ntepa Northern Territory Environment Protection Authority

Onshore Petroleum Activity – NT EPA Advice

SANTOS QNT PTY LTD – ENVIRONMENT MANAGEMENT PLAN (EMP) FOR THE MCARTHUR BASIN 2019 HYDRAULIC FRACTURING PROGRAM EP 161

BACKGROUND

The Minister for Environment and Natural Resources has formally requested under section 29B of the *Northern Territory Environment Protection Authority Act 2012* (NT EPA Act) that the Northern Territory Environment Protection Authority (NT EPA) provide advice on all Environment Management Plans (EMPs) received under the Petroleum (Environment) Regulations 2016.

That advice must include a recommendation on whether the EMP should be approved or not, supported by a detailed justification that considers:

- whether the EMP is appropriate for the nature and scale of the regulated activity to which the EMP relates (regulation 9(1)(b))
- whether the EMP demonstrates that the activity will be carried out in a manner by which the environmental impacts and environmental risks of the activity will be reduced to a level that is as low as reasonably practicable and acceptable (regulation 9(1)(c))
- the principles of ecologically sustainable development (regulation 9(2)(a)), and
- any relevant matters raised through the public submission process

In providing that advice, the NT EPA Act provides that the NT EPA may also have regard to any other matters it considers relevant.

ACTIVITY

Interest Holder	Santos QNT Pty Ltd
Petroleum interest(s)	Exploration Permit 161 (EP 161)
Environment Management Plan (EMP) title	McArthur Basin 2019 Hydraulic Fracturing Program EP 161
EMP document reference	McArthur Basin 2019 Hydraulic Fracturing Program EP 161 EMP, Revision 3, 2 October 2019
Regulated activity	This EMP covers the activities required to enable Santos to hydraulic fracture, test, maintain and suspend or decommission one vertical petroleum exploration well and two horizontal petroleum exploration wells within the 2019 – 2024 period. This includes all ancillary activities required to undertake the exploration activities proposed under this plan. The program occurs at two well site locations, Tanumbirini and Inacumba on EP 161, and includes the following exploration well activities: mobilisation of rig and hydraulic fracture materials to each well site, hydraulic fracturing preparation activities including pressure testing and cement bond logging, cased hole DFITs, installation of passive seismic monitoring surface array and tiltmeters at both

	well sites, vertical seismic profile (VSP) and microseismic monitoring at Tanumbirini, hydraulic fracture of each exploration well in the Velkerri formation, pressure monitoring, placement of chemical tracers, completion and flowback from each exploration well, storage and evaporation of flowback wastewater in tanks at each well site, extended production (appraisal) tests (EPT) including flaring of each exploration well, routine maintenance and monitoring activities, transport of wastewater from each well site to an authorised disposal facility, removal of tanks and other equipment and material from each well site, progressive stabilisation and rehabilitation of land disturbance areas, minor ancillary works associated with the above activities and well suspension or decommissioning of each exploration well
Public consultation	Public consultation on the EMP was required under 8A(1)(b) of the Petroleum (Environment) Regulations as the EMP proposes the drilling and hydraulic fracturing of a well. The EMP was made available for public comment for a period of 28 days from 30 August to 27 September 2019.

NT EPA ADVICE

1. Is the EMP appropriate for the nature and scale of the regulated activity (regulation 9(1)(b))

Information relating to the nature and scale of the regulated activity is provided in the EMP in a clear format. The technical works program includes hydraulic fracture and well testing one vertical petroleum exploration well and two horizontal petroleum exploration wells within the 2019 – 2024 period. On completion of well evaluation (testing hydrocarbon flows), the wells will either be suspended for future re-entry or decommissioned with permanent cement plugs, in accordance with the requirements outlined in the Code of Practice: Onshore Petroleum Activities in the Northern Territory (the Code). Decommissioning and rehabilitation are planned for December 2024. A comprehensive and progressive rehabilitation plan has been developed for the activity, to minimise the risk of site erosion and return the disturbed land to an environment similar to the original conditions.

A number of well evaluation techniques will be conducted prior to, during and on completion of hydraulic fracture of the Velkerri shale. Key information and data required across the phases of the activity are outlined below:

1.1 Seismic monitoring program

This includes installation of passive seismic monitoring surface array of geophones (like ultrasound) at various locations on the surface near the petroleum well and which detect tiny vibrations (micro-seismic waves), much below human detection, deep in the earth when the hydraulic fracturing occurs.

A vertical seismic profile (VSP) will be conducted at Tanumbirini by placing geophones (acoustic receivers) in the Tanumburini-1 vertical well at different depths while providing a seismic source (vibroseis truck) along existing seismic lines that intersect the well site. This enables reservoir engineers to calibrate the subsurface velocity distribution through the stratigraphic formations including the Velkerri shale. This improves the accuracy of downhole microseismic event location in the Velkerri shale more than 2 km below the surface during hydraulic fracturing (HF) operations.

During HF operations of Tanumbirini 2H, geophones at surface and downhole in the nearby Tanumburini-1 well will be deployed. These geophones will be connected to the microseismic office using a radio array. Events greater than a certain magnitude (determined from baseline data) will be sent to the microseismic office. Based on the layout of the acoustic receivers, the x, y, z location of microseismic events can be determined in real-time, allowing the propagation of fractures in the Velkerri shale to be mapped. Fracture geometry evaluation will also be monitored with tiltmeters at surface will be conducted at both well sites.

The overall objective of the seismic program is to monitor the degree of horizontal fracture propagation as well as vertical fracture orientation in the target reservoir (Velkerri shale) during the hydraulic fracturing operations and to enable microseismic mapping of fracturing extent (height, length, and orientation) for each hydraulic fracture stage. This enables reservoir engineers to evaluate several important parameters including estimations of stimulated rock volume (SRV), or fracture network, created in the Velkerri shale by the hydraulic fracturing process which subsequently enables the hydrocarbons to be released from the non-permeable shale and enable them to flow up the well. The objective is to maximise the fracture network in the Velkerri shale and at the same time contain the fracture network in the Velkerri shale to reduce cost and maximise efficiency of pumping resources. Reservoir engineers then relate the SRV to gas produced during the EPT to provide an approximation of the quantity of gas that is potentially recoverable from the Velkerri formation, termed the estimated ultimate recovery (EUR).

A traffic light system will be implemented in accordance with the Code to monitor anomalous seismicity (tremors) during the hydraulic fracturing operations at both well sites. The risk of induced earth tremors as a result of hydraulic fracturing that can be felt at surface is considered very low.

1.2 Diagnostic fracture injection testing (DFIT)

A cased hole DFIT is conducted once the overall integrity of the well has been confirmed by the engineers. This test involves pumping small volumes (<10,000 L) of water, with salts (mostly Sodium Chloride - NaCl) and biocide through small perforations made in the well casing, located at a selected depth level of the Velkerri shale, to create small hairline fractures in the shale, and then allowing the resulting pressure to fall naturally after stopping the pump. Proppant (sand) is not used during the DFIT; hence the fracture relaxes and closes naturally when the pumping pressure at surface is released. The pressure decline is monitored at the surface and this decline data is analysed to assist reservoir characterisation and inform subsequent modelling of the hydraulic fracturing operation. The purpose of a DFIT is to obtain information on reservoir properties to help determine subsequent hydraulic fracture design parameters in a reservoir modelling process. Modelling is completed prior to the commencement of hydraulic fracturing activities to establish the best hydraulic fracturing fluid mixture and pumping schedule necessary to propagate the fracture network to maximise the SRV (or fracture network) in the Velkerri shale and at the same time contain the fracture network in the Velkerri shale to reduce cost and maximise efficiency of pumping resources.

1.3 Hydraulic fracturing

This will involve perforating the 5 ½” steel casing section of the well at the depth of the Velkerri shale and hydraulic fracturing in a series 15 – 25 stages for Tanumbirini 2-H and Inacumba 1-H wells. The process commences at the end (toe) of the horizontal section of the well and the stages work back towards the “heel”. In the case of Tanumburini-1, which is a vertical well, hydraulic fracturing will target a series of 5 vertical zones (stages) in the Velkerri formation starting with the deepest zone. Each hydraulic fracturing stage consists of pressure pumping a slurry, primarily consisting of water and sand (proppant), plus a small percentage of chemicals, at high pressure down the well and through the perforated well bore into the target section of the Velkerri shale approximately 2,300 m – 3,500 m below ground level, depending on the well. Typically, 95% or higher of the total volume in hydraulic fracturing fluids is a combination of fresh water and proppant (e.g. sand), with the remainder of approximately 1% as fluid-conditioning additive chemicals.

As discussed above, hydraulic fracturing activities will not occur until the integrity of a well has been confirmed. Real-time monitoring of the pumping pressure is conducted during hydraulic fracturing operations to ensure maximum allowable operating (MAOP) is not exceeded. In addition anomalous pressure behaviour in the well annulus at surface is also monitored in real-time. The fracture network created in the Velkerri shale during the pumping operation (which may last 2 or more hours) is carefully monitored at the surface using seismic monitoring, pumping volume and pressure and a range of other measures in the control room of the operation. Each stage will be plugged in the well bore prior to perforation and pumping of the subsequent stage and is anticipated to take one day to complete.

1.4 Completion and Extended Production Test (EPT)

Following completion of the hydraulic fracturing operation the equipment for hydraulic fracturing (consisting of pump trucks and other equipment) will be demobilised and a smaller completion rig will be brought to the well site. A production wellhead will be installed. Flowback is then initiated by milling out the mechanical isolation plugs that were set during the fracturing operations between each hydraulic fracture stage. The existing over-burden pressure on the Velkerri shale causes water to return or "flowback" to the surface through the petroleum well. The proppant (sand) remains in the shale "propping open" the hairline fracture network that was developed during the hydraulic fracturing pumping operation. It is this principle in hydraulic fracturing that has enabled reservoir engineers to develop "artificial permeability" in shales, enabling hydrocarbons to be liberated from shale formations that would have otherwise taken tens of millions of years to have occurred[1.]

Subject to a successful reservoir outcome (good gas flow rates for example), each well will be flow tested for an initial EPT period of approximately 90 days and up to 12 months. Flowback water will be directed through a separator at surface to capture wastewater and separate gas to flare. Liquid hydrocarbons (longer chain hydrocarbons such as crude oil) aren't expected from the Velkerri Formation targets in EP 161; dry gas (methane) is most likely with the potential for "wet gas" (e.g. some ethane and propane) which will be gas at surface conditions and flare efficiently. The EPT will consist of characterising and measuring the gas qualities and quantity and any liquid hydrocarbon production as well as other "reservoir" characteristics. The EPT may continue until December 2020.

1.5 Well site closure operations

On completion of technical evaluation of the results from the hydraulic fracturing activity, each exploration well will either be suspended for future re-entry, or in a non-success case, a decision made to decommission the exploration well with permanent cement plugs in accordance with the Code. At the completion of operations all surface infrastructure will be removed (excluding the well head).

1.6 Description of sub-surface geology

The stratigraphic formations intersected by the petroleum wells have been adequately described; informed by 500 km of 2D seismic data acquired in 2013 over EP 161 which has been used to screen for large scale, regional faults or structures prior to the finalisation of any exploration well location. An additional seismic control line has also been surveyed at Tanumbirini well site in accordance with the approved McArthur Basin Civil and Seismic Program EP161 – June 2019. Tanumburini-1 vertical exploration well drilled almost 4 km deep in 2014 and a stratigraphic core hole (Marmbulligan-1), also provides nearby offset well control including stratigraphic, geological and petro-physical subsurface data and an assessment of potential subsurface geohazards (e.g. faults and hazardous gases). Current data of the broader Beetaloo exploration area indicates there are very few major faults present and that the strata within the Basin (i.e. away from the steep flanks) are relatively gently dipping[2]. In addition, stratigraphic information gained from groundwater monitoring bores bore holes that have been

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[1] Shale (mudstone) is the "source rock" from which almost all petroleum originates. It is the sedimentary rock in which organic matter that forms petroleum was deposited and subsequently buried, usually in a depositional nearshore marine environment; over one billion years ago in the case of the Beetaloo Sub-basin shales. "Conventional" petroleum reservoirs are more permeable rock formations such as sandstone or lime deposits (that don't require hydraulic fracturing) which were able to "trap" petroleum due to stratigraphy over tens of millions of years that was migrating very slowly from the shale to the surface.

[2] Scrimgeour I. (2016) Summary of current knowledge of petroleum geology, shale gas resources and exploration in the Beetaloo Sub-basin. Information Provided by the Northern Territory Geological Survey to the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory.

drilled at the well sites to the base of the regional Cambrian Limestone Aquifer (CLA) system, in compliance with the Code, is provided in the EMP to inform planning and design of petroleum exploration well construction to isolate and protect the regional aquifers[3].

1.7 Description of activity scope and duration

Estimations of consumables (e.g. water, sand and chemical additives) discussed in the EMP are based on a maximum 15 – 25 stage hydraulic fracturing program for each horizontal well. Water and sand make up the bulk of the materials of the hydraulic fracturing fluids per stage. The preliminary hydraulic fracturing design will involve pumping approximately 900,000 litres (L) of fluids and 140,000 kilograms (kg) of proppant per stage. The final designs will be determined after the Diagnostic Fracture Injection Test (DFIT) is performed. Total volume of flowback wastewater from hydraulic fracturing required for offsite disposal is estimated to be 3.6 ML (after evaporation) at each well site.

A temporary 120 person camp site will be established for the hydraulic fracturing stages of the activity. A smaller camp will be required during the longer well completion and testing stage. Approximately 85.2 ML of groundwater for the activity, in total, will be sourced from existing bores in accordance with a water extraction licence granted under the *Water Act 1992*. The traffic impact assessment indicates additional peak project vehicle movement is 44 vehicles per day in addition to the existing peak dry season traffic volumes of 827 vehicles/day, resulting in an additional 1.2% of large combination vehicles when compared to the total volume composition.

The existing environment has been adequately described through baseline surveys including groundwater quality characterisation at each well site and at existing pastoral bores across EP 161 and is suitably understood. The EMP includes an impact and risk assessment based on information gathered during environmental baseline surveys from 2012 to 2018 and previous exploration experience of the Interest Holder in EP 161. The potential impacts and risks of the regulated activity have been identified and relevant environmental outcomes, performance standards and measurement criteria have been provided in the EMP. Where appropriate the NT EPA has also provided advice relating to Ministerial Conditions for this preliminary stage of exploration in the Beetaloo at the end of this advice.

1.8 General compliance with code requirements

The EMP demonstrates how the Interest Holder will comply with relevant requirements of the Code in undertaking this regulated activity. This includes a list of applicable ISO/API standards that have been adopted for the selection of materials for use in well construction; hydraulic fracturing program environmental controls and related engineering controls contained in the Well Operations Management Plan (WOMP); a summary of which is provided in the EMP. The risk assessment provided in the EMP cross references relevant sections of the Code that apply to the mitigation and management measures to enable the reviewer to identify and confirm that the proposed hydraulic fracturing program activities comply with the Code. The EMP also provides the following plans which are compliant with the Code:

- Chemical Risk Assessment of chemicals to be used in the hydraulic fracturing activity
- Wastewater Management Plan – including management of flowback wastewater
- Spill Management Plan – including spill risk assessment and response strategy
- Emergency Response Plan
- Methane Emissions Management Plan
- Erosion and Sediment Control-Rehabilitation Plan,
- Weed Management Plan
- Fire Management Plan

[3] Aquifer defined in the Code as: A body of rock that is sufficiently permeable to conduct groundwater and currently supplying, or potentially being able to supply, water for environmental, cultural or consumptive (stock or domestic) uses, as determined by the Northern Territory Government.

The level of detail and quality of information provided in the EMP is sufficient to inform the evaluation and assessment of potential environmental impacts and risks, and meets the EMP approval criteria under Regulation 9(1)(b).

2. Principles of ecologically sustainable development (regulation 9(2)(a))

2.1 Conservation of biological diversity and ecological integrity

The potential impacts and risks to threatened flora and fauna species from clearing were assessed in the EMP for the Santos McArthur Basin Civil and Seismic Program EP 161 approved in June 2019. That EMP identified six birds, five mammals and one reptile that are listed threatened species that may occur within 10 km of the project area, based on availability of suitable habitat. Of these, only four species were considered to have a ‘medium’ likelihood of occurrence, the crested shrike tit, grey falcon, Gouldian finch and Mertens’ water monitor. The McArthur Basin Civil and Seismic Program EMP outlined mitigation measures associated with construction activities to minimise impacts on threatened species and on affected environmental values including the management of threatening processes such as weeds and fire. The NT EPA advised that it considered the conservation of biological diversity and integrity of threatened species would be maintained in the area if the EMP is complied with.

The potential impacts and risks of the activity identified in the current EMP relate primarily to animal welfare and do not pose a significant risk to threatened species at a population level due to the low likelihood of threatened species inhabiting the area and implementation of control measures to avoid impacts to fauna.

The EMP identifies other potential impacts and risks to biodiversity arising from vehicle strike, increased weeds, and ingestion of flowback wastewater generated during the activity. The fauna impact mitigation measures for risk sources from hydraulic fracture activities, flaring and entrapment are compliant with the Code and include:

- appropriate separation distances between flares and surrounding vegetation that provides fauna habitat
- driving is only permitted on designated access roads
- speeds on unsealed roads will be limited, with to a maximum of 60 km/hr
- all tank pads are above ground, with steep sides, to prevent ease of animal entry
- all wastewater will be stored in tanks more than 2m high
- fauna ladders will be installed at all open pits
- all hydraulic fracture work tanks will be enclosed
- daily checks of tank pads throughout the hydraulic fracturing program

Cumulative impacts to flora and fauna from the regulated activity and the approved civils activities are not considered to be significant. The NT EPA considers that implementation and compliance with the EMP will ensure the conservation of biological diversity and ecological integrity is not impacted by the regulated activity.

2.2 Integration of long-term and short-term economic, environmental, social and equitable considerations

The EMP has considered environmental controls in well design for hydraulic fracturing that ensures well integrity and long-term protection of aquifers. These controls include specific stages at which well integrity must be checked and verified by the regulator. These controls and a range of other routine procedures have been identified in the EMP, are compliant with the Code and can be checked and audited against the Well Operations Management Plan (WOMP) throughout the life-cycle of the well.

The regulated activity is low impact, small scale and has a duration of activity of 18 months, which includes flowback and tests for gas production. It forms one component of a broader exploration program to inform the Interest Holder on the potential for commercial gas production in the Beetaloo Basin from the Velkerri shale. Cumulative estimated volumes of groundwater extraction and greenhouse gas (GHG) emissions from the regulated activity, previously approved civils and seismic activities and well drilling activities, have been included in the EMP.

The regulated activity has potential to impact on groundwater drawdown associated with groundwater extraction. The total estimated groundwater volume required for the proposed activities is 85.2 ML. Tanumbirini 2H and Inacumba 1H wells each require 32 ML while Tanumbirini 1 requires 7 ML for the hydraulic fracturing operation. Based on transmissivity analysis, the total water extraction requirement is well within sustainable recharge levels in the Gum Ridge aquifer. Standing water level of the Gum Ridge aquifer is continuously measured using a logger at both Tanumbirini and Inacumba well sites. At Inacumba, the Bukulara Sandstone water level is also continuously measured.

An extraction licence has been granted to the Interest Holder for 193.5 ML per year for 3 years from May 2019 to December 2023 (GRF10280). The total cumulative volume of groundwater to be extracted is within this volume. Groundwater extraction is informed by the NT Water Allocation Planning Framework, which indicates the volume of groundwater held in storage in the Gum Ridge aquifer is estimated to range from 1,766,000 GL to 3,532,000 GL. The Framework states the total extraction over the period of at least 100 years should not exceed the estimated sustainable yield (ESY) range of 1,412,800 – 2,825,600 GL. Cumulative groundwater extraction from the Gum Ridge aquifer over the period May 2019 to December 2023 is approximately 1,492.5 ML, significantly less than the estimated water available for extraction under the framework. The Interest Holder's licence allocation is less than 0.01% of the ESY of the Gum Ridge aquifer. Groundwater extraction volumes will be recorded and submitted to the DENR Water Resources Division, in accordance with the requirements of the groundwater extraction licence.

Ground water level monitoring at Tanumbirini and Inacumba well sites has indicated that ground water levels have remained static since monitoring commenced in December 2018. During this time, the civil construction works for both well sites have largely been completed and this represents over 30% of the cumulative estimated water requirements for the 2019 program. This suggests water drawdown from the total cumulative impact provided in the GRF10280 licence will likely be negligible at both well sites.

Standard GHG mitigation measures outlined in the Code such as combustion flaring will be implemented. Combustion flaring is expected to reduce the emissions by approximately 85% compared to venting. A Methane Emissions Monitoring Plan is contained in the EMP in compliance with the Code. As a further precautionary step, the NT EPA has provided advice relating to Ministerial Conditions for this EMP requiring the Interest Holder to undertake leak detection and reporting (LDAR) at well sites and this is contained at the end of this advice.

The Interest Holder has calculated the total GHG emissions generated for the duration of the activity (hydraulic fracturing, well completion and EPT) to be approximately 130,000 tCO2e (tonnes of carbon dioxide equivalent); assuming a conservative well testing period of 12 months. The NT EPA notes that the EPT which involves measuring hydrocarbon flow from the exploration well over an extended period is the major component (89%) of total cumulative emissions for the entire Santos 2019-20 exploration program. An EPT is only required to be conducted during the exploration phase of petroleum operations to characterise the reservoir. Fugitive emissions of methane from well completion in the Activity (excluding flare tip inefficiency) is estimated to be 0.5% of total estimated GHG emissions. Assumed flare tip efficiency in these GHG calculations has been back calculated using published values and is estimated to be approximately 97% which is reasonably conservative.

Total cumulative GHG emissions for the approved activities in the Santos 2019-20 exploration program on EP 161 are estimated to be 144,000 tCO_2-e, assuming a worst case EPT period of 12 months. The total estimated GHG emissions for the Santos 2019 exploration program will likely result in an overall increase in NT GHG emissions of 0.9%, noting that this is largely incurred as a result of the EPT and only required in the exploration phase. Under these circumstances of preliminary exploration activity, the NT EPA considers that cumulative emissions are not significant when considered in context of 2017 NT and Australian emissions, which were approximately 16.5 million tonnes and 535 million tonnes respectively[4]. Therefore the NT EPA considers that GHG offsets are not required for the proposed activity.

The EMP adequately assesses the environmental impacts and risks associated with the regulated activity and outlines appropriate avoidance and mitigation measures. This includes the assessment and management of social impacts and risks, including the appropriate management of cultural heritage. The Interest Holder has demonstrated ongoing stakeholder engagement in the EMP as required by the Regulations with landholders and land managers, traditional owners, the Northern Land Council (NLC) and NT Government Agencies.

The regulated activity will be subject to requirements of an Aboriginal Areas Protection Authority Certificate. There are no significant economic, environmental, equitable adverse effects from the regulated activity.

2.3 Precautionary principle

The NT EPA considers there is a low threat of serious or irreversible damage from the regulated activity.

The Interest Holder's investigations into the physical, biological and cultural environment provide a satisfactory scientific basis to assess potential environmental impacts and risks for the activity, and to identify measures to avoid or minimise those impacts and risks and address scientific uncertainty. The risks of hydraulic fracturing are generally well understood and there are internationally recognised standards and established best practice management measures for hydraulic fracturing operations in geological surveying, well design, operational engineering safeguards and well integrity monitoring to ensure aquifer protection; these are reflected in the mandatory requirements of the Code. The Hydraulic Fracturing EMP also presents commitments to the precautionary controls and monitoring that have been adopted in the Code, in this preliminary stage of exploration using hydraulic fracturing in the Beetaloo sub-basin.

The McArthur Basin 2D Seismic Exploration Survey – 2013 and the existing Tanumburini-1 well provide the basis for the Interest Holder's subsurface geohazards assessment. An additional seismic control line has also been acquired at Tanumbirini wellsite under the previously approved McArthur Basin Civil and Seismic Program EP161. Wells are located away from known geohazards. Given the lack of major faults and structures across the deeper areas of the Beetaloo Sub-basin there is a low geohazard risk associated with through-going faults, therefore a very low likelihood of contamination to shallow aquifers occurring via this mechanism[2].

Published reports, mainly from North America, show considerable variation in the concentration of constituents of geogenic origin of particular interest (metals, hydrocarbons, NORMs) in flowback wastewater from hydraulic fracturing operations in shale formations between and within sedimentary basins[5]. Radium which forms naturally from the decay of uranium and thorium, elements that commonly occur in sandstones and shales in sedimentary environments, has been documented in the formation waters in many sedimentary basins and is often positively correlated with chlorinity[6]. In surface and shallow subsurface environments, radium can be relatively soluble and, therefore, mobile in groundwater. As a radioactive element, radium may represent a potential health hazard if it exceeds threshold levels of exposure. Radioactive isotopes are commonly quantified in terms of "activity concentration" or simply "activity," which

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[4] NT and Australian GHG emissions in 2017 were approximately 16.5 million tonnes and 535 million tonnes, respectively, as reported in the DOEE (2019) *State and Territory Greenhouse Gas Inventories 2017*. http://www.environment.gov.au/system/files/resources/917a98ab-85cd-45e4-ae7a-bcd1b914cfb2/files/state-territory-inventories-2017.pdf

[5] Hayes, T. 2009. Sampling and Analysis of Water Streams Associated with the Development of Marcellus Shale Gas, Final Report, 31 December 2009.

[6] Stephen Fisher, R. 1998. Geologic and Geochemical Controls on Naturally Occurring Radioactive Materials (NORM) in Produced Water from Oil, Gas, and Geothermal Operations 5(3): 139-150

in this context refers to a number of disintegrations per unit time. Significant variation in radium levels has been reported in flowback wastewater from producing shale fields in North America[7].

At this stage the Interest Holder has not conducted hydraulic fracturing in the Beetaloo sub-basin and therefore has no laboratory analysis of hydraulic fracturing flowback wastewater in accordance with the Code. Reports on flowback wastewater from two previously hydraulically fractured wells in the Beetaloo sub-basin are available on the DENR website. As a further precautionary step in this preliminary stage, the NT EPA recommends the Interest Holder be required to store flowback wastewater in enclosed tanks in the wet season until the Interest Holder provides a risk assessment on flowback wastewater following hydraulic fracturing in compliance with the Code. Of particular interest are constituents of geogenic origin.

The NT EPA is of the view that the precautionary principle has been considered in assessing the regulated activity and has not been triggered due to the low threat of serious or irreversible damage existing and the presence of a satisfactory scientific basis to assess potential impacts and risks. In addition, the environmental and engineering monitoring commitments contained in the EMP are compliant with the Code and should provide measurable performance measures to ensure that the environmental objectives are met. As a further precautionary step, the NT EPA has provided advice relating to Ministerial Conditions for this EMP contained at the end of this advice.

2.4 Principle of inter-generational equity

The potential environmental impacts and risks associated with the regulated activity can be adequately avoided or managed through the management measures and monitoring programs proposed in the EMP. The NT EPA considers that environmental values will be protected in the short and long term and that the health, diversity and productivity of the environment will be maintained for the benefit of future generations.

The NT EPA notes that the EPT is a significant component (89%) of total cumulative emissions for the entire Santos 2019 exploration program. An EPT is only required to be conducted during exploration activities to characterise the reservoir. Fugitive emissions of methane from well completion in the Activity (excluding flare tip inefficiency) is estimated to be 0.5% of total estimated GHG emissions.

The Interest Holder’s licence allocation is less than 0.01% of the ESY of the Gum Ridge aquifer. Groundwater extraction volumes will be recorded and submitted to the DENR Water Resources Division, in accordance with the requirements of the groundwater extraction licence.

The regulated activity will be subject to requirements of an Aboriginal Areas Protection Authority Certificate. Appropriate measures are proposed for the management of items of heritage value should they be discovered.

2.5 Promotion of improved valuation, pricing and incentive mechanisms

The Interest Holder would be required to prevent, manage, mitigate and make good any contamination or pollution arising from the regulated activity, including contamination of soils, groundwater and surface waters through accidental spills.

All stages of the regulated activity, including progressive rehabilitation of all disturbed areas to an acceptable standard, would be at the cost of the Interest Holder. The Interest Holder will be required to provide an adequate environmental rehabilitation security bond to indemnify the NT government. This is based on an assessment by DENR and approval of the rehabilitation security costs associated with the proposed Activity in the EMP provided by the Interest Holder.

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[7] Rowan, E.L., Engle, M.A., Kirby, C.S., and Kraemer, T.F., 2011, Radium content of oil- and gas-field produced waters in the northern Appalachian Basin (USA)—Summary and discussion of data: U.S. Geological Survey Scientific Investigations Report 2011–5135, 31 p. (Available online at http://pubs.usgs.gov/sir/2011/5135/)

3. Relevant matters raised through public submissions

The regulated activity includes the hydraulic fracturing of three petroleum exploration wells, and in accordance with the Petroleum (Environment) Regulations 2016, the EMP was made available for public comment for a period of 28 days from 30 August to 27 September 2019. The Department Of Environment and Natural Resources (DENR) received 10 submissions, five from community members and five from non-government organisations. The majority of submissions were from within the Northern Territory.

A number of submissions were opposed to onshore gas development and raised similar issues to those considered during the Scientific Inquiry into Hydraulic Fracturing of Onshore Unconventional Reservoirs in the Northern Territory (HFI) and subsequently being addressed through NT government implementation of the 135 HFI recommendations. However there were also specific key technical concerns raised in the submissions. This NT EPA Advice draws on the EMP, the findings of the HFI and other relevant published technical references and information to response to issues raised in submissions. The sources of this referenced information are cited where appropriate in this Advice.

Public submissions covered a range of social, environmental and regulatory issues (Table 1). Many of the issues raised in the public submissions are dealt with in other sections of this advice. Cross reference to the relevant sections is provided in Table 1 to avoid repetition. Where a matter has not been discussed elsewhere in this advice, it is considered below.

Table 1: Issues raised in public submissions

Theme	Issue	Response Reference
Regulation and compliance	• HFI Implementation strategy not complete	Sec. 3.0
	• lack of assessment of cumulative impacts in accordance with HFI recommendation 14.21	Sec. 2.2., 2.4
	• lack of security during initial exploration	Sec. 2.5
Social	• adequacy of stakeholder engagement with neighboring and downstream landholders, potentially affected business operators, affected Aboriginal communities	Sec. 3.8
	• lack of social license in the NT for onshore shale oil and gas fracking	Sec. 3.8
	• worker health during times of high seasonal temperatures	
	• impacts to public and tourism from increased traffic	Sec 1.7
Chemicals	• toxicity and harmfulness of chemicals	Sec. 3.2, 3.3, 3.4
	• adequacy of the chemical risk assessment to protect the community	Sec. 3.2, 3.3, 3.4, 3.5
	• naturally occurring radionuclide material (NORM)	Sec. 2.3
	• synergistic effects of hydraulic fracturing fluid chemical mixtures	Sec 3.4
Water	**Surface water**	
	• potential impacts to downstream areas from spills and/or loss of containment, particularly during the wet season	Sec 3.5
	Groundwater	
	• scarcity of the groundwater resource and impacts of the industry groundwater use on the resource	Sec. 2.4
	• lack of information on monitoring of fracture distances and potential groundwater contamination from hydraulic fracturing fluids	Sec. 1.6, 3.1, 3.2, 3.3, 3.6 Sec. 3.1, 3.6
	• implications of low estimated flowback water volumes of hydraulic fracturing fluids	Sec 3.1, 3.2

Theme	Issue	Response Reference
	Hydrogeology • inadequate understanding of the hydrogeology of the NT • potential for hydraulic fracturing fluids to contaminate aquifers via faults and fractures • potential for upward migration of brines over long term	Sec 1.6, 2.2, 3.6 Sec. 1.2, 1.3, 1.6, 3.6, 3.7
Flora and fauna environment	**Animal welfare** • fauna entrapment in sumps/tanks or ingestion of contaminated water/materials collected during drilling and hydraulic fracturing • deleterious impacts of land and/or water contamination on fauna in general, and threatened species • spread of feral pests (e.g. cane toads due to accessibility to wastewater tanks) **Baseline studies** • lack of comprehensive environmental baseline studies to demonstrate the level of impact that may be incurred by development of the onshore gas industry, including consideration of impacts to groundwater dependent ecosystems	Sec. 2.1, 2.3, 3.2 Sec. 2.1, 2.3, 4.1, 4.3 Sec. 2.1, 3.5 Sec. 1.1, 1.2, 1.3, 1.6, 2.1, 2.2
Climate change	• development of an industry that will result in increased GHG emissions and contribute to Australia's impact on climate change • the EMP does not propose offsets emission offsets as per HFI recommendation 9.8 • hydraulic fracturing may lead to undetected methane leaks occurring	Sec. 2.2 Sec. 2.2 Sec. 2.2
Human health	• lack of demonstrated experience regarding the regulatory framework to protect human health from of impact of activity • risk the chemicals used pose when human exposure pathway occurs	Sec. 3.1, 3.2, 3.3, 3.4 Sec. 3.1, 3.2, 3.3, 3.4
Other	• Public submission timeframe being insufficient	N/A

3.1 Subsurface geohazards

Seismic control and well control information that supports the identification of sub-surface geohazards at each of the well sites has been previously discussed in section 1.6.

To reduce the risk of hydraulic fractures reaching the base of existing aquifers to an acceptable level, the Code adopts an internationally accepted minimum offset distance between the target hydrocarbon formation and the base of the nearest aquifer of 600 m. This internationally accepted minimum offset, or protection distance, is based on extensive published research on how high hydraulic fractures can plausibly extend in shale formations[8].

The Bukulara Sandstone, which is stratigraphically deeper than the CLA, is recognised as an aquifer on a regional basis. At the Inacumba well site, the base of the Bukulara Sandstone is approximately 1,850 m from the target Velkerri shale and at the Tanumbirini well site, the Bukulara Sandstone is approximately 2,800 m from the target. Therefore, at both well sites the

8 Fisher, K, and N Warpinksi. (2012), 'Hydraulic-Fracture-Height Growth: Real Data.' SPE Production & Operations 27 (1): 8-19.

base of the Bukulara Sandstone and top of the target Velkerri shale interval have a minimum offset distance that greatly exceeds the minimum offset of 600 m required under the Code.

The Interest Holder has committed to establishing baseline passive seismic monitoring to address uncertainties regarding seismicity (earth tremors) in the Beetaloo sub-basin prior to conducting hydraulic fracturing. The passive seismic surface array will also provide real-time information regarding unlikely anomalous seismicity, above background baseline values, during hydraulic fracturing operations in compliance with the precautionary traffic-light system for induced seismicity required by the Code. Operations will cease if specified exceedance values in seismicity occur, established from baseline monitoring.

3.2 Hydraulic fracturing chemicals

A tiered chemical risk assessment was conducted on the hydraulic fracturing chemicals using a screening of the potential human health and ecological hazards that should be considered for potential exposure to the hydraulic fracturing fluids during transportation, hydraulic fracturing activities (including storage), and subsequent treatment and disposal of flowback water. The assessment includes the following steps:

- Tier 1 - Identify chemicals of low human health and ecological concern that do not require additional chemical risk assessment in the tier assessment process.
- Tier 2 – Chemicals that are not identified as a low human health and ecological concern, and therefore require additional risk assessment to characterise potential risks. This is done using a quantitative evaluation of the risks based on the potential complete exposure pathways and Tier 1 assessment.

All of the hydraulic fracturing chemicals proposed were classed as Tier 1 – low human health and ecological concern except for five chemicals, which were subsequently assessed under a Tier 2 risk assessment, which are listed in Table 2.

Four chemicals that were identified in the Tier 1 assessment with a high ecotoxicity hazard assessment were carried through to a Tier 2 assessment. These chemicals (#1-4) are listed in Table 2. One chemical (#5) was assessed under human health concerns. As an example, chlorine (#6) is also listed for comparative purposes in relation to toxicity. The four chemicals (#1-4) were considered in the Tier 2 assessment in relation to potential impact to avian wildlife based on the potential ingestion by birds of flowback water containing the selected chemicals, stored in wastewater tanks at the tank pad for over one year. Potential dietary intake of water containing these chemicals was compared to toxicity reference values developed specifically for avian wildlife to estimate a hazard quotient; a potential hazard quotient level less than one indicates there are *no unacceptable exposures* to the avian species. The hazard quotient for all the assessed avian species was orders of magnitude less than the threshold hazard quotient level of one. The reason for this is that the concentrations of these chemicals is extremely low in the fluid system as can be seen in the disclosure provided in the Chemical Risk Assessment in Appendix A. Based on the outcomes of this risk assessment for birds to hydraulic fracturing chemicals contained in flowback water, no further management controls were considered necessary to manage this aspect of risk to birds. Moreover, it is likely that the wastewater will have a salinity that is more than 3 times that of seawater as evidenced in the flowback water data analysis published[9] by DENR for two previously hydraulically fractured wells in the Beetaloo basin Shenandoah-1 an Amungee NW-1. Under these circumstances the wastewater is unlikely to be palatable to birds.

A Tier 2 assessment for Hydrotreated light petroleum distillate, due to the potential for inhalation exposures to workers during hydraulic fracturing activities, found the chemical is considered of low health concern for workers given the very low concentration in the fluid system. By way of comparison, chlorine (also listed in Table 2) which is a common chemical used in drinking water

[9] https://denr.nt.gov.au/onshore-gas/onshore-gas-in-the-northern-territory/industry-compliance-and-reporting/groundwater-monitoring-results.

treatment plants, swimming pools and household cleaning products has a higher toxicity in laboratory tests for terrestrial fauna than all five chemicals in the Tier 2 risk assessment as shown in Table 2. This is important to note because it demonstrates that none of the chemicals are particularly toxic in their concentrated form. In this example *the dose makes the poison* and this important principle applies in hydraulic fracturing fluid chemistry as much as it does in swimming pools and in all chemicals that interact with the environment and community.

Table 2: Tier 2 risk assessment hydraulic fracturing chemicals

#	Tier 2 Chemicals	CAS number	Purpose	Concentration	Toxicity (Rat)
1	Amine oxides, cocoalkyldimethyl	61788-90-7	Corrosion inhibitor	0.63 mg/L	800 mg/kg
2	Sodium chlorite	7758-19-2	Breaker	0.12 mg/L	280 mg/kg
3	Glutaraldehyde	111-30-8	Biocide	0.008 mg/L	77 mg/kg
4	Tributyl tetradecyl phosphonium chloride (TTPC)	81741-28-8	Biocide	0.3 mg/L	611 mg/kg
5	Hydrotreated light petroleum distillate	64742-47-8	Friction Reducer	6.52 mg/L	>5000 mg/kg
6	Chlorine	7782-50-5	Example	Example	56 mg/kg

3.3 Biocides

The purpose of biocides in hydraulic fracturing fluid is to ensure that bacteria are not introduced into the hydrocarbon reservoir. Biocides are also used in drilling muds for the same reason. The key biocides in the HF fluid system, Tributyl tetradecyl phosphonium chloride (TTPC) (CAS number 81741-28-8) and Glutaraldehyde (CAS number 111-30-8) are used at concentrations of 0.3mg/L and 0.008 mg/L respectively. This is equivalent to 0.75L and 0.02L respectively in an Olympic swimming pool of water; a volume equal to approximately two hydraulic fracture stages. At these low concentrations in the "whole fluid' system the biocidal effects are directed to aquatic organisms (e.g. bacteria) but will not affect terrestrial organisms through consumption.

TTPC is particularly efficacious, potent and targeted in its longer lasting biocidal effects on microbial biofilm forming microorganisms at low concentrations and is therefore also commonly used in other applications where this is desirable, such as building air conditioning plants to control potentially fatal *Legionella* outbreaks. The chemical risk assessment noted that TTPC is stable over a wide pH range and is not susceptible to photo-degradation. TTPC is biodegradable, but not readily biodegradable[10]. It will strongly adsorb to soil and sediment. TTPC is not expected to bioaccumulate. The overall conclusion was that TTPC is not a Persistent, Bioaccumulative and Toxic (PBT). That said, the TTPC chemical risk assessment confirms that flowback water must be stored and managed appropriately while degradation of the biocide occurs but that the biocide does not present a serious and irreversible risk to the environment.

The flowback water, contains the dissociation or breakdown products of the injected hydraulic fracturing fluid plus naturally occurring geogenic compounds i.e. hydrocarbons, minerals and other substances that are dissolved in the process from the shale reservoir. These geogenic

[10] A die-away [simulation] test was conducted with radiolabelled TTPC for 168 hours at the expected HF fluid concentration of 0.31 mg/L. The first-order rate constant was 0.69/hour and the half-life was 6.6 hours. After 24 and 168 hours, degradation was >81% and >98%, respectively (Buru Energy)

compounds must also be considered for potential health or environmental impact in the management of flowback water. While the vast bulk of these compounds are actually chloride brines such as salt (NaCl) other compounds such as heavy metals and radionuclides are sometimes present. Based on shale industry experience in the US, the concentration of chemical constituents in the flow back has been observed to be 50 percent or less of the injected fluid chemical concentration. In the early stages of flowback some of the water (~30%) that was pumped into the reservoir is expected to be returned to surface together with dissolved brine from the host shale rock. After several weeks the production of flowback water will have exponentially declined to less than 1% of 1st week of flowback. At the same time there is usually a marked increase in salinity with time, interpreted to represent a decreasing proportion of the lower salinity injected fluid and an increasing proportion of the saline formation water returning to the surface.

3.4 Potential synergistic effects of hydraulic fracture chemical mixtures in risk assessment

Cocktail effects and synergistic interactions of chemicals in mixtures are an area of concern to both the public and regulatory authorities. The main concern is whether some chemicals can enhance the effect of other chemicals, so that they jointly exert a larger effect than predicted. This phenomenon is called synergy. The three main groups of toxicants that have received considerable attention are pesticides, metals and antifoulants[11]. The reason that these three main groups have received attention is because of their Persistent, Bio-accumulative and Toxic (PBT) nature in the environment. All three groups have orders of magnitude (100's to 1000's) greater toxicity and persistence and potential to bio-accumulate in the environment than the chemicals used in hydraulic fracturing.

For synergistic interactions to take place in the environment, interacting chemicals have to both co-occur and be present at levels high enough to induce the synergy. It is, however, likely that a threshold for synergistic interactions exists for most synergists, and that only a few proven synergists will act as synergists at any endpoint when diluted down to realistic environmental levels.

Considering the generally high chemical concentrations needed to induce synergistic interactions, their importance as synergists within naturally occurring exposure scenarios is most likely of a relatively small importance compared to the additive effect of many co-occurring pollutants. Even if one compound enhances the effect of another compound four-fold, it only takes another three compounds of a similar strength to arrive at the same joint toxicity. And considering the complex pollution patterns monitored, the additive effect of the many co-occurring pollutants might likely project a larger hazard than those of the presence of a few synergists. Hence, in a regulatory perspective addressing the cumulative effect of co-occurring chemicals is the first and most important step in providing a more realistic hazard[12.] Given that the hydraulic fracturing fluid is pumped down and returns from inside a petroleum well (with multiple verified mechanical barriers that isolate the fluid from aquifers and other non-target formations) into an impermeable shale formation more than 2 km below the surface, places the focus on the risks associated with the management of wastewater at the surface to ensure it remains isolated from the environment. These risks are addressed in the Code, and the EMP has outlined how it will comply with the wastewater management requirements of the Code.

3.5 Wastewater management

Wastewater recovered from each well during the flowback phase is stored in above ground storage tanks which are double lined, located in a purpose designed bunded containment tank pad area with leak detection and water control structures. A total of 15.3 ML can be contained within the bunded tank pad area which exceeds the maximum enclosed storage capacity of 10.5

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[11] Cedergreen N (2014) Quantifying Synergy: A Systematic Review of Mixture Toxicity Studies within Environmental Toxicology. PLoS ONE 9(5): e96580. doi:10.1371/journal.pone.0096580

[12] Cedergreen N (2014) Quantifying Synergy: A Systematic Review of Mixture Toxicity Studies within Environmental Toxicology. PLoS ONE 9(5): e96580. doi:10.1371/journal.pone.0096580

ML. Tank levels are continuously monitored to ensure minimum freeboard is maintained. As a precautionary measure all wastewater must be stored under enclosed tanks in the event of significant rainfall. Additional open tanks on the tank pad will be used to reduce the volume of wastewater by evaporation. In compliance with the Code these open tanks must be operated with a sufficient freeboard to not overflow with an annual exceedance probability (AEP)[13] for a total 90-day rainfall event[14] that might be expected to occur once in a thousand years. This is a statistically derived probability from rainfall records and in the Beetaloo sub-basin region is equal to 1,448 mm. This is more than twice the average total annual rainfall (684 mm) for the Beetaloo and almost equal to the highest 12-month rainfall total reported in the 130-year rainfall record used in the analysis for the region. Wastewater can be transferred from evaporation tank area to enclosed tank area and vice versa within 8 hours as required by the Code. As a further precautionary step, the NT EPA has provided advice relating to provision to DENR of an updated look-ahead weather forecast for risk of early onset of wet weather for the duration of the regulated activity during the wet season.

The Spill Management Plan describes a spill scenario modelling using a worst-case- scenario-analysis for a site spill volume (15.3 ML), which exceeds the maximum carry capacity of the waste water tank arrangement (10.8 ML), to predict the extent of the spill. The modelling indicated such a release would be contained within the bunded tank pad. Moreover, the modelling, using real infiltration data from natural (non-compacted) soil cores taken from each of the well sites, predicted it would take 130 days (with a constant 3m head) to move through the first 1 metre of the well site soil horizon and approximately 22 years to reach the water table.

As a further precautionary step, the NT EPA has provided advice relating to Ministerial Conditions for this EMP relating to reporting and clean-up requirements of impacted soil in the event of accidental release (spill or leak) of flowback water and this is contained at the end of this advice.

3.6 Potential for upward migration of brine to surface aquifers

The NT EPA notes that issues of well integrity in relation to the Interest Holder's exploration program on EP161 have been dealt with in the NT EPA Statement of Reason and NT EPA Advice to the Minister for the McArthur Basin 2019 Drilling Program EP161 Environment Management Plan which was advertised for public comment and subsequently approved in July 2019.

An additional issue was raised in the public submissions in relation to the potential impact to the integrity of wells over the long term in high salinity formations that overlay the Velkerri shale in the Beetaloo basin. Increasing salinity with depth is a general feature of all sedimentary basins including the Beetaloo. In conventional petroleum reservoirs a salt "top seal" is a common feature of the stratigraphic trap that causes hydrocarbons to accumulate. This risk is therefore not unique to unconventional (e.g. shale) petroleum exploration and production. The concern raised is that over time, a failure in well integrity due to corrosion by salt may lead to upward migration of deeper saline water and other constituents into the shallower Gum Ridge aquifer, for example. The Moroak Sandstone and also the shallower Bukalorkmi Sandstone which will be intersected by the Tanumbirini and Inacumba petroleum wells are considered to be saline aquifers for the purposes of the petroleum well design in the Well Operations Management Plan (WOMP). For example a sample taken in the Moroak Sandstone during the drilling of Tanumbirini 1 in 2014 established a salinity of ~200,000 ppm which is approximately five times the salinity of seawater. Moreover, there was no indication of over-pressure reported in the Tanumbirini 1 well in this formation that could provide a potential hydraulic upward head gradient

The necessary ingredient for upward flow is an upward head gradient. In order for upward flow to occur, the head gradient must be large enough to overcome density gradients associated with increasing salinity with depth. These upward head gradients would need to be sustained over thick sequences (typically >1000 m) of highly permeable bedrock to drive a significant amount

[13] The probability that a given rainfall total accumulated over a given duration will be exceeded in any one year.
[14] The shorthand for this is 0.1% 90-day AEP

of brine into shallow fresh groundwater. These two conditions are mutually exclusive, suggesting that high upward fluxes of brine are not physically plausible for the following reasons:

- Although overpressure is common in the deeper parts of many hydrocarbon-bearing basins, there are mechanisms that can result in under-pressure, that is, pressures below hydrostatic that would induce downward rather than upward flow. One of these mechanisms is the extraction of hydrocarbons and resulting depressurization of the hydrocarbon-bearing formation. Under these conditions the formation-fluid differential between exterior formations and depressured low-gas-content petroleum well environments favours fluid flow into the well instead of out of the well because downhole pressure in an oil or gas well is reduced as oil or gas is removed[15.]
- A lower limit is needed to overcome density stratification, due to the tendency for dense brine to form a stable fluid layer at depth, with less dense fresh water floating on top.

The effective hydraulic isolation of these formations is demonstrated by the fact that fluids have been trapped at depth for tens to hundreds of millions of years. The target zones for hydraulic fracturing consist of clay rich, organically lean layers which act as impermeable aquitards to fluid migration, as illustrated by the organic-enriched layers still containing gas hundreds of millions of years after it was generated. They also provide effective barriers to vertical fracture growth during hydraulic fracturing operations. The overlying Hayfield Mudstone and Kyalla formation are notable thick aquitards[16] in this region. As a result, upward migration of hydraulic fracturing fluid and brine is controlled by pre-existing hydraulic gradients and bedrock permeability.

Recent international studies show that in cases where there is an upward gradient, permeability is low, upward flow rates are low, and mean travel times are long (often > 1 million years).[17] The studies concluded that unrealistically high estimates of upward flow are the result of invalid assumptions about hydraulic fracturing and the hydrogeology of sedimentary basins and the mechanism does not appear to be physically plausible.

3.7 Potential for contamination of surface aquifers via faults during hydraulic fracturing

An issue was raised regarding the potential for contamination of surface aquifers via faults during hydraulic fracturing The McArthur Basin 2D Seismic Exploration Survey – 2013 provides the basis for the Interest Holder's subsurface geohazards assessment. An additional seismic control line will also be surveyed for Tanumbirini 2H prior to hydraulic fracture of that well in accordance with the approved McArthur Basin Civil and Seismic Program EP161 – June 2019. Wells are located away from known geohazards identified through seismic surveys, offset wells and other geological information. Faults are mapped by field geologists. Identification at depth requires geophysical methods, of which imaging by the seismic reflection method is by far the best. Two-dimensional seismic profiles can image faults with a throw of about 30 m or more. So the 'resolution' - the finest detail that can be seen - is at least 30 m in length[18]. The 3D seismic technique improves the resolution to the order of 4-5 m. Given the lack of major faults and

[15] King, G. E., & King, D. E. 2013. Environmental Risk Arising From Well Construction Failure: Differences between Barrier Failure and Well Failure, and Estimates of Failure Frequency Across Common Well Types, Locations and Well Age. Society of Petroleum Engineers. doi:10.2118/166142-MS.

[16] Permeability is the ability of a rock to transmit fluids. Aquitards are low permeability rock formations. The grain-size distribution is the dominant control on permeability; however, other factors are also important at depth, including effective stress, partial saturation, and cementation, often reducing permeability by orders of magnitude. Overall, the preponderance of fine-grained rocks (i.e., shale, siltstone, and mudstone) and the layered structure of sedimentary basins will constrain the vertical permeability of bedrock above black shales toward the low end of measured values. Low permeability layers at depth in sedimentary basins are common, due to the effects of effective stress, cementation, and partial saturation.

[17] Flewelling, S, and Sharma, M. 2014. *Constraints on upward migration of hydraulic fracturing fluid and brine*. Groundwater: 52(4):492-4.

[18] Rutqvist R, Rinaldi A, Cappa F, Moridis G (2013). Modeling of Fault Reactivation and Induced Seismicity During Hydraulic Fracturing of Shale-Gas Reservoir. Journal of Petroleum and Science Engineering. Accessed at: http://www2.epa.gov/sites/production/files/2013-12/documents/faultreactivation.pdf

structures across the deeper areas of the Beetaloo Sub-basin[19] there is a low geohazard risk associated with through-going faults[20], therefore a very low likelihood of contamination to shallow aquifers occurring via this mechanism.

A recent assessment on the risk of fault reactivation during hydraulic fracturing of shale gas reservoirs from the US Department of Energy Berkley Science Laboratory[18] considered that:

- Faults in gas-bearing shales are likely to have low permeability, as otherwise the gas would have escaped over geological time
- If faults were permeable, they would be active and critically stressed and in such a case, only a seismic slip might occur and, because of ductile slip, the permeability would not change considerably.

The Berkley scientists concluded that the possibility of hydraulically induced fractures at great depth (thousands of meters) causing activation of faults and creation of a new flow path that can reach shallow groundwater resources (or even the surface) is remote[18] . A similar conclusion was reached by the US EPA which found that fault reactivation due to hydraulic fracturing would likely occur on small distances of a few meters[21].

However, small inactive faults (average 6 m of throw with a maximum ~15 m of throw) with limited vertical extent will occur in the Velkerri shale, and these are unlikely to show up on seismic surveys. These faults are typically located during drilling. The spacing and intervals selected for the hydraulic fracturing stages are based on modelled reservoir properties and the locations of interpreted small faults from drilling logs, with a suitable standoff (~20m) for perforation from the identified faults in the final hydraulic fracturing design contained in the WOMP.

3.8 Stakeholder engagement

The EMP provides detail on the stakeholder engagement process undertaken. The Interest Holder stakeholder identification was conducted prior to commencing drilling works at Tanumbirini 1 in 2014. The relevant stakeholder groups were identified and informed of the proposed activities and the associated risks and to help build an understanding of petroleum exploration in the Beetaloo. This included face-to-face briefing sessions with key stakeholders one-on-one and at local community events. Key relevant stakeholder groups include community, landholders, traditional owners and aboriginal peoples, and the Northern Territory Government. A list of the relevant stakeholders identified is provided in Appendix I of the EMP. Appendix I details the information that has been provided to these key stakeholders, including the type of information and date of engagement. Landholders have been directly involved in an on-ground inspection of proposed infrastructure locations. The EMP provides detail on the management process for complaint resolution and commits to ongoing stakeholder engagement throughout 2019 and 2020. Concerns were raised in some public submissions regarding perceived lack of stakeholder engagement. These have been further addressed in the revised EMP by the Interest Holder.

The NT EPA notes that stakeholder engagement is a matter for the Minister to consider in deciding whether to approve the EMP.

3.9 Regulation and compliance

Following the *Final Report of the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory, 2018* (the Report) the Minister for Environment and Natural Resources is responsible

[19]The likelihood of more critical faults may be higher at the margins of the basin

[20] Scrimgeour I. (2016) *Summary of current knowledge of petroleum geology, shale gas resources and exploration in the Beetaloo Sub-basin*. Information Provided by the Northern Territory Geological Survey to the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory.

[21] US EPA. 2012. Study of the potential impacts of hydraulic fracturing on drinking water resources: Progress report, Report, United States Environmental Protection Agency, Washington, D. C. Available at: http://www2.epa.gov/sites/production/files/documents/hfprogress-report-exec summary20121214.pdf

for environmental regulation the NT onshore petroleum industry. DENR supports the Minister in this responsibility by:

- liaising with industry prior to lodging applications for approval of an EMP authorisation
- assessing the environmental impacts of a proposal as provided through the EMP
- advising on the environmental standards and conditions to be included on an environmental approval
- monitoring and auditing compliance with EMPs
- administering and regulating environmental offences
- ensuring that all relevant industry monitoring and reporting requirements are published on the DENR webpage in the interest of transparency and accountability to the Community.

Amendments were made to the *Water Act 1992* so that petroleum activities require water extraction licences under the Act, to safeguard water and the environment. All bores used for the regulated activities must be metered and reported. Other regulatory reforms are ongoing. The Code has been finalised and is available on the DENR website. Experts, industry and the community have been engaged developing the Code.

The Well Operations Management Plan (WOMP) is a specialised engineering management plan that has been prepared and submitted for approval by well engineers of the Department of Primary Industry and Resources (DPIR). Key elements of the WOMP to ensure ongoing environmental protection of aquifers during and following hydraulic fracturing operations are included in the EMP risk mitigation and monitoring measures.

The NT EPA's assessment of this EMP, its potential impacts (positive and negative) and the management measures used to enhance positive and reduce negative impacts has considered the ESD principles. Exploration activities are necessary to enable commercial appraisal of resources. In the absence of reliable data regarding the shale resource, exploration will take a number of years to complete, in order to assess the viability of the resource prior to production. Ongoing design, development and implementation of management and monitoring programs by the Interest Holder, should all aim to meet the objectives of ESD.

4. Environmental impacts and risks reduced to a level that is as low as reasonably practicable (ALARP) and acceptable (regulation 9(1)(c))

The Interest Holder has undertaken a process to avoid impacts on environmental values, informed by appropriate baseline studies and surveys and timing of the regulated activity. The timing of works will be managed to ensure the risks arising from inclement wet weather and severe bushfire periods, including compliance with the Code, as a mechanism of demonstrating achievement of ALARP. The fire management plan included in the EMP provides adequate mitigation and management measures to reduce risk of bushfires occurring as a result of the Activity. These measures are ongoing in relation to the EPT which may continue for up to one year. An Emergency Response Plan will be implemented, which includes significant rainfall event response and fire management plan and mitigation measures. Evacuation and site readiness protocols are incorporated in standard operating procedures, including the evacuation of non-essential personnel. In the event of anomalous conditions (e.g. force majeure), the petroleum well can be immediately shut-in and safely secured; and flow back and EPT halted for as long as required.

The EMP demonstrates a systematic identification and assessment of environmental impacts and risks associated with the regulated activity. The key potential environmental impacts and risks are:

- surface and groundwater quality - a reduction in surface and groundwater quality due to chemical spills or waste water releases during hydraulic fracturing and well testing activities
- groundwater quality - a reduction in groundwater quality may occur as a result of failure in well integrity during hydraulic fracturing activities
- groundwater quantity – a reduction in groundwater quantity due to groundwater extraction associated with the activities

- terrestrial environmental quality – localised contamination of soil due to release of waste water.

Mitigation measures for the management of wastewater are discussed under Section 3 above. The EMP demonstrates compliance with the Code and the potential impacts and risks to surface water quality from flowback water have been reduced to a level that is ALARP and acceptable.

4.1 Well integrity

The risks of well integrity failure in hydraulic fracturing operations are well understood and the Interest Holder has extensive experience in hydraulic fracturing in other jurisdictions. All known controls measures for ensuring well integrity and aquifer isolation during hydraulic fracturing have been adopted. As an additional and precautionary measure during this early stage of exploration in the Beetaloo sub-basin, the Interest Holder will also implement passive seismic monitoring to provide real-time information regarding unlikely anomalous seismicity, above background baseline values, during hydraulic fracturing operations in compliance with traffic-light system for induced seismicity required by the Code. Operations will cease if specified exceedance values established from baseline monitoring occur. The Interest Holder has identified and addressed the potential impacts and risks to other groundwater users.

The aquifers intersected by the Tanumbirini and Inacumba petroleum wells are of high environmental value. As such, there should be 'no change' to existing baseline groundwater quality, i.e. no change in the natural range of values as a result of the regulated activity. The NT EPA has provided advice that the Interest Holder demonstrates 'no change' to existing groundwater quality at the Tanumbirini and Inacumba petroleum well sites.

Compliance with the ongoing groundwater monitoring at the well site, undertaken in accordance with the Code and Guideline, must be submitted to the DENR every quarter for three years from the approval date of the EMP. The information provides important scientific information regarding spatial and temporal trends in forty (40) key water quality analytes, including metals, hydrocarbons and naturally occurring radionuclide materials (NORM) in the Cambrian Limestone aquifer system, and also the Bukalara Sandstone at Inacumba, for these wellsite locations. This is published on the DENR website. Impact monitoring bores situated 20 m downgradient (downstream) of the petroleum wells will enable rapid detection of any anomalous water quality trends above established background values at the well sites. Water level monitoring data trends at both sites, as previously discussed, has been static. Any anomalous drawdown in water levels will also be detected.

The results of the groundwater monitoring will be published on the DENR website on a quarterly basis. The groundwater monitoring program includes ongoing groundwater level reporting at the well site.

4.2 Terrestrial environmental quality

The potential impacts and risks of contamination of soil, through inappropriate storage and handling of chemicals and wastewater has been identified by the Interest Holder. The EMP includes commitments that include bunded and spill containment of chemicals and wastewater and the implementation of the Wastewater Management Plan and Spill Management Plan, in accordance with the Code. The Interest Holder has not deviated from known industry codes and standards. The EMP documents how the Interest Holder will comply with the relevant mandatory requirements of the Code as a minimum best practice standard.

4.3 Terrestrial fauna

The Interest Holder has identified and addressed the potential impacts and risks to fauna with wastewater tanks. The Interest Holder has committed to implementing a routine monitoring program to log fauna interactions with wastewater tanks (including the area surrounding the lease pad). Where fauna interactions are identified (i.e. bird or fauna mortalities >5 individuals), additional controls such as netting or the use of other bird deterrents will be implemented.

The NT EPA considers that all reasonably practicable measures will be used to control the environmental impacts and risks, considering the level of consequence and the resources needed to mitigate them. The NT EPA considers that the environmental impacts and risks will be reduced to an acceptable level, considering the principles of ecologically sustainable development as discussed above, the sensitivity of the local environment, relevant standards and compliance with the Code.

5. Other relevant matters

Regulation 9 requires that an EMP provides a comprehensive description of the regulated activity, including provision of a detailed timetable for the activity. To meet this requirement, the NT EPA recommends that the Interest Holder be required to submit a detailed timetable for the regulated activity to DENR prior to approval of the EMP. The timetable should address all aspects of the activity and include, but not be limited to dates for the implementation of commitments and associated hold points. This should also include monitoring of weather conditions related to potential onset of the wet season and consequent demobilisation of the rig and ancillary infrastructure and stabilisation of the well sites. The NT EPA recommends that the timetable be updated each month or as seasonal weather forecasts emerge.

CONCLUSION

The NT EPA has reviewed the public submissions as part of its decision-making and when making recommendations to the Minister. This NT EPA advice to the Minister for Environment and Natural Resources considers and provides a response to any relevant matters raised in public submissions.

The NT EPA considers that, subject to the recommended EMP approval conditions, the EMP:

- is appropriate for the nature and scale of the regulated activity
- demonstrates that the regulated activity can be carried out in a manner that potential environmental impacts and environmental risks of the activity will be reduced to a level that is as low as reasonably practicable and acceptable.

In providing this advice the NT EPA has considered the principles of ecologically sustainable development. The NT EPA has also taken into consideration that prior to commencing well activities (including drilling), a WOMP will be prepared and approved by the DPIR.

RECOMMENDATION

The NT EPA recommends that should the EMP for Santos QNT Pty Ltd be approved, the following conditions be considered:

***Condition 1*:** The Interest Holder must submit to the DENR, an updated timetable for the regulated activity prior to the commencement of the activity and provide an updated timetable to the DENR each month. The timetable must include dates for the implementation of commitments, development of key documents and associated hold points.

Condition 2: The Interest Holder must provide to DENR:

i. results of ongoing groundwater monitoring in accordance with the Code of Practice: Onshore Petroleum Activities in the Northern Territory and the Preliminary Guideline: Groundwater Monitoring Bores for Exploration Petroleum Wells in the Beetaloo Sub-basin every quarter for three years from the approval date of the EMP for publishing on the DENR website, to inform the development of site-specific performance standards for groundwater quality
ii. notification of any results in the inter-quartile range of monitored parameters in groundwater above the natural distribution of values that occur at Inacumba and Tanumbirini well site within five days of discovery

Condition 3: The Interest Holder must provide to DENR, within 60 days of flowback commencing, a report on the risk assessment of flowback wastewater from the hydraulic fracturing phase prepared by a suitably qualified person[22] in accordance with the monitoring wastewater chemistry analytes specified in Section C.3 of the Code of Practice: Onshore Petroleum Activities in the Northern Territory

Condition 4: The Interest Holder must hold flowback wastewater from hydraulic fracturing in enclosed tanks during the wet season, as defined by the Code of Practice: Onshore Petroleum Activities in the Northern Territory, until otherwise advised in writing by DENR.

Condition 5: The Interest Holder undertake within seven days of commissioning and then every 6 months thereafter leak detection and reporting (LDAR) to DENR.

Condition 6: In the event of any accidental release (overflow, failure, spill or leak), to ground of flowback wastewater that exceeds 200 litres, the Interest Holder must provide a written report to DENR within 24 hours after the incident was detected. The report must include:

I. details of the incident specifying material facts, actions taken to avoid or mitigate environmental harm
II. the corrective actions taken including the volume and depth of impacted soil removed for appropriate disposal if required
III. any corrective actions proposed to be taken to prevent recurrence of an incident of a similar nature.

Condition 7: The Interest Holder must provide to DENR a soil contamination assessment report of the tank pad and well pad area that includes a comparison to the baseline soil assessment undertaken at the well sites. The report must be:

I. submitted to DENR within six months of removal of flowback water from the wellsite(s); and
II. prepared by a suitably qualified person.

Condition 8**:** The Interest Holder must provide to DENR daily on-site reports and five-day activity forecast for the duration of the regulated activity.

Condition 9**:** The Interest Holder must provide to DENR a fortnightly updated weather forecast for risk of onset of wet weather and high bushfire danger for the duration of the regulated activity.

Condition 10**:** The Interest Holder must provide to DENR a progressive site rehabilitation program in the monthly timetable schedule that reports on outcomes at each stage of rehabilitation of disturbance areas, including gravel pits and seismic lines, as a result of this activity.

DR PAUL VOGEL AM MAICD

CHAIRMAN

NORTHERN TERRITORY ENVIRONMENT PROTECTION AUTHORITY

15 OCTOBER 2019

[22] Defined in the Code as: person who has professional qualifications, training or skills or experience relevant to the nominated subject matters or tasks and can give authoritative assessment, advice and analysis about performance relevant to the subject matters using relevant protocols, standards, methods or literature or conduct tasks in accordance with requirements.