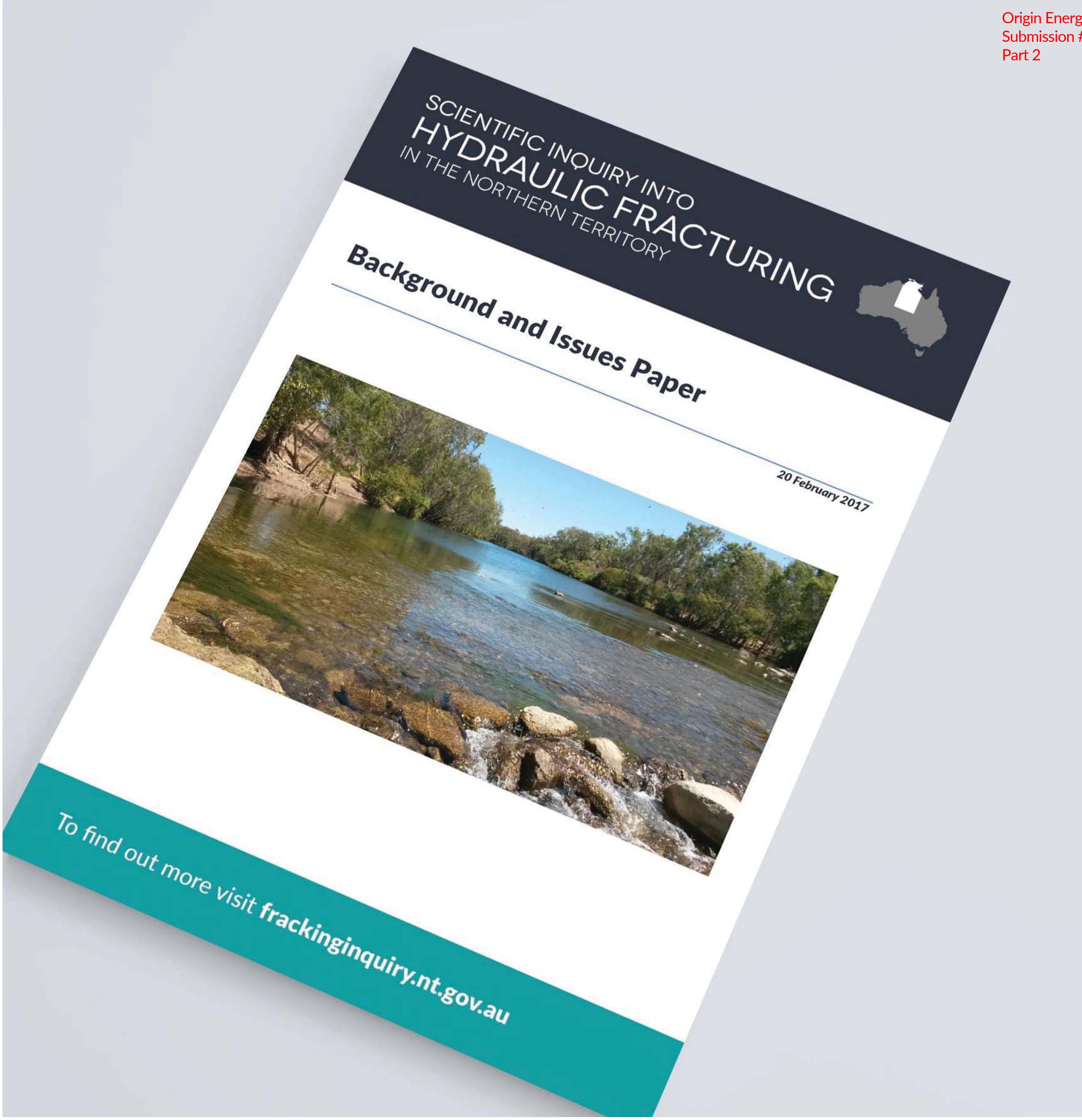


ADDRESSING THE BACKGROUND AND ISSUES PAPER

4 RISK THEME 1: WATER

The Water Risk Theme is focused on two potential impacts:

i. Water quality is negatively impacted through contamination

ii. Water supply to other users and/or the natural environment is threatened or limited due to the quantities required by the oil and gas industry

Preventing contamination: The fear that a contamination event will irreparably damage the Cambrian Limestone Aquifer in the Beetaloo is widely held, and concerns our stakeholders deeply. Origin commits to releasing on a publicly available website all baseline and monitoring groundwater data, so that concerned parties can verify for themselves that no damage to the aquifer has occurred.

With modern construction and appropriate regulatory guidance, well failures are exceedingly rare events (King and King, 2013) and there are no instances of systemic water contamination associated with HFS of shale gas (EPA, 2016).

Water supply sustainability: Origin recognises how critical groundwater is to Territorians, and is committed to using water sustainably while respecting the requirements of other users. In the case of the Cambrian Limestone Aquifer (CLA) in the Beetaloo, in the unlikely event that there is potential supply impacts on another user, Origin commits to working with the other party to find a mutually agreeable solution. We forecast an increase of 2.6% of the sustainable yield of the CLA is the maximum required during peak field development, with an average increase of 1.2% over the course of the development.

Make good: Origin is committed to making impacted stakeholders whole if they are impacted by our activities. If a landholder's business or well-being is adversely impacted, we commit to remediating and/or compensating for the financial loss or loss of amenity experienced. The trust of landholders in this commitment is fundamental to us.

4.1 Background and existing environment – contextual statement

Origin has engaged studies and monitoring programs to develop an improved understanding of water resources in the Beetaloo and to collect baseline data that will inform future environmental approvals processes. The sections below summarise information that is relevant to informing the assessment of risks associated with HFS, specifically within the Beetaloo.

4.1.1 Groundwater

There is a good understanding of the primary groundwater resources of the Beetaloo Basin as the result of numerous studies, summarised in Knapton and Fulton (2015). There are at least 813 registered bores in the basin.

Origin commenced a groundwater monitoring program (GMP; Appendix 3) in 2014 prior to any exploration activities, and are currently monitoring over 30 bores (Figure 16). Monitoring activity is concentrated in areas of activity, and exceeds any regulatory requirement.

The GMP focuses on potable water aquifers in the region, primarily the CLA; however, monitoring bores have also been installed into shallow sediments around the Amungee NW-1 lease where there is evidence of stored water in the phreatic zone following the wet season that could constitute a shallow, perched aquifer.

The term aquifer will be used to refer to any aquifer containing potable water. Aquifers containing non-potable water will be referred to as non- potable aquifers.

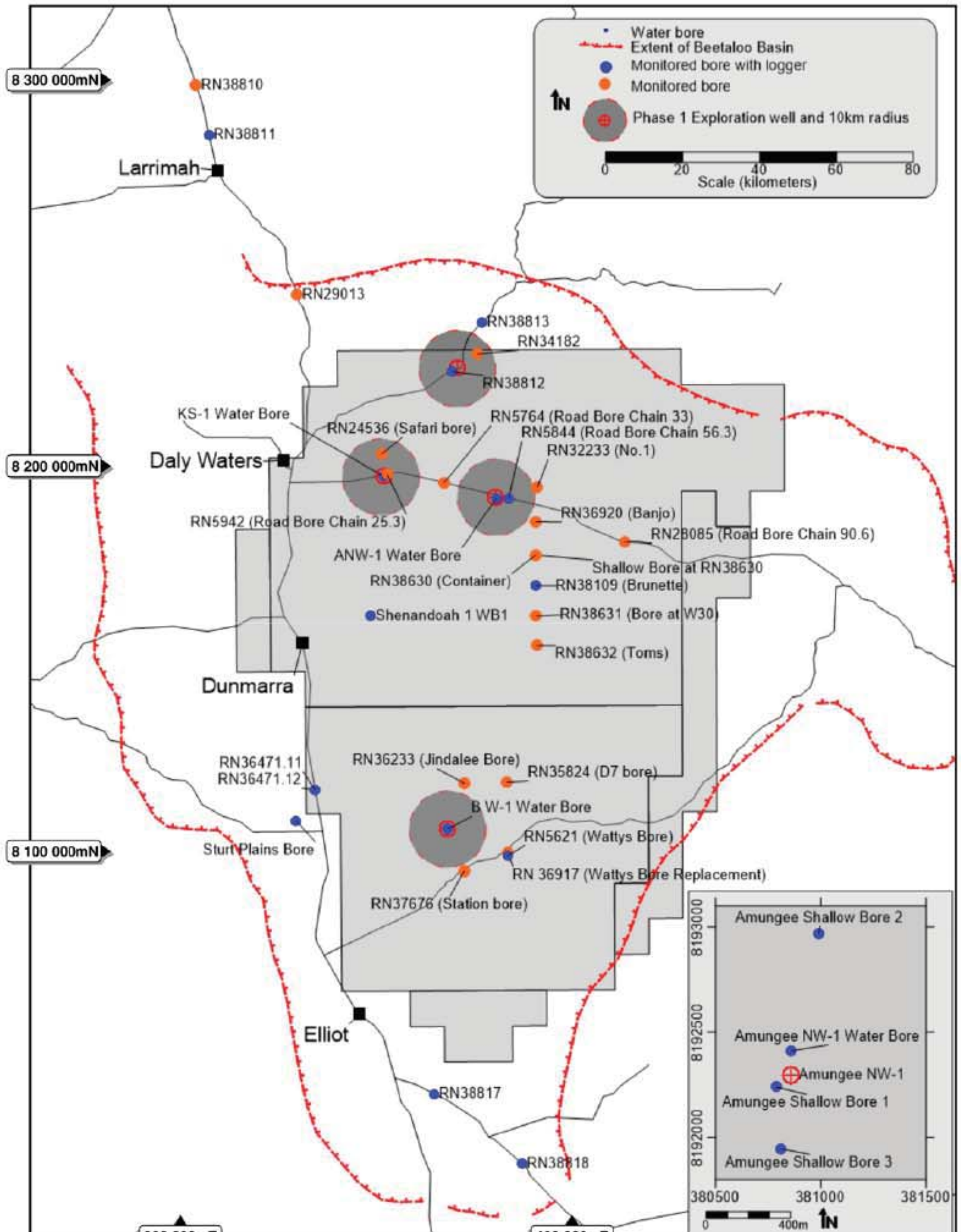


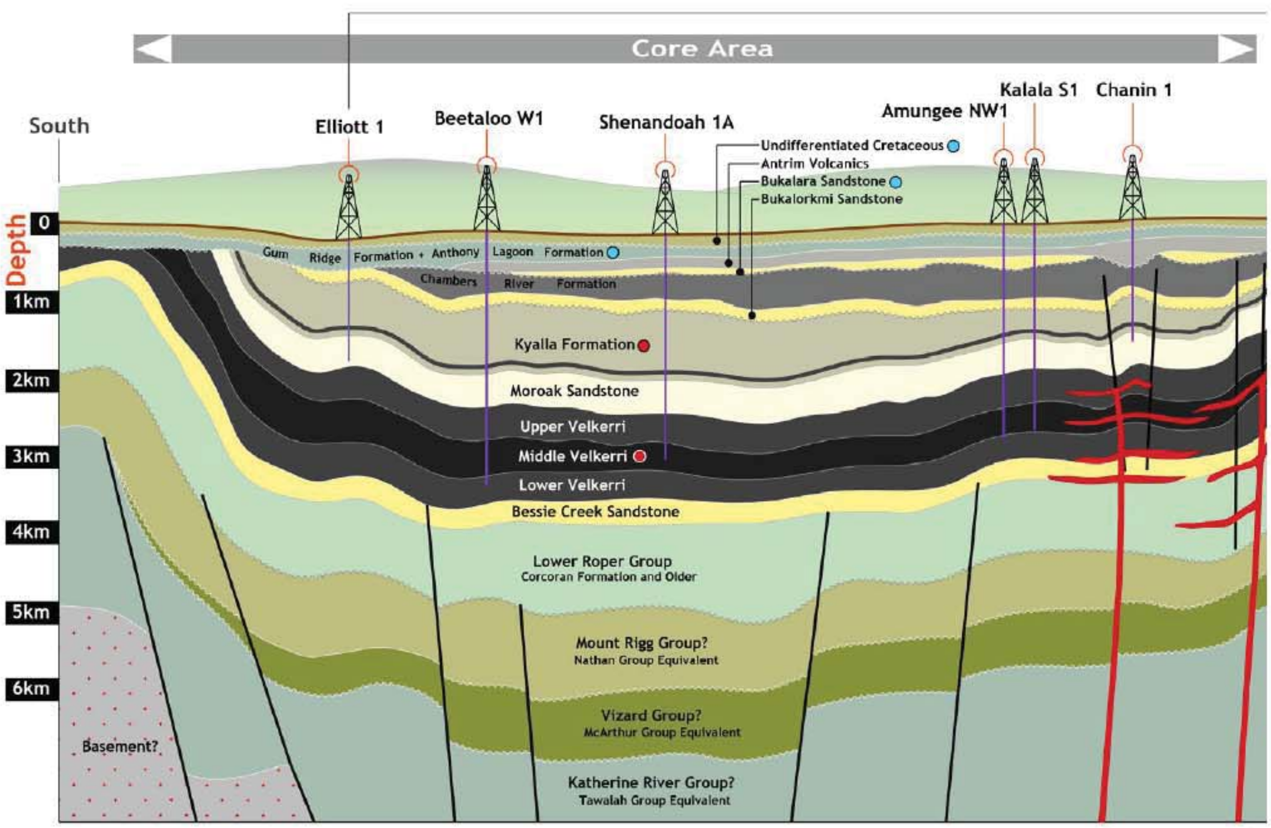
Figure 16. Origin's groundwater monitoring program, which began in 2014, is monitoring over 30 bores across the Beetaloo and provides data both on standing water level and water quality.

Monitoring includes twice yearly testing of all GMP wells, where samples are taken from each well and analysed for a range of water quality indicators at an independent laboratory. These data are critical to demonstrating that exploration activities, including HFS, have not impacted the aquifer(s). In addition to the discrete sampling program, approximately half of the wells being monitored are equipped with pressure logger devices, which provide a continuous recording of standing water level. These devices measure natural, long-term variations to levels in the CLA and will test whether exploration activities are adversely impacting water storage and supply in the CLA.

In the Beetaloo region the water quality and water levels in the CLA generally vary gradually and, hence, a relatively sparse data set can characterise the CLA effectively. The data being acquired through the GMP will be critical to proving the effectiveness of the controls in place to ensure that groundwater resources are not impacted by exploration and development activity.

4.1.1.1 Aquifers

The core area of the Beetaloo Basin comprises a thick sequence of relatively flat-lying geological groups or basins (Figure 17 and Figure 18). See section 14 for a more detailed discussion of the regional geology. The Roper Group, the target of Origin's exploration program, comprises mudstone and sandstone formations that were deposited between 1500 and 1350 million years ago (Ma) (Table 5). The Roper Group is estimated to reach 5000 m in thickness in the centre of the basin and with the exception of the north and east margins is first encountered at an average depth of around 500 m. The Roper Group is overlain by the Georgina Basin (630 – 497 Ma), which includes widespread basalts and a thick limestone sequence that forms the CLA, a significant water supply aquifer. The Georgina Basin is capped by Cretaceous mudstone and sandstone (145 – 66 Ma) and recent alluvial and laterite deposits.



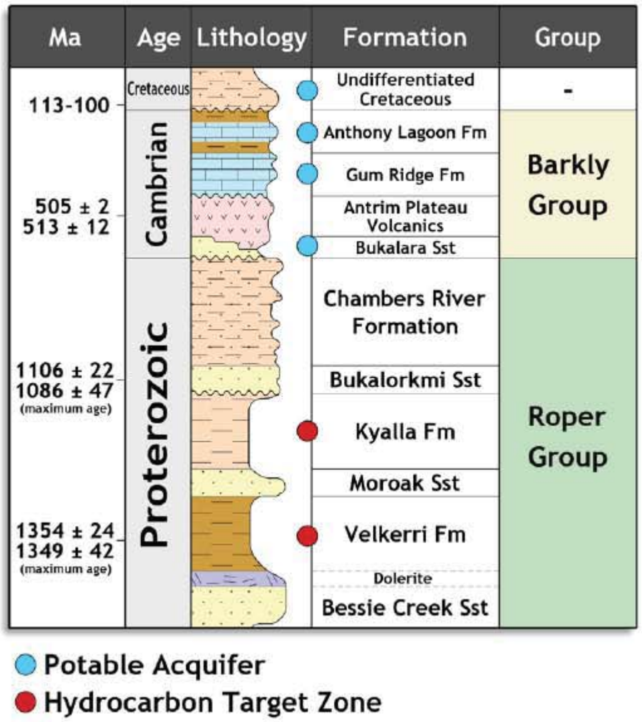


Figure 18 (right).. Stratigraphic section for the Beetaloo Basin region.

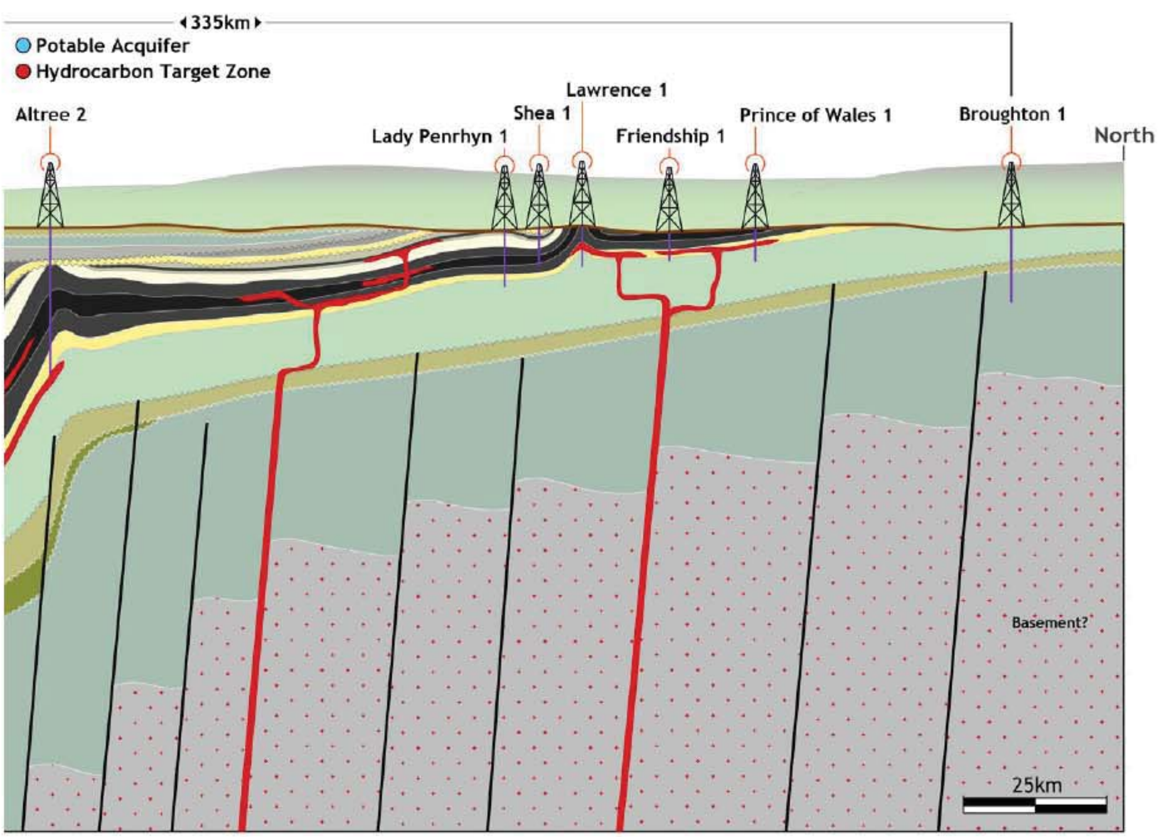


Figure 17 (below).. North-south cross section through the Beetaloo Basin showing the stacked nature of the basins and the relatively conformable and flat-lying nature of the geology.

PROVINCE	PERIOD / AGE	FORMATION		AQUIFER STATUS	THICKNESS (m)	YIELD (l/s)	AVE. EC (μs/cm)
CARPENTARIA BASIN	CRETACEOUS 145 – 66 Ma	Undifferentiated		Local Aquifer	0 - 20	NA	200
		Undifferentiated (formerly Mullamen Beds)		Local Aquifer	0 - 130	0.3 - 4	1800
GEORGINA BASIN	CAMBRIAN 497 - 630 Ma	Cambrian Limestone Aquifer (CLA)	Anthony Lagoon Formation	REGIONAL AQUIFER	0 - 200	1 - 10	1600
			Gum Ridge Formation	REGIONAL AQUIFER	0 - 300	0.3 - >20	1400
		Antrim Plateau Volcanics		REGIONAL AQUITARD *Local Aquifer*	0 – 75	0.3 - 5	1000
		Bukalara Sandstone		Local Aquifer			
BEETALOO BASIN (ROPER GROUP)	NOT KNOWN	Chambers River Formation (formerly Hayfield Mudstone		REGIONAL AQUITARD *Local Aquifer*	0 – 450	-	32000
		Bukalorkmi Sandstone (formerly Jamison Sandstone)		Local non-potable Aquifer	0 – 150	-	138000
	MESO-PROTEROZOIC 1350 - 1500 Ma	Kyalla Formation		REGIONAL AQUITARD	0 – 800	-	-
		Moroak Sandstone		Local non-potable Aquifer	0 – 500	0.5 - 5	131000
		Velkerri Formation		REGIONAL AQUITARD	700 – 900	-	-
		Bessie Creek Sandstone		Local non-potable Aquifer	450	0.5 - 5	-

Table 5. Summary of the Beetaloo Basin hydrostratigraphy (Knapton and Fulton, 2015).

The CLA, comprising the Gum Ridge Formation and the Anthony Lagoon Beds, is an extensive regional aquifer system that forms the principal water resource in the Beetaloo Basin. Limestone in the CLA is commonly fractured and cavernous and regionally bore yields of up to 100 litres per second (L/S) have been recorded from this aquifer. Around 80% of water bores drilled in the basin screen the CLA and supply water for the pastoral industry and communities including Elliot, Daly Waters, Larrimah and Newcastle Waters. The CLA contains a significant but largely undeveloped groundwater resource with the sustainable yield from the Georgina Basin estimated to be in the order of 100 000 ML/year (NALWTF, 2009). Existing groundwater use in the Beetaloo Basin is estimated at 6000 ML/year.

Where the CLA is absent, has limited saturated thickness or is deep, local-scale aquifers are targeted in Proterozoic fractured rock, Georgina Basin formations and the base of the overlying Cretaceous sequence. Groundwater resources in these aquifers are of limited extent and have a lower yield (< 5 l/s) relative to the CLA. Limited information exists on the hydrogeological characteristics of the Roper Group sequence as it occurs at depth within the Beetaloo Basin. Sandstone dominated formations may behave as aquifers, however, drilling results suggest these formations have limited permeability and will only form marginal, local scale aquifers. Groundwater in the Roper Group is highly saline (i.e. non-potable) and contrasts with the shallower, aquifers in which groundwater is generally of drinking water quality.

The regional groundwater flow direction in the CLA is north-west toward Mataranka, where the aquifer discharges into the Roper River and supports significant groundwater dependent ecosystems including the Roper River at Elsey National Park and Red Lily/57 Mile Waterhole. These discharge features occur around 100 km north-west of the Beetaloo Basin. Dry season flow in the Roper River has been gauged at 95 000 – 126 000 ML/yr and provides an estimate of the magnitude groundwater discharge from the CLA. Large decadal changes in the discharge to the Roper River suggest that most recharge input occurs close to the discharge zone (i.e. beyond the Beetaloo Basin region). Hence, activities in the Beetaloo are effectively hydrodynamically isolated from towns such as Mataranka and Katherine, and the important tourism and recreational areas associated with the Roper River and the Mataranka Hot Springs - further studies of the extent of isolation are underway in collaboration with CSIRO.

Groundwater recharge mechanisms to the CLA are poorly characterised but are likely to be dominated by infiltration through sinkholes and preferential recharge through soil cavities. Origin is collaborating with CSIRO and Santos to undertake regional and local scale studies to improve understanding of recharge mechanisms and total aquifer storage and sustainable yield in the region.

4.1.2 Surface water

The Development Area is located within the Wiso drainage basin (Randal and Brown, 1967) which is drained by the Georgina River and its major tributaries (Ranken, James, Buckley and Woodroffe rivers). The Georgina River flows south into Queensland and eventually reaches Lake Eyre in South Australia. These rivers only flow for short periods after heavy rains. Large areas of the Beetaloo have no apparent surface drainage – including the Development Area. The nearest significant watercourse is Newcastle Creek approximately 50 km to the south. Permanent or semi-permanent natural surface water is limited to waterholes near the terminus of creeks flowing into the internal basin – including Newcastle Creek – although Lake Woods to the south-west may hold water for months or even entire years after exceptional seasons.

4.2 Water quality: fluid migration related risks

Groundwater - risk

There may be a risk of groundwater contamination as a result of:

- *induced connectivity between hydraulically fractured shale formations and overlying or underlying aquifers.*
- *leaky wells as a result of poor design, construction, operation or abandonment practices or as a result of well degradation over the life of the well.*

Response and controls

Origin has demonstrated through its major unconventional gas development in Queensland that the risks to contamination of groundwater and surface water can be mitigated through following regulations and utilising best practice well and surface infrastructure design and construction techniques including:

- *Well completion in accordance with best practice standards using multiple barriers.*
- *Production water quality monitoring.*
- *Monitoring and maintenance of wells to ensure ongoing asset integrity.*
- *Baseline and ongoing surface and groundwater monitoring programs.*
- *Compliance with state and federal dangerous goods and hazardous chemicals legislation; including the use of stringent transportation, storage (bunding), handling and disposal practices.*
- *Design of containment facilities to withstand 1:100 ARI rainfall events.*
- *Location of infrastructure away from sensitive features.*
- *Diversion of stormwater and overland flow around gas infrastructure.*

The following sections address these risks using the format laid out by the EPA (2016). The risks listed above are identical to the two potential induced pathways recognised as risks by the EPA (2016).

4.2.1 Risks

The EPA (2016) has identified two potential induced pathways for fluid to migrate between the hydrocarbon bearing zones and drinking water resources:

1. Fluid migration pathways within and along the production well[3]
2. Fluid migration associated with induced fractures within the subsurface

4.2.1.1 Factors affecting frequency or severity of impacts

The EPA found that the primary factors that can affect the frequency or severity of groundwater impacts as a result of induced connectivity between HFS shale formations and aquifers are:

1. the construction and condition of the well that is being hydraulically fractured
2. the amount of vertical separation between the production zone and formations that contain drinking water resources
3. the location, depth, and condition of nearby wells or natural faults or fractures

Key observations made by the EPA (2016) are summarised in Table 6, which also includes commentary on how the observation is relevant or otherwise to Origin's current or potential operations in the Beetaloo.

3 Fluid migration pathways within and along the production well is a risk for all oil and gas wells regardless of reservoir type (conventional/unconventional) or completion (fracked/unfracked).

FACTORS AFFECTING FREQUENCY OR SEVERITY OF IMPACTS	KEY EPA OBSERVATIONS	RELEVANCE TO OR IMPACT OF OBSERVATION IN THE BEETALOO
Construction and condition of the well that is being hydraulically fractured	The presence and condition of the well's casing and cement are key factors that affect the frequency or severity of impacts to drinking water resources.	All HFS activity will occur on newly constructed fit for purpose wells, with rigourous acceptance criteria.
	Fully cemented surface casing that extends through the base of drinking water resources is a key protective component of the well. Risk evaluation studies of a limited number of injection wells show that, if the surface casing is not set deeper than the bottom of the drinking water resource, the risk of aquifer contamination increases a thousand-fold.	Origin's Beetaloo wells have their surface casing set below the aquifer. All hydrocarbon bearing zones are deeper than the aquifers and surface casing and are cased off by either the intermediate or production casing string. Both the intermediate and production casing strings are cemented to surface ensuring that the top of cement is above the hydrocarbon bearing zones.
	Older wells exhibit more mechanical integrity problems compared to newer wells when hydraulically fractured or re-fractured.	The risk is not applicable as there are no legacy wells that can be re-entered and HFS. All HFS will occur on newly constructed fit for purpose wells.
Vertical separation between the production zone and formations that contain drinking water resources	In areas where there is little or no vertical separation between the production zone and drinking water resources, there is a greater potential to increase the frequency or severity of impacts to drinking water quality.	There is substantial vertical offset between the HFS targets and the aquifer in Origin's Beetaloo permits (700-3000m TVD).
	The practice of injecting hydraulic fracturing fluids into a formation that also contains a drinking water resource can affect the quality of that water, because it is likely some of that fluid remains in the formation following hydraulic fracturing.	This is not a risk for the Velkerri and the Kyalla as neither is an aquifer.
	Research shows that fractures created during hydraulic fracturing can extend out of the production zone, and that the vertical component of fracture growth is generally greater in deeper formations than shallow formations. Out-of-zone fracturing could be a concern in deeper formations if there is little vertical separation between the production zone and a deep drinking water resource and fractures propagate to unintended vertical heights.	There is substantial vertical offset between the HFS targets and the aquifer in Origin's Beetaloo permits (700-3000m TVD); modelling and empirical, analogue data indicate this offset is sufficient to prevent communication through induced fractures from hydrocarbon bearing zones and potable aquifers.
Location, depth, and **condition** of **nearby wells** or natural faults or fractures	Regardless of the extent of the vertical separation between the production zone and drinking water resources, the presence of active or abandoned wells near hydraulic fracturing operations can increase the potential for hydraulic fracturing fluids to move to drinking water resources.	There are very few active or abandoned wells within Origin's Beetaloo permits, and all wells drilled in the permits will use modern construction techniques.
	The frequency of impacts to the quality of drinking water resources may increase where wells are densely spaced (particularly in shallow hydraulic fracturing operations where more fracture propagation is expected to be in the horizontal direction).	There are currently not many wells in the Beetaloo. However, in the event that HFS operations occur in the vicinity of production wells the risks can be managed by following guidelines such as the Alberta Energy Regulator's Directive 083
	The frequency of impacts may also be higher in mature oil and gas fields that pre-date the use of construction/plugging methods that can withstand the stresses associated with hydraulic fracturing operations. In these mature fields, wells tend to be older so degradation is a concern, and the location or condition of abandoned wells may not be documented.	This is a very low risk as there are very few active or abandoned wells within Origin's Beetaloo permits.

Table 6.. A summary of key EPA observations with comments on their relevance or forecast impact in the Beetaloo.

4.2.2 Controls for ensuring no fluid migration pathways within and along the production well

Origin designs all of its wells with multiple barriers in place to prevent fluid movement between hydrocarbon bearing zones and drinking water resources. Controls to prevent fluid migration pathways within and along the production well include the basis of well design, well construction, verification of the integrity of the constructed well, defining the operating envelope and real-time monitoring during HFS operations, the well integrity management system, and well abandonment.

Origin's Beetaloo well integrity operating philosophy

- ✔ Know where the aquifers and hydrocarbon bearing formations are
- ✔ Ensure a minimum of two barriers across the aquifer
- ✔ Ensure that any casing string that cases off a hydrocarbon bearing formation (irrespective of whether it is a production target or not) is cemented to surface
- ✔ Know the operating envelope and stay within it
- ✔ Ensure a well integrity management plan is in place for the life of the well

4.2.2.1 Design and Well Construction

Well design is the first step in ensuring well integrity for a proposed well. The subsurface team (geologists, geophysicists and petroleum engineers) summarizes key information and data required by the drilling engineers to design the well in the form of a basis of well design (BOWD). Critical inputs provided by the BOWD that influence well design include:

- The down hole formations that need to be protected (i.e. aquifer identification) or that could cause problems for drilling or well integrity. Most importantly, aquifer protection is considered here.
- The subsurface well objectives (either production or reservoir evaluation).
- The fracture gradient, which describes how much pressure is required to fracture the rock.
- The pore pressure, which is the pressure that fluids in the rocks are under.

The design process also includes the definition of well acceptance criteria (WAC). WAC are critical thresholds that are tested during well construction. The WAC must be met or exceeded to confirm well quality and integrity before proceeding with the next phase of well construction. If a WAC is not achieved, a remedy and/or risk assessment must be in place prior to moving forward with operations. Some of these WAC form critical pieces of the well's integrity or barrier envelope. The barrier envelope is simply the sum of the well elements that make up the whole system that isolates the well as required from subsurface formations and leaks at surface.

The Amungee NW-1 well, for example, was designed to satisfy regulatory requirements of the NT Department of Mines and Energy (DME; now the Department of Industry and Resources or DPIR) and the requirements of the Origin drilling and completions standards. Origin's standards document minimum acceptable requirements and consider both expert knowledge and industry best practice to ensure the safety of all personnel working on the well and protection of the environment during construction, and the integrity of the well through its entire life cycle. If regulatory requirements exceed those of Origin, regulatory requirements would supersede those of Origin. The Amungee NW-1/Amungee NW-1H well was subject to 12 WAC (Appendix 4) and each of these criteria was successfully met.

4.2.2.1.1 Barriers protecting aquifers

Origin's standards require that aquifers are protected with multiple barriers. All of Origin's wells drilled in the Beetaloo have three strings of casing protecting the shallow aquifers (surface, intermediate, and production casing strings). Origin designed its Beetaloo wells such that the surface casing is always set below the deepest aquifer and the intermediate and the production casing strings are cemented to surface to ensure isolation between the hydrocarbon bearing formations and the aquifers[4] (Figure 19). The design addresses the Environmental Protection Authority (EPA)'s two primary causal factors of aquifer contamination resulting from fluid migration pathways within and along the production well which are:

- Inadequate surface casing depth (i.e. casing not set below the aquifer).
- Inadequate top of cement (i.e. cement not set above the shallowest hydrocarbon bearing zone).

Stone et al. (2016), from the Colorado School of Mines, conducted a study on the failure rates of wells in the Wattenberg field in Colorado. Stone et al. (2016) grouped and ranked common vertical, deviated, and horizontal wellbore barrier designs based on risk of multiple barrier failures (Figure 20). The wells in the study area ranged from Category 1 to Category 7. The study shows (Figure 21) that wells with appropriate surface casing depths and cement tops (Category 6 and Category 7) have seen no failures in the field to date regardless of their orientation (i.e. vertical or horizontal). Origin's internal standards would require a well to meet Category 6 requirements, at a minimum, during production operations and at least Category 7 requirements for well abandonment. The design of Origin's Beetaloo wells align with the Category 9 requirements, as shown in Figure 20, which has an even lower risk profile than the wells in the Stone et al. (2016) study.

4 Due to CLA geology it is difficult to cement the surface casing string to surface. For this reason Origin cemented both the intermediate and production casing strings to surface.

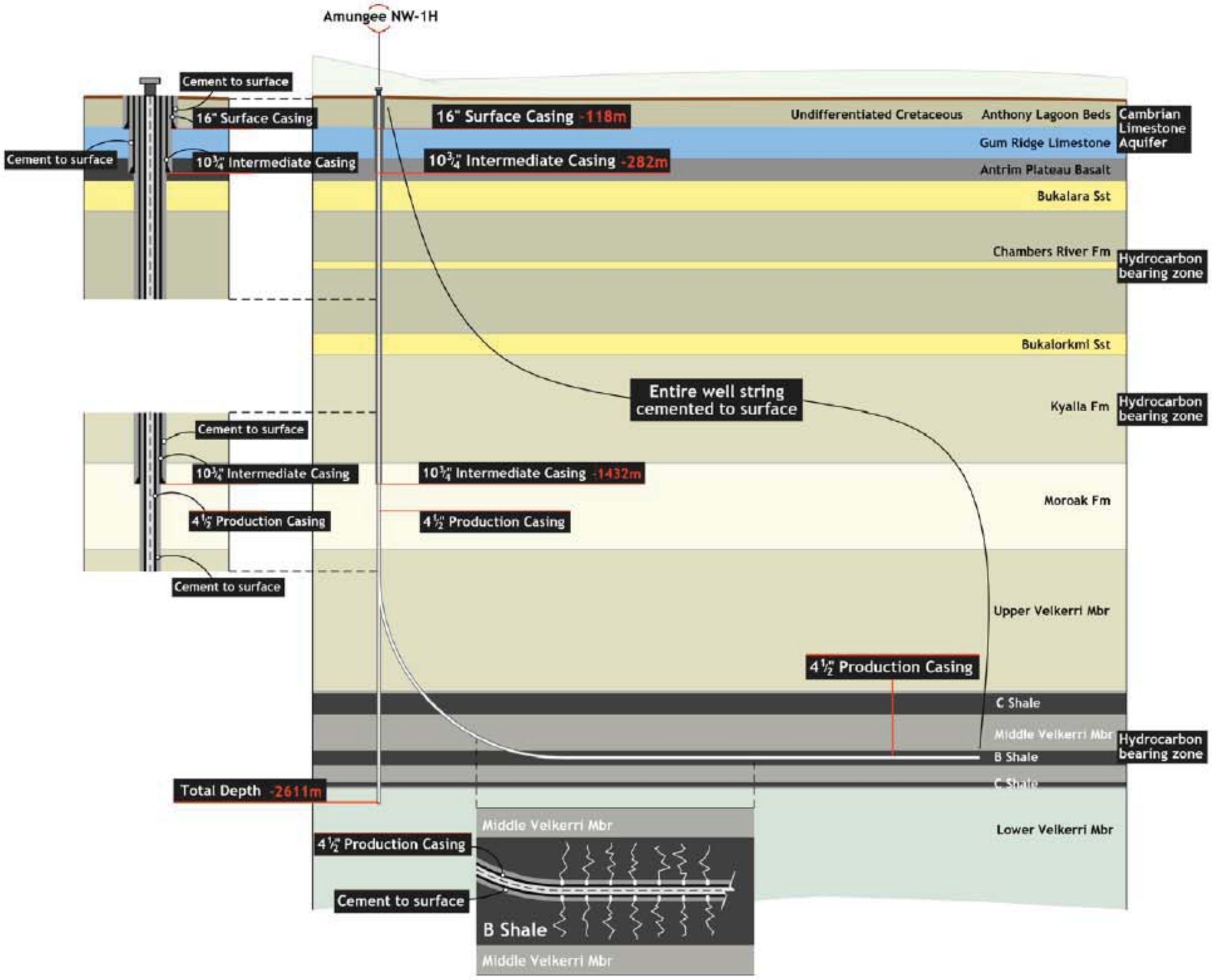


Figure 19.. Casing configuration for wells drilled in the Beetaloo by Origin that ensures isolation of aquifers and hydrocarbon bearing zones.

	Category	Description	Risk
	1	Shallow surface casing + top of production casing cement below over pressured hydrocarbon reservoir	High
	2	Shallow surface casing + top of production casing cement below under pressured hydrocarbon reservoir	
	3	Shallow surface casing + top of production casing cement above top of gas	
	4	Shallow surface casing + top of production casing cement above surface casing shoe	
	5	Deep surface casing + top of production casing cement below under pressured hydrocarbon reservoir	
Origin's minimum design requirement for a producing well	6	Deep surface casing + top of production casing cement above top of gas	
Origin's minimum design requirement for a P&A well	7	Deep surface casing + top of production casing cement above surface casing shoe	
	8	Deep surface casing + 1 intermediate casing + top of production casing cement below top of gas	
Origin's Beetaloo wells	9	Shallow surface casing + 1 intermediate casing + top of production casing cement above casing shoe	
	10	Deep surface casing + 1 intermediate casing + top of production casing cement above top of gas	
	11	Deep surface casing + 1 intermediate casing + top of production casing cement above casing shoe	
	12	Deep surface casing + 2 intermediate casing strings + top of production casing cement above casing shoe	Low

Figure 20.. Wellbore barrier categories ranked from the highest to the lowest risk (Modified from Stone et al., 2016).

(a) Vertical and deviated wells

CATEGORY	ORIGINAL WELL COUNT	POTENTIAL BARRIER FAILURES	POTENTIAL BARRIER FAILURES %	CATASTROPHIC BARRIER FAILURES	CATASTROPHIC BARRIER FAILURES %	AVG COMPLETION DATE	P&A WELL COUNT	CURRENT WELL COUNT	ORIGINAL AVG SURFACE CASING DEPTH (FT)	ORIGINAL AVG TOP OF PRODUCTION CEMENT (FT)
Category 1	166	100	60.24%	3	1.81%	1979	57	15	253	7,334
Category 2	621	219	35.27%	5	0.81%	1983	138	301	306	6,566
Category 3	46	16	34.78%	1	2.17%	1987	14	31	321	4,008
Category 4	7	0	0.00%	0	0.00%	1982	1	15	222	125
Category 5	8,789	77	0.88%	1	0.01%	1995	782	6,140	559	6,111
Category 6	5,433	6	0.11%	0	0.00%	2007	105	7,181	712	2,816
Category 7	1,766	0	0.00%	0	0.00%	2009	8	2,040	719	534
TOTAL	16,828	418	2.48%	10	0.06%		1,105	15,723		
D&A	147									

(b) Horizontal wells

CATEGORY	ORIGINAL WELL COUNT	POTENTIAL BARRIER FAILURES	POTENTIAL BARRIER FAILURES %	CATASTROPHIC BARRIER FAILURES	CATASTROPHIC BARRIER FAILURES %	AVG COMPLETION DATE	P&A WELL COUNT	CURRENT WELL COUNT	ORIGINAL AVG SURFACE CASING DEPTH (FT)	ORIGINAL AVG TOP OF PRODUCTION CEMENT (FT)
Category 1	0	0	0.00%	0	0.00%	NA	0	0	NA	NA
Category 2	0	0	0.00%	0	0.00%	NA	0	0	NA	NA
Category 3	0	0	0.00%	0	0.00%	NA	0	0	NA	NA
Category 4	0	0	0.00%	0	0.00%	NA	0	0	NA	NA
Category 5	0	0	0.00%	0	0.00%	NA	0	0	NA	NA
Category 6	269	0	0.00%	0	0.00%	2012	1	268	789	2,153
Category 7	704	0	0.00%	0	0.00%	2012	2	702	929	442
TOTAL	973	0	0.00%	0	0.00%		3	970		
D&A	0									

Figure 21. Potential and catastrophic barrier failures of a) vertical and deviated wells, and b) horizontal wells in the Wattenberg Field, Colorado (after Stone et al., 2016)

Selection of the most appropriate casing, in terms of its composition, weight, strength, and connection type is primarily a function of the expected forces and stresses, or load that must be withstood during the well lifecycle. The Origin Casing Design Standard stipulates which load cases must be considered when designing a well and are based on the forces that could be exerted on each casing string through the entirety of the well's life. The logic of a typical casing design (and that of the Amungee NW-1 and Amungee NW-1H wells) is that as the well gets progressively deeper, the pressures encountered are likely to be higher and therefore the casing must be stronger. It is also important that the final casing string (the production string) be robust enough to withstand the loads that will be applied during any stimulation and production activities, when higher internal pressures will be experienced.

The Amungee NW-1H well was drilled and completed with four casing strings (Table 7 and Figure 19). Casing is manufactured in a range of standard diameters and weights (defined by the American Petroleum Institute or API), and each of these casing types has individual ratings for compressive and shear strength (Table 8). Ratios of the yield or failure thresholds for a given casing type define minimum design factors, which cannot be exceeded during well operations. The ratio of the modelled or required force a casing string will experience divided by the yield thresholds must exceed the minimum design factors to be acceptable under the Casing Design Standard (Table 9) – if one of the failure type criteria are not met higher strength casing is required.

CASING STRING	SETTING DEPTH	WELL SECTION	DIAMETER (inches)	WEIGHT (lbs/ft)	GRADE [5]	THREAD
Conductor	113mTVD	Vertical	16	42	X42	Threaded and Coupled
Surface	276mTVD	Vertical	10 $\frac{3}{4}$	40.5	K55	Threaded and Coupled
Intermediate	1427mTVD	Vertical	7 5/8	29.7	P110	Premium Gas Tight Connection
Production (run 1 - unsuccessful)	N/A	Horizontal	4 1/2	11.6	P110	Premium Gas Tight Connection
Production (run 2 - successful)	3803mMD 2428mTVD	Horizontal	4 $\frac{1}{2}$	15.1	P110	Premium Gas Tight Connection

Table 7.. Summary of casing properties for Amungee NW-1H well.

CASING STRING	BURST PRESSURE	COLLAPSE RESISTANCE	YIELD STENGTH
Surface	3,130	1,580	629klbs
Intermediate	9.470	5,340	940kllbs
Production (run 1)	10,690	7,560	367klbs
Production (run 2)	14,420	14,320	485klbs

Table 8.. Summary of casing strength for different strings in the Amungee NW-1H well.

CASING STRING	PRESSURE – BURST	PRESSURE – COLLAPSE	AXIAL	TRIAXIAL
Minimum Design Factor	1.1	1.0	Static: 1.3 Dynamic: 1.6	1.25
Surface	3.24 (Pressure Test/LOT)	2.57 (Complete Evacuation)	2.10 (230klb Overpull)	2.10 (230klb Overpull)
Intermediate	1.43 (Production Casing Leak)	2.33 (Complete Evacuation)	3.17 (170klb Overpull)	1.75 (Production Casing Leak)
Production (run 1)	1.37 (Pressure Test)	1.21 (Full Evacuation Procedure)	1.65 (140klb Overpull)	1.64 (Pressure Test)
Production (run 2)	1.17 (Injection Screenout)	2.57 (Full Evacuation)	1.84 (Overpull 150klbs)	1.25 (Injection Screenout)

Table 9. Summary of modelled loads for each casing string at Amungee NW-1H.

5 A system of identifying and categorizing the strength of casing materials. Since most oilfield casing is of approximately the same chemistry (typically steel), and differs only in the heat treatment applied, the grading system provides for standardized strengths of casing to be manufactured and used in wellbores. The first part of the nomenclature, a letter, refers to the tensile strength. The second part of the designation, a number, refers to the minimum yield strength of the metal (after heat treatment) at 1000 psi [6895 KPa]. The casing grade P-110 designates a higher strength pipe with minimum yield strength of 110,000 psi [758,422 KPa].

Casing connections describe the threaded ends of each individual stand or piece of casing, which connects individual stands to create a continuous casing string. Connections can be sorted into two categories, standard or premium. Premium casing threads seal metal on metal and provide a positive long term seal against gas leakage. Premium connections also have a torque rating closer to that of the pipe body and can therefore withstand higher applied torque. In Amungee NW-1H both the intermediate and production strings have premium casing connections to ensure redundancy in the unlikely case of a leak from the production casing.

Another important consideration for lasting well integrity is the acidity of the fluids that may come into contact with the cement and casing. Some reservoirs may contain carbon dioxide (CO_2) or hydrogen sulphide (H_2S) which, if not prepared for, can cause corrosion of the casing, production valving and other gathering infrastructure. If corrosive fluids are expected, they can be safely produced using alloys that are less susceptible to corrosion than mild steel, and production of high CO_2 and high H_2S gas is done safely in Australia (e.g. Cooper Basin CO_2 content often exceeds 15% and can exceed 30%) and around the world (e.g. 'sour' gas production in Alberta and Texas that contains H_2S above levels that would corrode standard completions).

The Amungee well was designed for non-corrosive fluids. Based on offset data it was known that the potential for H_2S was remote and that CO_2 content was likely to be low (<5%). It was decided during design that if corrosive fluid was found to be present in high concentrations, the well would be operated for a short test period, or not at all, and then abandoned. This would provide the data required to design subsequent wells adequately to deal with long term corrosive production.

Aside from the steel casing itself, cement plays a vital role in supporting the casing and providing well integrity. There are several important things to consider when discussing cement barriers in oil and gas wells:

- The cement is a high quality material that is significantly different to average construction cement or concrete. The cement used is of a higher purity than lower grade cements, meaning that there is less chance of inclusion of impurities that would lower the strength of the cement.
- Some carefully considered additives are blended with the cement in order to enhance or change the properties of the cement being used. Examples include gas blockers (to prevent gas bubbling through the cement), retarders (to cause the cement to set more slowly, giving it time to be pumped into place), and expansive additives (to prevent the cement shrinking as it sets and therefore not fully filling the annuli).
- In order to fully understand the impact of additives and quality of cement, cement blends are tested in laboratories that provide information about time to set, time to develop strength and the ultimate strength of the cement before use in the field.
- For complex situations, such as the cyclical loading imposed on a cement sheath like that of the production casing at Amungee NW-1H by fracture stimulation, cementing service providers can model the ability of a cement sheath to provide lifelong integrity. As an example, modelling for Amungee NW-1H indicated that the production string blend needed to be adjusted to reduce shrinkage and provide sufficient isolation.

Cement placed in oil and gas wells is typically stronger and more stable than the rock adjacent to it when placed under ground. It is also exposed to lesser forces of erosion than it would experience if it were above ground (i.e. no oxygen, wind, rain or flowing water, sunlight, etc). What this means is that appropriately designed and effectively placed cement will provide isolation that will be effective for many hundreds or thousands of years to come, likely eroding more slowly than the rock surrounding it.

4.2.2.2 Testing and verification of well integrity

The well acceptance criteria (WAC) are the primary controls that ensure a well is constructed as per design and has all elements in place to ensure sufficient barriers, and redundancy in barriers, to isolate the well bore from the external environment and to ensure no communication between geological formations is possible as a result of the emplacement of the well. However, in addition to meeting the WAC, there are two key tests that confirm the cement emplaced around the casing has integrity and that the system or well as a whole has integrity when 'stress tested'.

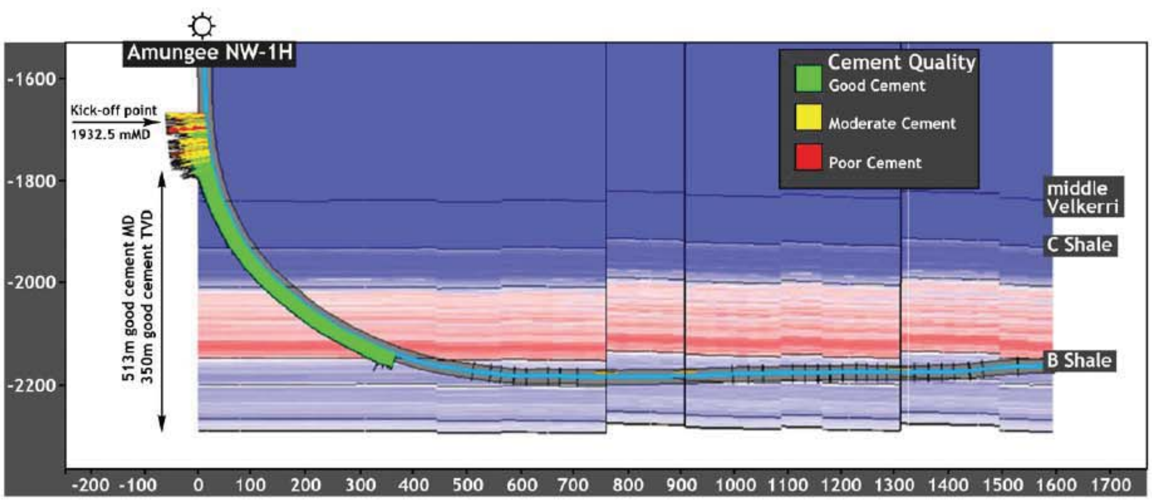
4.2.2.2.1 Cement integrity verification

A specifically engineered cement blend that is suitable for the formation fluid composition, temperature and pressure conditions, is pumped down the well and up the annulus between the casing and the wellbore to prevent migration of HFS fluid, formation brines, or hydrocarbons to shallower formations or aquifers.

The current Beetaloo well design has planned top of cement at surface (i.e. cement is continuous from the top of the well to the end of the relevant hole section) for all casing strings which exceeds common industry practices and Origin Standards. Cement returns to surface during execution is an effective method to confirm that there is a continuous cement column behind the casing and that hydrocarbon and water bearing zones are isolated.

Further cement integrity diagnostics may be carried out to validate isolation. A common methodology for cement evaluation is a cement bond log (CBL) and variable density log (VDL).

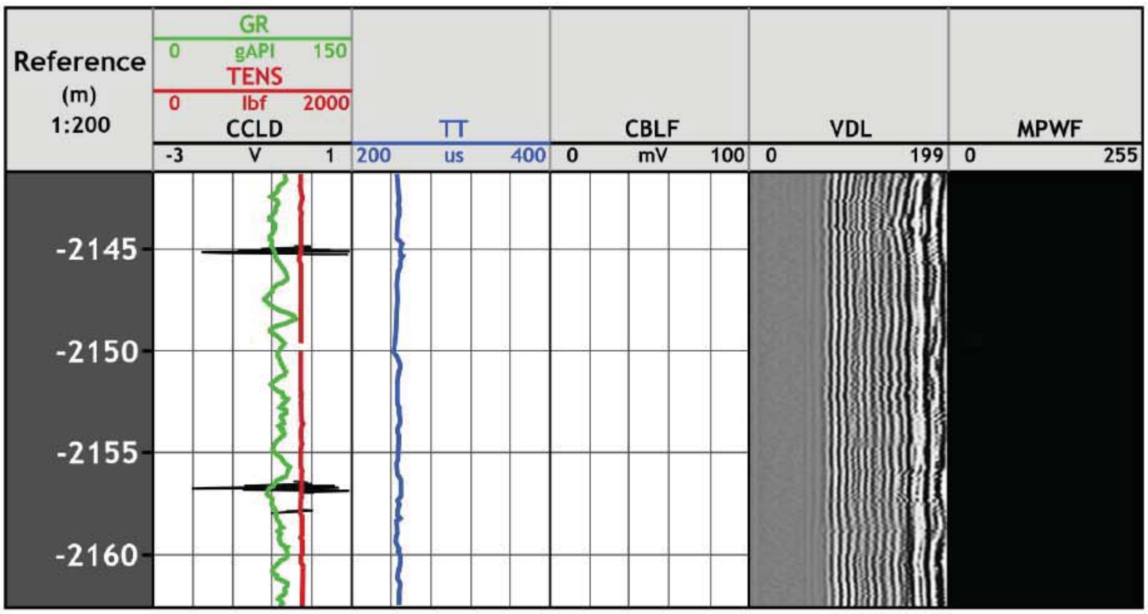
A wireline CBL/VDL for Amungee NW-1H was conducted on 29/07/2016 to a depth of 2563 metres Measured Depth (mMD) which correlates to the top of the Velkerri B shale package. This was the deepest depth achievable on wireline given the wellbore deviation. The CBL confirmed the presence of a >500 mMD section of good quality cement from the top of the Velkerri B shale at 2563 mMD up to above the Middle Velkerri Member at 2050mMD (Figure 22). The continuous section of good quality cement directly above the target reservoir provides a barrier to prevent any pressure or reservoir fluids from travelling up the wellbore during subsequent operations. This cement column exceeds the 150 mMD minimum requirement set out by the Origin Barrier Standard for hydraulic fracture stimulation



operations.

Figure 22. A section of over 500 mMD of good quality cement was confirmed at Amungee NW-1H by cement bond log data.

Good cement quality indicates that there is cement bonded to the casing and formation, which provides a secure barrier in the annulus space between production casing and formation. Moderate cement quality suggests there is cement present in the annulus space, however, there may be micro fractures or imperfect bonds to the formation or casing walls, which could potentially lead to unwanted interaction in the annulus space. Poor suggests there is likely to be inadequate cement bond to the casing or formation in the annulus space.



An example of the CBL and VDL data over the 2563-2050 m interval of good quality cement is shown in Figure 23. The casing to cement bond over this interval is confirmed by CBL amplitudes that are consistently low (<5 mV), and the cement to formation bond is confirmed by VDL data show strong formation arrivals.

Figure 23. An example of good quality cement from the Amungee NW-1H well. The CBL values are consistently below 5 mV, the threshold accepted as indicating a good cement job.

4.2.2.2.2 Well integrity verification and pressure testing

Pressure tests are conducted to verify the mechanical integrity of a wellbore. This test occurs prior to HFS operations and must successfully meet the design criteria before HFS can proceed.

Pressure tests also play an important role in defining a well's safe operating envelope. The operating envelope sets limits that must be followed during HFS operations. The most important limit is the maximum allowable pumping pressure. Similar to other pieces of pressure rated equipment, the lowest pressure rated component that makes up the well system determines the maximum allowable working pressure (MAWP). The design pressure to which the well is tested to determines maximum allowable operating pressure (MAOP) which is always equal or less than the MAWP.

Amungee NW-1H has a MAWP at surface of 10,000 psi based on a wellhead component limitation[6]. The production casing was pressure tested to 10,000 psi which set the MAOP. Testing parameters were set out by Origin's pressure testing well acceptance criteria which aligns with industry best practices. Origins acceptance criteria for a pressure test are:

- Maximum 1% pressure drop over a 5 minute stabilised period.
- A decreasing pressure drop trend (i.e. Pressure drop per minute is less than that of the previous minute).
- No visible leaks at surface.
- Pressure test durations:
  - Low test (300 psi): 5 minutes.
  - High test(5,000/10,000 psi): 20 minutes.

A successful 10,000 psi pressure test was achieved at Amungee NW-1H verifying the mechanical integrity of the production casing as shown in Figure 24.

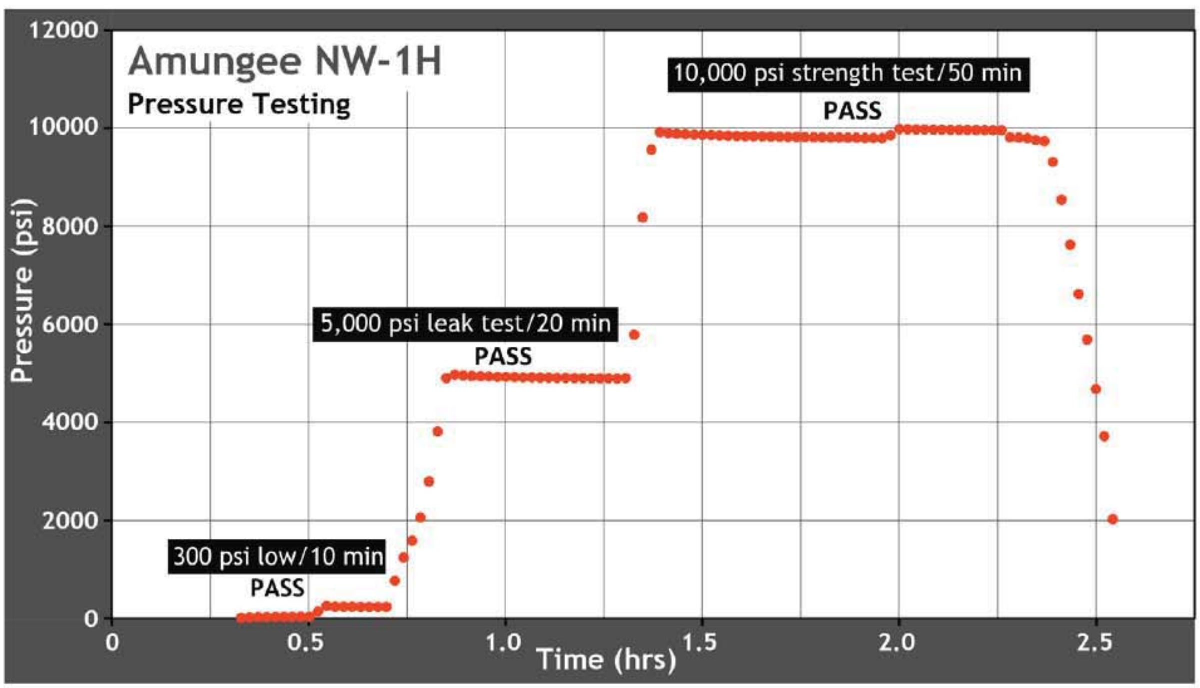


Figure 24. Data from pressure testing at Amungee NW-1H prior to prior to HFS. The mechanical integrity of the production casing is confirmed by the extended interval at 10,000 psi.

6 The production casing on its own had a MAWP of 10,700 psi.

4.2.2.3 Operating envelope and real-time monitoring

The previous section outlined how the MAOP pressure is determined. The MAOP is an important parameter used to define the operating envelope. The most important limit that the operating envelope defines is the maximum allowable pumping pressure (MAPP). The MAPP was set at 9,300 psi to allow for uncertainty and provide an additional safety margin (Figure 25). Two additional safety measures are set in place to ensure treating pressures do not exceed the MAWP of the system:

- Each HFS pumping unit has an automated high pressure shut off control set at the MAPP or lower, and
- A pressure relief valve was installed on the surface treating line to instantaneously bleed down pressures if the pressure exceeded the MAPP of 9300 psi.

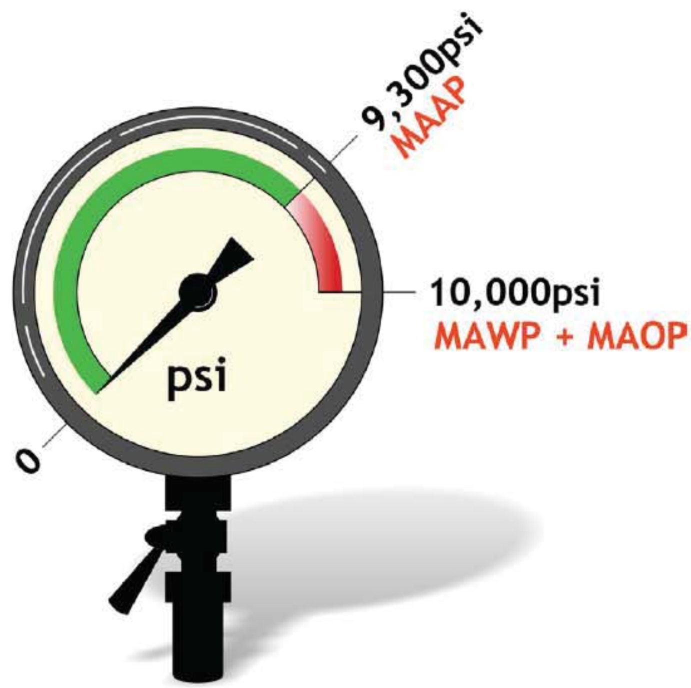


Figure 25. Schematic representation of pressure thresholds and safety factors for well operations.

To ensure the cyclic loads applied on the casing during stimulation operations have not compromised the integrity of the production casing or the cement behind it, the annular pressure was monitored during every HFS stage and subsequent flowback operations. The well head is designed to allow discrete measurements of the pressure in different annuli between adjacent casing strings. The "B-annulus" (Figure 26a) connects to the annulus between the intermediate and the production casing. The lack of change in pressure in this annulus (Figure 26b) during HFS and production testing operations confirms well integrity and that the cement has effectively isolated the section of the well being stimulated from the remainder of the well.

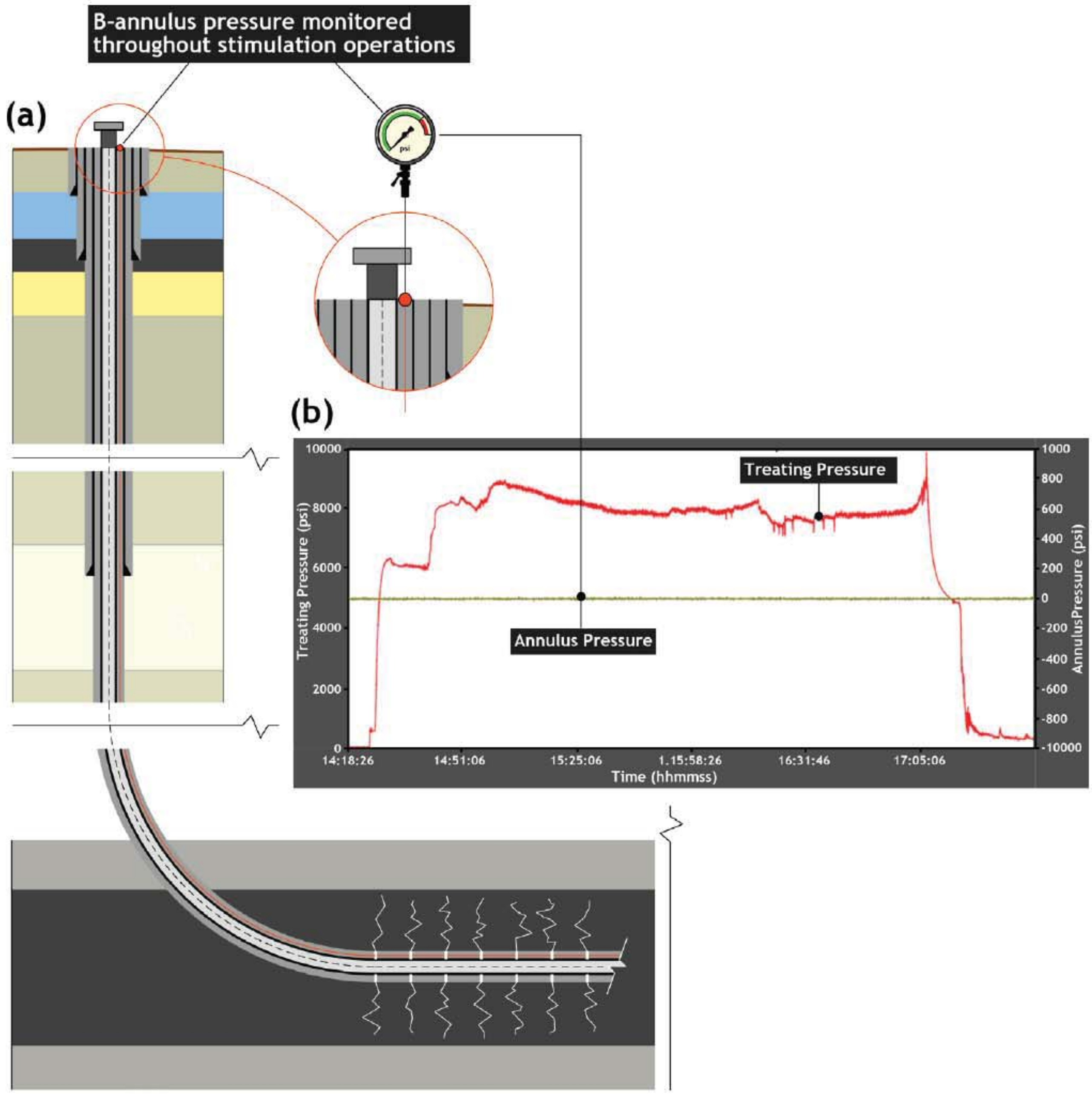


Figure 26.. a) Well and well-head schematic showing the "B Annulus" monitoring process, and b) An example from Stage 1 of the observed pressure of the B Annulus (0 psi) while high-pressure HFS operations were underway.

4.2.2.4 Ongoing monitoring and well integrity management

Following construction a well enters its operational phase (Figure 27) and typically an operations team would take accountability of the well at this point. The operations team have a separate, complimentary standard to manage integrity, known as the Integrity Management Plan (IMP). The IMP defines monitoring, maintenance and integrity testing requirements and frequencies, in addition to well integrity assurance activities. Well barriers are tested and pressures monitored regularly to ensure their performance over the lifecycle of the well.

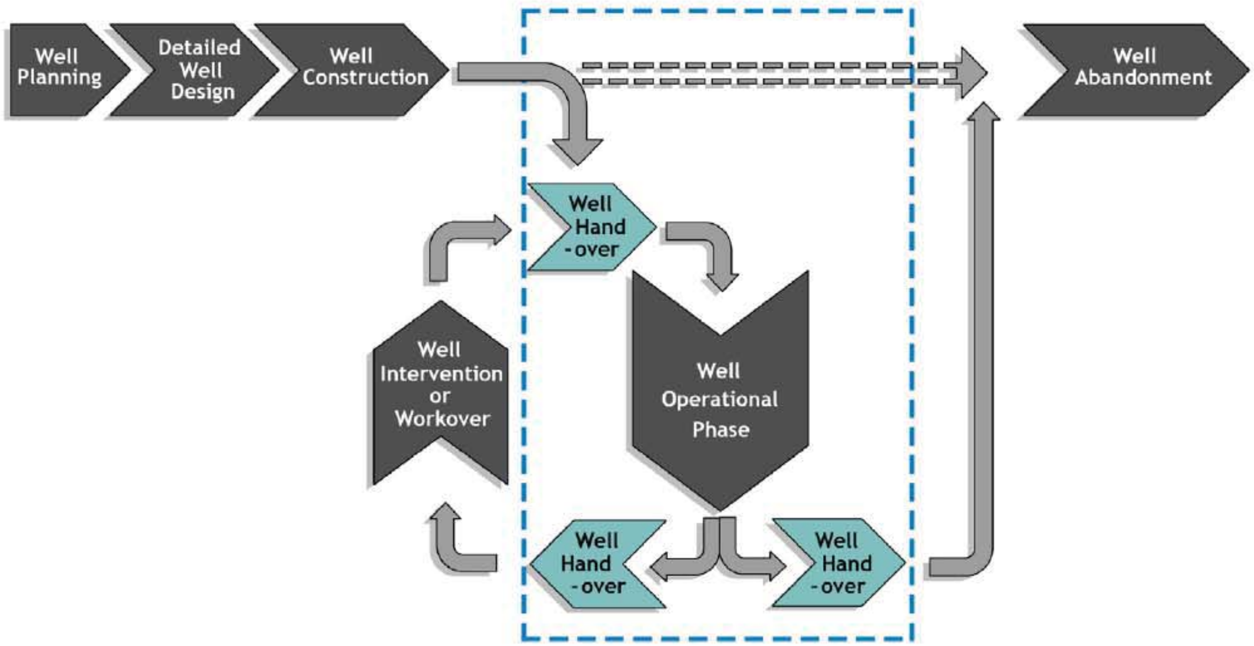


Figure 27.. Well lifecycle with operational phase highlighted where well integrity monitoring is a key activity.

Information from all Origin wells is gathered and stored in a database and made available to key technical staff via a software tool called a Well Integrity Management System (WIMS). WIMS contains information such as wellhead and production valve maintenance results, annular and tubing pressures, well operating windows, key well information and historical well integrity issues/failures and corrective maintenance. WIMS is used in the identification and assurance of the integrity of each individual well and also outlines the well integrity status for each well.

Origin has a well integrity team that is functionally independent from production operations, drilling and completions, and exploration and new resources teams. The well integrity team routinely monitors WIMS for well anomalies and also provide independent assurance of the integrity status of wells, typically during a regular monthly well integrity review that verifies well integrity status of all wells and reports upon well integrity key performance indicators (KPIs) such as preventative maintenance statistics, anomaly management requirements, etc. (Table 10).

Remediation of well integrity anomalies could include well integrity barrier replacements i.e. valves, tubing, and/or barrier remediation, such as casing patches, cement squeezes to ensure pressure isolation. If remediation does not prove to be a feasible option, plugging and abandonment operations will be considered to ensure well integrity.

A well integrity technical authority role exists within Origin and is applied in line with Origin's Technical Authority framework. In addition, a number of international guidelines and standards are consulted when managing well integrity in Origin, and these include, but are not restricted to:

- Oil & Gas Well Life Cycle Integrity Guidelines.
- ISO/TS 16530-2 Well Integrity for the Operational Phase.
- 117 – Norwegian Oil and Gas Recommended Guidelines for Well Integrity.
- NORSOK Standard D-010 Well Integrity in Drilling and Well Operations.

MONITORING FREQUENCY (DAYS)	NATURAL FLOW	HYDROSTATIC WELL
Production wells – monitor tubing and annular pressures, visual inspection	7 days	7 days
Shut-in wells – monitor tubing and annular pressures, visual inspection	28 days	28 days
Suspended wells – monitor tubing and annular pressures, visual inspection	28 days	28 days
WELL MAINTENANCE AND INTEGRITY TEST FREQUENCY (MONTHS)		
DHSV – maintain and test	6 months	6 months
XMT - maintain and test	12 months	12 months
WHD and Annular Valves - maintain and test	24 months	24 months

Table 10. Well integrity management plan schedule.

4.2.2.5 Well Abandonment

When a well is no longer required it is permanently plugged and abandoned. The only material Origin uses to permanently abandon wells is cement. Cement plugs are placed in wells to prevent cross flow between differently pressured formations and flow to surface. These plugs will undergo pressure testing to ensure that they have the integrity required of a long term barrier. As discussed previously, cements used in these applications are specially designed for the conditions and long term isolation. Abandonment is done in line with the cementing and barrier standards as well as local regulations. When Origin is satisfied that the abandonment plugs are in place and adequate, the regulator will be notified to provide approval of the abandonment. The wellhead is cut off and environmental cement plug installed at surface, along with a plaque engraved with the well details.

4.2.3 Controls for ensuring no fluid migration associated with induced fractures within the subsurface

The EPA identified four potential for pathways the migration of HFS fluid, hydrocarbons, or other formation fluids associated with induced fractures within the subsurface, which are summarised in Table 11 along with commentary on how they relate to Origin's Beetaloo operations.

POTENTIAL FLUID MIGRATION PATHWAY TO AN AQUIFER	FACTORS AFFECTING FREQUENCY OR SEVERITY OF IMPACTS	RELEVANCE TO OR IMPACT IN THE BEETALOO
Flow of fluids out of the production zone	**Vertical separation** between target zone and aquifer. As vertical separation increases risk decreases.	In Origin's Beetaloo Permits the separation between the target formations and the aquifers ranges from 750-3000+m.
	Permeability of the zones between the target zone and aquifer. As permeability decreases risk decreases.	The horizontal permeability in the target ranges from 1-1,000 nd. The vertical permeability is likely an order of magnitude lower that is effectively impermeable under ambient subsurface conditions. The targets within the Kyalla and Velkerri formations are encased in low permeability siltstone that have significantly lower permeability than the targets.
Fracture overgrowth out of the production zone	**Vertical separation** between target zone and aquifer. As vertical separation increases risk decreases.	In Origin's Beetaloo Permits the separation between the target formations and the aquifers ranges from 750-3000+m.
	Stress barriers between the target zone and the aquifer. As the number of stress barriers increases the risk decreases. As the stress differential of a stress barrier increases the risk decreases.	There are multiple stress barriers between the target zones and the aquifer that ensure no fracture growth out of zone. The target zones in the Beetaloo are straddled between organically lean and high clay content siltstones. The higher clay content increases the Poissons' Ratio resulting in the zones above and below the target zones being relatively higher stressed and acting as frac height barriers.
Migration via fractures intersecting geological features	Location and depth of geological features	There are very few large scale geological features within the proposed Development Area of Origin's Beetaloo permits. Most faults are interpreted to be subseismic (i.e. <25-50m in offset) and contained within a particular formation. In the Permits there are very few through-going faults that penetrate from the Velkerri Formation to the shallow subsurface (<500m). Large faults, most likely located towards the edges of the basin, are deliberately avoided as they increase the risks and costs of drilling and HFS the wells (e.g. increased likelihood of sidetracking or screenouts).
Migration via fractures intersecting with offset wells	Location, depth and condition of nearby wells	There are very few well penetrations in Origin's Beetaloo Permits. The closest well that to Amungee NW-1H that penetrates the Velkerri Formation is Kalala S-1, which is approximately 30 km away. There are nine legacy plugged and abandoned wells on the Permits, the location and depths of these wells are known and can easily be avoided. Origin supports the Alberta Energy Regulator's "Directive 83: Hydraulic Fracturing – Subsurface Integrity" as a guideline to manage the risks of inter-well communication.

Table 11. A summary of key EPA observations relating to the risk of induced fractures providing contamination pathways, with comments on their relevance or forecast impact in the Beetaloo.

A primary goal of HFS is to design an operation such that all fluid and proppant stays within the target zone. There is an additional economic incentive to the obvious environmental and reputational incentive to ensure successful containment, and that is that stimulating non-reservoir rock outside of the target is inefficient, reduces well deliverability and worsens the capital efficiency of a well. The controls to prevent fluid migration pathways associated with induced fractures within the subsurface are the same as the steps required to design an optimized HFS program to maximize efficiency. Controls include the construction of mechanical earth models (MEM) and HFS models, identification of geohazards, and monitoring of pump rates and pressures in real-time.

Origin's Beetaloo fracture containment operating philosophy

- ✔ Know the vertical offset between aquifers and hydrocarbon bearing formations
- ✔ Identify stress barriers
- ✔ Identify and assess subsurface hazards
- ✔ Monitor real time pressures during HFS for abnormal behaviour

4.2.3.1 Geological barriers to fracture height growth and hydraulic fracture stimulation modelling

Fractures in sedimentary basins have their vertical growth hindered because layered rock materials are not homogeneous or isotropic and the layering creates heterogeneous material properties between layers and variable interface properties. These heterogeneities result in large stress contrasts and interface variations between layers that create an environment where vertical fracture growth is hindered and lateral fracture growth is the preferred path of least resistance.

In-situ stress contrasts have the most significant effect on fracture height growth (Perkins and Kern 1961, Simonson et al. 1978; Voegele et al. 1983; Palmer and Luiskutty 1985, Warpinski et al. 1982, Fischer et al. 2011). Warpinski et al. (1982) gathered observations from experimental testing at sites that were mined back to allow fractures to be studied and confirmed that height growth is indeed impeded by lithology contrasts where in-situ stresses differ. Fischer et al. (2011) summarize three mechanisms by which material property contrasts limit fracture height growth:

- the effect of a fracture approaching an interface with modulus contrast.
- the effect of modulus on the width of the fracture and the resulting impact on flow resistance caused by a width change, and
- the difference in fracture toughness between layers.

Secondary controls on fracture height growth include inelastic forms of energy dissipation such as shear failure, bed slip, and plastic deformation.

Fischer (2011) also summarised microseismic data from several major US shale plays to demonstrate that induced fractures from HFS do not grow substantially above the well bore, in relation to the depth of the well, and that no uncontrolled fracture height growth into an aquifer has been observed (Figure 28). These data are evidence that aquifers are not at risk from uncontrolled fracture height growth during HFS operations.

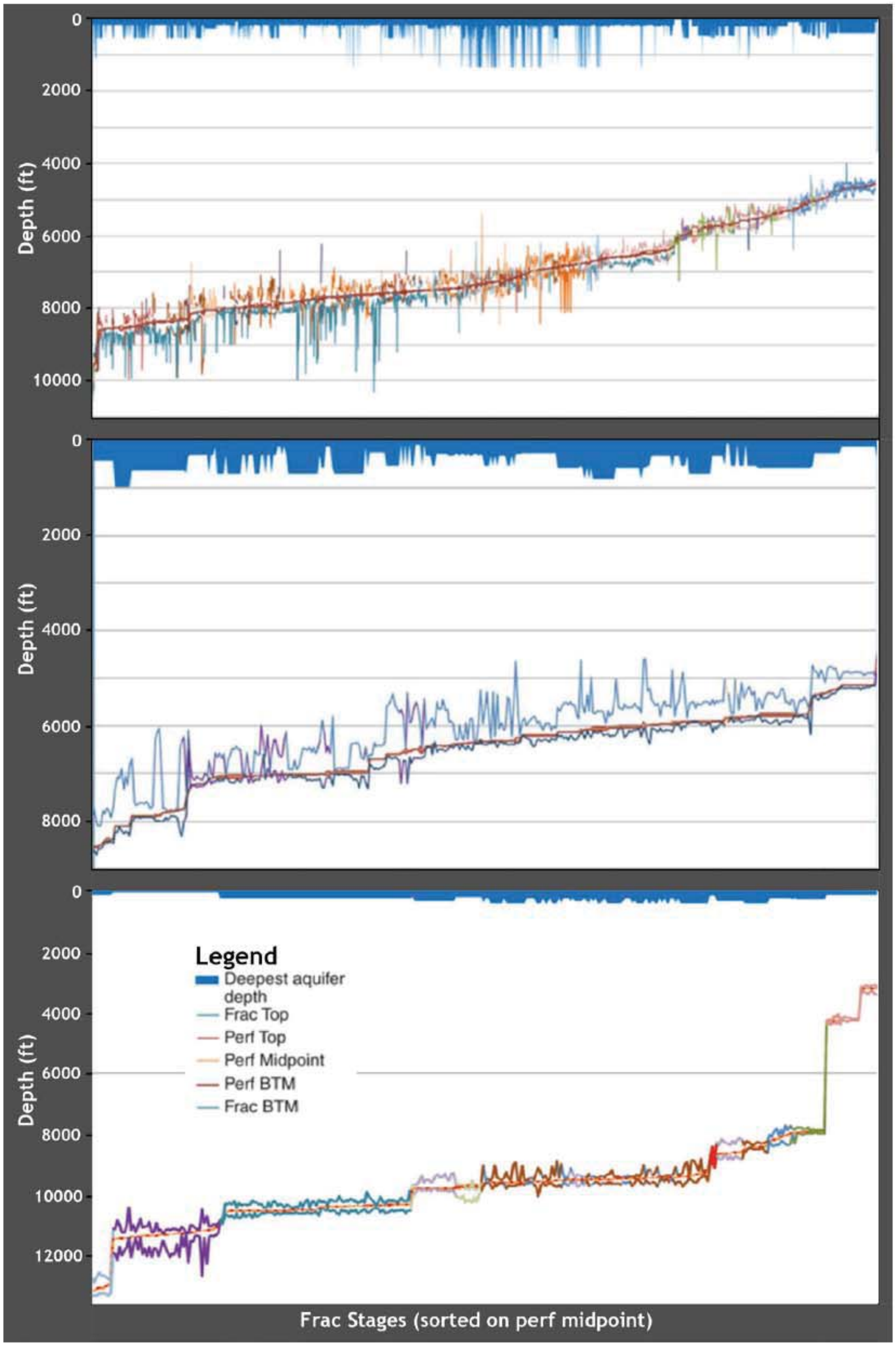


Figure 28.. Microseismic data from the US show that fractures induced by HFS operations are contained to the near well rocks, relative to the depth of the well, and that aquifers are not contacted by uncontrolled fracture height growth in shale gas HFS operations.

Prior to conducting the HFS operation at Amungee NW-1H Origin assessed the risk of induced connectivity between the hydraulically fractured shale formation and the aquifers. The risk was assessed as follows:

1. What is the vertical offset between the target zone and the aquifers?
2. Are there barriers to fracture height growth between the target zone and aquifers?
3. Do the barriers contain the fracture height growth for the designed pumping schedule?

The first step was to identify aquifers and the target zones. At Amungee NW-1H, (Figure 18) the identified aquifers are located at 92 mTVD (Anthony Lagoon Formation) and 109 mTVD (Gum Ridge Formation), and the target zone is located at 2418 mTVD (Velkerri B Shale). The vertical separation between the target and the aquifers is a substantial barrier which renders the likelihood of induced connectivity between the hydraulically fractured Velkerri B shale and the aquifers to below remote.

The second step required the construction of a mechanical earth model (MEM). Figure 29 shows how MEMs are used in conjunction with HFS models to assess fracture geometry. MEMs integrate all available geomechanical data to interpret the principal stress magnitudes along the wellbore (see section 14.5 for additional details on MEMs). The MEM allows for the identification of the major stress contrasts between rock layers that will act as fracture height barriers. Figure 30 shows the major stress barriers above the Amungee NW-1H lateral within the middle Velkerri.

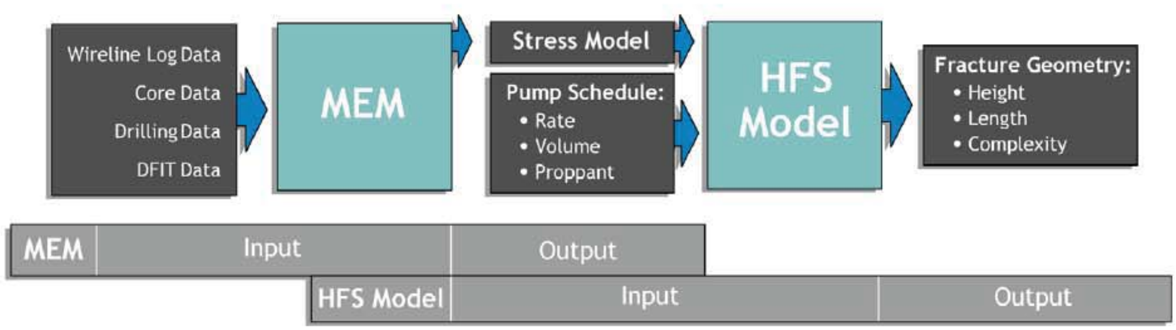


Figure 29.. MEM and HFS modelling workflow.

Next, the MEM was used as an input into Schlumberger's HFS modelling software. Each stimulation stage was modelled to determine fracture geometry (height growth, complexity, width and half length) for a given pumping schedule pumping schedule (rates, volume, and proppant). The pumping schedule was optimized through multiple iterations of modelling to achieve the desired fracture attributes while ensuring the fractures remained within the Velkerri B Shale (Figure 31a). The HFS models were also used to predict the fracture complexity. Results illustrated that fracture networks would have moderate complexity but remain relativity linear, with insignificant lateral propagation (Figure 31b).

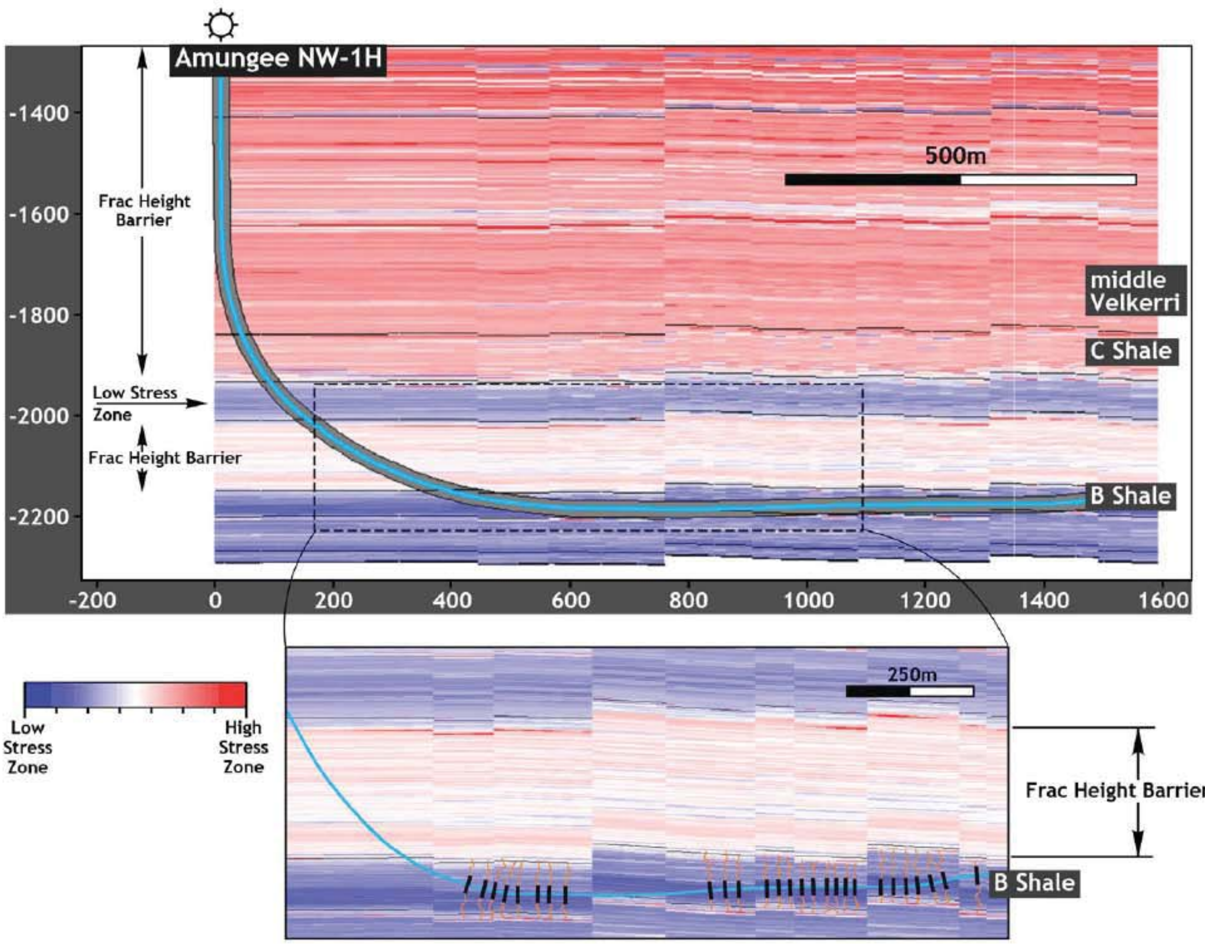
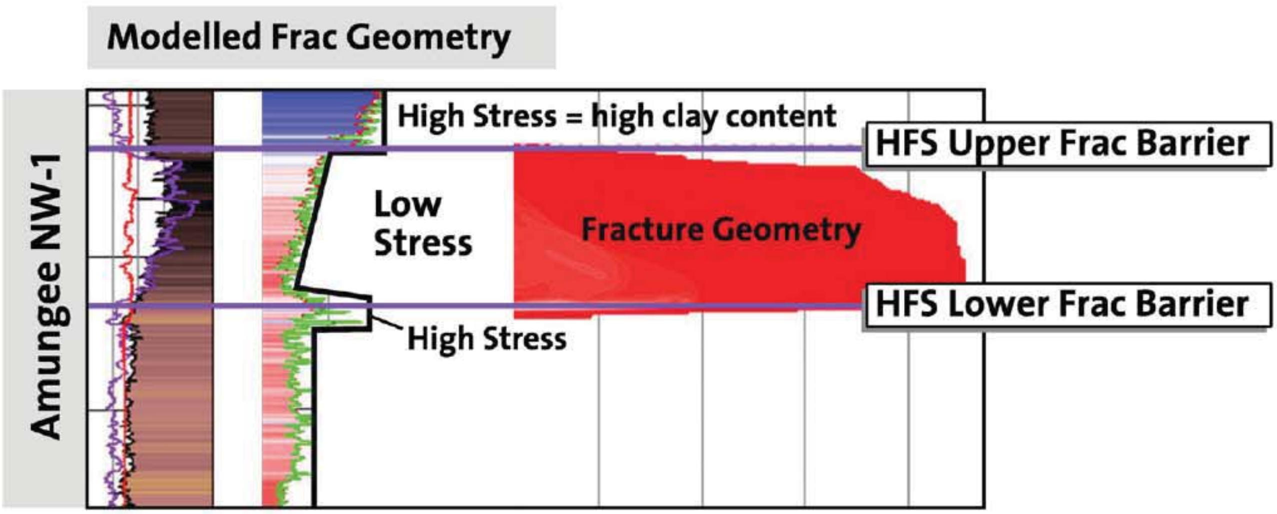


Figure 30. Major stress barriers and frac height barrier above the Amungee NW-1H lateral within the middle Velkerri.



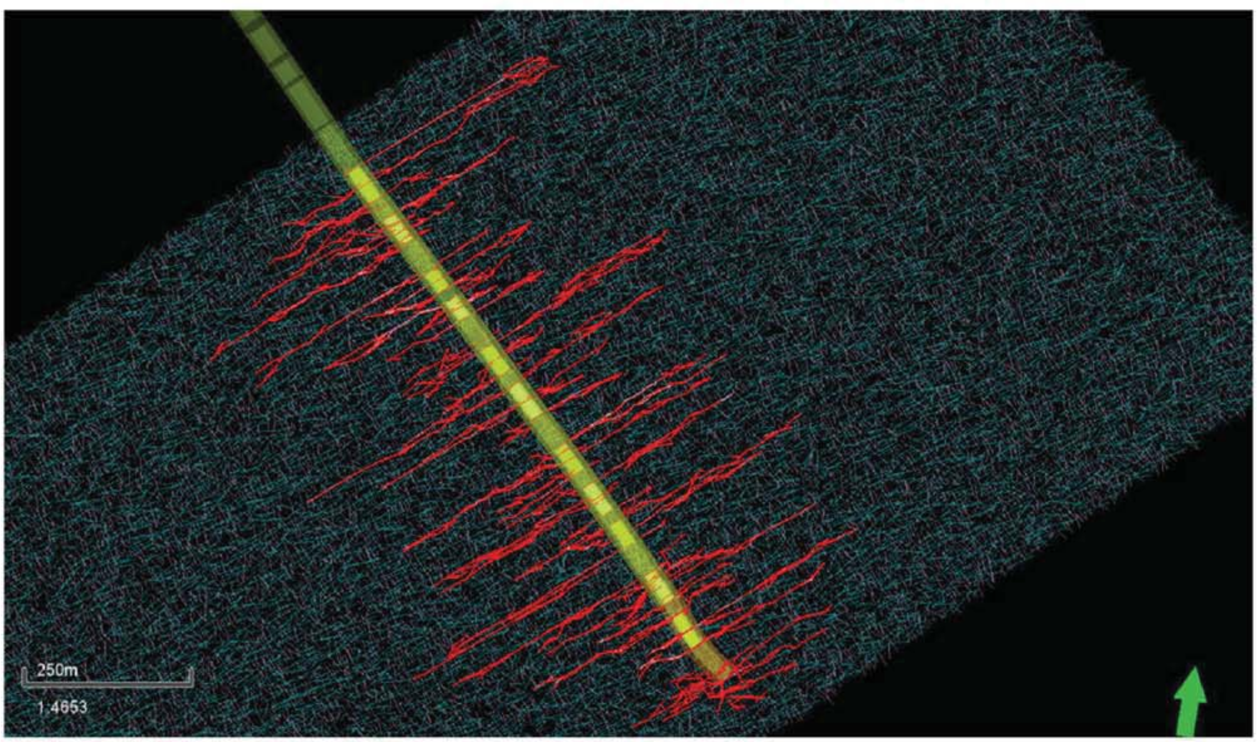


Figure 31.. a) Modelling of fracture geometry indicates very limited height growth due to stress contrasts around the target intervals within the middle Velkerri Formation; b) Prediction of fracture complexity (plan view).

Post stimulation, the actual pumping schedule for each stage was history matched against the pumping pressures to better understand the created fracture geometry. Assumptions from the MEM were adjusted until the modelled instantaneous shut in pressure (ISIP) and pressure fall off matched what was recorded on the actual pump job. The ISIP is used for this calibration process as it provides the best representation of the geomechanical system (i.e. is directly proportional to the net pressure) without external influences caused by the fracturing operation itself, such as fluid friction. The history matched HFS model for Amungee NW-1H confirmed that the most likely realisation is that the fractures were contained within the B Shale of the Velkerri Formation with minimal lateral propagation. The interburden between the B Shale and C Shale units acts as a resilient geological barrier preventing the generated fracture from propagating upwards into the C Shale, and certainly not out of the middle Velkerri Formation. It is estimated that on average the fractures have grown ~50m vertically and 150m laterally. The fracture networks created are certainly contained away from the fresh water aquifers 2000m above.

The substantial vertical separation that includes multiple geological barriers to fracture height growth is sufficient to ensure there is no chance of fractures propagating from the Velkerri Formation to the CLA (there is no reasonable scenario under which fractures would propagate outside of the middle Velkerri Formation let alone out of the upper Velkerri Formation).

4.2.3.2 Identifying and avoiding subsurface hazards and real-time pressure monitoring

Although there are currently no 3D seismic surveys in the Beetaloo, there are almost ~9,500 km of 2D data available. The data (examples of which are included in Chapter 14) illustrate that there are very few faults that extend through the Proterozoic and Cambrian sections that is there are very few major faults that offset strata at both the Velkerri Formation level and the level of the Cambrian Limestone Aquifer. The seismic data also demonstrate the strata within the basin (i.e. away from the steep flanks) are relatively gently dipping and unstructured with an absence of large scale, regional faults or structures. Hence, in the Beetaloo, Origin can avoid major structures that could provide pathways of pressure or fluid communication and therefore the opportunity for cross flow.

Operators are incentivised to avoid major faults as they can represent hazards to both drilling and HFS operations. But in addition to the ability to identify and avoid subsurface geohazards, real-time monitoring of pressures provides a secondary tool for managing risks of fault activation and fluid or pressure communication out of the target interval. During all HFS operations pressures are continuously monitored, if anomalous pressure behaviour is observed an HFS operation can be ceased almost immediately, thus preventing any substantial volume of fluid and or proppant being pumped into an open geological structure.

As outlined in Table 11 there are very few legacy wells in the Beetaloo that could provide a pathway if in connection with a major, open geological structure or fault. This risk can be effectively eliminated given the location and depths of the nine wells that have been drilled across the Permits are known.

4.3 Water quality: surface spill or water management related risks

Groundwater

- *There may be a risk of groundwater contamination as a result of:*
  - *surface spills of chemicals, flowback water or produced water into near-surface groundwater, and/or*
  - *re-injection of flowback water, produced water or treatment brines into a groundwater aquifer.*

Surface Water

- *There may be a risk of impacts on surface water quality as a result of the following types of incidents:*
  - *on-site spills, including as a result of extreme weather events such as cyclones and floods.*
  - *spills that occur during transportation of chemicals to or from the site during the development and production phases, and/or*
  - *spills of flowback water, produced water or brines produced by water treatment.*

Response and controls

Origin has demonstrated through its major unconventional gas development in Queensland that the risks to contamination of groundwater and surface water can be mitigated through following regulations and utilising best practice well and surface infrastructure design and construction techniques.

The risk of spills is highest during the chemical mixing and produced gas and water handling stages of the HFS process (Table 2). The oil and gas industry is not alone in needing to manage hazardous materials at surface and we minimise risk and consequence through processes and engineering.

4.3.1 Chemical mixing of hydraulic fracture stimulation fluid

This section covers the activities and the risk mitigating controls associated with the preparation of the HFS fluid for Amungee NW-1H (i.e. up until the HFS fluid enters the wellbore). Though specific to Amungee NW-1H the activities, risks, and controls would be similar to all HFS operations. Activities that are considered as part of the preparation of HFS fluid stage include:

- Design and disclosure of the HFS fluid.
- Transportation of additives to site.
- Storage of additives on site, and
- Handling and mixing of the base fluid, proppant, and additives on site.

4.3.1.1 Overview

The HFS fluids used to stimulate the Amungee NW-1H well were prepared on location as is standard. They are made by mixing a base fluid (water), a proppant (sand), and additives (chemicals) together using specialised equipment. Figure 32 provides a schematic diagram of the layout of hydraulic fracturing equipment used at Amungee NW-1H and would be very similar the layout at other HFS operations, the equipment is described in Table 12.

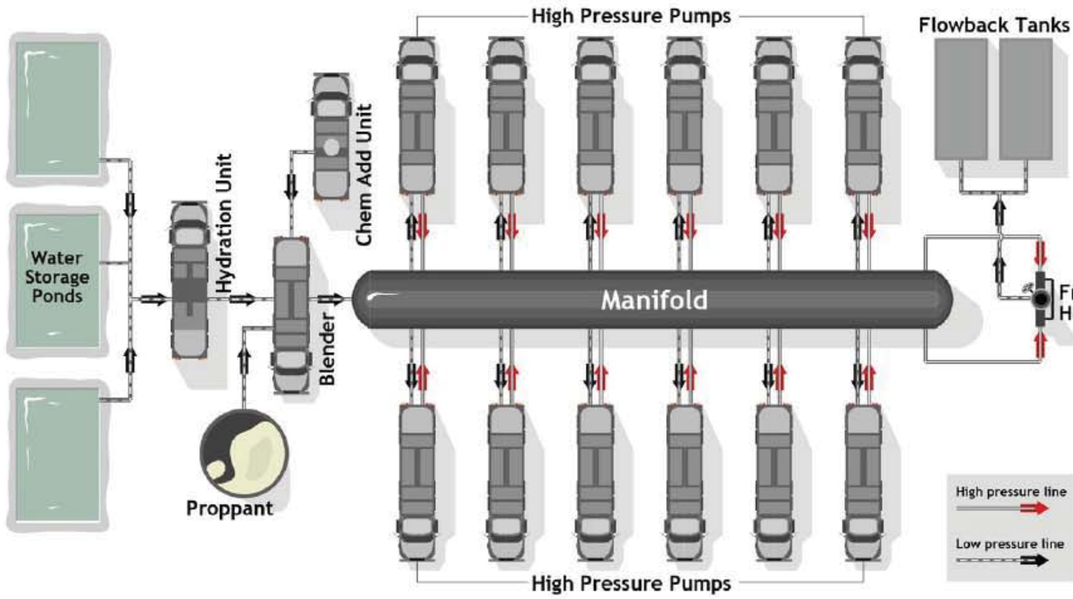


Figure 32. Layout of HFS equipment at Amungee NW-1H

EQUIPMENT	FUNCTION
Blender	Unit that blends in the proppant and remaining fluid additives after the hydration unit
Chemical storage	A dangerous goods rated trailer for chemical storage on location with secondary containment
Data van	Command center for HFS, monitors frac job, controls fracturing pumps and includes on site chemical testing laboratory
Flowback tanks	Flowback / produced fluid storage of fluids returned from the well
High pressure fracturing pumps	Takes fluid mixtures form the blender and delivers fluids to the wellhead at a high pressure/rate
Hydration unit	Unit that takes the source water and blends additives to form a linear gel fluid system
Manifold trailer	Fluid diversion equipment, diverts low pressure HFS fluids to the fracturing pumps and discharged high pressure fluids to the wellhead
Proppant storage	Holds and transfers proppant to the blender
Water storage	Source water storage if required volume for HFS
Wellhead/frac Tree	The mechanical barrier that allows the frac spread to be connected to the wellbore

Table 12. A description of equipment required for fracture stimulation operations.

origin

4.3.1.2 Fluid system

The HFS fluid was designed, tested, and assessed not only to meet the technical requirement of the Amungee NW-1H well, but also in the context of Origin's ability to safely handle the fluid pre- and post-stimulation. Due to the exploratory nature of the Amungee NW-1H well, two fluids systems were designed and made available on location for the HFS operations.

Slickwater (water based with fluid with friction reducing additives) was selected as the primary engineered fluid system for its ability to generate a complex fracture network and the reduced amount of fluid additives that could potentially impact the target reservoir performance. However, as there was limited offset HFS data, there was a concern that the slickwater HFS fluid would not effectively transport proppant into the fracture network. Therefore, contingency fluid additives were made available on location to change the fluids system into a hybrid design (hybrid describes the addition of primarily guar to increase the viscosity of the fluid). This alternative design was intended to increase fluid proppant carrying capacity during sand slurry stages thereby increasing the likelihood of placing all the proppant into the created fracture network.

After the first two slickwater HFS stages, it was observed that treating pressures progressively increased during the proppant slurry stages resulting in the HFS concluding prematurely (described in industry as a wellbore screen-out). The decision was made to switch over to a hybrid system (which includes gelling agents, such as guar gum, as an additive) for the remaining stages, which resulted in 100% job placement.

Every additive in the fluid system carries out a specific function. The additives, their concentrations, and their functions for both the slickwater HFS fluid and the Hybrid HFS fluid are presented in Table 13 and Table 14 respectively. The total volume of additives pumped at Amungee NW-1H is summarized in Table 15. Figure 33 illustrates graphically the composition of the HFS fluid, which was >99% water and sand. The remaining 1% comprised of the other chemical additives summarized above.

ADDITIVE	CONCENTRATION	FUNCTION
Source Water		Base fluid
Biocide	0.6 lb/Mgal	Controls bacteria growth in fluid
Clay Stabiliser	2.0 gal/Mgal	Prevents formation clay swelling
Friction Reducer	0.3 - 0.8 gal/Mgal	Reduces pipe friction in wellbore
Scale Inhibitor	0.5 gal/Mgal	Controls scale formation
Surfactant	2.0 gal/Mgal	Lowers surface tension
Hydrochloric Acid	15% (0.5% by volume)	Cleans up perforation and near wellbore damage
Silica Sand	2 lbs/gal	Prop fracture network open

Table 13. Additive description for the slickwater fluid design

ADDITIVE	CONCENTRATION	FUNCTION
Source Water		Base fluid
Biocide	0.6 lb/Mgal	Controls bacteria growth in fluid
Clay Stabiliser	2.0 gal/Mgal	Prevents formation clay swelling
Friction Reducer	0.3 - 0.8 gal/Mgal	Reduces pipe friction in wellbore
Scale Inhibitor	0.5 gal/Mgal	Controls scale formation
Surfactant	2.0 gal/Mgal	Lowers surface tension
Hydrochloric Acid	15% (0.2% by volume)	Cleans up perforation and near wellbore damage
Gelling agent (guar)	30 lb/Mgal	Base gel fluid for fluid viscosity
Cross linker	2.0 gal/Mgal	Increases fluid viscosity
PH buffering agent	1.2 gal/Mgal	Controls pH
Breaker	3.0 lbs/Mgal	Reduces fluid viscosity
Silica Sand	4 lbs/gal	Prop fracture network open

Table 14. Additive description for the hybrid fluid design.

The total volume of additives pumped at Amungee NW-1H is summarized in Table 15.

ADDITIVE	VOLUME	
Water	10,640	m^3
Hydrochloric acid	30	m^3
Microbiocide	1	m^3
Guar	29	m^3
Friction Reducer	4	m^3
Clay Stabiliser	21	m^3
Scale Inhibitor	5	m^3
Surfactant	20	m^3
Cross-linker	10	m^3
PH -buffer	6	m^3
High temp breaker	1	m^3
Sand	451	m^3

Table 15.. Total volumes of additives used in the Amungee NW-1H HFS operation.

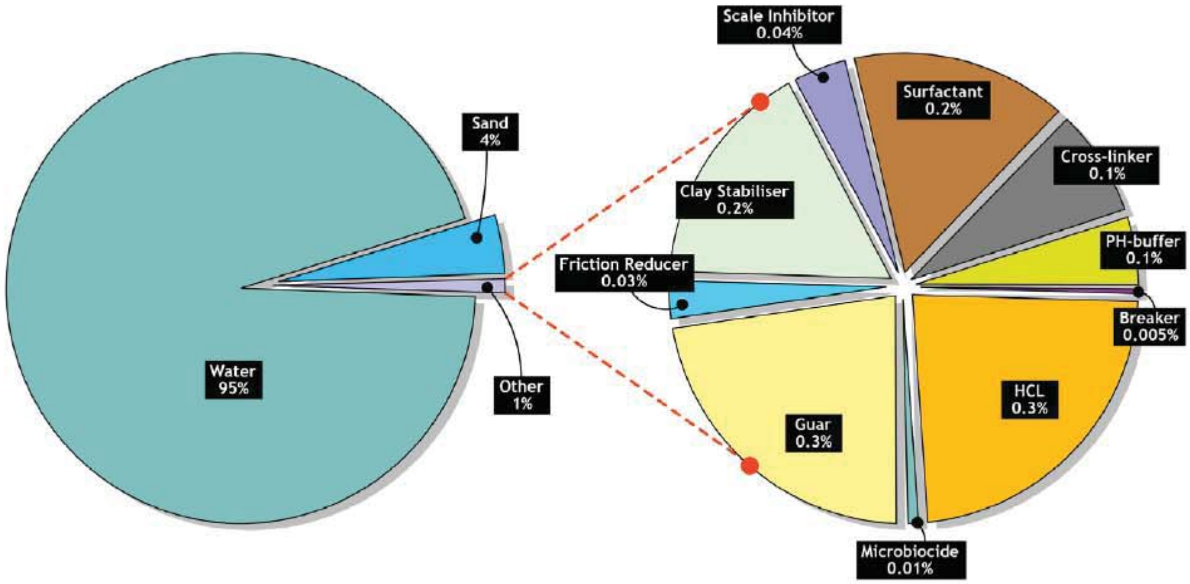


Figure 33. Breakdown of the composition of HFS fluid at Amungee NW-1H, additives make up a very minor component by volume and therefore the concentration of any given chemical is exceedingly low.

The use of additives is a highly regulated process within Australia. Origin's contractor for the HFS operations at Amungee NW-1h, Schlumberger, first had to register the chemicals with the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) to be allow for import into the country. All additives underwent a rigorous screening process to ensure it met Origin's technical expectation as well as its environmental and regulatory requirements. Each fluid system was screened for BTEX (benzene, toluene, ethylbenzene, and xylene) and PAH (polycyclic aromatic hydrocarbons) by a NATA (National Association of Testing Authorities) accredited laboratory.

As part of Origin's application for an authority to HFS, Origin provided the details of the two proposed fluids systems to the Department of Primary Industries and Resources (DPIR) and the Northern Territory Environmental Protection Authority (NTEPA). This is a requirement in the NT under the current regulations. The detailed chemical composition of all fluid additives are broken down and listed by the Chemical Abstract Service (CASE) number, along with estimated volumes and weights of each additive component. Origin selected additives that the service provider could fully disclose and does not anticipate any limitations to disclosure based on the intellectual property limitations of service companies.

At the conclusion of the HFS activity at Amungee NW-1H, a final, as pumped, fluid disclosure was submitted to the DPIR on a per zone basis. The full listing of additives as planned and as pumped has been submitted to the DPIR and is included in Appendix 5 (at time of writing the disclosed planned list was available on the DPIR website and we anticipate the as pumped list to be added in due course; *https://dpir.nt.gov.au/mining-and-energy/public-environmental-reports/chemical-disclosure-reports*).

4.3.2 Produced gas and water handling

Following the completion of HFS operations, the Amungee NW-1H site was prepared for flowback and production testing (Figure 34). Above ground, double lined ponds that had been used to store water used in HFS were now available for storage of flowback fluids (the tanks had been thoroughly tested as they held the fresh water used in the HFS phase for a number of weeks).

Flowback fluids, which are primarily made up of the frac fluid mixture, were stored in these ponds where they were allowed to evaporate as much as possible prior to the wet season to minimise the amount of material requiring disposal. As a condition of the Amungee NW-1H Environmental Management Plan (EMP), a freeboard of at least 0.5m was required at all times during the storage of flowback fluids to allow for the accommodation of a 1 in a 100 year frequency-intensity-duration rainfall event (>350 mm within 72 hours). All remaining produced fluids at the end of the production test were trucked off location to an approved waste disposal facility in Queensland.

All hydrocarbons produced during the flowback and testing phase were directed through a temporary test package to accurately measure the rates and then burnt via a flare. A flare is used to burn off the hydrocarbon content as it is the safest method of handling hydrocarbons rather than venting to atmosphere.

As the project moves towards a development phase, water recycling and permanent fluid handling facilities will be constructed to manage the produced fluids eliminating the need for temporary fluid storage. Historically, in analogous types of developments, less than 50% of the fluids injected during HFS are recovered during production/flowback of the well.

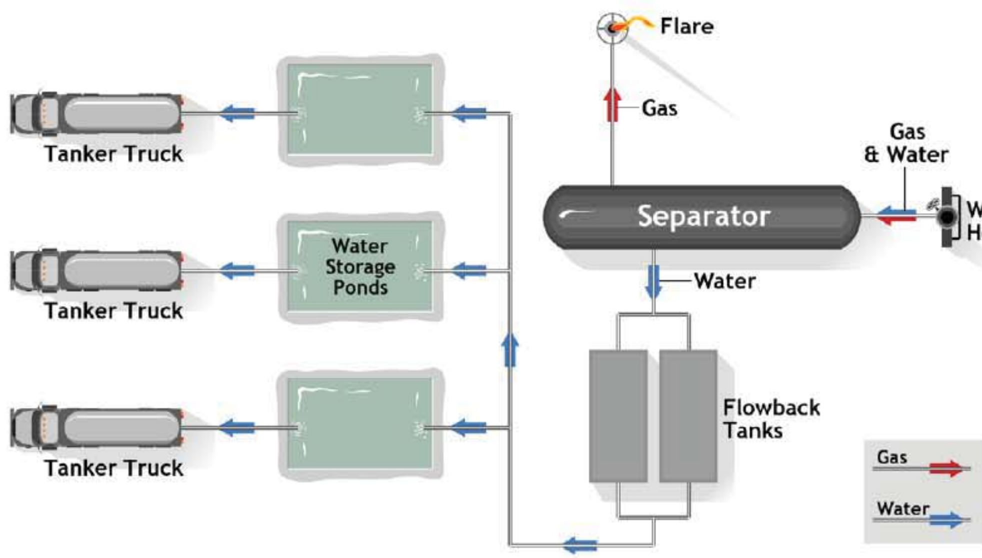


Figure 34.. a) A schematic representation of the Amungee NW-1H well during the flowback and production testing phase, and b) an aerial photograph of the lease during the same phase showing the above ground ponds.

4.3.3 Risks – surface spills

The primary risk in the chemical mixing and produced gas and water handling stages is the potential for spilled fluids to reach and impact ground or surface water resources. The specific factors that have the potential to affect the frequency and severity of impacts include the size and type of the fracturing operation; volume, mass, and concentration of chemicals spilled; type of chemicals and their properties; combination of chemicals spilled; environmental conditions; proximity to drinking water resources; employee training and experience; quality and maintenance of equipment; and spill containment and mitigation.

Origin has already undertaken site-specific contamination modelling (Knapton and Fulton, 2015). Drilling fluid leakage modelling (i.e. from a 3125 m^2 retention pond) undertaken prior to the drilling in 2015 found that the likelihood of groundwater contamination resulting from surface spillage is low when taking into consideration:

- the water table depth (> 90 m).
- the barrier presented by clay layers between the surface and aquifers.
- likely spill volumes.
- the short response timeframe for spill containment/remediation, and
- the existing standard controls and management procedures in place to prevent such spills.

4.3.4 Controls

Origin has a three tier barrier philosophy in place to prevent spilled fluids from reaching or impacting ground or surface water resources:

- Spill prevention.
- Spill containment.
- Spill remediation.

4.3.4.1 Transportation to site: spill prevention and containment

All fluid additives were transported to the Amungee-NW-1h lease with primary and secondary containment measures. Transport of additives to location adhered to the Australian Code for the Transport of Dangerous Goods by Road & Rail (7th edition).

Origin ensures that additives are stored and transported in properly designed primary containment. Liquid fluid additives are housed in Intermediate Bulk Containers (IBC), which are constructed from a high density polyethylene thermos plastic material and protected by a steel cage to maintain the structural integrity of the container.

Secondary containment measures were used to mitigate the risk of a spill in the event the primary containment failed. All the additives that were transported to the Amungee NW-1H lease were transported in trucks that had secondary containment on the trailer beds. In the event there had been a breach in integrity of the IBC (primary containment) the secondary containment is designed to prevent/ mitigate any uncontrolled release of chemicals to ground. No spills or losses of primary containment occurred during the transportation of additives to the Amungee Pad.

4.3.4.2 Storage on site: spill prevention and containment

All fluid additives were stored on the Amungee NW-1H lease with primary and secondary containment measures.

The same properly engineered primary containment storage units, IBC that the additives were transported in were used to store the additives on the lease.

The additives were either stored on the trailer they were transported on or if the additives were required to be on ground level they were placed on top of spill matts to prevent chemical migration to ground level in the event of a breach of the primary containment. No spills or losses of primary containment occurred during the storage of additives on the Amungee Pad.

4.3.4.3 Mixing of fluid, proppant, and additives on site: spill prevention and containment

Prior to mixing the additives and pumping the HFS job at Amungee NW-1H the operational integrity of the entire system was tested. Pressure tests were conducted, up to the maximum operating pressure, with fresh water to identify any leaks. Any leaks in the system that were identified were remediated and the system was re-tested. The HFS job at Amungee NW-1H did not proceed until the integrity of the surface equipment was validated.

At the end HFS job all the frac spread lines were flushed with fresh water. This ensured that there was no HFS fluid remaining in the surface lines before breaking the connections apart.

During the rig up and rig down process at the Amungee NW-1H well, standard operating procedures (SOPs) were followed to reduce the likelihood and/or impact of a potential spill. Areas that had a potential to have a spill to grade (e.g. hose connection points) were equipped with spill matts. Furthermore, SOPs required spill mats to be in place any time connections or lines containing additives were broken. This ensured that if any spillage occurred that it was contained and did not reach the environment. No spills or losses of primary containment occurred during the handling and mixing of additives during the Amungee NW-H HFS operations.

4.3.4.4 Flowback and production testing: spill prevention and containment

During the exploration phase of the Beetaloo, fluids produced back to surface will continue to be stored in temporary storage tanks with dual liners for fluid containment. The tanks are commissioned and tested with a clean fluid (fresh water) to validate their integrity before any produced fluids are transferred into them. For the Amungee NW-1H stimulation operations, modular surface tanks were selected for its ability to store the volumes required for stimulation and to maximise fluid surface area exposure for optimal evaporation.

Fluid levels in each tank were monitored daily and operated with a minimum of 1 m free board (double the EMP approved freeboard requirement of 0.5 m) when used for produced fluid storage as a contingency, in the event a severe rain event added fluid volumes to each tank (a 1 in 100 year frequency-intensity-duration rain event for the region based on historical data). Transfer pumps were set up to easily transfer fluids between tanks to control fluids levels of all four tanks.

As mentioned above the storage tanks had dual liners. The second liner acts as secondary containment.

4.3.4.5 Spill Response and Management Plan

If a spill were to have occurred during the HFS operations at the Amungee NW-1H lease Origin would have been prepared to respond and mitigate any consequences. Origin and the HFS service provider have an aligned Site Safety Management plan, which outline the protocols to action in the event of a loss of containment (Appendix 6 – Stimulation & Well Testing Oil Pollution Emergency Plan). At Amungee NW-1H spill kits were on location as well as access to a vacuum truck to remediate any hazards immediately if required during HFS operations. The HFS contractor is responsible for conducting routine drills for spill response and onsite inventory checks. In the unlikely event of a spill that is not contained, the lease is remediated. Any contaminated product (e.g. soil) is taken off location and disposed of at an approved waste disposal facility.

4.4 Quality: other risks

There may be a risk of groundwater contamination as a result of re-injection of flowback water, produced water or treatment brines into a groundwater aquifer

Response and controls

The re-injection of flowback fluid is not currently planned or envisaged and under no circumstances, except where water is treated to the same standard as the aquifer water and regulatory approval is provided, would injection into an aquifer occur.

This early in the planning stage of the project, Origin does not yet know how the water used in fracture stimulation will be disposed following treatment. Different methods are used across the industry – onsite treatment and recycling, deep disposal well injection, and/or removal for off-site disposal. Each of these approaches will be investigated for its suitability in the Beetaloo Basin context and within the regulatory framework.

There may be a risk of groundwater contamination as a result of induced connectivity between different groundwater systems as a result of seismic activity caused by hydraulic fracturing or reinjection of water.

Response and controls

Induced seismicity and associated risks in the Beetaloo are considered low.

The pressure exerted in hydraulic fracture stimulations is not sufficient to induce seismicity of a magnitude capable of deforming the approximately 1.5 km of heterogeneous layers (each with different mechanical properties) separating the Velkerri Formation from utilised aquifers (Knapton and Fulton, 2015). See section 14.7.2 for additional information on seismicity in the Northern Territory and Beetaloo Basin.

4.5 Water supply and distribution (quantity): supply risk

There may be a risk of adverse environmental impacts as a result of reduced water supply due to the large amounts of water being extracted for use in hydraulic fracturing

Response and controls

Origin considers the sustainable use of water is a fundamental principle for the unconventional gas industry. Origin will minimise impacts on other water users through strong water resource planning, minimising water use through recycling and monitoring. Examples include:

- *Flowback recycling.*
- *Use of non-potable groundwater sources where practicable.*
- *Groundwater monitoring to detect drawdown from HFS and cumulative activities.*
- *Surface water monitoring to detect potential impacts form industry related to HFS activities.*

The risk associated with water sourcing for HFS operations is that the withdrawals may impact an aquifer at a regional or local scale. This could arise if the water withdrawals exceed water availability. Potential consequences include reduced water availability or the alteration of ground water quality at either local or regional scales.

To better understand risks associated with water withdrawals and availability at a regional level in the Beetaloo Origin commissioned the Knapton and Fulton (2015) study in 2014 (this study has previously been provided to the Inquiry). This study shows that the CLA's water availability far exceeds current water withdrawals. The regional CLA can support withdrawals to support a large scale development. In addition to the Knapton and Fulton (2015) study, Origin has a regional ground water monitoring program in place to collect baseline data on ground water levels and quality within the CLA and to assess any impacts resulting from HFS activity. The data shows no regional impact to the CLA.

4.5.1 Regional impact assessment

For Origin's Beetaloo Basin project approximately 50-60 ML of water[7] is expected to be required to drill and stimulate a well. Once stimulated, a well may be productive for 25-30 years without the need for additional stimulation. By approximately year eight of a large scale development, recycled water could form a significant component of the water used for stimulation (we have assumed up to 30% for the purposes of water usage modelling associated with development).

During peak production the notional development could have up to 57 well pads active, with each pad comprising of eight wells. The stimulation of these 456 wells will be staggered over approximately 24 years. Average annual total water usage is forecast at 1,200 ML/year of which we forecast 30% is recycled and, therefore, approximately 840 ML/year of groundwater is required (Figure 35). Peak

7 The Amungee NW-1H well used ~10 ML for the HFS of 11 stages across ~750m of effectively stimulated lateral length. Our development assumptions are based on a 3 km long lateral section with 30-50 HFS stages per well; which is similar in scope to current analogues in North America such as the Utica and Marcellus shale plays. Although water usage is greater per well, there are less wells required than when shorter laterals and less HFS stages were typical. Therefore, the overall water volume is not increased and the total impact of a development is decreased by making each well as efficient as possible. More Beetaloo specific data are needed to understand how much water is required per well, and also how much of the pumped fluid will flowback and can be recycled – these data could be acquired during a low impact appraisal phase.

total water usage, including recycled flowback fluid, for drilling and stimulation is forecast at 2,600 ML in approximately 2028 (Figure 35). The construction, development and operations phases will have additional water requirements typical of those for a large-scale development in the region – but these are not expected to exceed a few megalitres per year.

Primarily drawing upon the CLA, Origin intends to use multiple bores spread across the Development Area to minimise local drawdown. The CLA is the principal water resource in the basin; the sustainable yield from the Georgina Basin (which includes the CLA) is estimated to be in the order of 100,000 ML/year (NALWTF 2009). Existing groundwater use in the Beetaloo Basin is estimated at 6,000 ML/year or 6% of the sustainable yield (Knapton and Fulton 2015). An additional ~840 ML/yr groundwater usage (on average) would increase the projected extraction from the CLA to ~6.8% of the estimated water resource available from the CLA in the Georgina Basin.

Where practicable, Origin will investigate using other available aquifers that are not currently utilised as they are not practically, or economically, accessible for other users and/or contain water that is unfit for human or livestock consumption. Such investigations have not yet been required, due to the exploration phase of the project where water requirements are negligible.

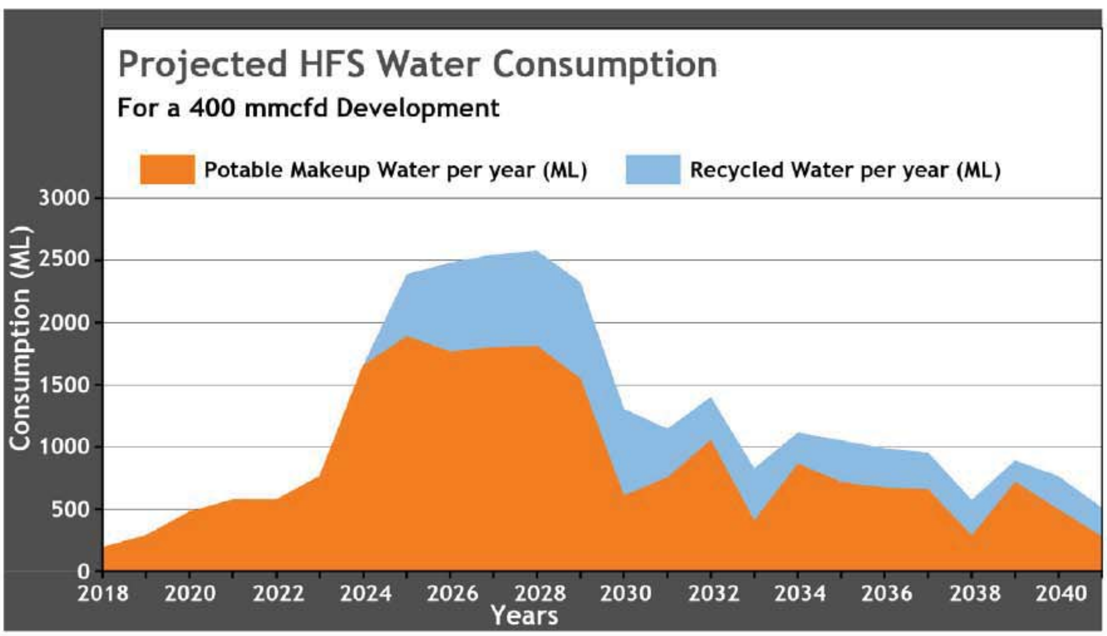


Figure 35.. Indicative water requirements for a full field gas development producing approximately 400 mmscf/d.

4.5.2 Local impact assessment

To better understand risks at a local level, Origin has analysed ground water data from around the Amungee NW-1H lease during preparation for the HFS operations when water extraction from the CLA was at a maximum. Approximately 10 ML were sourced from the CLA from three nearby water bores for the HFS operations at Amungee NW-1H between August and September. 2016. Table 16 summarises the withdrawal from the three bores and Figure 36 shows the location of the bores in relation to Amungee NW-1H.

BORE ID/RN	OWNER	FORMATION	ESTIMATED VOLUME WITHDRAWN	WITHDRAWAL DATES
Amungee NW-1 Waterbore 1	Origin	Cambrian Limestone Aquifer	3,758 m^3	August 1 – September 7
Amungee NW-1 Waterbore 2	Origin	Cambrian Limestone Aquifer	4,666 m^3	August 1 – August 8 & August 22 to August 28
RN 5942	NTG Roads and Highways Department	Cambrian Limestone Aquifer	1,576 m^3	August 29 to September 3

Table 16.. Summary of CLA withdrawals associated with the HFS operations at Amungee NW-1H.

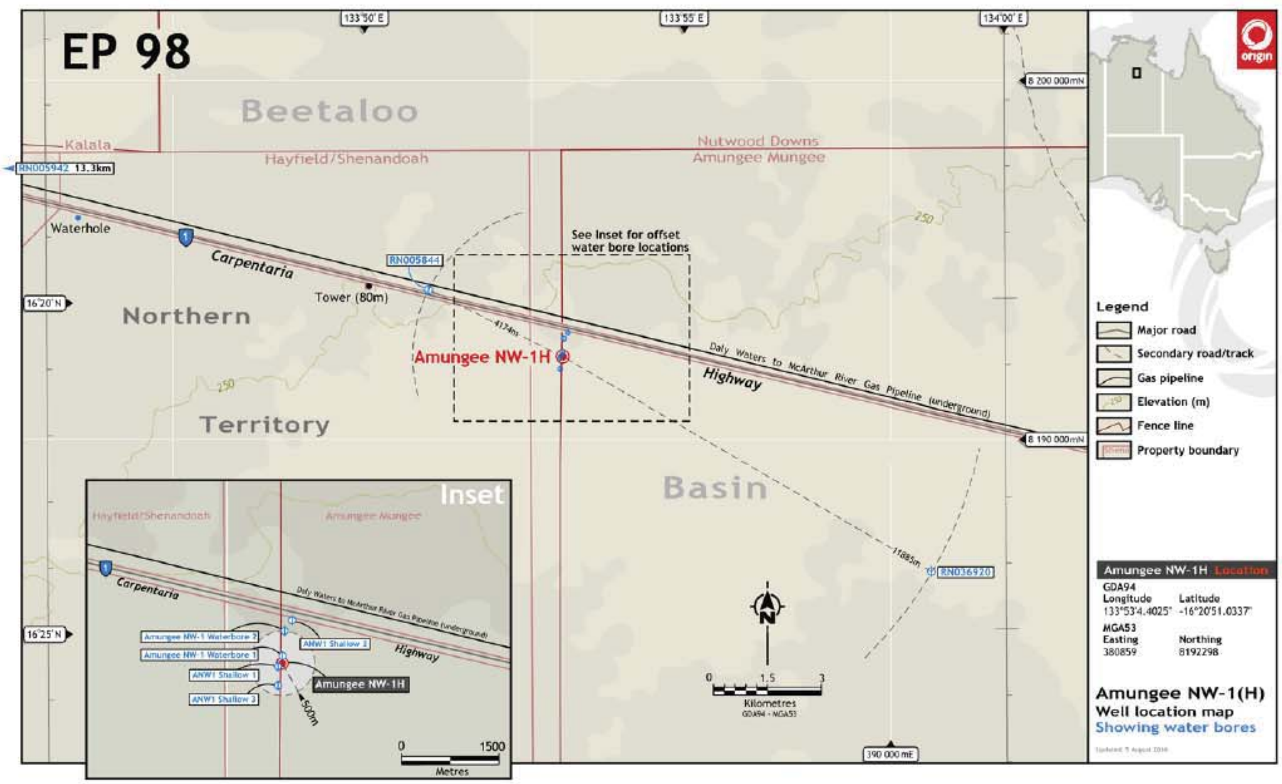


Figure 36.. Location of water bores included in Table 16 and used to source water for the Amungee NW-1H HFS.

Water was extracted from the Amungee NW-1 waterbores at a combined rate of 7.5-10 l/s. Due to the pump failure at Amungee NW-1 Waterbore 2, additional water was procured from a third bore (RN5942) and transported to location. Water level data (pressure loggers) and water quality (sampling) collected pre and post water withdrawals show no impact to the CLA. Pressure logger data from the Amungee Waterbore 1 (Figure 37), shows the drawdown before, during and after water acquisition for the HFS operation. The plot clearly shows no impact to the local water level as a result of the volume withdrawn, as the drawdown level immediately rebounds to pre-withdrawal level each time the pumping ceases.

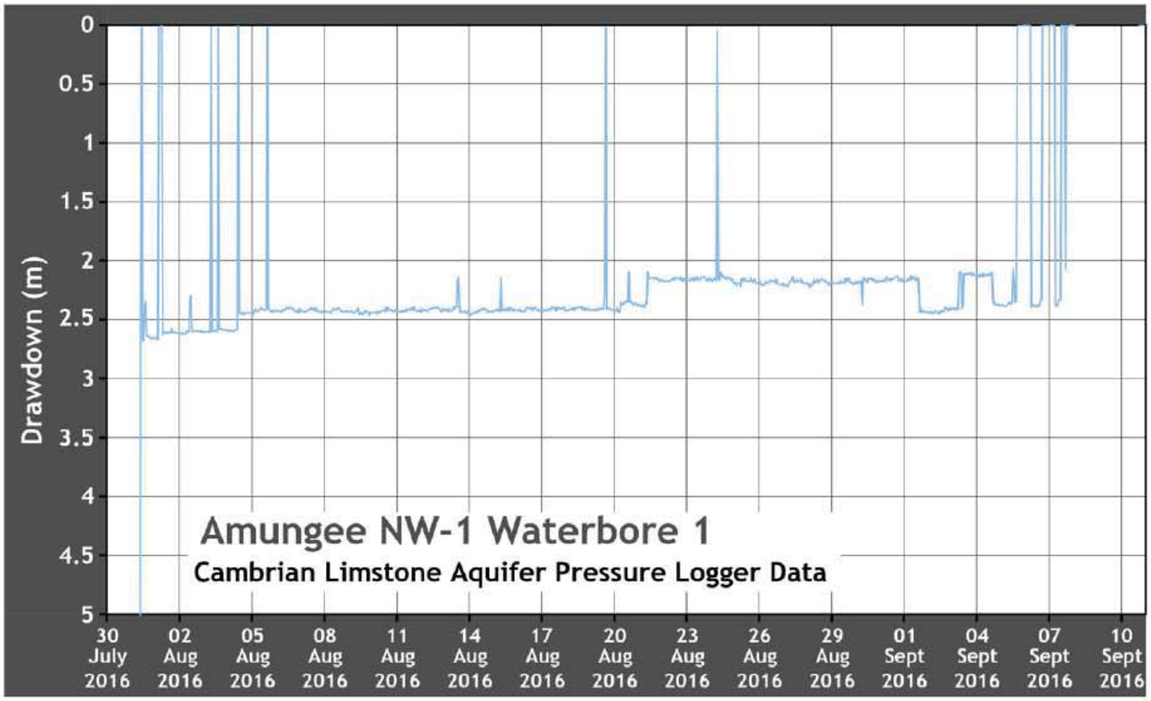


Figure 37. Pressure logger data from the Amungee Waterbore 1

4.6 Water supply and distribution (quantity): discharge or distribution risk

There may be a risk of changes to the timing and/or quantity of surface water flows because of the discharge of produced water, which may be significant particularly in arid to semi-arid landscapes

Response and controls

Origin does not plan on discharging any flowback or produced fluid to the environment.

Origin does not anticipate discharging any flowback or produced fluid to the environment. If a beneficial use for processed flowback fluid was identified, then the appropriate approvals for the specific use identified would be sought at that time. It is not anticipated that there will be any produced water associated with gas production.

4.7 Water supply and distribution (quantity): seismic activity risk

There may be a risk to surface water and groundwater flow processes as the result of possible seismic activity caused by hydraulic fracturing or reinjection of water.

Response and controls

Induced seismicity and associated risks are considered low for the Beetaloo.

Seismic activity of sufficient magnitude to be felt at the surface in the Beetaloo area is very rare (see Chapter 14.7). It is considered very unlikely that HFS activity will induce seismic activity of sufficient magnitude to be felt. The likelihood that a sufficiently large earthquake is induced that would cause offset at the surface sufficient to change established surface water and groundwater flow processes is remote (see Chapter 14.7).

4.8 Aquatic ecosystems and biodiversity

There may be a risk of adverse impacts on aquatic ecosystems and biodiversity, including groundwater dependent ecosystems. This may result from changes in the quality and/or quantity of surface and/or ground water available to them.

Response and controls

Origin is committed to the preservation of aquatic ecosystems and biodiversity and will assess the potential impacts and appropriate controls during a formal impact assessment phase through well defined regulation and well established industry controls. These controls include; well design, integrity management, water recycling, infrastructure design, monitoring, implementation of regional baseline and ongoing surface water monitoring programs and the design of infrastructure to divert overland flow and stormwater ingress to prevent surface water contamination.

Large areas of the Wiso drainage basin have no apparent surface drainage – including the Development Area. The nearest significant watercourse is Newcastle Creek approximately 50 km to the south. Permanent or semi-permanent natural surface water is limited. As such, there are no known aquatic ecosystems and associated biodiversity within the influence of the potential Origin development.

As there are no proximate watercourses or apparent drainage, there is no potential to impact aquatic ecosystems.

4.9 Amenity values

There may be adverse impacts on general amenity values such as national parks, rangelands and recreational fishing areas. This may result from changes in the quality and/or quantity of water available.

Response and controls

Origin is committed to reducing the impact to amenity values by working with the community to understand key amenities and ensuring controls are in place, like appropriate separation distances..

For the reasons presented in this chapter, Origin does not anticipate, as a consequence of a gas development, any significant changes to the quality or quantity of surface or groundwater that supports existing amenity values in the region.

4.10 Public health

There may be adverse impacts on human and livestock health due to changes to water quality, supply and distribution as a result of hydraulic fracturing and the associated activities.

Response and controls

Origin will not use water in such a way that impacts upon human or livestock health are triggered.

For the reasons presented in this chapter, Origin does not anticipate, as a consequence of a gas development, any significant changes to the quality or quantity of surface or groundwater available for human and livestock consumption.

4.11 Aboriginal people and their culture

Natural water bodies are central to traditional land use and many sites of significance to Aboriginal people relate to water. A reduction in either water quantity or quality may impair the traditional use and/or value of the sites.

Response and controls

Origin will not use water in such a way that impacts the Traditional Owner use of, or other values of cultural sites.

For the reasons presented in this chapter, Origin does not anticipate, as a consequence of a gas development, any significant changes to the quality or quantity of surface or groundwater that currently supports Aboriginal land use and sacred sites.

4.12 Economic

Changes to water quality, supply and distribution may have an adverse impact on industries that may co-exist with the onshore unconventional gas industry, such as agriculture, pastoralism and tourism.

Response and controls

Origin is committed to the preservation of the existing agriculture, pastoralism and tourism industries and the aquatic ecosystems and biodiversity that underpins these industries. Origin will assess the potential impacts and appropriate controls during a formal impact assessment phase.

For the reasons presented in this chapter, Origin does not anticipate, as a consequence of a gas development, any significant changes to the quality or quantity of surface or groundwater used in potentially coexisting industries.

4.13 Cumulative risks

There may be cumulative risks associated with some or all of the risks identified above.

Response and controls

Origin acknowledges that cumulative risks need to be understood and assessed as part of any formal project impact assessment. As a part of regional shale gas development, Origin is supportive of the development of a regional environmental monitoring program delivered by GISERA or another independent body.

For the reasons presented in this chapter, Origin does not anticipate a consequence of a gas development to be any significant changes to the quality or quantity of groundwater or surface water.

5 RISK THEME 2: LAND

The Land Risk Theme is focused on impacts to land, flora and fauna of HFS and associated gas development activities.

Existing environment: The core area of the Beetaloo Basin and the proposed location of a potential development hosts limited sensitive vegetation or threatened species and land is currently primarily used for cattle grazing; this provides an ideal environment to coexist with gas development without opening up any current wilderness areas.

Minimising our impact: Origin collaborates with landholders to design infrastructure that is located to minimise disturbance to their business. Even where there are no landholder impacts, Origin always seeks to minimise land impacts through constant optimization of surface infrastructure.

5.1 Background and existing environment – contextual statement

5.1.1 Bioregion

A bioregion is an area of land with common climate, geology, landform, native vegetation and species (DoEE, 2009). The notional Development Area is primarily located within the Sturt Plateau Bioregion, which occupies over 98,000 km^2 and comprises undulating plains, with predominantly neutral sandy red and yellow earth soils (Baker et al., 2005). The most extensive vegetation is Eucalypt woodland with tussock grass or spinifex understorey, but there are also large areas of lancewood (*Acacia shirleyi*) thickets, and bullwaddy (*Macropteranthes kekwickii*) woodlands

Typical land use within the region is for cattle grazing/pastoralism, with varying levels of development on the different pastoral stations the Permits cover. On some stations, such as Beetaloo Station, a substantial number of water bores and water distribution networks have been installed to increase the area that cattle can graze across the Station. Grid fencing has also been installed on some stations to allow the rotation of cattle in a systematic fashion without overgrazing a given area. Land condition in the bioregion is moderate to good but is threatened by impacts from weeds, feral animals, pastoralism and changed fire regimes (Baker et al., 2005).

5.1.2 Vegetation communities

Vegetation communities within and around the Development Area have been mapped and ground-truthed. The main vegetation communities within the general area are woodlands (Figure 38), typically dominated by bloodwoods (*Corymbia spp.*) and tall shrublands and woodlands of Bullwaddy and Lancewood with open grassland understorey. There are also small areas of Melaleuca woodland over grassland within the Development Area. These are also the most widespread vegetation types in the Sturt Plateau bioregion.

There is little to no sensitive vegetation within the Development Area. Sensitive vegetation is that deemed of special importance for conservation within the Northern Territory. Such vegetation communities include riparian vegetation, wetland vegetation, monsoon vine forest and old growth forest. The Development Area is in a location where there are no watercourses or wetlands, and which does not contain monsoon vine forest or old growth forest.

Figure 38. Photographs of indicative dominant vegetation at Amungee NW-1 (top) and Beetaloo W-1 (bottom).

5.1.3 Threatened Species

The proposed Development Area occurs in an area where there are very few records of threatened species compared to the savannah woodland habitats to the north and in the arid lands to the south. Although there are old records of threatened species proximate to the Development Area, almost all are of species whose ranges have since contracted northwards or southwards away from the Development Area. The bulk of the remainder of records are of nomadic species that can occur year-to-year anywhere in central Australia.

5.1.3.1 Fauna

To determine which threatened species (listed under the federal *Environment Protection and Biodiversity Conservation (EPBC) Act* (1999) and/or the NT *Territory Parks and Wildlife Conservation (TPWC) Act*) have the potential to occur within the Development Area, a desktop analysis was undertaken, informed by the results of the Commonwealth and NT threatened species search tools. For each fauna species, the likelihood that the species occurs within the potential impact area was then assessed based on habitat requirements, distribution, and the number and dates of proximate records. The review produced a list of five fauna species that can be considered as having a 'low' likelihood of occurrence within the Development Area (Table 17). That means that apart from the occasional vagrant, it is not expected that this species occurs, as there is no suitable habitat for the species and/or threatening processes in the region are known to have significantly impacted the species.

SPECIES	STATUS		NOTES
	CWLTH	NT	
Varanus panoptes **Floodplain Monitor**	-	Vulnerable	No records, but a habitat generalist known from the region.
Erythrura gouldiae **Gouldian Finch**	Endangered	Vulnerable	Occasional, foraging only, and no recent records.
Falco hypoleucos **Grey Falcon**	-	Vulnerable	Occasional, foraging only, nearby recent records, more likely in floodplain areas south of the Development Area)
Grantiella picta **Painted Honeyeater**	–	Vulnerable	Occasional in the NT when migrating from breeding area on east coast.
Rattus tunneyi **Pale Field-rat**	–	Vulnerable	One recent record nearby, but this is far from the species' known distribution.

Table 17. Threatened species which may occur within the Development Area.

Fauna surveys conducted in the area in 2014 found no threatened species. Species considered to be Near Threatened in the Northern Territory were recorded: Spectacled Hare-wallaby, Northern Nailtail Wallaby, Australian Bustard, Emu, Bush-stone Curlew, Western Chestnut Mouse, Chameleon Dragon and King Brown Snake. One species listed federally as Migratory was recorded – Rainbow Bee-eater.

5.1.3.2 Flora

No threatened flora species are recorded from, or are considered likely to occur within the Development Area.

5.1.4 Threatening Processes

As some of the possible risks identified in the Issues Paper refer to the industry's potential to contribute to threatening processes to biodiversity. This section provides a summary of the existing threatening processes relevant to biodiversity conservation in the Beetaloo.

5.1.4.1 Fire

According to the Northern Australia and Rangelands Fire Information database, the Development Area is within a region which has burnt relatively consistently in recent years, with most of the area affected between three to nine times in the past sixteen years – with the latest burn occurring in the past few years. Nearly all those fires occurred in the dry season (June to September) when fires are likely to be high intensity.

'Hot fires' usually start with lightning strikes or are accidental, and are something graziers seek to avoid by engaging in management practices to reduce fire risk. One means is by having the right stocking rate of cattle eat the grass and thereby reduce the fuel load through production. This works well for an average wet season, but can be disrupted in an above average year because the cattle cannot keep up with pasture growth. Landholders also ensure that fire breaks are in place around critical areas (mainly adjacent to highways because of travellers lighting fires). Active, controlled burning of 'cool fires' – i.e. of grass that is still partially green – is also undertaken to reduce fuel loads.

Surveys in 2014 at points near the Development Area showed evidence that fire had affected habitat condition – including large scale Acacia die-off at one site and reduced habitat logs at another.

5.1.4.2 Grazing

A study of Australian landscape health was undertaken as part of the Commonwealth National Land and Water Resources Audit to assess regional landscape health from the perspective of biodiversity and natural ecosystems. As part of this assessment, the grazing pressure within and around the Development Area was assessed as generally being low.

Field surveys near to the Development Area determined that there limited evidence of grazing pressure. There was no observed impact to land structure (i.e. erosion or compaction of soils) at any of the sites; however, there were signs that grazing stock had decreased understorey grasses and habitat quality at one site.

5.1.4.3 Weeds

There are a number of weeds known to occur within the Sturt Plateau bioregion. The August 2014 surveys near the Development Area found a low number of weed species, suggesting good habitat condition for biodiversity in the surrounding area. However, two listed species – Parkinsonia and Hyptis - were recorded during the survey. It is possible that additional species were present but were difficult to identify at this time of the year.

Parkinsonia is considered a Weed of National Significance (WoNS), and hence is a focus of national management programs for the purpose of restricting its spread and/or eradicating it from parts of Australia. Hyptis is declared a class B weed within the Northern Territory, meaning that its growth and spread are to be controlled.

5.2 Terrestrial ecosystems

5.2.1 Vegetation clearing

There may be a risk of vegetation loss on a local scale as a result of areas being cleared for roads, pipelines and drill pads or as a result of spills.

Response and controls

Origin is committed to the preservation of terrestrial ecosystems and biodiversity. Origin manages impacts to the terrestrial ecosystem and biodiversity through a gated disturbance approvals process, which reviews all the constraints including vegetation and seeks to avoid, minimise, mitigate and offset the residual impacts if required.

The local scale, in this specific instance, is a subset of the Development Area where disturbance will occur. A preliminary estimate of the disturbance associated with each well pad is 14 ha (0.14 km2). This area includes disturbance for: the well pad, pipeline connections and access roads. Based on a forecast of ~50 well pads within the Development Area, the total disturbance area per Development Area over the life of the Project is 700 ha. This equates to 1.4 % of the Development Area.

As noted in Section 5.1, the main vegetation communities within the Development Area are woodlands typically dominated by bloodwoods (Corymbia species) and tall shrublands, and woodlands of Bullwaddy and Lancewood with an open grassland understorey. These are also the most widespread vegetation types in the Sturt Plateau bioregion. Origin's Disturbance Approval process (e.g. Chapter 2.3) limits the risk of development in areas of high biodiversity value (such as a matter of national environment significance or threatened species). If avoidance is not possible, however, the use of offsets may be required as per the NT EPA guideline of Environmental Offsets and Associated Approval conditions and Environmental Protection and Biodiversity Conservation Act. Data to date indicate that no sensitive vegetation types occur within the Development Area that would result in the requirement for offsets.

Cleared areas which are no longer required for operational purposes will be rehabilitated. Rehabilitation strategies are typically based on assisted natural regeneration, which combines natural regeneration from locally collected native seed and soil, to enhance germination success.

A weed and erosion aerial assessment was conducted in 2007 (HLA, 2007), one year after seismic line clearing, which found that rehabilitation success in communities with a grassland understorey is high after only a single year (due to annual grass growth), whereas woodlands (mainly Lancewood and Bullwaddy) show low levels of natural regeneration after one year.

Clearing for the construction of pipelines will be rehabilitated such that ground cover vegetation is returned (i.e. tree regeneration will be prevented during operation) following burial. The return of ground cover species is important for both movement of animals and for erosion control. Ground cover is expected to return to the pipeline easements following the next wet season.

5.2.2 Habitat loss and fragmentation

There may be a risk of loss and/or fragmentation of habitat for fauna on a regional scale as a result of road and pipeline construction and operation.

Response and controls

The limited footprint of an unconventional gas development, and the scale of infrastructure required, will minimise the level of habitat loss and fragmentation. Additional controls include:

- *Avoidance of environmentally sensitive areas.*
- *Use of offsets where impacts to significant features cannot be avoided.*

Bioregions are large, geographically-distinct ecosystems distinguished by broad physical and biological characteristics that are used as the basis for regional comparisons and conservation of flora and floristic communities. As such, the bioregion is considered an appropriate unit with which to assess the level of loss and/or fragmentation of habitat for fauna on a 'regional' scale.

The Development Area occurs in the Sturt Plateau bioregion, which covers over 9.8 million hectares, and is mostly comprised of intact native vegetation – i.e. has not been cleared. Total land clearing associated with Origin's notional Development Area is predicted to be <20 ha (<0.0002%) of the total area of the bioregion.

The woodland habitats that will be affected by the development are the most common habitat type within the bioregion and are not recognised as being critical habitat for any listed threatened species. In this context, the development is not expected to result in loss of habitat that would impact biodiversity on a regional scale.

The Development Area involves a small area of clearing in the regional context. The well pads associated with the disturbance area are discrete disturbance areas which will be surrounded by un-cleared areas. There will be a single well in an approximately 9.6 km^2 block of land.

Pipeline construction will involve vegetation clearing, however, pipelines will be buried and vegetative cover will be returned to disturbed areas (ground cover only - no trees will be allowed to grow on the pipeline easement). The pipeline easement is likely to be between 20 and 40 m wide. Once buried and vegetation has returned (Figure 39), the pipeline easement is not expected to cause a barrier to fauna dispersal, meaning that fauna can utilise habitat on either side of the pipeline.

Figure 39. Pipeline during construction and following rehabilitation.

There are no development infrastructure requirements that are likely to create barriers to dispersal for fauna species. Given the potential species that could be found within the region and the width of the potential barriers, it is unlikely that access tracks or other infrastructure will create regional fragmentation or dispersal barriers. Moreover, the broader area is already developed with access roads associated with pastoral activities. The proposed access tracks to, and within, the Development Area are expected to be approximately 10 m wide. This is not considered wide enough to create isolated populations of habitat forming vegetation on either side of the road (open woodlands on either side of the Stuart Highway are not, for example, considered separate populations). Although roads can present barriers to dispersal for fauna, the significant species which do or may occur (confirmed, likely, possible) within the Development Area are all highly mobile and are not expected to be hindered by the creation of access roads.

5.2.3 Change in water quality and availability

There may be a risk of adverse impacts on terrestrial ecosystems, including fauna and flora, as a result of changes to water quality and availability.

Response and controls

Origin has demonstrated through its major unconventional gas development in Queensland that the risks to contamination of groundwater and surface water can be mitigated through:

- *Appropriate location of infrastructure away from water courses and sensitive features.*
- *Design of shale gas infrastructure to divert overland flow and stormwater ingress to prevent surface water contamination.*
- *Use of erosion sediment control measures to mitigate runoff from construction.*
- *Use of stringent chemical transportation, storage, handling and disposal practices in accordance with Territory and National legislation.*
- *Implementation of regional baseline and ongoing surface water monitoring programs.*

In the Beetaloo Basin context, terrestrial ecosystems that could be influenced by changes to groundwater and/or surface water availability are:

- Groundwater-dependent ecosystems.
- Wetlands.
- Riparian ecosystems.

The controls to prevent adverse impacts of development on groundwater and surface water quality and quantity are discussed in Chapter 4. As noted in those sections, there are no known groundwater-dependent ecosystems proximate to the Development Area. Localised, near-surface, perched aquifers may occur that support certain vegetation communities. Origin does not intend to extract water from these. There are also no known wetlands or riparian ecosystems within the influence of the Origin development.

5.2.4 Weed invasion

There may be a risk of a risk of weed invasion as a result of increased traffic

Response and controls

Management measures can effectively limit weed invasion risks, such measures are likely to be particularly effective given the limited (two-five) number of pastoral stations likely to host development infrastructure. Measures include:

- *Mandatory vehicle/ plant wash down and weed inspection certifications.*
- *Baseline weed surveys.*
- *Development of property specific weed management plans in conjunction with landholders.*
- *Routine inspections and active management.*

There were a number of weeds detected through database searches and surveys near the Development Area. Only two species listed under the Weed Management Act were detected during surveys. Parkinsonia was detected at the Amungee Mungee site and Hyptis was detected at the Beetaloo site. Both of these were detected along access tracks.

Access tracks create disturbed areas which facilitate weed establishment and subsequent spread into adjoining vegetation. Movement of vehicles along the access tracks can spread weeds from one area to another. As the project is developed there will be increased vehicle traffic along the access tracks. Transport of weeds or other exotic species between regions is a possible risk that will require management.

Vehicle movement already occurs throughout the Development Area, through pastoralism activities. Pastoral vehicles currently travel both on formed access tracks and over vegetation. Additionally, cattle movement through the area is a potential source of weed dispersal. Although there is potential for weed spread through such activities, with management measures, pastoralists have been able to successfully manage weeds in the area (as evidenced through the low number of weeds detected during surveys).

Management measures are proposed which are designed to minimise the risk of weed invasion. These will primarily include:

- Baseline weed surveys to identify potential weed infestation risks.
- Establishing working relationships with landholders to implement property scale weed management programs.
- Mandatory wash down for equipment, plant and vehicles before entering and moving between properties with known declared weeds.
- The use of certified weed inspections and declarations for all equipment.
- Installation of washdown bays within the Development Area to clean equipment.
- Ongoing inspection and treatment for weeds along constructed right of ways to mitigate weed infestations.

The nature of the development is such that weed infestations will occur along access tracks and around well pads, where they are readily identifiable and accessed for control. With prompt management, there are no foreseeable obstacles to managing potential invasions or proliferations of weed species during the project.

5.2.5 Change in fire regimes

There may be a risk of impacts on biodiversity and greenhouse gas emissions due to changed fire regimes.

Response and controls

Gas development is unlikely to adversely impact regional fire regimes. Additional access tracks may decrease risk of fire through improved access and provision of fire breaks.

Origin will ensure strict to prevent fires being caused by project activities. Although there will be a small disturbance footprint across the vast Development Area, Origin will need to engage with landowners and jointly undertake active fire management across the entire Development Area to minimise the chance of uncontrolled naturally-occurring fires impacting upon development infrastructure, operations and personnel.

It is possible that with the additional presence and activity of Origin in the Development Area, local hot fires will be a less frequent occurrence during the life of the project. This would be to the benefit of the savannah woodland fauna and flora that had evolved in response to the 'cool fires' historical undertaken by local Aboriginal people.

Another consequence of fewer 'hot fires' may be fewer greenhouse gas emissions than are released in the current situation.

5.2.6 Noise and light impacts

A risk of adverse impacts on fauna as a result of increased noise and light from petroleum operations.

Response and controls

A range of management measures can reduce any impact on fauna from noise and/or light. Such include:

- *Design of infrastructure to minimise noise emissions through the use of noise attenuation devices (shrouds, silencers, enclosures etc.).*
- *Location of infrastructure away from sensitive features.*
- *Flare minimisation through field automation.*

Some research has been undertaken on the impact of noise on some fauna species. The consensus is that potential noise impacts primarily relate to short-term noise events which can startle animals, but which are likely to return once the noise concludes. Because tolerances and impacts differ from species to species, there are no government policies or other guidelines mandating noise limits for fauna in general.

Some species are more sensitive to exposure to significant changes in noise – bats being the most relevant example for the Development Area. The Development Area is unlikely to present as suitable habitat (i.e. rocky, or caves or disused mines present) for any significant bat colonies or roosts. As mentioned in Section 3.1.2, there are expected to be few, if any, threatened species resident within the Development Area, and so noise is not a concern in that regard.

As mentioned in Section 3.1.2, there are expected to be few, if any, threatened species resident within the Development Area, and so noise is not a concern in that regard.

Noise assessments for activities will be conducted as part of the internal constraints analysis at the project planning stage. The noise assessment considers the activities to be conducted, the potential noise emissions, proximity to nearby sensitive features (habitat and landholders) and whether or not the relevant regulatory noise criteria is likely to be met. Where a sensitive ecological community has been identified through the constraints assessment, buffers are applied (activity dependent) to reduce noise impacts to below acceptable levels.

A range of noise management measures can be utilised to impact noise emission on sensitive ecological features and landholders. These include:

- Use of buffers to provide a minimum distances away from a sensitive feature.
- Relocation of the activity,
- Rescheduling of the activity,
- Selection of low noise emitting equipment or the use of noise attenuation devices.

The lighting requirements associated with a development such as this are commensurate to those of other large-scale developments, such as mines. The negative impacts of artificial lighting on marine turtles and certain marine bird species is well-documented, but there is little evidence of such impacts on fauna from lighting in habitats such as present within the Beetaloo. Impacts from facility lighting will be undertaken in detail as part of an EIA. Standard management controls include:

- Design of facilities to use low impact lighting (include light selection, light orientation, use of motion sensors etc.).
- Locating major facilities away from potentially sensitive habitat areas.
- Avoidance of flaring through the use of field automation.
- Unmanned infrastructure (such as lease pads) to have minimal to no lighting as they will not be frequented during the night.

5.3 Soil health

There may be a risk that the chemicals used in the drilling and hydraulic fracturing process will have an adverse impact on soil health, including as a result of spills of flowback water.

Response and controls

The risk of soil contamination caused by spills of drilling and hydraulic fracturing fluids is extremely low through well established regulatory and industry best practice controls. These controls include; well pad preparation (use of chemicals on designated lease area), bunding, engineering designs and transport regulations (chemical transportation, storage and handling legislation).

The risk of site contamination associated with a gas development (including HFS) is considered similar to many other major activities such as mining, conventional gas development, and industrial and commercial developments. Standard industry controls are required to ensure activities do not impact on soil health. Example of controls include:

- Topsoil stripping of lease areas to prevent from compaction. Topsoil is stockpiled around the lease areas and returned to the lease areas during decommissioning. Any contamination upon leases is likely to affect the subsoil and not the topsoil.
- Chemical handling and storage occurs on designated areas of the leases which are fenced and appropriately bunded.
- The majority of chemicals pose little threat to soil health and will rapidly biodegrade.
- Rigorous legislation controlling the storage and handling of dangerous goods and hazardous chemicals.
- Flow back storages are to be located where there is minimal risk to sensitive receptors (water courses, public places etc.).
- Flow back storage structures (ponds or tanks) are to be double lined to contain the wetting front.
- Flow back storages are to have defined top operating water limits (TOWL) to ensure containment structure are capable of withstanding a 1 in 100 rainfall event.
- Lease pads and major facilities shall be designed to prevent overland flow ingress, to reduce the risk of surface water contamination.
- Contaminated soils are to be rehabilitated as soon as practicable after a spill occurs in accordance with the National Environmental Protection (Site Contamination Assessment) Measure.

5.4 Aboriginal people and their culture

The landscape, terrestrial ecosystems, plants and animals are central to traditional cultural values. Adverse impacts to these things may have an adverse impact on Aboriginal cultural values.

Response and controls

Origin recognises Aboriginal and Torres Strait Islander peoples as the traditional custodians of the land. Any development will be undertaken in collaboration with Traditional Owners recognising cultural values.

Aboriginal cultural values are protected in the NT through the Aboriginal Sacred Sites Act, which is administered by the Aboriginal Areas Protection Authority. As part of Origin's drilling program in the Development Area, some Aboriginal sacred site surveys have been undertaken. Sacred sites were identified, and the Authority Certificate issued for the drilling program established Restricted Works Areas, to protect those sites.

Prior to any works in the Development Area, Aboriginal sacred sites surveys will be undertaken in consultation with the Northern Land Council and Aboriginal Areas Protection Authority. Origin will apply for an Authority Certificate pursuant to the Aboriginal Sacred Sites Act. This is a well-established regulatory process in place specifically to ensure Aboriginal cultural values are protected.

Archaeological assessments and field surveys have also been undertaken within the Development Area to identify any Aboriginal archaeological sites protected under the NT Heritage Act. A search of the Northern Territory Heritage Register identified 41 Aboriginal archaeological sites within a 125 km by 125 km area that includes the Development Area roughly at the centre. However, no archaeological sites are recorded within the Development Area. Field surveys did identify sites along existing access tracks (existing disturbance) to the east of the Development Area.

Prior to any development, archaeological surveys will also be undertaken. Any Aboriginal archaeological sites will be managed in accordance with a Works Approval pursuant to the requirements of the Heritage Act. This is a well-established regulatory process administered by the Heritage Branch and is expected to provide for effective protection of heritage values.

Given the above context, Origin does not anticipate a consequence of a development to be any significant changes to the quality or quantity of terrestrial ecosystems that currently support Aboriginal land use and sacred sites.

5.5 Economic

An adverse impact on terrestrial ecosystems may be a risk to industries that co-exist with the onshore unconventional gas industry, such as agriculture, pastoralism, fisheries and tourism.

Response and controls

Origin supports the need for further work to identify, assess and control terrestrial ecosystem impacts that could affect other industries.

The Development Area is located is an area which is used for pastoral activities. For the reasons presented herein, Origin does not anticipate a consequence of their proposed developments to be any significant changes to the quality or quantity of terrestrial ecosystems that will affect the co-existence of pastoral activities with an onshore unconventional gas development.

Other identified industries do not operate within the area and are unlikely to be affected by the project.

5.6 Amenity values

The Panel recognises that the Northern Territory has iconic wilderness values as a core part of the Australian outback. There may be a risk that the development of the unconventional gas industry will have an adverse impact on the outback experience (for example, tourism) through infrastructure development (for example, the construction of pipelines and processing plants), and increased traffic, noise and light (from flaring).

Response and controls

Origin's operations are in pastoral country and are not proximate to iconic wilderness and/or ecotourism destinations within the NT. Origin is, however, committed to the preservation of amenity values and utilises learnings from its other developments to reduce amenity impacts by consulting with landholders on siting infrastructure, co-locating infrastructure and using multi-well leases to reduce the disturbance footprints of developments impacts.

The Development Area is located on pastoral stations far from any tourist sites. It is approximately 50km from the Stuart Highway, and significantly further from any other roads or towns.

All major infrastructure (including gas processing facilities (GPF), pipeline compressor facilities (PCF), water treatment facilities (WTF), and camps etc.) will be specially designed and located to avoid visual amenity impacts. Management strategies to avoid a loss of visual amenity include:

- Completion of visual amenity and light impact assessments as a part of an EIS.
- Locating major facilities and well pads at appropriate offset distances away from major transportation routes and sensitive receptors.
- Utilisation of ground flares where practicable.
- Use of vegetation screens around major infrastructure.
- Colour selection of infrastructure to blend into background.
- Minimisation of flaring through production well automation.
- Minimisation of new road constructions through the use of multi well lease pads and horizontal wells.
- Use of inconspicuous road base material to ensure infrastructure fits in with surrounding land use.

During construction, there will be slightly more traffic in the immediate area (e.g. transport from Daly Waters accommodation to site), but during operation the traffic volume will be low. A Traffic Management Plan will be a requirement of any EIS for the project.

5.7 Cumulative risks

There may be cumulative risks associated with some or all of the risks identified above.

Response and controls

Origin acknowledges that cumulative risks need to be understood and assessed as part of any formal project impact assessment.

For the reasons presented here, Origin does not anticipate weeds, fire or land-clearing as a consequence of their development to have significant impacts on terrestrial ecosystems

6 RISK THEME 3: AIR

The Air Risk Theme is focused on local impacts on health and the contribution of any fugitive emissions to the global challenge of climate change.

Minimising and preventing emissions: We will utilise best practice well design and green completions to minimise the potential risks associated with emissions. We will monitor for methane and other greenhouse gases in the Beetaloo if a development goes ahead, and share these data transparently to test whether fugitive emissions are impacting public health or amenity or on a net basis contributing to global climate change. Data from CSIRO studies specifically seeking to detect fugitive emissions at gas wells (Day et al., 2014) confirm that the contribution of greenhouse gases from Australian oil and gas upstream activities are minimal. At a macro-level, the substitution of gas for coal for fixed electricity generation has the potential to substantially reduce global CO2 emissions (Bruckner et al., 2014) and Origin is an industry leader in our commitment to meeting the global challenge of climate change.

Origin is proud to be the first energy company globally to make a meaningful commitment to all seven of the We Mean Business Coalition climate leadership initiatives. Origin is already the largest purchaser of solar power in Australia and will continue and increase our investment in renewable energy.

6.1 Background and context

Air quality risks and controls from shale gas developments are well understood, based upon extensive Australian and US unconventional gas development experience. Emissions from shale development are similar to conventional drilling, with green completions likely to significantly reduce both the air emission and greenhouse gas intensity of flow back activities.

The emissions from Origin's Shale Gas Developments will be assessed against the relevant Australian National Environmental Protection Measures (NEPMs) to protect public health and wellbeing. Origin is in a unique position to be able to utilise proven best practice to mitigate the impacts observed in the US. Origin has a strong track record of implementing best practice emission mitigation and monitoring programs within its' Australian unconventional gas developments. The Beetaloo area is remote, with limited number of sensitive receptors within the proposed Development Area

6.2 Air emission legislative framework

Australia has an advanced air quality management framework designed to protect health and wellbeing. In 1998, the National Environmental Protection Council (NEPC) introduced a series of National Environmental Protection Measures (NEPMs) designed to assist in protecting and managing particular aspects of the environment. The NEPMs are legally binding on each level of government, including the NT. The standards were set in consultation with health professionals, environmental groups and the community and were based on scientific studies of air quality and human health from all over the world (Department of Environment and Energy, 2005).

For large-scale unconventional gas developments, an Environmental Impact Assessment (EIA) would be required, in accordance with the NT Environmental Assessment Act (2013). Such an assessment would be required to identify, characterise, assess and mitigate the impacts of shale gas development on air quality.

Although there are no NT specific air quality guidelines, all HFS related activities would likely be assessed against the NEPMs for Ambient Air Quality and Air Toxics. Additional standards for environmental protection could also be sourced from relevant Queensland, NSW and Victorian guidelines. Emissions associated with HFS related activities will be designed to comply with the highest standards, to ensure the risk to the environment and community is reduced to as low as reasonably practicable. A summary of the relevant NEPM and State ambient air guidelines are provided in Table 18 and Table 19.

Reporting of all emissions from all onshore shale gas developments will also be covered under the National Pollutant Inventory (NPI) NEPM. The NPI uses a combination of direct measurement and emission factors to estimate the emissions from certain activities. All data covered under the NPI is publically accessible and will cover emissions associated with:

- Fuel (Diesel) combustion.
- Particulate matter generation through construction activities, material handling and vehicle movements.
- Emissions from venting and flaring.

POLLUTANT	AVERAGING PERIOD	STANDARD/ MONITORING INVESTIGATION LEVELS
AMBIENT AIR QUALITY NEPM		
Nitrogen dioxide	1-hour	0.12ppm
	1-year	0.03ppm
Sulfur dioxide	1-hour	0.20ppm
	24-hour	0.08ppm
	1-year	0.02ppm
Carbon Monoxide	8-hour	9.0ppm
Photochemical Oxidants (as ozone)	1-Hour	0.10ppm
	4-Hours	0.08PPM
PM_{10}	24-hour	50 ug/m^3
	1-year	25 ug/m^3
$PM_{2.5}$	24-hour	25 ug/m^3
	1-year	8ug/m^3
Lead	1-year	0.50ug/m^3
AIR TOXICS NEPM[7]		
Benzene	1-year	0.003ppm
Benzo(a)pyrene as a marker for Polycyclic Aromatic Hydrocarbons	1-year	0.3ng/m^3
Toluene	24 Hour	1 ppm
	1-year	0.1ppm
Xylenes	24-hour	0.25ppm
	1-year	0.2ppm
Formaldehyde	24-hour	0.04ppm

Table 18. NEPM Air Quality Standards.

8 Air Toxic NEPM Levels are a monitoring Investigation Level. The monitoring investigation level values are levels of air pollution below which lifetime exposure, or exposure for a given averaging time, does not constitute a significant health risk. If these limits are exceeded in the short-term it does not mean that adverse health effects automatically occur. (Commonwealth Government of Australia, 2004)

POLLUTANT	AVERAGING PERIOD	QUEENSLAND	NSW	VICTORIA
Nitrogen dioxide	1-hour	250[a]	246	190[g]
	1-year	62[a], 33[b]		
Sulfur dioxide	10-minute		712	
	1-hour	570[a1]	570	450[g]
	24-hour	230[a]	228	
	1-year	57[a], 32[c], 22[d]	60	
Carbon dioxide	8-hour	11000[a1]	10000	
	1-hour		3000	29000[g]
	15-minute		100000	
Total suspended particulates	1-year	90[a]	90	
PM_{10}	1-hour			80[g]
	24-hour	50[a2]	50	
	1-year		30	
$PM_{2.5}$	24-hour	25[a]		
	1-year	8[a]		
Deposited Dust	1-year		4 g/m^2/month	
	1-month	120 mg/m^2/month[i]		
Benzene	1-year	10[a]		
	1-hour		29	
Ethylbenzene	3-minute			14500[g]
	1-hour		8000	
Toluene	3-minute			650[f]
	30-minutes	1100[e]		
	24-hour	4100[a]		
	1-year	410[a]		
Xylenes	3-minute			350[f]
	1-hour		190[f]	
	24-hour	1200[a]		
	1-year	950[a]		
Formaldehyde	3-minute			40[h]
	30-minutes	110[e]		
	1-hour		20	
	24-hour	54[a]		
Hydrogen sulfide	3-minute			0.14[f]
	30-minutes	7.5[e]		
	24-hour	160[a]		

Table Notes:

a. Health and wellbeing
b. Health and biodiversity of ecosystems
c. Protecting agriculture
d. Health and biodiversity of ecosystem (for forests and natural vegetation)
e. Protecting aesthetic environment
f. Odour
g. Toxicity
h. IARC Group 2A carcinogen
i. EHP design objective:
  1. 1 One day of exceedance allowed
  2. 2 Five days of exceedance allowed

Table 19. Summary of relevant state specific air quality objectives.

6.3 Origins air emission risk management approach

Air emissions associated with current exploration and future full-scale developments will be assessed using a source, pathway, receptor type approach. Information is gathered on the nature and characteristics of the emission (source), its behaviour and fate in the environment (pathway) and the receptors at risk of exposure (landholders, communities, ecosystems and cultural features). This information is combined within a dispersion model to determine whether the impacts to sensitive receptors are below the relevant NEPM or environmental objective. Where an exposure above an air quality standard is predicted, additional controls can be implemented during the design phase to reduce the potential air quality impacts to an acceptable level. Where the levels of a pollutant (or combination of pollutants) are approaching a relevant health guideline, a detailed health risk assessment will be completed. Such an assessment will be completed in accordance with the *Environmental Health Risk Assessment; Guidelines for assessing human health risks from environmental hazards* (enHealth, 2012).

The collection of information for an air impact assessment begins early on during the exploration phase and extends throughout the project design and feasibility stages. During these phases, information is collected on gas quality, anticipated emissions from proposed infrastructure and the collection of baseline, regional, ambient air quality data. The collection of baseline air quality data is critical as the presence of some compounds can increase the cumulative risk of exposure to a receptor from a development. This is particularly relevant for the formation of secondary pollutants such as ozone, which may be enhanced through natural emissions of precursor compounds such as VOC's and oxides of nitrogen.

6.4 Air emissions risks associated with HFS activities

Air emission risks associated with shale gas developments are well understood and covered extensively in literature and government reports associated with the US shale gas industry. Origin is able to leverage off these learning's to ensure appropriate pollution controls are included in the design phase of the project.

The major air quality risks specific to potential shale gas development in the Beetaloo are primarily associated with drilling, HFS, and gas processing and transportation. The risks associated with construction (i.e. dust generation), support infrastructure (camps, offices, warehouses etc.) and vehicle transportation are not discussed here as these risks are relatively standard across most industries and have well defined management practices. They would of course be assessed during a full Environmental Impact Assessment if required in due course.

6.4.1 Drilling

The main emissions associated with Drilling are summarised in Table 20. The emissions associated with this activity are similar to conventional drilling activities and are primarily:

- Diesel combustion emissions from drilling and support equipment; generators, pumps, trucks and compressors.
- Raw gas emission from shale shakers.
- Venting, and
- Dust generated from material handling.

The primary emissions during the drilling phase are likely to occur through the combustion of diesel within drilling related equipment. The level of risk introduced from the combustion of diesel during unconventional gas developments is anticipated to be comparable with existing industries in the NT; including mining, agriculture and rural power generation.

The primary emissions associated with the combustion of diesel are oxides of Nitrogen, Carbon Monoxide and particulate matter. Emissions of oxides of sulphur are likely to be low due to the absence of sulphur in the shale gas. Risks associated with diesel emissions will be minimised by the selection of low pollution (NOx and particulate) equipment; such as those compliant with the Diesel Vehicle Emissions NEPM (Commonwealth Government of Australia, 2001) or fitted with Diesel Oxidation Catalysts (DOC) and Diesel Particulate filters (DPF). There is also a growing trend to substitute diesel usage for compressed natural gas that is produced within the same Development Area. This practice is on this increase in the US (Kulkarni, 2013) and is something that could potentially significantly reduce diesel related emissions if viable.

Emissions associated with venting are likely to be extremely limited during this activity. Primary emissions are likely to be restricted to the shale shakers, where small volumes of gas are released from the shale rock that is brought to surface within drilling muds. Such emissions are anticipated to be extremely small and temporally limited to periods of drilling through shales. Testing of gas composition from the Amungee NW-1 well indicates the gas low to absent contamination from Naturally Occurring Radioactive Material (NORM), BTEX (Benzene, Ethylbenzene, Toluene and Xylenes) and mercury – consistent with other onshore conventional gas developments in Australia.

The risks associated with air emissions released during the drilling phase are likely to be further reduced by the isolated nature of the Beetaloo area. There are currently limited sensitive receptors in the region, reducing the risk of potential exposure to drilling related emissions to extremely unlikely.

ACTIVITY	RISK DESCRIPTION	RISK CONTROLS	OVERALL RISK SUMMARY
Diesel fired generators, pumps, trucks and compressor utilised to drill and complete shale gas development wells.	Fuel Burning emissions (Carbon Monoxide, Oxides of Nitrogen, Particulate Matter) associated with diesel combustion from activities causes air quality impacts	• Limited other major emissions sources. • Impacts consistent with existing industrial, mining and agricultural activities (not unconventional gas development specific). • Limited sensitive receptors due to remote location. • Low pollution engines utilised with standard pollution controls devices required as per Australian Standards. • Potential to utilise Compressed natural gas to fuel rigs during development phase.	The risk associated with the combustion of fuels to sensitive receptors is anticipated to be extremely low. Combustion of fuels is consistent with existing conventional gas, industrial, mining and agricultural activities
Raw Gas emissions from shale shakers	Emissions of raw gas (predominantly methane) form shale shakers impacts on sensitive receptors	• Limited sensitive receptors due to remote location. • Small volume of gas emitted from shale shakers during drilling. • Gas predominantly methane, high buoyancy and will disperse rapidly.	Emissions from raw gas that is release from the shale shakers during drilling is likely to be extremely small. The activity is temporally restricted, with limited sensitive receptors.
Venting		• Limited sensitive receptors due to remote location. • Venting to be minimised during drilling. • Well control (including blow out prevention) utilised to prevent uncontrolled release of gas. • Overweight drilling prevents gas ingress into well bore during high risk gas zones. • Use of gas diverters and flares to minimise venting. • Free gas unlikely to be present in the shale formations.	
Dust generated during material handling	Dust (PM 10 and Total Suspended Particles) created during materials handling impacts on sensitive receptors	• Limited sensitive receptors due to remote location. • Minimal open transfer of bulk material. • Storage and handling of material to comply with relevant Australian Standards and Occupational Health and Safety Regulations.	Material handling during drilling likely to be short lived and restricted to immediate vicinity of the lease area. Controls are put in place to limit occupational exposure.

Table 20. Summary of air related risks and controls associated with the drilling of shale exploration and development wells.

6.4.2 Hydraulic fracture stimulation and well completion

The main emissions associated with hydraulic fracture stimulation are summarised in Table 21. The main emissions associated with this activity can be summarised as:

- Flowback storage, venting and flaring.
- Diesel fired generators, pumps, trucks and compressor utilised to stimulate and complete shale gas development wells.
- Onsite stimulation chemical storage and handling emissions.

The largest potential air emission risk from HFS activities occurs during the return of the hydraulic fracture stimulation fluid to surface; referred to as flow back. During flow back activities, stimulation fluid is evacuated from the well to surface holding tanks. Historic practices in the US often allowed any entrained or free gas within the flow back to vent to atmosphere. This represented a significant source of volatile organic compounds (VOCS) and greenhouse gasses.

Recent advancements in reduced emissions completions (RECs) or green completions has significantly reduced the emission associated with HFS activities. During HFS with green completions, gas collected during flow back is captured and piped, rather than flared. In order to reduce emissions from flaring within the US shale developments, the US EPA introduced regulations in January 2015 to mandate the use of green completions. This is believed to reduce emissions from HFS by approximately 95%. (United States Environmental Protection Agency , 2012).

Origin's shale gas development will utilise the learning's form the US industry through the deployment of industry best practice. Development wells within the Beetaloo Basin will utilise a green completion, where free gas is directed into the gas gathering network. Flaring of entrained gas during flow back will still be required for exploration activities in the absence of pipeline infrastructure. The use of industry best practice, such as green completions, is likely to significantly reduce the risks to air quality identified

The emissions from the combustion of diesel in compressors, generators and pumps during stimulation and completion activities are likely to be consistent with those during the drilling phase.

Emissions of particulates may also occur during chemical storage and handling. The impact to sensitive receptors from this activity is likely to be legible based on the following:

- Chemical handling and storage of dangerous goods controlled under various Australian Standards and Codes of practice (Such as the National Code of Practice for the storage and Handling of Workplace Dangerous Goods)
- Exposure to employees from chemical storage and handling of chemicals controlled under the NT Workplace Health and Safety Act (2011)

The risks associated with air emissions released during the HFS phase are likely to be further reduced by the isolated nature of the Beetaloo area. There are currently limited sensitive receptors in the region, reducing the risk of potential exposure of emissions to extremely unlikely.

ACTIVITY	RISK DESCRIPTION	RISK CONTROLS	OVERALL RISK SUMMARY
Diesel fired generators, pumps, trucks and compressors	Fuel Burning emissions associated with diesel combustion from activities causes air quality impacts	As per Drilling	As per Drilling
Flaring	Flaring emissions (Carbon Monoxide, Oxides of Nitrogen and non-combusted hydrocarbons) impacts on sensitive receptors	• Limited sensitive receptors due to remote location. • Use of flares efficiently destroy pollutants (hydrocarbons). • Flare designed with a combustion efficiency above 98%. • Activity restricted to exploration activity.	Flares are a critical pollution control device designed to reduce the potential impact associated with raw gas venting
Flaring and venting during flowback and completion activities	Emissions (Volatile Organic Compounds) from flow back activities impact on sensitive receptors.	• Flaring and venting during completion activities to be minimised. • Green completions will be utilised to capture all returned gas during flow back activities. • Flares will be utilised for exploration activities where pipelines are not available.	
Onsite stimulation chemical storage, handling and mixing	Emission (Particulate and volatiles) from onsite storage and handling of stimulation chemicals impact a sensitive receptor	• Limited sensitive receptors due to remote location. • Storage and handling of material to comply with relevant Australian Standards and Occupational Health and Safety Regulations. • Stimulation fluid selected based on stability and low exposure risk to employees. • Use of open decanting and mixing tanks to be avoided.	

Table 21. Summary of air related risks and controls associated with the hydraulic fracture stimulation and completion of shale exploration and development wells.

6.4.3 Gas processing and transport

The main emissions associated with the gas processing and transport phase of gas developments are summarised in Table 22. The emissions from the gas processing facility (GPF) are likely to require less processing than some conventional developments; due to the absence of sulphur compounds and the low carbon dioxide content within the gas.

The anticipated emissions associated with this activity can be summarised as:

- Gas processing facilities.
- Pipeline compression facilities.
- Flaring.
- Equipment leaks.
- Pipeline leaks.
- Condensate storage tanks (if required).

The largest emission source from gas developments is associated with natural gas fired engines and flaring associated with major GPFs, pipeline compression facilities (PCFs) and flares. The primary emissions from these activities are likely to be the oxides of Nitrogen, Carbon Monoxide and un-burnt hydrocarbons.

Key risk mitigation strategies to reduce the impact associated with emissions from major facilities include:

- Use of flares to combust hydrocarbon during plant disruptions and maintenance shut-downs.
- Siting of major facilities away from sensitive receptors.
- Emission dispersion modelling to assess the impacts of facilities against the relevant NEPM and Environmental standards.
- Selection of low NOx engines; such as lean burn compressors.
- Routine maintenance and tuning of engines.
- Use of field automation to shut in wells during plant upsets and maintenance; this reduces the requirement to flare.

Gas processing and pipeline infrastructure are designed in accordance with recognised Australian and international standards to minimise the potential for gas leaks. Equipment leaks from gas plants and pipelines are likely to be detected and mitigated promptly due to the inherent explosion risks. GPF and PCFs are equipped with online gas detectors to detect leaks from facilities which may result in an explosion. Routine inspections of gas plants and pipelines are completed using specialised gas detection equipment, such as forward looking infra-red (FLIR) gas detector cameras and aircraft mounted tuneable diode laser gas analsyers. Emissions of VOCs from condensate storage tanks may occur in the future if condensate is encountered. Results from Amungee NW-1 did not encounter wet gas and therefore liquid hydrocarbon storage is not required. If condensate storage is required, emissions will be managed through the use of floating roofs and flares. This risk is considered identical to conventional oil and gas developments.

ACTIVITY	RISK DESCRIPTION	RISK CONTROLS	OVERALL RISK SUMMARY
Gas processing facility (GPF)	Emissions (Oxides of Nitrogen, Carbon Monoxide and non-combusted Hydrocarbons) from gas fired compressors, generators and dehydration units impacts sensitive receptors	• Limited sensitive receptors due to remote location. • Dispersion modelling to assess impact of activity on receptors against NEPM levels. • Site selection to account for anticipated emission intensity. • Low pollution engines utilised to minimise emissions (such as Low NOx engines). • Low sulphur content in fuel gas. • Flares used to manage plant upsets. • Routine maintenance and tuning of equipment.	Gas Fired GPF's are likely to represent that largest emission source of a development. The risks are Identical to conventional oil and gas development with well defined controls.
Pipeline compression facility (PCF)	Emissions (Oxides of Nitrogen, Carbon Monoxide and non-combusted Hydrocarbons) from gas fired compressors	• Limited sensitive receptors due to remote location. • Dispersion modelling to assess impact of activity on receptors against NEPM levels. • Site selection to account for anticipated emission intensity. • Low pollution engines utilised to minimise emissions (such as Low NOx engines). • Low sulphur content in fuel gas. • Flares used to manage plant upsets. • Routine maintenance and tuning of equipment.	Gas Fired GPF's are likely to represent that largest emission source of a development. The risks are Identical to conventional oil and gas development with well defined controls.
Flaring	Flaring emissions (Carbon Monoxide, Oxides of Nitrogen and non-combusted hydrocarbons) impacts on sensitive receptors	• Limited sensitive receptors due to remote location. • Use of flares efficiently destroy pollutants (hydrocarbons). • Field automation to shut in wells during plant trips reducing flaring. • Flare designed with a combustion efficiency above 98%. • Dispersion modelling to assess the impacts of activity on receptors against NEPM levels.	Flares are a critical pollution control device designed to reduce the potential impact associated with raw gas venting.

General Equipment Leaks	Emissions of gas from leaks impact receptor	• Wells are designed not to leak for safety. • Well surface infrastructure pressure tested during commissioning to detect weak points/ leaks. • Well head inspections. • Gas predominantly methane, high buoyancy and will disperse rapidly. • Limited sensitive receptors due to remote location.	
Pipelines	Pipeline leak emissions impact receptor	• Pipelines designed, constructed and tested in accordance with stringent Australian and international standards. • Gas flow meters can detect potential major pipe ruptures and automatically shut down pipelines. • Pipeline inspections are conducted routinely by operators and at least 6 monthly using advanced airborne gas detection sensors. • Limited sensitive receptors due to remote location.	
Condensate storage tanks	Emissions of VOC's from condensate storage tanks impact receptor	• Use of floating roof storage tanks. • Flaring of tank emissions if appropriate. • Gas predominantly methane, low toxicity, high buoyancy and will disperse rapidly. Low NORMs risk. • Limited sensitive receptors due to remote location.	

Table 22. Summary of air related risks and controls associated with the gas processing and piping of shale exploration and development wells.

6.4.4 Cumulative shale gas development impacts

The cumulative emissions from regional shale and industrial developments needs to be assessed cumulatively to ensure potential impacts to receptors from a range of independent activities are considered. This is one of the key learnings from the US, where cumulative assessments of impacts from various shale gas developments were often lacking in the onset of the industry.

The EIA that assesses the impacts of Origin proposed development activities will include the contribution from a range of existing and future emissions sources. This will include emissions predicted from any other proximal gas developments, as well as relevant natural, agricultural, mining and industrial emission sources (Table 23).

Cumulative emissions from the industry are also proposed to be assessed and mitigated through the following:

- Baseline air quality studies to identify existing natural/anthropogenic pollutant sources
- Completion of independent regional impact assess similar to that of the GISERA Surat Basin Ambient Air Quality Monitoring and Modelling program (GISERA, 2016).
- Collaboration between unconventional shale gas developments to share emissions source and intensity data

ACTIVITY	RISK DESCRIPTION	RISK CONTROLS	OVERALL RISK SUMMARY
Full shale gas development	Cumulative emissions from all Origin shale gas development activities and background sources (including other shale developments) impact on regional air quality	• Limited existing industries within and surrounding exploration area. • Baseline air quality monitoring studies to identify natural contaminant levels and seasonal variation (i.e. biomass burning). • Limited sensitive receptors due to remote location. • Dispersion modelling to assess impact of all proposed activities on receptors against NEPM levels. • Engineering designs to minimise impacts to air quality from shale development activities.	Cumulative risk to public health and the environment will be assessed in full as a part of an environmental impact assessment. This will include the collection of baseline ambient air quality data and assessment of all existing and future industry emissions. Potential implementation of a GISERA based regional industry modelling and monitoring program

Table 23. Summary of cumulative risks to air quality associated with shale gas development

6.5 Greenhouse gas emissions

Natural gas is an abundant, low carbon intensity fuel that will play an important role in maintaining global energy security while the world transitions to a low carbon intensity economy. Recent lifecycle assessments indicate that emissions from modern natural gas combined-cycle power plants are roughly 50% of the emissions from a normal coal fired power station (Burnham, 2012). The success of the rapid advancements within the US shale gas industry in reducing greenhouse gas emissions is reflected in the significant decline in emission observed in the US (Bruckner, 2014).

There have been a large number of contradictory studies released in the last five years that have raised the issue of fugitive emissions associated with unconventional gas developments. Origin accepts that the management of fugitive emissions is a critical component of a future development scenario and believes the actual and/or perceived issues associated with the US industry can largely be avoided through:

- the adoption of industry best practice such as modern well integrity practice, green completions, and routine infrastructure leak detections.
- A strong national and Territory regulatory framework that drives international best practice.
- The absence of legacy oil and gas production wells with outdated well design and surface infrastructure.
- understanding of geohazards likely to result in gas migration and use of offset buffers.

6.6 Origin's operational experience

Air and Greenhouse gas emission risks associated with the Australian Pacific LNG project were largely mitigated during the design phase through:

- Use of electrified gas compression and well surface facilities to reduce fuel consumption.
- Use of field automation to increase well control and reduce flaring.
- Design, construction, operation and maintenance of equipment/infrastructure to prevent leaks.
- Use of overweight drilling to maintain well control and prevent gas emissions.
- Minimisation of gas venting.

Origin has participated in a number of additional research programs into the air quality and greenhouse impacts of Origin's Australian Pacific LNG CSG development, which are summarised here.

6.6.1 GISERA Surat Basin Ambient Air Quality Program

The perceived impact of unconventional gas developments on ambient air quality has been a long running concern within Origin's Surat and Bowen basin CSG developments. In 2014, Origin engaged CSIRO to develop and implement a world first program to monitor air quality at five locations within the Surat Basin to validate its performance claims. The project was transitioned into GISERA in mid-2015 and now live streams data via the EHP website from the five sites. This data can be accessed via: *https://www.ehp.qld.gov.au/air/data/search.php*.

In addition to the five online ambient air stations, approximately 50 additional parameters are monitored from 10 locations across the Surat Basin. To date, the program has confirmed CSG developments are not adversely impacting air quality and that no breaches of NEPM or environmental guidelines related to CSG activities have been observed. The transparency and outcomes of the project have received positive feedback from the community and government agencies.

Additional information on the GISERA Surat Basin Ambient Air Monitoring Program is available at: *https://gisera.org.au/project/ambient-air-quality-in-the-surat-basin/*

6.6.2 Greenhouse gas research

There is currently an extensive amount of research underway within the QLD CSG fields to quantify the Greenhouse Gas emissions from CSG. A large number of these studies are in an advanced stage and are likely to release information on the performance of the industry in the coming months:

- CSIRO Report on Field Measurements of Fugitive Emissions from Equipment and Well Casings in Australian Coal Seam Gas Production Facilities: *http://www.resourcesandenergy.nsw.gov.au/__data/assets/pdf_file/0010/559549/Fugitive-Greenhouse-Gas-Emissions-from-Coal-Seam-Gas-Production-in-Australia-CSIRO-report.pdf*
- GISERA regional methane characterisation: *https://gisera.org.au/wp-content/uploads/2016/04/ghg-emission-proj-1-lit-review.pdf*
- CSIRO research for NSW Government on methane characterisation: *http://www.epa.nsw.gov.au/esdsmoky/methanestudy.htm*
- Macquarie University ARC fugitive emissions grant: *https://researchdata.ands.org.au/linkage-projects-grant-id-lp140100460/618640*
- GISERA Greenhouse Gas Life Cycle Assessment: *https://gisera.org.au/wp-content/uploads/2017/01/Whole-of-life-cycle-greenhouse-gas-assessment_project-order.pdf*

6.7 Public health

The possible health risks associated with the release of gases from the hydraulic fracturing process are discussed below in "Public health".

Response and controls

Origin has demonstrated that hydraulic fracturing can be conducted without impacts to air quality and any associated health impacts. All activities associated with HFS will be assessed using the framework providing in the Health Impact Assessment Guidelines (Commonwealth Government of Australia 2001). Origin is supportive of establishing a an air quality monitoring program that publishes live air quality monitoring data similar to that of Queensland gasfield operations. .

The potential risk and controls associated with HFS are summarised in Table 21. The risk to public safety will be mitigated through:

- Impacts for exploration and development activities (including HFS) will be assessed using the enHealth Health Impact Assessment guidelines (Commonwealth Government of Australia 2001).

- Assessment of air emissions will be made against NEPM ambient air and air toxic guidelines which have been developed based on scientific studies on air quality and human health.
- The use of "green completions" to reduce emissions associated with HFS flowback activities. This technology is widely utilised in the US and is estimated to reduce the emissions from HFS flow back activities by 95% (United States Environmental Protection Agency , 2012).
- The selection of low pollution fuel combustion infrastructure/ plant to minimise emissions from diesel and natural gas combustion.
- The low population density within the Beetaloo development area will inherently reduce the potential exposure of the public to HFS activities.

6.8 Climate change

There may be a risk that greenhouse gases, including hydrocarbons (methane and ethane) and carbon dioxide, will be released during hydraulic fracturing and the associated activities. Emissions may be from sources such as well heads, pipelines, compression stations and final use. The potential contribution of hydraulic fracturing and the associated activities to the burden of greenhouse gas emissions will be assessed by the Panel.

Response and controls

Design, development and operation of unconventional gas facilities are undertaken with the express purpose of containing hydrocarbons. Climate change impacts will be managed through:

- *Adoption of green completions for development wells to mitigate emissions during HFS flowback.*
- *Use of API standard infrastructure to minimise leaks.*
- *Routine equipment leak detection and verification programs.*
- *Ongoing reporting of emissions under relevant greenhouse gas legislation.*

The risks associated with increasing Greenhouse gas emissions from shale developments is discussed in section 6.4. Origin accepts that the management of fugitive emissions is a critical component of a future development scenario and believes the similar issues associated with the US shale industry can largely be avoided through:

- the adoption of industry best practice such as modern well integrity practice, green completions, and routine infrastructure leak detections.
- A strong national and Territory regulatory framework that drives international best practice.
- The absence of legacy oil and gas production wells with outdated well design and surface infrastructure.
- The geology of the region reducing the risk of gas migration.

6.9 Amenity values

There may be a risk that there will be adverse impacts on amenity values such as national parks and rangelands due to gaseous emissions and flaring.

Response and controls

The risk to amenity values from air emissions is extremely low due to both the small quantum and proximity of any emissions. All impacts will be assessed as a part of a detailed environmental impact assessment.

The risk to amenity values from gas development emissions (including flares) will be mitigated through:

- Emissions from shale gas development activities will be assessed against environmental related guidelines as summarised in Table 19 – compliance with these guidelines will ensure the protection of sensitive receptors from emissions.
- locating infrastructure away from sensitive features such as national parks.
- Providing adequate buffers between major infrastructure and transport corridors.
- Co-locating infrastructure to minimise disturbance footprint (such as pipelines and roads).
- Use of ground flares where appropriate.
- Automated well shut-ins during GPF upsets to reduce flare intensity and duration.
- Choosing appropriate infrastructure colours to blend into environment.
- Completion of a detailed amenity assessment during the environment impact assessment.

6.10 Cumulative risk

There may be cumulative risks associated with some or all of the risks identified above.

Response and controls

Origin acknowledges that cumulative risks need to be understood and assessed as part of any formal project impact assessment.

The cumulative impact of emissions from future shale gas development are discussed in section 6.4 and summarised in Table 23.

The cumulative impacts associated with amenity will be assessed in detailed during the EIA process. This is summarised in section 6.4 and is likely to include:

- Use of buffers around protected places.
- Equipment design and colour to blend into surroundings.
- Use of ground flares.
- Locating of major processing infrastructure away from transportation corridors.