

Saxon Rigs 182, 183 & 184

Gas Completion Plan

Drawing No. 1000-40-901 Rev. 1

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All dimensions and tolerances will be QA Audited.

APPENDIX E

Historical Well Hydraulic Stimulations in SWQ

Appendix E - Historical Well Hydraulic Fracturing Events in SW Queensland

Name	Latitude	Longitude	Date Fractured
Challum 1	-27.393	141.574	Sep-1987
Brumby 2	-28.381	140.959	Jun-1989
Wilson 4	-27.566	142.426	Jul-1989
Brumby 1	-28.409	140.991	Aug-1991
Epsilon 2	-28.142	141.133	Dec-1991
Epsilon 1	-28.145	141.154	Apr-1992
Thungo 2	-27.735	142.577	Jan-1993
Patroclus 1	-28.111	141.681	Dec-1994
Stokes 1	-28.345	141.029	Mar-1997
Yanda 8	-27.452	141.821	Jun-1997
Challum 3	-27.388	141.537	Oct-1998
Coolah 2	-26.956	141.835	Nov-1998
Challum 13	-27.373	141.571	May-1999
Wolgolla 2	-28.193	141.334	May-2002
Dartmoor 1	-27.687	142.540	Sep-2002
Thungo 7	-27.722	142.582	Sep-2002
Juno 5	-27.697	141.829	Oct-2002
Thungo 7	-27.722	142.582	Oct-2002
Juno 5	-27.697	141.829	Oct-2002
Juno 2	-27.688	141.829	Oct-2002
Juno 5	-27.697	141.829	Oct-2002
Coonaberry 1	-26.851	142.104	Oct-2002
Ramses 1	-26.764	142.102	Nov-2002
Moon 1	-28.227	141.042	Nov-2002
Ipundu North 2	-26.911	143.307	Jan-2004
Talgeberry 2	-26.948	143.430	Jan-2004
Talgeberry 8	-26.952	143.432	Jan-2004
Challum 24	-27.381	141.598	Jan-2004
Challum 22	-27.408	141.650	Jan-2004
Karmona 3	-27.304	141.883	Jan-2004
Ipundu North 11	-26.917	143.310	Jan-2004
Ipundu North 11	-26.917	143.310	Jan-2004

Name	Latitude	Longitude	Date Fractured
Thungo 8	-27.719	142.585	Jan-2004
Ipundu North 2	-26.911	143.307	Feb-2004
Mulberry 1	-26.892	143.402	Feb-2004
Roti West 1	-27.367	142.143	Mar-2004
Gimboola West 1	-26.872	143.403	Oct-2004
Winninia 1	-27.856	141.836	Nov-2004
Winninia North 2	-27.828	141.894	Nov-2004
Baryulah 6	-27.753	141.869	Dec-2004
Baryulah 6	-27.753	141.869	Dec-2004
Baryulah 6	-27.753	141.869	Dec-2004
Baryulah 6	-27.753	141.869	Dec-2004
Baryulah 6	-27.753	141.869	Dec-2004
Baryulah 6	-27.753	141.869	Dec-2004
Winninia North 3	-27.826	141.879	Jan-2005
Winninia North 3	-27.826	141.879	Jan-2005
Winninia North 3	-27.826	141.879	Jan-2005
Winninia North 3	-27.826	141.879	Jan-2005
Winninia North 3	-27.826	141.879	Jan-2005
Endeavour 1	-26.789	143.382	Feb-2005
Endeavour 2	-26.796	143.379	Feb-2005
Talgeberry 7	-26.944	143.430	Feb-2005
Talgeberry 7	-26.944	143.430	Feb-2005
Cranstoun 1	-26.814	143.387	Apr-2005
Takyah 1	-27.010	143.301	Apr-2005
Takyah 1	-27.010	143.301	Apr-2005
Mulberry 2	-26.891	143.397	May-2005
Mulberry 3	-26.895	143.409	May-2005
Ipundu North 9	-26.918	143.305	May-2005
Ipundu North 4	-26.914	143.306	May-2005
Mulberry 4	-26.890	143.405	Jun-2005
Ipundu North 9	-26.918	143.305	Jun-2005
Ipundu North 4	-26.914	143.306	Jul-2005
Ipundu North 4	-26.914	143.306	Jul-2005

Name	Latitude	Longitude	Date Fractured
Iliad 1	-28.294	141.366	Aug-2005
Iliad 2	-28.294	141.355	Aug-2005
Jackson 45	-27.578	142.414	Aug-2005
Ipundu 12	-26.936	143.332	Aug-2005
Ipundu 12	-26.936	143.332	Aug-2005
Tartulla 6	-27.207	142.139	Oct-2005
Psyche 4	-27.929	141.810	Oct-2005
Baryulah 8	-27.738	141.834	Nov-2005
Baryulah 8	-27.738	141.834	Nov-2005
Baryulah 8	-27.738	141.834	Nov-2005
Baryulah 8	-27.738	141.834	Nov-2005
Baryulah 7	-27.750	141.857	Nov-2005
Baryulah 7	-27.750	141.857	Nov-2005
Baryulah 7	-27.750	141.857	Nov-2005
Baryulah 7	-27.750	141.857	Nov-2005
Talgeberry 6	-26.945	143.420	Nov-2005
Ipundu 4A	-26.936	143.333	Nov-2005
Ipundu 4A	-26.936	143.333	Nov-2005
Wellington 5	-27.739	141.865	Nov-2005
Thoar 3	-28.025	141.775	Nov-2005
Baryulah 9	-27.759	141.847	Dec-2005
Baryulah 9	-27.759	141.847	Dec-2005
Baryulah 9	-27.759	141.847	Dec-2005
Baryulah 9	-27.759	141.847	Dec-2005
Wellington 5	-27.739	141.865	Dec-2005
Juno 4	-27.687	141.837	Dec-2005
Juno 4	-27.687	141.837	Dec-2005
Juno 4	-27.687	141.837	Dec-2005
Juno 4	-27.687	141.837	Dec-2005
Juno 4	-27.687	141.837	Dec-2005
Juno 4	-27.687	141.837	Dec-2005
Psyche 3	-27.942	141.824	Dec-2005
Durham Downs North 2	-27.054	141.821	Jan-2006

Name	Latitude	Longitude	Date Fractured
Barylah 10	-27.756	141.878	Jan-2006
Barylah 10	-27.756	141.878	Jan-2006
Barylah 10	-27.756	141.878	Jan-2006
Barylah 10	-27.756	141.878	Jan-2006
Winna 4	-27.725	142.540	Jan-2006
Talgeberry 4	-26.945	143.435	Jan-2006
Talgeberry 4	-26.945	143.435	Jan-2006
Tickalara 10	-28.344	141.378	Feb-2006
Iliad 3	-28.293	141.364	Feb-2006
Tickalara 3	-28.341	141.384	Mar-2006
Sigma 1	-28.335	141.340	Mar-2006
Sigma 2	-28.340	141.341	Mar-2006
Mulberry 6	-26.894	143.399	Mar-2006
Dululu 1	-28.326	141.440	Mar-2006
Yanda 16	-27.449	141.826	Apr-2006
Tickalara 3	-28.341	141.384	Apr-2006
Mulberry 8	-26.899	143.399	Apr-2006
Yanda 16	-27.449	141.826	Apr-2006
Mulberry 9	-26.899	143.406	May-2006
Mulberry 10A	-26.902	143.414	May-2006
Chancett 1	-26.856	143.406	May-2006
Mulberry 14	-26.899	143.411	May-2006
Mulberry 16	-26.888	143.399	May-2006
Gimboola 3	-26.880	143.412	May-2006
Epsilon 3	-28.161	141.137	Jun-2006
Toby 1	-26.685	142.368	Jun-2006
Mulberry 15	-26.888	143.393	Jun-2006
Kercummurra 1	-27.108	142.433	Jul-2006
Endeavour 8	-26.800	143.377	Jul-2006
Mulberry 17	-26.899	143.388	Jul-2006
Gimboola 2	-26.880	143.418	Jul-2006
Mulberry 12	-26.884	143.392	Jul-2006
Gimboola 4a	-26.875	143.412	Aug-2006

Name	Latitude	Longitude	Date Fractured
Endeavour 9	-26.781	143.391	Aug-2006
Endeavour 7	-26.795	143.382	Aug-2006
Talgeberry 12	-26.941	143.433	Aug-2006
Talgeberry 13	-26.940	143.427	Aug-2006
Minni Ritchi 1	-26.825	143.375	Aug-2006
Cranstoun 3	-26.817	143.390	Sep-2006
Talgeberry 9	-26.948	143.424	Sep-2006
Talgeberry 11	-26.948	143.436	Sep-2006
Patroclus 1	-28.111	141.681	Sep-2006
Patroclus 1	-28.111	141.681	Sep-2006
Orientos 2	-28.048	141.428	Oct-2006
Talgeberry 14	-26.946	143.441	Oct-2006
Endeavour 18	-26.800	143.370	Oct-2006
Kooyong 1	-26.809	143.355	Oct-2006
Endeavour 19	-26.806	143.370	Oct-2006
Mulberry 19	-26.899	143.393	Oct-2006
Mulberry 22	-26.904	143.405	Oct-2006
Mulberry 21	-26.904	143.400	Oct-2006
Mulberry 23	-26.910	143.399	Oct-2006
Endeavour 5	-26.789	143.377	Oct-2006
Mulberry 5	-26.894	143.405	Oct-2006
Endeavour 16	-26.795	143.370	Nov-2006
Endeavour 13	-26.789	143.370	Nov-2006
Barrolka 9	-26.862	141.758	Nov-2006
Barrolka 9	-26.862	141.758	Nov-2006
Yanda 19	-27.459	141.793	Nov-2006
Durham Downs 4	-27.077	141.786	Nov-2006
Winninia North 1	-27.814	141.888	Nov-2006
Yanda 20	-27.453	141.796	Nov-2006
Yanda 19	-27.459	141.793	Nov-2006
Baryulah 12	-27.740	141.847	Nov-2006
Endeavour 15	-26.795	143.376	Nov-2006
Baryulah 12	-27.740	141.847	Dec-2006

Name	Latitude	Longitude	Date Fractured
Baryulah 12	-27.740	141.847	Dec-2006
Baryulah 12	-27.740	141.847	Dec-2006
Baryulah 12	-27.740	141.847	Dec-2006
Baryulah 12	-27.740	141.847	Dec-2006
Baryulah 11	-27.753	141.843	Dec-2006
Yanda 20	-27.453	141.796	Dec-2006
Baryulah 11	-27.753	141.843	Dec-2006
Baryulah 11	-27.753	141.843	Dec-2006
Baryulah 11	-27.753	141.843	Dec-2006
Yanda 24	-27.458	141.808	Dec-2006
Baryulah 11	-27.753	141.843	Dec-2006
Yanda 21	-27.449	141.804	Dec-2006
Baryulah 11	-27.753	141.843	Dec-2006
Theta 1	-27.979	141.745	Jan-2007
Yanda 22	-27.446	141.814	Jan-2007
Theta 1	-27.979	141.745	Jan-2007
Kooroopa North 1	-27.001	143.230	Feb-2007
Kooroopa North 2	-26.996	143.218	Feb-2007
Jackson 28	-27.583	142.413	Feb-2007
Endeavour 34	-26.803	143.373	Mar-2007
Endeavour 33	-26.803	143.367	Mar-2007
Endeavour 26	-26.783	143.388	Mar-2007
Mulberry 11	-26.894	143.393	Mar-2007
Thungo 9	-27.725	142.583	May-2007
Thungo 13	-27.734	142.581	May-2007
Dilkera North 1	-27.739	142.641	May-2007
Thungo 10	-27.728	142.583	May-2007
Thungo 11	-27.729	142.573	May-2007
Endeavour 28	-26.789	143.388	May-2007
Mulberry 29	-26.893	143.388	May-2007
Mulberry 42	-26.888	143.381	May-2007
Mulberry 44	-26.899	143.382	May-2007
Mulberry 26	-26.886	143.389	May-2007

Name	Latitude	Longitude	Date Fractured
Endeavour 39	-26.806	143.364	May-2007
Endeavour 25	-26.783	143.381	May-2007
Endeavour 35	-26.787	143.373	May-2007
Talgeberry 5	-26.936	143.435	May-2007
Mulberry 27	-26.888	143.387	May-2007
Currambar 1	-27.753	142.666	Jun-2007
Muthero 6	-27.712	142.615	Jun-2007
Muthero 7	-27.712	142.612	Jun-2007
Endeavour 29	-26.793	143.367	Jun-2007
Mulberry 35	-26.913	143.403	Jun-2007
Yanda 25	-27.460	141.799	Jun-2007
Takyah 2	-27.011	143.282	Jul-2007
Kooroopa 3	-27.024	143.236	Jul-2007
Coonaberry 2	-26.842	142.109	Aug-2007
Coonaberry 2	-26.842	142.109	Aug-2007
Challum West 1	-27.358	141.503	Aug-2007
Lepard 1	-27.827	141.732	Aug-2007
Lepard 1	-27.827	141.732	Aug-2007
Lepard 1	-27.827	141.732	Aug-2007
Lepard 1	-27.827	141.732	Aug-2007
Lepard 1	-27.827	141.732	Aug-2007
Patroclus 4	-28.116	141.689	Sep-2007
Ipundu 2	-26.926	143.321	Sep-2007
Ipundu 14	-26.937	143.337	Sep-2007
Mulberry 33	-26.896	143.402	Oct-2007
Mulberry 34	-26.896	143.402	Oct-2007
Mulberry 31	-26.896	143.402	Oct-2007
Mulberry 32	-26.896	143.402	Oct-2007
Talgeberry 18	-26.945	143.427	Oct-2007
Talgeberry 22	-26.940	143.438	Oct-2007
Dilkera 2	-27.744	142.629	Jan-2008
Jackson 17	-27.598	142.419	Mar-2008
Mama 1	0.000	0.000	Aug-2008

Name	Latitude	Longitude	Date Fractured
Yanda 15	-27.452	141.807	Sep-2008
Durham Downs North 1	-27.054	141.810	Oct-2008
Tartulla 8	-27.195	142.151	Oct-2008
Ramses 2	-26.755	142.106	Nov-2008
Iliad 4	-28.294	141.370	Nov-2008
Iliad 6	-28.297	141.365	Nov-2008
Galex 2	-27.453	141.852	Nov-2008
Yawa 2	-27.376	141.929	Nov-2008
Vega 3	-27.719	141.864	Dec-2008
Vega 3	-27.719	141.864	Dec-2008
Vega 3	-27.719	141.864	Dec-2008
Vega 3	-27.719	141.864	Dec-2008
Vega 3	-27.719	141.864	Dec-2008
Vega 3	-27.719	141.864	Dec-2008
Vega 3	-27.719	141.864	Dec-2008
Iliad 5	-28.296	141.353	Sep-2009
Barylah 4	-27.752	141.873	Sep-2009
Baryulah 4	-27.752	141.873	Sep-2009
Baryulah 4	-27.752	141.873	Sep-2009
Baryulah 4	-27.752	141.873	Oct-2009
Baryulah 4	-27.752	141.873	Oct-2009
Baryulah 5	-27.755	141.865	Oct-2009
Baryulah 5	-27.755	141.865	Oct-2009
Baryulah 5	-27.755	141.865	Oct-2009
Baryulah 5	-27.755	141.865	Oct-2009
Theta 2	-27.960	141.726	Oct-2009
Psyche 6	-27.903	141.818	Oct-2009
Okotoko West 2	-27.351	141.956	Oct-2009
Baryulah 5	-27.755	141.865	Nov-2009
Ipundu 16	-26.928	143.320	Jun-2010
Ipundu North 13	-26.916	143.302	Jun-2010
Patroclus 3	-28.114	141.687	Jun-2010
Moon 1	-28.227	141.042	Jul-2010

Name	Latitude	Longitude	Date Fractured
Moon 1	-28.227	141.042	Jul-2010
Moon 1	-28.227	141.042	Jul-2010
Moon 1	-28.227	141.042	Jul-2010
Challum 5	-27.416	141.657	- (1)
Dingera 2	-27.957	141.901	- (1)
Dilkera 3	-27.742	142.634	- (1)
Psyche 2	-27.916	141.836	- (1)
Mulberry 24	-26.910	143.417	- (1)
Psyche 2	-27.916	141.836	- (1)
Endeavour 11	-26.791	143.385	- (1)
Ramses 2	-26.755	142.106	- (1)
Genoa 2	-28.141	141.853	- (1)
Challum 23	-27.403	141.589	Mar-13
Challum 5	-27.416	141.657	Mar-13
Karmona 5	-27.312	141.89	Mar-13
Durham Downs 2	-27.104	141.811	Mar-13
Psyche 1	-27.913	141.813	Mar-13
Baryulah 15	-27.762	141.835	Mar-13
Baryulah 13	-27.755	141.883	Apr-13
Brumby 13	-28.388	141.002	Apr-13
Baryluah 14	-27.756	141.87	Apr-13
Lepard 2	-27.836	141.736	Jul-13
Psyche 7	-27.921	141.814	Jul-13
Juno 6	-27.701	141.823	Jul-13
Karmona 6	-27.303	141.901	Jul-13
Galex 2	-27.453	141.852	Aug-13
Curri 1	-27.365	141.821	Aug-13
Challum 7	-27.39	141.55	Aug-13
Raffle 1	-28.011	141.588	Aug-13
Okotoko West 3ST1	-27.354	141.963	Oct-13
Barrolka 12	-26.88	141.761	Mar-14
Barrolka 11	-26.863	141.743	Apr-14
Barrolka 13	-26.851	141.776	Apr-14

Name	Latitude	Longitude	Date Fractured
Durham Downs 1	-27.081	141.79	Apr-14
Baryulah 18	-27.74	141.844	Apr-14
Baryulah 17	-27.75	141.878	May-14
Vega 4	-27.72	141.875	Jul-14
Vega 5	-27.725	141.881	Jul-14
Kanook 1	-27.106	141.915	Jul-14
Bolah 1	-26.969	141.638	Jul-14
Toby 1	-26.685	142.368	Aug-14
Hera 3	-27.689	141.862	Aug-14
Hera 4	-27.689	141.862	Aug-14
Durham Downs 6	-27.066	141.78	Nov-14
Durham Downs 7ST1	-27.096	141.795	Nov-14
Durham Downs 8	-27.112	141.791	Nov-14
Durham Downs North 4	-27.041	141.806	Nov-14
Cook 29H	-26.692	141.291	Dec-14
Monte 1	-27.29	141.775	May-15
Beeree 1	-26.91	141.614	Jun-15
Barrolka 15	-26.894	141.762	Jun-15
Barrolka 17	-26.86	141.672	Jun-15
Barrolka 16	-26.838	141.7	Jun-15
Barrolka 14	-26.86	141.672	Jun-15
Toby 2	-26.676	142.371	Aug-15
Whanto 2	-26.523	142.186	Aug-15
Whanto 3	-26.523	142.186	Aug-15
Mt Howitt 3DW1	-26.594	142.489	Aug-15
Hebe 1	-27.73	141.958	Aug-15
Bolah 2	-26.986	141.661	Dec-15
Cuisinier 14	-26.669	141.232	Dec-15
Cuisinier 9	-26.704	141.233	Dec-15
Cuisinier 5	-26.704	141.224	Dec-15
Cuisinier 12	-26.675	141.231	Dec-15
Cuisinier 3	-26.693	141.226	Dec-15
Durham Downs North 6	-27.058	141.826	Nov-16

Name	Latitude	Longitude	Date Fractured
Whanto 3	-26.523	142.186	Aug-15
Whanto 2	-26.523	142.186	Aug-15
Whanto 4	-26.535	142.213	Nov-16
Whanto South West 1	-26.607	142.16	Nov-16
Whanto West 1	-26.526	142.157	Oct-16
Barta North 1	-26.705	141.184	Dec-16
Cuisinier 22	-26.658	141.229	Dec-16
Dilkera 3	-27.742	142.634	Dec-16
Maxwell 2	-27.886	142.695	Dec-16
Wippo East 1	-27.294	142.121	Apr-17
Roti South 1	-27.397	142.149	Apr-17
Windigo 3	-27.391	142.112	Apr-17
Galex 4	-27.455	141.856	May-17
Galex 5	-27.455	141.856	May-17
Coolah 3	-26.955	141.814	May-17
Whanto West 1	-26.526	142.157	Jul-17
Marama West 1	-26.056	142.099	Jul-17
Kaiden 1	-26.337	142.053	Aug-17
Lepard 3	-27.825	141.717	Sep-17
Wippo 1	-27.286	142.091	Oct-17
Roti 3	-27.389	142.181	Nov-17
Roti 5	-27.379	142.164	Oct-17
Roti 6	-27.379	142.164	Oct-17
Takyah 6	-27.006	143	Feb-18
Epsilon 4	-28.176	141.13	Mar-18
Mountain Goat 1	-27.407	141.145	Jul-18
Cocinero 6	-26.721	141.268	Aug-18
Shefu 1	-26.674	141.169	Aug-18
Cuisinier North 1	-26.665	141.232	Aug-18
Cuisinier 24	-26.701	141.24	Aug-18
Cocinero 2	-26.705	141.262	Aug-18
Whanto 5	-26.536	142.17	Aug-18
Coonaberry 4	-26.866	142.102	Aug-18

Name	**Latitude**	**Longitude**	**Date Fractured**
Cuisinier 19	-26.724	141.244	Dec-18
Cocinero 3	-26.695	141.257	Dec-18
Bearcat 1	-27.752	141.726	Mar-19
Bolah 3	-26.985	141.646	Jan-19
Bolah 4	-26.986	141.646	Feb-19
Ipundu 20	-26.924	143.311	Mar-19
Ipundu 19	-26.946	143.339	Mar-19
Cuisinier 28	-26.698	141.232	May-19
Cuisinier 27	-26.699	141.247	May-19
Cuisinier 21	-26.666	141.214	May-19
Cuisinier 15	-26.695	141.237	May-19
Barrolka 20	-26.876	141.742	May-19
Anna North 1	-27.099	141.693	May-19

(1) No record

APPENDIX F

Potential Hydraulic Stimulation Locations

Appendix F – Potential Hydraulic Fracture Locations

	Proposed Fracture Dates		
Field	**2020**	**2021**	**2022**
ANNA NORTH	0	1	0
BARROLKA	3	4	1
BASSET	1	0	0
BEARCAT	0	1	0
BOLAH	1	1	0
BOLAN EAST	0	1	0
COCINERO	0	3	0
COOLAH	0	4	0
CORRIDOR NORTH	0	1	0
COUGAR	0	1	0
CUISINIER	3	3	3
DILKERA	0	0	1
DURHAM DOWNS	1	1	0
ENDEAVOUR	0	0	2
HEMNANT	0	1	0
HERA	0	0	1
HOUBY	0	1	0
KANOOK SOUTH	0	1	0
MAYA	0	0	1
MIRANDA	1	0	0
MOOLIAMPAH	0	0	1
MOON	1	0	0
MOUNTAIN GOAT	0	1	0
PSYCHE	0	1	0
SNOWBALL	1	0	0
TARTULLA	1	0	0
THUNGO	0	0	1
TOBY	0	2	0
VEGA	0	0	1
WACKETT	2	0	0
WATSON NORTH	2	0	2

	Proposed Fracture Dates		
Field	**2020**	**2021**	**2022**
WOLGOLLA WEST	1	0	0
DUNADOO/ DUNADOO EAST	0	4	0
JUNO/ JUNO NORTH	0	0	1
WIPPO/WIPPO SOUTH	1	1	0

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REPORT

Stimulation Risk Assessment - Santos Southwest Queensland Tenements

Human Health and Ecological Risk Assessment - Halliburton

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29 June 2020

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Executive Summary

Introduction

Santos Ltd (Santos) engaged Golder Associates Pty Ltd (Golder) to prepare this desktop risk assessment of stimulation activities for conventional oil and gas production in their Southwest Queensland (SWQ) tenements. This Stimulation Risk Assessment (SRA) is undertaken to meet Department of Environment and Science (DES; formerly Department of Environment and Heritage Protection (DEHP)) Environmental Authority (EA) consent conditions.

An earlier version of this report was prepared in 2012. This current version has been updated with new information on revised fluid systems and EA consent conditions. As a consequence, the Product Descriptions (Section 3.0), and chemical assessments in Sections 4.0 (Aquatic Assessment), 5.0 (Terrestrial Assessment), and 6.0 (Human Health Assessment) in this report have been updated with new chemicals and new data on previously identified chemicals. Within these report sections, however, the approach to the chemical hazard assessments has largely remained the same. Section 7.0 (Risk Characterisation) has also been updated with the new chemical information.

This desktop SRA is presented in two report volumes, as follows:

- Volume One discusses the environmental and geological settings within which Santos' stimulation activities take place and the general techniques for the drilling, completion and stimulation of wells. The report also discusses why stimulation is essential in SWQ and outlines Santos' current forward programme for fracture-stimulation, although it should be noted that for a variety of reasons (including but not limited to future production performance and / or access-related issues such as the flooding of the Cooper Creek system), the forward program is frequently reviewed and is subject to change.
- Volume Two (this report) relates specifically to the stimulation fluids proposed to be used by *Halliburton* on Santos wells in the SWQ. Stimulation fluids specifically assessed in this report are:
    - '*DeltraFrac(H) Treatments*'
    - '*DFS-BCG Treatments'*
    - '*DFS-BCG(H)* (formally *HyborH*) *Treatments*'
    - '*High Temperature Acid Spearheads*'.

Halliburton stimulation fluid proprietary chemical information was disclosed directly to Golder by Santos on 24 October 2019. Full disclosure was provided for the chemical constituents in each of the fluids considered, including the mass of each constituent in a typical fluid mixture.

Comparison of Conventional Oil and Gas Operations to Coal Seam Gas (CSG) Operations

There are key differences between CSG and conventional oil and gas production, both in the geographic and geological setting of the resource and the methodology for accessing the resource, that have a substantial bearing on the risk profile presented by stimulation activities. These include:

- Santos' conventional oil and gas operations in SWQ are located in an arid, sparsely populated area of central Australia. Whilst groundwater is an important water supply to support the rural land uses, the extent of water supply development is limited (commensurate with the small population base)
- In Santos' SWQ operations, the hydrocarbon reservoirs generally occur in anticlines capped with thick, laterally-extensive low permeability formations that isolate the reservoirs from overlying water-bearing formations; and
- The oil and gas reservoirs in the SWQ study area are very deep, of the order of 1500 to 3000 m below ground level, which provides hundreds to over a thousand metres vertical separation between the

formations in which stimulation activities are proposed and the shallow groundwater resources. There is also no requirement to remove formation water in order to facilitate gas flow, with the possible exception of well blow downs on a case by case frequency.

Hence, the combination of the remote project location, low population density (and limited water supply development), and the substantial vertical separation of oil and gas reservoirs from primary groundwater supply aquifers results in an inherently low risk profile with regard to stimulation activities.

Environmental Setting and Environmental Values

Santos operates conventional gas and oil fields within scattered petroleum production tenements that, along with Santos' exploration licences cumulatively cover approximately 30,000 km^2 of Southwest Queensland. These tenements, exploration licenses and the land surrounding the Santos tenements comprise the Santos SWQ *study area*. The study area is described in detail within Volume One of the SWQ SRA report.

The terrain in the study area is generally characterised by low undulating topography (hills and ridges) between the various river and creek systems and associated floodplains. The area is sparsely developed, and generally comprises rural communities and homesteads that are largely engaged in farming and livestock. The oil and gas reservoirs which are the targets for stimulation lie within the Cooper Basin and the overlying Eromanga Basin.

Based on an understanding of the environmental setting, this risk assessment considered the following key environmental values:

Groundwater Environmental Values:

- Town water supply
- Stock and domestic water supply
- Sandstone aquifers of the GAB; and
- Groundwater Dependant Ecosystems (GDEs).

Surface Water Environmental Values:

- Protection of aquatic ecosystems
- Recreation and aesthetics: primary recreation with direct contact, and visual appreciation with no contact; and
- Cultural and spiritual values.

Terrestrial Environmental Values:

- Protection of flora and fauna, such as small mammals reptiles and birds.

Environmental values are further considered and evaluated in Volume One of the SWQ SRA report.

Stimulation Process Description Summary

With regard to the process of stimulation, the requirements of the EA approval conditions are considered within Volume One of the SWQ SRA report, with the following specific information included:

- Practices and procedures to ensure that the stimulation activities are designed to be contained within the target gas producing formation.
- Indicative details of where, when and how often stimulation is to be undertaken on the tenures covered by this environmental authority.
- A description of Santos' well mechanical integrity testing program.
- Process control and assessment techniques to be applied for determining extent of stimulation activity(ies) (e.g. microseismic measurements, modelling etc.); and

- A process description of the stimulation activity to be applied, including equipment and a comparison to best international practice.

Evaluation of Exposure Pathways

Potential exposure pathways were evaluated for on-site (i.e. within the well lease), and those relevant for off-site (i.e. anything beyond the well lease boundary). Potentially complete exposure pathways were evaluated for workers, trespassers, native fauna and flora and livestock. The environment immediately surrounding the well lease (i.e. off-site) throughout the study area may vary from lease to lease, but, was considered to potentially include homesteads (adult and child residents), water supply bores, creeks or wetlands/waterholes, livestock and native flora and fauna.

The on-site assessment indicated that the majority of potential exposure pathways were unlikely or incomplete, given the application of operational controls by Santos. These operational controls include:

- Occupational health & safety procedures implemented during stimulation operations to prevent workers from direct contact and inhalation exposure to chemicals during standard operations, spills and when handling flowback water or sediments.
- Implementation of spill containment procedures during operations to prevent migration of and exposure to chemicals.
- Vacuum removal of sediments and fluids contained within panel tanks, to prevent exposure to contaminants in windborne dust.
- Installation of signs to indicate the well lease (including the panel tank area) is a work zone to be accessed by authorised personnel only; and
- The use of lined above ground panel tanks (several metres high) to store flowback fluids, reducing access to the majority of potential ecological receptors including livestock and large mammals.

Within the well pad area, reasonable measures will be implemented to discourage entry of native fauna and livestock into the well lease area during stimulation operations. However, a potentially complete exposure pathway was identified for birds coming in direct contact with the flowback water in the panel tanks.

Potential off-site exposure pathways were evaluated for homesteads, livestock, native flora and fauna and aquatic ecosystems. Three possible chemical sources were identified: injected stimulation fluids, sediments from the panel tanks and flowback water. The exposure assessment concluded:

- Subsurface exposure to stimulation fluids is controlled by Santos' well design, well integrity testing procedures and operational monitoring, and this pathway (whereby stimulation fluids could escape into the formation and contaminate adjacent aquifers that are used for domestic or stock water supply) is considered unlikely or incomplete.
- Based on an understanding of the Eromanga and Cooper Basin geology and hydrogeology, and the nature and extent of groundwater supply development, exposure to residual stimulation chemicals through subsurface pathways is considered unlikely and incomplete, due to:
    - Significant vertical offset between the beneficial use aquifers and the shallowest hydrocarbon reservoirs (oil reservoirs of the Cadna-Owie Formation - 400 to 800 m). These formations are separated by low permeability formations and form a thick, competent and regionally extensive seal. The vertical offset to gas reservoirs is much greater (1,000 m to 1,800 m).
- Within formations that host both aquifers and hydrocarbon reservoirs (e.g. Hooray Sandstone), the water-bearing zones are separated from hydrocarbon reservoirs by intra-formational seals. However, there is not enough information available to discretise the internal stratigraphy of these formations. Where petroleum activities (including stimulation) occur within a formation that hosts both aquifers and hydrocarbon reservoirs, the lateral distance of the water supply bores accessing the aquifer to Santos' tenements was considered.

- The closest beneficial use bore to the Santos tenements targeting the Hooray Sandstone in the DES (formerly DEHP) database records is the Coothero Bore, which is located approximately 45 km from the closest tenement with stimulation activities proposed.
- At the surface, a spill or leak of flowback water from a panel tank was considered as a potential exposure scenario, however the implementation of operational controls, including use of liners in panel tanks, removal of fluid and sediment using vacuum techniques and engineering and operational controls (grading of well leases and stormwater controls) is considered sufficient to limit the potential for uncontrolled releases of flowback water to the environment. A further margin of safety is provided by Santos' evaluation of 'environmentally sensitive areas' when establishing well leases, which includes the establishment of buffers between petroleum (and stimulation) activities and features of potential environmental concern. Subsequently, the potential off-site exposure scenarios are considered unlikely and incomplete.

Hazard Assessment

The toxicity of the chemicals used in the stimulation process by Halliburton have been assessed for persistence, bioaccumulation and aquatic toxicity (PBT), terrestrial toxicity and human health toxicity including the physical hazards of fire and explosion. The review of toxicity is qualitative in that it has provided a relative ranking of chemicals considered to represent a high, moderate or low hazard in respect to the ecological or human health end points with qualification of health issues arising from the ranking.

The evaluation of the hazards was based on the available data obtained from a range of literature sources and databases. As a consequence, data are limited to the quantity and quality of information available in those sources. A measure of the data completeness for the toxicological and hazard parameters used has been estimated using a percentage of the parameters for which data were available. An assessment of the quality of the available data is beyond the scope of this report. In the absence of verifying the data by going to the primary literature sources, the selection of data for use in the assessment has been confined to established, robust and reputable sources such as WHO (World Health Organisation) and US EPA (United States Environmental Protection Agency) where available. As new toxicological data are generated and becomes available in the published literature, the information presented in this hazard evaluation and the associated conclusions may be subject to change. This was realised in 2013 with the publication of new human health chemical hazard assessment approaches (NICNAS, 2013). As a result chemicals assessed after this date have been reviewed on the basis of the new national approach which incorporates a weighting for specific toxicological parameters. It should be noted that this methodology has not been employed for chemicals assessed prior to 2013, and so no change is reflected in previous assessments.

This hazard assessment did not consider the combined effects of the constituents when present in a mixture. Assessment of mixtures is considered beyond the scope of a screening level human health and ecological risk assessment.

Environmental Hazard

Approaches for environmental risk assessment of individual chemicals are inherently conservative and designed to over-estimate risk as a precautionary approach and in recognition of the uncertainty surrounding effects of mixtures.

Aquatic Ecosystems

Based on the hazard classification of the stimulation chemicals, seven chemicals were classified as a high hazard and considered to be COPC, as follows:

- Alcohols, C12-C15, Ethoxylated
- Surrogate for Amides, tall-oil fatty, N-N-bis(hydroxyethyl)
- Tall-oil, fatty, N,N-bis(hydroxyethyl)

- Chlorous acid, sodium salt
- Disodium octaborate tetrahydrate
- Sodium bisulfite
- Sodium iodide; and
- Surrogate for Ulexite.

The certainty of the hazard classification varies depending on the extent of data gaps and the reliance on modelled data. The percentage data gaps for the high hazard chemicals ranged from very low (Alcohols, C12-C15, Ethoxylated) to relatively high (Sodium iodide).

Terrestrial Ecosystems

The organic chemicals classified as high hazard to terrestrial ecosystems were assessed according to their toxicological and physico-chemical properties. The following organic chemicals were assessed to have the potential to pose a higher environmental hazard to terrestrial ecosystems relative to the other chemicals assessed based on persistence (including volatility and soil half-life), and potential to biomagnify:

- Diethanol amine; and
- Hydrotreated light petroleum distillate.

Diethanol amine has low volatility but it does not persistent in the soil and it does not biomagnify. Hydrotreated light petroleum distillate has a high potential to biomagnify but it does not persist in the environment based on its fast half-life and high volatility. Therefore, although these chemicals appear to pose a higher hazard than others, their risk profile to terrestrial receptors is relatively low.

The remaining chemicals were considered likely to degrade quickly or moderately quickly and/or have a high or moderate volatility. Hence, whilst direct toxicity to terrestrial receptors could occur from exposure to these chemicals (for example, following a spill or breach of containment, or from direct exposure via accidental entry into a panel tank) the effect will likely be reduced over time.

Human Health Hazard

The hazard evaluation for human health undertaken in accordance with the ‘low-medium-high’ hazard ranking methodology indicated three of the twenty chemicals assessed to have a ‘moderate to high’ relative ranking:

- Methanol
- Sodium iodide
- Acetic acid.

The hazard evaluation for human health undertaken in accordance with the IMAP Framework hazard ranking methodology indicated twelve of the seventeen chemicals assessed under this methodology to be a Hazard Rank of 4 or 3.

- Ethylene Glycol
- Sodium bisulfite
- Ulexite
- Diethanolamine
- Sodium polyacrylate
- Butyl alcohol
- Tributyl tetradecyl phosphonium chloride

- Guar gum
- Hydrotreated light petroleum distillate
- Glutaraldehyde
- Monoethanolamine borate.

The hazard evaluation for human health suggests that the dominant concerns are related to occupational hazards such as carcinogenicity, silicosis, skin, eye and respiratory irritancy or corrosivity and sensitisation. In some cases, physical hazards of flammability and explosion prevail and are identified in this report. While extensive dilution of the stimulation chemicals is anticipated such that potential exposure concentrations would be much reduced for fluids injected into the well and in flowback fluid, there are a number of hazards that are suggested from this human health evaluation. These include the potential for:

- Residual elevation of organic moieties e.g. some salts have an organic part that will be present following dissociation that may increase in environmental waters.
- Changes in pH of environmental waters due to alkaline or acidic components.
- Elevations of certain metal concentrations in environmental waters.
- Some additives to exert endocrine disruption effects.
- Certain inorganic substances to generate atmospheric particulates that may impact nearby communities; and
- Volatile components to comprise nuisance or irritant effects should atmospheric concentrations be elevated in close proximity to communities.

These environmental hazards may be assessed further, and/or managed as required.

Golder notes that benzene, toluene, ethylbenzene and xylene (BTEX) and polycyclic aromatic hydrocarbon (PAH) compounds were not identified in the confidential disclosure of stimulation fluids chemicals provided to Golder by Halliburton on 13 July 2012 and to Golder by Santos in October 2019.

Qualitative Assessment of Fluids

In 2012 Santos collected seven fluid samples during South Australian stimulation activities for chemical analysis. Two of these fluids ('*DFS-BCG(H) (formally HyborH) Treatments*' and '*High Temperature Acid Spearheads*') are still in use or proposed for use by Haliburton in SWQ stimulation activities. The other two fluids assessed in this report *('DeltaFrac(H) Treatments' and 'DFS-BCG Treatments'*) were not assessed in the qualitative assessment of fluids.

These stimulation activities were undertaken by Halliburton in 2012 and are considered reasonably indicative of the proposed SWQ activities. The samples included:

- 'Stimulation fluid additives mixed with distilled water to assess the quality of the additives in isolation.
- Formation make up water prior to mixture with stimulation fluid additives to assess the quality of the formation water; and
- Flowback fluids as they were returned from the subsurface to assess the overall fluid quality (including the contribution of reservoir fluids to the overall flowback fluid quality).

Detectable concentrations of toluene, xylenes and hydrocarbon fractions were reported in two samples of distilled water mixed with stimulation fluid additives, prepared by Halliburton. The reported concentrations were below the DES BTEX standard.

Review of the data indicates that the flowback fluids contain substantially higher concentrations of hydrocarbons, which are considered to represent geogenically derived substances and these exceed the respective water quality guideline concentrations (where available). The presence of geogenic hydrocarbons represents a key difference between conventional formations and those targeted through CSG production.

Examination of the make-up water drawn from formation water sources suggests the hydrocarbon concentrations are lower and range from concentrations below the limits of reporting to concentrations approaching or in some cases exceeding the respective water quality guidelines. This includes both potable water quality guidelines and ecological guidelines from both the Netherlands (RIVM, 2004) and Canada (CCME, 2008), which were referenced in the absence of water quality guidelines for hydrocarbon fractions in Australia. This represents a gap in the literature and needs to be addressed on an Industry wide basis. These exceedances only apply to the TPH fractional ranges and the aesthetics-based health values for ethyl benzene and total xylenes. It is noted that comparison of flowback water quality to potable water quality guidelines constitutes a conservative, screening level assessment as the exposure scenario upon which the guidelines were derived (i.e. chronic exposure from direct ingestion of water) is not strictly relevant to the management of flowback fluids.

The distilled water fluid formulations present a similar hydrocarbon concentration profile to the make-up water, with generally lower concentrations albeit with exceptions in some TPH fractional ranges and for p-isopropyltoluene. The latter are within an order of magnitude of the make-up water concentrations. In the case of the BTEX group the distilled water formulations have not identified BTEX concentrations exceeding BTEX water quality criteria specified in the Queensland Environmental Protection Regulation.

These results suggest that stimulation fluid formulations are not contributing substantial amounts of BTEX and TPH into the subsurface regions, and certainly at concentrations that are both below the regulated criteria (where available) and below the concentrations in the hydrocarbon reservoirs being fractured. Some qualification of this statement is required as a result of residual uncertainties. These uncertainties require further exploration and reflect:

a) Limited sampling frequencies for the respective fluids examined.

b) Confidence in the sampling integrity and any potential for introduction of extraneous contamination. There is potential in view of the immediate environmental surrounds of the stimulation conditions.

c) The sampling process and its consistency with stimulation procedures at the time of sampling including spatial and temporal references, i.e. what was happening at the time of sampling and process locations, etc.

At the time of reporting, no information on fluid chemical volume per stimulation event for the two new fluids (*‘DeltaFrac(H) Treatments’ and ‘DFS-BCG Treatments’*) had been provided to Golder and has therefore not been included in this report.

Overall Risk Evaluation and Management Measures

Considering the hazard, exposure assessment and qualitative assessment of fluids, although unlikely, flowback water at surface presents a possible risk. However, with Santos operational controls and management, the overall risk to human health and environment associated with the chemicals involved in stimulation are expected to be low. The management measures implemented through operational controls include:

- OH&S procedures implemented during stimulation operations to prevent workers from direct contact with chemicals during spills and when handling make up and flowback waters and sediments.
- Santos operational procedures regarding well integrity verification and fracture design to stay within the target formation.

- Assigning buffers during establishment of well leases between petroleum operations and potential “environmentally sensitive areas” identified though database review and site-specific ecological assessments.
- Implementation of spill containment procedures during operations to prevent migration of and exposure to chemicals.
- Vacuum removal of sediments and fluids contained within panel tanks, to prevent exposure to contaminants in fluids and windborne dust.
- Installation of signs to indicate that the well lease (including the panel tank area) is a work zone to be accessed by authorised personnel only.
- Lining (double lining) of panel tanks to prevent seepage of flowback water into the underlying aquifer; and
- Engineering and operational controls (grading of well leases and stormwater controls) to limit the potential for uncontrolled surface releases of flowback water to the environment.

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1.0 INTRODUCTION

1.1 Preamble

Santos Ltd (Santos) is a holder of numerous existing Environmental Authorities (EAs) for activities and operations throughout Southwest Queensland (SWQ), collectively referred to as “SWQ”. To meet EA consent conditions, a formal risk assessment of stimulation activities is required and subsequently, Golder Associates Pty Ltd (Golder) has been engaged by Santos to prepare this Stimulation Risk Assessment (SRA).

This version of the Stimulation Risk Assessment (SRA) updates a 2012 version (127666004-014-Rev3, dated August 2013 previously referred to as a Hydraulic Stimulation Risk Assessment (HSRA)). Updated contents include reference to the updated Environment Authority (EA) Blueprint Conditions (updated December 2019) and new information on revised fluid systems. As a consequence, the Product Descriptions (Section 3.0) and the chemicals assessments in Sections 4.0 (Aquatic Assessment), 5.0 (Terrestrial Assessment), and 6.0 (Human Health Assessment) of this report have been updated with new chemicals and new data on previously identified chemicals. Within these report sections, however, the approach to the chemical hazard assessments has largely remained the same. Section 7.0 (Risk Characterisation) has also been updated with the new chemical information.

This desktop SRA is presented in two volumes, as follows:

- Volume One discusses the environmental and geological settings within which Santos’ stimulation operations take place and the general techniques for the drilling, completion and stimulation of wells. The report also discusses why stimulation is essential in SWQ and outlines Santos’ current forward programme for fracture-stimulation, although it should be noted that for a variety of reasons (including but not limited to future production performance and / or access-related issues such as the flooding of the Cooper Creek system), the forward programme is frequently reviewed and is subject to change.
- Volume Two (this report) relates specifically to the stimulation fluids proposed to be used by *Stimulation Service Providers* on Santos wells in the SWQ conventional oil and gas fields. The report considers the ecological and human health toxicity of the chemical constituents in the stimulation fluids and includes an exposure pathway assessment and risk characterisation based on a review of complete exposure pathways and controls to mitigate exposure.

This reporting structure has been developed to accommodate the chemical assessment requirements of various stimulation fluids as they are introduced to the Australian market, for which the remainder of the EA conditions relating to the environmental setting and stimulation process description remain consistent over time. This reporting structure also affords greater ability to manage commercial-in-confidence issues associated with certain stimulation fluids.

This report specifically addresses the requirements of EA conditions related to the assessment of chemical constituents for the following *Halliburton* stimulation fluids:

- ‘*DeltraFrac(H) Treatments’*
- *‘DFS-BCG Treatments’*
- *‘DFS-BCG(H) (formally HyborH) Treatments’*
- ‘*High Temperature Acid Spearheads*’

Halliburton stimulation fluid proprietary chemical information was disclosed directly to Golder by Santos on 24 October 2019. Full disclosure was provided for the chemical constituents in each of the fluids considered, including the mass of each constituent in a typical fluid mixture.

This report should be read in conjunction with report entitled, *Stimulation Risk Assessment, Site Setting and Fracturing Process* [Volume One], (reference: 127666004-011-R-Rev0, dated 8 April 2020); which discusses the environmental and geological settings within which Santos' stimulation operations take place in Southwest Queensland (SWQ) and the general techniques for the drilling, completion and stimulation of wells. The same report also evaluates exposure pathways and Santos management and control measures.

1.1.1 EA Consent Conditions

The Environmental Authority (EA) approval requirements for the Santos' SWQ operations necessitate the collection and provision of information on stimulation. Detailed regulatory requirements contained in these approvals and the sections of this risk assessment where the conditions are met are provided in Table 1. Conditions related to stimulation risk assessments can vary between Santos SWQ EAs and can also vary to include those with DES' Streamlined model conditions for petroleum activities guideline (ESR/2016/1989).

Table 1: Summary of Consent Conditions Related to Stimulation Fluid Chemical Assessment

Condition		Report Volume	Report Section
(a)	a process description of the stimulation activity to be applied, including equipment	One	3.3
(b)	provide details of where, when and how often stimulation is to be undertaken on the tenures covered by this environmental authority	One	3.4.1
(c)	a geological model of the field to be stimulated including geological names, descriptions and depths of the target gas producing formation(s)	One	2.4 and 2.5
(d)	naturally occurring geological faults	One	2.4.3.5 and 2.4.5
(e)	seismic history of the region (e.g. earth tremors, earthquakes)	One	2.4.5
(f)	proximity of overlying and underlying aquifers	One	2.5
(g)	description of the depths that aquifers with environmental values occur, both above and below the target gas producing formation	One	2.6
(h)	identification and proximity of landholders' active groundwater bores in the area where stimulation activities are to be carried out	One	2.5.7
(i)	the environmental values of groundwater in the area	One	2.6
(j)	an assessment of the appropriate limits of reporting for all water quality indicators relevant to stimulation monitoring in order to accurately assess the risks to environmental values of groundwater	Refer Stimulation Impact Monitoring Program	-
(k)	description of overlying and underlying formations in respect of porosity, permeability, hydraulic conductivity, faulting and fracture propensity	One	2.4.4 and 2.5.5
(l)	consideration of barriers or known direct connections between the target formation and the overlying and underlying aquifers	One	2.5.2.3, 3.3.4 and 3.3.7
(m)	a description of the well mechanical integrity testing program	One	3.2.2
(n)	process control and assessment techniques to be applied for determining extent of stimulation activities (e.g. microseismic measurements, modelling etc.)	One	3.3.4 and 3.3.7
(o)	practices and procedures to ensure that the stimulation activities are designed to be contained within the target gas producing formation	One	3.3.4 and 3.3.7

Condition		Report Volume	Report Section
(p)	groundwater transmissivity, flow rate, hydraulic conductivity and direction(s) of flow	One	2.5.3, 2.5.4 and 2.5.5
(q)	a description of the chemicals used in stimulation activities (including estimated total mass, estimated composition, chemical abstract service numbers and properties), their mixtures and the resultant compounds that are formed after stimulation	Two	3.0
(r)	a mass balance estimating the concentrations and absolute masses of chemicals that will be reacted, returned to the surface or left in the target gas producing formation subsequent to stimulation	Two	3.2
(s)	an environmental hazard assessment of the chemicals used including their mixtures and the resultant chemicals that are formed after stimulation including: (i). toxicological and ecotoxicological information of chemicals used (ii). information on the persistence and bioaccumulation potential of the chemical compounds used (iii). identification of the chemicals of potential concern in stimulation fluids derived from the risk assessment	Two	4.0, 5.0, 6.0 and 7.3.2
(t)	an environmental hazard assessment of the chemicals used including mixtures and the resultant chemicals that are formed after stimulation	Two	4.0, 5.0, 6.0 and 7.3.2
(u)	identification and an environmental hazard assessment of using radioactive tracer beads in stimulation activities where such beads have been used or are proposed to be used	One	3.3.7.10
(v)	an environmental hazard assessment of leaving chemical compounds in stimulation fluids in the target formation for extended periods subsequent to stimulation	Two	2.1.2.1
(w)	human health exposure pathways to operators and the regional population	Two	6.0
(x)	risk characterisation of environmental impacts based on the environmental hazard assessment	Two	7.0
(y)	potential impacts to landholder bores as a result of stimulation activities	Two	2.2.3.1
(z)	an assessment of cumulative underground impacts, spatially and temporally of the stimulation activities to be carried out on the tenures covered by this environmental authority	Two	7.5
(aa)	potential environmental or health impacts which may result from stimulation activities including but not limited to water quality, air quality (including suppression of dust and other airborne contaminants), noise and vibration	One and Two	1.3 (Report Version One) 4.0, 5.0, 6.0 and 7.3.2 (Report Version 2)

*Consent conditions from Schedule K (Well Construction, Maintenance and Stimulation), subsection K6, 21 December 2019

1.2 Risk Assessment Process

This report discusses the constituents used by Halliburton[1] with regard to toxicity to human health and the environment. The techniques used to assess the human health and environmental hazards of the constituents are described in the following sections. Where there was insufficient chemical and/or toxicological information to assess the hazards of individual constituents, an assessment was not performed.

The scope of the qualitative risk assessment comprises of:

- **Issue Identification** (Volume One) - A description of the current environmental setting (including a description of potential receiving environments and the various factors which act upon them, including climatic influences), detailed geological and hydrogeological information, gas well integrity and a description of the stimulation process including an identification of the constituents of the stimulation fluid.
- **Exposure Assessment** (This Volume) **–** The exposure assessment comprises of an evaluation of surface and subsurface exposure pathways assessment.
- **Hazard Assessment** (This Volume) **–** An evaluation of the environmental hazard of relevant chemical additives in the stimulation fluid based on aquatic toxicity, environmental persistence and bioaccumulation. The environmental hazard assessment provides a relative ranking of the chemical additives and those chemicals considered to represent a high hazard are identified as chemicals of potential concern (COPC) for further assessment. An evaluation of terrestrial and human health toxicity will also be presented; and
- **Risk Characterisation** (This Volume) **–** A qualitative evaluation of environmental and human health risk associated with the stimulation activities based on the identification of complete exposure pathways and hazard identification.

Human health risk assessment is limited to assessment of effects on one population: *humans*. Ecological risk assessment is concerned with assessment of effects on the ecosystem (populations and communities) and therefore is not limited to one receptor. The guidance framework for ecological risk assessment in Australia is the “Guideline on Ecological Risk Assessment” (NEPM, Schedule B(5), 2013) which refers to draft guidance prepared by EPA Victoria (Gibson *et al.*, 1997). These guidance documents focus on risks to terrestrial environments although the overall approach for assessment or risk is the same. The risk assessment was undertaken in general accordance with these guidelines and national guidelines for risk assessment recommended by enHealth (enHealth-Environmental Health Risk Assessment, “Guidelines for Assessing Human Health Risks from Environmental Hazards”, June 2012).

This hazard assessment did not consider the combined effects of the constituents when present in a mixture. Assessment of mixtures is considered beyond the scope of a screening level human health and ecological risk assessment.

If, in the future, conditions, stimulation methodologies and/or regulatory requirements change, and/or additional exposure pathways to additional receiving environments are identified, further evaluation of the associated risks *may* be warranted.

1.3 Limitations

Your attention is drawn to the document - “Limitations”, which is included in APPENDIX A of this report. The statements presented in this document are intended to advise you of what your realistic expectations of this report should be. The document is not intended to reduce the level of responsibility accepted by Golder, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

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[1] Water was not assessed because it is an intrinsic constituent of all living organisms and is not inherently toxic.

2.0 EXPOSURE ASSESSMENT

This aspect of risk assessment provides perspective on the potential for COPC to become available and be taken up by human and other ecological species. Exposure assessment seeks to qualify or quantify such uptake by considering the human population groups and other organisms or group of organisms (receptors) which may be exposed to the COPCs identified for the study and outlines the mechanisms (exposure pathways) by which these receptors may be exposed.

The assessment of exposure involves the evaluation of the data available for the study and the arising issues; the details associated with the surrounding environment that influence fate and transport processes; the nature of planned operations that use the COPC; the physico-chemical characteristics of the COPC and the respective potential exposure pathways consistent with the planned operations. This allows the nature of the potential exposure to be identified taking into consideration the fate and transport potential of the COPC.

For an exposure pathway to be considered to be complete there must be all of the following:

- Source of COPC - how the chemical entered the environment and which environmental media are affected.
- A transport media - how the chemical moves or migrates through the environment from one location to another, or from one environmental medium to another.
- An exposure point - how organisms can come into contact with the chemicals (e.g. direct contact or via the food web); and
- An exposure route - how the chemical could enter the organism (e.g. inhalation, ingestion or dermal contact).

If any one of these steps (source, transport media, exposure point or route) is not present, the exposure pathway is incomplete and further assessment of risks is not required. Conclusions regarding the completeness of exposure pathways may change over time in response to new information or developments, and as such should be periodically reviewed for verification.

2.1 Identification of Exposure Pathways and Populations

A detailed description of the study area environment is provided in Volume One. In general, the area is sparsely developed, and comprises rural communities and homesteads that are largely engaged in farming and livestock production. The identification of exposure pathways and populations or ecological receptors has been split into those considered relevant for on-site (i.e. within the well lease), and those relevant for off-site (i.e. anything beyond the well lease boundary). A general description of the well lease is provided in Volume One. Individual configurations of well leases may change; however, the general layout is considered adequate for the identification of exposure pathways and receptors.

The environment surrounding the well lease (i.e. off-site) may vary. In order to provide a conservative assessment, it has been assumed there is a homestead with a water supply bore located down gradient of the well lease. It is further assumed that the distance to the homestead is over two kilometres which thus then limits the potential consideration of:

- Vapour intrusion concerns into dwellings.
- The environmental distribution of chemicals as vapours producing odours or particulates that may deposit onto roof tops and indirectly into potable water supplies; and
- The potential for entrainment of chemicals used in and around the well leases into the indoor environment of homesteads and into areas where local (homegrown) food crops may be produced.

It has also been assumed that an ephemeral creek, livestock and native flora and fauna, are present in the surrounding environment. This hypothetical assumption was considered for the purposes of the exposure pathway assessment and may not actually occur in the vicinity of a stimulated well.

2.1.1 On-site Exposure Pathways

A well lease is a defined area that contains all of the equipment and infrastructure required to stimulate a well. A typical well lease is described in Volume One. Of particular note for the exposure assessment are the panel tank and the blender unit.

As such a well lease is an occupational environment and accordingly it is unnecessary to consider any on-site residential scenarios. Workers are typically housed in existing camps or camps specifically designed for stimulation (frac camps).

The environmental receptors on a well lease are limited. Livestock and large native animals such as kangaroos are deterred from entering the pad by human activity. However, Santos have indicated that cattle and kangaroos have been noted on well leases infrequently. Smaller fauna such as rodents, lizards, snakes and birds are known to enter well leases.

As described in Volume One stimulation fluid is blended on site to the specific requirements of the fracture design. The additives required for the fracture are brought onto site and stored in storage containers, blender unit or sand trailer. Blending of the fluid is a contained and completely automated process. A typical stimulation operation is of limited duration (two to three days). As such the chemicals are on site for a short period of time prior to and during the stimulation event. The likelihood of occupational or environmental exposure to these additives prior to injection during normal operation is considered low, as long as robust operational management measures are present and implemented appropriately. Potential occupational exposure to stimulation chemicals associated with a spill prior to injection is considered to be dealt with under appropriate occupational health and safety procedures and has not been considered further in this report.

The primary pathways for environmental and occupational exposures outside of spills are considered to be dermal, ingestion and inhalation and ingestion of particulates. Inhalation of volatile chemicals is considered to be of lesser concern as there are limited indoor or confined environments with all activities conducted outside, however, large atmospheric emissions in close proximity to the source would require evaluation from both an acute and chronic exposure perspective.

The main areas on site that are considered for occupational and environmental exposure is the lined panel tank used for flowback fluid storage and this is discussed in more detail below.

2.1.1.1 Panel Tank

The panel tank is constructed during the stimulation phase, to provide containment for fluids associated with well fluids management (flowback fluids etc.) post drilling. Santos has indicated that panel tanks are approximately 2 m in height and are double lined. The length and width of the panel tank varies with the volume of fluid required to be contained. The panel tank is used during stimulation as the initial reservoir for flowback fluids. The fluid is held in the tank to allow the sediment to settle and until water and sediments can be removed via vacuum truck for offsite disposal as soon as practicable.

Human exposure to the water in the panel tank during normal operation would be limited but may occur if the tank or liner becomes damaged and requires repair. Normal OH&S procedures are expected to limit workers exposure to flowback water under these scenarios. Human and/or ecological exposure may occur in the event of a flood where the freeboard is breached.

Exposure to the sediment in the panel tank may occur if the tank is drained and the sediments dry out and contribute to wind borne dust. However, the majority of sediments are removed from the tank via vacuum truck for off-site disposal as soon as practicable. Dust generation from a small volume of residual sediments is not likely to be of concern to human or ecological receptors and has not been considered further. Should the scale of operations result in multiple areas of residual sediments in closer proximity to townships then such an exposure pathway would warrant re-evaluation.

Cooper Basin activities are remote, and trespassers are unlikely to access the site even if the pad is not fully secure and accidental or deliberate exposure to chemicals in the flowback water in the panel tank is considered unlikely to occur.

Ecological exposures to stimulation chemicals within flowback water in the panel tank may occur for birds or flying mammals (such as bats) or from contact with sediments following drainage.

2.1.1.2 Measures to Limit Exposure

Typically implemented measures to limit exposure include:

- Exposure to trespassers is limited through the use of signs which are clearly displayed indicating the well lease is a work zone and is to be entered by authorised personnel only.
- Height of the panel tanks (approximately 2 m) and the use of signage to indicate that the panel tanks are for access by authorised personnel only.
- Exposure of livestock and other terrestrial mammals to stimulation chemicals and/or flowback water is limited due to the presence of workers during stimulation activities (which is a deterrent to animals in the lease area), the height of the panel tanks and/or fencing (if required) on site during stimulation activities.
- Exposure to sediments in the lined panel tanks is limited by effective and efficient (as soon as practicably possibly) removal and off-site disposal.

A summary of the on-site qualitative exposure assessment is provided in Table 2.

Table 2: On-site Exposure Assessment Summary

Source	Exposure Scenario	Receptors	Exposure Pathways	Likelihood of Exposure Scenario	Comments
Lined panel tank sediments	Entry to panel tank or excavation/stockpiling of tank sediments	Workers, trespassers	Ingestion, dermal, inhalation of volatiles	Unlikely	OH&S procedures and PPE limit workers exposure to sediment. Associated risks are covered in inductions that all personnel and contractors must attend.
	Entry to panel tank	Birds, and potentially flying mammals such as bats	Ingestion, dermal, uptake	Possible	The presence of humans during stimulation activities is expected to deter majority of wildlife during operations. There is a possibility that birds and small mammals that can fly into the tanks may seek out the flowback water for drinking water or as a rest area.
	Panel tank sediment dries and sediments become windblown dusts	Workers, trespassers	Inhalation of dusts, indirect exposures through re-entrainment mechanisms	Possible	Sediments / residues are removed from site using vacuum truck and appropriately treated and disposed as soon as practicable.
	Panel tank sediment dries and sediments become windblown dusts	Native terrestrial fauna (mammals, reptiles, birds), terrestrial flora	Ingestion, inhalation of dusts, deposition of dust on foliage, uptake via roots	Possible	Sediments / residues are removed from site and appropriately treated and disposed as soon as practicable. Additionally, the height of the tanks should reduce potential dispersion of dusts to the environment. The volume of any residual sediment, mobilise as dust, from the panel tank is expected to be insufficient to adversely affect terrestrial flora.
Flowback water in panel tank	Working with panel tank inlet, liner, or extraction.	Workers	Ingestion, dermal, inhalation of volatiles, inhalation/ingestion of aerosols	Possible	OH&S procedures and PPE limit workers exposure to flowback water. Associated risks are covered in inductions that all personnel and contractors must attend.
	Entry (accidental or deliberate) to panel tank.	Trespassers	Ingestion, dermal inhalation of volatiles, inhalation/ingestion of aerosols	Possible	Trespassers entry is limited via remote location, height of panel tanks and signage. Trespassers can not be entirely precluded from areas.
	Entry to panel tank.	Birds, and potentially flying mammals such as bats	Ingestion	Possible	The presence of humans and stimulation activities is expected to deter majority of wildlife during operations. There is a possibility that birds and small mammals that can fly into the tanks may seek out the flowback water for drinking water or as a rest area.

Source	Exposure Scenario	Receptors	Exposure Pathways	Likelihood of Exposure Scenario	Comments
	Entry (accidental or deliberate) to panel tank.	Livestock	Ingestion	Unlikely	Panel tanks are approximately 2 m in height precluding potential exposure to livestock
Stimulation Chemicals	Spill, leak of well delivery system failure during surface handling. Supply or disposal vehicle accident on site	Workers	Ingestion, dermal inhalation of volatiles, inhalation/ingestion of aerosols indirect exposures through re-entrainment mechanisms	Unlikely	OH&S, PPE and spill containment, procedures adequately address this exposure. Associated risks are covered in inductions that all personnel and contractors must attend.
	Spill, leak of well delivery system failure during surface handling. Supply or disposal vehicle accident on site	Terrestrial fauna (mammals, reptiles, birds), terrestrial flora	Ingestion, dermal	Unlikely	The presence of humans and stimulation activities is expected to deter wildlife. The greatest hazard is to terrestrial flora in the immediate vicinity of a spill. Provided flora populations are not unique to the area of the well lease, re-colonisation is expected post-completion of stimulation activities.
Flowback Water	Spill, leak, delivery system failure or overflow	Workers, trespassers	Ingestion, dermal, inhalation (volatiles and aerosol)	Possible	OH&S procedures and PPE limit workers exposure to flowback water. Associated risks are covered in inductions that all personnel and contractors must attend.
	Spill, leak, delivery system failure or overflow	Terrestrial fauna (mammals, reptiles, birds), terrestrial flora	Ingestion, dermal, uptake via roots	Possible	The presence of humans and stimulation activities is expected to deter wildlife. The greatest hazard is to terrestrial flora in the immediate vicinity of a spill. Provided flora populations are not unique to the area of the well lease, re-colonisation is expected post-spill clean-up.

2.1.2 Off-site Exposure Pathways

The off-site environment is considered to be anything outside the boundary of the well lease. As discussed in Volume One the study area is sparsely developed with the predominant land use being for livestock. Volume One indicates the location of wells to be stimulated and indicates there are no major towns or homesteads within close proximity of a stimulation well.

As discussed in Volume One, published research indicates, on the basis of water level and water quality analysis (including major and minor ion chemistry and stable isotope analysis), that the surface water features in the study area (typically consisting of semi-permanent waterholes that form between episodic flood event) do not receive shallow groundwater recharge (Hamilton et al., 2005; Bunn et al., 2006; Costelloe et al., 2007, Cendon et al., 2010). The reported characteristic quality of groundwater in the shallow unconsolidated aquifers in the study area is saline, and the water quality and isotopic signature is distinct from that of the fresher water in the water holes of the Channel Country. In addition, reported water levels in the shallow aquifer are inferred to be below the base of the surface water features in the study area, such that water holes, and flowing river channels during flood events, are considered to be losing water features (i.e. exhibit leakage of water into the ground but do not receive groundwater baseflow). Hence, the potential exposure pathway comprising leakage of stimulation fluid down to shallow groundwater, off-site migration with groundwater flow and discharge to an aquatic environment associated with a surface water feature is considered to be an incomplete exposure pathway in the study area and has therefore been excluded from further consideration.

In the majority of instances, the well lease sites where stimulation will be conducted will be remote from water supply bores and will maintain an appropriate buffer distance from environmentally sensitive areas.

Table 3 provides a summary of the possible sources, exposure scenarios, human populations, ecological receptors and exposure pathways considered relevant for off-site. The main possible sources identified are the stimulation fluid, sediments in a panel tank and flowback water. These are discussed in more detail below.

2.1.2.1 Exposure to Stimulation Fluid

Potential human and ecological exposures to stimulation fluid is unlikely but theoretically could occur due to casing failures or through fractures into overlying aquifers. However, Santos currently uses an extensive system of procedures to minimise the likelihood of the fracture (and then the fluid) leaving the target area and the loss of well integrity; these are described in Volume One. The systems include extensive testing programs and operational and systems monitoring to ensure stimulation activities are confined to the target units. If a loss of integrity is identified in a well immediate measures are employed to decommission or rectify the situation.

On this basis it is considered unlikely that exposure to stimulation fluids could occur due to the fluid escaping the target formation and contaminating adjacent aquifers that are used for domestic or stock water supply.

This conclusion is supported by a study completed by Osborn et al (2011) which evaluated aquifers overlying the Marcellus and Utica shale formations of north-eastern Pennsylvania and upstate New York. The study evaluated a number of issues associated with stimulation including:

‘*Concerns for impacts to groundwater resources, from (i) fluid (water and gas) flow and discharge to shallow aquifers due to the high pressure of the injected stimulation fluids in the gas wells’*

The study evaluated groundwater from 68 private water wells which ranged in depth from 36 to 190 m. The area of the study is undergoing an expansion of gas well drilling and stimulation and is in an area with extensive fracture systems with several major faults and lineaments. The study found:

'*no evidence for contamination of the shallow wells near active drilling sites from deep brines and/or stimulation fluids*''

A second source of possible human and ecological exposure to stimulation fluids is residual fluid in the target formation. It is conservatively assumed that up to 40% of fluid may remain in the target formation immediately following stimulation. Based on the depth and separation of the target formations in the Cooper and Eromanga Basin, it is considered unlikely that exposure would occur if chemicals in the residual fluid migrate down gradient in the target formation. Residual stimulation fluids captured during the production stage of the well operations would act to reduce the residual volume in the reservoir over time and would be managed in accordance with the produced formation water management systems. In addition, stimulation fluid chemicals are likely to rapidly reduce through dissociation of organic chemicals and the relatively short biotransformation half-lives of the majority of the organic chemicals.

As indicated in Volume One, the results of the bore inventory in the study area indicated that the closest water supply bores installed in proximity of a hydrocarbon-bearing formation (Hooray Sandstone) to Santos production wells potentially targeting the same formation is approximately 45 km. Residual stimulation fluid constituents in groundwater would be expected to attenuate well within this distance. This conclusion is based on review of the information in the DES registered bore database, and the available results of an ongoing Water Bore Baseline Assessment program to verify the information in the database. This conclusion is subject to review, if warranted, on the basis of future bore inventory results and fracture locations.

2.1.2.2 Exposure to Sediments in the Panel Tank

Potential off-site human and ecological exposure to the sediment could occur if the panel tank is drained and the sediments were left to dry out and contribute to wind-borne dust. However, the majority of sediment is removed via vacuum truck and disposed of off-site. The volume of residual sediments in the panel tank is therefore considered to be small and unlikely to be of concern to either humans or ecological receptors. Additionally, the height of the panel tanks (approximately 2 m) is likely to minimise the potential for windblown dust to enter the environment.

2.1.2.3 Exposure to Flow Back Water

Potential off-site human and ecological exposure to chemicals in the flowback water is unlikely but could possibly occur under a range of conditions; however, the implementation of controls makes this unlikely. Exposure scenarios are considered unlikely to include the potential for releases or infiltration of flowback water into shallow aquifers that are used for domestic or stock water supply or which discharge to surface water, and direct releases to surface water.

For this exposure pathway to be complete there must be all of the following:

- A failure of the panel tank and the panel tank double lining.
- A high permeability unit beneath the well lease that is able to transmit the flowback water to an underlying aquifer; and
- A shallow aquifer present in the subsurface beneath the well lease, that is either used as water supply or discharges into a creek.

If any of the above conditions are missing, no exposure will occur. The surface lithology of the Cooper Creek drainage was described as comprising a thick layer of low permeability "mud" overlying sand beds that host the shallow, saline aquifer (e.g. Nanson et al., 2008). The fine-grained surface deposits would substantially reduce the potential for infiltration of leaking flowback water to reach the shallow aquifer, and the shallow "water table" aquifers have been reported to be saline to the extent that they are unsuitable for most beneficial uses (e.g. Cendon et al., 2010). The shallowest groundwater supply in the study area is typically sourced from either the Glendower Formation or the Winton Formation, which underlie the Quaternary unconsolidated sediments. Surface water bodies have been reported to be disconnected from the shallow groundwater system.

The concentrations of stimulation chemicals in the flowback water are expected to be lower than those injected due to the capture of first flush, although flowback water is likely to contain concentrations of 'geogenic' chemicals from the hydrocarbon reservoir. However, the toxicity of those chemicals is expected to rapidly decrease due to dissolution, the relatively rapid biodegradation and volatilisation of many of the chemicals. The likelihood of exposure to stimulation chemicals under this scenario in concentrations likely to be of concern is considered to be low.

2.1.2.3.1 Spills and Overflows from Panel Tanks

Potential off-site human and ecological exposure to flowback water is considered unlikely but could possibly occur in the event of a spill or overflow from the panel tank. However, the panel tanks are approximately 2 m in height and are adjusted (width and length ways) to be able to hold the maximum expected amount of flow back water and stormwater for a location. On this basis, a release could only occur during a prolonged period (weeks) of heavy rainfall. The probability of a spill or overflow event occurring is further reduced by minimising the duration that flowback fluids are stored in panel tanks. In addition, the toxicity of the chemicals in the flowback fluid are likely to rapidly reduce based on the dissociation of the inorganic chemicals, and the relatively short biotransformation half-lives of the majority of organic chemicals. In the event of a release, human and ecological receptors could possibly be exposed however sampling of soil, groundwater and surface water (if relevant) in the affected area would be required to determine if unacceptable exposures had occurred.

2.1.2.4 Management Measures to Reduce Off-site Exposure

Management measures that are implemented to reduce the potential for off-site exposure or to assess the potential for exposure include:

- Double lining of panel tanks to prevent seepage of flowback water into an underlying aquifer. This is already undertaken as a minimum standard.
- Establishment of buffers during establishment of well leases between petroleum operations and potential "environmentally sensitive areas" identified though database review and site-specific ecological assessment where warranted.
- Vacuum removal and disposal of the sediments during fluid drainage of the panel tank as soon as practicably possible.
- Soil, groundwater and surface water sampling of affected area following any spill/ overflow of a panel tank.

Table 3 provides a summary of the possible sources, exposure scenarios, populations and receptors and exposure pathways considered relevant for off-site exposure concerns.

Table 3: Off-Site Exposure Assessment Summary

Source	Exposure Scenario	Receptors	Exposure Pathways	Likelihood of Exposure Scenario	Comment
Stimulation Fluids	Fracture fluid escapes into aquifer via a well casing failure, or a fault/ fracture/ unconformity in formation/strata, and fluids enter aquifer used down gradient for stock and domestic water supply	Residents: adults and children Livestock	Ingestion, dermal, inhalation Ingestion	Unlikely	The exposure scenario is unlikely given the pathway linking source to receptor is predominantly absent. The shallowest occurrence of groundwater is generally at a depth that precludes hydraulic connection with surface water features resulting in a lack of GDEs within the study area. The well lease sites are remote with limited human inhabitants in the proximity of the operations – groundwater supply development is accordingly very limited, with large vertical or lateral separation of water supply wells from hydrocarbon reservoirs. Extraction of groundwater for domestic and livestock use is limited in the study area, as evidenced by the small number of registered bores (and even smaller number whose existence was confirmed during recent bore inventory and baseline assessment). The closest groundwater to surface water discharge points occur at significant distances down-hydraulic gradient of the well lease sites (i.e. of the order of 100 km or more). Exposure concentrations of stimulation chemicals at the receptor are likely to be insignificant. Management measures include Santos operational procedures i.e. well integrity testing and design of fracture to stay with the target formation. No recorded instances in peer-reviewed literature of stimulation chemicals in down gradient water supplies (Osborn et al 2011).
	Fracture fluid escapes into aquifer via a well casing failure, or a fault/fracture/unconformity in formation/strata, and fluids enter aquifer that discharges to surface water	Aquatic ecosystems	Direct exposure	Unlikely	
	Residual stimulation fluid in the formation migrates down gradient and enters a spring or water supply bore	Residents, aquatic ecosystems, livestock	Ingestion, dermal, inhalation	Unlikely	
Panel Tank Sediments	Panel tank sediment dry and become windblown dusts, contaminating surrounding soil	Native terrestrial flora and fauna, stock, Residents adults and children	Direct exposure/ inhalation/ ingestion of dusts	Unlikely	The majority of sediments / residues are removed from site using vacuum truck and appropriately treated and disposed as soon as practicable. Residual sediments are considered to be minimal.
Flowback Water	Seepage of chemicals to a shallow aquifer used downgradient for domestic water supply	Residents: adults and children	Ingestion, dermal, inhalation	Unlikely	Panel tanks are double lined as a minimum standard. The shallowest aquifer in the Quaternary sediments is reported to be very saline and is covered by a thick layer of low permeability mud which substantially limits

Source	Exposure Scenario	Receptors	Exposure Pathways	Likelihood of Exposure Scenario	Comment
	Seepage of chemicals to a shallow aquifer used downgradient for stock water supply	Livestock	Ingestion	Unlikely	infiltration. Extraction of groundwater for domestic and livestock use is limited in the study area, with a small number of bores whose existence was confirmed during a bore inventory. Identified bores are typically remote from the well lease operations, or access groundwater resources that would be very unlikely to be affected by surface seepage of flowback fluid; hence exposure pathway is considered to be incomplete.
	Seepage of chemicals to a shallow aquifer that discharges to surface water	Aquatic ecosystems	Direct exposure	Unlikely	
	Spill or leak from panel tank or tank overflow	Terrestrial fauna (mammals, reptiles, birds), terrestrial flora	Ingestion, dermal, uptake	Possible	Possible overflows during prolonged periods of high rainfall (>300 mm of rainfall required). The panel tank size is based on maximum expected flow back and environmental waters to try to prevent overflow. The greatest hazard is to terrestrial flora in the immediate vicinity of an overflow. Provided flora populations are not unique to the area, re-colonisation is expected post-overflow event. Likelihood of occurrence can be reduced through minimising storage duration, and transition to storage tanks for flowback water transport. The toxicity of fluid is likely to decrease rapidly due to short biotransformation half-lives of most chemicals.

2.2 Identification of Complete Exposure Pathways

2.2.1 On-site Exposure Pathways

The potential on-site exposure pathways are discussed in Section 2.1.1. The most likely potential exposures were evaluated for workers, trespassers, small fauna, flora and soil microorganisms.

Based on information provided by Santos, there does not appear to be complete exposure pathways identified for on-site workers under normal circumstances, provided the following conditions are met:

- Adequate OH&S procedures are adhered to that prevent direct contact and inhalation exposure with chemicals during spills and when handling flowback water or sediments; and
- Sediments in the panel tanks are disposed of appropriately and as soon as practicable.

Exposure of trespassers is considered to be an unlikely occurrence due to the nature of the sites and their remote locations. Exposure to flowback water is a complete exposure pathway (ingestion, dermal and inhalation) if trespassing occurs on unsecured sites. Exposure will be limited through ensuring all panel tanks are at least 2m in height with signage clearly displayed to indicate that the well lease is a work zone and access is restricted to authorised personnel.

Exposure pathways to the flowback water and dried sediments in the panel tanks for large native fauna (i.e. kangaroos) and livestock can be considered incomplete on the basis that the panel tanks are at least 2 m high and the majority of sediments are removed for off-site disposal.

Exposure pathways (direct contact) for small flora and fauna (i.e. soil microorganisms, plants, small mammals, snakes, lizards and birds) is considered complete for exposure to the flowback water in the panel tanks if a spill or leak was to occur or if birds or small mammals entered the tanks. Practical measures implemented by Santos will minimise potential exposures.

2.2.2 Off-site Exposure Pathways

The on-site exposure pathways are discussed in Section 2.1.2. The most likely potential exposures were evaluated for residents, livestock, native flora and fauna and aquatic ecosystems. Three possible sources were identified: stimulation fluids, sediments from the panel tank or flowback water.

Exposures were considered unlikely for all scenarios based on the engineering (liners) and operational controls that are being implemented by Santos, and the geographical remoteness of the stimulation activities. In the unlikely event that an uncontrolled release was to occur potential exposures could include direct contact and inhalation exposures for residents, livestock, native flora and fauna and aquatic ecosystems. The probability of a release from a panel tank occurring can be reduced through minimising the duration of flowback fluid storage. In addition, the toxicity of the chemicals in the flowback fluid are likely to rapidly reduce through dissociation of organic chemicals and the relatively short biotransformation half-lives of the majority of the organic chemicals.

The potential exposure to stimulation fluids due to entry into an overlying water supply aquifer via a well casing breach or a natural preferential pathway (fault/fracture) is considered unlikely. Santos has established operational procedures to foster well integrity and that fractures are contained within the target formation. The exposure pathways associated with residual fluid in the target formation is discussed in Section 2.1.2.1.

The potential exposure to residual sediments in the panel tank becoming windblown dusts (direct contact/inhalation and ingestion of dust) and contaminating surrounding soil is considered unlikely. Sediments are removed via a vacuum truck during fluid removal and the residual volume of tank sediments is likely to be insufficient to result in concentrations in soil that would be of concern in the surrounding terrestrial environment. Additionally, the height of the panel tanks (approximately 2m) would act to reduce sediments becoming windblown dusts.

The potential for seepage of flowback fluids from the panel tank into an underlying aquifer and migration to a domestic water supply or discharge into a creek are considered unlikely. Santos are using double lined panel tanks to prevent the loss of fluids onto the surface and subsequently into the subsurface. If releases were to occur, the typical surface lithology in the study area comprises a thick layer of fine-grained material overlying the sand beds that host a saline aquifer (e.g. Nanson et al., 1998). The fine-grained material will substantially reduce the infiltration potential of released fluids, and the shallowest aquifer is generally too saline for most beneficial uses (e.g. Cendon et al., 2010). The shallowest groundwater resource developed for water supply in the study area is the Tertiary Glendower Formation, which underlies the unconsolidated Quaternary sediments.

2.2.3 Residual Stimulation Fluids in Target Formations

The depths to oil target formations in the study area exceed 1,300 mbgl, and typical depths of stimulation operations targeting gas formations occur at depths greater than 2,000 m bgl. The exposure pathways associated with injected stimulation fluids are considered to include water supply bores screened either within the oil target formation itself, or in an aquifer formation immediately adjacent to the target formation.

2.2.3.1 Groundwater Extraction in the Eromanga Basin

Due to the depth (1,300 m bgl) and variable water quality of the oil target formations in the Eromanga Basin, and of the presence of shallower resources of suitable quality and yield, groundwater from the target formations is not typically used by the few pastoralists and residential users within the study area.

The following observations are made based on the proximity of water supply wells to oil and gas well locations in Volume One:

- The average offset between the base of the deepest (Hutton Sandstone) aquifer and the top of the Permian gas reservoirs is of the order of 200 to 300 m, with most of the intervening section consisting of impermeable mudstones and shales. However, landholder bores generally access the shallowest viable aquifer which, in the vicinity of the site, can be the shallow Glendower or Winton Formations. The vertical offset between these aquifers and the top of the gas-bearing Permian interval is of the order of 1,300 m to 1,800 m for the Glendower and 1,000 m to 1,500 m for the Winton.
- The active landholder bores in the oil fields of the *study area* range from approximately 3 to 10 km from the nearest proposed oil fracture stimulation target well. The upper-most formation proposed for stimulation is the Wyandra Sandstone (Upper Cadna-Owie). The nearest bore, Mt Margaret No 14, targets the relatively shallow Winton formation for stock purposes. The vertical distance at this location between the Winton Formation and the Wyandra Sandstone is at least 750 m.
- The active landholder bores within, or near, the gas fields of the *study area* range from approximately 45 to 90 km away from the nearest proposed stimulation location. The upper-most targets proposed for stimulation are formations within the Nappamerri Group. The vertical distance between the Hooray Sandstone and the Nappamerri group at this location is greater than 600 m; and
- The Coothero Bore was observed during the WBBA, and according to DEHP, targets the Hooray Sandstone for stock water. The Coothero Bore is located approximately 45 km from the nearest proposed location for gas production, and more than 80 km from the nearest location proposed for oil production from the Hooray Sandstone.

Hence, based on the available information, it appears unlikely that a complete exposure pathway exists in the study area for stimulation fluids to reach a water supply well.

2.2.3.2 Groundwater Extraction in the Cooper Basin

Due to the significant depth of the Cooper Basin aquifers, these have not been accessed for water supply and are only intercepted while targeting gas production. This is supported by WERD and DES (formerly DEHP) Groundwater Databases and a recent Water Bore Baseline Assessment.

While no known water supply wells are completed within the Cooper Basin, although significantly separated, water supply development in the Eromanga Basin is considered as the next vertically closest aquifer in the study area (as discussed above). However, the important water supply aquifers of the Eromanga Basin are separated from the Cooper Basin reservoir formations by a major structural unconformity and basal aquitard units of the Eromanga Basin, and therefore, hydraulic connection is limited.

Based on the absence of water supply development in the Cooper Basin formations, and the limited hydraulic connectivity and significant vertical distance between the Cooper Basin and Eromanga Basin formations, the potential for a complete exposure pathway for either an environmental or water supply receptor is considered to be very low.

3.0 PRODUCT DESCRIPTION

Halliburton provided chemical information for stimulation fluids (a.k.a, fluid systems), as follows:

- *DeltaFrac(H) Treatments'*
- *'DFS-BCG Treatments'*
- *'DFS-BCG(H) (formally HyborH) Treatments'*
- '*High Temperature Acid Spearheads*'.

Golder understands these fluids are used in SWQ stimulation operations, for stimulation oil and gas formations.

3.1 Chemical Constituents

A list of the individual stimulation fluid chemicals considered in this risk assessment and their respective Chemical Abstracts Service Registry numbers (CAS RN) are listed in Table 4. This list is similar to, but will inevitably vary from, other published sources of stimulation fluid compositions, as the specific stimulation fluid mixtures are proprietary products of the stimulation contractors and their product suppliers.

None of the stimulation fluid chemical constituents presented by Halliburton in the 13 July 2012 disclosure and in the information provided by Santos (November 2019) contained benzene, toluene, ethylbenzene, xylenes (BTEX) or polycyclic aromatic hydrocarbons (PAHs). It is noted, however, that TPH, PAHs and BTEX occur naturally in conventional oil and gas condensate and it is possible that these chemicals may naturally be present in the reservoir groundwater used in the stimulation process. In terms of the reaction by products of these chemicals none of the reaction by products are known to exhibit higher toxicity than the parent compounds. However, it is recognised that geochemical reactions in the formation are complex and there are knowledge gaps in this specific area.

Table 4: Stimulation Chemicals Sorted into Organic and Inorganic

Chemical Type	Chemical Name	CAS RN
Organic	Acetic acid	64-19-7
	Alcohols, C12-16, ethoxylated	68551-12-2
	Amine oxides, cocoalkyldimethyl	61788-90-7
	Benzaldehyde	100-52-7
	Cinnamaldehyde	104-55-2
	Citric acid	77-92-9
	Diethylene glycol	111-46-6
	Methanol	67-56-1
	Triethanol amine	102-71-6
	Diethanol amine	111-42-2
	Ethanol	64-17-5
	Hydrotreated light petroleum distillate	64742-47-8
	Sodium polyacrylate	9003-04-7
	Alcohols, C12-C15, ethoxylated	68131-39-5
	Amides, tall-oil fatty, N,N-bis(hydroxyethyl)	68155-20-4
	Fatty acids, tall-oil, ethoxylated	61791-00-2
	Butyl alcohol	71-36-3
	Tributyl tetradecyl phosphonium chloride	81741-28-8
	Glutaraldehyde	111-30-8
	Monoethanolamine borate	26038-87-9
	Guar gum	9000-30-0
	Ethylene glycol	107-21-1
	Hydroxylpropyl guar	39421-75-5
Inorganic	Aluminium oxide	1344-28-1
	Chlorous Acid, sodium Salt	7758-19-2
	Disodium octaborate tetrahydrate	12008-41-2
	Hydrochloric acid	7647-01-0
	Iron oxide	1309-37-1
	Sodium bisulfite	7631-90-5
	Sodium carbonate	497-19-8
	Sodium chloride	7647-14-5

Chemical Type	Chemical Name	CAS RN
	Sodium hydroxide	1310-73-2
	Sodium iodide	7681-82-5
	Titanium dioxide	13463-67-7
	Ulexite	1319-33-1
	Aluminium silicate	1302-76-7
	Crystalline silica, cristobalite	14464-46-1
	Crystalline Silica, quartz	14808-60-7
	Silica Gel	112926-00-8

3.2 Mass Balance Calculations

A quantitative mass balance assessment of stimulation fluid components was undertaken. Four ‘fluid systems’ were assessed. For each mixture, Halliburton provided to Santos 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 stimulation fluids and calculated total mass and injected concentrations of the individual chemicals are summarised in further detail in Table D1, APPENDIX C. The fluid compositions in Table C1 were divided into chemical additives, proppants, water in additives, and makeup water.

Mass and mass fraction calculations were undertaken by Santos based on information provided by the stimulation service provider in their “Stimulation Fluid Disclosure”. Table 5 presents the estimated mass (constituent weight) 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 5: Estimated Component Mass per Stimulation Event in Typical Stimulation Fluid Systems

Fluid System	DeltaFrac(H)	DFS-BCG	DFS-BCG(H)	High Temp. Acid Spearhead
Typical Fluid Volume [1]				
Mass of Stimulation Fluid Components (kg)				
Additives	566	1,904	2,064	307
Proppant	49,895	49,895	49,895	0
Water in additives	442	1298	1319	540
Makeup water	56,932	189,976	189,975	647
Proportion of Stimulation Fluid Components by Mass (%)				
Additives	0.5%	0.8%	0.8%	20.5%
Proppant	46.3%	20.5%	20.5%	-
Water in additives	0.4%	0.5%	0.5%	36.2%
Makeup water	52.8%	78.2%	78.1%	43.3%

Notes: [1]Fluid volume per stimulation event, information not provided at time of preparation of this report

The additives in typical stimulation fluid mixtures comprise approximately 0.5 to 0.8 wt.% of the injected mixture for the primary fluid systems (DeltraFrac(H), DFS-BCG and DFS-BCG(H)) 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 DeltraFrac(H), DFS-BCG or DFS-BCG(H) 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 1,840 kg to 12,000 kg.

Following completion of the stimulation process, a considerable volume of the injected stimulation fluids are recovered upon flowback of the injected fluid. Studies performed by the USEPA (2004) indicated that approximately 60% of the stimulation 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 stimulation fluid volume remains in the formation (this being the “worst case”) this would correspond to 120 to 830 kg per stimulation event, or 740 kg to 5,000 kg per production well where up to six stimulation stages are performed (excluding proppant).

4.0 AQUATIC HAZARD ASSESSMENT

An environmental hazard assessment was undertaken to classify the stimulation chemicals based on persistence (P), bioaccumulation (B) and toxic (T) potential (hereafter referred to as PBT). Using PBT, stimulation chemicals were classified into one of three hazard groups: low, moderate or high. Chemicals classified as high hazard were considered to be chemicals of potential concern (COPC). Identification of a chemical as a COPC did not indicate an unacceptable hazard, nor did it include an evaluation of whether there was a link between source, pathway, and receptor. A high hazard classification indicated the need to evaluate exposure to these chemicals in greater detail. A discussion of possible exposure pathways (to people and the environment) is presented later in Section 2.0 and a qualitative (in the absence of exposure concentrations) characterization of risk is presented in Section 7.0.

The environmental hazard assessment approach developed for this study used national and international guidance for assessment of PBT in the risk assessment, classification, and regulation of chemicals. The guidance used is predominantly focussed on hazard to aquatic receptors. The available guidance for assessment of hazard to terrestrial receptors is somewhat limited. Consequently, in the assessment of environmental hazard, aquatic and terrestrial toxicity were considered separately. This section presents the environmental hazard and includes assessment of toxicity to aquatic receptors. Section 5.0 presents the assessment of toxicity to terrestrial ecological receptors. Section 6.0 presents the human health toxicity assessment.

4.1 Chemical Information Sheets

In order to assess environmental hazard, readily available chemical and physical properties and aquatic ecotoxicological data were collated for the chemicals assessed. This information was compiled into a chemical information sheet for each chemical. The chemical information sheets are presented in APPENDIX E. The data used in the environmental hazard assessment of each chemical, are discussed in the following paragraphs.

4.1.1 Chemical and Physical Properties

Physical and chemical properties that affect the fate and behaviour of chemicals in the environment were used in the assessment of environmental P and B were obtained from the following sources in order of priority:

1) European Chemicals Agency (ECHA).
2) U.S. National Library of Medicine, National Center for Biotechnology Information, PubChem (PubChem).
3) Modelled data from USEPA (2009) EPISUITE™ (Estimation Programs Interface Suite™ for Microsoft® Windows) modelling software (only when data were not available from the SDS or the HSDB); and
4) For data poor chemicals, an internet search for reputable agencies or researchers who may have published data.
5) The Material Safety Datasheet (SDS) provided to Golder by the contractor (provided in APPENDIX B for reference).

USEPA (2009) EPISUITE™ software was developed by Syracuse Research Corporation (SRC) for the USEPA Office of Pollution Prevention and Toxics. EPISUITE™ provides a package of modelling software programs that can estimate physical/chemical, environmental fate and ecotoxicity data for organic chemicals. Inorganic chemicals should not be evaluated using EPISUITE™ because the estimation methods used are developed based on organic chemicals.

In using EPISUITE™, the following limitations for modelling organic chemicals are noted:

1) Chemicals that rapidly hydrolyse are unsuitable to be modelled namely, acid halides[2], isocyanates[3], sulphonyl chlorides[4], siloxanes[5], and alpha-chloro ethers. No chemicals identified in the list of stimulation chemicals considered for this study meeting this description were subject to modelling.
2) Data generated for organic salts may not be reliable, namely cationic salts of Group I, Group II, transition metals, Actinides, and Lanthanides. These should not be profiled because there are not adequate data in the estimation models' databases to predict properties with confidence. Organic salts however of Sodium (Na), Potassium (K), and Ammonium (NH_4^+) may be evaluated reliably. No chemicals identified in the list of the stimulation chemicals considered for this study meeting this description were subject to modelling.
3) Organo-metallic compounds should not be evaluated. No chemicals identified in the list of the stimulation chemicals considered for this study meeting this description were subject to modelling.
4) Highly reactive compounds should not be modelled. No chemicals identified in the list of the stimulation chemicals considered for this study meeting this description were subject to modelling; and
5) High molecular weight compounds with a molecular weight greater than 1000 should not be modelled. No chemicals identified in the list of the stimulation chemicals considered for this study meeting this description were subject to modelling.

The EPISUITE™ estimation programs are simple to use, requiring only one input (e.g., CAS RN or SMILES notation[6]) from the user and a nomination of the program to be used based on the data required by the user. EPISUITE™ includes a database of chemical and physical properties, algorithms, and Quantitative Structure Activity Relationships (QSAR) models with which to estimate parameters. The following programs were used to generate physical and chemical data for this study:

- KOWWIN™ - octanol/water partition coefficient (K_{ow}).
- HENRYWIN™ - Henry's Law Constant.
- BIOWIN™ - Biodegradation rate.
- LEV3EPI™ - Fugacity model to estimate partitioning to soil air, water and sediment.
- KOCWIN™ - Soil organic carbon partition coefficient (K_{oc}); and
- BCFBAF™ - Bioconcentration factor.

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[2] Acid halides are organic compounds containing the group -COX where X is a halogen atom (e.g., fluorine, chlorine, bromine, iodine). The inherent reactivity of acid halides precludes their free existence in nature; all are made by synthetic processes.

[3] Isocyanates are salts or esters of isocyanic acid, they are nitrogen based and may be described as neutral derivatives of primary amines. Isocyanates are represented by the general formula RNCO where R typically represents an alkly (a monovalent radical, such as ethyl or propyl, having the general formula CnH2n +1) or aryl (an organic group derived from an aromatic hydrocarbon by removal of one hydrogen), but sometimes is linked to elements such as sulphur (S), silicon (Si), phosphorous (P), nitrogen (N), or the halogens (e.g., fluorine, chlorine, bromine, iodine).

[4] Sulfonyl chlorides have the general formula R-SO_2-Cl which hydrolyse readily and are reactive with alcohols and amines.

[5] Siloxanes may be organic or inorganic and are made up of silicon, oxygen, plus (usually) carbon and hydrogen. They have the structural unit R_2SiO, where R is an alkyl group, usually methyl.

[6] SMILES (**S**implified **M**olecular **I**nput **L**ine **E**ntry **S**ystem) string is a linear notation for chemical structures.

4.1.2 Aquatic Toxicity Information

Acute and chronic aquatic ecotoxicological data were obtained from the following sources in order of priority:

1) USEPA (2009 and 2019) ECOTOXicology Database Version 4.0.
2) European Chemicals Agency (ECHA).
3) U.S. National Library of Medicine, National Center for Biotechnology Information, PubChem (Pubchem).
4) Safety Data Sheets (SDS) provided to Golder under this contract.
5) Australasian Journal of Ecotoxicology; and
6) Hazardous Substances Data Bank (HSDB, a toxicology database on the U.S. National Library of Medicine's Toxicology Data Network.

Where ecotoxicological data were not available for the chemicals of interest or a suitable surrogate, data were modelled using ECOSAR™ software version 1.11 dated July 2012. ECOSAR™ (which stands for Ecological Structure Activity Relationships) estimates the toxicity of chemicals to fish, aquatic invertebrates and microalgae in water. Toxic effect predictions are made using a set of QSARs models. QSARs predict the aquatic toxicity of untested chemicals based on their structural similarity to chemicals for which aquatic toxicity data are available. The toxicity data used to build the QSARs come from a database of publicly available and confidential data submitted to the US EPA New Chemicals Program. The QSARs used in ECOSAR™ correlate a compound's physicochemical properties and its aquatic toxicity within specific chemical classes and applies rules for selecting the appropriate chemical class for the compound. ECOSAR™ generates acute (short-term) toxicity and, when available, chronic (long-term or delayed) toxicity.

In using ECOSAR™, the following limitations are noted:

1) ECOSAR™, is designed to be used by individuals with some knowledge of environmental toxicology and organic chemistry, it is not designed to be used by individuals without experience in these fields.
2) Inorganic chemicals (e.g., sodium chloride, and non-polar inorganics such as titanium dioxide) should not be evaluated using ECOSAR™. No chemicals meeting this description identified in the list of stimulation chemicals considered for this study were subject to modelling.
3) Organo-metallic chemicals[7] should not be evaluated using ECOSAR™. No chemicals meeting this description identified in the list of stimulation chemicals considered for this study were subject to modelling.
4) For chemicals that rapidly hydrolyse or highly reactive chemicals it is suggested that evaluations using ECOSAR™ should take into consideration the degradation products in addition to the parent compounds. As a general rule, where:
    - Half-life < 1 hour, an assessment of degradation products may be recommended.
    - Half-life = 1 hour – 14-days, an assessment of parent and degradation products may be recommended.
    - Half-life > 14-days, an assessment of the parent product may be recommended.
5) Complex salts[8] with a complex organic cation and anion are difficult to model using ECOSAR™. In cases such as these the anion, cation and dissociation products should be taken into consideration. Based on the individual compounds it should be modelled as a single compound (neutralized with both cation and anion attached) or as separate individual compounds (dissociated with no charge). No

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[7] Organo-metalls are chemicals that contain carbon bonded to a metal species such as methyl mercury compounds.

[8] Complex salts such as potassium ferricyanide ($K_3Fe(CN)_6$) which consists of a complex ion that does not dissociate in solution, differ from simple inorganic salts such as sodium chloride (NaCl) that readily dissociates in solution.

chemicals meeting this description identified in the list of stimulation chemicals considered for this study were subject to modelling, either as a compounds or as individual components.

6) Compounds with a molecular weight greater than 1,000 should not be evaluated using ECOSAR™. However, many polymers are made up of dimers, trimers and oligomers with a molecular weight of less than 1,000 and therefore the individual components could be assessed using the ECOSAR™ model separately. No chemicals meeting this description identified in the list of stimulation chemicals considered for this study were subject to modelling, either as compounds or as individual components.
7) The ECOSAR™ model does not have the ability to take into consideration molecular conformation, and therefore cannot distinguish between stereoisomers, optical isomers, tautomers, or specific conformations. This is important as three-dimensional molecular properties or molecular conformation can be important as this relates to absorption, binding, and resulting toxicity potential of a chemical; and
8) Chemicals with unknown or variable composition (UVCs, such as oligomers, natural fats, or a product mixture) may have different results using ECOSAR™ depending on the composition assessed with the model. For chemicals such as these the representative structures would need to be identified and noted or all possible compositions would need to be assessed. No chemicals meeting this description identified in the list of stimulation chemicals considered for this study were subject to modelling.

4.2 Hazard Versus Risk

The approach presented in the following paragraphs is an assessment of environmental hazard, rather than environmental risk. Risk assessment of chemicals in the environment is based on a comparison between the levels to which an organism in a particular environmental compartment (e.g. water) is exposed, and a maximum level which an organism can tolerate based on a defined exposure scenario (in an environmental compartment) without significant adverse effect. The environmental hazard assessment presented herein, is not a risk assessment *per se* because it does not consider likely exposure concentrations for most of the stimulation chemicals. A qualitative assessment of the risk will be conducted based on an identification of relevant exposure pathways associated with the stimulation fluid COPC.

Approaches to ranking or screening chemicals for the purposes of assessing relative “hazard” or “risk” can include likelihood and consequence matrices. In these matrices, a chemical may be scored high for consequence (which may be a function of PBT) but low for likelihood (which may be a function of whether the chemical is considered likely to be present in the environment at hazardous concentrations). Overall, such a chemical may then score a relatively lower hazard or risk than would be identified from its consequence (or PBT) score alone. The environmental hazard assessment approach here works on the premise of potential for PBT; that is, the data that may apply to “consequence”. “Likelihood” of exposure was not assessed.

4.3 Hazard Assessment Approach

The environmental hazard assessment approach developed for this study is consistent with national and international guidance for assessment of potential for PBT in the risk assessment, classification, and regulation of chemicals. Physical and chemical properties that affect the fate and behaviour of chemicals in the environment (including degradation rates, partition coefficients, and aquatic ecotoxicological data) were used in assessment of environmental PBT potential.

The Australian National Framework for Chemicals Environmental Management (NChEM) guidance manuals were consulted in preparation of the environmental hazard assessment approach, namely:

- EPHC (2009a). Environmental Risk Assessment Guidance Manual for Industrial Chemicals; and
- EPHC (2009b). Environmental Risk Assessment Guidance Manual for Agricultural and Veterinary Chemicals.

These guidance manuals present the data requirements and methodology for assessment for environmental hazard and risk assessment of industrial and agriculture and veterinary chemicals, consistent with international best practice. NChEM guidance was prepared by the National Environment Protection and Heritage Council (EPHC) for the Department of the Environment, Water, Heritage and the Arts (DEWHA). DEWHA undertakes environmental risk assessments of industrial chemicals for the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) and of agricultural and veterinary chemicals for the Australian Pesticides and Veterinary Medicines Authority (APVMA).

In addition, the following literature was consulted for PBT assessment guidance:

- ANZECC and ARMCANZ (2000). Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, National Water Quality Management Strategy, Australian and New Zealand Guidelines for Fresh and Marine Water Quality, October 2000.
- ANZG (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia.
- CCME (2008) Canadian Council of Ministers of the Environment, The National Classification System for Contaminated Sites (NCSCS) Guidance Document.
- Christensen et al. (2003) Assessment Tools under the New European Union Chemicals Policy.
- Environment Canada (2003) Existing Substances Branch Guidance Manual for the Categorization of Organic and Inorganic Substances on Canada’s Domestic Substances List, Determining Persistence, Bioaccumulation Potential, and Inherent Toxicity to Non-human Organisms.
- European Commission (2003) Technical Guidance Document on Risk Assessment in support of Commission Directive 93/67/EEC on Risk Assessment for New Notified Substances, Part II Chapter 3 Environmental Risk Assessment.
- ECETOC (2005) Risk Assessment of PBT Chemicals.
- Franke et al. (1994) The Assessment of Bioaccumulation.
- Langley (1993) Refining Exposure Assessment. In: The Health Risk Assessment and Management of Contaminated Sites. Proceeding of the Second National Workshop on the Health Risk Assessment and Management of Contaminated Sites.
- Swann et al. (1983) A rapid method for the estimation of the environmental parameters octanol/water partition coefficient, soil sorption constant, water to air ratio, and water solubility. Residue Reviews; and
- UNECE (2011) Globally Harmonised System (GHS) of Classification and Labelling of Chemicals. Revision 4. Part 4 Environmental Hazards and Annex 9 Guidance on hazards to the aquatic environment.

The above guidance is predominantly focussed on hazard to aquatic receptors. Guidance for assessment of hazard to terrestrial receptors is limited. The following sources were consulted in developing an approach for assessment of hazard to terrestrial receptors (this is discussed later in Section 5.0):

- European Commission (2003) Technical Guidance Document on Risk Assessment in support of Commission Directive 93/67/EEC on Risk Assessment for New Notified Substances, Part II Chapter 3 Environmental Risk Assessment; and
- National Environment Protection Council (NEPC) (2013). National Environment Protection (Assessment of Site Contamination) Amendment Measure.

4.4 Environmental Hazard Classes

The environmental hazard assessment approach presented herein uses several lines of evidence (LOE) that were assessed in a weight of evidence (WOE) framework. Physical, chemical and toxicological parameters selected for assessment of potential for PBT were assigned values that equate to the following hazards:

- High Hazard
- Moderate Hazard; and
- Low Hazard.

Golder has refined this approach on a variety of projects including for assessment of stimulation chemicals. Hazard may be assessed using numeric or non-numeric approaches. Golder's experience using numeric indices is that greater sensitivity (than is possible) in the assessment of hazard is implied when generating statistical averages (e.g., to one or more decimal place). For example, using a numeric score of 1, 2, and 3 for low, moderate, and high hazard respectively for a variety of parameters, average scores of 1.7 or 2.2 could be obtained. These scores imply differences in hazard where none may be determined from the data assessed and the approach. Assessment of hazard via a non-numeric, descriptive approach avoids this and hence a non-numeric approach was used herein.

Hazard was assigned to individual parameters representative of P, B, or T. The LOE were used to assign an overall hazard classification (based on the WOE) for each chemical. There were no minimum data requirements (i.e. in some instances a hazard was evaluated on few data for each of P, B, or T). In order to quantify this uncertainty, a measure of data gaps was calculated for each chemical. In the assessment of T, the highest hazard assigned to either acute or chronic data was adopted as the final hazard classification for T. The approach for assessment of T differed from P and B because some chemicals have few aquatic ecotoxicological data. This resulted in weighting of the assessment towards T and is considered conservative and appropriate for a screening level risk assessment.

Not all the physical and chemical parameters collated for the stimulation chemicals presented in the chemical information sheets (refer to APPENDIX E) were used in the environmental hazard assessment.

The hazard benchmarks set for this study are considered a relative assessment. The benchmarks were assigned with the intent of incorporating the precautionary principle (i.e., designed to be inherently conservative and therefore biased towards capturing, rather than rejecting chemicals that are likely to pose PBT hazard).

The individual hazards assigned to the respective benchmarks for each parameter are presented in Section 4.6.

4.5 Assessment of Organic Versus Inorganic Substances

The approach for the aquatic hazard assessment of inorganic and organic substances differs. The approach for the assessment of inorganic substances[9] was devised based predominantly on guidance published by Environment Canada (2003). Following the Environment Canada (2003) approach, toxicity is considered in conjunction with persistence. The assessment of bioaccumulation potential of inorganic chemicals is more difficult to interpret in hazard assessment and was not included in the approach presented herein.

Non-metal-containing inorganic substances may be assessed following guidance for organic substances.

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[9] Inorganic substances may be described as metal-containing inorganic salts, organic-metal salts, and ionizable inorganics

Justification for the hazard assigned to the individual parameters and the adopted ranges are discussed in the following section.

4.6 Environmental Hazard Assessment Parameters

The physical, chemical and aquatic ecotoxicological data collated and assessed in the aquatic environmental hazard assessment are presented in the chemical information sheets (refer to APPENDIX E) and summarised in Table 6 below.

Table 6: Physical, Chemical and Toxicological Parameters Used in Environmental Hazard Assessment

PBT	Applicable to Organic / Inorganic Chemicals	Parameter	Units
Persistence	Inorganic / Organic	Solubility	mg/L
	Organic	Henry's Law constant	atm m3/mol
	Organic	log K_{oc}	L/kg
	Organic	EPISUITE™ Ready biodegradability	Qualitative
	Organic	EPISUTE™ Ultimate Biodegradation (Biowin 3)	Qualitative
	Organic	EPISUTE™ Primary Biodegradation (Biowin 4)	Qualitative
	Organic	EPISUTE™ Anaerobic Biodegradation (Biowin 7)	Qualitative
Bioaccumulation	Organic	BCF	unitless
	Organic	log K_{ow}	unitless
Toxicity	Inorganic / Organic	Aquatic ecotoxicological data for: Plants Invertebrates Fish Acute L(E)C50 Chronic NOEC Chronic LOEC/MATC//EC50	mg/L

The following sections describe in more detail the parameters used, the benchmarks set, and the hazard assigned.

4.6.1 Data Gaps

Where data were unavailable for a chemical, and/or data could not be modelled using EPISUITE™ the parameter was excluded from the environmental hazard assessment. An overall hazard was assigned for each of grouping for P, B and T based on the WOE (i.e., there were no minimum data requirements). In some instances, a hazard was evaluated on few data for each of P, B, or T. Because of this it was necessary to quantify the extent of data gaps. This is expressed as a percentage in the PBT summary in Table C2 (APPENDIX C).

4.6.2 Surrogates

Where data for listed chemicals were unavailable, data for a suitable surrogate chemical were adopted. Surrogate chemicals were selected on the basis of structural similarity (or structure activity relationships, SAR), functional groups present, relevant precursors or breakdown products, data availability, and professional judgement. The approach taken assumes that the chemical and physical parameters of the surrogate are predominantly the same as the chemical in question. Use of surrogates is supported by relevant guidance (Environment Canada, 2003; NEPC, 2013; and UNECE, 2011) and is considered to be scientifically defensible.

Where chemicals were assessed using a surrogate, this is documented in this report for transparency. Where chemicals could not be assessed using a surrogate, they were not assessed due to insufficient data.

4.6.3 Persistence

The approach for assessment of persistence for inorganic and organic chemicals differs.

Inorganic chemicals were not directly assessed for persistence, although high solubility (particularly compared with toxicity) was considered a potential hazard as this could lead to rapid uptake into organisms. Chemicals that are soluble through dissociation into simple anions and cations have been discussed separately.

Organic chemicals were assessed based on solubility, Henry's Law Constant, K_{oc}, and degradation rates.

4.6.3.1 Solubility

Aqueous solubility is measured in units of mg/L (or g/m^3) at temperatures of 20°C – 25°C. Aqueous solubility is temperature dependent. The solubility of a chemical will influence the rate of migration (or mobility) of that chemical in the environment. An increase in solubility leads to a decrease in adsorption to soil and greater mobility (Langley, 1993). Poor solubility may result in low bioavailability and lower biodegradation rates. A poorly soluble chemical may be considered to have a tendency to persist and therefore have more time to exert a toxic effect. Conversely, high solubility could also imply greater mobility, greater bioavailability and greater hazard. Solubility, rather than effective solubility[10], was adopted in this hazard assessment for simplicity. Effective solubility is a more accurate measure of chemical availability and mobility. However, effective solubility cannot be reliably predicted or modelled and is dependent on the chemical mixture and environmental factors (e.g. pH, temperature, oxidising or reducing conditions, etc). Solubility is a conservative and simple measure of mobility and availability of a chemical in groundwater and hence was used in this hazard assessment.

Organic substances with low water solubility typically have high predicted bioaccumulation factors and / or high log K_{ow} and hence may be considered highly bioaccumulative unless there is evidence to suggest otherwise (Environment Canada, 2003).

Inorganic substances generally need to be dissolved in water to exert deleterious effects (to aquatic receptors) and consequently solubility should be considered in conjunction with aquatic toxicity, as recommended by Environment Canada (2003). Environment Canada (2003) recommends that when the solubility of the substance is greater than the acute toxicity, the substance is likely to pose a hazard. Herein, the lowest acute ecotoxicological endpoint obtained for the chemical of interest was used for data considered in assessment of toxic potential). Where solubility data were not found for the inorganic chemicals considered, solubility was assumed to be greater than acute toxicity. This is conservative and results in a high hazard classification.

Low solubility was signed a high hazard (based on likelihood of persistence and high bioaccumulation tendency) for organic chemicals. Conversely, low solubility was assigned a low hazard for inorganic chemicals. The hazard category benchmarks adopted in this study are summarised in Table 7 and Table 8 for organic and inorganic substances, respectively. These were derived based on professional judgement (noting that the UNECE (2009) consider a substance with a solubility of less than 1 mg/L to be poorly soluble).

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[10] Effective solubility is the solubility of a compound that will dissolve from a chemical mixture (e.g., gasoline). The effective solubility of a compound from a chemical mixture is less than its aqueous solubility.

Table 7: Solubility Benchmarks for Organic Substances

Hazard Category	Hazard Symbol	Solubility (mg/L)
High Hazard	●	<10
Moderate Hazard	◖	10 – 100
Low Hazard	○	>100

Table 8: Solubility Benchmarks for Inorganic Substances

Hazard Category	Hazard Symbol	Solubility (mg/L)
High Hazard	●	>10
Moderate Hazard	◖	1 – 10
Low Hazard	○	<1

The benchmarks for the assessment of solubility in conjunction with aquatic toxicity for inorganic chemicals are presented in Table 9. The benchmarks were set following Environment Canada (2003). Because only two categories exist, a moderate hazard is not possible.

Table 9: Benchmarks for Solubility Considered in Conjunction with Acute Toxicity (Inorganic Substances)

Hazard Category	Hazard Symbol	Solubility & Toxicity (mg/L)
High Hazard	●	Solubility > Acute toxicity
Low Hazard	○	Solubility < Acute toxicity

4.6.3.2 *Henry’s Law Constant*

Henry’s Law is a partition coefficient which is a measure of the tendency of a substance to partition into air from water at constant temperature and pressure. It can be used as a measure of environmental fate and transport of a substance. Henry’s Law Constant is calculated using vapour pressure, molecular weight and water solubility for a chemical and is commonly expressed either as ‘dimensionless’ (i.e., no units) or in ‘dimensions’ (i.e., units of atmospheres (atm) m^3/mol or Pa m^3 mol-1). Henry’s Law Constant data were used in the environmental hazard assessment even though one of the parameters on which it is based (namely solubility) is assessed and scored separately.

Organic chemicals with a low Henry’s Law Constant (i.e., low volatility and high solubility) are likely to be more persistent in the environment. Organic chemicals with a high Henry’s Law Constant (i.e., high volatility, low water solubility) are likely to be less persistent in the environment. Organic chemicals with a low Henry’s Law Constant were considered to present a greater environmental hazard in this assessment.

Henry’s Law Constant benchmarks were assigned based on ranges provided in CCME (2008), Langley (1993) and professional judgement. The benchmarks are summarised in Table 10.

Inorganic chemicals were not assessed using Henry’s Law Constant.

Table 10: Benchmarks for Henry’s Law Constant

Hazard Category	Hazard Symbol	Henry’s Law Constant (atm m3/mol)
High Hazard	●	<6.1x10^{-09}
Moderate Hazard	◖	6.1x10-^{09}- 6.1x10^{-05}
Low Hazard	○	>6.1x10^{-05}

4.6.3.3 Soil Adsorption Partition Coefficient (K_{oc})

The soil organic carbon-water partitioning coefficient is the ratio of the mass of a chemical that is adsorbed in the soil per unit mass of organic carbon in the soil. It is a measure of the tendency for organic substances to be adsorbed by soil or sediment. K_{oc} values are useful in predicting the mobility of organic contaminants in soil and sediment. Higher K_{oc} values correlate to less mobile organic chemicals while lower K_{oc} values correlate to more mobile organic chemicals. Organic chemicals with lower mobility (greater persistence) are considered in this assessment to be a greater environmental hazard. The benchmarks for K_{oc} used are presented in Table 11. These benchmarks were derived after consideration of information provided in CCME (2008); Langley (1993) and Swann et al. (1983) and professional judgement.

Table 11: Log K_{oc} Benchmarks

Hazard Classification	Hazard Symbol	Log Koc Range (L/kg)
High	●	<3.7
Moderate	◖	2.7-3.7
Low	○	>2.7

4.6.3.4 Biodegradation

Degradation takes into account physical, biological, and chemical changes in a chemical over time (Langley, 1993). Biodegradation is “the process by which organic substances are decomposed by micro-organisms (mainly aerobic bacteria) into simpler substances such as carbon dioxide, water and ammonia” (UN, 1997 cited in OECD, 2010). The rate of biodegradation is generally described as percentage degradation over a period of days (28 days is often the benchmark), but sometimes longer or shorter exposure periods are reported. The longer the time taken for a substance to degrade, the more environmentally persistent that chemical is considered to be. Lower percentages of biodegradation over 28 days were considered to be indicative of higher environmental hazard.

The benchmarks assigned were based on guidance in Environment Canada (2003), UNECE (2011), the European Commission (2003) and professional judgement.

The following biodegradation data were sought:

- Aerobic Ready Biodegradability.
- Ultimate Biodegradation.
- Primary Biodegradation; and
- Anaerobic Biodegradation.

The use of more than one biodegradation measure was to capture appropriate measures of biodegradation for the likely environmental exposures to stimulation chemicals. Summary details of the tests are described below.

i) **Aerobic Ready Biodegradation**. The aerobic ready biodegradability test is considered a stringent test likely to generate slower degradation rates than may actually occur in the natural environment or in a sewage treatment plant. It employs a high concentration of the test chemical and biodegradation rates are measured via non-specific parameters such as dissolved organic carbon, biological oxygen demand, and carbon dioxide production. Ready biodegradability testing is commonly used as the first screen to test for biodegradation potential and employs the use of microorganisms that are not pre-adapted to degradation of the chemical substance. A negative result in a test for ready biodegradability does not necessarily mean that the chemical will not be degraded under relevant environmental conditions;

ii) **Anaerobic Biodegradation**. Anaerobic biodegradation testing is a screening test to measure the potential for biodegradation under anoxic conditions. The test substance (the only source of added organic carbon in the test) is exposed to diluted anaerobically digested sludge. Biodegradability of the test substance is measured via increased headspace pressure resulting from the evolution of carbon dioxide, methane and total inorganic carbon. The test is performed at 35°C to simulate the temperature in heated digesters or anaerobic sludge treatment. This temperature favours anaerobic biodegradation of chemicals with low or moderate toxicity to anaerobic bacteria. On the other hand, because this test uses a high concentration of test substance, negative results may be observed for some chemicals that would otherwise be biodegradable at lower concentrations. Anaerobic biodegradation half-lives were sought on the basis that the groundwater environment is likely to be anaerobic;

iii) **Ultimate Biodegradation**. Ultimate biodegradation[11] testing aims to measure the time taken for a test substance to biodegrade completely into simple molecules e.g. carbon dioxide, biomass, water and other inorganic substances like ammonia; and

iv) **Primary Biodegradation**. Primary biodegradation[12] testing measures the disappearance of the compound as a result of its biotransformation to another product.

A summary of the nominated aerobic ready biodegradation and anaerobic biodegradation benchmarks and the associated hazards assigned are presented in Table 12. These data were generated by EPISUTE™ BIOWIN™ and represent one of two potential outputs and hence a moderate hazard is not possible.

Table 12: Ready Aerobic and Anaerobic Biodegradation Benchmarks

Hazard Classification	Hazard Symbol	Aerobic Ready Biodegradability (EPISUITE™)	Anaerobic Biodegradation (EPISUITE™ BIOWIN 7)
High	●	No	≤0.5 Does not biodegrade fast
Low	○	Yes	≥0.5 Biodegrades fast

A summary of the nominated Ultimate Survey Biodegradation and Primary Biodegradation benchmarks and associated hazards are presented in Table 13. These data were generated using EPISUITE™ and BIOWIN™.

Table 13: Ultimate and Primary Biodegradation Benchmarks

Hazard Classification	Hazard Symbol	Ultimate Survey Biodegradability (EPISUITE™ BIOWIN 3)	Primary Biodegradation (EPISUITE™ BIOWIN 4)
High	●	<2 (2 equates to months, 1 equates to longer than months)	<2 (2 equates to months, 1 equates to longer than months)
Moderate	◖	2 – 3 (2 equates to months, 3 equates to weeks)	2-3 (2 equates to months, 3 equates to weeks)
Low	○	>3 (3 equates to weeks, 4 equates to days, 5 equates to hours)	>3 (3 equates to weeks, 4 equates to days, 5 equates to hours)

4.6.4 Bioaccumulation

Bioaccumulation potential was assessed for organic chemicals only and using two parameters: BCF and log K_{ow}, as discussed below.

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[11] Ultimate biodegradation is a measure of inherent biodegradability. Inherent biodegradability is similar to ready biodegradability testing with the exception that a low concentration of the test substance is used with a greater proportion of microorganisms that may be pre-adapted to the test substance. The conditions of an inherent biodegradation test are optimised to achieve rapid biodegradation. Inherent aerobic biodegradation data may over estimate the potential for biodegradation in the natural environment.

[12] Primary biodegradation is a measure of inherent biodegradability.

Bioaccumulation was not assessed for inorganic chemicals because the bioaccumulation of inorganic chemicals is difficult to predict and was considered beyond a screening level risk assessment.

4.6.4.1 Octanol / Water Partition Coefficient (K_{ow})

The octanol-water partition coefficient (K_{ow}) is the ratio of the solubility of a chemical in octanol divided by its solubility in water. It is a measure of the preference for an organic substance to dissolve in an organic solvent or water and is used as a measure of lipophilicity and movement of a substance across a cell membrane. It is usually expressed as Log K_{ow}. It can be used to estimate environmental fate and transport of a chemical.

There is general consensus in the literature that a Log K_{ow} of less than 3.5 represents low or moderate potential to bioaccumulate, and a Log K_{ow} of greater than 3.5 represents an increased potential to bioaccumulate. UNECE (2009) consider that substances with Log K_{ow} less than 4 have no potential to bioaccumulate. UNECE (2009) and CCME (2008) consider that substances with Log K_{ow} greater than 4 have the potential to bioaccumulate. The European Commission (2003) consider that substances with Log K_{ow} greater than 4.5 have the potential to bioaccumulate. The benchmarks used in this study are summarised in Table 14 and were largely based on the classes provided by European Commission (2003), UNECE (2009), CCME (2008) and professional judgment.

Log K_{ow} is assessed for organic chemicals only.

Table 14: Log K_{ow} Benchmarks

Hazard Classification	Hazard Symbol	Log Kow (unitless)
High	●	>5
Moderate	◖	3-5
Low	○	<3

4.6.4.2 Bioconcentration Factor (BCF)

The bioconcentration factor (BCF) is a measure of the tendency for a substance in water to accumulate in organisms, in particular fish. This parameter is an important determinant for uptake into organisms, potential for biomagnification and secondary poisoning (food chain transfer to higher trophic levels). The higher the BCF, the greater the potential for bioconcentration and secondary poisoning. The benchmarks assigned are summarised in Table 15. These benchmarks were assigned after consideration of information provided in ANZECC and ARMCANZ (2000), Franke et al. (1994), European Commission (2003), UNECE (2009) and professional judgment. The benchmarks presented by Franke et al. (1994) were more conservative than those presented by ANZECC and ARMCANZ (2000), the European Commission (2003) and UNECE (2009). As ANZECC and ARMCANZ (2000), European Commission (2003) and UNECE (2011) guidance were prepared with significant peer review by international scientific experts in their development, these guidance frameworks were given precedence over Franke et al. (1994). BCF was assessed for organic chemicals only.

Table 15: BCF Benchmarks

Hazard Classification	Hazard Symbol	BCF (unitless)
High	●	>5000
Moderate	◖	1000 - 5000
Low	○	<1000

4.6.5 Toxicity

There were frequently insufficient data to enable an assessment of both acute and chronic toxicity hence the highest hazard assigned to either the acute or chronic data was adopted as the classification of hazard for toxic (T) potential for the stimulation chemicals. This resulted in weighting of the assessment towards T. This was considered conservative and appropriate for a screening level hazard assessment.

4.6.5.1 Aquatic Ecotoxicology

To assess the toxic (T) potential of the chemicals, readily available acute (i.e., predominantly L(E)C_{50}[13]) and chronic (i.e., NOEC[14], LOEC[15], MATC[16] and non-lethal EC_{50}) data for aquatic organisms were collated.

Chronic aquatic ecotoxicology data are preferred over acute because exposure occurs over a longer time-period, usually during a significant period of the organism's life-cycle or during a sensitive life-stage. However, acute ecotoxicological data dominate in the literature compared to chronic data. Acute toxicity is relevant if the anticipated environmental exposure concentrations are in the acute toxicity concentration range. The receptor groupings considered (plants, invertebrates and fish) and endpoints considered (acute, chronic) were given equal weighting.

As freshwater aquatic organisms were considered the most likely aquatic receptor exposed to stimulation chemicals albeit the likelihood for exposure is low (refer Section 7.0), freshwater ecotoxicological data were used in the assessment of toxic potential. There are generally few aquatic ecotoxicological data available for amphibians and reptiles, and no guidance was found in the international literature on the assessment of hazard for these receptor groups. Hence these receptors groups were excluded from the assessment of T.

The data obtained from USEPA ECOTOX database were screened as follows:

- Endpoints selected included mortality (acute), growth (chronic) and reproduction (chronic) for plants, invertebrates and fish;
- Chronic mortality exposures were not considered.
- Studies longer than 7 d were considered to be chronic (with the exception of microalgae).
- Studies shorter than 24hrs were not considered; and
- L(E)C_x endpoints other than L(E)C_{50} were not considered (namely EC_0, EC_{100}, EC_{10}, EC_{20}, etc).

Although included in the environmental hazard assessment, NOECs are not statistical or empirical point estimates of ecological effect. NOECs are hypothesis-based and reflect the test design (i.e., concentrations of exposure) rather than the dose-response curve. However, NOECs are well documented in the literature and are commonly used in ecological risk assessment and in derivation of risk-based ecological guidelines (preferred endpoints are EC10s (Warne et al. 2018)). Additional chronic endpoints namely LOEC, MATC and EC_{50} were included in the hazard assessment to reduce the uncertainly associated with NOEC data.

Chronic data modelled using ECOSAR™ represent the geomean of NOEC and LOEC endpoints. Because the hazard assessment differentiated between NOEC and LOEC in assessment, these ECOSAR data were not used.

The chronic aquatic ecotoxicology ranges (for plants, invertebrates and fish) were assigned after consideration of information provided in European Commission (2003); UNECE (2009) and professional judgement. As a conservative approach to assessment of T, the lowest chronic effect concentration for each

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[13] Lethal (or effect) concentration that kills (or effects) 50% of the test population.

[14] No observed effect concentration.

[15] Lowest observed effect concentration.

[16] Maximum acceptable tolerable concentration.

of NOEC, LOEC/MATC/EC_{50}, and the lowest acute effect concentration for $L(E)C_{50}$ were used. The benchmarks adopted for chronic aquatic toxicological data are summarised in Table 16 and Table 17. The chronic studies represent non-lethal endpoints of growth and reproduction.

Table 16: Chronic Aquatic Toxicity NOEC Benchmarks

Hazard Classification	Hazard Symbol	Chronic Aquatic NOEC (mg/L)
High	●	<0.01
Moderate	◖	0.01 – 0.1
Low	○	>0.1

Table 17: Chronic Aquatic Toxicity LOEC/MATC/EC50 Benchmarks

Hazard Classification	Hazard Symbol	Chronic Aquatic NOEC (mg/L)
High	●	<0.1
Moderate	◖	0.1 – 1
Low	○	>1

The acute aquatic ecotoxicity benchmarks (for plants, invertebrates and fish) were assigned after consideration of information provided in European Commission (2003); UNECE (2005) and professional judgement. The acute aquatic toxicity benchmarks are summarised in Table 18. The acute toxicity studies represent lethal, growth and reproduction endpoints.

Table 18: Acute Aquatic Toxicity L(E)C/50 Benchmarks

Hazard Classification	Hazard Symbol	Acute Aquatic L(E)C50 (mg/L)
High	●	<1
Moderate	◖	1 – 100
Low	○	>100

4.6.6 Environmental Hazard Classification

The environmental hazard classification assigned was based on the WOE for multiple LOE. The classifications were based on the available data, even if there were data gaps. Consequently, a measure of data gaps was assigned to quantify this uncertainty.

It should be noted that T classifications for a number of chemicals were based on modelled, rather than measured data. The modelled ecotoxicological data were from ECOSAR™ (discussed in Section 4.1.2). There is uncertainty associated with modelled data. The one (1) chemical for which modelled toxicological data was used is shown below in Table 19.

Table 19: List of Chemicals Assessed Using Modelled ECOSAR™ Data

Chemical	CAS RN
Amine oxides, cocoalkyldimethyl	61788-90-7

Surrogate chemicals were used for chemicals where the physico-chemical and/or toxicological data were insufficient. The four (4) chemicals assessed using surrogates are presented in Table 20.

Table 20: List of Surrogate Chemicals

Chemical	CAS RN	Surrogate Descriptor
Amides, C18-unsaturated, N,N-bis(hydroxyethyl)	93-83-4	Surrogate for Amides, tall-oil, fatty, N,N-bis(hydroxethyl) (CAS RN 68155-20-4)
Tetra-n-butyl phophonium chloride	2304-30-5	Surrogate for Tributyl tetradecyl phosphonium chloride (CAS RN 81741-28-8)
Rection products of monoethanolamine and boric acid	94095-04-2	Surrogate for Monoethanolamine borate (CAS RN 26038-87-9)
Disodium octaborate tetrahydrate	12008-41-2	Surrogate for Ulexite (CAS RN 1319-33-1)

There was an additional chemical for which physico-chemical and/or toxicological data were insufficient and for which a suitable surrogate could not be found. This chemical is presented in Table 21 below and was not included in the environmental hazard classification assessment.

Table 21: Chemicals Not Assessed

Chemical	CAS RN
Hydroxylpropyl guar	39421-75-5

A further group of four (4) inorganic chemicals presented in Table 22 below were not assessed as these were considered to chemically equivalent to sand and therefore assessed as such.

Table 22: Chemicals Equivalent to Sand

Chemical	CAS RN
Crystalline silica, quartz	14808-60-7
Silica gel	112926-00-8
Aluminium silicate	1302-76-7
Crystalline silica, cristobalite	14464-46-1

Of the thirty-nine (39) stimulation chemicals assessed[17], thirty-four (34) were classified for hazard (excluding the sand compounds). Of these thirty-four chemicals, seventeen (17) were classified low hazard, ten (10) were classified moderate hazard, and seven (7) were classified high hazard. The remaining five (5) chemicals were not subject to PBT assessment as discussed earlier and presented in Table 21 and Table 22.

Five (5) chemicals, hydrochloric acid, sodium carbonate, sodium chloride, sodium hydroxide and sodium iodide were not scored for persistence as these chemicals readily dissociate in the environment. An additional chemical, guar gum was not scored for persistence as it expected to be readily biodegradable based on its composition (a polysaccharide composed of galactomannan).

The stimulation chemical environmental hazard classifications of the thirty-four (34) chemicals are summarised in Table 23, with the detailed PBT values for each chemical provided in Table C2, APPENDIX C.

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[17] Excluding hydroxylpropyl guar. Guar gum was assessed

Table 23: Stimulation Chemicals Environmental Hazard Classifications

Rank	Name For Report	CAS RN	Data Gaps %
High	Alcohols, C12-C15, Ethoxylated	68131-39-5	6%
	Surrogate for Amides, tall-oil, fatty, N,N-bis(hydroxyethyl)	93-83-4	11%
	Chlorous acid, sodium salt	7758-19-2	27%
	Disodium octaborate tetrahydrate	12008-41-2	18%
	Sodium bisulfite	7631-90-5	36%
	Sodium iodide	7681-82-5	82%
	Surrogate for Ulexite	12008-41-2	18%
Moderate	Alcohols, C12-16, ethoxylated	68551-12-2	67%
	Amine oxides, cocoalkydimethyl	61788-90-7	33%
	Cinnamaldehyde	104-55-2	33%
	Hydrotreated light petroleum distillate	64742-47-8	17%
	Fatty acids, tall-oil, ethoxylated	61791-00-2	33%
	Glutaraldehyde	111-30-8	11%
	Guar gum	9000-30-0	89%
	Sodium carbonate	497-19-8	64%
	Sodium hydroxide	1310-73-2	82%
	Titanium dioxide	13463-67-7	55%
Low	Acetic acid	64-19-7	33%
	Benzaldehyde	100-52-7	17%
	Citric acid	77-92-9	44%
	Diethylene glycol	111-46-6	39%
	Methanol	67-56-1	17%
	Triethanol amine	102-71-6	22%
	Diethanol amine	111-42-2	17%
	Ethanol	64-17-5	22%
	Sodium polyacrylate	9003-04-7	61%
	Butyl alcohol	71-36-3	28%
	Surrogate for Tributyl tetradecyl phosphonium chloride	2304-30-5	33%
	Surrogate for Monoethanolamine borate	94095-04-2	67%
	Ethylene glycol	107-21-1	22%
	Hydrochloric acid	7647-01-0	82%

Rank	Name For Report	CAS RN	Data Gaps %
	Sodium chloride	7647-14-5	27%
	Aluminium oxide	1344-28-1	82%
	Iron oxide	1309-37-1	73%

4.6.7 Identification of Chemicals of Potential Concern (COPC) to Aquatic Ecosystems

Based on the hazard classification of the stimulation chemicals (as presented in Table 23), the seven chemicals classified as a potential high hazard were considered to be COPC.

The certainty of the hazard classification varies depending on the extent of data gaps and the reliance on modelled data. The percent of data gaps were calculated and are presented in Table 23. The percentage data gaps for the high hazard chemicals ranged from 6% (Alcohols, C12-C15, Ethoxylated) to 82% (Sodium iodide).

4.6.8 Evaluation of Mixture Toxicity

The environmental hazard assessment did not directly consider the combined effects of the stimulation chemicals when present in a mixture. However, the approach of assessing individual chemicals for environmental risk assessment is inherently conservative and designed to over-estimate risk as a precautionary approach and so allow for the potential for some mixture toxicity beyond that exhibited by individual chemicals.

There is a limited, endorsed mixture toxicity assessment guidance in Australia and elsewhere. The Australian National Water Quality Management Strategy (ANZECC & ARMCANZ, 2000 and ANZG, 2018) guidance recommends the use of direct toxicity assessment (DTA) for assessment of mixture impacts on the environment. Direct toxicity assessment (DTA) entails collection of an environmental sample containing the chemical mixture and undertaking ecotoxicological testing (exposing test organisms to the environmental sample and measuring effect). DTA considers the nature of the receiving ecosystem (freshwater or marine), and the potential influence of environmental factors that can modify the effect of the stressor (such as water hardness on metal toxicity). DTA typically involves laboratory-raised cultures of test organisms that broadly represent various trophic levels in a receiving waterbody (e.g., fish, aquatic invertebrates, plants, algae).

The use of a more conservative assessment (screening level assessment) as adopted in this SRA is considered more appropriate than DTA for Santos' SWQ operations, because Santos is not authorised to discharge hydraulic fracturing fluids to a specific environment, and there is a wide diversity of potential receptors and receiving environments within the Santos SWQ Project Area that cannot easily be accommodated by DTA. The individual chemical assessment approach in this SRA is considered appropriate to meet the requirements of mixture toxicity assessment for the EA to ensure the protection of all ecological receptors.

4.7 Exclusions and Limitations

The environmental hazard assessment is a qualitative assessment of environmental hazard. The following limitations with regard to the hazard assessment and source data are noted:

- The approaches consulted for assessment of PBT in devising the environmental hazard assessment approach were predominantly focussed on the assessment of organic chemicals. There was limited guidance for PBT assessment of inorganic chemicals.
- The hazard assessment approach relied in part on professional judgment and the evaluator's subjectivity in designating the parameter ranges for each parameter assessed.

- The assessment did not consider, *inter alia*.
  - Breakdown or reactive products of the chemicals that may pose more or less of an environmental hazard than the parent compound.
  - The quality, adequacy or accuracy of the available information sourced, noting that only sources considered to be reputable were used.
  - Endocrine disruption effects that are not assessed by standard ecotoxicological tests.
- The environmental hazard assessment approach did not adequately assess chemicals which were:
  - Hydrophilic i.e., highly soluble with low K_{ow}. Where aquatic ecotoxicological data were limited for these types of chemicals, toxicity may be underestimated because there is potential for these chemicals to be highly toxic.
  - Poorly biodegradable, of low acute toxicity, but were bioaccumulative (based on the BCF or K_{ow}). These chemicals may exert chronic effects via accumulation in tissues over time.
- The data collated in the chemical information sheets (presented in APPENDIX E) were treated the same regardless of whether the data were measured experimental values or modelled / calculated values.
- It is noted in relation to the aquatic ecotoxicological data:
  - The species *Daphnia magna* are a sensitive species, frequently displaying sensitivity to chemicals orders of magnitude greater than other invertebrate species.
  - The test endpoint description in the (secondary) sources consulted was relied upon although it should be noted that true chronic and acute NOEC, LOEC, MATC and L(E)C50 depend on a variety of factors such as test duration, species tested, stage in the life-cycle, etc. which can only be verified by review of the primary literature.
  - Sources of Australian aquatic ecotoxicological data were consulted but the information was very limited. Furthermore, many species reported in the Australian literature were not necessarily indigenous species; and
  - There were no minimum data requirements (i.e. some chemicals were assessed based on few data for each of P, B, or T). In order to quantify this uncertainty, a measure of data gaps expressed as a percentage is identified in Table 23.

5.0 TERRESTRIAL TOXICITY ASSESSMENT

The previous Section (4.0) presented the assessment of environmental hazard based on P, B and T, where the toxic (T) potential was limited to aquatic receptors. As the following terrestrial receptors (soil microorganisms, plants and animals (vertebrates and invertebrates)) are considered possible or likely receptors[18] that may come into contact with stimulation fluid chemicals, an assessment of hazard to terrestrial receptors was developed in accordance with guidance presented in the following frameworks:

- European Commission (2003) Technical Guidance Document on Risk Assessment in support of Commission Directive 93/67/EEC on Risk Assessment for New Notified Substances, Part II Chapter 3 Environmental Risk Assessment; and
- National Environment Protection Council (NEPC) (2013). National Environment Protection (Assessment of Site Contamination) Amendment Measure.

5.1 Methodology

The methodology for selection, collation and assessment of terrestrial toxicological data for the purposes of assessing potential hazard to terrestrial receptors from the stimulation fluid chemicals is described in the following paragraphs.

Note that the approach for assessment of hazard to terrestrial receptors differs from the assessment of hazard to aquatic receptors presented in Section 4.3. Collation of physico-chemical and toxicological data for PBT hazard assessment (as was done with the aquatic toxicological data) was not undertaken. The available physical, chemical, and toxicological data were not considered sufficiently robust for a PBT assessment. Consequently, the chemicals of concern to terrestrial receptors were identified based on the terrestrial toxicological data. Physico-chemical data were then used to assess the likelihood for environmental exposure (discussed in Section 5.1.2 below). This approach results in a semi-quantitative or qualitative assessment of hazard to terrestrial receptors.

5.1.1 Terrestrial Toxicological Data Sources

Where terrestrial toxicological data are available, this may be limited to results from short-term tests using earthworms and plants, rather than (preferred) long-term test results (European Commission, 2003). Studies that assess effects on soil function are rarely available in the literature, and the potential for food chain transfer (e.g., secondary poisoning via bioaccumulation) is not assessed via ecotoxicological studies. This can pose challenges for development of soil screening criteria protective of terrestrial receptors. To address these data deficiencies, the approach developed was to use QSARs to predict toxicity (using aquatic data), and laboratory mammal toxicological data as lines of evidence to identify COPC for terrestrial receptors. This approach has been adopted in this report based on guidance in the European Commission (2003) and NEPC (2013). However, guidance on assessment of effects on soil function was not found during the preparation of this report.

The European Commission (2003) suggest that the equilibrium partitioning method can be applied to aquatic data to identify a probably no effect concentration (PNEC) for soil organisms. The equilibrium partitioning method uses aquatic toxicological data combined with chemical partitioning properties (between soil and water) and soil density to predict the toxicity to soil organisms. This method cannot replace toxicity data for soil organisms and should only be considered as a screen for identifying substances requiring further testing (EC, 2003). The Amended NEPM (NEPC 2013) similarly recommends the use of the equilibrium partitioning method only where QSARs are unavailable.

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[18] Note that the exposure pathway assessment of this report (Section 7.0) lists the sources, pathways of exposure, and receptors that may come into contact with the stimulation fluid chemicals.

The approach adopted was to draw from the large dataset of laboratory mammal (rat, mouse, rabbit) toxicological data and use these animals as surrogates for the potential mammalian terrestrial receptors (e.g., livestock and native mammalian fauna) that may come in contact with stimulation fluid chemicals on or near to a well lease. It is acknowledged that these data are limited in application as they generally comprise acute (LC50) data for receptors that are not of direct interest for exposures of terrestrial receptors in a stimulation risk assessment. Moreover, toxicological data from laboratory mammals are unsuitable surrogates for other terrestrial receptors such as reptiles, birds, invertebrates and plants.

The following sections (5.1.1.1 to 5.1.1.2) list the sources of information and data used to collate and generate terrestrial toxicological data.

5.1.1.1 Toxicological Databases

Laboratory mammalian, earthworm, plant and bird data were sourced from readily available databases and literature. Acute oral LD50 laboratory data for rats, mice and rabbits were selected from sources such as the European Chemicals Agency (ECHA), U.S. National Institute of Medicine (PubChem) and USEPA ECOTOX. The studies used to generate laboratory mammal data are designed with the aim of assessing chemical hazard to human health. Consequently, the relevance of these studies to Australian mammalian receptors is uncertain. Given the paucity of terrestrial toxicological data for the stimulation fluid chemicals on Australian fauna, rabbits and mice were considered as the best surrogates for mammalian receptors potentially present on well leases.

Earthworm data were used where the toxicological endpoint was mortality or reproduction and reported in units of milligrams of chemical per kilogram soil (mg/kg). Earthworm studies with other endpoints (e.g., behaviour) and/or units in other forms (e.g., micro-grams per cm^2) were not considered.

Similarly, plant data were used where the toxicological endpoint (e.g., NOEC) was reproduction or population (e.g., biomass or abundance) and reported in milligrams of chemical per kilogram of soil (mg/kg). Plant studies with other endpoints (e.g., foliar damage) and/or units in other forms (e.g., % or mg/mL of applied solution) were not considered.

5.1.1.2 QSARs

As indicated previously, QSARs are empirical relationships between the toxicity of contaminants to a particular test organism and one or more physicochemical properties of the contaminant (NEPC 2013). QSARs are derived for contaminants with either the same mechanism of action or similar molecular structure (NEPC 2013).

Three QSARs were used to derive additional terrestrial data for this report. NEPC (2010) reference the QSAR of Huzelbos et al. (1991) which predicts the concentration at which 50% growth inhibition (EC50, in units of micro-mol per litre) in lettuce (*Lactuca sativa*) would occur. The equation for the QSAR uses the chemical property log K_{ow} (described in Section 4.6.4.1 and recorded on the chemical information sheets). The QSAR equation of Huzelbos et al. (1991) is:

$\log EC50 = -0.72 \log K_{ow} + 3.37$

The Hulzelbos et al. (1991) QSAR was used to predict toxicity of organic chemicals to terrestrial plants, acknowledging that lettuce is not a native flora species, nor of relevance as receptor on a well lease. This QSAR provided the main dataset of terrestrial plant toxicity for the chemicals assessed. It could not be used for inorganic chemicals.

The second QSAR used was that of van Gestel (1992), which predicts the toxicity of earthworms (as the NOEC) in units of mg chemical per kg soil. This QSAR is referenced both by the European Commission (2003) and NEPC (2013) and uses equilibrium partitioning to predict the toxicity of a chemical in soil using aquatic toxicity data. It is not suitable for chemicals with a log K_{ow} greater than 4 or for chemicals with a specific mode of action (e.g., endocrine disruptors).

The van Gestel (1992) QSAR was used to predict the toxicity of organic chemicals to earthworms and uses soil density (RHO in kg soil per m^3 of soil) and the soil to water partitioning coefficient (K_d in m^3 water per m^3 soil), in combination with the NOEC (in mg/L) for the aquatic environment. The equation is:

$NOEC_{soil} = K_d/RHO_{soil} * NOEC_{water} * 1000$

The soil to water partitioning coefficient (K_d, m^3water/m^3soil) is a function of both the fraction organic carbon content (f_{oc} in kg organic carbon per kg of soil) of soil and the soil organic carbon partitioning coefficient (K_{oc} in L water per kg organic carbon), and the equation is:

$K_d = f_{oc} \times K_{oc}$

An f_{oc} of 0.01 and bulk density of 1.6 g/cm^3 for soil was assumed in the use of this QSAR.

The third QSAR used was that used in the ECOSAR™ modelling programme. The programme uses the log K_{ow} to estimate toxicity (14-day LC50) to earthworms in units of mg/L. The equation is:

$\text{Log 14-d LC50 (mmol/L)} = - 0.1037 \log K_{ow} + 0.4476$

The programme converts the units from mmol/L to mg/L. ECOSAR™ was used to estimate the toxicity of the stimulation fluid chemicals to earthworms.

5.1.2 Use of Physico-chemical Data

Following guidance in NEPC (2013), the relative importance of an exposure pathway to a terrestrial receptor can be determined by assessment of the chemicals-specific properties, and the soil-specific properties that affect chemical bioavailability and environmental fate. Some physicochemical properties of chemicals, for example, partitioning between octanol and water (K_{ow}), partitioning from soil to water (K_d), and volatility (using Henry's law constant (K_H)), can be used to predict the most important exposure pathways for a chemical in terrestrial environments. Organic and inorganic chemicals have different physicochemical properties that control their environmental fate. Consequently, different methods apply to assessment of organic vs. inorganic chemical exposures in terrestrial environments.

The environmental fate of organic chemicals is largely controlled by the following physicochemical properties:

- Half-life (t ½), Table 24.
- Henry's Law Constant (K_H), Table 25; and
- The octanol-water partition coefficient (K_{ow}) which, in general, determines a chemicals potential to cause secondary poisoning.

5.1.2.1 Half-life

The half-life (t½) of a chemical is a measure of persistence (P) in the environment. It represents the time taken for 50% of the chemical to be lost from the environment. The loss may occur through biodegradation (microbial mediated degradation) or abiotic pathways (hydrolysis, oxidation, reduction, etc.). The more persistent a contaminant in the environment (that is, larger t½), the longer is the potential exposure time of species to the contaminant and the more deleterious the effects that could occur (NEPC 2013).

Table 25 (taken from NEPC 2013) provides benchmarks for assessment of persistence in terrestrial ecosystems using half-life.

Table 24: Half Life Benchmarks

Classification	T ½ (Days)
Degrades Fast	<22.5
Degrades Moderately Fast	22.5 – 45
Degrades Slow	>45

5.1.2.2 Henry's Law Constant

Henry's law constant (K_H) is a measure of the volatility of a chemical. The higher the volatility (or value of K_H) the more of the contaminant will volatilise and be found in the soil air spaces and in the atmosphere. K_H is a temperature-dependent constant. Vapour transport for many contaminants may constitute an important pathway of loss and exposure to organisms (NEPC 2010). Together with half-life (t ½) of the chemical, K_H was used to assess the potential for transfer and persistence of the chemical in the soil.

NEPC (2013) have provided benchmarks for assessment of volatility of chemicals in terrestrial ecosystems. This is reproduced in Table 25 below.

Table 25: Henry's Law Constant Benchmarks

Classification	Henry's Law Constant (dimensionless)
Highly volatile (H)	$>2.5 \times 10^{-3}$
Moderately volatile (M)	2.5×10^{-7} - 2.5×10^{-3} *
Not volatile (L)	$< 2.5 \times 10^{-7}$

* It is noted that NEPC (2013) provides a range for moderately volatile of $2.5\text{x}10^{-7}$ to $2.5\text{x}10^{-5}$, leaving two orders of magnitude ($2.5\text{x}10^{-5}$ to $2.5\text{x}10^{-3}$) unclassified. It was assumed that this was an error and the moderately volatile range has been extended from $2.5\text{x}10^{-5}$ to $2.5\text{x}10^{-3}$.

5.1.2.3 Octanol-Water Partition and Organic Carbon-water Coefficient

The octanol-water partition coefficient (K_{ow}) is the ratio of the concentration of a chemical that is dissolved in n-octanol to that dissolved in water at equilibrium and at a specified temperature. It is used to estimate the potential for chemicals to accumulate in tissue, both plant and animal (NEPC, 2013).

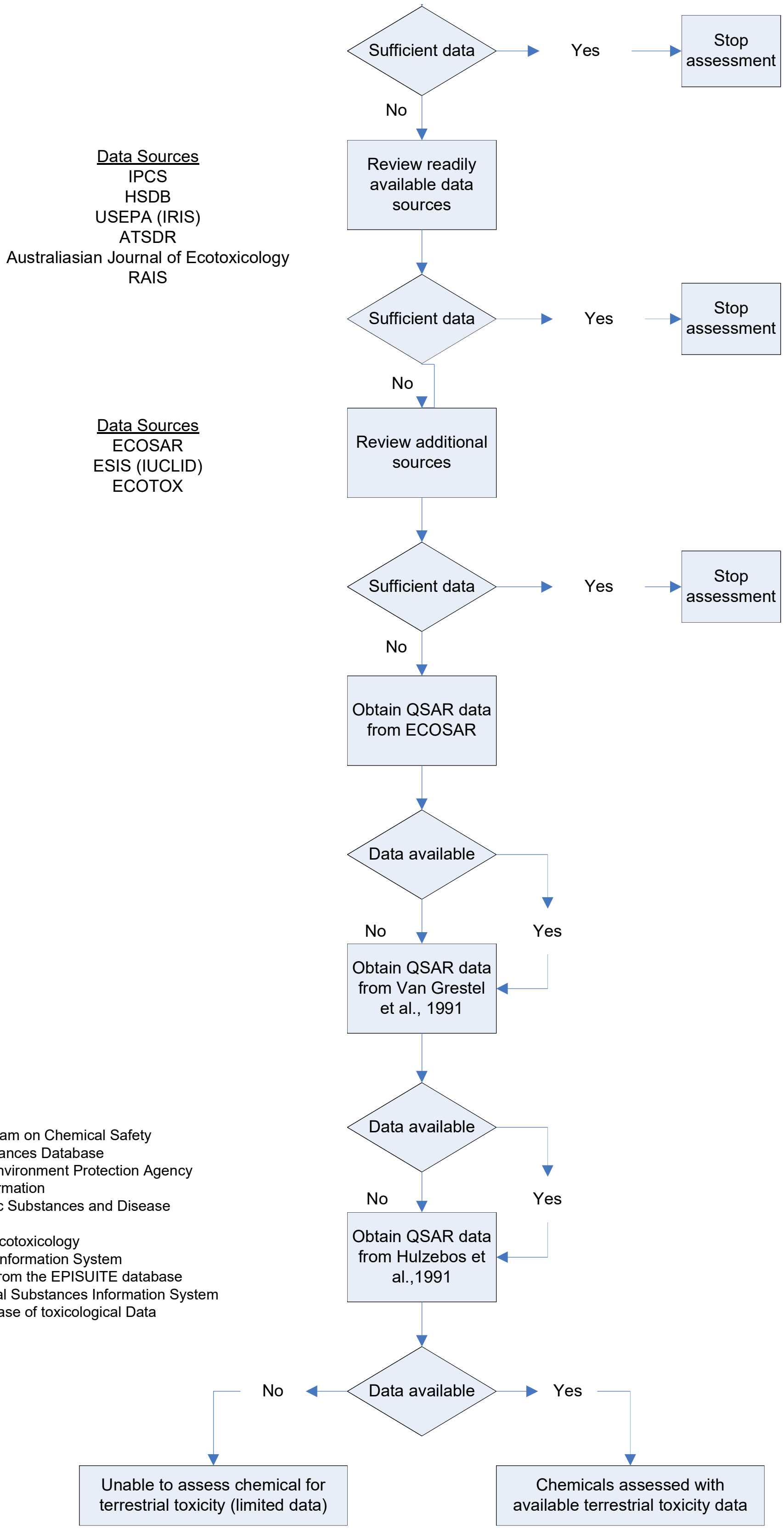
Chemicals with high log K_{ow} values are more likely to accumulate in plants and soil invertebrates than chemicals with low K_{ow} values. If further magnification of these chemicals occurs in the food chain, a predator might experience toxicity while its prey does not. This effect is known as secondary poisoning. Chemicals with log K_{ow} values below 3 were not considered to biomagnify. Chemicals with log K_{ow} values greater than 4 were considered to be highly fat soluble and lipophilic, and therefore posing the potential to biomagnify and result in secondary poisoning.

For the purpose of this report, and consistent with NEPC (2013), the log K_{ow} values of chemicals were divided into two classes. These were:

- Low, log K_{ow} <4: the chemical has a low potential to biomagnify.
- High, log K_{ow} ≥ 4: the chemical has a high potential to biomagnify.

5.1.3 Summary of Approach

In summary, toxicological data, as guidelines, as measured endpoints (e.g., LD50) or based on measurement data (e.g. PNEC) or as modelled data from QSAR were collated in a step-wise process. Figure 1 indicates that steps followed for the collection of terrestrial toxicological data.



Notes
IPCS : International Program on Chemical Safety
HSDB : Hazardous Substances Database
USEPA : United States Environment Protection Agency
IRIS :Integrated Risk Information
ATSDR : Agency for Toxic Substances and Disease Registry
Australiasian Journal of Ecotoxicology
RAIS : Risk Assessment Information System
ECOSAR : Toxicity data from the EPISUITE database
ESIS : European Chemical Substances Information System
ECOTOX : USEPA database of toxicological Data

Figure 1: Approach Used for Collation and Generation of Terrestrial Toxicological Data

5.2 Results

Out of the thirty-nine (39) chemicals assessed (one (1) chemical was not assessed due to insufficient data and four (4) were not assessed because they were considered to be sand, refer to Table 21 and Table 22 in Section 4.6.6). In addition to the chemicals listed in Table 21 and Table 22, eight chemicals (aluminium oxide, chlorous acid sodium salt, hydrochloric acid, iron oxide, sodium chloride, sodium hydroxide, sodium iodide and titanium dioxide) were unable to be assessed for terrestrial toxicity due to lack of available data. It is noted that the chemicals unable to be assessed comprise inorganics for which bioaccumulation is unlikely to be of concern. In addition, most of these chemicals will dissociate in the environment to anions and cations.

5.2.1 Mammalian Acute Oral LD50

Acute oral LC50 data for mammals were found for twenty-five (25) of the chemicals. The lowest LD50 value for rats, mice and rabbits was selected and are presented in Table 26.

5.2.2 QSAR data

The lettuce EC50 of Huzelbos et al. (1991) was used to predict plant toxicity for fourteen (14) of the organic chemicals. Whilst the EC50 for this QSAR reports in micromole per litre, the units were not altered as the output was used as a process to rank chemicals against each other, not as an absolute measure of toxicity. Of the fourteen (14) chemicals assessed it should be noted that eleven (11) were derived using a log Kow < 1 which reduces the reliability of the outcome (as indicated in Huzelbos et al. 1991). As a result, these eleven compounds were not used in determining the final hazard assessment. The results of this QSAR are also shown in Table 26.

The QSAR of van Gestel (1992) was used to predict soil invertebrate toxicity for fourteen (14) organic chemicals. The results of this QSAR are also shown in Table 26.

The earthworm QSAR of the ECOSAR programme in EPISUITE was used to predict toxicity to earthworms of seventeen (17) chemicals. The results of this QSAR are shown in Table 26.

5.2.3 Summary of Toxicological Data

A summary of the terrestrial toxicological data (including measured and modelled) collated is presented in Table 26 below.

Table 26: Summary of Terrestrial Toxicological Data

Chemical	CAS RN	EC/LC50 Earthworm[1] (QSAR) (mg/L)	Lowest LD50 mammals (mg/kg/bw)	EC50[2] lettuce (QSAR) (mg/L)	LC50 Soil invertebrate[3] (QSAR) (µg/kg)
Acetic acid	64-19-7	1649	600[4]	0.210*	9.3
Alcohols, C12-C16, Ethoxylated	68551-12-2		4500[4]		977120
Amine oxides, cocoalkydimethyl	61788-90-7		846[5]		
Benzaldehyde	100-52-7		27.8[5]	0.245	
Cinnamaldehyde	104-55-2		200[6]	0.265	46.7
Citric acid	77-92-9	8030	3000[4]	0.874*	27500
Diethylene glycol	111-46-6	423	3300[6]	0.470*	31250
Methanol	67-56-1	105	5628[6]	0.126*	231
Triethanolamine	102-71-6		2200[7]	0.610*	29375
Diethanolamine	111-42-2		1100[8]	0.462*	25
Ethanol	64-17-5	134	2000[8]	0.167*	1800
Hydrotreated light petroleum distillate	64742-47-8	108	>5000[8]		
Sodium polyacrylate	9003-04-7		>1000[9]		
Alcohols, C12-C15, Ethoxylated	68131-39-5		>5000[8]		
Surrogate for Amides, tall-oil, fatty, N,N-bis(hydroxyethyl)	93-83-4		10000[8]		
Fatty acids, tall-oil, ethoxylated	61791-00-2	351	10000[10]		
Butyl alcohol	71-36-3	170	1200[8]	0.196	28779
Surrogate for Tributyl tetradecyl phosphonium chloride	2304-30-5	162	300[8]	1.091*	739556
Glutaraldehyde	111-30-8		27[11]	0.363*	2.3
Surrogate for Monoethanolamine borate	94095-04-2		2000[8]	1.132*	2957
Guar gum	9000-30-0		7060[12]		
Ethylene glycol	107-21-1	232	4000[13]	0.270*	100
Aluminium oxide	1344-28-1				
Chlorous Acid, Sodium Salt	7758-19-2				
Disodium Octaborate Tetrahydrate	12008-41-2		2550[8]		

Chemical	CAS RN	EC/LC50 Earthworm[1] (QSAR) (mg/L)	Lowest LD50 mammals (mg/kg/bw)	EC50[2] lettuce (QSAR) (mg/L)	LC50 Soil invertebrate[3] (QSAR) (µg/kg)
Hydrochloric Acid	7647-01-0				
Iron oxide	1309-37-1				
Sodium bisulfite	7631-90-5		1420[8]		
Sodium Carbonate	497-19-8	194			
Sodium Chloride	7647-14-5				
Sodium Hydroxide	1310-73-2				
Sodium Iodide	7681-82-5				
Titanium dioxide	13463-67-7				
Surrogate for Ulexite	12008-41-2		2550[8]		

1 ECOSAR (2012)
2 Huzelbos et al. (1991)
3 van Gestel (1992)
4 International Uniform Chemical Information Database (IUCLID) (2012)
5 International Program for Chemical Safety (INCHEM) (2012)
6 Hazardous Substances Data Bank (HSBD) (2012)
7 U.S. National Institute of Medicine PubChem (PubChem) (2020)
8 European Chemical Agency (ECHA) (2020)
9 European Human and Environmental Risk Assessment Program (HERA) (2014)
10 European Chemical Agency (ECHA) (2018)
11 European Chemical Agency (ECHA) (2019)
12 USEPA Federal Register (FR) (2011)
13 ATSDR 2010 US Agency for Toxic Substances and Disease Registry (ATSDR) (2010)
* based on a log Kow of <1.

5.3 Hazard Assessment

5.3.1 Toxicological Data

Examination of the data in Table 26 above does not provide consistent findings between data sources for highest hazard chemicals.

For the organic chemicals, for which the most data are available, the three most hazardous chemicals using the different techniques are shown in Table 27 below:

Table 27: Highest Hazard Organic Chemicals for Terrestrial Receptors Using the Different Datasets

Mammalian LD50 data	Lettuce QSAR (Huzelbos et al. 1991)*	Invertebrate QSAR (van Gestel 1992)	Earthworm QSAR (EPISUITE)
Glutaraldehyde	Butyl alcohol	Glutaraldehyde	Methanol
Benzaldehyde	Benzaldehyde	Acetic acid	Hydrotreated light petroleum distillate
Cinnamaldehyde	Cinnamaldehyde	Diethanolamine	Ethanol

*Excluding data for those chemicals with LogKow<1

On the basis of Table 27, nine organic chemicals: glutaraldehyde, benzaldehyde cinnamaldehyde, butyl alcohol, acetic acid, diethanol amine, methanol, ethanol and hydrotreated light petroleum distillate have the highest toxicity to terrestrial plants and invertebrates. These chemicals were assessed for persistence and bioaccumulation using the physico-chemical data described in Section 5.1.2 and are discussed further in Section 5.3.2.

Data for the inorganic chemicals were limited. The three QSARs could not be used. NEPC (2013) provides only limited discussion on how the environmental fate and persistence of inorganic substances should be assessed. Further assessment of the hazards of the inorganic chemicals to terrestrial receptors has not been undertaken. The three highest hazard inorganic chemicals ranked using the mammalian LD50 data are:

- Sodium carbonate.
- Disodium carbonate tetrahydrate; and
- Sodium bisulfite.

5.3.2 Persistence and Bioaccumulation of the Organic Chemicals

The nine high hazard organic chemicals identified in Section 5.3.1 were classified based on the half-life as described in Section 5.1.2.1. Glutaraldehyde, benzaldehyde and cinnamaldehyde were the most persistent with moderate half-lives. Butyl alcohol, acetic acid, diethanolamine, methanol, ethanol and hydrotreated light petroleum distillate were the least persistent with fast half-lives (Table 28).

Table 28: Soil Half-life (t ½) Classification for High Hazard Organic Chemicals

Chemical	CAS RN	Half-life in Soil (days)	Half-life in Soil (t ½) Classification
Glutaraldehyde	111-30-8	30	Moderate
Benzaldehyde	100-52-7	30	Moderate
Cinnamaldehyde	104-55-2	30	Moderate
Butyl alcohol	71-36-3	17.3	Fast
Acetic acid	64-19-7	17.3	Fast

Chemical	CAS RN	Half-life in Soil (days)	Half-life in Soil (t ½) Classification
Diethanolamine	111-42-2	17.3	Fast
Methanol	67-56-1	17.3	Fast
Ethanol	64-17-5	17.3	Fast
Hydrotreated light petroleum distillate	64742-47-8	17.3	Fast

The nine high hazard organic chemicals identified in Table 28 were classified based on the Henry's Law constant benchmarks presented in Section 5.1.2.2; the results are summarised in Table 29. Diethanolamine was classified as low volatility, and is therefore considered to be likely to persist longer than the other organic chemicals. Glutaraldehyde, benzaldehyde, cinnamaldehyde, butyl alcohol, acetic acid, methanol and ethanol were classified as moderately volatile (M), and hydrotreated light petroleum distillate were classified as having the highest volatility (H) and therefore are the least persistent (Table 29).

Table 29: Henry's Law Constant Classification for High Hazard Organic Chemicals

Chemical	CAS RN	Henry's Law (atm m^3/mol at 25°C)	Henry's Law (Dimensionless)	Henry's Law Constant Classification
Glutaraldehyde	111-30-8	1.10E-07	4.51E-06	Moderately volatile
Benzaldehyde	100-52-7	2.60E-05	1.07E-03	Moderately volatile
Cinnamaldehyde	104-55-2	3.50E-06	1.43E-04	Moderately volatile
Butyl alcohol	71-36-3	9.99E-06	4.09E-04	Moderately volatile
Acetic acid	64-19-7	1.00E-07	4.10E-06	Moderately volatile
Diethanolamine	111-42-2	3.90E-11	1.60E-09	Low volatility
Methanol	67-56-1	4.55E-06	1.86E-04	Moderately volatile
Ethanol	64-17-5	5.76E-06	2.36E-04	Moderately volatile
Hydrotreated light petroleum distillate	64742-47-8	9.35E-00	3.83E+02	Highly volatile

Based on the octanol-water partitioning coefficient classification in Section 5.1.2.3, hydrotreated light petroleum distillate was classified as high potential to biomagnify. The remaining eight chemicals are considered to have low potential for biomagnification (refer to Table 30).

Table 30: Low Kow Classification for High Hazard Chemicals

Chemical	CAS RN	Log Kow	Potential to Biomagnify
Glutaraldehyde	111-30-8	-0.36	Low
Benzaldehyde	100-52-7	1.48	Low
Cinnamaldehyde	104-55-2	1.90	Low
Butyl alcohol	71-36-3	1.00	Low
Acetic acid	64-19-7	-0.17	Low

Chemical	CAS RN	Log Kow	Potential to Biomagnify
Diethanolamine	111-42-2	-1.43	Low
Methanol	67-56-1	-0.77	Low
Ethanol	64-17-5	-0.35	Low
Hydrotreated light petroleum distillate	64742-47-8	6.10	High

5.3.3 Identification of Terrestrial Chemicals of Potential Concern (COPC)

Using the three physico-chemical measures in combination it was possible to identify the COPC to terrestrial receptors posing a potential high hazard (see Table 31).

Table 31: Henry's Law Constant Classification for High Hazard Organic Chemicals

Chemical	CAS RN	Half-life in Soil (t ½) Classification	Potential to Biomagnify	Henry's Law Constant Classification	Primary Exposure Route
Glutaraldehyde	111-30-8	Moderate	Low	Moderately volatile	Direct toxicity
Benzaldehyde	100-52-7	Moderate	Low	Moderately volatile	Direct toxicity
Cinnamaldehyde	104-55-2	Moderate	Low	Moderately volatile	Direct toxicity
Butyl alcohol	71-36-3	Fast	Low	Moderately volatile	Direct toxicity
Acetic acid	64-19-7	Fast	Low	Moderately volatile	Direct toxicity
Diethanolamine	111-42-2	Fast	Low	***Low volatility***	Direct toxicity
Methanol	67-56-1	Fast	Low	Moderately volatile	Direct toxicity
Ethanol	64-17-5	Fast	Low	Moderately volatile	Direct toxicity
Hydrotreated light petroleum distillate	64742-47-8	Fast	***High***	Highly volatile	Direct toxicity

Cells in bold, underline and italics = Classified as persistent or possessing a high potential to biomagnify.

The organic chemicals classified as high hazard in Section 5.3.1 were assessed according to their toxicological and physio-chemical properties. The following organic chemicals were assessed to have the potential to pose a higher environmental hazard relative to the other chemicals assessed based on persistence and potential to biomagnify:

- Diethanolamine (low volatility); and
- Hydrotreated light petroleum distillate (high potential to biomagnify)

Diethanol amine has low volatility but it does not persistent in the soil and does not biomagnify. Hydrotreated light petroleum distillate has a high potential to biomagnify but it does not persist in the environment based on its fast half-life and high volatility. Therefore, although these chemicals appear to pose a higher hazard than others, their risk profile to terrestrial receptors is relatively low.

The remaining chemicals were considered likely to degrade quickly or moderately quickly and/or have a high or moderate volatility. Hence, whilst direct toxicity to terrestrial receptors may occur from exposure to these chemicals either after a spill or breach of containment, or from direct exposure via accidental entry into a panel tank (refer Section 2.1.1); effects are unlikely to persist over time.

5.4 Limitations and Uncertainties

The terrestrial environmental hazard assessment is a relative assessment and not a comprehensive evaluation of environmental hazards. The following limitations with regard to the terrestrial hazard assessment and source data were noted:

- Sources of Australian terrestrial ecotoxicological data were consulted but the information was limited. No terrestrial ecotoxicological data on the assessed chemicals were available for Australian birds, mammals, reptiles or flora.
- The terrestrial toxicological data used in this report do not include endpoints that assess effects on soil function or secondary poisoning via bioaccumulation in the food chain. Assessment of impacts via secondary poisoning has been assessed qualitatively from the chemical-specific physical and chemical data.
- The terrestrial toxicity assessment was largely based on modelled data of lettuce and earthworm that may not be receptors present in soil on well leases. Modelled data introduces greater uncertainty compared to use of measured data.
- The effects of exposure to the inorganic chemicals identified as posing a higher hazard relative to other chemicals could not be fully assessed.
- The terrestrial toxicity assessment identifies chemicals with the highest hazard relative to the chemicals assessed. Actual hazard is based on the exposure concentration and exposure scenario, as discussed in Section 2.0.
- Toxicological data were obtained for surrogates for a number of chemicals; and
- The data collated in the chemical information sheets (presented in APPENDIX E) were treated the same regardless of whether the data were measured experimental values or modelled / calculated values.

6.0 HUMAN HEALTH TOXICITY ASSESSMENT

6.1 Objective

As discussed in Section 4.2, the assessment of toxicity represents an assessment of hazard rather than risk. In terms of elements of the risk assessment process, the hazard assessment identifies a potential due to intrinsic properties of the chemical of interest, the exposure assessment provides information on the likelihood of the hazard being realised, and the risk characterisation provides a qualitative or semi-quantitative measure of the potential for the hazard to be realised.

The aim of the hazard assessment is therefore to provide a qualitative hazard ranking of chemicals based on human health toxicity and other hazardous endpoints to identify COPC. Further evaluation of the risk posed by the COPC is provided with an evaluation of exposure pathways. There are qualifiers related to the hazard ranking process. These are summarised in the concluding comments of each human health hazard profile presented in APPENDIX D

The end result of the human health hazard assessment is to provide direction for the mitigation of environmental and occupational health hazards that have the potential to be realised. This may be achieved by suitable management measures or in some cases, additional investigations (e.g., sampling and analytical programs and further risk assessment).

6.2 Historical Human Health Hazard Ranking

Human health hazard ranking may adopt a variety of approaches depending on the project or site-specific needs. A variety of hazard ranking or chemical screening methods are available in the published, peer-reviewed literature. Some of these methods are described in the following paragraphs.

Pennington and Bare (2001) described two methods developed by the US EPA: the Waste Minimisation Prioritization Tool (WMPT); and the Toxic Equivalency Potential (TEP). The WMPT examines screening in terms of key physical-chemical properties and includes measures for persistence, bioaccumulation and toxicity (PBT) that are calculated. Each PBT measure is scored to provide a single measure of relative concern. TEPs evaluate chemical fate, multi-pathway exposure and toxicity using a model-based approach. The TEP approach was considered by the authors to represent a less subjective and thus improved approach. TEPs are based on a generic version of CalTox - an integrated multimedia fate, multi-pathway exposure and toxicity model initially developed for human health risk assessments. The authors further stated that "*in typical applications and given the currently available transformation data, neither approach should be used to provide insights beyond a qualitative basis such as high, medium and low concern*" (p 910).

Pittinger *et al*. (2003) described seven discrete hazard and risk assessment tools and proposed a systematic framework to assist users in selecting the appropriate tool for a given application. The framework used a hazard-risk continuum with varying amount and specificity of data requirements. The continuum commenced with toxicity and physical-chemical properties on the hazard end and progressed to site-specific risk assessment. Pittinger et al. (2003) discussed approaches from:

- The American Industrial Health Council (AIHC).
- European Risk Ranking Method (EURAM).
- US Chemical Hazard Evaluation for Management Strategies (CHEMS-1).
- US Risk Screening Environmental Indicators.
- US EPA Clusters Scoring System for particular tasks.
- Exposure, Fate Assessment Screening Tool (E-FAST) used in US EPA's New Chemicals Program; and
- The OECD's "Tools for R&D Screening" which is part of the OECD's Chemical Risk Management Program.

Logue et al., (2011) published an approach that used indoor air exposure data and air guidelines to rank 267 chemicals. Thirty-one chemicals were identified as posing hazards with nine as priority pollutants. Dunn (2009) presented an approach for a relative risk ranking of select substances on the Canadian National Pollutant Release Inventory using the CHEMS-1 model listed by Pittinger et al. (2003) discussed above.

OECD (2001) published an initial approach to a harmonised integrated classification system for human health and environmental hazards of chemical substances and mixtures was updated to a Globally Harmonised System of Classification and Labelling of Chemicals (GHS) in 2003, with subsequent updates in 2005, 2007, 2009 and then in 2011 (UNECE, 2011). These guidelines provide categorisation across ten toxicity parameters and provide specific guidance for separation into those categories based on available toxicological data. The approach ranks within the respective categories but not across the toxicological parameters.

While the paper by Dunn (2009) highlights the use of CHEMS-1 in the Canadian approach to the National Pollutant Release inventory, the model does not include some elements that have more recently been included in evaluations by agencies such as the US EPA Design for the Environment (DfE). DfE focuses on the principles of green chemistry and applies these principles to work towards the replacement of hazardous chemicals by safer chemicals and considers a broader range of variables.

Recent green chemistry initiatives such as "*The Green Screen for Safer Chemicals*" (Clean Production Organisation, 2009) provide comprehensive ranking approaches embodying health risk assessment principles with the objectives of achieving safer chemical use. These approaches integrate data and categorisations from the following environment agencies: US EPA, the European Union/Commission (EU), United Nations Economic Commission for Europe (UNECE) GHS, International Agency for Research on Cancer (IARC), and US National Toxicology Program (NTP) sources to establish Very High (VH), High (H), Moderate (M), and Low (L) categories. The basis of these evaluations is to produce an overall categorisation into four benchmarks with 'Benchmark 4' reflecting a preferred safer chemical – a "green" objective. While the green chemistry initiative objectives differ somewhat from the objectives of the stimulation hazard ranking described in this report, the basis to the use of data reflects current approaches in hazard categorisation and includes toxicological parameters drawn from the UN GHS, IARC and other reputable sources. The stimulation hazard approach also includes a consideration of endocrine disruptor potential and physical hazards such as explosive capability and flammability. The approach has been employed with suitable adjustments for human health hazard ranking of stimulation chemicals. This is discussed in the following sections.

6.3 Historical Hazard Assessment and Ranking Methodology

The literature described above presented a variety of models and approaches to hazard rank chemicals. There is no one model or approach that is ideally suited to assess the potential environmental distribution, potential for human exposure, and subsequent hazard of stimulation chemicals.

Golder has structured an approach which integrates a number of the above methods to assess and rank hazards to humans exposed to stimulation chemicals. The approach is summarised as follows:

1) The inventory of stimulation chemicals was reviewed and all substances with reported CAS numbers collated. Those with no CAS numbers were separated into a "*Separate listing for review*" and additional information sought;
2) All substances with CAS numbers were reviewed to determine listing on Safework Australia's Hazardous Substances Information System (HSIS). Safework Australia's HSIS reports chemicals that have been reviewed under the National Occupational Health and Safety Commission (NOHSC, 2004) "*Approved Criteria for Classifying Hazardous Substances, 3rd Edition*" and/or have National Exposure Standards declared under the Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment [NOHSC:1003(1995)]. These classifications are based on a range of toxicological properties consistent with international approaches used in hazard ranking and health risk assessment.

3) Compositional data from SDSs were not used as a screening process in this instance because of the potential for low percentage substances to alter in availability due to environmental fate and transport processes. This is in contrast to occupational settings and product use where exposure controls and chemical alteration are limited compared with environmental settings. The issue of mass input into the environment as an index of potential exposure was considered at the end of the ranking process for each health hazard profile.

4) Data for all substances was collated based on the following variables:

    a. Carcinogenicity
    b. Mutagenicity/Genotoxicity
    c. Reproductive toxicity
    d. Developmental toxicity/Teratogenicity
    e. Endocrine disruption
    f. Neurotoxicity
    g. Acute toxicity (oral, dermal or inhalation)
    h. Corrosion/irritation of the skin or eye
    i. Sensitisation of the skin or respiratory system
    j. Immune system effects
    k. Systemic toxicity/Organ effects
    l. Flammable potential
    m. Explosive potential.

5) Thresholds were employed based on a combination of EU, IARC, US EPA, US NTP and the UNECE GHS approaches for hazard characterisation consistent with the ““*Green Screen for Safer Chemicals*”.

6) It should be noted that the “*Green Screen for Safer Chemicals*” (described in the previous section) includes an evaluation of persistence, bioaccumulation and aquatic toxicity (PBT). Rather than use the classification outlined in the “*Green Screen for Safer Chemicals*” the PBT analysis described in Section 4.6 has been used for consistency. This is appropriate as the evaluation is a comprehensive assessment of multiple parameters. In addition the classification of high, medium and low categories in Section 4.6 utilises more conservative thresholds for the hazard cut offs than presented in the “*Green Screen for Safer Chemicals”*. Finally, the classification scheme in Section 4.6 does not differentiate within hazard classifications (such as use a ‘Very High’ grouping adopted in the human health assessment), rather any chemical classified as posing a ‘High Hazard’ is considered a COPC. The Very High grouping in “*Green Screen for Safer Chemicals*” relates only to the PB assessment, as such this grouping has not been used in this assessment.

7) These thresholds allowed data to be ranked into strata of High, Moderate and Low concern and numerically converted as follows.

    a. High = 3
    b. Moderate = 2
    c. Low = 1

    Values were then averaged based on the available data that generated each score. This ensured scores were not biased by the amount of data for any one chemical, e.g. ten sets of data, the total was divided by ten, four sets of data, the total score was divided by 4, etc; and

8) The values were then converted into a qualitative expression of hazard described as Low (1), Low to Moderate (1-2), Moderate (2), Moderate to High (2-3) and High (3). These hazard classes were designed to reflect a relative ranking and were further qualified in terms of key hazards and potential scenarios requiring consideration. The latter was provided in a concluding section with summary comments for the

human health hazard profiles developed. The summary comments to each profile placed the health hazard ranking in perspective.

The application of this approach is iterative and subject to further refinement should additional information and or methodologies become available. As new information becomes available these rankings may be subject to change. As a consequence, the human health hazard evaluation presents uncertainty for each chemical assessed, expressed as a percentage. The percentage is calculated based on the data availability across the 13 hazard categories investigated. The percentage uncertainty is not a measure of data quality, but data availability.

Further discussion of these parameters is provided in the Section 4.0 including the threshold values used for each parameter.

6.4 Human Health Hazard Assessment Parameters

A description of each parameter is provided below, along with the threshold values for each parameter as presented in the "*Green Screen for Safer Chemicals*". The threshold values for these parameters as presented in the "*Green Screen for Safer Chemicals*" are drawn from the following sources:

- EU's recently enacted chemicals policy legislation (Registration, Evaluation and Authorization of Chemicals–REACH) (EU 2006).
- UNECE (2011) Globally Harmonized System of Classification and Labelling of Chemicals (GHS). Fourth revised edition. United Nations, New York and Geneva.
- The International Agency for Research on Cancer (IARC) monographs on Carcinogens, available at http://monographs.iarc.fr.
- US Environmental Protection Agency, Design for Environment Program. (USEPA DfE) 2005. Environmental Profiles of Chemical Flame-Retardant Alternatives for Low-Density Polyurethane Foam.
- US Department of Health and Human Services, Public Health Service, National Toxicology Program (US NTP). 2005. Report on Carcinogens, Eleventh Edition.
- State of California, Environmental Protection Agency, Office of Environmental Health Hazard Assessment. 2006. Chemicals Known to the State to Cause Cancer or Reproductive Toxicity.
- Japan Ministry of Environment. 1998. Endocrine Disrupting Chemicals Database, Table of Chemicals Suspected of Having Endocrine Disrupting Effects; and
- US Department of Labour Occupational Safety and Health Administration (OSHA) List of OSHA carcinogens.

6.4.1 Acute Toxicity

Acute toxicity refers to the occurrence of adverse effects following exposure to a single dose of a substance or multiple doses within a 24-hour period (OECD 2009). In toxicity studies acute effects are often characterised by lethality, commonly reported in lethal dose or concentration at which 50% of the animals tested die (LD50 or LC50). Non-lethal acute effects are sometimes included. Routes of administration commonly used are the oral, dermal and inhalation pathways. The threshold values for acute toxicity are presented in Table 32.

Table 32: Acute Toxicity (Oral, Dermal or Inhalation) Threshold Values

High	Medium	Low
■ LD50 <50 mg/kg bodyweight (oral) ■ LD50 <200 mg/kg bodyweight (dermal) ■ LC50 <500 ppm (gas) ■ LC50 <2.0 mg/l (vapour) ■ LC50 <0.5 mg/l (dust or mist) ■ US EPA Extremely Hazardous Substance List ■ GHS Category 1 or 2	■ LD50 50-2000 mg/kg bodyweight (oral) ■ LD50 200-2000 mg/kg bodyweight (dermal) ■ LC50 500-5000 ppm (gas) ■ LC50 2-20 mg/l (vapour) ■ LC50 0.5-5 mg/l (dust or mist) ■ GHS Category 3 or 4	No basis for concern identified

6.4.2 Corrosion/Irritation of the Skin or Eye/s

Skin corrosion is the production of irreversible damage to the skin namely, visible necrosis through the epidermis and into the dermis following the application of a substance for up to four hours (OECD, 2009). Corrosion is often indicated by ulcers and bleeding and after 14 days discolouration of the skin, alopecia and scars. Skin irritation is the production of reversible damage to the skin following application of a substance (OECD, 2009).

Serious eye damage (i.e. corrosion) is indicated by tissue damage of the eye or serious physical decay of vision following application of the anterior surface of the eye which is not fully reversible within 21 days (OECD, 2009). Eye irritation is indicated by changes in the eye following application of the anterior surface of the eye which is fully reversible within 21 days (OECD, 2009).

The threshold values for corrosion/Irritation of the skin or eye are presented in Table 33.

Table 33: Corrosion/Irritation of the Skin or Eye Threshold

High	Medium	Low
■ Evidence of irreversible effects in studies of human populations ■ Weight of evidence of irreversible effects in animal studies ■ GHS Category 1 (skin or eye)	■ Evidence of reversible effects in humans or animals ■ GHS Category 2 or 3 — skin irritation ■ GHS Category 2A or 2B — eye	■ No basis for concern identified

6.4.3 Sensitisation of the Skin or Respiratory System

A respiratory sensitiser is a substance that will lead to hypersensitivity of the airways following inhalation of the substance (OECD, 2009). A skin sensitizer is a substance that will lead to an allergic response following skin contact (OECD 2009).

The threshold values for sensitisation of the skin or respiratory system are presented in Table 34.

Table 34: Sensitisation of the Skin or Respiratory System Threshold

High	Medium	Low
■ Evidence of adverse effects in humans; ■ Weight of evidence demonstrates potential for adverse effects in humans ■ GHS Category 1 – (skin or respiratory) ■ Positive responses in predictive Human Repeat ■ Insult Patch Tests (HRIPT) (skin)	■ Suggestive animal studies of adverse effects ■ Analogue data ■ Chemical class known to produce toxicity	■ No basis for concern identified

6.4.4 Carcinogenicity

A carcinogen is a substance or a mixture which induces cancer or increases its incidence. The classification of a substance or mixture as a carcinogenic hazard is based on its inherent properties and does not provide information on the level of human cancer risk which the use of a substance may represent (OECD, 2009).

The threshold values for carcinogenicity are presented in Table 35.

Table 35: Carcinogenicity Thresholds

High	Medium	Low
■ Evidence of adverse effects in humans ■ Weight of evidence demonstrates potential for adverse effects in humans ■ NTP known or reasonably anticipated to be human carcinogen ■ OSHA carcinogen ■ California Prop 65 ■ IARC Group 1 or 2A ■ EU Category 1 or 2 ■ GHS Category 1A or 1B	■ Suggestive animal studies of adverse effects ■ Analogue data ■ Chemical class known to produce toxicity ■ IARC Group 2B ■ EU Category 3 ■ GHS Category 2	■ No basis for concern identified ■ IARC Group 3 or 4

6.4.5 Developmental Toxicity

Developmental toxicity refers to the *in-utero* effects such as death, malformations, functional deficits and developmental delays (enHealth, 2004). It can also include delayed toxicity associated with epigenic effects during the sensitive phases of foetal development.

The threshold values for developmental toxicity are presented in Table 36.

Table 36: Developmental Toxicity Threshold

High	Medium	Low
■ Evidence of adverse effects in humans ■ Weight of evidence demonstrates potential for adverse effects in humans ■ NTP Center for the Evaluation of Risks to Human Reproduction ■ California Prop 65	■ Suggestive animal studies of adverse effects ■ Analogue data ■ Chemical class known to produce toxicity	■ No basis for concern identified

6.4.6 Mutagenicity/Genotoxicity

Mutagenesis occurs when chemicals cause changes in the genetic material which can be transmitted during call division (Davis et al., 1994). The OECD (2009) indicates a mutagen is a chemical that may cause mutations in the germ cells of humans that can be transmitted to the progeny. A mutation is defined as a permanent change in the amount or structure of the genetic material in a cell. The more general terms genotoxic and genotoxicity apply to agents or processes which alter the structure, information content or segregation of deoxyribonucleic acid (DNA) (OECD, 2009).

The threshold values for mutagenicity and genotoxicity are presented in Table 37.

Table 37: Mutagenicity/Genotoxicity Thresholds

High	Medium	Low
■ Evidence of adverse effects in humans ■ Weight of evidence demonstrates potential for adverse effects in humans ■ EU Category 1 or 2 ■ GHS Category 1A or 1B	■ Suggestive animal studies of adverse effects ■ Analogue data ■ Chemical class known to produce toxicity ■ EU Category 3 ■ GHS Category 2	■ No basis for concern identified

6.4.7 Reproductive Toxicity

Reproductive toxicity includes adverse effects on sexual function and fertility in adult males and female as well as developmental toxicity in the offspring (OECD, 2009). This may include effects on mating behaviour, gonadal function, oestrous cycling, conception, implantation, parturition and lactation (Draft enHealth, 2010). The threshold values for reproductive toxicology are presented in Table 38.

Table 38: Reproductive Toxicity Thresholds

High	Medium	Low
■ Evidence of adverse effects in humans ■ Weight of evidence demonstrates potential for adverse effects in humans ■ NTP Centre for the Evaluation of Risks to Human Reproduction ■ California Prop 65 ■ EU Category 1 or 2 ■ GHS Category 1A or 1B	■ Suggestive animal studies of adverse effects ■ Analogue data ■ Chemical class known to produce toxicity ■ EU Category 3 ■ GHS Category 2	■ No basis for concern identified

6.4.8 Neurotoxicity

Neurotoxicity refers to any adverse effects on the structure or functional integrity of the developing or adult nervous system. Neurotoxic effects may involve a spectrum of biochemical, morphological, behavioural, and physiological abnormalities whose onset can vary from immediate to delayed following exposure to a toxic substance, and whose duration may be transient or persistent (US Department of Food and Drug Administration, 2000).

The threshold values for neurotoxicity are presented in Table 39.

Table 39: Neurotoxicity Thresholds

High	Medium	Low
■ Evidence of adverse effects in humans ■ Weight of evidence demonstrates potential for adverse effects in humans	■ Suggestive animal studies of adverse effects ■ Analogue data ■ Chemical class known to produce toxicity	■ No basis for concern identified

6.4.9 Endocrine Disruption

Endocrine disruptors are chemicals that may interfere with the body’s endocrine system and produce adverse developmental, reproductive, neurological, and immune effects (OECD, 2009).

The threshold values for endocrine disruption are presented in Table 40.

Table 40: Endocrine Disruption Thresholds

High	Medium	Low
■ Evidence of adverse effects in humans ■ Weight of evidence demonstrates that mechanisms of action lead to adverse effects	■ Suggestive animal studies of adverse effects ■ Analogue data ■ Chemical class known to produce toxicity ■ EU Draft List - Category 1 or 2 ■ Japanese list	■ No basis for concern identified

6.4.10 Systemic Toxicity/Organ Effects

This relates to substances that produce specific non- lethal organ toxicity arising either from a single or repeated dose. All significant health effects that can impair function, reversible and irreversible, immediate and/or delayed are included (OECD, 2009).

The threshold values for systemic toxicity / organ effects are presented in Table 41.

Table 41: Systemic Toxicity Thresholds

High	Medium	Low
■ Evidence of adverse effects in humans ■ Weight of evidence demonstrates potential for adverse effects in humans ■ GHS Category 1 — organ/systemic toxicity following single or repeated exposure	■ Suggestive animal studies of adverse effects ■ Analogue data ■ Chemical class known to produce toxicity ■ GHS Category 2 or 3 single exposure ■ Category 2 repeated exposure	■ No basis for concern identified

6.4.11 Immune System Effects

The threshold values for immune system effects are presented in Table 42.

Table 42: Immune System Effect Thresholds

High	Medium	Low
■ Evidence of adverse effects in humans Weight of evidence demonstrates potential for adverse effects in humans	■ Suggestive animal studies of adverse effects ■ Analogue data ■ Chemical class known to produce toxicity	■ No basis for concern identified

6.4.12 Explosive Potential

An explosive substance is a solid or liquid which is capable by chemical reaction of producing gas at such high temperature and pressure and at such a speed as to cause damage to the surroundings (OECD, 2009).

The threshold values for explosive potential effects are presented in Table 43.

Table 43: Explosive Potential Threshold Values

High	Medium	Low
■ GHS Category: Unstable Explosives or Divisions 1.1, 1.2 or 1.3	■ GHS Category: Divisions 1.4, 1.5	■ No basis for concern identified

6.4.13 Flammable Potential

A flammable liquid has a flash point of not more than 93˚C (OECD, 2009). A flammable solid is readily combustible or may cause or contribute to fire through friction. A readily combustible solid is a powdered, granular or pasty substance which is dangerous if it can be ignited by brief contact with an ignition source and the flame spreads rapidly (OECD, 2009).

The threshold values for flammable potential effects are presented in Table 44.

Table 44: Flammable Potential Thresholds

High	Medium	Low
■ GHS Category 1 - Flammable Gases ■ GHS Category 1 - Flammable Aerosols ■ GHS Category 1 or 2 — Flammable Liquids	■ GHS Category 2- Flammable Gases ■ GHS Category 2- Flammable Aerosols ■ GHS Category 3 or 4 — Flammable Liquids	■ No basis for concern identified

6.5 Historical Human Health Hazard Ranking

6.5.1 Process of Hazard Review

As an initial assessment of hazard, all chemicals listed in Table 4 were queried via the SafeWork Australia Hazardous Chemical Information System (HCIS) to determine if they were classified as "*hazardous*"" based on the in accordance with the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) 3rd revised edition. The GHS classifications are based on a range of toxicological properties consistent with approaches used in hazard ranking and health risk assessment. A limitation of this initial search is that although the HCIS database includes over 5,000 substances, only substances that have been assessed and subsequently classified as hazardous are included. Absence of a chemical from the database does not imply a chemical is non-hazardous. The listings are summarised in Table 45. Of the total of 39 substances reviewed in this report, 26 were listed, 13 were not listed.

Table 45: Hazardous Chemical Information System Listing

Chemical Name	CAS RN	HCIS
Acetic acid	64-19-7	Listed
Alcohols, C12-16, ethoxylated	68551-12-2	Listed*
Amine oxides, cocoalkyldimethyl	61788-90-7	Not Listed
Benzaldehyde	100-52-7	Listed
Cinnamaldehyde	104-55-2	Listed*
Citric acid	77-92-9	Listed
Diethylene glycol	111-46-6	Listed
Methanol	67-56-1	Listed
Triethanol amine	102-71-6	Listed
Diethanol amine	111-42-2	Listed
Ethanol	64-17-5	Listed
Hydrotreated light petroleum distillate	64742-47-8	Listed

Chemical Name	CAS RN	HCIS
Sodium polyacrylate	9003-04-7	Not Listed
Alcohols, C12-C15, ethoxylated	68131-39-5	Listed
Amides, tall-oil fatty, N,N-bis(hydroxyethyl)	68155-20-4	Not Listed
Fatty acids, tall-oil, ethoxylated	61791-00-2	Not Listed
Butyl alcohol	71-36-3	Listed
Tributyl tetradecyl phosphonium chloride	81741-28-8	Listed
Glutaraldehyde	111-30-8	Listed
Monoethanolamine borate	26038-87-9	Listed
Guar gum	9000-30-0	Not Listed
Ethylene glycol	107-21-1	Listed
Aluminium oxide	1344-28-1	Not Listed
Chlorous Acid, sodium Salt	7758-19-2	Listed*
Disodium octaborate tetrahydrate	12008-41-2	Listed*
Hydrochloric acid	7647-01-0	Listed
Iron oxide	1309-37-1	Not Listed
Sodium bisulfite	7631-90-5	Listed
Sodium carbonate	497-19-8	Listed
Sodium chloride	7647-14-5	Not Listed
Sodium hydroxide	1310-73-2	Listed
Sodium iodide	7681-82-5	Not Listed
Titanium dioxide	13463-67-7	Not Listed
Ulexite	1319-33-1	Listed
Hydroxylpropyl guar	39421-75-5	Not Listed
Aluminium silicate	1302-76-7	Not Listed
Crystalline silica, cristobalite	14464-46-1	Listed
Crystalline Silica, quartz	14808-60-7	Listed
Silica Gel	112926-00-8	Not Listed

Note:" * "These chemicals have been added to the HCIS since the previous search of the database (formerly the Hazardous Substances Information System HSIS) Golder conducted in 2012.

Of the chemicals listed in Table 45, two chemicals have not been assessed or considered further in this report:

- Sodium chloride (7647-14-5) is a naturally occurring ubiquitous salt and not considered to be a hazardous substance

- Hydroxylpropyl guar (39421-75-5) which has been considered to be sufficiently addressed by the assessment of guar gum (9000-30-0).

Readily available human health toxicity and hazard data were collated from the following online data bases:

- Safework Australia sources, specifically the Hazardous Chemical Information System (HCIS).
- National Industrial Chemicals Notification and Assessment Scheme (NICNAS)
- World Health Organisation (WHO) sources such as International Program of Chemical Safety (IPCS) INCHEM, including Concise International Chemical Assessment Documents (CICADS) and Environmental Health Criteria (EHC) monographs.
- European Chemicals Agency (ECHA) REACH registration dossiers
- United States sources such as:
  - United States National Medical Library of Medicine Toxicology (Toxnet) and Hazardous Substances Data Bank (HSDB).
  - United States Environmental Protection Agency (US EPA) Integrated Risk Information System (IRIS).
  - Agency for Toxic Substances and Disease Registry (ASTDR) toxicological profiles; and
  - Risk Assessment Information System (RAIS).

If no information was available from these databases then the search was extended to access other sources of toxicity information, preference was given to peer-reviewed data.

Toxicity information for each parameter was then categorised as High, Medium or Low concern according to the thresholds described in Section 4.6. The categories were numerically converted as follows:

- High = 3
- Moderate to High = 2-3
- Moderate = 2
- Low to Moderate = 1-2
- Low = 1

The scoring system is semi-quantitative in that scores are assigned to ranges for a particular parameter. The scores are largely assigned using some quantitative data and professional judgement following consideration of the guidance from the ranking thresholds specified for each parameter. In order to provide some measure to the availability of data an estimation of uncertainty was presented by calculating the percentage of parameters for which data were available, e.g. if data for 2 parameters only were obtained, this represented 2/13 or 15%. This allowed some appreciation of data gaps that, if available, may alter the estimated hazard assessment.

6.5.2 Surrogate Selection

Surrogates compounds were selected consistent with the approach described in Section 4.6.2. Where chemicals were assessed using a surrogate, this is documented in this report for transparency. Where chemicals could not be assessed using a surrogate, they were not assessed due to insufficient data. In total nine surrogates were employed for all the substances considered in this assessment. These are presented in Table 46.

Table 46: Surrogates Used in Human Health Hazard Evaluation

Chemical	CAS No	Surrogate Descriptor
Kaolin	1332-58-7	Surrogate for aluminium silicate

Chemical	CAS No	Surrogate Descriptor
Amides, C18-unsaturated, N,N-bis(hydroxyethyl)	93-83-4	Surrogate for Amides, tall-oil, fatty, N,N-bis(hydroxethyl) (CAS RN 68155-20-4)
Tetra-n-butyl phophonium chloride	2304-30-5	Surrogate for Tributyl tetradecyl phosphonium chloride (CAS RN 81741-28-8)
Rection products of monoethanolamine and boric acid	94095-04-2	Surrogate for Monoethanolamine borate (CAS RN 26038-87-9)
Disodium octaborate tetrahydrate	12008-41-2	Surrogate for Ulexite (CAS RN 1319-33-1)

6.5.3 Human Health Chemicals of Potential Concern (Historical Assessment Method)

The evaluation process detailed above provided a relative ranking of human health hazard scores to enable a prioritization of COPC to be made. On this basis, chemicals ranged from a hazard score of 1.0, representing classification of "*no cause for concern*" to those considered "*Moderate to High*" cause for concern. The data completeness ranged from 31% to 100%. This data completeness measures provides some confidence in the ranking such that where data are limited there is a greater possibility that the hazard profile may change with increase information.

A summary of the available human health hazard information for each chemical is presented in the Health Hazard Profiles for each substance in APPENDIX D.

The selection of a chemical as a COPC does not indicate an unacceptable risk (which is reflection of the realisation of a hazard); rather it indicates that potential exposures to these chemicals should be evaluated in greater detail to ascertain if they may present an unacceptable risk. Furthermore, adverse health effects are a reflection of intrinsic chemical or physical toxicity, the physico-chemical parameters of the substance concerned, and the exposure setting and affected populations. Subsequently, it is not possible within a numerical ranking system to capture all possible exposure settings that may apply with product use and the possible chemical exposures. Consequently, qualitative comments have been provided for each of the ranked chemicals as concluding summary comments. These qualifying comments should be read and understood. These are presented in the human health profiles in APPENDIX D.

The recognition of human health hazards provides a basis to assigning public health protection measures to ensure exposures to substances identified as having intrinsic toxic effects are adequately controlled. Public health protection may be differentiated between occupational health and environmental health where the former involves workers and respective legislative requirements and the latter involves the general community sector. Of the 64 substances that were examined, 44 substances recorded hazard scores greater than 1.0 and these substances are have been the subject of further comment in Table 47. This table presents the substances, their hazard score, and indication of persistence and key hazard determinants and potential areas of concern. The latter provides direction on the differentiation of occupational health and environmental health concerns and provides further focus on hazard mitigation measures including assessment.

The assessment of human health hazards has been undertaken on individual substances. Assessment of the combined effects of the constituents (when present in a mixture) was outside the scope of this assessment.

Table 47: Summary of Human Health Hazard Classification and Potential Outcomes (Historical Assessment Method)

Substance	CAS No	Environmental Behaviour	Key Determinants and Potential Hazard Outcomes
Moderate to High Hazard			
Methanol	67-56-1	Dilution/biodegradation/volatile	Occupational exposure concerns – volatile and flammable/explosive.
Sodium iodide	7681-82-5	Dilution/dissociation/persistence	Occupational irritant. Toxicity concerns of iodine warrant both occupational and environmental exposure assessment.
Acetic acid	64-19-7	Dilution/dissociation/biodegradation	Concentrated form is an occupational hazard. Flammable and explosive.
Moderate Hazard			
Crystalline silica, quartz	14808-60-7	Dilution/Persistence	Occupational respiratory effects (cancer, silicosis)
Sodium carbonate	497-19-8	Dilution/dissociation	Occupational irritant and sensitiser – product and concentrated solutions are alkaline. May increase alkalinity of environmental waters.
Crystalline silica, cristobalite	14464-46-1	Dilution/Persistent	Occupational respiratory effects (cancer, silicosis)
Low to Moderate Hazard			
Chlorous acid, sodium salt	7758-19-2	Dilution/degradation	Occupational hazard – suspect mutagen and irritant. Developmental toxicity concerns (female workers).
Sodium hydroxide	1310-73-2	Dilution/dissociation	Occupational hazard - highly corrosive to skin, eyes and mucous membranes. May increase alkalinity in environmental waters.
Hydrochloric acid	7647-01-0	Dilution/dissociation	Occupational hazard – irritant, corrosive and necrotic to lung, eyes, skin and mucous membranes. May increase acidity of environmental waters.
Citric acid	77-92-9	Dilution/dissociation	Occupational hazard – skin and eye irritant. May contribute to elevations in acidity of environmental waters.
Low to Moderate Hazard (cont.)			
Disodium octaborate tetrahydrate	12008-41-2	Dilution/dissociation/persistence	Occupational and environmental hazard – reproductive (males and females) and developmental toxicity (female workers). May elevate boron levels in environmental surface waters.

Substance	CAS No	Environmental Behaviour	Key Determinants and Potential Hazard Outcomes
Aluminium oxide	1344-28-1	Dilution/persistence	Occupational and environmental hazard. Respiratory irritant and neurotoxin. May elevate aluminium levels in environmental waters.
Benzaldehyde	100-52-7	Dilution/biodegradation	Occupational and environmental hazard – irritant and evidence of acute and chronic toxicity. Environmental concentrations require evaluation. Flammable.
Cinnamaldehyde	104-55-2	Dilution/biodegradation	Occupational hazard – skin and eye irritant and sensitiser. Low toxicity.
Diethylene glycol	-	Dilution/biodegradation	Occupational hazard – skin and eye irritant. Low toxicity based on available information.
Surrogate for aluminium silicate	1302-76-7	Dilution/Persistent	Occupational respiratory particulate hazard. Limited evidence of developmental toxicity (by ingestion),
Amine oxides, cocoalkyldimethyl	61788-90-7	Dilution/readily biodegradation	Occupational hazard - skin, eye and respiratory irritant.
Low to Moderate Hazard (cont.)			
Iron oxide	1309-37-1	Limited mobility as not soluble in water but the ferric cation will persist	Occupational inhalation hazard and skin irritant and sensitiser. Low oral toxicity. May result in elevations of iron levels in environmental waters.
Alcohols, C12-16, ethoxylated	68551-12-2	Dilution/biodegradation	Occupational hazard – skin and eye irritant. Low toxicity. Volatile.
Titanium dioxide	13463-67-7	Dilution/Persistence	Occupational hazard – eye and respiratory irritant. Pulmonary effects from particulate inhalation. Low oral toxicity.

6.6 New Hazard Assessment Approach (IMAP Framework)

In addition to the chemicals assessed under the above described historical ‘high-moderate-low’ hazard ranking system, eight new chemicals were assessed using the following approach which is based on the Inventory Multi-tiered Assessment and Prioritisation (IMAP) Framework recently published by the National Industrial Chemicals Notification and Assessment Scheme (NICNAS, 2013). This framework has been designed to enable prioritisation of chemicals by hazard, exposure and use in the community for the purposes of national chemical assessment programs. This involves hazard bands, exposure bands and five broad categories: cosmetic, domestic, commercial, site-limited and non-industrial. The exposure assessment considers volumes and uses multipliers in conjunction with the hazard assessment to provide the risk characterisation for prioritisation and subsequent national assessment of the chemical. Integral to this process is review of international classifications and assessments following the prioritisation process with further increasingly detailed Tier I, Tier II and Tier III assessments.

The IMAP Framework for hazard assessment uses a hierarchy of indicators developed and agreed by the Human Health Expert Working Group (HHEWG) which reflects the following weighting:

- Carcinogenicity, Genotoxicity, Reproductive/developmental toxicity, Endocrine disruption, Neurotoxicity
- Acute toxicity
- Repeat dose toxicity
- Sensitisation
- Irritation.

This facilitates a Hazard Banding which is structured across five bands from Hazard Band 4 (highest) to Hazard Band 0 (lowest). The approaches employed within the IMAP framework adopt global harmonisation practices for classification and labelling of chemicals with assessment thresholds consistent with the previous historical approach used. The major difference is the national weighting applied for the above specific toxicological parameters.

The following chemicals have been assessed using the above approach. The results of which are included in APPENDIX D and summarised in Table 48.

- Ethylene Glycol
- Sodium bisulfite
- Triethanolamine
- Diethanolamine
- Ethanol
- Hydrotreated light petroleum distillate
- Sodium polyacrylate
- Alcohols, C12-C15, ethoxylated
- Amides, tall-oil fatty, N,N-bis(hydroxyethyl)
- Fatty acids, tall oil, ethoxylated
- Butyl alcohol
- Tributyl tetradecyl phosphonium chloride
- Glutaraldehyde
- Monoethanolamine borate

- Guar gum
- Ulexite
- Silica gel.

It should be noted that the IMAP framework has not been employed for the balance of chemicals, and so no change is reflected in previous chemical assessments.

Table 48: Summary of Human Health Hazard Classification and Potential Outcomes (as per the IMAP Framework Ranking Approach)

Substance	CAS No	IMAP Hazard Ranking	Environmental Behaviour	Key Determinants and Potential Hazard Outcomes
Sodium bisulfite	7631-90-5	3	Readily dissociates / dilutes in waters. Oxides of sulphur may be produced from the bisulphite anion.	Low order of toxicity. Rating reflects the hypersensitivity responses to sulphur and oxides of sulphur for sensitive populations (common) Concerns thus limited to occupational setting as sulphur (as oxide) is expected to be distributed (e.g. to atmosphere) within the environmental setting.
Ulexite	1319-33-1	4	Slightly soluble. The surrogate for ulexite, disodium octaborate is converted to boric acid and disodium borate in water. Unlikely to bioaccumulate.	Potential to cause reproductive toxicity (infertility) and its potential for damaging the unborn child. In aqueous solutions sodium borates are likely to convert to boric acid/borate and at physiological and acidic pH, predominately exist as un-dissociated boric acid. Based on this, the potential human toxicity of ulexite can be based on boric acid. The reproductive toxicity of boric acid and its salts occurs at high doses via the oral route. It is unlikely to present a reproductive toxicity hazard via skin contact and when inhaled as dust below the occupational exposure limit.
Triethanolamine	102-71-6	2	Highly soluble, readily biodegradable with a low to moderate potential to bioaccumulate	Triethanolamine has a low order of acute and chronic toxicity. It is classified as a skin sensitiser and eye irritant. It is not genotoxic, carcinogenic, or toxic to development or the reproductive system.
Amides, tall-oil fatty, N,N-bis(hydroxyethyl)	68155-20-4	2	Readily biodegradable in soil, potential to persist and bioaccumulate	Based on chronic dermal exposure and being an eye and skin irritant.
Ethylene Glycol	107-21-1	3	Rapid degradation following dilution.	Ethylene glycol exhibits a diverse range of adverse toxicological outcomes in animal studies including reproductive, developmental and teratogenic effects and renal effects after chronic exposure, although it is not considered highly acutely toxic via the oral, dermal and inhalation pathways. In humans it is considered to be acutely toxic. Furthermore, while ECHA has not classified ethylene glycol as a reproductive toxicant, ATSDR (2010) highlight the developmental toxicity of ethylene glycol in animals.
Diethanolamine	111-42-2	3	Highly soluble, readily biodegradable with a low to moderate potential to bioaccumulate.	Based on carcinogenic and reproductive toxicity potential. Diethanolamine was assigned Group 2B by IARC indicating it is possibly carcinogenic to humans and it is classified by the ECHA dossier as Category 2 for reproductive toxicity (H361). The ECHA dossier also classifies diethanolamine for chronic (repeated dose) oral toxicity and as irritating to the skin and highly irritating to the eyes. Diethanolamine is considered to

Substance	CAS No	IMAP Hazard Ranking	Environmental Behaviour	Key Determinants and Potential Hazard Outcomes
				have moderate acute oral toxicity and low toxicity following inhalation exposure. It is considered to be not sensitising to the skin.
Fatty acids, tall-oil, ethoxylated	61791-00-2	2	Likely to persist in soils, immobile in water with a potential to bioaccumulate	Based on the potential for it to be sensitising to skin. Although it is noted that sensitising test produced mixed results. Fatty acids, tall-oil, ethoxylated has low oral acute and chronic toxicity.
Ethanol	64-17-5	1	Highly soluble, readily biodegradable with a low potential to bioaccumulate.	Based on being an eye irritant. This ranking is based on the exclusion of data specific to extremely high exposure to ethanol, as observed for consumption of alcoholic beverages. Adverse effects for several endpoints (carcinogenicity, mutagenicity/genotoxicity, reproductive/developmental toxicity and chronic toxicity) were observed at high dose rate. However, these dose rates are not considered relevant when considering industrial uses and potential occupational exposure.
Sodium polyacrylate	9003-04-7	3	Highly soluble in water.	Based on the potential effects of inhalation of the respirable dust of the polymer. It is noted that this is based upon a no observed effect concentration, which was the highest concentration in a study. Given the limited information, it is concluded that there is the potential for toxicity effects due to chronic inhalation of respirable dust. Potential inhalation exposures would require management.
Butyl alcohol	71-36-3	3	Highly soluble, readily biodegradable with a low potential to bioaccumulate.	Because it is corrosive to the eyes, causing serious and irreversible eye damage (classified as Category 1, H318: “Causes serious eye irritation”). It is also a skin irritant (classified as Category 2, H315: Causes skin irritation). As typical of alcohols, butyl alcohol can result in transient effects on the central nervous systems (CNS) consistent with general impairments of neurological and behavioural functions (drowsiness and dizziness). As such, butyl alcohol is also classified as specific target organ toxicity (STOT) Single Exposure Category 3 (H335: May cause respiratory irritation/ H336: May cause drowsiness or dizziness), and is also classified for acute oral toxicity as Category 4 (H302: Harmful if swallowed).
Tributyl tetradecyl phosphonium chloride	81741-28-8	3	Insoluble in water, readily biodegradable with a low potential to bioaccumulate	Due to acute inhalation and dermal toxicity, and corrosivity to skin and eyes. It is considered fatal if inhaled, toxic following contact with the skin and harmful if shallowed. It is also considered corrosive to the skin and eyes and sensitising to the skin. Data is lacking for the assessment of the chronic toxicity, reproductive toxicity and respiratory sensitization potential of tetrabutylphosphonium chloride.

Substance	CAS No	IMAP Hazard Ranking	Environmental Behaviour	Key Determinants and Potential Hazard Outcomes
Guar gum	9000-30-0	3	Insoluble in water, biodegradable and unlikely to bioaccumulate	Based on reported occupational asthma suggestive of Type 1 hypersensitivity responses while dermal and eye irritancy is the other main consideration. The potential for dust generation with such a product may result in both of these adverse outcomes under conditions of occupational exposure and subsequently warrant management measures. In addition, as the product is an organic dust, ignition and explosion are further concerns related to worker safety during on-site use of this product during chemical stimulation activities.
Hydrotreated light petroleum distillate	64742-47-8	3	Insoluble in water, readily biodegradable with a low potential to bioaccumulate	Based on a classification of Aspiration Hazard – Category 1; H304 (May be fatal if swallowed and enters airways). In addition, Kerosines are classified as Skin Irritation Category 2 (H315), irritating to the skin, and have the hazard statement AUH066 (Repeated exposure may cause skin dryness and cracking). Other than these hazards, studies reported low acute and chronic toxicity via the oral, dermal and inhalation route.
Alcohols, C12-C15, ethoxylated	68131-39-5	1	Volatile, low potential to bioaccumulate	Reflects a low order of acute toxicity and its associated irritant properties, the latter of greater concern for the occupational setting. Overall, alcohols, C10-16, ethoxylated, propoxylated, exhibit a lack of carcinogenic, genotoxic, reproductive and developmental toxicities with the latter only evidenced at maternally toxic doses. It is not considered a sensitiser.
Glutaraldehyde	111-30-8	3	Insoluble in water, readily biodegradable with a low potential to bioaccumulate	Based on the potential for it to be corrosive to the skin and eyes, a respiratory sensitiser and acutely toxic via the oral route of exposure.
Monoethanolamine borate	26038-87-9	4	Soluble, biodegradable and unlikely to bioaccumulate	Based on potential reproductive and developmental toxicity, Safe Work Australia (2020) has classified Monoethanolamine borate as Category 1B for reproductive and developmental toxicity (H360FD May damage fertility. May damage the unborn child). This is based on the classification of sodium borate, anhydrous (CAS No. 1330-43-4), tetraboron disodium heptaoxide, hydrate (CAS No. 12267-73-1) and orthoboric acid, sodium salt (CAS No. 13840-56-7) as Category 1B and the recommendation by NICNAS to extent this classification to the group (‘salts of boric acid’).

Substance	CAS No	IMAP Hazard Ranking	Environmental Behaviour	Key Determinants and Potential Hazard Outcomes
Silica gel	112926-00-8	0	Porous and water absorbing. Chemically stable (unlikely to react with other substances in the environment).	Amorphous silica is chemically and biologically inert when ingested in any of its many physical forms such as amorphous siliceous earth (diatomaceous earth, diatomite, kieselguhr) or colloidal silica gels and is not classifiable as to its carcinogenicity to humans. SAS is not considered as having acute or chronic health effects when administered via oral, dermal and inhalation exposure pathways nor as having any reproductive, development/teratogenicity and mutagenicity/genotoxicity effects. SAS is not classified as a skin sensitiser nor does it cause irreversible irritation of the skin or eye. For this reason it is categorized as Hazard Band 0. Safe Work Australia has listed amorphous silica as a hazardous substance under the respective legislation and developed an exposure standard for amorphous silica dust which is the generic standard for dusts. Due to its low solubility, amorphous silica in aqueous solution and as introduced during chemical stimulation activities would settle into soils and sediments and become indistinguishable from those materials. The principle hazard is subsequently the generation of dusts under occupational settings which require management.

6.7 Uncertainty Analysis and Concluding Comments

The evaluation of the hazards presented in Table 48is based on the available data obtained from the selected sources presented in Section 6.5. As a consequence, the hazard evaluation is limited to the quantity and quality of information available in those sources. An assessment of the quality of the available data is beyond the scope of this report. In the absence of verifying the data by going to the primary literature sources, the selection of data for use in the assessment has been confined to established, robust and reputable sources such as NICNAS, EU, IARC, WHO and US EPA where available. As new toxicological data are generated and become available in the published literature, the information presented in this hazard evaluation and the associated conclusions may be subject to change. Specific areas where such information is being generated include the areas of endocrine disruptors and nanotoxicity. The latter has at this stage not been a focus of these current evaluations due to the paucity of available peer-reviewed information but may be required as new information becomes available.

The hazard evaluation for human health suggests that the dominant concerns are related to occupational hazards such as carcinogenicity, silicosis, skin, eye and respiratory irritancy or corrosivity and sensitisation. In some cases, physical hazards of flammability and explosion prevail and are identified in this report. While extensive dilution of the stimulation chemicals is anticipated such that exposure concentrations will be much reduced compared to concentrations injected into the well, and in flowback fluid, there are a number of environmental hazards that are suggested from this human health evaluation. These include the potential for:

- Residual elevation of organic moieties. e.g. some salts have an organic part that will be present following dissociation that may increase in environmental waters.
- Changes in pH of environmental waters due to alkaline or acidic components.
- Elevations of certain metal concentrations in environmental waters.
- Some additives to exert endocrine disruption effects.
- Certain inorganic substances to generate atmospheric particulates that may impact nearby communities; and
- Volatile components to comprise nuisance or irritant effects should atmospheric concentrations be elevated in close proximity to communities.

These environmental hazards may be assessed further, and/or managed as required.

7.0 RISK CHARACTERISATION

Risk characterisation is the final step in a risk assessment process. It traditionally involves the incorporation of the exposure assessment and toxicological dose-response data. In this qualitative risk assessment, the process has embodied a hazard assessment and discussion of potential exposure pathways as part of a qualitative assessment of risk.

7.1 Discussion of Hazard Assessment

A hazard assessment of the chemicals used in the stimulation process by Santos contractor Halliburton have been assessed through the evaluation of persistence, bioaccumulation and aquatic toxicity (PBT) for aquatic receptors, terrestrial toxicity, and human health toxicity including physical hazards such as fire and explosion. The review of hazards is qualitative in that it has provided a relative ranking of chemicals considered to represent a high, moderate or low hazard in respect to the ecological or human health end points.

It should be noted that the selection of a substance as a COPC does not indicate an unacceptable risk; rather it indicates that potential exposures to these chemicals should be evaluated in greater detail to assess whether they might present an unacceptable risk. Further assessment usually entails evaluation of likely environmental concentrations and refinement of the exposure assessment.

The hazard assessment incorporates the assessment of toxicity and is based on the assumption that the pure substance is present; this is not true of either the stimulation fluid or the resultant concentration in the environment. The concentration of chemicals in the stimulation fluid during a release into the environment is expected to be less than the starting concentration calculated in the mass balance. The concentrations are expected to be reduced due to chemical processes during the stimulation process that result in transformation of the chemicals to simpler end products. In addition, chemicals will be subject to degradation, dispersion and adsorption all of which will result in attenuation of chemical concentrations with distance from the radius of stimulation.

7.1.1 Aquatic and Terrestrial Assessment

Based on the hazard classification of the stimulation chemicals (as presented in Table 4), the seven chemicals classified as a high hazard for aquatic receptors were considered to be COPC and these were alcohols, C12-C15, ethoxylated; surrogate for amides, tall-oil, fatty, N,N-bis(hydroxyethyl); chlorous acid, sodium salt; disodium octaborate tetrahydrate, sodium bisulfite, sodium iodide and surrogate for ulexite.

The certainty of the hazard classification varies depending on the extent of data gaps and the reliance on modelled data. The percent of data gaps were calculated and are presented in Table 23. The percentage data gaps for the high hazard chemicals ranged from relatively low (Alcohols, C12-C15, Ethoxylated) to relatively high (Sodium iodide).

In terms of terrestrial receptors, the following organic chemicals were assessed to have the potential to pose a higher environmental hazard relative to the other chemicals assessed based on persistence and potential to biomagnify:

- Diethanolamine; and
- Hydrotreated light petroleum distillate.

Diethanolamine has low volatility but it does not persistent in the soil and does not biomagnify. Hydrotreated light petroleum distillate has a high potential to biomagnify but it does not persist in the environment based on its fast half-life and high volatility. Therefore, although these chemicals appear to pose a higher hazard than others, their risk profile to terrestrial receptors is relatively low.

The remaining chemicals were considered likely to degrade quickly or moderately quickly and/or have a high or moderate volatility. Hence, whilst direct toxicity to terrestrial receptors may occur from exposure to these chemicals either after a spill or breach of containment, the effect will likely be reduced over time.

7.1.2 Human Health Assessment

The hazard evaluation for human health undertaken in accordance with the 'low-medium-high' hazard ranking methodology indicated three of the twenty chemicals assessed to have a 'moderate to high' relative ranking:

- Methanol
- Sodium iodide
- Acetic acid.

The hazard evaluation for human health undertaken in accordance with the IMAP Framework hazard ranking methodology indicated twelve of the seventeen chemicals assessed under this methodology to be a Hazard Rank of 4 or 3.

- Ethylene Glycol
- Sodium bisulfite
- Ulexite
- Diethanolamine
- Sodium polyacrylate
- Butyl alcohol
- Tributyl tetradecyl phosphonium chloride
- Guar gum
- Hydrotreated light petroleum distillate
- Glutaraldehyde
- Monoethanolamine borate.

The hazard evaluation for human health suggests that the dominant concerns are related to occupational hazards such as carcinogenicity, silicosis, skin, eye and respiratory irritancy or corrosivity and sensitisation. In some cases, physical hazards of flammability and explosion prevail and are identified in this report. While extensive dilution of the stimulation chemicals is anticipated such that potential exposure concentrations will be much reduced compared to concentrations injected into the well and in flowback fluid, there are a number of hazards that are suggested from this human health evaluation. These include the potential for:

- Residual elevations of organic moieties, e.g. some salts have an organic part that will be present following dissociation that may increase in environmental waters.
- Changes in pH of environmental waters due to alkaline or acidic components.
- Elevations of certain metal concentrations in environmental waters.
- Some additives to exert endocrine disruption effects.
- Certain inorganic substances to generate atmospheric particulates that may impact nearby communities in close proximity; and
- Volatile components to comprise nuisance or irritant effects should atmospheric concentrations be elevated in close proximity to communities.

These environmental hazards may be assessed further, and/or managed as required. Some of the exposure pathways identified (linking source to receptor) may be absent.

7.2 Discussion of Exposure Assessment

Potential exposure pathways were evaluated for on-site (i.e. within the lease) and those relevant for off-site (i.e. anything beyond the well lease boundary). Potentially complete exposure pathways were evaluated for workers, trespassers, native fauna and flora and livestock. The environment immediately surrounding the well lease (i.e. off-site) throughout the study area may vary from lease to lease, but was considered to potentially include homesteads (adult and child residents), water supply bores, creeks or waterholes, livestock and native flora and fauna.

The on-site assessment indicated that the majority of potential exposure pathways were unlikely or incomplete, given the application of operational controls by Santos. These operational controls include:

- OH&S procedures implemented during stimulation operations to prevent workers from direct contact and inhalation exposure to chemicals during spills and when handling flowback water or sediments.
- Implementation of spill containment procedures during operations to prevent migration of and exposure to chemicals.
- Vacuum removal of sediments and fluids contained within panel tanks, to prevent exposure to contaminants in windborne dust.
- Installation of signs to indicate the well lease (including the panel tank) is a work zone to be accessed by authorised personnel; and
- The use of panel tanks of approximately 2 m in height to prevent access by livestock and large native fauna.

One potentially complete exposure pathway was identified, which is direct contact to the flowback water in the panel tank for birds and flying mammals such as bats. All reasonable measures will be implemented to discourage entry of small native fauna into the well lease area during stimulation operations.

Potential off-site exposure pathways were evaluated for homesteads, livestock, native flora and fauna and aquatic ecosystems. Three possible sources were identified: stimulation fluids, sediments from the panel tank and flowback water. The exposure assessment concluded:

- Based on understanding of the Eromanga and Cooper Basin geology and hydrogeology, and Santos' well integrity testing procedures and operational monitoring, exposure to residual stimulation chemicals through subsurface pathways is considered unlikely and incomplete; and
- At the surface, a spill or leak of flowback water from the panel tank was considered possible, however the implementation of operational controls, including use of liners in the tank, removal of fluid and sediment using vacuum techniques and engineering and operational controls (grading of well leases and stormwater controls) is considered sufficient to limit the potential for uncontrolled releases of flowback water to the environment. A further margin of safety is provided by Santos' evaluation of 'environmentally sensitive areas' when establishing well leases, which includes the establishment of buffers between petroleum (and stimulation) activities and features of potential environmental concern. Subsequently, the potential off-site exposure scenarios are considered unlikely and incomplete.

7.3 Qualitative Risk Assessment of Fluids

In 2012 Santos collected seven fluid samples during South Australian stimulation activities for chemical analysis. Two of these fluids ('*DFS-BCG(H) (formally HyborH) Treatments*' and '*High Temperature Acid Spearheads*') are still in use or proposed for use by Haliburton in SWQ stimulation activities. The other two fluids assessed in this report *('DeltaFrac(H) Treatments' and 'DFS-BCG Treatments'*) were not assessed in the qualitative assessment of fluids.

A preliminary characterisation of stimulation fluids, makeup and site waters, and flowback quality was performed, comprising a broad suite of chemical analyses with the purpose of initial identification of the types of chemicals present, relative concentrations of chemicals detected, and to assess the concentrations against readily available benchmarks[19]. The initial suite may be refined progressively as required.

The initial chemical suite and assessment was to assist in further identification of potential hazards to humans and the environment using reported concentrations of stimulation fluid constituents at a Santos wellsite targeting conventional gas in Cooper Basin, South Australia. While located in a different jurisdiction, the stratigraphy, geology and fracture stimulation methodology was similar to that proposed for SWQ and is therefore considered to be representative. Direct contact with flowback fluid in the panel tanks has been identified as a potentially complete exposure pathway for human and ecological receptors. This preliminary assessment of flowback fluid quality will inform the scope of future investigations, where required.

At the time of reporting, no information on fluid chemical composition for the two new fluids *('DeltaFrac(H) Treatments' and 'DFS-BCG Treatments'*) had been provided to Golder and has therefore not been included in this report.

7.3.1 Methodology for Qualitative Risk Assessment

7.3.1.1 Field Work and Sampling Approach

The objective of the sampling was to provide a preliminary perspective of substances in stimulation flowback fluids. The approach is not a definitive representation of chemical or physical contamination, as this would ideally require a larger number of samples over a longer time frame. It does, however, provide some confidence to the hazard assessment process.

Santos indicated that the following sampling procedure was adopted:

- When collecting a sample from a pond or pit, a surface water sampler with a dedicated sampling container was used to collect a sample from 100 mm below the surface of the water in the pit. Prior to sampling, the sampling container was rinsed out three times with fluid obtained from that Flare Pit or vessel (as relevant).
- The fluid sample was placed in a sample jar prepared by the analytical laboratory. The sample bottle was filled to the top to minimise loss of volatile chemicals, and oxidation of the sample.
- Disposable gloves were used during sampling.
- The fluid sample was placed in a chilled, insulated container and delivered to the laboratory under a chain of custody (COC) procedure within recommended holding times for the specific analytical suite; and
- Subsequent samples were obtained with a new sampling container to minimise cross contamination.

7.3.1.2 Analytical Approach

ALS Environmental (ALS) was engaged to perform chemical analyses. ALS is registered by the National Association of Testing Authorities (NATA) for the analyses performed. Analysis of the flowback fluid sample included a range of parameters consistent with those traditionally examined to assess water quality and to account for information from stimulation mixtures as follows:

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[19] Assessment of individual chemicals used in stimulation was not proposed because the number of stimulation chemicals used at sites varies and because some stimulation chemicals cannot be readily analysed by commercial laboratories. For some stimulation chemicals, reliable measurement in environmental media requires the laboratory to develop in-house analytical techniques, which is demanding in time and cost. Furthermore, readily available risk-based screening benchmarks for environmental media do not exist for many of the stimulation chemicals.

- Metals and metalloids (Al, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Se, Sn, Sr, U, V, Zn).
- pH
- TDS
- Major cations and anions
- Nutrients (ammonia, nitrate, nitrite, total nitrogen, total phosphorous, reactive phosphorous, Total Kjeldahl Nitrogen (TKN)).
- Cyanide
- Total organic carbon
- Volatile organic compounds (VOC)
- Semi-volatile organic compounds (SVOC)
- Phenols
- Surfactants
- Formaldehyde
- Silica
- Chlorine
- Iodide
- Monocyclic aromatic hydrocarbons (MAH)
- Polycyclic aromatic hydrocarbons (PAH)
- Petroleum hydrocarbons (PHC)
- Organochlorine pesticides; and
- Organophosphorus pesticides.

These analyses represent a broad screen of organic and inorganic chemicals that may be present in stimulation or flowback fluids and may be used in a toxicity assessment of the fluid. The analytical suite is broad and is designed to capture the majority of substances of potential concern. There may be some unique proprietary substances that may not have been included and further evaluation of these may be required. The tabulated results of the fluid, waters and flowback analysis are presented in full in APPENDIX F at the end of this report. The laboratory certificates are also presented in APPENDIX F. Chemicals exceeding adopted benchmarks are discussed below in Sections 7.3.2.1 and 7.3.2.2.

7.3.2 Flowback Fluid Risk Assessment

The purpose of the flowback fluid assessment was a preliminary, qualitative assessment of risk to humans and the environment.

The analytical suite for assessment of the flowback fluid was developed after consideration of the following information and guidance documents:

- *Baseline Assessment Guideline*, DERM, May 2011; and
- Santos GLNG CSG *Groundwater Baseline Suite*, *CSG Water Characterisation Suite* and *Hydraulic Stimulation Suite*.

In review of these documents it is noted that the EVs for aquatic ecosystems and for human uses of water (e.g. water for drinking, farm supply, agriculture, industry and recreational use) under the Queensland Environmental Protection (Water) Policy 2009 (EPP Water) have not yet been developed for SWQ. In the absence of regionally defined water quality objectives for the study area, adoption of national water quality guidelines for screening are considered appropriate, namely:

- **Ecological receptors (aquatic ecosystems, livestock drinking water, crop irrigation)**: *Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand "Australian and New Zealand Guidelines for Fresh and Marine Water Quality".*
- **Human health, potable water**: *National Health and Medical Research Council (NHMRC) and Natural Resource Management Ministerial Council (NRMMC) (2011). Guidelines for Drinking Water Quality in Australia; and*
- **Human health, recreational water**: *NHMRC (2008). Guidelines for Managing Risks in Recreational Water.*

The above water quality guidelines are suitable for qualitative assessment of flowback water with regard to sensitive environmental receptors and humans. In addition, consideration was given to benchmarks for petroleum hydrocarbon fractions prepared by international regulatory and research agencies or ministerial councils, namely the Dutch National Institute for Public Health and the Environment (RIVM), the Canadian Council of Ministers of the Environment (CCME), and the American Petroleum Institute (API). It is noted that comparison of flowback water quality to potable water quality guidelines constitutes a conservative, screening level assessment as the exposure scenario upon which the guidelines were derived (i.e. chronic exposure from direct ingestion of water) is not strictly relevant to the management of flowback fluids.

The screening assessment of risk from the flowback fluid to ecological receptors and people is presented in Sections 7.3.2.1 and 7.3.2.2, respectively.

7.3.2.1 Ecological Assessment

Fluid data reported from the Tindilpie Pad Fluid Pit were evaluated against the following ecological benchmarks:

- ANZECC and ARMCANZ (2000) 95% Species Protection Level and Low Reliability Trigger Values for Freshwater.
- ANZECC and ARMCANZ (2000) Livestock Drinking Water Guidelines.
- ANZECC and ARMCANZ (2000) Crop Irrigation Guidelines.
- CCME (2008) Toxicity Aquatic Life Benchmarks.
- American Petroleum Institute (API) Risk Based Screening Levels (2004) for livestock; and
- RIVM (2004) Serious Risk Concentrations for Ecological Receptors (SRC eco).

Table 49 presents the chemical concentrations that exceeded the adopted benchmarks for the flowback fluid sample.

Table 49: Concentrations of Chemicals above Adopted Ecological Benchmarks

Chemical	Lowest Ecological Benchmark (mg/L)	Benchmark Reference	Concentration (mg/L)
Chemical Parameters			
Total dissolved solids (TDS)	4,000	ANZG (2018)	***10,100***
Anions and Cations			
Chloride	40	ANZG (2018) [3]	***3,710***
Sodium	115	ANZG (2018) [3]	***2,810***
Fluoride	1	ANZG (2018) [3]	***1.8***
Metals and Metalloids			
Arsenic	0.013	ANZG (2018)	***0.182***
Boron	0.37	ANZG (2018)	***57.9***
Copper	0.0014	ANZG (2018)	***0.061***
Lead	0.0034	ANZG (2018)	***0.088***
Manganese	1.9	ANZG (2018)	***2.68***
Nickel	0.011	ANZG (2018)	***0.028***
Zinc	0.008	ANZG (2018)	***0.052***
Aluminium	0.055	ANZG (2018)	***0.09***
BTEX			
Xylene (o-)	0.35	ANZG (2018)	***1.35***
Xylene (m+p)	0.275	ANZG (2018)	***7.21***
PAH			
Naphthalene	0.016	ANZG (2018)	***0.156***
Phenanthrene	0.002	ANZG (2018) LR [1]	***0.032***
Miscellaneous Organics			
Phenol	0.32	ANZG (2018)	***0.418***
Nutrients			
Ammonia (as N)	0.025	ANZG (2018) [2]	***55.4***
Nitrogen (total)	1	ANZG (2018) [2]	***166***
Phosphorous	0.025	ANZG (2018) [2]	***2.22***

Chemical	Lowest Ecological Benchmark (mg/L)	Benchmark Reference	Concentration (mg/L)
Petroleum Hydrocarbons			
Aromatic >EC7-8[5]	1.6	RIVM (2004)	***4.42***
Aromatic >EC8-10	0.14	CCME (2008)	***10.1***
Aromatic >EC10-12	0.096	RIVM (2004)	***4.1***
Aromatic >EC12-16	0.0554	CCME (2008)	***3.66***
Aromatic >EC16-21	0.071	RIVM (2004)	***2.78***
Aromatic >EC21-35	0.0061	RIVM (2004)	***0.64***
Aliphatic >EC5-6	0.33	RIVM (2004)	***3.44***
Aliphatic >EC6-8	0.0465	CCME (2008)	***24.1***
Aliphatic >EC8-10	0.0076	CCME (2008)	***47.4***
Aliphatic >EC10-12	0.00118	CCME (2008)	***5.18***
Aliphatic >EC12-16	0.000074	CCME (2008)	***12.5***

Notes:

[1] Low Reliability Trigger Value
[2] Default Trigger Value for South Central Australia – low rainfall areas, freshwater lakes and reservoirs
[3] Crop irrigation
[4] Livestock Drinking Water
[5] EC represents an equivalent carbon range (EC).

Chemicals reported below the laboratory limit of reporting (LOR), even where the screening benchmarks were below the LOR, were considered unlikely to pose a risk and were not considered further.

7.3.2.2 Human Health Assessment

Flowback fluid data reported from the Tindilpie Pad Frac Pit were screened against the following human health benchmarks:

- NHMRC (2011) Drinking Water Guidelines.
- NHMRC (2008) Recreational (Primary contact recreation).
- WHO (2005) Petroleum Products in Drinking Water.
- USEPA (2012b) Tap Water Guideline; and
- TPHCWG (1997) Total Petroleum Hydrocarbon Criteria Working Group.

Table 50 reports the concentrations in the flowback sample that exceeded adopted human health benchmarks.

Table 50: Concentrations of Chemicals above Adopted Human Health Benchmarks

Chemical	NHMRC 2008 (Primary Contact Recreation) mg/L	NHMRC 2011 (Human Health) mg/L	Concentration (mg/L)
Chemical Parameters			
Total Dissolved Solids @180°C	-	600	***10,100***
Anions and Cations			
Fluoride	1.5	1.5	***1.8***
Sodium	-	180	***2810***
Chloride	-	250	***3710***
Iodide	0.1	0.5	***1.29***
Metals and Metalloids			
Arsenic	0.007	0.01	***0.182***
Barium	0.7	2	***31.6***
Boron	4	4	***57.9***
Copper	2	2	***0.061***
Iron	-	0.3	***15.6***
Lead	0.01	0.01	***0.088***
Manganese	0.5	0.1	***2.68***
Nickel	0.02	0.02	***0.028***
Zinc	-	3	***0.052***
Aluminium	-	0.2	***0.09***
Miscellaneous Organics			
2,4-dimethylphenol	-	0.27 [1]	***0.337***
2-methylnaphthalene	-	0.027 [1]	***0.33***
1,2,4-trimethylbenzene	-	0.015 [1]	***2.55***
1,3,5-trimethylbenzene	-	0.087 [1]	***1.76***
n-propylbenzene	-	0.53 [2]	***0.628***
Formaldehyde	-	0.5	***2.9***
PAH[6]			
Naphthalene	-	0.00014 [1]	***0.156***
BTEX			
Benzene	0.001	0.001	***0.848***
Ethylbenzene	0.3	0.003	***0.533***

Chemical	NHMRC 2008 (Primary Contact Recreation) mg/L	NHMRC 2011 (Human Health) mg/L	Concentration (mg/L)
Toluene	0.8	0.025	***5.32***
Xylene (o)	-	0.5	***1.35***
Xylenes (m & p)	-	0.5	***7.21***
Petroleum Hydrocarbons			
Aromatic >EC5-7[5]	-	0.001 [3]	***0.837***
Aromatic >EC7-8	-	0.025 [3]	***4.42***
Aromatic >EC8-10	-	0.003 [4]	***10.1***
Aromatic >EC10-16	-	0.1 [4]	***7.76***
Aromatic >EC16-35	-	0.09 [4]	***3.42***
Aliphatic >EC5-8	-	15 [4]	***27.54***
Aliphatic >EC8-16	-	0.3 [4]	***65.08***

Notes:

[1] USEPA (2012b) tap water guideline
[2] N propylbenzene USEPA (2012b) tap water guideline
[3] WHO (2005)
[4] Benchmark for Ethylbenzene.
[5] EC represents an equivalent carbon range (EC).
[6] This has not included a Toxic Equivalency Factor (TEF) approach which examines the combined effects of PAHs based on their potency against benzo(a)pyrene.

Chemicals reported below the laboratory LOR, even where the screening benchmarks were below the LOR, were considered unlikely to pose a risk and were not considered further. The exclusions here are benzo(a)pyrene where the laboratory LOR exceeded the NHMRC (2011) guideline value, some chlorinated hydrocarbons and some of the pesticides such as the organochlorines aldrin, dieldrin and heptachlor. This uncertainty is not considered to be significant on this occasion as many other chemicals exceeded the potable and recreation water quality criteria.

In addition, the evaluation of PAHs as a mixture has not been undertaken at this stage as the naphthalene guideline is already exceeded. This would normally involve the calculation of BaP equivalents (BaPE) using potency data for other PAHs against BaP and their summation and comparison against the BaP guideline. This could be addressed in subsequent evaluation.

7.3.2.3 Chemicals for which Guidelines were Unavailable

The following chemicals were reported above the laboratory detection limit but there were no available guidelines or benchmarks for risk assessment:

- 2- methylphenol (0.5 mg/L);
- 3- and 4- methylphenol (0.35 mg/L);
- Fluorene (0.01 mg/L);
- Isopropyltoluene (2.7 mg/L);
- 1-propanol (23 mg/L); and
- 2-propanol (2.8 mg/L).

7.3.2.4 Discussion

Analysis of the flowback fluid sample analytical results identified concentrations of PHC, phenolics, BTEX, some PAH, metals, formaldehyde, nutrients, and cations and anions in excess of a large number of the adopted human health and ecological benchmarks. Based on the chemical information disclosed by the stimulation service provider in relation to the SWQ study area, it is considered likely that the petroleum hydrocarbon constituents reported in the flowback fluid sample are 'geogenic' and originated from the sandstone formation being fractured. The results are summarised as follows:

- The highest reported concentrations relative to guidelines were some PHC fractions, some BTEX compounds, PAHs such as naphthalene and BaP equivalents, and nutrients (ammonia and total nitrogen) were many times greater (orders of magnitude) than the applicable ecological and/or human health benchmarks.
- Greater concentrations of aliphatic petroleum hydrocarbon fractions (equivalent carbon chain length) were reported relative to aromatic fractions. The aliphatic carbon chain lengths which dominated the analyses were >EC6-C8 (24 mg/L[20]), >EC5-C8 (28 mg/L) and >EC8-C10 (47 mg/L[21]). The aromatic carbon chain lengths which dominated the analyses were >EC8-C10 (10 mg/L[22]) and >EC10-C16 (8 mg/L). These are all volatile hydrocarbon fractions and may present additional risks associated with inhalation exposure.
- The BTEX compounds: benzene (0.8 mg/L), toluene (5 mg/L), ethyl benzene (0.5 mg/L), and the PAH: naphthalene (0.15 mg/L) were 100 or more times greater than the applicable human health benchmarks. These substances are also volatile and may in addition present inhalation exposure risk.
- The presence of reported concentrations of solvents (ethanol and propanol) in the flowback fluid. These are volatile alcohols.
- The following metals were reported in the flowback fluid above adopted screening benchmarks: iron, manganese, barium, boron, arsenic, lead, nickel, aluminium, copper and zinc.
- The following cations and anions were reported in flowback fluid above adopted screening benchmarks: sodium, chloride, iodide, fluoride.
- The flowback fluid was of neutral pH (pH 7.5) and reported total dissolved solids (TDS[23]) concentrations that were considered to be moderately saline based on a reported concentration of 10,100 TDS mg/L compared to rainwater (<1 mg/L), surface[24], ground or sea water (35,000 mg/L); and
- The reported concentrations of nutrients (phosphorous, total nitrogen, ammonia) were elevated above the default[25] ecological benchmarks.

The following chemicals were not detected in the flowback fluid sample: OCPs and OPPs. Petroleum-based constituents are included in some stimulation fluid additive products (DEC, 2011). Review of TPHCWG (1998) reports that crude oil includes some of the individual chemicals reported in the flowback fluid, such as BTEX, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, n-propylbenzene, and PAHs. Based on the chemical information indicated or disclosed to Golder by Santos or its contractors in relation to the SWQ study area, no PHC constituents have been identified or proposed for use in the fluid systems assessed in this report. It is considered highly likely that the PHC constituents reported in the flowback fluid sample originated from the sandstone formation being fractured (i.e. a hydrocarbon reservoir).

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[20] Several hundred times above the lowest adopted ecological screening benchmark.

[21] Several thousand times above the lowest adopted ecological screening benchmark.

[22] Several thousand times above the lowest adopted human health screening benchmark

[23] TDS is a measure of all inorganic salts dissolved in water.

[24] Surface waters generally have TDS concentrations lower than groundwaters and higher than rainwater.

[25] The default trigger values for physical and chemicals stressors (i.e., different to toxicants) in ANZECC and ARMCANZ (2000) are not risk-based benchmarks. The default trigger values are indicative of unmodified or slightly-modified ecosystems reference or 'background' ranges for Central South Australia – low rainfall areas, freshwater lakes and reservoirs.

Some substances such as PHC, phenolics, BTEX, PAH, metals, nutrients, anions and cations reported in the flowback fluid may originate from the reservoir geology and/or the stimulation fluid constituents used. The reported concentrations of nutrients were considered likely to reflect organic inputs from stimulation chemicals rather than those naturally present in the formation. However, without additional information (namely, characterisation of (i) the produced water before mixture with stimulation fluid additives, (ii) mixed stimulation fluid prior to injection into the well, and (iii) background groundwater quality data) relative contributions from the stimulation fluid compared to naturally occurring concentrations cannot be assessed.

While some substances such as formaldehyde and the alcohols are not expected within the geological formations the presence of BTEX requires further evaluation as these are explicitly excluded from use in stimulation as stipulated by the EA.

As an initial step to examine this issue, stimulation mixtures were formulated with distilled water and subsequently analysed consistent with the previous analytical suites. These are discussed in Section 7.3.3.

7.3.3 Halliburton Stimulation Fluid Evaluations

As a preliminary step in the evaluation of hydrocarbon components in stimulation mixes two mixtures were formulated with distilled water and submitted for broad screen analyses consistent with the previous analytical profiles. Complete results are presented in Figure 2 and the results summarised in Table 52.

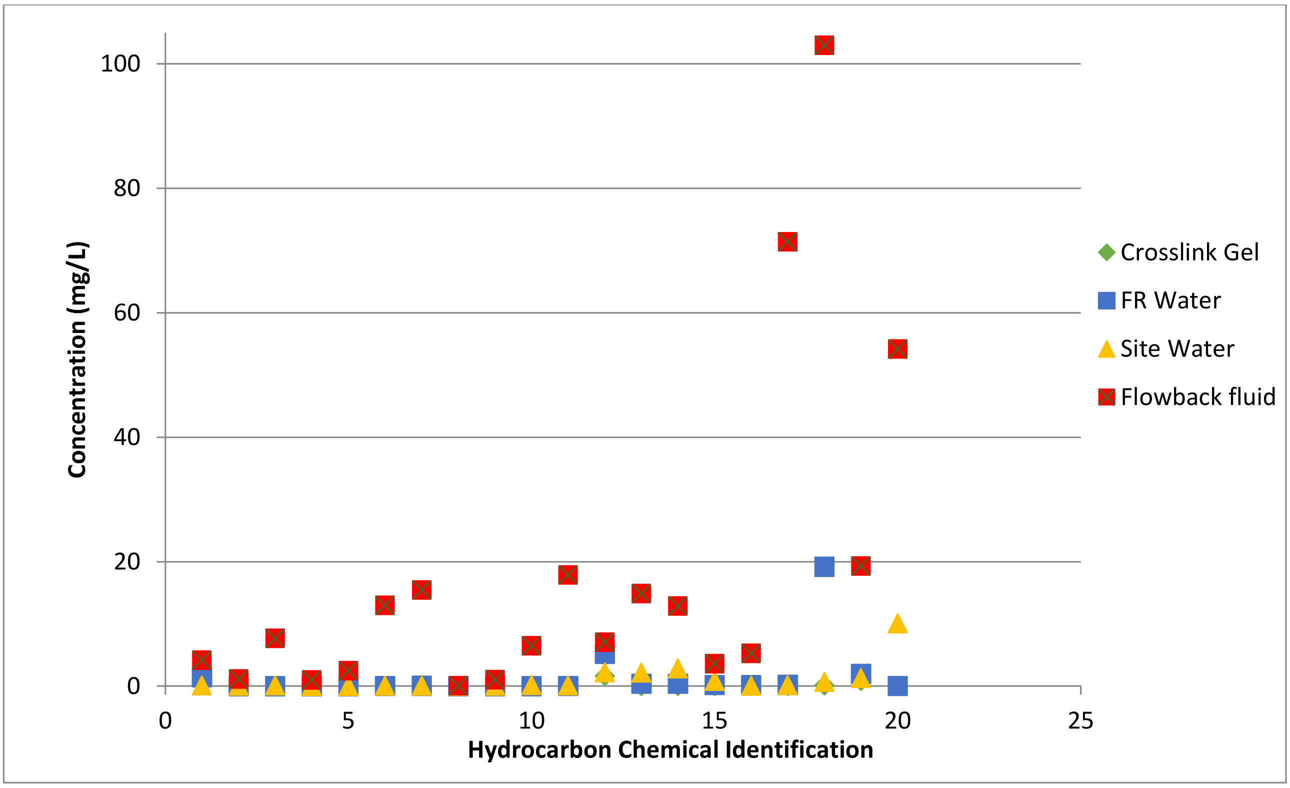

Figure 2: Hydrocarbon Concentrations in Stimulation Fluids (mg/L)

Review of the information suggests that the flowback fluids are substantially higher in residual concentrations of hydrocarbons that are considered to represent geogenically-derived substances, and these exceed conservative, potable water quality guideline concentrations.

Examination of the make up water drawn from formation water sources suggests the hydrocarbon concentrations are substantially lower, although still detectable, and range from concentrations below the limits of reporting to those concentrations approaching or in some cases exceeding certain water quality guidelines. This includes both potable water quality guidelines and ecological guidelines from both the Netherlands (RIVM, 2004) and Canada (CCME, 2008). These exceedances only apply to the TPH fractional ranges and the aesthetics-based health values for ethyl benzene and total xylenes.

The distilled water formulations (Crosslink Gel and FR Water) present a similar PHC concentration profile to the make up water with generally lower concentrations albeit with exceptions in some TPH fractional ranges and for p-isopropyltoluene. The latter are within an order of magnitude of the make up water concentrations. The BTEX results for the distilled water formulations are summarised in Table 51 below. The reported BTEX concentrations were either below the laboratory LOR or, where detected, were below the DEHP regulated criteria for stimulation fluid additives in Queensland.

Table 51: Summary of BTEX Analytical Results for Distilled Water Formulations (mg/L)

Analyte	DEHP Criteria	Crosslink Gel	FR Water
Benzene	0.001	<0.001	<0.01 [1]
Toluene	0.18	0.013	0.026
Ethylbenzene	0.08	<0.002	<0.01 [1]
o-Xylene	0.35	<0.002	<0.01 [1]
m & p-Xylene	0.275 [2]	0.017	0.05

Notes:

1. The laboratory reported that this sample was diluted prior to analysis due to matrix interferences, and the LOR was raised accordingly. While the raised LOR exceeds the benzene criterion of 0.001 mg/L, it does not represent an actual benzene concentration in the sample in exceedance of the criterion.
2. The m & p-Xylene criterion is the sum of the criteria for the individual m- and p-Xylene isomers (0.075 and 0.2 mg/L, respectively). Neither of the reported concentrations exceeds the lower of the individual isomer criteria.

Table 52 presents a comparison of the hydrocarbon results across the distilled water formulations and the (formation) makeup water and the flowback fluid results. It also provides the respective water guidelines based on either the NHMRC/NMMRC potable water quality guidelines and recreational contact guidelines and the ANZECC (2000) ecological guidelines where available. Where Australian guidelines were unavailable, specifically the TPH fractions, human health data were drawn from WHO (2005) and the ecological criteria drawn consistently from RIVM (2004) for this table as a guide.

These results suggest that generally formulations are not contributing substantial amounts of BTEX and TPH into the subsurface regions, however, some qualification of this statement is required as a result of residual uncertainties. These uncertainties require further exploration and reflect:

- Limited sampling frequencies for the respective fluids examined.
- Confidence in the sampling integrity and any potential for introduction of extraneous contamination. This potential is considered possible in view of the immediate environmental surrounds of the stimulation conditions; and
- The sampling process and its consistency with stimulation procedures at the time of sampling including spatial and temporal references, i.e. what was happening at the time of sampling and process locations, etc.

Table 52: Preliminary Stimulation Fluid Makeup Analyses and Fluid Flowback Comparisons (mg/L)

Chemical	NHMRC 2008 Human Health,(Primary Contact Recreation)	NHMRC 2011 (Human Health, Potable)	RIVM (2004); CCME (2008); ANZECC (2000) (Ecological)	Concentration			
				Crosslink Gel	FR Water	Make up water	Flow back fluids
(1) p-isopropyltoluene	NA	NA	NA	0.316	1.45	<0.005-0.11	1.83-4.19
(2) benzene	0.001	0.001	0.95	<0.001	<0.01	0.002-0.065	0.848-1.16
(3) toluene	0.8	0.025	0.18	0.013	0.026	0.004-0.148	5.32-7.7
(4) ethyl benzene	0.3	0.003 (aesthetic) 0.3 (health)	0.08	<0.002	<0.01	<0.002-0.011	0.533-0.995
(5) o-xylene	NA	NA	0.35	<0.002	<0.01	<0.002-0.023	1.35-2.48
(6) m- and p-xylene		NA	0.275	0.017	0.05	<0.002-0.08	7.21-13
(7) xylenes	As for potable	0.02 (aesthetic) 0.6 (health)	NA	<0.19	<0.06	<0.004-0.103	8.56-15.48
(8) iodomethane	NA	NA	NA	0.019	<0.01	<0.005	<0.1
(9) Aromatic EC5-7[a]	(0.001)	(0.001)	2.6	<0.005	<0.01	<0.005-0.07	0.837-1.04
(10) Aromatic >EC7-8[b]	(0.8)	(0.025)	1.8	0.012	0.023	<0.005-0.164	4.42-6.49
(11) Aromatic >EC8-10	NA	0.003[c]	1.3	0.018	0.047	<0.005-0.142	10.1-17.9
(12) Aromatic>EC10-12	NA	0.1	0.94	1.64	5.2	<0.05-2.24	4.1-7.07
(13) Aromatic >EC12-16[e]	NA		0.67	<0.05	0.41	<0.05-2.18	3.66-14.9
(14) Aromatic >EC16-21[e]	NA	0.09	0.6	<0.05	0.41	<0.05-2.86	2.78-12.9
(15) Aromatic >EC21-35	NA		1.2	0.056	0.205	0.099-0.871	0.64-3.61
(16) Aliphatic EC5-6	NA	15.0[d]	0.42	0.038	<0.2	<0.02-0.086	3.44-5.3

Chemical	NHMRC 2008 Human Health,(Primary Contact Recreation)	NHMRC 2011 (Human Health, Potable)	RIVM (2004); CCME (2008); ANZECC (2000) (Ecological)	Concentration			
(17) Aliphatic >EC6-8	NA		0.17	<0.02	0.216	0.02-0.162	22-71.4
(18) Aliphatic >EC8-10	NA	0.3	0.094	0.155	19.2	<0.02-0.688	47.1-103
(19) Aliphatic >EC10-12	NA		0.16	0.85	1.98	<0.05-1.34	5.18-19.3
(20) Aliphatic >EC12-16	NA		1.7	<0.05	<0.05	<0.05-10.1	12.5-54.2

Footnotes:

a. This fractional TPH group is based on benzene.

b. This fractional TPH group is based on toluene.

c. This fractional range includes ethylbenzene for which an aesthetic guideline of 0.003 mg/L has been established but also xylenes and methylethylbenzene that exhibit low taste and odour thresholds.

d. This value exceeds solubility threshold.

e. As PAHs are found within this fractional range these should be evaluated separately.

7.3.4 Assumptions and Limitations

The preliminary assessment of flowback data is subject to the following assumptions and limitations.

- The screening is conservative in that the benchmarks are intended for screening freshwater waters protective of ecological receptors (aquatic plants and animals, livestock drinking water, and plants[26]), and waters for recreation or for potable use by humans. The likelihood of these exposure pathways being realised differs for the receptors identified as discussed in Section 2.0. However, a conservative approach adopts the precautionary principle in risk assessment and provides additional confidence when there are uncertainties.
- The small sample size (six primary samples) for which variance in the flowback fluid cannot be assessed. The exact mix of the flowback fluid may be influenced by the aquifer being fractured and may vary between fracture locations. This may change in space and time so additional sampling strategies would seek to address spatial and temporal variance.
- Limited (one duplicate) quality assurance / quality control (QA/QC) samples were included in this investigation. Consideration of other sources of chemicals/contaminants: the quality and chemical characterisation of the make-up water; contamination status of the tankers used to transport and store water and to mix stimulation fluids: note this to a degree was addressed by making up representative samples of fracture chemicals using distilled water.
- Sampling was performed by non-Golder personnel, although managed by experienced Santos personnel in consultation with Golder. It is uncertain whether the sample represented a homogeneous sample of the distribution of contaminants throughout the water column, although all reasonable efforts were made to address this.
- The screening benchmarks adopted do not account for risk to humans via the vapour inhalation exposure pathway. A number of substances are volatile and present an inhalation hazard from ambient or confined atmospheric sources; and
- Further review of stimulation chemical constituents and mass balance data was not performed.

The combined effects of the stimulation chemical mixture were not assessed as it was considered outside the scope of a preliminary screening level risk assessment. Such an assessment reflects the ability for components to biologically interact and result in enhanced or minimised effects.

7.3.5 Conclusions

Based on this preliminary qualitative risk assessment, some substances (refer to Table 52) reported in the flowback fluid may originate from the reservoir geology and the reported concentrations of these chemicals may pose unacceptable risks to humans and ecological receptors exposed to flowback fluids. Further risk assessment would assist in better defining these risks and preliminary evaluations. It is noted that limited presence of toluene, xylenes and some TPH components were reported albeit at or near target acceptable concentrations. These may require further exploration and clarification to reduce residual uncertainties.

However, these risks may be managed by appropriate occupational and environmental health safety procedures and controls provided there is consistency in materials and methods. Changes in materials would require re-evaluation.

7.4 Overall Evaluation of Risk

Considering the hazard and exposure assessment and operational controls discussed, the overall risk to human health and environment associated with the chemicals involved in stimulation are expected to be low. These operational controls include:

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[26] Crop irrigation.

- OH&S procedures implemented during stimulation operations to prevent workers from direct contact and inhalation exposure to chemicals during spills and when handling flowback water or sediments.
- Assigning buffers during establishment of well leases between petroleum operations and potential “environmentally sensitive areas” identified though database review and site-specific ecological assessment where warranted.
- Implementation of spill containment procedures during operations to prevent migration of and exposure to chemicals.
- Removal of sediments and fluids contained within drained panel tanks to prevent exposure to contaminants in windborne dust.
- Installation of signs to indicate well leases (including panel tanks) are a work zones to be accessed by authorised personnel.
- The use of panel tanks of approximately 2m in height to prevent access by livestock and large native fauna.
- Santos operational procedures regarding well integrity verification and fracture design to stay within the target formation.
- Double lining of panel tanks as a minimum standard, to prevent seepage of flowback water into the underlying aquifer; and
- Engineering and operational controls (grading of well leases and stormwater controls to limit the potential for uncontrolled surface releases of flowback water to the environment.

7.5 Other Considerations

7.5.1 Noise and Vibration

The activities associated with stimulation have the potential to generate noise or vibration that could potentially impact nearby receptors. However, given the remote nature of Cooper Basin stimulation activities the presence of nearby receptors is considered unlikely. In addition, whilst the proposed activities will take place on a continuous basis, they will be undertaken sequentially for short periods of time at different sites over a wide area. As a result, individual sensitive receivers are only likely to be exposed to the effects of noise and vibration from these activities for a few weeks at a time. On this basis, risk associated with noise and vibration to offsite receptors has not been considered further in this report.

Potential for onsite noise and vibration exposure to workers exist during stimulation activities. Santos and stimulation service provider’s equipment are subject to noise emission testing by a professional third party. Prevention of exposure to workers is managed through Santos OH&S procedures.

7.5.2 Cumulative Impacts

Cumulative underground impacts from stimulation processes in a well lease are not anticipated based on the controls described in this report. Stimulation will be confined to the target sequences and vertical fracturing into overlying aquifer units is highly unlikely to occur.

Potential cumulative impacts associated with the development activities on a well lease may be associated with extraction of water from the reservoirs (after completion of the stimulation activities) and associated aquifer systems within respective formations. These cumulative impacts have been assessed separately and a groundwater monitoring and management plan developed which includes “make-good” provisions for potentially affected wells which may see reductions in water levels and associated yield.

8.0 CONCLUSIONS

8.1 Environmental Setting

Santos operates conventional gas and oil fields across petroleum tenements within an approximately 30,000 km^2 portion of Southwest Queensland. These tenements and the land surrounding the Santos tenement boundaries comprise the Santos SWQ *study area*.

The terrain in the study area is generally characterised by low undulating topography (hills and ridges) between the drainage channel systems of the Cooper Creek. The area is sparsely developed, and generally comprises rural communities and homesteads that are largely engaged in farming and livestock.

It is within the stratigraphy that comprises the Eromanga Basin and the underlying Cooper Basin that oil and gas reservoirs are located which contain the proposed target formations for stimulation. A detailed description of key geological and hydrogeological features is provided in Volume One, including geological models for the study area, target hydrocarbon-bearing sandstone formations (oil in the Eromanga Basin formations at depths ranging from 700 to 1,200 mbgl, and gas in the Cooper Basin formations at depths of 1,500 to greater than 2,000 mbgl), their hydraulic characteristics, adjacent aquifers and aquitards, structural features including faults and fracture characteristics (and their potential to behave as barriers or conduits), regional and local seismicity characteristics, aquifer environmental values and the location of groundwater users.

In terms of the environmental setting, Volume One of the SWQ HSRA has provided specific information which addresses the requirements anticipated of the EA conditions regarding stimulation that will apply to existing and new areas.

Based on understanding of the environmental setting, this qualitative risk assessment considered the key environmental values as follows:

Groundwater Environmental Values:

- Town water supply
- Stock and domestic water supply
- Sandstone aquifers of the GAB; and
- GDEs.

Surface Water Environmental Values:

- Protection of aquatic ecosystems
- Recreation and aesthetics: primary recreation with direct contact, and visual appreciation with no contact; and
- Cultural and spiritual values.

Terrestrial Environmental Values:

- Protection of flora and fauna, such as small mammals, reptiles and birds.

The report has considered each in terms of the risk to aquatic ecosystems, terrestrial ecosystems and human health.

8.2 Stimulation Process Description Summary

With regard to the process of stimulation, information addressing the EA blueprint conditions (with reference to the model conditions) are located within Volume One of the SWQ HSRA, including:

- Practices and procedures to ensure that the stimulation activity(ies) is designed to be contained within the target gas producing formation.

- Provide details of where, when and how often stimulation is to be undertaken on the tenures covered by this environmental authority.
- A description of the well mechanical integrity testing program.
- Process control and assessment techniques to be applied for determining extent of stimulation activity(ies) (e.g. microseismic measurements, modelling etc); and
- A process description of the stimulation activity to be applied, including equipment and a comparison to best international practice.

8.3 Toxicological Evaluation

The toxicity of the chemicals used in the stimulation process by Halliburton has been assessed for persistence, bioaccumulation and aquatic toxicity (PBT), terrestrial toxicity and human health toxicity including the physical hazards of fire and explosion. The review of toxicity is qualitative and has provided a ranking of chemicals considered to represent a high, moderate or low hazard in respect to the ecological or human health end points with qualification as appropriate.

A preliminary quantitative assessment has also been undertaken, with Santos and Halliburton in 2012 collecting a total of seven fluid samples during South Australian stimulation activities for chemical analysis. These stimulation activities are undertaken by Halliburton and are considered reasonably indicative of the proposed SWQ activities. At the data of reporting no quantitative assessment had been undertaken for DeltaFrac(H) and DFS-BCG(H).

Concentrations of toluene, xylenes and PHC fractions were reported in two samples of distilled water mixed with stimulation fluid additives, prepared by Halliburton. The concentrations were reported below the DEHP (2012) BTEX standard.

Review of the data indicates that the flowback fluids contain substantially higher concentrations of hydrocarbons, which are considered to represent geogenically derived substances and these exceed the respective water quality guideline concentrations (where available).

Examination of the make up water drawn from formation water sources suggests the hydrocarbon concentrations are lower and range from concentrations below the limits of reporting to concentrations approaching or in some cases exceeding the respective water quality guidelines. This includes both potable water quality guidelines and ecological guidelines from both the Netherlands (RIVM, 2004) and Canada (CCME, 2008), which were referenced in the absence of water quality guidelines for hydrocarbon fractions in Australia. These exceedances only apply to the TPH fractional ranges and the aesthetics-based health values for ethyl benzene and total xylenes.

The distilled water fluid formulations present a similar hydrocarbon concentration profile to the make up water, with generally lower concentrations albeit with exceptions in some TPH fractional ranges and for p-isopropyltoluene. The latter are within an order of magnitude of the make up water concentrations. In the case of the BTEX group the distilled water formulations have not identified BTEX concentrations exceeding BTEX water quality criteria specified in the Queensland Environmental Protection Regulation.

These results suggest that stimulation fluid formulations are not contributing substantial amounts of BTEX and TPH into the subsurface regions, and certainly at concentrations that are both below the regulated criteria (where available) and below the concentrations in the hydrocarbon reservoirs being fractured. Some qualification of this statement is required as a result of residual uncertainties.

8.4 Evaluation of Exposure Pathways

Potential exposure pathways were evaluated for on-site (i.e. within the well lease), and those relevant for off-site (i.e. anything beyond the well lease boundary). The on-site assessment indicated that the majority of possible exposures were unlikely or incomplete. One complete exposure pathway was identified, which is direct contact to the flowback water in the panel tanks for small fauna (i.e. birds and flying mammals such as bats). All reasonable measures will be conducted to discourage entry of small native fauna into the well lease area during stimulation operations. Improvement of flowback water containment will further reduce the potential for this exposure scenario to occur.

For the off-site exposure assessment, it was assumed that potential off-site receptors could include homesteads (adult and child residents), water supply bores, creeks and waterholes, livestock and native flora and fauna. Three possible chemical sources were identified: injected stimulation fluids, sediments from panel tanks and flowback water. The exposure assessment concluded:

- Subsurface exposure to stimulation fluids is controlled by Santos' well integrity testing procedures and operational monitoring, and this pathway (whereby stimulation fluids could escape into the formation and contaminate adjacent aquifers that are used for domestic or stock water supply) is considered unlikely or incomplete.
- Based on an understanding of the Eromanga and Cooper Basin geology and hydrogeology, and the nature and extent of groundwater supply development, exposure to residual stimulation chemicals through subsurface pathways is considered unlikely and incomplete; and
- At the surface, a spill or leak of flowback water from the panel tank was considered as a possible exposure scenario, however the implementation of operational controls, including use of liners in panel tanks, removal of fluid and sediment using vacuum techniques and engineering and operational controls (grading of well leases and stormwater controls) is considered sufficient to limit the potential for uncontrolled releases of flowback water to the environment. A further margin of safety is provided by Santos' evaluation of 'environmentally sensitive areas' when establishing well leases, which includes the establishment of buffers between petroleum (and stimulation) activities and features of potential environmental concern. Subsequently, the potential off-site exposure scenarios are considered unlikely and incomplete.

8.5 Overall Risk Evaluation

Considering the hazard, exposure assessment and qualitative assessment of fluids, although unlikely, flowback water at surface presents some inherent risk. However, with Santos operational controls and management, the overall or residual risk to human health and environment associated with the chemicals involved in stimulation are expected to be low. The management measures implemented through operational controls include:

- OH&S procedures implemented during stimulation operations to prevent workers from direct contact with chemicals during spills and when handling flowback water or sediments.
- Santos operational procedures regarding well integrity verification and fracture design to stay within the target formation.
- Assigning buffers during establishment of well leases between petroleum operations and potential "environmentally sensitive areas" identified though database review and site-specific ecological assessment where warranted.
- Implementation of spill containment procedures during operations to prevent migration of and exposure to chemicals.
- Vacuum removal of sediments and fluids contained within panel tanks, to prevent exposure to contaminants in fluids and windborne dust.

- Installation of signs to indicate that well leases (including panel tanks) are work zones to be accessed by authorised personnel.
- The use of panel tanks of approximately 2m in height to prevent access by livestock and large native fauna. Double lining of panel tanks to prevent seepage of flowback water into the underlying aquifer; and
- Engineering and operational controls (grading of well leases and stormwater controls) to limit the potential for uncontrolled surface releases of flowback water to the environment.

The adequacy and appropriateness of these exposure controls will be routinely evaluated by Santos and modifications and revisions made, where necessary, to achieve continuous improvement.

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Signature Page

Golder Associates Pty Ltd

NC:MT/CMB/ro

A.B.N. 64 006 107 857

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APPENDIX A

Limitations

The document ("Report") to which this page is attached and which this page forms a part of, has been issued by Golder Associates Pty Ltd ("Golder") subject to the important limitations and other qualifications set out below.

This Report constitutes or is part of services ("Services") provided by Golder to its client ("Client") under and subject to a contract between Golder and its Client ("Contract"). The contents of this page are not intended to and do not alter Golder's obligations (including any limits on those obligations) to its Client under the Contract.

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Any uncertainty as to the extent to which this Report can be used or relied upon in any respect should be referred to Golder for clarification

APPENDIX B

Safety Data Sheets

SAFETY DATA SHEET

ACETIC ACID 55%-90%

Revision Date: 20-Aug-2018 **Revision Number:** 3

1. Product Identifier & Identity for the Chemical

Statement of Hazardous Nature Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Dangerous Goods according to the criteria of ADG.

1.1. Product Identifier

Product Name ACETIC ACID 55%-90%

Other means of Identification

Synonyms None
Hazardous Material Number: MC600186

Recommended use of the chemical and restrictions on use

Recommended Use Scale Control
Uses advised against Consumer use

Supplier's name, address and phone number

Manufacturer/Supplier
Multi-Chem Mintech
1 Ward Road
East Rockingham
WA 6168
Australia

Telephone Number: 61 (08) 9419 5300
Fax Number: 61 (08) 9439 1055
Emergency Telephone Number: + 61 1 800 686 951

E-mail Address fdunexchem@halliburton.com

Emergency phone number

+ 61 1 800 686 951
Global Incident Response Access Code: 334305
Contract Number: 14012

Australian Poisons Information Centre
24 Hour Service: - 13 11 26
Police or Fire Brigade: - 000 (exchange): - 1100

2. Hazard Identification

Statement of Hazardous Nature Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Dangerous Goods according to the criteria of ADG.

Classification of the hazardous chemical

Skin Corrosion/Irritation	Category 1 - H314
Serious Eye Damage/Irritation	Category 1 - H318
Specific Target Organ Toxicity - (Single Exposure)	Category 3 - H335
Flammable liquids.	Category 3 - H226

Label elements, including precautionary statements

Hazard Pictograms

Signal Word DANGER

Hazard Statements:

H226 - Flammable liquid and vapor
H314 - Causes severe skin burns and eye damage
H318 - Causes serious eye damage
H335 - May cause respiratory irritation

Precautionary Statements

Prevention

P210 - Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.
P233 - Keep container tightly closed
P240 - Ground and bond container and receiving equipment.
P241 - Use explosion-proof electrical/ventilating/lighting/equipment
P242 - Use only non-sparking tools
P243 - Take action to prevent static discharges.
P260 - Do not breathe dust/fume/gas/mist/vapors/spray
P261 - Avoid breathing dust/fume/gas/mist/vapors/spray
P271 - Use only outdoors or in a well-ventilated area
P280 - Wear protective gloves/protective clothing/eye protection/face protection

Response

P301 + P330 + P331 - IF SWALLOWED: rinse mouth. Do NOT induce vomiting
P303 + P361 + P353 - IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water [or shower].
P363 - Wash contaminated clothing before reuse
P304 + P340 - IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing
P305 + P351 + P338 - IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing
P310 - Immediately call a POISON CENTER or doctor/physician
P370 + P378 - In case of fire: Use water spray for extinction

Storage

P403 + P233 - Store in a well-ventilated place. Keep container tightly closed
P403 + P235 - Store in a well-ventilated place. Keep cool
P405 - Store locked up

Disposal

P501 - Dispose of contents/container in accordance with local/regional/national/international regulations

Contains Substances	**CAS Number**
Acetic acid	64-19-7

Other hazards which do not result in classification

This mixture contains no substance considered to be persistent, bioaccumulating nor toxic (PBT).
This mixture contains no substance considered to be very persistent nor very bioaccumulating (vPvB).

For the full text of the H-phrases mentioned in this Section, see Section 16

3. Composition/information on Ingredients

Substances	CAS Number	PERCENT (w/w)	GHS Classification - Australia
Acetic acid	64-19-7	60 - 100%	Skin Corr. 1A (H314) Eye Corr. 1 (H318) STOT SE 3 (H335) Flam. Liq. 3 (H226)

4. First aid measures

Description of necessary first aid measures

Inhalation	If inhaled, remove from area to fresh air. Get medical attention if respiratory irritation develops or if breathing becomes difficult.
Eyes	In case of contact, immediately flush eyes with plenty of water for at least 30 minutes. Remove contact lenses after the first 5 minutes and continue washing. Seek immediate medical attention/advice. Suitable emergency eye wash facility should be immediately available
Skin	In case of contact, immediately flush skin with plenty of soap and water for at least 30 minutes and remove contaminated clothing, shoes and leather goods immediately. Get medical attention immediately.
Ingestion	Rinse mouth with water many times. Get medical attention, if symptoms occur

Symptoms caused by exposure

Causes severe skin irritation with tissue destruction. Causes severe eye irritation which may damage tissue. May cause respiratory irritation.

Medical Attention and Special Treatment

Notes to Physician	Treat symptomatically

5. Fire Fighting Measures

Suitable extinguishing equipment

Suitable Extinguishing Media

Water fog, carbon dioxide, foam, dry chemical.

Extinguishing media which must not be used for safety reasons

Do NOT spray pool fires directly with water. A solid stream of water directed into hot burning liquid can cause splattering.

Specific hazards arising from the chemical

Special exposure hazards in a fire

Decomposition in fire may produce harmful gases.

Special protective equipment and precautions for fire fighters

Special protective equipment for firefighters

Full protective clothing and approved self-contained breathing apparatus required for fire fighting personnel.

6. Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

Ensure adequate ventilation. Use appropriate protective equipment. Do not breathe dust/fume/gas/mist/vapors/spray. Remove sources of ignition. Take precautionary measures against static discharges All equipment used when handling the product must be grounded Avoid contact with skin, eyes and clothing.

6.2. Environmental precautions

Prevent from entering sewers, waterways, or low areas.

6.3. Methods and material for containment and cleaning up

Dike far ahead of liquid spill for later disposal. Soak up with inert absorbent material. Pick up and transfer to properly labeled containers. Remove ignition sources and work with non-sparking tools.

7. Handling and storage

7.1. Precautions for safe handling

Handling Precautions

Do not breathe dust/fume/gas/mist/vapors/spray. Ensure adequate ventilation. Use appropriate protective equipment. Remove sources of ignition. Ground and bond containers when transferring from one container to another. Avoid contact with eyes, skin, or clothing.

Hygiene Measures

Handle in accordance with good industrial hygiene and safety practice.

7.2. Conditions for safe storage, including any incompatibilities

Storage Information

Store in a cool well ventilated area. Keep from heat, sparks, and open flames.

Other Guidelines

No information available

8. Exposure Controls/Personal Protection

Control parameters - exposure standards, biological monitoring

Exposure Limits

Substances	CAS Number	Australia NOHSC	ACGIH TLV-TWA
Acetic acid	64-19-7	TWA: 10 ppm TWA: 25 mg/m^3 STEL: 15 ppm STEL: 37 mg/m^3	TWA: 10 ppm STEL: 15 ppm

Appropriate engineering controls

Engineering Controls	Ensure adequate ventilation, especially in confined areas

Personal protective equipment (PPE)

Personal Protective Equipment	If engineering controls and work practices cannot prevent excessive exposures, the selection and proper use of personal protective equipment should be determined by an industrial hygienist or other qualified professional based on the specific application of this product.
Respiratory Protection	If engineering controls and work practices cannot keep exposure below occupational exposure limits or if exposure is unknown, wear a NIOSH certified, European Standard EN 149, AS/NZS 1715:2009, or equivalent respirator when using this product. Selection of and instruction on using all personal protective equipment, including respirators, should be performed by an Industrial Hygienist or other qualified professional.
Hand Protection	Use gloves which are suitable for the chemicals present in this product as well as other environmental factors in the workplace.
Skin Protection	Wear impervious protective clothing, including boots, gloves, lab coat, apron, rain jacket, pants or coverall, as appropriate, to prevent skin contact.
Eye Protection	None known.
Other Precautions	None known.
Environmental Exposure Controls	No information available

9. Physical and Chemical Properties

9.1. Information on basic physical and chemical properties

Physical State:	Liquid	**Color**	Light Amber to Dark Amber , Clear to Slightly Hazy
Odor:	Pungent	**Odor Threshold:**	No information available

Property Remarks/ - Method	Values
pH:	2.5-3.8 (10% in 1:1 IPA:H2O)
Freezing Point / Range	No data available
Melting Point / Range	No data available
Boiling Point / Range	No data available
Flash Point	> 40 °C / > 104 °F (SFCC)
Evaporation rate	No data available
Vapor Pressure	No data available
Vapor Density	No data available
Specific Gravity	1.0653-1.0903 (20 °C/68 °F)
Water Solubility	Soluble in water
Solubility in other solvents	No data available
Partition coefficient: n-octanol/water	No data available
Autoignition Temperature	No data available
Decomposition Temperature	No data available
Viscosity	No data available
Explosive Properties	No information available
Oxidizing Properties	No information available

9.2. Other information

VOC Content (%)	No data available
Liquid Density	8.88-9.09 lbs/gal
Bulk Density	1065-1090 kg/m^3

10. Stability and Reactivity

10.1. Reactivity
Not expected to be reactive.

10.2. Chemical stability
Stable

10.3. Possibility of hazardous reactions
Will Not Occur

10.4. Conditions to avoid
Keep away from heat, sparks and flame.

10.5. Incompatible materials
Strong oxidizers.

10.6. Hazardous decomposition products
Carbon oxides.

11. Toxicological Information

Information on routes of exposure

Principle Route of Exposure Skin contact. Eye contact. Inhalation.

Symptoms related to exposure

Most Important Symptoms/Effects

Causes severe skin irritation with tissue destruction. Causes severe eye irritation which may damage tissue. May cause respiratory irritation.

Toxicology data for the components

Substances	CAS Number	LD50 Oral	LD50 Dermal	LC50 Inhalation
Acetic acid	64-19-7	No data available	1060 mg/kg-bw (rabbit)	11.4 mg/L (rat, 4 h, vapor)

Immediate, delayed and chronic health effects from exposure

Inhalation	May cause respiratory irritation.
Eye Contact	Causes serious eye damage.
Skin Contact	Causes severe burns.

Ingestion Causes burns of the mouth, throat and stomach.

Exposure Levels
No data available

Interactive effects
No data available

Data limitations
No data available

Substances	CAS Number	Skin corrosion/irritation
Acetic acid	64-19-7	Extremely corrosive and destructive to tissue Skin, rabbit:

Substances	CAS Number	Serious eye damage/irritation
Acetic acid	64-19-7	Eye, rabbit: Causes serious eye damage

Substances	CAS Number	Skin Sensitization
Acetic acid	64-19-7	Not regarded as a sensitizer.

Substances	CAS Number	Respiratory Sensitization
Acetic acid	64-19-7	No information available

Substances	CAS Number	Mutagenic Effects
Acetic acid	64-19-7	In vivo tests did not show mutagenic effects. In vitro tests did not show mutagenic effects.

Substances	CAS Number	Carcinogenic Effects
Acetic acid	64-19-7	Did not show carcinogenic effects in animal experiments

Substances	CAS Number	Reproductive toxicity
Acetic acid	64-19-7	Did not show teratogenic effects in animal experiments. Animal testing did not show any effects on fertility.

Substances	CAS Number	STOT - single exposure
Acetic acid	64-19-7	May cause respiratory irritation. No information available

Substances	CAS Number	STOT - repeated exposure
Acetic acid	64-19-7	No significant toxicity observed in animal studies at concentration requiring classification.

Substances	CAS Number	Aspiration hazard
Acetic acid	64-19-7	Not applicable

12. Ecological Information

Ecotoxicity

Product Ecotoxicity Data
Product is not classified as hazardous to the environment.

Substance Ecotoxicity Data

Substances	CAS Number	Toxicity to Algae	Toxicity to Fish	Toxicity to Microorganisms	Toxicity to Invertebrates
Acetic acid	64-19-7	EC50(72 h)=55.22 mg/L (Anabaena flos-aquae)	LC50(96 h)=251 mg/L (Gambusia affinis) LC50(96 h)=75 mg/L (Lepomis macrochirus)	NOAEC (16 h) =1150 mg/L (Pseudomonas putida)	EC50(48 h)=65 mg/L (Daphnia magna)

12.2. Persistence and degradability

Substances	CAS Number	Persistence and Degradability
Acetic acid	64-19-7	Readily biodegradable (99% @ 7d)

12.3. Bioaccumulative potential

Substances	CAS Number	Bioaccumulation
Acetic acid	64-19-7	LogPow-0.17

12.4. Mobility in soil

Substances	CAS Number	Mobility
Acetic acid	64-19-7	No information available

12.6. Other adverse effects

Endocrine Disruptor Information
This product does not contain any known or suspected endocrine disruptors

13. Disposal Considerations

Safe handling and disposal methods

Disposal should be made in accordance with federal, state, and local regulations.

Disposal of any contaminated packaging

Follow all applicable national or local regulations.

Environmental regulations

Not applicable

14. Transport Information

Transportation Information

Australia ADG

UN Number	UN2789
UN proper shipping name:	Acetic Acid Solution
Transport Hazard Class(es):	8 (3)
Packing Group:	III
Environmental Hazards:	Not applicable

IMDG/IMO

UN Number	UN2789
UN proper shipping name:	Acetic Acid Solution
Transport Hazard Class(es):	8 (3)
Packing Group:	III
Environmental Hazards:	Not applicable
EMS:	EmS F-E, S-C

IATA/ICAO

UN Number	UN2789
UN proper shipping name:	Acetic Acid Solution
Transport Hazard Class(es):	8 (3)
Packing Group:	III
Environmental Hazards:	Not applicable

Special precautions during transport

None

HazChem Code

•2P

15. Regulatory Information

Safety, health and environmental regulations specific for the product

International Inventories

Australian AICS Inventory	All components are listed on the AICS or are subject to a relevant exemption, permit, or assessment certificate.
New Zealand Inventory of Chemicals	All components are listed on the NZIoC or are subject to a relevant exemption, permit, or assessment certificate.
EINECS (European Inventory of Existing Chemical Substances)	This product, and all its components, complies with EINECS
US TSCA Inventory	All components listed on inventory or are exempt.
Canadian Domestic Substances List (DSL)	All components listed on inventory or are exempt.

Poisons Schedule number

S6

International Agreements

Montreal Protocol - Ozone Depleting Substances:	Does not apply.
Stockholm Convention - Persistent Organic Pollutants:	Does not apply
Rotterdam Convention - Prior Informed Consent:	Does not apply.
Basel Convention - Hazardous Waste:	Does not apply.

16. Other information

Date of preparation or review

Revision Date: 20-Aug-2018

Revision Note

Update to Format

Full text of H-Statements referred to under sections 2 and 3

H226 - Flammable liquid and vapor
H314 - Causes severe skin burns and eye damage
H318 - Causes serious eye damage
H335 - May cause respiratory irritation

Additional information For additional information on the use of this product, contact your local Halliburton representative.

For questions about the Safety Data Sheet for this or other Halliburton products, contact Chemical Stewardship at 1-580-251-4335.

Key abreviations or acronyms used

bw – body weight
CAS – Chemical Abstracts Service
EC50 – Effective Concentration 50%
LC50 – Lethal Concentration 50%
LD50 – Lethal Dose 50%
LL50 – Lethal Loading 50%
mg/kg – milligram/kilogram
mg/L – milligram/liter
NOEC – No Observed Effect Concentration
OEL – Occupational Exposure Limit
PBT – Persistent Bioaccumulative and Toxic
ppm – parts per million
STEL – Short Term Exposure Limit
TWA – Time-Weighted Average
vPvB – very Persistent and very Bioaccumulative
h - hour
mg/m^3 - milligram/cubic meter
mm - millimeter
mmHg - millimeter mercury

w/w - weight/weight
d - day

Key literature references and sources for data
www.ChemADVISOR.com/

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End of Safety Data Sheet

HALLIBURTON

SAFETY DATA SHEET

ACETIC ACID 60%

Revision Date: 26-Jun-2019 **Revision Number:** 11

1. Product Identifier & Identity for the Chemical

Statement of Hazardous Nature Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Dangerous Goods according to the criteria of ADG.

1.1. Product Identifier

Product Name ACETIC ACID 60%

Other means of Identification

Synonyms None
Hazardous Material Number: HM004481

Recommended use of the chemical and restrictions on use

Recommended Use Solvent
Uses advised against No information available

Supplier's name, address and phone number

Manufacturer/Supplier
Halliburton Australia Pty. Ltd.
15 Marriott Road, Jandakot, WA 6164
Australia
ACN Number: 009 000 775
Telephone Number: + 61 1 800 686 951
Fax Number: 61 (08) 9455 5300
E-mail Address fdunexchem@halliburton.com

Emergency phone number

+ 61 1 800 686 951
Global Incident Response Access Code: 334305
Contract Number: 14012

Australian Poisons Information Centre
24 Hour Service: - 13 11 26
Police or Fire Brigade: - 000 (exchange): - 1100

2. Hazard Identification

Statement of Hazardous Nature Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Dangerous Goods according to the criteria of ADG.

Classification of the hazardous chemical

Skin Corrosion/Irritation	Category 1 - H314
Serious Eye Damage/Irritation	Category 1 - H318
Specific Target Organ Toxicity - (Single Exposure)	Category 3 - H335
Flammable liquids.	Category 3 - H226

Label elements, including precautionary statements

Hazard Pictograms

Signal Word

DANGER

Hazard Statements:

H314 - Causes severe skin burns and eye damage
H318 - Causes serious eye damage
H335 - May cause respiratory irritation
H226 - Flammable liquid and vapor

Precautionary Statements

Prevention

P210 - Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.
P233 - Keep container tightly closed
P240 - Ground and bond container and receiving equipment.
P241 - Use explosion-proof electrical/ventilating/lighting/equipment
P242 - Use only non-sparking tools
P243 - Take action to prevent static discharges.
P260 - Do not breathe dust/fume/gas/mist/vapors/spray
P264 - Wash face, hands and any exposed skin thoroughly after handling
P271 - Use only outdoors or in a well-ventilated area
P280 - Wear protective gloves/protective clothing/eye protection/face protection

Response

P301+ P330 + P331 - IF SWALLOWED: Rinse mouth. Do NOT induce vomiting
P303 + P361 + P353 - IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water [or shower].
P363 - Wash contaminated clothing before reuse
P312 - Call a POISON CENTER or doctor/physician if you feel unwell
P305 + P351 + P338 - IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing
P310 - Immediately call a POISON CENTER or doctor/physician
P370 + P378 - In case of fire: Use water spray for extinction
P304 + P340 - IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing

Storage

P403 + P233 - Store in a well-ventilated place. Keep container tightly closed
P403 + P235 - Store in a well-ventilated place. Keep cool
P405 - Store locked up

Disposal

P501 - Dispose of contents/container in accordance with local/regional/national/international regulations

Contains

Substances	**CAS Number**
Acetic acid	64-19-7

Other hazards which do not result in classification

None known

For the full text of the H-phrases mentioned in this Section, see Section 16

3. Composition/information on Ingredients

Substances	CAS Number	PERCENT (w/w)	GHS Classification - Australia
Acetic acid	64-19-7	60 - 100%	Skin Corr. 1A (H314) Eye Corr. 1 (H318) STOT SE 3 (H335)

			Flam. Liq. 3 (H226)

4. First aid measures

Description of necessary first aid measures

Inhalation	If inhaled, move victim to fresh air and seek medical attention.
Eyes	Immediately flush eyes with large amounts of water for at least 30 minutes. Seek prompt medical attention.
Skin	In case of contact, immediately flush skin with plenty of soap and water for at least 30 minutes and remove contaminated clothing, shoes and leather goods immediately. Get medical attention immediately.
Ingestion	Do NOT induce vomiting. Give nothing by mouth. Obtain immediate medical attention.

Symptoms caused by exposure

Causes severe eye irritation which may damage tissue. Causes severe skin irritation with tissue destruction. May cause respiratory irritation.

Medical Attention and Special Treatment

Notes to Physician	Treat symptomatically

5. Fire Fighting Measures

Suitable extinguishing equipment

Suitable Extinguishing Media

Water fog, carbon dioxide, foam, dry chemical.

Extinguishing media which must not be used for safety reasons

None known.

Specific hazards arising from the chemical

Special exposure hazards in a fire

Use water spray to cool fire exposed surfaces. Decomposition in fire may produce harmful gases. Do not allow runoff to enter waterways.

Special protective equipment and precautions for fire fighters

Special protective equipment for firefighters

Full protective clothing and approved self-contained breathing apparatus required for fire fighting personnel.

6. Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

Use appropriate protective equipment.

6.2. Environmental precautions

Prevent from entering sewers, waterways, or low areas.

6.3. Methods and material for containment and cleaning up

Isolate spill and stop leak where safe. Contain spill with sand or other inert materials. Neutralize to pH of 6-8. Scoop up and remove.

7. Handling and storage

7.1. Precautions for safe handling

Handling Precautions

Avoid contact with eyes, skin, or clothing. Avoid breathing vapors. Wash hands after use. Launder contaminated clothing before reuse.

Hygiene Measures

Handle in accordance with good industrial hygiene and safety practice.

7.2. Conditions for safe storage, including any incompatibilities

Storage Information

Store in a cool well ventilated area. Keep container closed when not in use. Product has a shelf life of 24 months. Store locked up.

Other Guidelines

No information available

8. Exposure Controls/Personal Protection

Control parameters - exposure standards, biological monitoring

Exposure Limits

Substances	CAS Number	Australia NOHSC	ACGIH TLV-TWA
Acetic acid	64-19-7	TWA: 10 ppm TWA: 25 mg/m³ STEL: 15 ppm STEL: 37 mg/m³	TWA: 10 ppm STEL: 15 ppm

Appropriate engineering controls

Engineering Controls	Use in a well ventilated area. Local exhaust ventilation should be used in areas without good cross ventilation.

Personal protective equipment (PPE)

Personal Protective Equipment	If engineering controls and work practices cannot prevent excessive exposures, the selection and proper use of personal protective equipment should be determined by an industrial hygienist or other qualified professional based on the specific application of this product.
Respiratory Protection	Organic vapor/acid gas respirator.
Hand Protection	Impervious rubber gloves.
Skin Protection	Full protective chemical resistant clothing.
Eye Protection	Chemical goggles; also wear a face shield if splashing hazard exists.
Other Precautions	Eyewash fountains and safety showers must be easily accessible.
Environmental Exposure Controls	No information available

9. Physical and Chemical Properties

9.1. Information on basic physical and chemical properties

Physical State:	Liquid	**Color**	Clear
Odor:	Acrid	**Odor Threshold:**	No information available

Property Remarks/ - Method	Values
pH:	1.38
Freezing Point / Range	16 °C
Melting Point / Range	No data available
Pour Point / Range	No data available
Boiling Point / Range	117 °C / 244 °F
Flash Point	55 °C / 131 °F (PMCC)
Upper flammability limit	16%
Lower flammability limit	5.4%
Evaporation rate	No data available
Vapor Pressure	11.7 mmHg @ 20 C
Vapor Density	No data available
Specific Gravity	1.05
Water Solubility	Soluble in water
Solubility in other solvents	No data available
Partition coefficient: n-octanol/water	No data available
Autoignition Temperature	No data available
Decomposition Temperature	No data available
Viscosity	No data available
Explosive Properties	No information available
Oxidizing Properties	No information available

9.2. Other information

Molecular Weight	60.6 (g/mole)
VOC Content (%)	No data available

10. Stability and Reactivity

10.1. Reactivity
Not expected to be reactive.

10.2. Chemical stability
Stable

10.3. Possibility of hazardous reactions
Will Not Occur

10.4. Conditions to avoid
Keep away from heat, sparks and flame.

10.5. Incompatible materials
Strong alkalis.

10.6. Hazardous decomposition products
Carbon monoxide and carbon dioxide.

11. Toxicological Information

Information on routes of exposure

Principle Route of Exposure	Eye or skin contact, inhalation.

Symptoms related to exposure

Most Important Symptoms/Effects

Causes severe eye irritation which may damage tissue. Causes severe skin irritation with tissue destruction. May cause respiratory irritation.

Toxicology data for the components

Substances	CAS Number	LD50 Oral	LD50 Dermal	LC50 Inhalation
Acetic acid	64-19-7	No data available	1060 mg/kg-bw (rabbit)	11.4 mg/L (rat, 4 h, vapor)

Immediate, delayed and chronic health effects from exposure

Inhalation	Causes severe respiratory irritation.
Eye Contact	Causes eye burns
Skin Contact	Causes skin burns which may not be immediately painful or visible.
Ingestion	Causes burns of the mouth, throat and stomach.
Chronic Effects/Carcinogenicity	Prolonged, excessive exposure may cause erosion of the teeth.

Exposure Levels
No data available

Interactive effects
Skin disorders.

Data limitations
No data available

Substances	CAS Number	Skin corrosion/irritation
Acetic acid	64-19-7	Extremely corrosive and destructive to tissue Skin, rabbit:

Substances	CAS Number	Serious eye damage/irritation
Acetic acid	64-19-7	Eye, rabbit: Causes serious eye damage

Substances	CAS Number	Skin Sensitization
Acetic acid	64-19-7	Not regarded as a sensitizer.

Substances	CAS Number	Respiratory Sensitization
Acetic acid	64-19-7	No information available

Substances	CAS Number	Mutagenic Effects
Acetic acid	64-19-7	In vivo tests did not show mutagenic effects. In vitro tests did not show mutagenic effects.

Substances	CAS Number	Carcinogenic Effects
Acetic acid	64-19-7	Did not show carcinogenic effects in animal experiments

Substances	CAS Number	Reproductive toxicity
Acetic acid	64-19-7	Did not show teratogenic effects in animal experiments. Animal testing did not show any effects on fertility.

Substances	CAS Number	STOT - single exposure
Acetic acid	64-19-7	May cause respiratory irritation. No information available

Substances	CAS Number	STOT - repeated exposure
Acetic acid	64-19-7	No significant toxicity observed in animal studies at concentration requiring classification.

Substances	CAS Number	Aspiration hazard
Acetic acid	64-19-7	Not applicable

12. Ecological Information

Ecotoxicity

Substance Ecotoxicity Data

Substances	CAS Number	Toxicity to Algae	Toxicity to Fish	Toxicity to Microorganisms	Toxicity to Invertebrates
Acetic acid	64-19-7	EC50(72 h)=55.22 mg/L (Anabaena flos-aquae)	LC50(96 h)=251 mg/L (Gambusia affinis) LC50(96 h)=75 mg/L (Lepomis macrochirus)	NOAEC (16 h) =1150 mg/L (Pseudomonas putida)	EC50(48 h)=65 mg/L (Daphnia magna)

12.2. Persistence and degradability

Substances	CAS Number	Persistence and Degradability
Acetic acid	64-19-7	Readily biodegradable (99% @ 7d)

12.3. Bioaccumulative potential

Substances	CAS Number	Bioaccumulation
Acetic acid	64-19-7	LogPow-0.17

12.4. Mobility in soil

Substances	CAS Number	Mobility
Acetic acid	64-19-7	No information available

12.6. Other adverse effects

Endocrine Disruptor Information

This product does not contain any known or suspected endocrine disruptors

13. Disposal Considerations

Safe handling and disposal methods

Disposal should be made in accordance with federal, state, and local regulations.

Disposal of any contaminated packaging

Follow all applicable national or local regulations.

Environmental regulations
Not applicable

14. Transport Information

Transportation Information

Australia ADG

UN Number	UN2790
UN proper shipping name:	Acetic Acid Solution
Transport Hazard Class(es):	8
Packing Group:	II
Environmental Hazards:	Not applicable

IMDG/IMO

UN Number	UN2790
UN proper shipping name:	Acetic Acid Solution
Transport Hazard Class(es):	8
Packing Group:	II
Environmental Hazards:	Not applicable
EMS:	EmS F-A, S-B

IATA/ICAO

UN Number	UN2790
UN proper shipping name:	Acetic Acid Solution
Transport Hazard Class(es):	8
Packing Group:	II
Environmental Hazards:	Not applicable

Special precautions during transport
None

HazChem Code
2R

15. Regulatory Information

Safety, health and environmental regulations specific for the product

International Inventories

Australian AICS Inventory	All components are listed on the AICS or are subject to a relevant exemption, permit, or assessment certificate.
New Zealand Inventory of Chemicals	All components are listed on the NZIoC or are subject to a relevant exemption, permit, or assessment certificate.
US TSCA Inventory	All components listed on inventory or are exempt.
Canadian Domestic Substances List (DSL)	All components listed on inventory or are exempt.

Poisons Schedule number
S6

International Agreements

Montreal Protocol - Ozone Depleting Substances:	Does not apply.
Stockholm Convention - Persistent Organic Pollutants:	Does not apply
Rotterdam Convention - Prior Informed Consent:	Does not apply.
Basel Convention - Hazardous Waste:	Does not apply.

16. Other information

Date of preparation or review

Revision Date:	26-Jun-2019

Revision Note
SDS sections updated:
2

Full text of H-Statements referred to under sections 2 and 3
H226 - Flammable liquid and vapor
H314 - Causes severe skin burns and eye damage
H318 - Causes serious eye damage
H335 - May cause respiratory irritation

Additional information For additional information on the use of this product, contact your local Halliburton representative.

For questions about the Safety Data Sheet for this or other Halliburton products, contact Chemical Stewardship at 1-580-251-4335.

Key abreviations or acronyms used

bw – body weight
CAS – Chemical Abstracts Service
EC50 – Effective Concentration 50%
LC50 – Lethal Concentration 50%
LD50 – Lethal Dose 50%
LL50 – Lethal Loading 50%
mg/kg – milligram/kilogram
mg/L – milligram/liter
NOEC – No Observed Effect Concentration
OEL – Occupational Exposure Limit
PBT – Persistent Bioaccumulative and Toxic
ppm – parts per million
STEL – Short Term Exposure Limit
TWA – Time-Weighted Average
vPvB – very Persistent and very Bioaccumulative
h - hour
mg/m^3 - milligram/cubic meter
mm - millimeter
mmHg - millimeter mercury
w/w - weight/weight
d - day

Key literature references and sources for data
www.ChemADVISOR.com/
NZ CCID

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End of Safety Data Sheet

HALLIBURTON

SAFETY DATA SHEET

BC-140C

Revision Date: 01-Oct-2015 **Revision Number:** 18

1. Product Identifier & Identity for the Chemical

Statement of Hazardous Nature Non-Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Non-Dangerous Goods according to the criteria of ADG.

1.1. Product Identifier

Product Name BC-140C

Other means of Identification

Synonyms: None
Product Code: HM000110

Recommended use of the chemical and restrictions on use

Recommended Use Crosslinker
Uses Advised Against No information available

Supplier's name, address and phone number

Manufacturer/Supplier
Halliburton Australia Pty. Ltd.
15 Marriott Road
Jandakot
WA 6164
Australia

ACN Number: 009 000 775
Telephone Number: + 61 1 800 686 951
Fax Number: 61 (08) 9455 5300
E-Mail address: fdunexchem@halliburton.com

Emergency phone number

+ 61 1 800 686 951

Australian Poisons Information Centre
24 Hour Service: - 13 11 26
Police or Fire Brigade: - 000 (exchange): - 1100

2. Hazard Identification

Statement of Hazardous Nature Non-Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Non-Dangerous Goods according to the criteria of ADG.

Classification of the hazardous chemical

Not classified

Label elements, including precautionary statements

Hazard Pictograms

Signal Word Not Hazardous

Hazard Statements	Not Classified

Precautionary Statements

Prevention	None
Response	None
Storage	None
Disposal	None

Contains

Substances	**CAS Number**
Contains no hazardous substances in concentrations above cut-off values according to the competent authority	NA

Other hazards which do not result in classification
This mixture contains no substance considered to be persistent, bioaccumulating nor toxic (PBT).
This mixture contains no substance considered to be very persistent nor very bioaccumulating (vPvB).

Australia Classification
For the full text of the H-phrases mentioned in this Section, see Section 16

Classification	Not Classified
Risk Phrases	None

3. Composition/information on Ingredients

Substances	CAS Number	PERCENT (w/w)	GHS Classification - Australia
Contains no hazardous substances in concentrations above cut-off values according to the competent authority	NA	60 - 100%	Not Applicable

4. First aid measures

Description of necessary first aid measures

Inhalation	If inhaled, move victim to fresh air and seek medical attention.
Eyes	In case of contact, or suspected contact, immediately flush eyes with plenty of water for at least 15 minutes and get medical attention immediately after flushing.
Skin	In case of contact, immediately flush skin with plenty of soap and water for at least 15 minutes. Get medical attention. Remove contaminated clothing and launder before reuse.
Ingestion	Do NOT induce vomiting. Give nothing by mouth. Obtain immediate medical attention.

Symptoms caused by exposure
No significant hazards expected.

Medical Attention and Special Treatment

Notes to Physician	Treat symptomatically

5. Fire Fighting Measures

Suitable extinguishing equipment
Suitable Extinguishing Media
Water fog, carbon dioxide, foam, dry chemical.

Extinguishing media which must not be used for safety reasons
None known.

Specific hazards arising from the chemical

Special Exposure Hazards
Decomposition in fire may produce harmful gases.

Special protective equipment and precautions for fire fighters

Special Protective Equipment for Fire-Fighters
Full protective clothing and approved self-contained breathing apparatus required for fire fighting personnel.

6. Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures
Use appropriate protective equipment. Avoid contact with skin, eyes and clothing. Avoid breathing vapors. Ensure adequate ventilation.

6.2. Environmental precautions
Prevent from entering sewers, waterways, or low areas.

6.3. Methods and material for containment and cleaning up
Isolate spill and stop leak where safe. Contain spill with sand or other inert materials. Scoop up and remove.

7. Handling and storage

7.1. Precautions for Safe Handling

Handling Precautions
Avoid contact with eyes, skin, or clothing. Avoid breathing vapors. Ensure adequate ventilation. Wash hands after use. Launder contaminated clothing before reuse. Use appropriate protective equipment.

Hygiene Measures
Handle in accordance with good industrial hygiene and safety practice.

7.2. Conditions for safe storage, including any incompatibilities

Storage Information
Store away from oxidizers. Store in a cool well ventilated area. Keep container closed when not in use. Product has a shelf life of 36 months.

Other Guidelines
No information available

8. Exposure Controls/Personal Protection

Control parameters - exposure standards, biological monitoring

Exposure Limits

Substances	CAS Number	Australia NOHSC	ACGIH TLV-TWA
Contains no hazardous substances in concentrations above cut-off values according to the competent authority	NA	Not applicable	Not applicable

Appropriate engineering controls

Engineering Controls	Use in a well ventilated area. Local exhaust ventilation should be used in areas without good cross ventilation.

Personal protective equipment (PPE)

Respiratory Protection	Not normally needed. But if significant exposures are possible then the following respirator is recommended: Organic vapor respirator.
Hand Protection	Impervious rubber gloves.
Skin Protection	Rubber apron.
Eye Protection	Safety glasses.

Other Precautions	None known.
Environmental Exposure Controls	Do not allow material to contaminate ground water system

9. Physical and Chemical Properties

9.1. Information on basic physical and chemical properties

Physical State:	Liquid	**Color:**	Blue
Odor:	Amine	**Odor Threshold:**	No information available

Property Remarks/ - Method	Values
pH:	7.9
Freezing Point/Range	No data available
Melting Point/Range	No data available
Boiling Point/Range	No data available
Flash Point	No data available
Evaporation rate	No data available
Vapor Pressure	No data available
Vapor Density	No data available
Specific Gravity	1.16
Water Solubility	Soluble in water
Solubility in other solvents	No data available
Partition coefficient: n-octanol/water	No data available
Autoignition Temperature	No data available
Decomposition Temperature	No data available
Viscosity	No data available
Explosive Properties	No information available
Oxidizing Properties	No information available

9.2. Other information

VOC Content (%)	No data available
Liquid Density	9.66 lbs/gal @ 20 C

10. Stability and Reactivity

10.1. Reactivity

Not expected to be reactive.

10.2. Chemical Stability

Stable

10.3. Possibility of Hazardous Reactions

Will Not Occur

10.4. Conditions to Avoid

None anticipated

10.5. Incompatible Materials

Strong oxidizers. Dehydrating agents.

10.6. Hazardous Decomposition Products

Toxic fumes. Carbon monoxide and carbon dioxide.

11. Toxicological Information

Information on routes of exposure

Principle Route of Exposure Eye or skin contact, inhalation.

Sympotoms related to exposure

Most Important Symptoms/Effects

No significant hazards expected.

Numerical measures of toxicity

Toxicology data for the components

Substances	CAS Number	LD50 Oral	LD50 Dermal	LC50 Inhalation
Contains no hazardous substances in concentrations above cut-off values according to the competent authority	NA	No data available	No data available	No data available

Immediate, delayed and chronic health effects from exposure

Inhalation	May cause mild respiratory irritation.
Eye Contact	May cause mild eye irritation.
Skin Contact	May cause mild skin irritation.
Ingestion	None known.

Chronic Effects/Carcinogenicity No data available to indicate product or components present at greater than 0.1% are chronic health hazards.

Exposure Levels
No data available

Interactive effects
Skin disorders. Eye ailments.

Data limitations
No data available

12. Ecological Information

Ecotoxicity
Product Ecotoxicity Data
No data available

Substance Ecotoxicity Data

Substances	CAS Number	Toxicity to Algae	Toxicity to Fish	Toxicity to Microorganisms	Toxicity to Invertebrates
Contains no hazardous substances in concentrations above cut-off values according to the competent authority	NA	No information available	No information available	No information available	No information available

12.2. Persistence and degradability

Substances	CAS Number	Persistence and Degradability
Contains no hazardous substances in concentrations above cut-off values according to the competent authority	NA	No information available

12.3. Bioaccumulative potential

Substances	CAS Number	Log Pow
Contains no hazardous substances in concentrations above cut-off values according to the competent authority	NA	No information available

12.4. Mobility in soil

Substances	CAS Number	Mobility
Contains no hazardous substances in concentrations above cut-off values according to the competent authority	NA	No information available

12.6. Other adverse effects

Endocrine Disruptor Information

This product does not contain any known or suspected endocrine disruptors

13. Disposal Considerations

Safe handling and disposal methods

Disposal should be made in accordance with federal, state, and local regulations.

Disposal of any contaminated packaging

Follow all applicable national or local regulations.

Environmental regulations

Not applicable

14. Transport Information

Transportation Information

UN Number:	Not restricted
UN Proper Shipping Name:	Not restricted
Transport Hazard Class(es):	Not applicable
Packing Group:	Not applicable
Environmental Hazards:	Not applicable

Special precautions during transport

None

HazChem Code

None Allocated

15. Regulatory Information

Safety, health and environmental regulations specific for the product

International Inventories

Australian AICS Inventory	All components listed on inventory or are exempt.
New Zealand Inventory of Chemicals	All components listed on inventory or are exempt.
EINECS Inventory	This product, and all its components, complies with EINECS
US TSCA Inventory	All components listed on inventory or are exempt.
Canadian DSL Inventory	All components listed on inventory or are exempt.

Poisons Schedule number

None Allocated

16. Other information

Date of preparation or review

Revision Date:	01-Oct-2015

Revision Note
SDS sections updated: 2

Full text of R-phrases referred to under Sections 2 and 3
None

Full text of H-Statements referred to under sections 2 and 3
None

Additional information	For additional information on the use of this product, contact your local Halliburton representative. For questions about the Safety Data Sheet for this or other Halliburton products, contact Chemical Stewardship at 1-580-251-4335.

Key abreviations or acronyms used

bw – body weight
CAS – Chemical Abstracts Service
EC50 – Effective Concentration 50%
LC50 – Lethal Concentration 50%
LD50 – Lethal Dose 50%
LL50 – Lethal Loading 50%
mg/kg – milligram/kilogram
mg/L – milligram/liter
NOEC – No Observed Effect Concentration
OEL – Occupational Exposure Limit
PBT – Persistent Bioaccumulative and Toxic
ppm – parts per million
STEL – Short Term Exposure Limit
TWA – Time-Weighted Average
vPvB – very Persistent and very Bioaccumulative
h - hour
mg/m^3 - milligram/cubic meter
mm - millimeter
mmHg - millimeter mercury
w/w - weight/weight
d - day

Key literature references and sources for data
www.ChemADVISOR.com/

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End of Safety Data Sheet

HALLIBURTON

SAFETY DATA SHEET

BE-9

Revision Date: 13-Oct-2017 **Revision Number:** 20

1. Product Identifier & Identity for the Chemical

Statement of Hazardous Nature	Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Dangerous Goods according to the criteria of ADG.

1.1. Product Identifier

Product Name	BE-9

Other means of Identification

Synonyms	None
Hazardous Material Number:	HB006583

Recommended use of the chemical and restrictions on use

Recommended Use	Biocide
Uses advised against	No information available

Supplier's name, address and phone number

Manufacturer/Supplier	Halliburton Australia Pty. Ltd. 15 Marriott Road, Jandakot, WA 6164 Australia ACN Number: 009 000 775 Telephone Number: + 61 1 800 686 951 Fax Number: 61 (08) 9455 5300
E-mail Address	fdunexchem@halliburton.com

Emergency phone number

+ 61 1 800 686 951
Global Incident Response Access Code: 334305
Contract Number: 14012

Australian Poisons Information Centre
24 Hour Service: - 13 11 26
Police or Fire Brigade: - 000 (exchange): - 1100

2. Hazard Identification

Statement of Hazardous Nature	Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Dangerous Goods according to the criteria of ADG.

Classification of the hazardous chemical

Skin Corrosion/Irritation	Category 1 - H314
Serious Eye Damage/Irritation	Category 1 - H318
Acute Aquatic Toxicity	Category 1 - H400
Chronic Aquatic Toxicity	Category 2 - H411

Label elements, including precautionary statements

Hazard Pictograms

Signal Word	DANGER
Hazard Statements:	H314 - Causes severe skin burns and eye damage H318 - Causes serious eye damage H400 - Very toxic to aquatic life H411 - Toxic to aquatic life with long lasting effects

Precautionary Statements

Prevention	P260 - Do not breathe dust/fume/gas/mist/vapors/spray P273 - Avoid release to the environment P280 - Wear protective gloves/protective clothing/eye protection/face protection
Response	P301 + P330 + P331 - IF SWALLOWED: rinse mouth. Do NOT induce vomiting P303 + P361 + P353 - IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water [or shower]. P363 - Wash contaminated clothing before reuse P304 + P340 - IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing P310 - Immediately call a POISON CENTER or doctor/physician P305 + P351 + P338 - IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing P391 - Collect spillage
Storage	P405 - Store locked up
Disposal	P501 - Dispose of contents/container in accordance with local/regional/national/international regulations

Contains

Substances	**CAS Number**
Tributyl tetradecyl phosphonium chloride	81741-28-8

Other hazards which do not result in classification

None known

For the full text of the H-phrases mentioned in this Section, see Section 16

3. Composition/information on Ingredients

Substances	**CAS Number**	**PERCENT (w/w)**	**GHS Classification - Australia**
Tributyl tetradecyl phosphonium chloride	81741-28-8	5 - 10%	Acute Tox. 4 (H302) Acute Tox. 2 (H330) Skin Corr. 1B (H314) Eye Corr. 1 (H318) Aquatic Acute 1 (H400) Aquatic Chronic 1 (H410)

4. First aid measures

Description of necessary first aid measures

Inhalation	If inhaled, move victim to fresh air and seek medical attention.
Eyes	Immediately flush eyes with large amounts of water for at least 30 minutes. Seek prompt medical attention.

Skin	In case of contact, immediately flush skin with plenty of soap and water for at least 30 minutes and remove contaminated clothing, shoes and leather goods immediately. Get medical attention immediately.
Ingestion	Do NOT induce vomiting. Give nothing by mouth. Obtain immediate medical attention.

Symptoms caused by exposure

Causes severe eye irritation which may damage tissue. Causes severe skin irritation with tissue destruction.

Medical Attention and Special Treatment

Notes to Physician Treat symptomatically

5. Fire Fighting Measures

Suitable extinguishing equipment

Suitable Extinguishing Media

Water fog, carbon dioxide, foam, dry chemical.

Extinguishing media which must not be used for safety reasons

None known.

Specific hazards arising from the chemical

Special exposure hazards in a fire

Decomposition in fire may produce harmful gases. Do not allow runoff to enter waterways. Use water spray to cool fire exposed surfaces.

Special protective equipment and precautions for fire fighters

Special protective equipment for firefighters

Full protective clothing and approved self-contained breathing apparatus required for fire fighting personnel.

6. Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

Use appropriate protective equipment.

6.2. Environmental precautions

Prevent from entering sewers, waterways, or low areas.

6.3. Methods and material for containment and cleaning up

Isolate spill and stop leak where safe. Contain spill with sand or other inert materials. Scoop up and remove.

7. Handling and storage

7.1. Precautions for safe handling

Handling Precautions

Avoid contact with eyes, skin, or clothing. Wash hands after use. Launder contaminated clothing before reuse. Do NOT consume food, drink, or tobacco in contaminated areas.

Hygiene Measures

Handle in accordance with good industrial hygiene and safety practice.

7.2. Conditions for safe storage, including any incompatibilities

Storage Information

Store in a cool well ventilated area. Keep container closed when not in use. Store away from direct sunlight. Store in a dry location. Store in a manner to prevent commingling with incompatible materials. Store away from alkalis. Store away from reducing agents. Store locked up.

Other Guidelines

No information available

8. Exposure Controls/Personal Protection

Control parameters - exposure standards, biological monitoring

Exposure Limits

Substances	CAS Number	Australia NOHSC	ACGIH TLV-TWA
Tributyl tetradecyl phosphonium chloride	81741-28-8	Not applicable	Not applicable

Appropriate engineering controls

Engineering Controls	Use in a well ventilated area. Local exhaust ventilation should be used in areas without good cross ventilation.

Personal protective equipment (PPE)

Personal Protective Equipment	If engineering controls and work practices cannot prevent excessive exposures, the selection and proper use of personal protective equipment should be determined by an industrial hygienist or other qualified professional based on the specific application of this product.
Respiratory Protection	If engineering controls and work practices cannot keep exposure below occupational exposure limits or if exposure is unknown, wear a NIOSH certified, European Standard EN 149, AS/NZS 1715:2009, or equivalent respirator when using this product. Selection of and instruction on using all personal protective equipment, including respirators, should be performed by an Industrial Hygienist or other qualified professional. Dust/mist respirator. (N95, P2/P3)
Hand Protection	Chemical-resistant protective gloves (EN 374) Suitable materials for longer, direct contact (recommended: protection index 6, corresponding to > 480 minutes permeation time as per EN 374): Neoprene gloves. (>= 0.75 mm thickness) This information is based on literature references and on information provided by glove manufacturers, or is derived by analogy with similar substances. Please note that in practice the working life of chemical-resistant protective gloves may be considerably shorter than the permeation time determined in accordance with EN 374 as a result of the many influencing factors (e.g. temperature). If signs of wear and tear are noticed then the gloves should be replaced. Manufacturer's directions for use should be observed because of great diversity of types.
Skin Protection	Wear impervious protective clothing, including boots, gloves, lab coat, apron, rain jacket, pants or coverall, as appropriate, to prevent skin contact.
Eye Protection	Chemical goggles; also wear a face shield if splashing hazard exists.
Other Precautions	Eyewash fountains and safety showers must be easily accessible.
Environmental Exposure Controls	No information available

9. Physical and Chemical Properties

9.1. Information on basic physical and chemical properties

Physical State:	Liquid	**Color**	Clear colorless
Odor:	Slight	**Odor Threshold:**	No information available

Property Remarks/ - Method	Values
pH:	6-8
Freezing Point / Range	-8 - -10 °C
Melting Point / Range	No data available
Boiling Point / Range	100 °C / 212 °F
Flash Point	No data available
Evaporation rate	No data available
Vapor Pressure	No data available
Vapor Density	No data available
Specific Gravity	0.95 - 1.0
Water Solubility	Miscible with water
Solubility in other solvents	No data available
Partition coefficient: n-octanol/water	No data available
Autoignition Temperature	No data available
Decomposition Temperature	No data available
Viscosity	No data available
Explosive Properties	No information available
Oxidizing Properties	No information available

9.2. Other information

VOC Content (%) No data available

10. Stability and Reactivity

10.1. Reactivity
Not expected to be reactive.

10.2. Chemical stability
Stable

10.3. Possibility of hazardous reactions
Will Not Occur

10.4. Conditions to avoid
None anticipated

10.5. Incompatible materials
Reducing agents. Strong alkalis.

10.6. Hazardous decomposition products
Chlorine. Phosphorus acids. Carbon monoxide and carbon dioxide.

11. Toxicological Information

Information on routes of exposure

Principle Route of Exposure Eye or skin contact, inhalation.

Symptoms related to exposure

Most Important Symptoms/Effects

Causes severe eye irritation which may damage tissue. Causes severe skin irritation with tissue destruction.

Toxicology data for the components

Substances	CAS Number	LD50 Oral	LD50 Dermal	LC50 Inhalation
Tributyl tetradecyl phosphonium chloride	81741-28-8	= 611 mg/kg (rat)	No data of sufficient quality are available	> 0.908 mg/L (rat, 4hr, mist)

Immediate, delayed and chronic health effects from exposure

Inhalation	May cause respiratory irritation.
Eye Contact	Causes severe eye irritation which may damage tissue. May cause eye burns.
Skin Contact	Causes severe skin irritation with tissue destruction.
Ingestion	Irritation of the mouth, throat, and stomach. May cause abdominal pain, vomiting, nausea, and diarrhea.

Chronic Effects/Carcinogenicity No data available to indicate product or components present at greater than 0.1% are chronic health hazards.

Exposure Levels
No data available

Interactive effects
Lung disorders. Skin disorders.

Data limitations
No data available

Substances	CAS Number	Skin corrosion/irritation
Tributyl tetradecyl phosphonium chloride	81741-28-8	Causes burns (Rabbit)

Substances	CAS Number	Serious eye damage/irritation
Tributyl tetradecyl phosphonium chloride	81741-28-8	Causes severe eye irritation which may damage tissue. (Rabbit)

Substances	CAS Number	Skin Sensitization
Tributyl tetradecyl phosphonium chloride	81741-28-8	No information available

Substances	CAS Number	Respiratory Sensitization
Tributyl tetradecyl phosphonium chloride	81741-28-8	No information available

Substances	CAS Number	Mutagenic Effects
Tributyl tetradecyl phosphonium chloride	81741-28-8	No data of sufficient quality are available.

Substances	CAS Number	Carcinogenic Effects
Tributyl tetradecyl phosphonium chloride	81741-28-8	No information available

Substances	CAS Number	Reproductive toxicity
Tributyl tetradecyl phosphonium chloride	81741-28-8	No information available

Substances	CAS Number	STOT - single exposure
Tributyl tetradecyl phosphonium chloride	81741-28-8	No information available

Substances	CAS Number	STOT - repeated exposure
Tributyl tetradecyl phosphonium chloride	81741-28-8	No data of sufficient quality are available.

Substances	CAS Number	Aspiration hazard
Tributyl tetradecyl phosphonium chloride	81741-28-8	No information available

12. Ecological Information

Ecotoxicity

Substance Ecotoxicity Data

Substances	CAS Number	Toxicity to Algae	Toxicity to Fish	Toxicity to Microorganisms	Toxicity to Invertebrates
Tributyl tetradecyl phosphonium chloride	81741-28-8	No information available	LC50 (96 h) 0.46 mg/L (Oncorhynchus mykiss) LC50 (96 h) 0.06 mg/L (Lepomis macrochirus)	No information available	EC50 (48 h) 0.025 mg/L (Daphnia sp.)

12.2. Persistence and degradability

Substances	CAS Number	Persistence and Degradability
Tributyl tetradecyl phosphonium chloride	81741-28-8	(0% @ 28d)

12.3. Bioaccumulative potential

Substances	CAS Number	Log Pow
Tributyl tetradecyl phosphonium chloride	81741-28-8	< 3

12.4. Mobility in soil

Substances	CAS Number	Mobility
Tributyl tetradecyl phosphonium chloride	81741-28-8	No information available

12.6. Other adverse effects

Endocrine Disruptor Information

This product does not contain any known or suspected endocrine disruptors

13. Disposal Considerations

Safe handling and disposal methods
Disposal should be made in accordance with federal, state, and local regulations. Incineration recommended in approved incinerator according to federal, state, and local regulations. Substance should NOT be deposited into a sewage facility.

Disposal of any contaminated packaging
Follow all applicable national or local regulations.

Environmental regulations
Not applicable

14. Transport Information

Transportation Information
Australia ADG

UN Number	UN2922
UN proper shipping name:	Corrosive Liquid, Toxic, N.O.S. (contains Tributyl Tetradecyl Phosphonium Chloride)
Transport Hazard Class(es):	8, (6.1)
Packing Group:	II
Environmental Hazards:	Marine Pollutant

IMDG/IMO

UN Number	UN2922
UN proper shipping name:	Corrosive Liquid, Toxic, N.O.S. (contains Tributyl Tetradecyl Phosphonium Chloride)
Transport Hazard Class(es):	8, (6.1)
Packing Group:	II
Environmental Hazards:	Marine Pollutant
EMS:	EmS F-A, S-B

IATA/ICAO

UN Number	UN2922
UN proper shipping name:	Corrosive Liquid, Toxic, N.O.S. (contains Tributyl Tetradecyl Phosphonium Chloride)
Transport Hazard Class(es):	8, (6.1)
Packing Group:	II
Environmental Hazards:	Marine Pollutant

Special precautions during transport
None

HazChem Code
2X

15. Regulatory Information

Safety, health and environmental regulations specific for the product

International Inventories

Australian AICS Inventory	All components are listed on the AICS or are subject to a relevant exemption, permit, or assessment certificate.
New Zealand Inventory of Chemicals	All components are listed on the NZIoC or are subject to a relevant exemption, permit, or assessment certificate.
EINECS (European Inventory of Existing Chemical Substances)	This product, and all its components, complies with EINECS
US TSCA Inventory	All components listed on inventory or are exempt.
Canadian Domestic Substances List (DSL)	All components listed on inventory or are exempt.

Poisons Schedule number

None Allocated

International Agreements

Montreal Protocol - Ozone Depleting Substances:	Does not apply
Stockholm Convention - Persistent Organic Pollutants:	Does not apply
Rotterdam Convention - Prior Informed Consent:	Does not apply
Basel Convention - Hazardous Waste:	Does not apply

16. Other information

Date of preparation or review

Revision Date: 13-Oct-2017

Revision Note
SDS sections updated:
2

Full text of H-Statements referred to under sections 2 and 3
H302 - Harmful if swallowed
H314 - Causes severe skin burns and eye damage
H318 - Causes serious eye damage
H330 - Fatal if inhaled
H400 - Very toxic to aquatic life
H401 - Toxic to aquatic life
H410 - Very toxic to aquatic life with long lasting effects
H411 - Toxic to aquatic life with long lasting effects

Additional information

For additional information on the use of this product, contact your local Halliburton representative.

For questions about the Safety Data Sheet for this or other Halliburton products, contact Chemical Stewardship at 1-580-251-4335.

Key abreviations or acronyms used
bw – body weight
CAS – Chemical Abstracts Service
EC50 – Effective Concentration 50%
LC50 – Lethal Concentration 50%
LD50 – Lethal Dose 50%
LL50 – Lethal Loading 50%
mg/kg – milligram/kilogram
mg/L – milligram/liter
NOEC – No Observed Effect Concentration
OEL – Occupational Exposure Limit
PBT – Persistent Bioaccumulative and Toxic
ppm – parts per million
STEL – Short Term Exposure Limit
TWA – Time-Weighted Average
vPvB – very Persistent and very Bioaccumulative
h - hour
mg/m^3 - milligram/cubic meter
mm - millimeter
mmHg - millimeter mercury
w/w - weight/weight
d - day

Key literature references and sources for data
www.ChemADVISOR.com/
NZ CCID

Disclaimer Statement

End of Safety Data Sheet

HALLIBURTON

SAFETY DATA SHEET

CAUSTIC SODA LIQUID

Revision Date: 16-Apr-2015 **Revision Number:** 8

1. Product Identifier & Identity for the Chemical

Statement of Hazardous Nature	Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Dangerous Goods according to the criteria of ADG.

1.1. Product Identifier

Product Name	CAUSTIC SODA LIQUID

Other means of Identification

Synonyms	None
Hazardous Material Number:	HM005652

Recommended use of the chemical and restrictions on use

Recommended Use	pH Control
Uses advised against	No information available

Supplier's name, address and phone number

Manufacturer/Supplier

Halliburton Australia Pty. Ltd.
15 Marriott Road, Jandakot, WA 6164
Australia
ACN Number: 009 000 775
Telephone Number: + 61 1 800 686 951
Fax Number: 61 (08) 9455 5300

E-mail Address fdunexchem@halliburton.com

Emergency phone number

+ 61 1 800 686 951
Global Incident Response Access Code: 334305
Contract Number: 14012

Australian Poisons Information Centre
24 Hour Service: - 13 11 26
Police or Fire Brigade: - 000 (exchange): - 1100

2. Hazard Identification

Statement of Hazardous Nature	Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Dangerous Goods according to the criteria of ADG.

Classification of the hazardous chemical

Skin Corrosion/Irritation	Category 1 - H314
Serious Eye Damage/Irritation	Category 1 - H318
Specific Target Organ Toxicity - (Single Exposure)	Category 3 - H335
Substances/mixtures corrosive to metal.	Category 1 - H290

Label elements, including precautionary statements

Hazard Pictograms

Signal Word	DANGER
Hazard Statements:	H290 - May be corrosive to metals H314 - Causes severe skin burns and eye damage H318 - Causes serious eye damage H335 - May cause respiratory irritation

Precautionary Statements

Prevention	P234 - Keep only in original packaging. P260 - Do not breathe dust/fume/gas/mist/vapors/spray P261 - Avoid breathing dust/fume/gas/mist/vapors/spray P264 - Wash face, hands and any exposed skin thoroughly after handling P271 - Use only outdoors or in a well-ventilated area P280 - Wear protective gloves/eye protection/face protection
Response	P301 + P330 + P331 - IF SWALLOWED: rinse mouth. Do NOT induce vomiting P303 + P361 + P353 - IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water [or shower]. P363 - Wash contaminated clothing before reuse P310 - Immediately call a POISON CENTER or doctor/physician P305 + P351 + P338 - IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing P390 - Absorb spillage to prevent material damage P304 + P340 - IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing
Storage	P403 + P233 - Store in a well-ventilated place. Keep container tightly closed P405 - Store locked up
Disposal	P501 - Dispose of contents/container in accordance with local/regional/national/international regulations

Contains

Substances	**CAS Number**
Sodium hydroxide	1310-73-2

Other hazards which do not result in classification

None known

For the full text of the H-phrases mentioned in this Section, see Section 16

3. Composition/information on Ingredients

Substances	CAS Number	PERCENT (w/w)	GHS Classification - Australia
Sodium hydroxide	1310-73-2	30 - 60%	Skin Corr. 1A (H314) Eye Corr. 1 (H318) STOT SE 3 (H335) Met. Corr. 1 (H290)

4. First aid measures

Description of necessary first aid measures

Inhalation	If inhaled, move victim to fresh air and seek medical attention.

Eyes	Immediately flush eyes with large amounts of water for at least 30 minutes. Seek prompt medical attention.
Skin	Remove contaminated clothing and launder before reuse. Destroy or properly dispose of contaminated shoes. In case of contact, immediately flush skin with plenty of soap and water for at least 30 minutes and remove contaminated clothing, shoes and leather goods immediately. Get medical attention immediately.
Ingestion	Do NOT induce vomiting. Give nothing by mouth. Obtain immediate medical attention.

Symptoms caused by exposure

May cause eye and skin burns. May cause respiratory irritation. Causes severe skin irritation with tissue destruction. Causes severe eye irritation which may damage tissue.

Medical Attention and Special Treatment

Notes to Physician	Treat symptomatically

5. Fire Fighting Measures

Suitable extinguishing equipment

Suitable Extinguishing Media

All standard fire fighting media

Extinguishing media which must not be used for safety reasons

None known.

Specific hazards arising from the chemical

Special exposure hazards in a fire

May form explosive mixtures with strong acids. Reaction with steel and certain other metals generates flammable hydrogen gas.

Special protective equipment and precautions for fire fighters

Special protective equipment for firefighters

Full protective clothing and approved self-contained breathing apparatus required for fire fighting personnel.

6. Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

Use appropriate protective equipment.

6.2. Environmental precautions

Prevent from entering sewers, waterways, or low areas.

6.3. Methods and material for containment and cleaning up

Contain spill with sand or other inert materials. Neutralize to pH of 6-8. Scoop up and remove. Isolate spill and stop leak where safe.

7. Handling and storage

7.1. Precautions for safe handling

Handling Precautions

Avoid contact with eyes, skin, or clothing. Avoid breathing vapors. Wash hands after use. Launder contaminated clothing before reuse.

Hygiene Measures

Handle in accordance with good industrial hygiene and safety practice.

7.2. Conditions for safe storage, including any incompatibilities

Storage Information

Store away from acids. Store in a cool well ventilated area. Keep container closed when not in use. Product has a shelf life of 12 months.

Other Guidelines

No information available

8. Exposure Controls/Personal Protection

Control parameters - exposure standards, biological monitoring

Exposure Limits

Substances	CAS Number	Australia NOHSC	ACGIH TLV-TWA
Sodium hydroxide	1310-73-2	2 mg/m^3	Not applicable

Appropriate engineering controls

Engineering Controls	Use in a well ventilated area. Local exhaust ventilation should be used in areas without good cross ventilation.

Personal protective equipment (PPE)

Personal Protective Equipment	If engineering controls and work practices cannot prevent excessive exposures, the selection and proper use of personal protective equipment should be determined by an industrial hygienist or other qualified professional based on the specific application of this product.
Respiratory Protection	If engineering controls and work practices cannot keep exposure below occupational exposure limits or if exposure is unknown, wear a NIOSH certified, European Standard EN 149, AS/NZS 1715:2009, or equivalent respirator when using this product. Selection of and instruction on using all personal protective equipment, including respirators, should be performed by an Industrial Hygienist or other qualified professional. Dust/mist respirator. (N95, P2/P3)
Hand Protection	Chemical-resistant protective gloves (EN 374) Suitable materials for longer, direct contact (recommended: protection index 6, corresponding to > 480 minutes permeation time as per EN 374): Butyl rubber gloves. (>= 0.7 mm thickness) This information is based on literature references and on information provided by glove manufacturers, or is derived by analogy with similar substances. Please note that in practice the working life of chemical-resistant protective gloves may be considerably shorter than the permeation time determined in accordance with EN 374 as a result of the many influencing factors (e.g. temperature). If signs of wear and tear are noticed then the gloves should be replaced. Manufacturer's directions for use should be observed because of great diversity of types.
Skin Protection	Full protective chemical resistant clothing.
Eye Protection	Chemical goggles; also wear a face shield if splashing hazard exists.
Other Precautions	Eyewash fountains and safety showers must be easily accessible.
Environmental Exposure Controls	No information available

9. Physical and Chemical Properties

9.1. Information on basic physical and chemical properties

Physical State:	Liquid	**Color**	Clear colorless
Odor:	Odorless	**Odor Threshold:**	No information available

Property Remarks/ - Method	Values
pH:	14
Freezing Point / Range	12 °C
Melting Point / Range	No data available
Boiling Point / Range	144 °C / 291 °F
Flash Point	No data available
Evaporation rate	No data available
Vapor Pressure	13 mmHg
Vapor Density	No data available
Specific Gravity	1.52
Water Solubility	Miscible with water
Solubility in other solvents	No data available
Partition coefficient: n-octanol/water	No data available
Autoignition Temperature	No data available
Decomposition Temperature	No data available
Viscosity	No data available

Explosive Properties	No information available
Oxidizing Properties	No information available

9.2. Other information

Molecular Weight	40
VOC Content (%)	No data available

10. Stability and Reactivity

10.1. Reactivity
Not expected to be reactive.

10.2. Chemical stability
Stable

10.3. Possibility of hazardous reactions
Will Not Occur

10.4. Conditions to avoid
None anticipated

10.5. Incompatible materials
Strong acids. Peroxides. Halogenated compounds. Amphoteric metals such as aluminum, magnesium, lead, tin, or zinc.

10.6. Hazardous decomposition products
None known.

11. Toxicological Information

Information on routes of exposure

Principle Route of Exposure Eye or skin contact, inhalation.

Symptoms related to exposure

Most Important Symptoms/Effects

May cause eye and skin burns. May cause respiratory irritation. Causes severe skin irritation with tissue destruction. Causes severe eye irritation which may damage tissue.

Toxicology data for the components

Substances	CAS Number	LD50 Oral	LD50 Dermal	LC50 Inhalation
Sodium hydroxide	1310-73-2	Not applicable due to corrosivity of the substance.	Not applicable due to corrosivity of the substance.	Not applicable due to corrosivity of the substance.

Immediate, delayed and chronic health effects from exposure

Inhalation	Causes severe respiratory burns.
Eye Contact	Causes severe eye burns.
Skin Contact	Causes severe burns.
Ingestion	Causes burns of the mouth, throat and stomach.

Chronic Effects/Carcinogenicity Prolonged, excessive exposure may cause erosion of the teeth.

Exposure Levels
No data available

Interactive effects
Skin disorders.

Data limitations
No data available

Substances	CAS Number	Skin corrosion/irritation
Sodium hydroxide	1310-73-2	Causes severe burns

Substances	CAS Number	Serious eye damage/irritation
Sodium hydroxide	1310-73-2	Causes severe eye burns (Rabbit)

Substances	**CAS Number**	**Skin Sensitization**
Sodium hydroxide	1310-73-2	Did not cause sensitization on laboratory animals (guinea pig)

Substances	**CAS Number**	**Respiratory Sensitization**
Sodium hydroxide	1310-73-2	No information available

Substances	**CAS Number**	**Mutagenic Effects**
Sodium hydroxide	1310-73-2	Did not show mutagenic effects in animal experiments In vitro tests did not show mutagenic effects.

Substances	**CAS Number**	**Carcinogenic Effects**
Sodium hydroxide	1310-73-2	No data of sufficient quality are available.

Substances	**CAS Number**	**Reproductive toxicity**
Sodium hydroxide	1310-73-2	No information available

Substances	**CAS Number**	**STOT - single exposure**
Sodium hydroxide	1310-73-2	May cause respiratory irritation.

Substances	**CAS Number**	**STOT - repeated exposure**
Sodium hydroxide	1310-73-2	No significant toxicity observed in animal studies at concentration requiring classification. Not applicable due to corrosivity of the substance.

Substances	**CAS Number**	**Aspiration hazard**
Sodium hydroxide	1310-73-2	Not applicable

12. Ecological Information

Ecotoxicity

Substance Ecotoxicity Data

Substances	CAS Number	**Toxicity to Algae**	**Toxicity to Fish**	**Toxicity to Microorganisms**	**Toxicity to Invertebrates**
Sodium hydroxide	1310-73-2	No information available	LC50(48h) 189 mg/L (Leuciscus idus melanotus) LLC50(48h) 189 mg/L (Leuciscus melanotus) LC50(24h) 145 mg/L (Poecilia reticulate) LC50(96h) 125 mg/L (Gambusia affinis) LOEL(150 d) = 25 mg/L (Lebistes reticulatus)	No information available	EC50 (48h) 40.4 mg/L (Ceriodaphnia sp.)

12.2. Persistence and degradability

Substances	**CAS Number**	**Persistence and Degradability**
Sodium hydroxide	1310-73-2	The methods for determining biodegradability are not applicable to inorganic substances.

12.3. Bioaccumulative potential

Substances	**CAS Number**	**Log Pow**
Sodium hydroxide	1310-73-2	No information available

12.4. Mobility in soil

Substances	**CAS Number**	**Mobility**
Sodium hydroxide	1310-73-2	No information available

12.6. Other adverse effects

Endocrine Disruptor Information

This product does not contain any known or suspected endocrine disruptors

13. Disposal Considerations

Safe handling and disposal methods
Disposal should be made in accordance with federal, state, and local regulations.

Disposal of any contaminated packaging
Follow all applicable national or local regulations.

Environmental regulations
Not applicable

14. Transport Information

Transportation Information

Australia ADG

UN Number	UN1824
UN proper shipping name:	Sodium Hydroxide Solution
Transport Hazard Class(es):	8
Packing Group:	II
Environmental Hazards:	Not applicable

IMDG/IMO

UN Number	UN1824
UN proper shipping name:	Sodium Hydroxide Solution
Transport Hazard Class(es):	8
Packing Group:	II
Environmental Hazards:	Not applicable
EMS:	EmS F-A, S-B

IATA/ICAO

UN Number	UN1824
UN proper shipping name:	Sodium Hydroxide Solution
Transport Hazard Class(es):	8
Packing Group:	II
Environmental Hazards:	Not applicable

Special precautions during transport
None

HazChem Code
2R

15. Regulatory Information

Safety, health and environmental regulations specific for the product

International Inventories

Australian AICS Inventory	All components are listed on the AICS or are subject to a relevant exemption, permit, or assessment certificate.
New Zealand Inventory of Chemicals	All components are listed on the NZIoC or are subject to a relevant exemption, permit, or assessment certificate.
EINECS (European Inventory of Existing Chemical Substances)	This product, and all its components, complies with EINECS
US TSCA Inventory	All components listed on inventory or are exempt.
Canadian Domestic Substances List (DSL)	All components listed on inventory or are exempt.

Poisons Schedule number

None Allocated

International Agreements

Montreal Protocol - Ozone Depleting Substances:	Does not apply
Stockholm Convention - Persistent Organic Pollutants:	Does not apply
Rotterdam Convention - Prior Informed Consent:	Does not apply
Basel Convention - Hazardous Waste:	Does not apply

16. Other information

Date of preparation or review

Revision Date: 16-Apr-2015

Revision Note

Full text of H-Statements referred to under sections 2 and 3
H290 - May be corrosive to metals
H314 - Causes severe skin burns and eye damage
H318 - Causes serious eye damage
H335 - May cause respiratory irritation

Additional information For additional information on the use of this product, contact your local Halliburton representative.

For questions about the Safety Data Sheet for this or other Halliburton products, contact Chemical Stewardship at 1-580-251-4335.

Key abreviations or acronyms used
bw – body weight
CAS – Chemical Abstracts Service
EC50 – Effective Concentration 50%
LC50 – Lethal Concentration 50%
LD50 – Lethal Dose 50%
LL50 – Lethal Loading 50%
mg/kg – milligram/kilogram
mg/L – milligram/liter
NOEC – No Observed Effect Concentration
OEL – Occupational Exposure Limit
PBT – Persistent Bioaccumulative and Toxic
ppm – parts per million
STEL – Short Term Exposure Limit
TWA – Time-Weighted Average
vPvB – very Persistent and very Bioaccumulative
h - hour
mg/m^3 - milligram/cubic meter
mm - millimeter
mmHg - millimeter mercury
w/w - weight/weight
d - day

Key literature references and sources for data
www.ChemADVISOR.com/

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End of Safety Data Sheet

HALLIBURTON

SAFETY DATA SHEET

CERAMIC PROP PLUS

Revision Date: 28-Sep-2018 **Revision Number:** 18

1. Product Identifier & Identity for the Chemical

Statement of Hazardous Nature	Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Non-Dangerous Goods according to the criteria of ADG.

1.1. Product Identifier

Product Name	CERAMIC PROP PLUS

Other means of Identification

Synonyms	None
Hazardous Material Number:	HM004807

Recommended use of the chemical and restrictions on use

Recommended Use	Proppant
Uses advised against	No information available

Supplier's name, address and phone number

Manufacturer/Supplier	Halliburton Australia Pty. Ltd. 15 Marriott Road, Jandakot, WA 6164 Australia ACN Number: 009 000 775 Telephone Number: + 61 1 800 686 951 Fax Number: 61 (08) 9455 5300
E-mail Address	fdunexchem@halliburton.com

Emergency phone number

+ 61 1 800 686 951
Global Incident Response Access Code: 334305
Contract Number: 14012

Australian Poisons Information Centre
24 Hour Service: - 13 11 26
Police or Fire Brigade: - 000 (exchange): - 1100

2. Hazard Identification

Statement of Hazardous Nature	Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Non-Dangerous Goods according to the criteria of ADG.

Classification of the hazardous chemical

Carcinogenicity	Category 1A - H350
Specific Target Organ Toxicity - (Repeated Exposure)	Category 1 - H372

Label elements, including precautionary statements

Hazard Pictograms

Signal Word	DANGER
Hazard Statements:	H350 - May cause cancer by inhalation H372 - Causes damage to organs through prolonged or repeated exposure if inhaled

Precautionary Statements

Prevention	P201 - Obtain special instructions before use P202 - Do not handle until all safety precautions have been read and understood P260 - Do not breathe dust/fume/gas/mist/vapors/spray P264 - Wash face, hands and any exposed skin thoroughly after handling P270 - Do not eat, drink or smoke when using this product P281 - Use personal protective equipment as required
Response	P308 + P313 - IF exposed or concerned: Get medical advice/attention P314 - Get medical attention/advice if you feel unwell
Storage	P405 - Store locked up
Disposal	P501 - Dispose of contents/container in accordance with local/regional/national/international regulations

Contains

Substances	**CAS Number**
Crystalline silica, cristobalite	14464-46-1

<u>Other hazards which do not result in classification</u>
This substance is not considered to be persistent, bioaccumulating nor toxic (PBT).
This substance is not considered to be very persistent nor very bioaccumulating (vPvB).

For the full text of the H-phrases mentioned in this Section, see Section 16

3. Composition/information on Ingredients

Substances	CAS Number	PERCENT (w/w)	GHS Classification - Australia
Crystalline silica, cristobalite	14464-46-1	10 - 30%	Carc. 1A (H350) STOT RE 1 (H372)

4. First aid measures

<u>Description of necessary first aid measures</u>

Inhalation	If inhaled, remove from area to fresh air. Get medical attention if respiratory irritation develops or if breathing becomes difficult.
Eyes	In case of contact, immediately flush eyes with plenty of water for at least 15 minutes and get medical attention if irritation persists.
Skin	Remove contaminated clothing. wash skin with water, using soap if available. Get medical attention if irritation persists.
Ingestion	Rinse mouth with water many times.

<u>Symptoms caused by exposure</u>
Breathing crystalline silica can cause lung disease, including silicosis and lung cancer. Crystalline silica has also been associated with scleroderma and kidney disease.

Medical Attention and Special Treatment

Notes to Physician Treat symptomatically

5. Fire Fighting Measures

Suitable extinguishing equipment

Suitable Extinguishing Media

All standard fire fighting media

Extinguishing media which must not be used for safety reasons

None known.

Specific hazards arising from the chemical

Special exposure hazards in a fire

Not applicable

Special protective equipment and precautions for fire fighters

Special protective equipment for firefighters

Full protective clothing and approved self-contained breathing apparatus required for fire fighting personnel.

6. Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

Use appropriate protective equipment. Avoid creating and breathing dust. Ensure adequate ventilation. Avoid contact with skin, eyes and clothing.

6.2. Environmental precautions

None known.

6.3. Methods and material for containment and cleaning up

Collect using dustless method and hold for appropriate disposal. Consider possible toxic or fire hazards associated with contaminating substances and use appropriate methods for collection, storage and disposal.

7. Handling and storage

7.1. Precautions for safe handling

Handling Precautions

This product contains quartz, cristobalite, and/or tridymite which may become airborne without a visible cloud. Avoid breathing dust. Avoid creating dusty conditions. Use only with adequate ventilation to keep exposure below recommended exposure limits. Wear a NIOSH certified, European Standard En 149, or equivalent respirator when using this product. Material is slippery when wet.

Hygiene Measures

Handle in accordance with good industrial hygiene and safety practice.

7.2. Conditions for safe storage, including any incompatibilities

Storage Information

Store in a cool well ventilated area. Use good housekeeping in storage and work areas to prevent accumulation of dust. Close container when not in use.

Other Guidelines

No information available

8. Exposure Controls/Personal Protection

Control parameters - exposure standards, biological monitoring

Exposure Limits

Substances	CAS Number	Australia NOHSC	ACGIH TLV-TWA
Crystalline silica, cristobalite	14464-46-1	TWA: 0.1 mg/m^3	TWA: 0.025 mg/m^3

Appropriate engineering controls

Engineering Controls	Use approved industrial ventilation and local exhaust as required to maintain exposures below applicable exposure limits.

Personal protective equipment (PPE)

Personal Protective Equipment	If engineering controls and work practices cannot prevent excessive exposures, the selection and proper use of personal protective equipment should be determined by an industrial hygienist or other qualified professional based on the specific application of this product.
Respiratory Protection	Wear a NIOSH certified, European Standard EN 149 (FFP2/FFP3), AS/NZS 1715, or equivalent respirator when using this product.
Hand Protection	Normal work gloves.
Skin Protection	Wear clothing appropriate for the work environment. Dusty clothing should be laundered before reuse. Use precautionary measures to avoid creating dust when removing or laundering clothing.
Eye Protection	Wear safety glasses or goggles to protect against exposure.
Other Precautions	None known.
Environmental Exposure Controls	No information available

9. Physical and Chemical Properties

9.1. Information on basic physical and chemical properties

Physical State:	Granules	**Color**	Gray to tan
Odor:	Odorless	**Odor Threshold:**	No information available

Property Remarks/ - Method	Values
pH:	No data available
Freezing Point / Range	No data available
Melting Point / Range	No data available
Pour Point / Range	No data available
Boiling Point / Range	No data available
Flash Point	No data available
Evaporation rate	No data available
Vapor Pressure	No data available
Vapor Density	No data available
Specific Gravity	2.7
Water Solubility	Insoluble in water
Solubility in other solvents	No data available
Partition coefficient: n-octanol/water	No data available
Autoignition Temperature	No data available
Decomposition Temperature	No data available
Viscosity	No data available
Explosive Properties	No information available
Oxidizing Properties	No information available

9.2. Other information

VOC Content (%)	No data available

10. Stability and Reactivity

10.1. Reactivity

Not expected to be reactive.

10.2. Chemical stability

Stable

10.3. Possibility of hazardous reactions

Will Not Occur

10.4. Conditions to avoid

None anticipated

10.5. Incompatible materials

Hydrofluoric acid.

10.6. Hazardous decomposition products

Amorphous silica may transform at elevated temperatures to tridymite (870 C) or cristobalite (1470 C).

11. Toxicological Information

Information on routes of exposure

Principle Route of Exposure Eye or skin contact, inhalation.

Symptoms related to exposure

Most Important Symptoms/Effects

Breathing crystalline silica can cause lung disease, including silicosis and lung cancer. Crystalline silica has also been associated with scleroderma and kidney disease.

Toxicology data for the components

Substances	CAS Number	LD50 Oral	LD50 Dermal	LC50 Inhalation
Crystalline silica, cristobalite	14464-46-1	> 15000 mg/kg (human) (similar substance)	No information available	No data available

Immediate, delayed and chronic health effects from exposure

Inhalation Inhaled crystalline silica in the form of quartz or cristobalite from occupational sources is carcinogenic to humans (IARC, Group 1). There is sufficient evidence in experimental animals for the carcinogenicity of tridymite (IARC, Group 2A).

Breathing silica dust may cause irritation of the nose, throat, and respiratory passages. Breathing silica dust may not cause noticeable injury or illness even though permanent lung damage may be occurring. Inhalation of dust may also have serious chronic health effects (See "Chronic Effects/Carcinogenicity" subsection below).

Eye Contact May cause mechanical irritation to eye.
Skin Contact None known.
Ingestion None known.

Chronic Effects/Carcinogenicity Silicosis: Excessive inhalation of respirable crystalline silica dust may cause a progressive, disabling, and sometimes-fatal lung disease called silicosis. Symptoms include cough, shortness of breath, wheezing, non-specific chest illness, and reduced pulmonary function. This disease is exacerbated by smoking. Individuals with silicosis are predisposed to develop tuberculosis.

Cancer Status: The International Agency for Research on Cancer (IARC) has determined that crystalline silica inhaled in the form of quartz or cristobalite from occupational sources can cause lung cancer in humans (Group 1 - carcinogenic to humans) and has determined that there is sufficient evidence in experimental animals for the carcinogenicity of tridymite (Group 2A - possible carcinogen to humans). Refer to IARC Monograph 68, Silica, Some Silicates and Organic Fibres (June 1997) in conjunction with the use of these minerals. The National Toxicology Program classifies respirable crystalline silica as "Known to be a human carcinogen". Refer to the 9th Report on Carcinogens (2000). The American Conference of Governmental Industrial Hygienists (ACGIH) classifies crystalline silica, quartz, as a suspected human carcinogen (A2). There is some evidence that breathing respirable crystalline silica or the disease silicosis is associated with an increased incidence of significant disease endpoints such as scleroderma (an immune system disorder manifested by scarring of the lungs, skin, and other internal organs) and kidney disease.

Exposure Levels

No data available

Interactive effects

Individuals with respiratory disease, including but not limited to asthma and bronchitis, or subject to eye irritation, should not be exposed to quartz dust.

Data limitations

No data available

Substances	CAS Number	Skin corrosion/irritation
Crystalline silica, cristobalite	14464-46-1	Non-irritating to the skin

Substances	CAS Number	Serious eye damage/irritation
Crystalline silica, cristobalite	14464-46-1	Mechanical irritation of the eyes is possible.

Substances	CAS Number	Skin Sensitization
Crystalline silica, cristobalite	14464-46-1	No information available

Substances	CAS Number	Respiratory Sensitization
Crystalline silica, cristobalite	14464-46-1	No information available

Substances	CAS Number	Mutagenic Effects
Crystalline silica, cristobalite	14464-46-1	Not regarded as mutagenic.

Substances	CAS Number	Carcinogenic Effects
Crystalline silica, cristobalite	14464-46-1	Contains crystalline silica which may cause silicosis, a delayed and progressive lung disease. The IARC and NTP have determined there is sufficient evidence in humans of the carcinogenicity of crystalline silica with repeated respiratory exposure. Based on available scientific evidence, this substance is a threshold carcinogen with a mode of action involving indirect genotoxicity secondary to lung injury.

Substances	CAS Number	Reproductive toxicity
Crystalline silica, cristobalite	14464-46-1	No information available

Substances	CAS Number	STOT - single exposure
Crystalline silica, cristobalite	14464-46-1	No significant toxicity observed in animal studies at concentration requiring classification.

Substances	CAS Number	STOT - repeated exposure
Crystalline silica, cristobalite	14464-46-1	Causes damage to organs through prolonged or repeated exposure if inhaled: (Lungs)

Substances	CAS Number	Aspiration hazard
Crystalline silica, cristobalite	14464-46-1	Not applicable

12. Ecological Information

Ecotoxicity

Substance Ecotoxicity Data

Substances	CAS Number	Toxicity to Algae	Toxicity to Fish	Toxicity to Microorganisms	Toxicity to Invertebrates
Crystalline silica, cristobalite	14464-46-1	No information available	LL0(96 h)=10000 mg/L (Danio rerio)	No information available	LL50(24 h)>10000 mg/L (Daphnia magna)

12.2. Persistence and degradability

Substances	CAS Number	Persistence and Degradability
Crystalline silica, cristobalite	14464-46-1	The methods for determining biodegradability are not applicable to inorganic substances.

12.3. Bioaccumulative potential

Substances	CAS Number	Bioaccumulation

Crystalline silica, cristobalite	14464-46-1	Not bioaccumulative

12.4. Mobility in soil

Substances	CAS Number	Mobility
Crystalline silica, cristobalite	14464-46-1	No information available

12.6. Other adverse effects

Endocrine Disruptor Information

This product does not contain any known or suspected endocrine disruptors

13. Disposal Considerations

Safe handling and disposal methods

Bury in a licensed landfill according to federal, state, and local regulations.

Disposal of any contaminated packaging

Follow all applicable national or local regulations.

Environmental regulations

Not applicable

14. Transport Information

Transportation Information

Australia ADG

UN Number	Not restricted
UN proper shipping name:	Not restricted
Transport Hazard Class(es):	Not applicable
Packing Group:	Not applicable
Environmental Hazards:	Not applicable

IMDG/IMO

UN Number	Not restricted
UN proper shipping name:	Not restricted
Transport Hazard Class(es):	Not applicable
Packing Group:	Not applicable
Environmental Hazards:	Not applicable

IATA/ICAO

UN Number	Not restricted
UN proper shipping name:	Not restricted
Transport Hazard Class(es):	Not applicable
Packing Group:	Not applicable
Environmental Hazards:	Not applicable

Special precautions during transport

None

HazChem Code

None Allocated

15. Regulatory Information

Safety, health and environmental regulations specific for the product

International Inventories

Australian AICS Inventory	All components are listed on the AICS or are subject to a relevant exemption, permit, or assessment certificate.
New Zealand Inventory of	All components are listed on the NZIoC or are subject to a relevant exemption, permit, or

Chemicals	assessment certificate.
US TSCA Inventory	All components listed on inventory or are exempt.
Canadian Domestic Substances List (DSL)	All components listed on inventory or are exempt.

Poisons Schedule number

None Allocated

International Agreements

Montreal Protocol - Ozone Depleting Substances:	Does not apply.
Stockholm Convention - Persistent Organic Pollutants:	Does not apply
Rotterdam Convention - Prior Informed Consent:	Does not apply.
Basel Convention - Hazardous Waste:	Does not apply.

16. Other information

Date of preparation or review

Revision Date: 28-Sep-2018

Revision Note

SDS sections updated:
2

Full text of H-Statements referred to under sections 2 and 3

H350 - May cause cancer by inhalation
H372 - Causes damage to organs through prolonged or repeated exposure if inhaled

Additional information For additional information on the use of this product, contact your local Halliburton representative.

For questions about the Safety Data Sheet for this or other Halliburton products, contact Chemical Stewardship at 1-580-251-4335.

Key abreviations or acronyms used

bw – body weight
CAS – Chemical Abstracts Service
EC50 – Effective Concentration 50%
LC50 – Lethal Concentration 50%
LD50 – Lethal Dose 50%
LL50 – Lethal Loading 50%
mg/kg – milligram/kilogram
mg/L – milligram/liter
NOEC – No Observed Effect Concentration
OEL – Occupational Exposure Limit
PBT – Persistent Bioaccumulative and Toxic
ppm – parts per million
STEL – Short Term Exposure Limit
TWA – Time-Weighted Average
vPvB – very Persistent and very Bioaccumulative
h - hour
mg/m^3 - milligram/cubic meter
mm - millimeter
mmHg - millimeter mercury
w/w - weight/weight
d - day

Key literature references and sources for data

www.ChemADVISOR.com/

Disclaimer Statement

End of Safety Data Sheet

SAFETY DATA SHEET

PREMIUM PROP

Revision Date: 18-Sep-2018 **Revision Number:** 13

1. Product Identifier & Identity for the Chemical

Statement of Hazardous Nature	Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Non-Dangerous Goods according to the criteria of ADG.

1.1. Product Identifier

Product Name	PREMIUM PROP

Other means of Identification

Synonyms	None
Hazardous Material Number:	HM004809

Recommended use of the chemical and restrictions on use

Recommended Use	Proppant
Uses advised against	No information available

Supplier's name, address and phone number

Manufacturer/Supplier	Halliburton Australia Pty. Ltd. 15 Marriott Road, Jandakot, WA 6164 Australia ACN Number: 009 000 775 Telephone Number: + 61 1 800 686 951 Fax Number: 61 (08) 9455 5300
E-mail Address	fdunexchem@halliburton.com

Emergency phone number

+ 61 1 800 686 951
Global Incident Response Access Code: 334305
Contract Number: 14012

Australian Poisons Information Centre
24 Hour Service: - 13 11 26
Police or Fire Brigade: - 000 (exchange): - 1100

2. Hazard Identification

Statement of Hazardous Nature	Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Non-Dangerous Goods according to the criteria of ADG.

Classification of the hazardous chemical

Carcinogenicity	Category 1A - H350
Specific Target Organ Toxicity - (Repeated Exposure)	Category 1 - H372

Label elements, including precautionary statements

Hazard Pictograms

Signal Word	DANGER
Hazard Statements:	H350 - May cause cancer by inhalation H372 - Causes damage to organs through prolonged or repeated exposure if inhaled

Precautionary Statements

Prevention	P201 - Obtain special instructions before use P202 - Do not handle until all safety precautions have been read and understood P260 - Do not breathe dust/fume/gas/mist/vapors/spray P264 - Wash face, hands and any exposed skin thoroughly after handling P270 - Do not eat, drink or smoke when using this product P281 - Use personal protective equipment as required
Response	P308 + P313 - IF exposed or concerned: Get medical advice/attention P314 - Get medical attention/advice if you feel unwell
Storage	P405 - Store locked up
Disposal	P501 - Dispose of contents/container in accordance with local/regional/national/international regulations

Contains

Substances	**CAS Number**
Crystalline silica, cristobalite	14464-46-1

<u>Other hazards which do not result in classification</u>

This substance is not considered to be persistent, bioaccumulating nor toxic (PBT).
This substance is not considered to be very persistent nor very bioaccumulating (vPvB).

For the full text of the H-phrases mentioned in this Section, see Section 16

3. Composition/information on Ingredients

Substances	CAS Number	PERCENT (w/w)	GHS Classification - Australia
Crystalline silica, cristobalite	14464-46-1	1 - 5%	Carc. 1A (H350) STOT RE 1 (H372)

4. First aid measures

<u>Description of necessary first aid measures</u>

Inhalation	If inhaled, remove from area to fresh air. Get medical attention if respiratory irritation develops or if breathing becomes difficult.
Eyes	In case of contact, immediately flush eyes with plenty of water for at least 15 minutes and get medical attention if irritation persists.
Skin	Get medical attention if irritation persists.
Ingestion	Under normal conditions, first aid procedures are not required.

<u>Symptoms caused by exposure</u>

Breathing crystalline silica can cause lung disease, including silicosis and lung cancer. Crystalline silica has also been associated with scleroderma and kidney disease.

<u>Medical Attention and Special Treatment</u>

Notes to Physician	Treat symptomatically

5. Fire Fighting Measures

Suitable extinguishing equipment

Suitable Extinguishing Media
All standard fire fighting media
Extinguishing media which must not be used for safety reasons
None known.

Specific hazards arising from the chemical

Special exposure hazards in a fire
Not applicable

Special protective equipment and precautions for fire fighters

Special protective equipment for firefighters
Not applicable

6. Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures
Use appropriate protective equipment. Avoid creating and breathing dust.

6.2. Environmental precautions
None known.

6.3. Methods and material for containment and cleaning up
Collect using dustless method and hold for appropriate disposal. Consider possible toxic or fire hazards associated with contaminating substances and use appropriate methods for collection, storage and disposal.

7. Handling and storage

7.1. Precautions for safe handling

Handling Precautions
This product contains quartz, cristobalite, and/or tridymite which may become airborne without a visible cloud. Avoid breathing dust. Avoid creating dusty conditions. Use only with adequate ventilation to keep exposure below recommended exposure limits. Wear a NIOSH certified, European Standard En 149, or equivalent respirator when using this product. Material is slippery when wet.
Hygiene Measures
Handle in accordance with good industrial hygiene and safety practice.

7.2. Conditions for safe storage, including any incompatibilities

Storage Information
Use good housekeeping in storage and work areas to prevent accumulation of dust. Close container when not in use.
Other Guidelines
No information available

8. Exposure Controls/Personal Protection

Control parameters - exposure standards, biological monitoring

Exposure Limits

Substances	CAS Number	Australia NOHSC	ACGIH TLV-TWA
Crystalline silica, cristobalite	14464-46-1	TWA: 0.1 mg/m^3	TWA: 0.025 mg/m^3

Appropriate engineering controls

Engineering Controls	Use approved industrial ventilation and local exhaust as required to maintain exposures below applicable exposure limits.

Personal protective equipment (PPE)

Personal Protective Equipment	If engineering controls and work practices cannot prevent excessive exposures, the selection and proper use of personal protective equipment should be determined by an industrial hygienist or other qualified professional based on the specific application of this product.
Respiratory Protection	Wear a NIOSH certified, European Standard EN 149 (FFP2/FFP3), AS/NZS 1715, or equivalent respirator when using this product.
Hand Protection	Normal work gloves.
Skin Protection	Wear clothing appropriate for the work environment. Dusty clothing should be laundered before reuse. Use precautionary measures to avoid creating dust when removing or laundering clothing.
Eye Protection	Wear safety glasses or goggles to protect against exposure.
Other Precautions	None known.
Environmental Exposure Controls	No information available

9. Physical and Chemical Properties

9.1. Information on basic physical and chemical properties

Physical State:	Solid	**Color**	Dark brown
Odor:	Odorless	**Odor Threshold:**	No information available

Property Remarks/ - Method	Values
pH:	No data available
Freezing Point / Range	No data available
Melting Point / Range	No data available
Pour Point / Range	No data available
Boiling Point / Range	No data available
Flash Point	No data available
Evaporation rate	No data available
Vapor Pressure	No data available
Vapor Density	No data available
Specific Gravity	3.17
Water Solubility	Insoluble in water
Solubility in other solvents	No data available
Partition coefficient: n-octanol/water	No data available
Autoignition Temperature	No data available
Decomposition Temperature	No data available
Viscosity	No data available
Explosive Properties	No information available
Oxidizing Properties	No information available

9.2. Other information

Molecular Weight	228.1
VOC Content (%)	No data available

10. Stability and Reactivity

10.1. Reactivity

Not expected to be reactive.

10.2. Chemical stability

Stable

10.3. Possibility of hazardous reactions

Will Not Occur

10.4. Conditions to avoid

None anticipated

10.5. Incompatible materials

Hydrofluoric acid.

10.6. Hazardous decomposition products

Amorphous silica may transform at elevated temperatures to tridymite (870 C) or cristobalite (1470 C).

11. Toxicological Information

Information on routes of exposure

Principle Route of Exposure Eye or skin contact, inhalation.

Symptoms related to exposure

Most Important Symptoms/Effects

Breathing crystalline silica can cause lung disease, including silicosis and lung cancer. Crystalline silica has also been associated with scleroderma and kidney disease.

Toxicology data for the components

Substances	CAS Number	LD50 Oral	LD50 Dermal	LC50 Inhalation
Crystalline silica, cristobalite	14464-46-1	> 15000 mg/kg (human) (similar substance)	No information available	No data available

Immediate, delayed and chronic health effects from exposure

Inhalation Inhaled crystalline silica in the form of quartz or cristobalite from occupational sources is carcinogenic to humans (IARC, Group 1). There is sufficient evidence in experimental animals for the carcinogenicity of tridymite (IARC, Group 2A).

Breathing silica dust may cause irritation of the nose, throat, and respiratory passages. Breathing silica dust may not cause noticeable injury or illness even though permanent lung damage may be occurring. Inhalation of dust may also have serious chronic health effects (See "Chronic Effects/Carcinogenicity" subsection below).

Eye Contact May cause mechanical irritation to eye.

Skin Contact None known.

Ingestion None known.

Chronic Effects/Carcinogenicity Silicosis: Excessive inhalation of respirable crystalline silica dust may cause a progressive, disabling, and sometimes-fatal lung disease called silicosis. Symptoms include cough, shortness of breath, wheezing, non-specific chest illness, and reduced pulmonary function. This disease is exacerbated by smoking. Individuals with silicosis are predisposed to develop tuberculosis.

Cancer Status: The International Agency for Research on Cancer (IARC) has determined that crystalline silica inhaled in the form of quartz or cristobalite from occupational sources can cause lung cancer in humans (Group 1 - carcinogenic to humans) and has determined that there is sufficient evidence in experimental animals for the carcinogenicity of tridymite (Group 2A - possible carcinogen to humans). Refer to IARC Monograph 68, Silica, Some Silicates and Organic Fibres (June 1997) in conjunction with the use of these minerals. The National Toxicology Program classifies respirable crystalline silica as "Known to be a human carcinogen". Refer to the 9th Report on Carcinogens (2000). The American Conference of Governmental Industrial Hygienists (ACGIH) classifies crystalline silica, quartz, as a suspected human carcinogen (A2). There is some evidence that breathing respirable crystalline silica or the disease silicosis is associated with an increased incidence of significant disease endpoints such as scleroderma (an immune system disorder manifested by scarring of the lungs, skin, and other internal organs) and kidney disease.

Exposure Levels

No data available

Interactive effects

Individuals with respiratory disease, including but not limited to asthma and bronchitis, or subject to eye irritation, should not be exposed to quartz dust.

Data limitations
No data available

Substances	CAS Number	Skin corrosion/irritation
Crystalline silica, cristobalite	14464-46-1	Non-irritating to the skin

Substances	CAS Number	Serious eye damage/irritation
Crystalline silica, cristobalite	14464-46-1	Mechanical irritation of the eyes is possible.

Substances	CAS Number	Skin Sensitization
Crystalline silica, cristobalite	14464-46-1	No information available

Substances	CAS Number	Respiratory Sensitization
Crystalline silica, cristobalite	14464-46-1	No information available

Substances	CAS Number	Mutagenic Effects
Crystalline silica, cristobalite	14464-46-1	Not regarded as mutagenic.

Substances	CAS Number	Carcinogenic Effects
Crystalline silica, cristobalite	14464-46-1	Contains crystalline silica which may cause silicosis, a delayed and progressive lung disease. The IARC and NTP have determined there is sufficient evidence in humans of the carcinogenicity of crystalline silica with repeated respiratory exposure. Based on available scientific evidence, this substance is a threshold carcinogen with a mode of action involving indirect genotoxicity secondary to lung injury.

Substances	CAS Number	Reproductive toxicity
Crystalline silica, cristobalite	14464-46-1	No information available

Substances	CAS Number	STOT - single exposure
Crystalline silica, cristobalite	14464-46-1	No significant toxicity observed in animal studies at concentration requiring classification.

Substances	CAS Number	STOT - repeated exposure
Crystalline silica, cristobalite	14464-46-1	Causes damage to organs through prolonged or repeated exposure if inhaled: (Lungs)

Substances	CAS Number	Aspiration hazard
Crystalline silica, cristobalite	14464-46-1	Not applicable

12. Ecological Information

Ecotoxicity

Substance Ecotoxicity Data

Substances	CAS Number	Toxicity to Algae	Toxicity to Fish	Toxicity to Microorganisms	Toxicity to Invertebrates
Crystalline silica, cristobalite	14464-46-1	No information available	LL0(96 h)=10000 mg/L (Danio rerio)	No information available	LL50(24 h)>10000 mg/L (Daphnia magna)

12.2. Persistence and degradability

Substances	CAS Number	Persistence and Degradability
Crystalline silica, cristobalite	14464-46-1	The methods for determining biodegradability are not applicable to inorganic substances.

12.3. Bioaccumulative potential

Substances	CAS Number	Bioaccumulation
Crystalline silica, cristobalite	14464-46-1	Not bioaccumulative

12.4. Mobility in soil

Substances	CAS Number	Mobility
Crystalline silica, cristobalite	14464-46-1	No information available

12.6. Other adverse effects

Endocrine Disruptor Information

This product does not contain any known or suspected endocrine disruptors

13. Disposal Considerations

Safe handling and disposal methods

Bury in a licensed landfill according to federal, state, and local regulations.

Disposal of any contaminated packaging

Follow all applicable national or local regulations.

Environmental regulations

Not applicable

14. Transport Information

Transportation Information

Australia ADG

UN Number	Not restricted
UN proper shipping name:	Not restricted
Transport Hazard Class(es):	Not applicable
Packing Group:	Not applicable
Environmental Hazards:	Not applicable

IMDG/IMO

UN Number	Not restricted
UN proper shipping name:	Not restricted
Transport Hazard Class(es):	Not applicable
Packing Group:	Not applicable
Environmental Hazards:	Not applicable

IATA/ICAO

UN Number	Not restricted
UN proper shipping name:	Not restricted
Transport Hazard Class(es):	Not applicable
Packing Group:	Not applicable
Environmental Hazards:	Not applicable

Special precautions during transport

None

HazChem Code

None Allocated

15. Regulatory Information

Safety, health and environmental regulations specific for the product

International Inventories

Australian AICS Inventory	All components are listed on the AICS or are subject to a relevant exemption, permit, or assessment certificate.
New Zealand Inventory of Chemicals	All components are listed on the NZIoC or are subject to a relevant exemption, permit, or assessment certificate.
US TSCA Inventory	All components listed on inventory or are exempt.

Canadian Domestic Substances List (DSL) All components listed on inventory or are exempt.

Poisons Schedule number
None Allocated

International Agreements

Montreal Protocol - Ozone Depleting Substances:	Does not apply.
Stockholm Convention - Persistent Organic Pollutants:	Does not apply
Rotterdam Convention - Prior Informed Consent:	Does not apply.
Basel Convention - Hazardous Waste:	Does not apply.

16. Other information

Date of preparation or review

Revision Date: 18-Sep-2018

Revision Note
SDS sections updated:
2

Full text of H-Statements referred to under sections 2 and 3
H350 - May cause cancer by inhalation
H372 - Causes damage to organs through prolonged or repeated exposure if inhaled

Additional information For additional information on the use of this product, contact your local Halliburton representative.

For questions about the Safety Data Sheet for this or other Halliburton products, contact Chemical Stewardship at 1-580-251-4335.

Key abreviations or acronyms used
bw – body weight
CAS – Chemical Abstracts Service
EC50 – Effective Concentration 50%
LC50 – Lethal Concentration 50%
LD50 – Lethal Dose 50%
LL50 – Lethal Loading 50%
mg/kg – milligram/kilogram
mg/L – milligram/liter
NOEC – No Observed Effect Concentration
OEL – Occupational Exposure Limit
PBT – Persistent Bioaccumulative and Toxic
ppm – parts per million
STEL – Short Term Exposure Limit
TWA – Time-Weighted Average
vPvB – very Persistent and very Bioaccumulative
h - hour
mg/m^3 - milligram/cubic meter
mm - millimeter
mmHg - millimeter mercury
w/w - weight/weight
d - day

Key literature references and sources for data
www.ChemADVISOR.com/

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conditions nor if this material is used in combination with other materials or in any process. Final determination of suitability of any material is the sole responsibility of the user.

End of Safety Data Sheet

HALLIBURTON

SAFETY DATA SHEET

CERAMIC PROP

Revision Date: 07-Jun-2018 **Revision Number:** 12

1. Product Identifier & Identity for the Chemical

Statement of Hazardous Nature	Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Non-Dangerous Goods according to the criteria of ADG.

1.1. Product Identifier

Product Name	CERAMIC PROP

Other means of Identification

Synonyms	None
Hazardous Material Number:	HM004805

Recommended use of the chemical and restrictions on use

Recommended Use	Proppant
Uses advised against	No information available

Supplier's name, address and phone number

Manufacturer/Supplier	Halliburton Australia Pty. Ltd. 15 Marriott Road, Jandakot, WA 6164 Australia ACN Number: 009 000 775 Telephone Number: + 61 1 800 686 951 Fax Number: 61 (08) 9455 5300
E-mail Address	fdunexchem@halliburton.com

Emergency phone number

+ 61 1 800 686 951
Global Incident Response Access Code: 334305
Contract Number: 14012

Australian Poisons Information Centre
24 Hour Service: - 13 11 26
Police or Fire Brigade: - 000 (exchange): - 1100

2. Hazard Identification

Statement of Hazardous Nature	Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Non-Dangerous Goods according to the criteria of ADG.

Classification of the hazardous chemical

Carcinogenicity	Category 1A - H350
Specific Target Organ Toxicity - (Repeated Exposure)	Category 1 - H372

Label elements, including precautionary statements

Hazard Pictograms

Signal Word	DANGER
Hazard Statements:	H350 - May cause cancer by inhalation H372 - Causes damage to organs through prolonged or repeated exposure if inhaled

Precautionary Statements

Prevention	P201 - Obtain special instructions before use P202 - Do not handle until all safety precautions have been read and understood P260 - Do not breathe dust/fume/gas/mist/vapors/spray P264 - Wash face, hands and any exposed skin thoroughly after handling P270 - Do not eat, drink or smoke when using this product P281 - Use personal protective equipment as required
Response	P308 + P313 - IF exposed or concerned: Get medical advice/attention P314 - Get medical attention/advice if you feel unwell
Storage	P405 - Store locked up
Disposal	P501 - Dispose of contents/container in accordance with local/regional/national/international regulations

Contains

Substances	**CAS Number**
Crystalline silica, cristobalite	14464-46-1

Other hazards which do not result in classification

This substance is not considered to be persistent, bioaccumulating nor toxic (PBT).
This substance is not considered to be very persistent nor very bioaccumulating (vPvB).

For the full text of the H-phrases mentioned in this Section, see Section 16

3. Composition/information on Ingredients

Substances	CAS Number	PERCENT (w/w)	GHS Classification - Australia
Crystalline silica, cristobalite	14464-46-1	10 - 30%	Carc. 1A (H350) STOT RE 1 (H372)

4. First aid measures

Description of necessary first aid measures

Inhalation	If inhaled, remove from area to fresh air. Get medical attention if respiratory irritation develops or if breathing becomes difficult.
Eyes	In case of contact, immediately flush eyes with plenty of water for at least 15 minutes and get medical attention if irritation persists.
Skin	Wash with soap and water. Get medical attention if irritation persists.
Ingestion	Under normal conditions, first aid procedures are not required.

Symptoms caused by exposure

Breathing crystalline silica can cause lung disease, including silicosis and lung cancer. Crystalline silica has also been associated with scleroderma and kidney disease.

Medical Attention and Special Treatment

Notes to Physician Treat symptomatically

5. Fire Fighting Measures

Suitable extinguishing equipment

Suitable Extinguishing Media
None - does not burn.
Extinguishing media which must not be used for safety reasons
None known.

Specific hazards arising from the chemical

Special exposure hazards in a fire
Not applicable

Special protective equipment and precautions for fire fighters

Special protective equipment for firefighters
Full protective clothing and approved self-contained breathing apparatus required for fire fighting personnel.

6. Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

Use appropriate protective equipment. Avoid creating and breathing dust. Avoid contact with skin, eyes and clothing.

6.2. Environmental precautions

None known.

6.3. Methods and material for containment and cleaning up

Collect using dustless method and hold for appropriate disposal. Consider possible toxic or fire hazards associated with contaminating substances and use appropriate methods for collection, storage and disposal.

7. Handling and storage

7.1. Precautions for safe handling

Handling Precautions
This product contains quartz, cristobalite, and/or tridymite which may become airborne without a visible cloud. Avoid breathing dust. Avoid creating dusty conditions. Use only with adequate ventilation to keep exposure below recommended exposure limits. Wear a NIOSH certified, European Standard En 149, or equivalent respirator when using this product. Material is slippery when wet.
Hygiene Measures
Handle in accordance with good industrial hygiene and safety practice.

7.2. Conditions for safe storage, including any incompatibilities

Storage Information
Store in a cool well ventilated area. Store locked up. Store in a cool, dry location. Use good housekeeping in storage and work areas to prevent accumulation of dust. Close container when not in use.
Other Guidelines
No information available

8. Exposure Controls/Personal Protection

Control parameters - exposure standards, biological monitoring

Exposure Limits

Substances	CAS Number	Australia NOHSC	ACGIH TLV-TWA
Crystalline silica, cristobalite	14464-46-1	TWA: 0.1 mg/m³	TWA: 0.025 mg/m³

Appropriate engineering controls

Engineering Controls Use approved industrial ventilation and local exhaust as required to maintain exposures below applicable exposure limits.

Personal protective equipment (PPE)

Personal Protective Equipment	If engineering controls and work practices cannot prevent excessive exposures, the selection and proper use of personal protective equipment should be determined by an industrial hygienist or other qualified professional based on the specific application of this product.
Respiratory Protection	Wear a NIOSH certified, European Standard EN 149 (FFP2/FFP3), AS/NZS 1715, or equivalent respirator when using this product.
Hand Protection	Normal work gloves.
Skin Protection	Wear clothing appropriate for the work environment. Dusty clothing should be laundered before reuse. Use precautionary measures to avoid creating dust when removing or laundering clothing.
Eye Protection	Wear safety glasses or goggles to protect against exposure.
Other Precautions	None known.
Environmental Exposure Controls	No information available

9. Physical and Chemical Properties

9.1. Information on basic physical and chemical properties

Physical State:	Solid	**Color**	Gray to tan
Odor:	Odorless	**Odor Threshold:**	No information available

Property Remarks/ - Method	Values
pH:	No data available
Freezing Point / Range	No data available
Melting Point / Range	No data available
Pour Point / Range	No data available
Boiling Point / Range	No data available
Flash Point	No data available
Evaporation rate	No data available
Vapor Pressure	No data available
Vapor Density	No data available
Specific Gravity	3.1
Water Solubility	Insoluble in water
Solubility in other solvents	No data available
Partition coefficient: n-octanol/water	No data available
Autoignition Temperature	No data available
Decomposition Temperature	No data available
Viscosity	No data available
Explosive Properties	No information available
Oxidizing Properties	No information available

9.2. Other information

VOC Content (%)	No data available

10. Stability and Reactivity

10.1. Reactivity

Not expected to be reactive.

10.2. Chemical stability

Stable

10.3. Possibility of hazardous reactions

Will Not Occur

10.4. Conditions to avoid

None anticipated

10.5. Incompatible materials

Hydrofluoric acid.

10.6. Hazardous decomposition products

Amorphous silica may transform at elevated temperatures to tridymite (870 C) or cristobalite (1470 C).

11. Toxicological Information

Information on routes of exposure

Principle Route of Exposure Eye or skin contact, inhalation.

Symptoms related to exposure

Most Important Symptoms/Effects

Breathing crystalline silica can cause lung disease, including silicosis and lung cancer. Crystalline silica has also been associated with scleroderma and kidney disease.

Toxicology data for the components

Substances	CAS Number	LD50 Oral	LD50 Dermal	LC50 Inhalation
Crystalline silica, cristobalite	14464-46-1	> 15000 mg/kg (human) (similar substance)	No information available	No data available

Immediate, delayed and chronic health effects from exposure

Inhalation Inhaled crystalline silica in the form of quartz or cristobalite from occupational sources is carcinogenic to humans (IARC, Group 1). There is sufficient evidence in experimental animals for the carcinogenicity of tridymite (IARC, Group 2A).

Breathing silica dust may cause irritation of the nose, throat, and respiratory passages. Breathing silica dust may not cause noticeable injury or illness even though permanent lung damage may be occurring. Inhalation of dust may also have serious chronic health effects (See "Chronic Effects/Carcinogenicity" subsection below).

Eye Contact May cause mechanical irritation to eye.

Skin Contact None known.

Ingestion None known.

Chronic Effects/Carcinogenicity Silicosis: Excessive inhalation of respirable crystalline silica dust may cause a progressive, disabling, and sometimes-fatal lung disease called silicosis. Symptoms include cough, shortness of breath, wheezing, non-specific chest illness, and reduced pulmonary function. This disease is exacerbated by smoking. Individuals with silicosis are predisposed to develop tuberculosis.

Cancer Status: The International Agency for Research on Cancer (IARC) has determined that crystalline silica inhaled in the form of quartz or cristobalite from occupational sources can cause lung cancer in humans (Group 1 - carcinogenic to humans) and has determined that there is sufficient evidence in experimental animals for the carcinogenicity of tridymite (Group 2A - possible carcinogen to humans). Refer to IARC Monograph 68, Silica, Some Silicates and Organic Fibres (June 1997) in conjunction with the use of these minerals. The National Toxicology Program classifies respirable crystalline silica as "Known to be a human carcinogen". Refer to the 9th Report on Carcinogens (2000). The American Conference of Governmental Industrial Hygienists (ACGIH) classifies crystalline silica, quartz, as a suspected human carcinogen (A2). There is some evidence that breathing respirable crystalline silica or the disease silicosis is associated with an increased incidence of significant disease endpoints such as scleroderma (an immune system disorder manifested by scarring of the lungs, skin, and other internal organs) and kidney disease.

Exposure Levels

No data available

Interactive effects

Individuals with respiratory disease, including but not limited to asthma and bronchitis, or subject to eye irritation, should not be exposed to quartz dust.

Data limitations
No data available

Substances	CAS Number	Skin corrosion/irritation
Crystalline silica, cristobalite	14464-46-1	Non-irritating to the skin

Substances	CAS Number	Serious eye damage/irritation
Crystalline silica, cristobalite	14464-46-1	Mechanical irritation of the eyes is possible.

Substances	CAS Number	Skin Sensitization
Crystalline silica, cristobalite	14464-46-1	No information available

Substances	CAS Number	Respiratory Sensitization
Crystalline silica, cristobalite	14464-46-1	No information available

Substances	CAS Number	Mutagenic Effects
Crystalline silica, cristobalite	14464-46-1	Not regarded as mutagenic.

Substances	CAS Number	Carcinogenic Effects
Crystalline silica, cristobalite	14464-46-1	Contains crystalline silica which may cause silicosis, a delayed and progressive lung disease. The IARC and NTP have determined there is sufficient evidence in humans of the carcinogenicity of crystalline silica with repeated respiratory exposure. Based on available scientific evidence, this substance is a threshold carcinogen with a mode of action involving indirect genotoxicity secondary to lung injury.

Substances	CAS Number	Reproductive toxicity
Crystalline silica, cristobalite	14464-46-1	No information available

Substances	CAS Number	STOT - single exposure
Crystalline silica, cristobalite	14464-46-1	No significant toxicity observed in animal studies at concentration requiring classification.

Substances	CAS Number	STOT - repeated exposure
Crystalline silica, cristobalite	14464-46-1	Causes damage to organs through prolonged or repeated exposure if inhaled: (Lungs)

Substances	CAS Number	Aspiration hazard
Crystalline silica, cristobalite	14464-46-1	Not applicable

12. Ecological Information

Ecotoxicity
Product Ecotoxicity Data
Product is not classified as hazardous to the environment.

Substance Ecotoxicity Data

Substances	CAS Number	Toxicity to Algae	Toxicity to Fish	Toxicity to Microorganisms	Toxicity to Invertebrates
Crystalline silica, cristobalite	14464-46-1	No information available	LL0(96 h)=10000 mg/L (Danio rerio)	No information available	LL50(24 h)>10000 mg/L (Daphnia magna)

12.2. Persistence and degradability

Substances	CAS Number	Persistence and Degradability
Crystalline silica, cristobalite	14464-46-1	The methods for determining biodegradability are not applicable to inorganic substances.

12.3. Bioaccumulative potential

Substances	CAS Number	Bioaccumulation

Crystalline silica, cristobalite	14464-46-1	Not bioaccumulative

12.4. Mobility in soil

Substances	CAS Number	Mobility
Crystalline silica, cristobalite	14464-46-1	No information available

12.6. Other adverse effects

Endocrine Disruptor Information

This product does not contain any known or suspected endocrine disruptors

13. Disposal Considerations

Safe handling and disposal methods

Bury in a licensed landfill according to federal, state, and local regulations.

Disposal of any contaminated packaging

Follow all applicable national or local regulations.

Environmental regulations

Not applicable

14. Transport Information

Transportation Information

Australia ADG

UN Number	Not restricted
UN proper shipping name:	Not restricted
Transport Hazard Class(es):	Not applicable
Packing Group:	Not applicable
Environmental Hazards:	Not applicable

IMDG/IMO

UN Number	Not restricted
UN proper shipping name:	Not restricted
Transport Hazard Class(es):	Not applicable
Packing Group:	Not applicable
Environmental Hazards:	Not applicable

IATA/ICAO

UN Number	Not restricted
UN proper shipping name:	Not restricted
Transport Hazard Class(es):	Not applicable
Packing Group:	Not applicable
Environmental Hazards:	Not applicable

Special precautions during transport

None

HazChem Code

None Allocated

15. Regulatory Information

Safety, health and environmental regulations specific for the product

International Inventories

Australian AICS Inventory	All components are listed on the AICS or are subject to a relevant exemption, permit, or assessment certificate.
New Zealand Inventory of	All components are listed on the NZIoC or are subject to a relevant exemption, permit, or

Chemicals	assessment certificate.
US TSCA Inventory	All components listed on inventory or are exempt.
Canadian Domestic Substances List (DSL)	All components listed on inventory or are exempt.

Poisons Schedule number
None Allocated

International Agreements

Montreal Protocol - Ozone Depleting Substances:	Does not apply.
Stockholm Convention - Persistent Organic Pollutants:	Does not apply
Rotterdam Convention - Prior Informed Consent:	Does not apply.
Basel Convention - Hazardous Waste:	Does not apply.

16. Other information

Date of preparation or review

Revision Date: 07-Jun-2018

Revision Note
SDS sections updated:
2

Full text of H-Statements referred to under sections 2 and 3
H350 - May cause cancer by inhalation
H372 - Causes damage to organs through prolonged or repeated exposure if inhaled

Additional information For additional information on the use of this product, contact your local Halliburton representative.

For questions about the Safety Data Sheet for this or other Halliburton products, contact Chemical Stewardship at 1-580-251-4335.

Key abreviations or acronyms used
bw – body weight
CAS – Chemical Abstracts Service
EC50 – Effective Concentration 50%
LC50 – Lethal Concentration 50%
LD50 – Lethal Dose 50%
LL50 – Lethal Loading 50%
mg/kg – milligram/kilogram
mg/L – milligram/liter
NOEC – No Observed Effect Concentration
OEL – Occupational Exposure Limit
PBT – Persistent Bioaccumulative and Toxic
ppm – parts per million
STEL – Short Term Exposure Limit
TWA – Time-Weighted Average
vPvB – very Persistent and very Bioaccumulative
h - hour
mg/m^3 - milligram/cubic meter
mm - millimeter
mmHg - millimeter mercury
w/w - weight/weight
d - day

Key literature references and sources for data
www.ChemADVISOR.com/

Disclaimer Statement

End of Safety Data Sheet

SAFETY DATA SHEET

CL-28M CROSSLINKER

Revision Date: 03-Apr-2015 **Revision Number:** 19

1. Product Identifier & Identity for the Chemical

Statement of Hazardous Nature	Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Non-Dangerous Goods according to the criteria of ADG.

1.1. Product Identifier

Product Name	CL-28M CROSSLINKER

Other means of Identification

Synonyms:	None
Product Code:	HM000346

Recommended use of the chemical and restrictions on use

Recommended Use	Crosslinker
Uses Advised Against	No information available

Supplier's name, address and phone number

Manufacturer/Supplier

Halliburton Australia Pty. Ltd.
15 Marriott Road
Jandakot
WA 6164
Australia

ACN Number: 009 000 775
Telephone Number: + 61 1 800 686 951
Fax Number: 61 (08) 9455 5300

E-Mail address: fdunexchem@halliburton.com

Emergency phone number

+ 61 1 800 686 951

Australian Poisons Information Centre

24 Hour Service: - 13 11 26
Police or Fire Brigade: - 000 (exchange): - 1100

2. Hazard Identification

Statement of Hazardous Nature	Hazardous according to the criteria of the 3rd Revised Edition of the Globally Harmonised System of Classification and Labelling of Chemicals (GHS), Non-Dangerous Goods according to the criteria of ADG.

Classification of the hazardous chemical

Serious Eye Damage / Eye Irritation	Category 2 - H319
Carcinogenicity	Category 1A - H350
Reproductive Toxicity	Category 1B - H360
Specific Target Organ Toxicity - (Repeated Exposure)	Category 2 - H373

Label elements, including precautionary statements

Hazard Pictograms

Signal Word Danger

Hazard Statements

H319 - Causes serious eye irritation
H350i - May cause cancer by inhalation
H360 - May damage fertility or the unborn child
H373 - May cause damage to organs through prolonged or repeated exposure if inhaled

Precautionary Statements

Prevention

P201 - Obtain special instructions before use
P202 - Do not handle until all safety precautions have been read and understood
P260 - Do not breathe dust/fume/gas/mist/vapors/spray
P264 - Wash face, hands and any exposed skin thoroughly after handling
P280 - Wear eye protection/face protection
P281 - Use personal protective equipment as required

Response

P305 + P351 + P338 - IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing
P337 + P313 - If eye irritation persists: Get medical advice/attention
P308 + P313 - IF exposed or concerned: Get medical advice/attention
P314 - Get medical attention/advice if you feel unwell

Storage

P405 - Store locked up

Disposal

P501 - Dispose of contents/container in accordance with local/regional/national/international regulations

Contains

Substances	**CAS Number**
Borate Salts	Proprietary
Crystalline silica, quartz	14808-60-7

<u>Other hazards which do not result in classification</u>
None known

Australia Classification
For the full text of the H-phrases mentioned in this Section, see Section 16

Classification T - Toxic.

Risk Phrases

R36 Irritating to eyes.
R49 May cause cancer by inhalation.
R62 Possible risk of impaired fertility.
R48/20 Harmful: danger of serious damage to health by prolonged exposure through inhalation.

3. Composition/information on Ingredients

Substances	CAS Number	PERCENT (w/w)	GHS Classification - Australia