



HYDROGEOLOGICAL ASSESSMENT OF SANTOS QNT BEETALOO BASIN APPRAISAL PILOT – ENVIRONMENTAL MANAGEMENT PLAN.

PREPARED FOR | Environment Centre NT (ECNT)

PREPARED BY | Hydro Geo Enviro Pty Ltd

ABN | 92 624 961 360

CONTACT | Dr Ryan Vogwill, Director

TELEPHONE | M: +61 427 427 269

EMAIL | ryanv@hydrogeoenviro.com.au

DATE | 19/12/2025

Contents

Introduction	4
Overall Summary	4
Environmental Impacts and Risks	8
Recommendations	8
Specific Comments	10
References	15
Appendix A - Hydraulic Stimulation Environmental Impacts - Context and Background	16
Annexure A - Expert Brief from Johnson Legal	18

Introduction

Santos has developed an environmental management plan (EMP) that covers the installation of up to 12 new petroleum appraisal wells (either vertical or horizontal well types) at two separate well pads within Exploration Permit (EP) 161. Santos has been undertaking seismic and drilling exploration activity within EP161 since 2012 and is now seeking approval to undertake further appraisal works to determine the size, potential production rate, and characteristics of the shale gas reservoir.

EP161 is within the Beetaloo Sub-Basin located approximately 350 kilometres south-east of Katherine in the Northern Territory. The project will rely on groundwater as the main source of water and up to 20 groundwater bores will be constructed to support petroleum operations; this includes monitoring and control bores. The target aquifer for groundwater abstraction is the Cambrian Limestone Aquifer (CLA), specifically the Gum Ridge Formation (GRF). Water Extraction Licence (WEL) GRF10280 authorises the extraction of 193.5 ML/year from the Gum Ridge Formation and was reissued to Santos on 6 December 2023 for a period of 10 years (expires 31 December 2033). Santos proposes to seek authorisation to extract up to 750 ML/year in total to support the proposed activities but hasn't yet submitted an application to increase the current licence amount (according to the EMP).

HydroGeoEnviro has been engaged by Environment Centre NT (ECNT) via Johnson Legal to provide advice regarding how the EMP addresses potential impacts and risks to water and the environment associated with Santos carrying out this program. The brief for the review is provided in Annexure A. Dr Ryan Vogwill is the primary author of the report but was assisted by Rachel Hamilton who scanned the EMP highlighting critical content for review and compiled other relevant publicly available material. The review begins with an overall summary of the concerns related to the EMP followed by an evaluation of impacts and risks. Recommendations to better ameliorate these impacts and risks are then provided, along with specific EMP comments made at the end of the document. Where considered appropriate specific page numbers within the EMP (referred to by the PDF file's page numbers) are referenced or referred to. HydroGeoEnviro has reviewed other petroleum projects in Western Australia and the Northern Territory. These notes are located at the end of this review as Appendix A to provide background context and holistically describe the potential impacts of hydraulic stimulation activities on water resources and the environment. The EMP has appendices that total over 2500 pages. Therefore, this document provides an initial review and highlights our key areas of concern regarding our expertise in hydrogeology, hydrology and environmental impacts but a detailed review of all material is warranted. We have also cross referenced the EMP against the Key Recommendations relevant to hydrogeology, hydrology and environmental impacts in the Pepper Inquiry (i.e. their Table 16.11).

This review has been prepared in accordance with the NT Supreme Court's Practice Direction No. 6 of 2015 – Expert Reports, which we agree to adhere to.

Overall Summary

A greater understanding of the connectivity and structural controls in the Beetaloo basin are required prior any petroleum development being approved past the exploratory stages, as per recommendations by The Panel in the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory – *“The conclusions from a SREBA must therefore be available and taken into account prior to the grant of any further production approvals.”* (NT Government 2018). If exploration involves hydraulic fracturing, then there is a greater risk of impact than non-fracked wells (which can still leak

even if not hydraulically fracked). The ongoing Strategic Regional Baseline Assessment (SREBA) studies, particularly the work focussed on aquifer inter connectivity, sources of springs and the origins of methane, will help build these understandings. However, until high level technical studies that conclusively address basin groundwater dynamics and connections are available it is the proponents' responsibility to demonstrate lack of risk, not assume it. In our opinion, based on our experience, Santos has not adequately demonstrated a lack of risk in several areas and therefore risks have not been reduced to as low as reasonably practicable. These areas are discussed further below.

Inter-Aquifer Connectivity (deep/shallow/surface)

A lack of shallow deep connectivity potential between aquifers has been assumed and needs to be better demonstrated. The hydrogeological status of faults and fractures as flow barriers or conduits is critical to impact risk as these features could allow drawdown and contamination to impact the shallow/deep aquifers. This can occur via naturally occurring features (that could be enhanced by hydraulic stimulation) or well annuluses (that could be installed incorrectly or have their integrity compromised by hydraulic stimulation). The consequences of not identifying faults/fractures and potential migration pathways underlying the site could result in irreversible environmental damage. The geological cross-sections presented by Evans et al. (2020), *see extracted figure herein below*, shows a number of faults underlying the project area; however, it is hard to determine the exact project location on these. It is also noted a portion of the cross-sections have not been assessed and these portions align to the east of the project area. It is also likely that more faults and fractures exist than the regional scale features currently mapped hence why a detailed shallow seismic survey is recommended.

The project is in an area where deep groundwater resources are predominantly unexplored and shallow-deep aquifer connectivity exists. Nineteen springs have been identified within EP161 and the "Hot Springs Valley" (~45km north of Jibera South well pad) is associated with Beetaloo Sub-basin faults and the outcropping of Roper Group Mesoproterozoic sandstone formations e.g. Bessie Sandstone. The impermeability between the Velkerri Formation (gas target) and the underlying Bessie Creek Sandstone needs to be demonstrated not just assumed. Tickell and Zaar (2023) studied deep groundwater sources around 12 km northeast of the Beetaloo Sub-basin, in an area underlain by rocks that lie stratigraphically beneath the main gas producing zone within the Sub-basin. At one spring bubbles were rising intermittently and a gas detector indicated methane and ethane, an oily film was also present on the water and steam was rising from the water surface of the spring. The study concluded –*"the temperature of the spring waters suggests that they originate from considerable depths, of the order of 500 m for Gorge Spring and 1000m for Beauty Creek Hot Spring. In order for deep hot groundwater to reach the surface with relatively high flow rates, permeable conduits must be present to those depths. The most likely mechanism is via faults. The area is known to be within a major fault zone, the OT Downs Fault Zone."* Creating new fractures and increasing the size, extent and connectivity of the natural fractures (via hydraulic stimulation) can have significant implications for groundwater flow and conduits underground. A detailed understanding of these structural connections and controls needs to be obtained to enable a robust risk assessment to be undertaken. Flow pathways can be created during fracturing and can lead to contamination of aquifers with fracturing fluid or other contaminants e.g. saline aquifer mixing with fresh aquifer. These shallow deep connectivity issues are essentially not explored in this EMP.

These fractures and faults could allow discharge of naturally occurring groundwater or hydraulic stimulation effluent with potential to permanently impact the upper aquifers, reducing water quality and quantity for other users and have irreversible environmental and cultural impacts. Once

hydraulically stimulated an area cannot be un hydraulically stimulated hence we would recommend the highest levels of caution prior to approval to protect the groundwater resources of the area, dependent ecosystems and related cultural values.

Essentially the vertical connectivity between deep aquifers and the surface, as well as deep shallow connectivity between aquifers needs considerably more consideration.

Pending Groundwater Licence Increase and Supporting Information

The CLA (of which the Gum Ridge Formation is the lower unit and the target aquifer for water extraction) contributes to numerous springs (e.g. Mataranka Thermal Pools and Flora River) that are located down hydraulic gradient from the Beetaloo basin region and the project area (Evans et al. 2020). The aquifer discharges into the Roper River approximately 100 kilometres north-west of the Beetaloo Basin, supporting important groundwater-dependent ecosystems (*Pg. 111 EMP*). Appendix A-K (*Pg. 2306*) states that extraction could potentially influence groundwater pressure in the Gum Ridge Formation and that this was assessed during the previous water licence (proposed extraction volume of 193.5 ML/year). This assessment has not been updated to reflect the required 750ML/yr licence proposed to support the EMP. Significant groundwater storage and regular recharge have been used to assume extraction will not impact GDEs in the current EMP. This is not precautionary, does not meet best scientific practice and not backed by data, essentially an inadequate impact assessment. Typically, water licence applications require aquifer testing and groundwater modelling. It is advised the documents that support the groundwater licence increase application (i.e. 750ML/yr to support the EMP) be assessed in conjunction with EMP approvals.

The EMP does not present critical data from previously installed groundwater monitoring bores nearby (e.g. water bores at Mount Brown (formerly Tanumbirini) and Inacumba). Santos has been active on this site since 2012, have had ample opportunity to conduct site specific groundwater investigations and collect baseline monitoring data but haven't. Aquifer testing plots, derived hydraulic parameters, bore construction logs, lithological logs and hydrographs are a suggested starting place. This is particularly important regarding the imminent groundwater licence application increase and technical assessments related to this.

The EMP considers the CLA is the only aquifer present (Anthony Lagoon and Gum Ridge formations) and states, "*No other formations in this area are classified as aquifers.*" The Bukalara Sandstone aquifer is well recognised, and two studies have indicated potential for upwards groundwater flow into the CLA from this sandstone (DEPWS 2021). The Moroak Sandstone is not utilised as a groundwater resource within the Beetaloo GBA region however outside the Beetaloo GBA region (where these rocks occur near surface), the Moroak and other sandstones in the Roper Group are utilised and may also be a source aquifer for some springs (Evans et al. 2020). The degree of inter-aquifer connectivity is not well characterised (Evans et al. 2020). In some areas, the unnamed Cambrian sandstone directly underlies the CLA and may thus connect groundwater from deep Beetaloo Basin units and shallow aquifers (ELA, 2022). The disregard of several aquifers underlying the project is a broad concern regarding environmental risk impact evaluations.

Well Integrity

The integrity of the exploratory wells annular seals are of particular importance in this setting. The Cambrian Limestone is described as vast vuggy limestone aquifer, which can often be cavernous. This type of geology provides difficult conditions for drilling, cementing and installing annular seals, heightening well completion and failure risk and the potential for rapid transport of contaminants in what is a highly porous and permeable aquifer. The cavernous and vuggy nature of the CLA

introduces risks as aquifer hydraulic conductivities will be relatively high for this unit and cementing operations will be challenging, especially obtaining an annular seal across the CLA to the surface. CSIRO found that historically, the highest instance of well barrier integrity failure is due to insufficient or poor-quality cement coverage to seal aquifers and/or hydrocarbon-bearing formations. Therefore, the quality and extent of vertical coverage along the well during the initial cementing job, together with the maintenance of the integrity of the cement over time, are critical (NT Government 2018).

It is advised that Well Integrity Management Systems and the Well Operations Management Plan be reviewed in detail by a relevant independent drilling expert. There are multiple regulatory agencies, codes of practice and management plans for the project, this creates the potential for environmental impact mechanisms to be missed as there is no clear regulatory agency that has control over all aspect of this project's potential environmental impacts. An example of this is the information that supports the planned groundwater abstraction licence (750ML/yr) has not been included in the EMP. The new groundwater licence application would be best reviewed concurrently with the EMP.

GDEs and Cultural Value Assessments

Groundwater dependent vegetation communities have been identified within 5km of the well pads and licenced extraction bores, however no impact has been assumed as they are likely accessing a perched groundwater system. While this is likely the case, inter aquifer connectivity is not well understood and potential deeper groundwater sources (e.g. GRF) need to be better characterised in order to estimate any contribution to shallower/perched aquifers or the springs/seeps/surface. Also, the risk of surface contamination still exists to these terrestrial GDEs (see section below).

Santos has committed to collaborating with the NLC and to consider developing cultural heritage management with relevant parties in the future (*pg 17 EMP*). Traditional owners should be consulted on infrastructure locations e.g. gravel pits, well pads or camps. Consideration of aspects of cultural significance such as trees (e.g. trees with individual spiritual connections or scar trees) or springs/wetlands/soaks need to be incorporated into impact assessments better. It is important to note that the highest biodiversity values don't always line up with the highest cultural values, i.e. relatively common trees can be highly culturally significant. Traditional owners need to document (even if not released to government/licence applicants) where and what their cultural values are linked to in the environment and have an understanding of the relative cultural value of these different features or "assets." Knowledge co-production with remote land-attached Indigenous peoples can improve adaptive environmental planning and management where it fosters learning together, is grounded in the Indigenous-led institutions and addresses their priorities (Hill et. al 2022).

Surface Contamination

Spills of additives and hydraulic fracturing fluids can result in large volumes or high concentrations of chemicals reaching groundwater and/or surface water, with the potential to also impact dependant ecosystems. Unanticipated spills of hydraulic stimulation fluids have already occurred in this area even without widespread unconventional hydrocarbon development hence a detailed understanding of water table flow paths, travel times and receptors is required. Inflow dependant ecosystems (IDEs) and GDEs need to be considered in this context. Disposal practices (such as poorly lined pits) can release inadequately treated or untreated hydraulic fracturing wastewater to groundwater and surface water resources and subsequently the wider environment. Flooding

controls and shutdown/evacuation procedures will need to be well planned to avoid adverse environmental and infrastructure incidents. Some questions that need more exploration are: Can operations be paused? If hydraulic fracturing has begun, can it be shut down during the process if a natural disaster (bushfire or flooding/cyclone) occurs? Can flowlines (pipelines) be flooded safely and not exposed/compromised? Is there telemetry data to check flowlines pressure data to detect leaks while offsite. If a major leak is detected during a flood, how will this be dealt with? If flowback %'s have been underestimated, how quickly can storage tanks accommodate overflow or mitigate flowback volumes?

Also, by mid-century extreme rain events in the Northern Territory are projected to become more intense and recent trends show increased rainfall between December to February (Climate Change in Australia 2024 - <https://www.climatechangeinaustralia.gov.au/en/changing-climate/state-climate-statements/northern-territory/>). Have these climate change trends been accounted for in current flood modelling? From the flood modelling presented in the EMP this does not appear to be the case; with 1 in 10, 1 in 50 and 1 in 100 flooding events presented in the flood modelling.

Environmental Impacts and Risks

The potential impact mechanisms of this project have not been adequately addressed as detailed herein in our opinion. Whether the risk is acceptable is unable to be properly evaluated due to a lack of data and assessment across several areas. These areas predominantly relate to:

1. Shallow deep connectivity potential between aquifers and GDEs, including the nearby “Hot Springs” Valley and its connections to deeper aquifers e.g. Bessie Sandstone. This includes both naturally occurring fractures/connections but also those produced or enhanced by hydraulic stimulation;
2. Further local characterisation of all types of GDEs and IDEs within and around the project area including groundwater and surface water regimes supporting them;
3. Obtaining hydrogeological parameters from aquifer testing on proposed extraction bores;
4. Groundwater model development and refinement;
5. Contamination of groundwater and surface water from petroleum operations; and
6. Expansion of groundwater monitoring sites related to cultural assets and GDEs including obtaining baseline data prior to undertaking project activities.

In our opinion, based on our experience, risks have not been reduced to as low as reasonably practicable. Carrying out the work detailed herein would reduce uncertainty allowing a realistic and site-specific contamination risk assessment, groundwater abstraction impact predictions, facilitate a comprehensive local scale GDE and IDE assessment and develop robust groundwater monitoring network including collecting of baseline data.

Recommendations

In terms of recommendations for further work which needs to be completed before water supply and hydraulic stimulation activities occur:

1. All exploration wells should be drilled to a Category 9 (or above) standard of well construction incorporating cement casing from the shale formation to the surface, as per SREBA recommendation 5.3 (NT Government 2018). Current Santos well design does not have cement to surface stipulated around the 5 ½” production casing (see pg. 65 Fig. 11 of EMP);

2. Detailed seismic survey across the area to identify the locations of minor fractures and faults that may be activated or act as existing conduits;
3. Baseline surface gas survey in all existing bores and oil gas wells, the latter of which need to be also evaluated for current well seal status;
4. Installation of groundwater monitoring network in the target aquifers, including aquifer testing, typically this occurs in the context of other development before a water licence approval and also noting the large increase currently not approved as part of the current water licence;
5. Extended constant rate aquifer tests (minimum 72hrs) should be carried out on all groundwater abstraction bores, and data should be collected from a comprehensive monitoring bore network that should be installed for all GDE types once a holistic assessment is completed. During testing discharge water should be frequently monitored (e.g. every 30 mins) for water quality parameters such as pH and salinity as this can provide important additional data. Robust estimates of hydraulic conductivity need to be available so a more defensible and preferably precautionary groundwater model can be developed/presented (see item 9 below);
6. A network of nested piezometers or a set of monitoring bores (targeting shallower aquifer units at each site $\sim <1\text{km}$) should be established. The groundwater monitoring network should include (recommendations 7.1 and 7.3 SERBA) multilevel monitoring bores. This should include at least one site that includes all aquifers likely to be intersected (e.g. Anthony Lagoon Beds, Gum Ridge Formation, Unnamed Sandstone, Bukalara Sandstone). The deeper aquifers (e.g. Bukalara Sandstone, Moroak Sandstone and Bessie Creek Sandstone) may require a more pragmatic approach to monitoring. Deeper (than 1km) groundwater heads should be measured in all hydrostratigraphic units via techniques such as drill stem tests (DST) during hydrocarbon exploration drilling. Connections between the formations above and below the Cambrian Limestone need to be better established, including the Bessie Sandstone unit underlying the Velkerri Formation (target gas zone) prior to approval. A hydrograph of groundwater levels at each current monitoring site would be a helpful inclusion;
7. A bore census for water quality and gas at all pre-existing bores and in exploration/monitoring bores (see above) that should be installed before any approval is given to better understand the current hydrogeological conditions. This should include a methane isotopes sampling program to differentiate between biogenic and thermogenic sources of methane;
8. A detailed assessment of the distribution and groundwater dependency of GDEs is required. The first stage of the GDE toolkit (Richardson et al., 2011a) needs to be applied at all project locations at a minimum. If GDEs are detected then application of Part 2 of the GDE toolkit (Richardson et al., 2011b). This will ensure the impact assessment will include all possible drawdown receptors. To be explicit all 3 broad groups of GDEs - Aquatic (pools, springs, soaks, seeps etc), Subterranean (stygo fauna and troglo fauna) and Terrestrial (groundwater dependent vegetation) need to be assessed. These investigations should be completed prior to any further disturbance. Note that this should include a stygo faunal survey on all current and future groundwater monitoring bores and that linked cultural values should also be considered;
9. A groundwater model (that has undergone a sensitivity analysis, incorporating the data suggested herein) needs presenting, incorporating conceptual mechanisms (i.e. fault/fracture water and gas transport) by which any impacts may manifest. Once this is completed and a more robust impact assessment is presented, the potential impact area

may increase, in which case the receptor survey from the dot point above may need to be increased;

10. The following is a list of recommendations that should also be addressed in the context of the fault seal analysis:
 - a. Gas logging during all drilling both for water bores and hydrocarbon wells;
 - b. Water quality needs evaluation in deep aquifers prior to HFS, the area has unexplored water resources that could be impacted;
 - c. Pressure monitoring in bores screened in the deep aquifer (i.e. the groundwater monitoring bores proposed above) with real time pressure monitoring during hydraulic stimulation should be considered. This type of monitoring is a more reliable way of assessing how the transient pressure during hydraulic fracture stimulation propagates and impacts on deep aquifers located in critical areas, particularly near faults and fractures;
 - d. Monitoring of breakouts and drilling induced tensile fractures during drilling;
 - e. Fracture stability assessment should be conducted as a routine. Maximum bounds for stimulation pressure require site specific thresholds based on a consideration of both the stress state and reservoir type;
 - f. Fracture propagation modelling, G Function analysis and interpretation, stress barriers assessment. Stress barriers, not just geomechanical contrasts, are required for fractures to be contained within the hydraulic stimulation zone. There needs to be more detailed consideration of minimum horizontal stress in the cap rock and this needs to be completed for all areas where hydraulic stimulation is proposed.

Specific Comments

Page 15 – “A Tier 2 assessment has been undertaken (Appendix D) on these chemicals with the results showing no unacceptable risks to workers or avian species from the activity.”

Comment – Were stygofauna, troglifauna or aquatic species considered? What about contamination risks to aquifers via fractures/faults or inadequate well integrity?

Page 66 – “An intermediate casing pipe may be installed to isolate deeper aquifer systems (if present), for example the Bukalara Sandstone may be cased off to reduce the risk of impact to this layer.”

Comment – The intermediate casing should isolate any deeper aquifer systems intersected during drilling. The use of the term ‘may be’ makes it unclear whether deeper aquifers will be isolated by intermediate casing. Wells should be constructed to Category 9 standards as per the SERBA recommendation 5.3.

Page 66 – “After the production hole is drilled and logged, the production casing pipe is lowered to the total depth of the borehole (including horizontal laterals) and cemented in place (vertical pilot well total depth typically ten to 20 metres below the base of the lowermost hydrocarbon-bearing unit, but ideally not penetrating the underlying aquifer systems (if present)). The pilot hole will be isolated with cement. At both Jibera South and Newcastle south this is not anticipated, as the Velkerri formation (an interlaminated mudstone and siltstone) is anticipated to provide an impermeable layer between the lowest drill point and the potentially underlying Bessy Creek Sandstone partial aquifer.”

Comment – This impermeability between the Velkerri Formation and underlying Bessie Creek Sandstone needs to be demonstrated, not just anticipated. The Beetaloo Basin

Hydrogeological Assessment (Fulton & Knapton 2015 pg. 21) states that The Bessie Creek Sandstone outcrops on Tanumbirini and Carpentaria stations. The appraisal location is on Tanumbirini Station. Figure 11 in the EMP has The Bessie Creek Sandstone at 3500m below ground. The vertical separation can only be explained by faulting or major structural deformation of units. This needs to be better understood across the project, particularly to the east. Noting that the geological cross-section presented in Evans et al. (2020) do not contain information to the east of the project, see figure extracted below with approximate project area. Horizontal wells are planned to be up to 3.5km, this also needs be considered in the impact assessments.

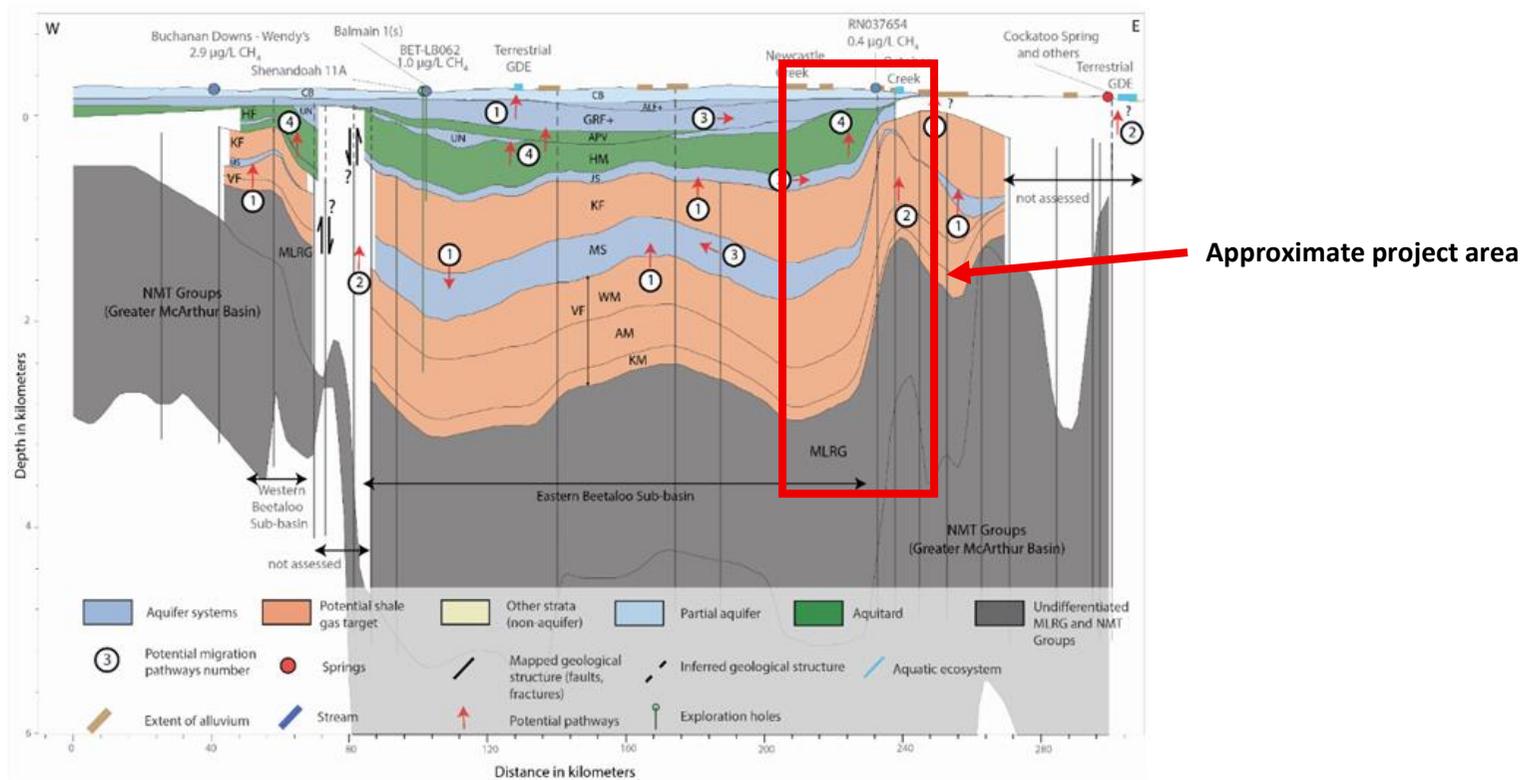


Figure 46 Cross-section B-B', with west–east orientation, across the Beetaloo GBA region, showing five potential hydrological connections for water or gas migration

The five potential hydrological connections are: 1. via direct stratigraphic contact; 2. via faults; 3. through porous/karst aquifers; 4. through partial aquifers/aquitards reaching overlying aquifers; 5. via groundwater discharge from CLA aquifer to springs.

NMT – Nathan/McArthur/Tawallah Groups; MLRG – Middle to Lower Roper Group; VF – Velkerri Formation (WM – Wyworrie Member, AM – Amungee Member; KM – Kalala Member); MS – Moroak Sandstone; KF – Kyalla Formation; JS – Jamison sandstone; APV – Antrim Plateau Volcanics; GRF+ - Gum Ridge Formation and equivalents (lower CLA); ALF+ - Anthony Lagoon Formation and equivalents (upper CLA) .

Data: faults sourced from Betts et al. (2015) , unconventional gas plays footprints from Geological and Bioregional Assessment Program (2019b), springs from Department of Environment and Natural Resources (NT) (2013) and geology from Geological and Bioregional Assessment Program (2019a) and Frogtech Geoscience (2018a); methane data from Wilkes et al. (2019) Element: GBA-BEE-2-348

Page 66 – “The production casing pipe is cemented, from bottom to inside the previous casing (and sometimes to surface), to achieve robust and effective isolation of the well from the various subsurface layers (aquifers and aquitards alike).”

Comment – Note underline; a Category 9 standard of well construction incorporates cement casing from the shale formation to the surface. It forms part of SREBA recommendation 5.3 (NT Government 2018) “*all onshore shale gas wells (including exploration wells constructed for the purposes of production testing) be constructed to at least a Category 9 standard (unless it can be demonstrated by performance modelling/assessment that an alternative design would give at least an equivalent level of protection), with cementing extending up to at least the shallowest problematic hydrocarbon-bearing, organic carbon rich or saline aquifer zone;*” This has not been demonstrated and therefore cementing to the surface along the length of the well from the target zone upwards is required. Current Santos well design does not have cement to surface around the 5 ½” production casing (see pg. 65 EMP) and the shoe is planned to be located just above the Moroak Sandstone (a known aquifer).

Page 75 – “If the casing bond log from the primary cement job typically executed during the drilling phase identifies issues with the integrity of the cement, further evaluation is undertaken. If it is determined that the loss of integrity poses an unacceptable risk, remedial cementing works will be undertaken. This is managed by the WOMP.”

Comment - The integrity of the wells annular seals are of particular importance in this setting. The Cambrian Limestone is described as vast vuggy limestone aquifer, which can often be cavernous. Particular care needs to be taken when cementing to surface during bore construction to ensure a complete seal. The WOMP should be reviewed to assess the remedial works and whether they are sufficient.

Page 95 – “No impacts to potential Groundwater Dependent Ecosystems (GDE) are anticipated as the targeted aquifer depth for the water bore at the well site is around 120 metres below ground. Therefore, there is significant separation and geological barriers between the target zones and the shallow perched groundwater system GDEs would be sourcing from (see section 4.4.11 for further discussion on GDEs).”

1. Comment - Any shallow ‘surface’ aquifers in the project area have not been discussed. The identification of GDEs (*see EMP pg. 136*) in the project area means there must be a water source shallower than the Cambrian Limestone. This water source may not be productive from a water supply context and may not ‘produce’ water during drilling operations but vegetation will be accessing a shallower system than the CLA. The Anthony Lagoon Formation and the Gum Ridge Formation of the Cambrian Limestone aquifer appear to be hydraulically connected. The major knowledge gap is the hydrogeological units that overlie the Cambrian Limestone aquifer and how they are hydraulically connected. Water table and potentiometric surface maps need to be developed for all aquifers. Essentially, will water abstraction from the Cambrian Limestone affect water levels or quality in overlying aquifers closer to the surface which could impact on GDE’s?

Page 111 – “The north-eastern portion of EP 161 is outside of the spatial extent of the CLA and is characterized by Proterozoic-aged geology.”

Comment – A structural geology map would be a useful inclusion here to show the vertical uplift/faults associated with the Proterozoic aged geology.

Page 111 – “At the location of the proposed activities, the CLA is the only aquifer present (Anthony Lagoon and Gum Ridge formations). No other formations in this area are classified as aquifers.”

Comment – The Bessie Creek Sandstone and Bukalara Sandstone are classified as aquifers and predicted to lie beneath the site. Also, the Unnamed Sandstone and Moroak Sandstone are local aquifers.

Page 118 – “There is also a range of small wetlands associated with springs, sinkholes and minor depressions in the generally flat landscape.”

Comment – These potential GDEs need better assessment as described herein.

Page 137 – “Given the absence of detections and the spatial separation from known occurrences, it is considered unlikely that stygofauna are present within the Project Area.”

Comment – This is an assumption and should be demonstrated by a stygofaunal survey on all current and future groundwater monitoring bores.

Page 137 – “The closest mapped spring, Stone Spring, is located approximately 45 kilometres to the north of Jibera South well pad. Stone Spring is situated within 'Hot Springs Valley' within Tanumbirini Station. The 'Hot Spring Valley' is a series of springs likely relating to outcropping of Roper Group Mesoproterozoic formations. Lagoon Creek Spring within 'Hot Springs Valley' is interpreted to be likely sourced from the Bessie Creek Sandstone (CSIRO. 2025). The Moroak and Bessie Creek Sandstone formations within the Roper Group, believed to supply the Hot Springs Valley springs, are not considered environmentally sensitive for the Beetaloo Basin Appraisal Pilot because they occur at substantial depth beneath the proposed well pads.”

Comment -This shows that there is connectivity in the basin between the deeper units and the surface. This needs a lot more consideration.

Appendix A-K Page 2269 – “A review of the groundwater conditions, including quantity and quality, of the lithological units intersected by the project appraisal bores indicate that the sandstone units below the CLA, due to the significant depth and poor water quality, are not classified as viable aquifers. These units are therefore not included in the project groundwater monitoring program.”

Comment – The Bukalara Sandstone aquifer is well recognised, and two studies have indicated potential for upwards groundwater flow into the CLA from this sandstone (DEPWS 2021). The Moroak Sandstone is not utilised as a groundwater resource within the Beetaloo GBA region however outside the Beetaloo GBA region (where these rocks occur near surface), the Moroak and other sandstones in the Roper Group are utilised and may also be a source aquifer for some springs (Evans et al. 2020). Not including these aquifers in the assessment is a major oversight.

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Appendix A - Hydraulic Stimulation Environmental Impacts - Context and Background

According to the United States Environmental Protection Agency (US EPA 2016), there are five stages to a hydraulic stimulation project and the potential areas of impact to groundwater and surface waters are highlighted:

1. Water Acquisition - the withdrawal of groundwater or surface water to make hydraulic fracturing fluids. Groundwater and surface water resources that provide water for hydraulic fracturing fluids can also support groundwater dependant ecosystems. This is a key issue in arid areas and areas of limited water resources.
2. Chemical Mixing - the mixing of a base fluid to create hydraulic fracturing fluids. Spills of additives and hydraulic fracturing fluids can result in large volumes or high concentrations of chemicals reaching groundwater potentially impacting groundwater and surface water, with the potential to also impact dependant ecosystems where a pathway from source to receptor is present.
3. Well Injection - the injection and movement of hydraulic fracturing fluids through the production well and in the targeted rock formation. Belowground pathways, including the production well itself if there is an integrity breach, natural fractures (faults etc) and newly-created fractures, can allow hydraulic fracturing fluids, other fluids and gases to reach underground drinking water resources. Given groundwater can also support surface water resources (Winter et al. 1998) this can potentially impact on surface and groundwater resources and dependant ecosystems (Entrekin et al. 2015).
4. Produced Water Handling - the onsite collection and handling of water that returns to the surface after hydraulic fracturing and the transportation of that water for disposal or reuse. Spills of produced water can impact groundwater and surface water.
5. Wastewater storage, disposal and/or Reuse - the disposal and reuse of hydraulic fracturing wastewater. Storage and disposal practices (such as in unlined or poorly lined pits) can release inadequately treated or untreated hydraulic fracturing wastewater to groundwater and surface water resources, agricultural water quality and subsequently the wider environment.

With regards to shallow groundwater or environmental impact from deep target formation and shallow aquifer connectivity, Reagan et al. (2015) identified five plausible failure scenarios which are:

- (1) Extensive vertical fracturing of the formations bounding the reservoir because of inadequate design or implementation of the hydraulic stimulation operation, with the resulting fractures reaching shallow aquifers or even permeable formations connected to these formations.
- (2) Sealed/dormant fractures and faults that can be reactivated by the hydraulic stimulation creating pathways for upward migration of gas, hydrocarbons and other contaminants.
- (3) Induced fractures/faults that reach groundwater resources after intercepting conventional hydrocarbon reservoirs, which may create an additional pollutant source.
- (4) Hydraulic stimulation creates fractures that intercept older, abandoned unplugged wells (or wells with integrity failure) in their vicinity. This can be caused by lack of information about the location and installation specifics of the abandoned wells, or because of inadequate design or implementation of the stimulation operation resulting in excessively long fractures. These aging wells can intersect and communicate with freshwater aquifers, and

inadequate or failing completions/cement can create pathways for contaminants to reach the potable groundwater resources.

- (5) Failure of the well completion during stimulation because of inadequate/inappropriate design, installation and/or weak cement. In this case, the well itself is the weak link, and it either includes open voids, or is fractured during the stimulation process, or both. Thus, improper cementing and well completion can result in continuous, high-permeability pathways connecting the reservoir with the shallow aquifer, through which contaminants can be discharged towards the surface. Note that the overlying formations may or may not be fractured in this case.

The likelihood of these impact scenarios manifesting will vary on a site by site and case by case basis but Reagan et al. (2015) conclude they are all possible. Hence these issues need to be assessed on case by case basis. These pathways are not only important for contamination impacts via hydraulic stimulation, they also could allow groundwater production related drawdown to propagate to the surface.

Annexure A - Expert Brief from Johnson Legal.

EXPERT BRIEF

CONFIDENTIAL AND LEGALLY PRIVILEGED

Date: 12 December 2025

To: Dr Ryan Vogwill
Director & Principal Hydrogeologist
Hydro Geo Enviro Pty Ltd

By e-mail only: rvany@hydrogeoenviro.com.au

ENVIRONMENT CENTRE NT

SANTOS – BEETALOO BASIN APPRAISAL PILOT EMP

From: Johnson Legal
Level 21, 8 Chifley Square
SYDNEY NSW 2000

Dear Dr Vogwill

Environment Centre NT (ECNT) – Santos QNT Pty Ltd Beetaloo Basin Appraisal Pilot Environment Management Plan (EMP)

1. We confirm that we act for ECNT in the above matter, who wish to provide submissions in relation to the EMP currently under assessment with the Northern Territory Government.
2. We wish to brief you to provide a preliminary expert report for ECNT in relation to the likely impacts and risks to water and the environment associated with the carrying out of the Project, within your scope of expertise.

The EMP

3. As part of the assessment process, the EMP was published for comment on 21 November 2025.
4. Comments on the EMP will close on **19 December 2025**.
5. The key documents subject to assessment is linked below:
 - a. [EMP](#) currently open to comment and relevant appendices, including:
 - [Appendix A-K](#) - Summary of Approved Regulated Activities
 - [Appendix L](#) - Cultural Heritage Assessment
 - [Appendix M](#) - Emergency Response Plan – Mcarthur and Ameadeus Basins

The Project

6. Santos is an Interest Holder and operator of Exploration Permit (EP) 161 located in the Beetaloo Basin, approximately 350 kilometres south-east of Katherine in the Northern Territory.
7. Santos proposes to drill and test petroleum appraisal wells across two locations within EP 161, collectively referred to as the Beetaloo Appraisal Pilot.
8. The subject EMP covers the installation of up to twelve new petroleum appraisal wells at two separate well pads within EP 161. Some of the proposed activities include:
 - a. Clearing and earthworks for 2 new well pad locations – The clearing and construction to create two new well pads and ancillary infrastructure at well pad locations referred;
 - b. Drilling up to 12 appraisal wells, either vertical or horizontal well types;

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- c. Operating, testing, maintenance and decommissioning and hydraulic fracture stimulation of up to 12 appraisal wells;
 - d. Wastewater management – each well pad will include evaporation tanks, storage tanks, drilling sumps, cutting pits and any transfer infrastructure within the well pad. This also includes transportation onsite and disposal of these wastes (unless otherwise approved for reuse or burial).
9. The approval criteria are set out in reg 9 of the [Petroleum \(Environment\) Regulations 2016 \(the Regulations\)](#) and include that the EMP must demonstrate that the Project will be carried out in a manner by which the environmental impacts and environmental risks will be reduced to a level that is 'as low as reasonably practicable' (ALARP) and 'acceptable'.
10. In determining whether or not to approve the EMP, the Minister must consider whether the EMP for the Project should be approved pursuant to the [Petroleum Act 1984](#) and the Regulations and if so, on what conditions.

Your brief

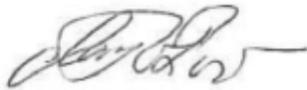
11. We request that you:
- a. Provide an expert report for ECNT by **16 December 2025** in relation to:
 - i. The environmental impacts and risks (specifically, regarding wastewater spills and risks in respect of inter-aquifer connectivity) associated with the Project and the carrying out of the Project. This would include your assessment of the likelihood of any risks identified and the environmental impacts and consequences if those risks crystallise; and
 - ii. Any recommended conditions or recommended amended conditions for the EMP to ameliorate the environmental impacts and risks you have identified in (i). This aspect should address the degree to which the EMP and proposed works meet the standards set by the legislation and the standards recommended by the [Scientific Inquiry into Hydraulic Fracturing in the Northern Territory](#) (Pepper Inquiry).
12. We ask that you prepare your opinion in accordance with the [NT Supreme Court's Practice Direction No. 6 of 2015 – Expert Reports](#).
13. We note that under the Practice Direction, an expert witness is not an advocate for a party and has a paramount duty, overriding any duty to the party to the proceedings or other person retaining the expert witness, to assist the Court impartially on matters relevant to the area of expertise of the witness.

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Your fees

12. Please provide us with an estimate of your fees for carrying out this work at your earliest convenience.

Yours faithfully
Johnson Legal Pty Ltd



Matt Floro
Principal Lawyer

Encl.

INDEX TO BRIEF

An index to the materials briefed is below. A copy of the annexures is contained at this [Dropbox](#) link.

No.	Document	Date
1	Beetaloo Basin Appraisal Pilot Environmental Management Plan	November 2025
2	Appendix A-K	November 2025
3	Appendix L	November 2025
4	Appendix M-P	November 2025

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