AMUNGEE NW DELINEATION PROGRAM

Environment Management Plan (ORI11-3)

EP 98

Review record

Rev	Date	Reason for issue	Author	Reviewer	Approver
0	10/7/2022	EMP released for acceptance	L Pugh	M Kernke	M Kernke
1	13/09/2022	EMP amended to address Regulation 10 and Regulation 11 feedback	L Pugh	M Kernke	M Kernke
2	14/10/2022	EMP amended to address Regulation 10 and Regulation 11 feedback	L Pugh	M Kernke	M Kernke

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1 Executive Summary

Origin Energy B2 Pty Ltd (Origin) is a registered holder and the operator of Exploration Permit (EP) 98, located in the Beetaloo Sub-basin. This Environment Management Plan (EMP) forms the basis of Origin's application to the Northern Territory (NT) Minister for Environment for a series of exploration activities proposed for the Amungee Delineation Area for the financial year (FY) 2023 to 2026 period. Activities proposed in this EMP include:

- Civil construction of up to 4 exploration and appraisal (E&A) well sites and associated infrastructure (access tracks, camp pads, helipads, laydown yards, fence lines, firebreaks, water bore, a gravel pit and all other ancillary infrastructure)
- Drilling, hydraulic fracture stimulation (HFS) and well testing of up to 12 exploration and appraisal (E&A) wells at four (4) new exploration locations.
- Acquisition of 10 x 2D seismic survey totalling approximately 60 km (31.66 ha)

Drilling, HFS and well testing

The Amungee Delineation Area is located around the existing Amungee NW site, on the Shenandoah East and Amungee Mungee pastoral stations within EP98. It contains the existing Amungee NW-1H E&A well, which was drilled and stimulated in 2015/2016 under the previously approved Beetaloo Sub-basin EP98 and EP117 Exploration Drilling EMP NT-2050-15-MP-0010.

The drilling, stimulation and well testing of the 12 E&A wells will target the Velkerri shale resource at 4 "step out" locations surrounding the existing Amungee NW location. The location of the proposed 4 E&A well pads and associated infrastructure within the Amungee Delineation Area is provided in Figure 1. Figure 2 shows the indicative layout for each exploration lease pad.

The scope covered in this EMP is considered an important step in confirming the technical and commercial feasibility of the Velkerri dry gas shale resource which could underpin a future development.

The appraisal results collected from these wells will be used to:

- Validate reservoir flows from the Velkerri target formation at the sites with multiple wells.
- Optimise HFS design and spacing between adjacent horizontal wells in a multi-well pad operation.
- Optimise multi-well pad layout of surface operations for a potential future development scenario with the core objective of minimising the environmental footprint, including minimising land clearance, maximising water re-use and reducing greenhouse gas (GHG) emissions.
- Determine optimal well spacing at a well pad to inform development of the Mechanical Earth Model (MEM) for a future potential development (subject to exploration success).
- Demonstrate design requirements and operability of multi-well pad operations across all seasons in the Beetaloo Sub-basin.
- Assess the financial competitiveness in multi-well pad development scenario to inform Final Investment Decision for future development scenarios.
- Demonstrate no impact on groundwater quality at a well site in a multi-well pad operation.

- Collect additional data on flowback quality and quantity during a multi-well pad operation to assess options for minimising off-site wastewater disposal through future treatment and re-use.
- Provide key data as input into future production approvals, including footprint optimisation, flowback characterisation, GHG emission intensity and solid and liquid waste management.

Seismic Survey

The 2D seismic survey is located within the Amungee Delineation Area as outlined in Figure 3. The survey occurs across the Amungee Mungee Station (portion 1079) and Shenandoah East Station[1] (portion 7027).

The survey consists of 10 x 2D lines orientated north-west to south-east to align with planned horizontal well azimuths, and several east-west and north-south tie lines.

The objectives of the Amungee NW 2D seismic survey will be to:

- High-grade well landing location based on seismic attributes.
- Provide insight to reservoir quality and completions quality
- Test multiple data acquisition methods to optimise image capture quality and minimise future disturbance

The EMP has been prepared in compliance with the NT Petroleum (Environment) Regulations 2016 (the "Regulations"), Code of Practice: Onshore Petroleum Activities in the Northern Territory (the "Code") and the Exploration Agreements between Origin, Native Title holders and the Northern Land Council (NLC).

The overall objective of the EMP is to ensure that the proposed activities are carried out in such a manner that the environmental impacts and risks will be reduced to as low as reasonably practicable (ALARP) and acceptable.

[1] Also referred to as "Hayfield Shenandoah".

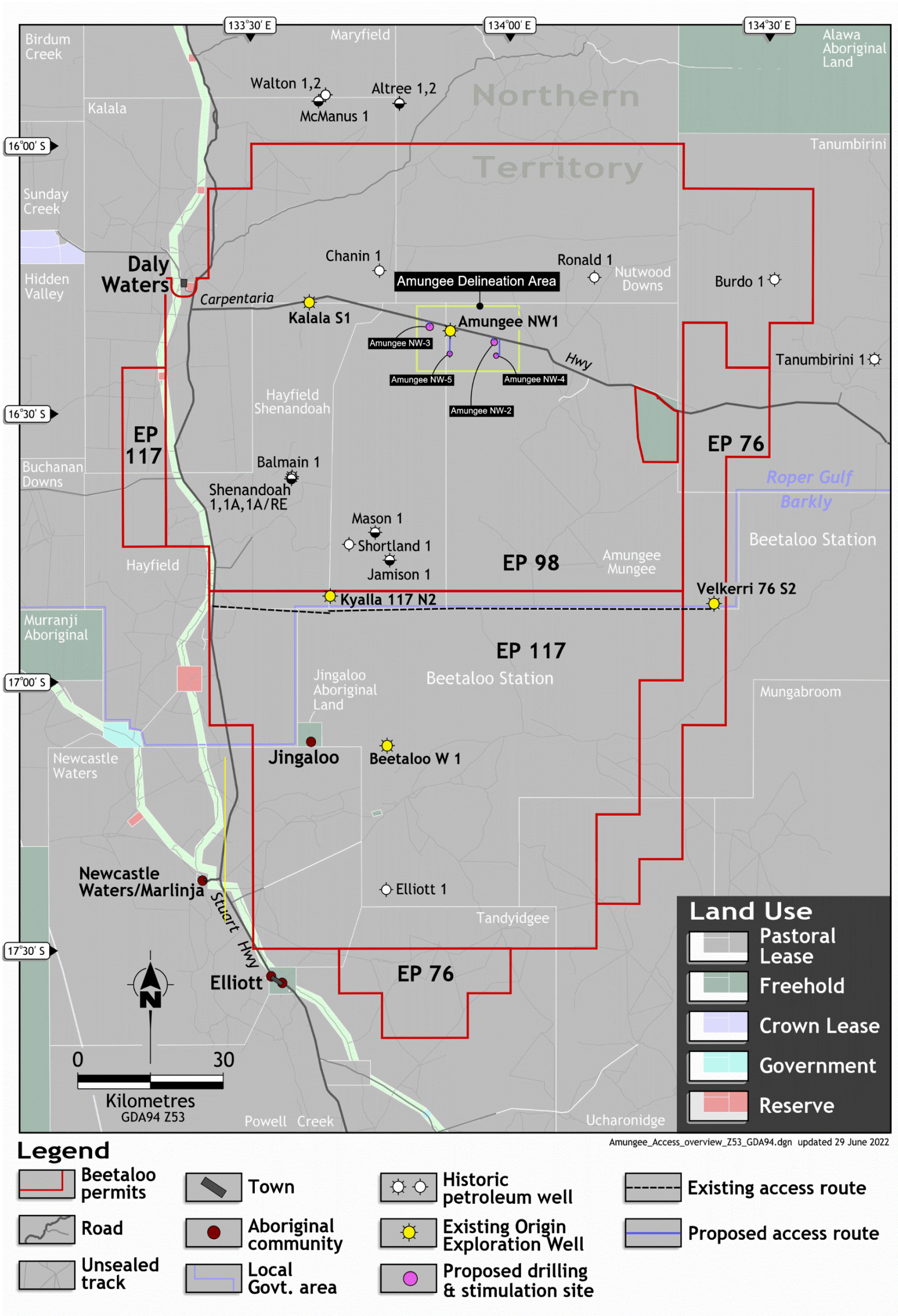

Figure 1: Location of the proposed 4 Amungee Delineation Area and proposed sites in relation to the existing Amungee NW site

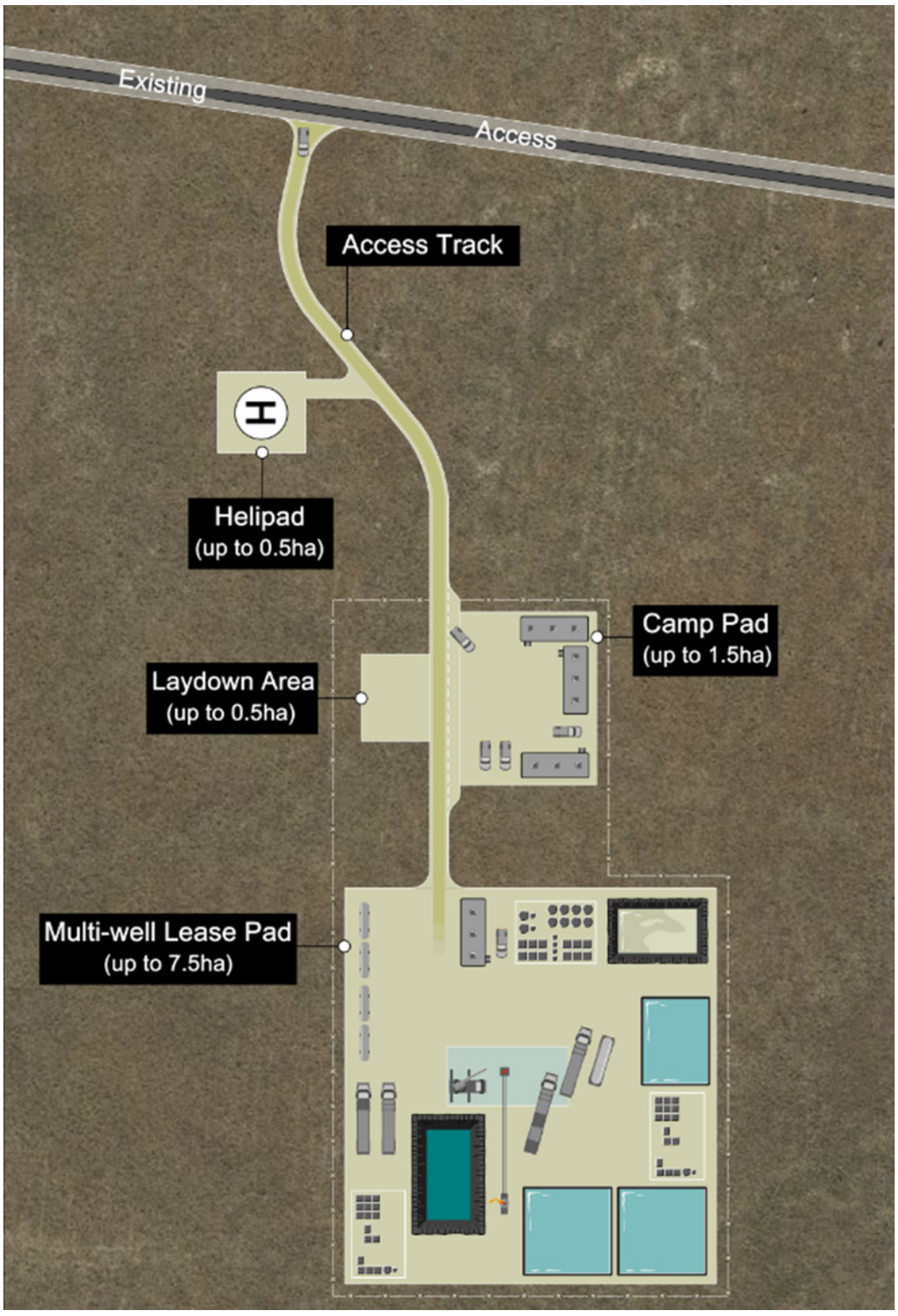

Figure 2: Indicative site layout for each proposed exploration site

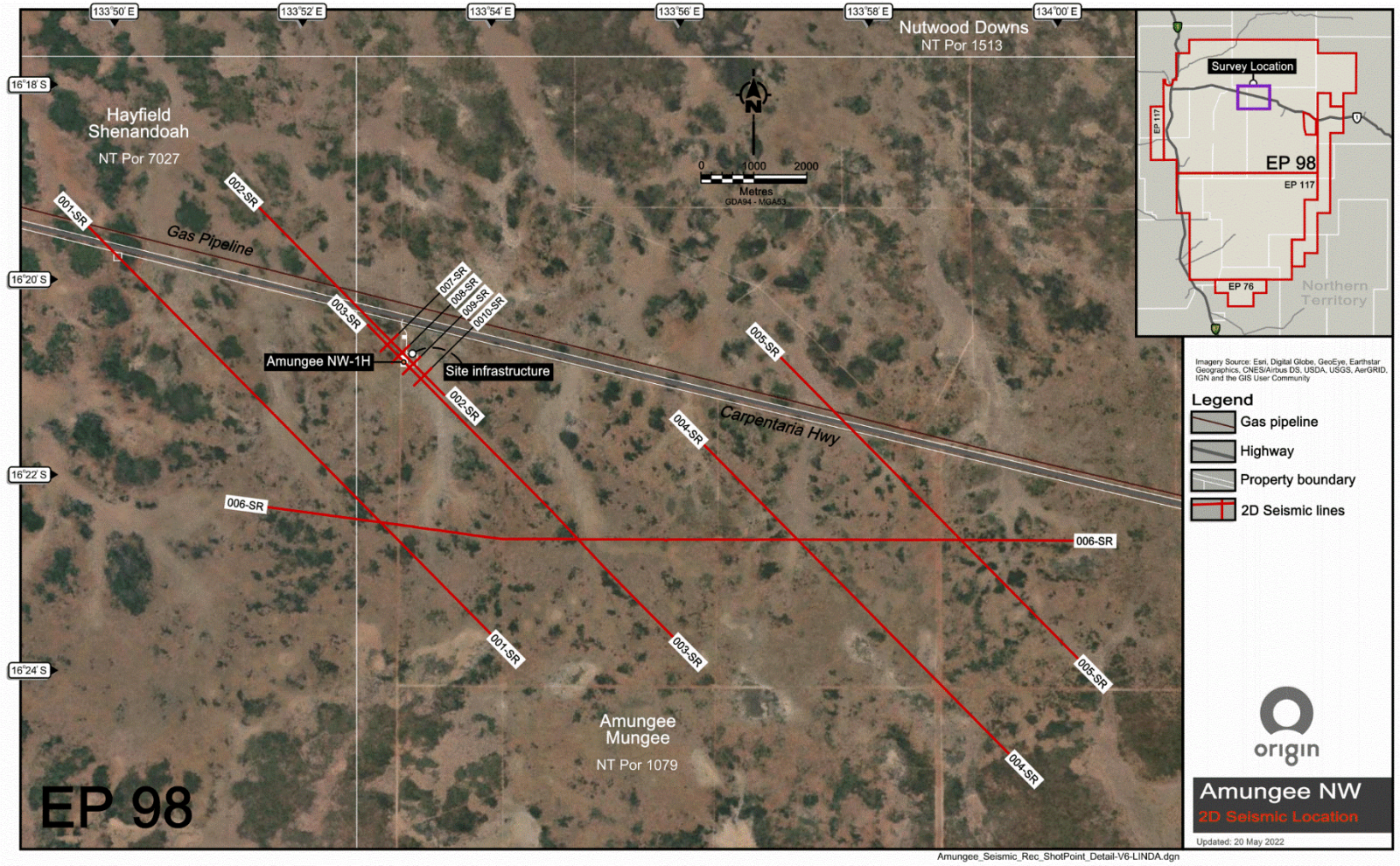

Figure 3: Location of 2D seismic across Amungee Mungee and Shenandoah East pastoral stations

Description of the activity

This EMP covers the regulated activities required to enable Origin to drill, stimulate, test, maintain and potentially decommission up to 12 additional E&A wells at 4 sites on EP 98 (Figure 1). A description of the proposed E&A scope at each site is provided in Table 1.

Each of the four (4) new exploration sites will contain a lease pad, access tracks, camp pad, fence line, firebreak, laydown and helipad. A typical E&A well site layout with associated infrastructure is provided in Figure 2. A new gravel pit will be constructed to provide gravel for access track and pad surface sheeting.

The EMP also covers approximately 60 km (31.66 ha) of 2D seismic survey on EP 98 to support the evaluation of the underlying shale resources in the vicinity of the proposed exploration sites (Figure 3). The seismic lines occur on the Amungee Mungee and Shenandoah East stations. A summary of the proposed 2D seismic scope is provided in Table 1.

The proposed activities will occur within the subject land area which has been approved by the Native Title holders and the Northern Land Council (NLC) and covered by AAPA Certificate C2022/002.

Table 1: Description of the proposed Amungee NW 2, Amungee NW 3, Amungee NW 4 and Amungee NW 5 delineation exploration and appraisal activities, including 2D seismic

Activity	Parameter	Description
Exploration site civil construction	Lease pad 7.5 ha per pad	• Construction of four (4) new 7.5ha lease pads at each exploration site, consisting of: - Amungee NW 2, includes 2 ha cleared under EMP modification 10-3.1 - Amungee NW 3 - Amungee NW 4 - Amungee NW 5
	Access tracks- 18.9 ha	• Construction/ upgrade of access tracks: - Construction of a 2 km access track from the Carpentaria Highway to Amungee NW 3 - including intersection works - Construction of a 5km access track from the Carpentaria Highway to Amungee NW 4- including intersection works - Construction of a 6.5 km access track from the Carpentaria Highway to Amungee NW 5- including intersection works • Access tracks constructed up to 14 m wide • Use of an existing approved access track to the Amungee NW 2 site (1.5 ha)
	Camp pads- 1.2 ha per site	• Construction of a 1.2 ha camp pad at each exploration site (4 in total) • Camp pad will only be constructed if a centralised camp is not used.

Activity	Parameter	Description
	3 Cellars per lease	• Installation of 3 E&A well cellars and conductors on each lease pad to accommodate the proposed wellheads and surface facilities
	1 sump per lease pad	• Construction of a drilling sump on each lease pad to manage drilling fluids, muds and cuttings of up to 5,000 m^3
	1 bund per lease pad	• Construction of a site bund for wastewater storage
	1 stormwater basin per lease pad	• Construction of a sediment basin to manage stormwater during wastewater storage
	4 water extraction bores / monitoring bores per lease pad	• Drilling of up to four additional groundwater monitoring/ extraction bores at each of the proposed E&A sites
	~0.5 ha per exploration site	• Construction of a laydown area at each exploration site
	~0.5 ha per site	• Construction of a helipad at each exploration site
	~4.0 ha per site	• Construction of a 20 m x 2 km fence line and firebreak around each exploration site
	~3.5 ha	• Construction of the new gravel pit within the vicinity of the scouted area of Amungee NW 3.
Site set-up and mobilisation to support the E&A wells	Camps	• The existing Amungee NW camp pad may be used to establish a centralised camp to reduce camp mobilisations/ new disturbance across the Amungee Delineation Area work program. • Where a centralised camp is not used, a temporary main camp will be located on the newly constructed camp pad • Each main camp will typically have a ~70-person capacity. • A drilling mini-camp will also be located on the lease pad during drilling to accommodate 24-hour operations (~8-person capacity).
	Chemical storage areas	• Set-up of chemical and material storage areas.
	Material transportation	• Transportation, handling and storage of bulk chemicals, fuels and wastes

Activity	Parameter	Description
	Drilling rig and equipment	• Set-up of drilling rig, including blow-out preventors, fluid systems and associated equipment such as pipe racks, power generation, offices, ablution blocks and cementing units.
	Frack spread	• Set-up of hydraulic fracture stimulation (HFS) equipment, completions rig and equipment, well testing equipment, and other associated equipment at each Amungee NW site.
	Traffic	• Approximately 44 traffic movements per day, per site during site demobilisation.
Camp operation	~70-person camp	• Operation of a main camp – either centralised (existing Amungee NW) or at each site • Operation of drilling camp on each lease pad during drilling
E&A well Drilling	3 E&A wells	• Drilling of 3 horizontal E&A wells at each site, including the vertical pilot well (where required) and collection of reservoir quality data during drilling
Hydraulic fracturing	3 E&A wells per site	• HFS of all 12 wells across 4 sites • 10-30 stages per well depending on horizontal length (typically 15 stages) • Recycling of flowback wastewater for stimulation fluid makeup to reduce raw water use
Well completion	3 E&A wells per site	• Completion of 12 E&A wells across 4 proposed E&A sites
Well testing	90 – 135 days per well (average)	• Extended production testing of 12 wells across 4 sites- average well test duration is anticipated to be 135 days- subject to operational requirements
		• Gas flaring in accordance with Code requirements and as per US EPA 40 CFR 63.11, with a flare tip combustion efficiency of 98%
Well maintenance and monitoring	3 wells per site	• Maintenance and monitoring works on 12 wells across 4 sites (including well workovers) in accordance with approved WOMP
Build up testing	3 wells per site	• Build up testing to monitor the pressure build-up within each E&A well
Well suspension and decommissioning	3 wells per site	• suspension and decommissioning (if required) across 4 sites in accordance with the Code.
Groundwater extraction	107.5 ML per site	• Groundwater extraction under existing groundwater extraction licence (WEL GRF 10285)

Activity	Parameter	Description
Environmental monitoring	4 well sites	• Monitoring activities (including groundwater, stormwater, soils, leak detection, seismicity and all other low impact ancillary data collection programs)
On-site wastewater management to support ongoing E&A program	4 well sites	• On-site wastewater storage and treatment in accordance with Code • Use of the drilling sump, enclosed wastewater storage tanks and wastewater treatment tanks to manage drilling and flowback wastewater • Drill cuttings and flowback fluid quality testing in accordance with the Code • Drilling waste storage – including centralised storage of drilling waste from other approved locations • Disposal of drill cuttings subject to the outcomes of chemical analysis in accordance with clause C.4.1.2 of the Code • On-site treatment of wastewater through evaporation or other alternative methods (such as enhanced evaporation or other mechanical water treatment options) • Recycling of flowback wastewater for stimulation fluid makeup to reduce raw water use • Off-site disposal of flowback wastewater in accordance with the Waste Management and Pollution Control Act
Site decommissioning	4 well sites and associated infrastructure (access tracks, gravel pit, seismic lines etc.)	• Decommissioning and removal of all surface infrastructure and wastes from site including the removal of drilling sump, wastewater tanks, cellars, equipment, non-drilling waste, wastewater and all ancillary equipment
Site demobilisation	4 Well sites and 12 wells	• Demobilisation of exploration equipment, including camps, drilling rigs, HFS equipment, completion rigs, well testing equipment, wastewater storage tanks and various service provider equipment • Approximately 44 traffic movements per day during site demobilisation
Seismic acquisition	~60 km (31.66 ha)	• Seismic program to utilise 2 energy sources to evaluate optimal energy source type: vibroseis and seismic charges • Civil construction of 10 x 2D seismic lines:

Activity	Parameter	Description
		○ Clearing of approximately 60km of seismic lines with a 5 m cleared track width ○ Seismic lines to be weaved through vegetation to a path of least resistance. Slashing can be utilised in otherwise untraversable vegetation. Deviations in lines must be constructed in a way that is accessible by equipment/vehicles such as heavy-rigid body trucks (minimum 15 m turning radius) ○ A small turning circle to be constructed at the end of each seismic line to allow equipment and vehicles to exit ○ A 250 m buffer /deviation from either side of the centreline pre-plot data where required to avoid any unsuitable terrain or obstacles. ○ Estimated maximum surface disturbance of 31.66 ha, noting that all efforts will be deployed to avoid clearing. ○ Estimated groundwater use ~1 ML. • Construction of 2 fenced areas 12 m(L) x 9 m (W) for explosive storage magazines (AS2187) along cleared lines: ○ Fenced areas to be constructed as per AS1725. ○ Gates minimum 4 m opening. ○ Surface within the magazine storage area to be smooth and free of debris, loose zones and soft spots. ○ Surface compaction ≥ 100 kPa. • Shot hole drilling for 400 x 20 m depth holes @ 80 mm – 100 mm OD at a shot hole interval of 60 m. • Low disturbance node deployment • Seismic acquisition, including vibroseis deployment, charge detonation and data collection • Rehabilitation of cleared lines and shot holes by respreading any windrowed soil and reinstating vegetation from stockpiled area back across the seismic line.
Total disturbance & Rehabilitation (approx.)	106.86 ha	• Final rehabilitation activities to return the sites back to a safe, stable and non-polluting form consistent with pre-disturbed condition

Description of the existing environment

The proposed sites of the exploration program are located on the Shenandoah East and Amungee Mungee Pastoral station.

A Land Condition Assessment was completed in 2014, 2018, 2021and 2022 to review the physical, natural and cultural heritage environment. A summary of the existing environment in which the 4 lease pads will be located is provided in Table 2 – Table 5. Further information on sites is provided in section 4. The dominant vegetation community across the 2D seismic lines is typically *Corymbia* spp. mid high open woodland, over *Terminalia canescens, Petalostigma pubescens, Erythrophleum chlorostachys* mid high open shrubland, over mid high open tussock grassland. Further information regarding the vegetation communities with the 2D seismic activity is provided in section 5.2.

The existing Amungee NW site and extension represents the current disturbance footprint of approximately 18.3 ha. The works proposed under this EMP will increase the disturbance footprint across the Amungee NW site within the delineation area to approximately 130 ha.

The Amungee Delineation Area is located surrounding the existing Amungee NW site. The main vegetation communities identified within the proposed activity area are woodlands, typically dominated by bloodwoods (*Corymbia* spp.) and Eucalypt and patches of tall shrubland / woodland of Lancewood (*Acacia shirleyi*) and Bullwaddy (*Macropteranthes kekwickii*) with open grassland understorey. These vegetation types are widespread in the tropical savannas of the NT and may provide habitat for some threatened species, such as the Crested Shrike-tit (*Falcunculus frontatus whitei*) and Gouldian Finch (*Erythrura gouldiae*).

Ongoing routine field weed surveys have been completed across the site. *Sida acuta*, *Hyptis suaveolens* (Class B & C under the NT *Weeds Management Act 2001*) were the dominant weeds found during the 2022 survey. A single occurrent of *Cenchrus pedicellatus* (environmental weed of concern) was recorded along the proposed track to the Amungee NW 5 site. Weeds were observed predominantly along the Carpentaria Highway, fence lines and in areas heavily disturbed by cattle, such as where drinking troughs were located. The low number of weed species at and around the sites indicates the surrounding habitat is in good condition. Weed management will continue to focus on preventing the introduction and spread of weeds.

The archaeology assessment did not identify any culturally sensitive landforms, but it did identify several archaeological sites the vicinity of the proposed NW 5 lease pad, Amungee NW 3 lease pad and Amungee NW 3 gravel pit. The proposed NW 5 lease pad has been moved north of the site to avoid any disturbance to an artefact scatter identified during scouting. The artefacts identified at Amungee NW 3 and Amungee NW 3 gravel pit area are both isolated stone chip type finds and are proposed to be either relocated (with prior approval via the NT Heritage Branch and Native title holders) or avoided.

Aboriginal Areas Protection Authority (AAPA) Certificate C2022/002 has been granted for activities within the Amungee Delineation Area. The closest identified sacred site is located over 9 km away from the closest proposed exploration well location. Origin has committed to comply with the conditions of the AAPA certificates.

Table 2: Summary of existing environment and surrounds – Amungee NW 2

Amungee NW 2 (Scouting Id AMS 1)		**Survey photos of the vegetation/habitat of the surrounding environment**
Location	GDA94, zone 53, 0389927E, 8190027N	   
Landform and soil	Dark reddish brown sandy loam grading to sandy clay loam material at 0.2 m, well drained on simple slope (1%)	
Vegetation community	*Corymbia dichromophloia* and *Eucalyptus chlorophylla* open woodland	
Vegetation description	*Corymbia dichromophloia* and *Eucalyptus chlorophylla* mid high open woodland, over *Erythrophleum chlorostachys, Acacia difficilis* and *Santalum lanceolatum* mid high open shrubland, over *Chrysopogon fallax and Sorghum plumosum* open tussock grassland	
Dominant flora species	*Eucalyptus chlorophylla*, *Macropteranthes kekwickii*, *Acacia difficilis*, *Corymbia*	

Amungee NW 2 (Scouting Id AMS 1)		Survey photos of the vegetation/habitat of the surrounding environment	
	ferruginea, *Erythrophleum chlorostachys*, *Terminalia canescens*, *Brachychiton paradoxus*, *Bauhinia cunninghamii*		
Habitat condition	Scattered tree hollows, common falling logs. Mistletoe and flowering plants absent. No canopy cover across 68.2%. Tree hollows, mistletoe and flowering plants absent. Fire damage > 2 years ago. No erosion. Cattle impacts. Termite mounds sparse. Ground cover: 20% vegetation, 10% litter, 70% bare soil	**Potential listed threatened species**	Grey Falcon, Northern Shrike-tit, Plains Death Adder, Gouldian Finch
		Weeds	During the 2022 survey, Hyptis and Sida (*Sida acuta*) were predominantly observed in the upper portion of Amungee Mungee Station, along the Carpentaria Highway corridor, fence lines and areas heavily disturbed by cattle – i.e. at drinking troughs.
		Hydrogeology	Groundwater resources and use is from the Gum Ridge Formation. A seasonal perched shallow alluvium system has also been locally identified by is not a groundwater source. The Anthony Lagoon Formation and undifferentiated Cretaceous are unsaturated.

Table 3: Summary of existing environment and surrounds – Amungee NW 3

Amungee NW 3 (Scouting ID AMS 2)		**Survey photos of the vegetation/habitat of the surrounding environment**
Location	GDA94, zone 53, 0376604E, 8193091N	   
Landform and soil	Brown sandy loam grading to silty clay loam at 0.3 m, imperfectly drained on simple slope (1%).	
Vegetation community	*Corymbia dichromophloia* open woodland	
Vegetation description	*Corymbia dichromophloia mid high open woodland, over Terminalia canescens, Petalostigma pubescens and Hakea arborescens mid high sparse shrubland, over Chrysopogon fallax, Schizachyrium fragile open tussock grassland*	
Dominant flora species	*Corymbia dichromophloia, Terminalia canescens, Petalostigma pubescens, Erythrophleum chlorostachys, Hakea arborescens, Grevillea parallela, Ehretia saligna, Erythroxylum ellipticum*	

<table>
<tr><th colspan="2">Amungee NW 3 (Scouting ID AMS 2)</th><th colspan="2">Survey photos of the vegetation/habitat of the surrounding environment</th></tr>
<tr><td rowspan="4">Habitat condition</td><td rowspan="4">Common tree hollows and scattered fallen logs. No canopy cover across 66%. Tree hollows, mistletoe and flowering plants absent. Fire damage >2 years ago. No erosion. Cattle impacts. Termite mounds common.

Ground cover: 20% vegetation, 5% litter, 35% bare soil, 40% gravel</td><td colspan="2"></td></tr>
<tr><td>Potential listed threatened species</td><td>Grey Falcon, Northern Shrike-tit, Plains Death Adder, Gouldian Finch</td></tr>
<tr><td>Weeds</td><td>Moderate to dense predominantly Hyptis (Mesophaerum suaveolens) within the upper portion of Shenandoah East in the Carpentaria Highway corridor. Low number of localised records.[2]</td></tr>
<tr><td>Hydrogeology</td><td>Groundwater resources and use is from the Gum Ridge Formation. A seasonal perched shallow alluvium system has also been locally identified by is not a groundwater source. The Anthony Lagoon Formation and undifferentiated Cretaceous are unsaturated.</td></tr>
</table>

[2] NR Maps 2022. Shenandoah East Station Portion 7027 Land Resources (nt.gov.au), viewed online 30 June 2022.

Table 4: Summary of existing environment and surrounds – Amungee NW 4

Amungee NW 4 (Scouting ID AMS3)		Survey photos of the vegetation/habitat of the surrounding environment
Location	GDA94, zone 53, 0390418E, 8186954N	   
Landform and soil	Dark reddish brown loamy sand grading to sandy loam at 0.2 m. Well drained over simple slope <1%.	
Vegetation community	*Corymbia dichromophloia* and *Erythrophleum chlorostachys* woodland	
Vegetation description	*Corymbia dichromophloia* and *Erythrophleum chlorostachys* mid high woodland, over *Acacia calligera*, *Grevillea parallela* and *Hakea arborescens* mid high open shrubland, over *Chrysopogon fallax* and *Triodia bitextura* open tussock grassland	
Dominant flora species	*Corymbia dichromophloia*, *Erythrophleum chlorostachys*, *Hakea arborescens*, *Grevillea parallela*, *Terminalia canescens*, *Denhamia cunninghamii*	
Habitat condition	Scattered tree hollows and fallen logs. Mistletoe and flowering plants absent. No canopy cover across 58%. Fire damage >2 years ago. No erosion. Cattle impacts. Termite mounds sparse.	

Amungee NW 4 (Scouting ID AMS3)		Survey photos of the vegetation/habitat of the surrounding environment	
	Ground cover: 15% vegetation, 65% litter, 5% bare soil, 15% gravel.	**Potential listed threatened species**	Grey Falcon, Northern Shrike-tit, Plains Death Adder, Gouldian Finch
		Weeds	During the 2022 survey, Hyptis and Sida (*Sida acuta*) were predominantly observed in the upper portion of Amungee Mungee Station, along the Carpentaria Highway corridor, fence lines and areas heavily disturbed by cattle – i.e. at drinking troughs.
		Hydrogeology	Groundwater resources and use is from the Gum Ridge Formation. A seasonal perched shallow alluvium system has also been locally identified by is not a groundwater source. The Anthony Lagoon Formation and undifferentiated Cretaceous are unsaturated.

Table 5: Summary of existing environment and surrounds – Amungee NW 5

Amungee NW 5 (Scouting ID AMS4)		**Survey photos of the vegetation/habitat of the surrounding environment**
Location	GDA94, zone 53, 0390418E, 8186954N	   
Landform and soil	Dark reddish brown loamy sand grading to sandy loam. Well drained over simple slope 1%.	
Vegetation community	*Corymbia dichromophloia* and *Eucalyptus chlorophylla* open woodland	
Vegetation description	*Corymbia dichromophloia* and *Eucalyptus chlorophylla* mid high open woodland, over *Erythrophleum chlorostachys, Petalostigma pubescens* and *Terminalia volucris* mid high open shrubland, over *Themeda triandra, Chrysopogon fallax* and *Schizachyrium fragile* tussock grassland	
Dominant flora species	*Erythrophleum chlorostachys*, *Corymbia dichromophloia*, *Eucalyptus chlorophylla*, *Terminalia canescens*, *Terminalia volucris*, *Petalostigma pubescens*, *Corymbia polycarpa*, *Acacia shirleyi*, *Macropteranthes kekwickii*, *Grevillea parallela*	

Amungee NW 5 (Scouting ID AMS4)		Survey photos of the vegetation/habitat of the surrounding environment	
Habitat condition	Scattered tree hollows and fallen logs. Mistletoe and flowering plants absent. No canopy cover across 70.25%. Fire damage >2 years ago. No erosion. Cattle impacts. Termite mounds common. Ground cover: 40% vegetation, 40% bare soil, 20% leaf litter.		
		Potential listed threatened species	Grey Falcon, Northern Shrike-tit, Plains Death Adder, Gouldian Finch
		Weeds	During the 2022 survey, Hyptis and Sida (Sida acuta) were predominantly observed in the upper portion of Amungee Mungee Station, along the Carpentaria Highway corridor, fence lines and areas heavily disturbed by cattle – i.e. at drinking troughs. One localised occurrence of Annual Mission grass (*Cenchrus pedicellatus*) recorded on the proposed access track to the site.
		Hydrogeology	Groundwater resources and use is from the Gum Ridge Formation. A seasonal perched shallow alluvium system has also been locally identified by is not a groundwater source. The Anthony Lagoon Formation and undifferentiated Cretaceous are unsaturated.

Chemical risk assessment

A chemical risk assessment has been completed for all chemicals to be used in drilling and HFS. All chemicals were considered low concern when standard chemical handling, storage and disposal practices were applied. The chemicals and estimated quantities that may be added to the HFS proppant (sand) are shown in Table 6.

Table 6: Chemicals that may be added to the proppant during stimulation activities and held on each lease pad (3 wells per pad)

Material name	Typical volume	Maximum volume	Unit	Storage area
Acetic Acid - 60% pH control	3,000	9,000	L	Stimulation chemical storage area
BE-9 biocide	17,000	51,000	L	Stimulation chemical storage area
Caustic soda liquid pH control/ buffer	15,000	45,000	L	Stimulation chemical storage area
DCA-11001 breaker activator	5,000	15,000	L	Stimulation chemical storage area
DCA-13002 breaker	300	900	kg	Stimulation chemical storage area
DCA-13003 breaker	10,000	30,000	L	Stimulation chemical storage area
DCA-16001 clay stabiliser	42,000	126,000	L	Stimulation chemical storage area
DCA-17001 corrosion inhibitor	1,000	3,000	L	Stimulation chemical storage area
DCA-19001 crosslinker	600	1,800	kg	Stimulation chemical storage area
DCA-19002 crosslinker	10,000	30,000	L	Stimulation chemical storage area
DCA-23001 friction reducer	5,000	15,000	kg	Stimulation chemical storage area
DCA-23003 friction reducer	18,000	54,000	L	Stimulation chemical storage area
DCA-25005 gelling agent	35,000	105,000	kg	Stimulation chemical storage area
DCA-30001 scale inhibitor	15,000	45,000	L	Stimulation chemical storage area
DCA-32002 surfactant	15,000	45,000	L	Stimulation chemical storage area
DCA-32014 surfactant	200	600	L	Stimulation chemical storage area
FE-2 buffer	200	600	kg	Stimulation chemical storage area
Hydrochloric acid - 32%	50,000	150,000	L	Stimulation chemical storage area
100 mesh sand: proppant	91,000	273,000	kg	Stimulation chemical storage area
40/70 sand: proppant	1,650,000	4,950,000	kg	Stimulation chemical storage area
30/50 sand: proppant	610,000	1,830,000	kg	Stimulation chemical storage area

Key environmental risks assessed in the program

The environmental, heritage and social risks associated with drilling, stimulation and well testing activities have been assessed using the Origin risk assessment framework. The detailed risk assessment presents the range of potential impacts, corresponding mitigation measures and residual risk ratings based on their assessed worst-case consequence and likelihood of occurrence. Key risks assessed under this EMP include:

- protection of groundwater through sustainable groundwater use and zonal isolation
- loss of containment:
  - assessment and management of chemicals
  - generation and management of wastewater, including prevention of spills
  - well integrity
- generation and management of waste, associated with drilling and hydraulic fracturing
- managing cultural heritage finds
- managing of erosion and sediment control
- managing traffic
- managing the risk of bushfire in the area
- mitigating the introduction and spread of weeds
- managing unsustainable greenhouse gas emissions from the activity.

It was considered that with the appropriate controls implemented to mitigate the impacts there were no residual risks above a rating of medium (Table 5).

Table 7: Summary of residual risk ratings

	Residual Environmental Risk Level			
	Low	**Medium**	**High**	**Very High**
Total 83	71	12	0	0

The medium risks identified were consistent with standard project and pastoral activities completed across the NT, and are related to soil erosion, spread of weeds, accidental ignition of fire/bushfires and nuisance dust generation.

The medium residual risks sources assessed under this EMP include:

1. Loss in soil productivity and viability due to soil erosion from cleared areas (existing access tracks, lease pads, camp pads and 2D seismic) – risk ID 24
2. Impact to listed threatened habitats and listed threatened flora and fauna, including non-listed fauna and livestock through the introduction and spread of weeds in the area – risk ID 35 and risk ID 43
3. Impact to listed threatened habitats and listed threatened flora and fauna, including non-listed fauna and livestock from exploration activities (drilling, HFS, flaring, general access, 2D seismic) – risk ID 36 and risk ID 44

4. Impact to listed threatened habitats and listed threatened flora and fauna from poor rehabilitation of 2D seismic lines – risk ID 45
5. Disturbance of sacred site or culturally sensitive area and decline in environmental value of area used for cultural purposes through the accidental ignition of fire by site activities – risk ID 48 and risk ID 52
6. Reduction in agriculture productivity through the introduction and spread of weeds in the area – risk ID 60
7. Reduction in agriculture productivity through bushfire from accidental ignition by site activities or site personnel – risk ID 63
8. Increased nuisance from dust emissions associated with the activities – risk ID 72
9. Increased nuisance from dust and particulate emissions due to accidental ignition of bushfire during the site activities – risk ID 73

The assessment demonstrates that the risks associated with drilling and stimulation-related activities have been reduced to as low as reasonably practicable (ALARP) and acceptable through multiple well integrity safeguards, including isolation barriers to protect against contamination of groundwater aquifers. The environmental outcomes to be achieved during the proposed activities include no significant impacts to the following aspects:

- Ecological function and productivity of soils
- Ecological function of surface water bodies
- The viability of groundwater systems to support ecological, economic and community activities
- The protection of high valued habitats and threatened flora and fauna
- The maintenance of air quality, including the offsetting of residual GHG emissions
- The protection and enhancement of community and cultural values, places and amenity.

At completion of E&A activities, the sites will be returned to a safe, stable and non-polluting form consistent with pre-disturbed condition.

Stakeholder engagement

Stakeholder engagement for Origin's E&A project has focused on the host Traditional Owners (facilitated by the NLC) and host pastoralists directly affected by the proposed activity. Detailed community and stakeholder engagement is ongoing and covers Origin's activities on a broader level and includes the information required under the Regulations. This includes providing the stakeholders of the activity description, location, impacts, potential risk, proposed environmental controls and potential impacts to the stakeholders rights.

2 Introduction

2.1 Purpose

Origin Energy B2 Pty Ltd (Origin) is a registered holder and the operator of Exploration Permit (EP) 98, located in the Beetaloo Sub-basin. This Environment Management Plan (EMP) forms the basis of Origin's application to the Northern Territory (NT) Minister for Environment for a series of exploration activities proposed for the Amungee Delineation Area for the Financial Year (FY) 2023 to 2026 period. Activities proposed in this EMP include:

- Civil construction of up to 4 exploration and appraisal (E&A) well sites and associated infrastructure (access tracks, camp pads, helipads, laydown yards, fence lines, firebreaks, water bore, a gravel pit and all other ancillary infrastructure)
- Drilling, hydraulic fracture stimulation (HFS) and well testing of up to 12 exploration and appraisal (E&A) wells at four (4) new exploration locations.
- Acquisition of 10 x 2D seismic survey totalling approximately 60 km (31.66 ha)

This EMP has been prepared in compliance with the Regulations, the Code and the Exploration Agreement(s) between Origin, Native Title holders and the NLC.

The overall objective of the EMP is to ensure that the proposed activities are carried out in such a manner that the environmental impacts and risks will be reduced to a level that is as low as reasonably practicable and acceptable.

More specifically, this EMP aims to:

- address regulatory requirements
- provide site-specific impact management strategies to assist Origin in maintaining a positive position in the local community throughout its program
- align with the principles of Ecological Sustainable Development (ESD) through the adoption of responsible development practices that are designed to maximise social benefit, while minimising the level of impact on the surrounding ecosystems
- provide a description of site-specific aspects of the existing environment (physical, biological, social and cultural)
- provide site-specific plans for monitoring and rehabilitation
- be a practical and usable document, with environmental management principles that are easily implemented and effective.

2.2 Project boundary

Origin proposes to drill, stimulate and test up to 12 additional petroleum E&A wells on 4 locations within the Amungee Delineation Area within EP98 over the Financial Year (FY) 2023 to 2026 period. These E&A wells will target the Velkerri shale resource at "step out" locations surrounding the existing Amungee NW location.

The boundary of this EMP is defined as the area which may be affected by E&A activities and the 2D seismic survey – i.e. within the Amungee Delineation Area (Figure 1). This includes:

- existing Amungee NW access tracks, lease pad, camp pad, water bores and all other associated infrastructure

- construction and operation of 4 new lease pads and camp pad(s), including the installation of a new fence line and fire break
- proposed construction of a helipad and laydown yard at each site
- proposed installation of 4 groundwater extraction/ monitoring bores at each site
- proposed construction of 1 new gravel pit (Amungee NW 3 gravel pit)
- proposed drilling, stimulation, well testing, maintenance, suspension, and abandonment of up to 12 petroleum E&A wells; 3 wells per site
- acquisition of approximately 60 km (~31.66 ha) of 2D seismic.

The proposed indicative locations of the infrastructure and associated regulated activities for the 4 lease pads and 2D seismic acquisition is provided in Figure 4 and Table 8. The location of each of the seismic lines is provided in Table 9.

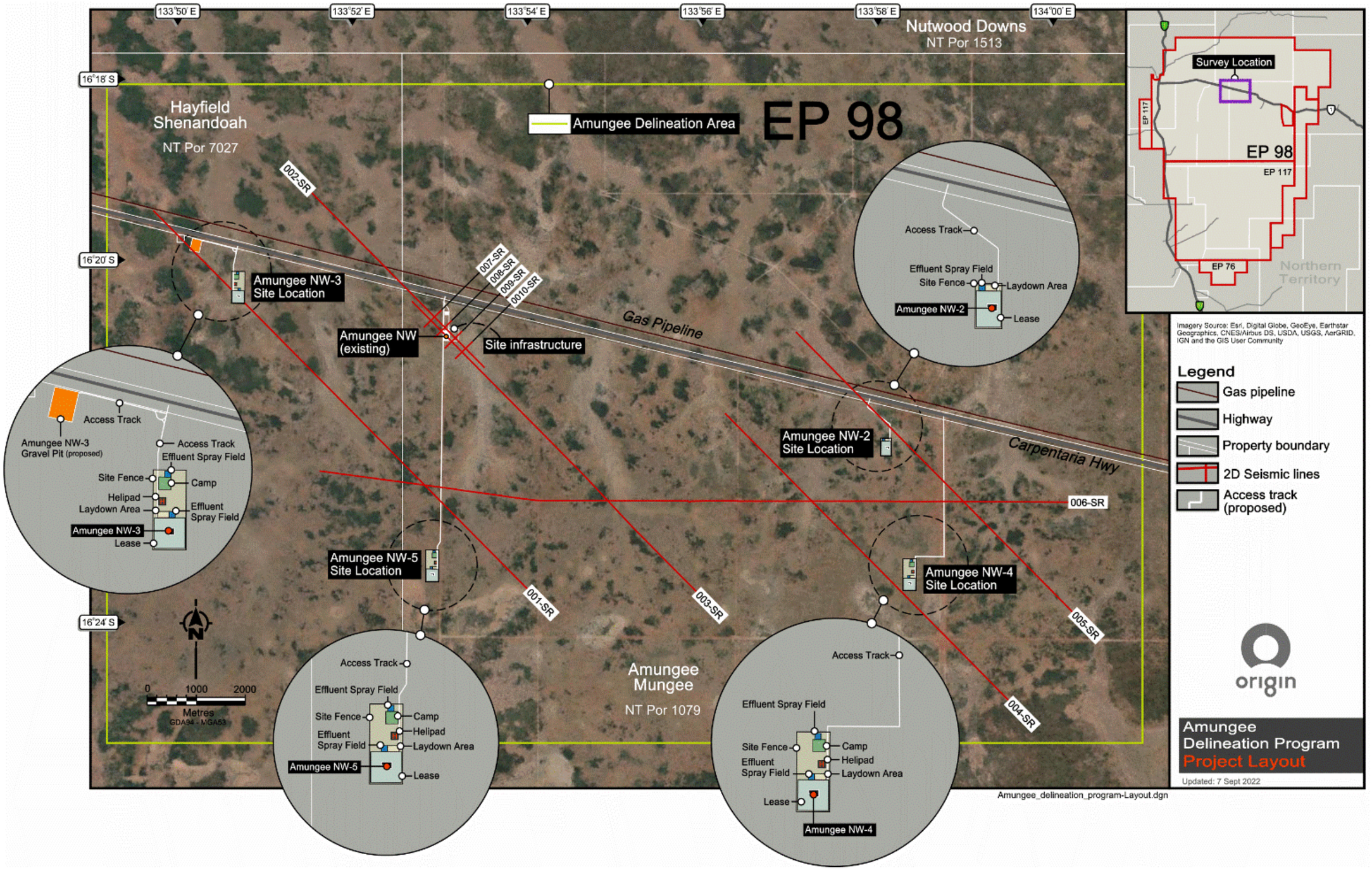

Figure 4: Amungee delineation layout - lease pads and 2D seismic

Table 8: Associated exploration sites and infrastructure covered under this EMP

Exploration Permit	Infrastructure name	Station	Zone*	Lat	Long
EP 98	Amungee NW (existing site; approved)	Amungee Mungee	53	-16.347	133.884
EP98	Amungee NW 2	Amungee Mungee	53	-16.367	133.968
EP98	Amungee NW 2 access track (existing, approved)	Amungee Mungee	53	-16.359	133.965
EP98	Amungee NW 3	Shenandoah East	53	-16.340	133.844
EP98	Amungee NW 3 access track	Amungee Mungee	53	Refer Figure 4	
EP98	Amungee NW 4	Amungee Mungee	53	-16.393	133.973
EP98	Amungee NW 4 Access track	Amungee Mungee	53	Refer Figure 4	
EP98	Amungee NW 5	Amungee Mungee	53	-16.391	133.882
EP98	Amungee NW 5 Access track	Amungee Mungee	53	Refer Figure 4	
EP98	Amungee NW 3 gravel pit	Amungee Mungee	53	-16.330	133.837
EP98	Amungee NW 3 gravel pit access track	Amungee Mungee	53	Refer Figure 4	

**Universal Transverse Mercator (UTM) geographic coordinate system is Geocentric Datum of Australia (GDA) 94.*

Table 9: Indicative coordinates of the 2D seismic survey program on EP 98

Line	Seismic line coordinates				Total length (km)	Total area (ha)*
	Start of line		End of line			
	Lat	Long	Lat	Long		
001-SR	-16.32434	133.82875	-16.39386	133.89996	10.81	5.95
002-SR	-16.32112	133.85894	-16.35325	133.89186	5.00	2.75
003-SR	-16.34104	133.87802	-16.39438	133.93218	8.27	4.55
004-SR	-16.36162	133.93763	-16.41430	133.99165	8.20	4.51
005-SR	-16.34667	133.95114	-16.39806	134.00384	8.00	4.40
006-SR	-16.37223	133.86042	-16.37795	134.00306	15.29	8.41

Line	Seismic line coordinates				Total length (km)	Total area (ha)*
	Start of line		End of line			
	Lat	Long	Lat	Long		
007-SR	-16.34267	133.88364	-16.34584	133.88032	0.50	0.28
008-SR	-16.34459	133.88562	-16.34777	133.88229	0.50	0.28
009-SR	-16.34652	133.88759	-16.34970	133.88427	0.50	0.28
0010-SR	-16.34845	133.88957	-16.35163	133.88624	0.50	0.28
Total					**57.27**	**31.66**

* Footprint area based on 5 m wide seismic lines

2.3 Project proponent

The proponent and Operator for the project is Origin Energy B2 Pty Ltd. Contact details:

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Approvals Manager-Growth Assets
Origin Energy B2 Pty Ltd (ABN 42 105 431 525)
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3 Environmental legislation and other requirements

Key NT and Commonwealth legislation, agreements, operating consents, guidelines and Codes of Practice relevant to the activities described in this EMP are summarised in Table 10. This EMP has been prepared in relation to these requirements.

Table 10: Key legislation

Legislation	Requirement	How Origin meets the requirement	Administered by
Northern Territory			
Petroleum Act 1984	Petroleum exploration licences are required in the areas where activities are proposed.	Exploration permits obtained. Minister provides the final sign off authorising Petroleum activities.	Department of Industry, Tourism and Trade (DITT)
	Compensation to be paid to Native Title holders and owners/occupiers of land where petroleum activities are proposed.	Exploration Agreements obtained with Native Title holders. Compensation paid to pastoralists for all activities proposed under this EMP.	
	The NT Schedule of Onshore Petroleum Exploration and Production Requirements ('NT Schedule'), should be listed. It covers key regulatory requirements for operational management of well activities in conjunction with the *Code of Practice: Onshore petroleum activities in the Northern Territory* (the Code).	Requirements addressed in the Well Operations Management Plan (WOMP).	
Petroleum Regulations 2020	Underpins the integrity of shared land use arrangements between petroleum companies and landholders in the NT.	While land access requirements under the Petroleum Regulations 2020 are separate to the EMP approval process, no activities will be undertaken without Land Access Agreements registered with all relevant affected landholders.	DITT
	Ensuring all regulated activities have an approved EMP.	This EMP has been developed to satisfy this requirement	

Legislation	Requirement	How Origin meets the requirement	Administered by
Petroleum (Environment) Regulations 2016	That the EMP is developed in accordance with the NT Petroleum (Environment) Regulations 2016 (the Regulations).	Origin has developed this EMP in accordance with the Regulations.	Department of Environment, Parks and Water Security (DEPWS)
	That stakeholder engagement for the regulated activities is undertaken.	Origin has completed stakeholder engagement in accordance with the Regulations, as summarised in section 6 of this EMP.	
	That activities are conducted in accordance with the Code.	The EMP outlines how the activities will be conducted in accordance with the Code.	
	Reporting requirements for incidents and hydraulic fracturing.	The EMP summarises how incidents and flowback monitoring results will be reported.	
***Bushfires Management Act 2016* and associated regulations**	Compliance with total fire bans and fire permitting.	Origin will not undertake flaring or the lighting of fires during periods of total fire bans and will obtain a permit where flaring occurs during declared fire danger periods.	Bushfires NT
	Requirements for occupiers to prevent and control fires.	Addressed through Origin's Bushfire Management Plan (Appendix A) which includes bushfire preventative and response measures.	
	Aerial burning permits.	Origin will acquire permits where aerial burning to manage fuel loads is proposed as a part of its ongoing bushfire management activities. Origin does not consider that aerial burning will be required.	

Legislation	Requirement	How Origin meets the requirement	Administered by
Control of Roads Act 1953* and *Northern Territory Traffic Act 1987	Any proposed development which may affect the NT road network, including traffic, operation (including seismic within the road corridor), management, capacity or safety, or result in the construction or installation of new infrastructure within the NTG road network, requires assessment and Road Agency Approval.	Origin will continue to engage with the Department of Infrastructure, Planning and Logistics (DIPL) regarding proposed and ongoing traffic management.	Department of Infrastructure, Planning and Logistics (DIPL)
Emergency Management Act 2013	Establishes the requirements for local, regional and Territory emergency management plans. Describes the functions and powers of the NTES, Territory Emergency Controller, Territory Recovery Controller and Territory Emergency Management Committee.	Origin complies with the Act through the development of an emergency response plan and the identification of NTFES as a stakeholder.	Northern Territory Emergency Service
Environment Protection Act 2019	Activities which have the potential to cause a significant impact to the environment are required to be referred to the NT EPA for assessment under the *Environment Protection Act 2019*.	Origin has completed a self-assessment. The level of potential environmental impact is not considered significant.	Northern Territory Environment Protection Authority (NT EPA) DEPWS
Heritage Act 2011	Requirements to avoid impacts to heritage places and objects	Origin completed desktop studies and field scouts to confirm the presence/absence of heritage places and objects within the vicinity of the proposed activities.	Heritage Branch, Department of Tourism and Culture
Northern Territory Aboriginal Sacred Sites Act 1989	The legislation establishes a procedure for the protection and registration of sacred sites and the issuing of sacred site clearance	All areas of Origin's proposed activities have had sacred site clearances completed by Traditional Owners.	Aboriginal Areas Protection Authority (AAPA)

Legislation	Requirement	How Origin meets the requirement	Administered by
	certificates. Access and work within sacred sites require authorisation.	AAPA certificates for all exploration activities have been obtained for all activities proposed in this EMP.	Minister for Environment
Public and Environmental Health Act 2011	Requirements for camp kitchens and wastewater (sewage and greywater) management and permitting in the NT.	Origin's camps are registered, and a wastewater works design approval for the main camp and mini-camp sewage treatment plant irrigation area has been obtained.	Department of Health
Radiation Protection Act 2004	Requirements for the management of radiation for the health and safety of community and protection of the environment.	Origin complies with the Act through proper handling of and disposal of drill cuttings.	Department of Health
Territory Parks and Wildlife Conservation Act 1976	Prohibits impacts to protected places, impacts to threatened flora and fauna and interference with protected wildlife.	Origin complies with the Act through the avoidance of impacts to protected places (essential habitat, sanctuaries, parks etc.) and flora and fauna. This is completed through ecological surveys and the controls implemented to limit the impact on wildlife.	Parks and Wildlife DEPWS
Transport of Dangerous Goods by Road and Rail (National Uniform Legislation) Regulations 2011	Regulations stipulating the transportation requirements for dangerous goods by road and rail. This includes implementing all required signage, spill management, reporting and licencing requirements for chemical transportation during drilling and stimulation activities.	Any chemical transported and stored for exploration activities is undertaken in a manner that will comply with these requirements.	NT WorkSafe, Department of the Attorney-General and Justice

Legislation	Requirement	How Origin meets the requirement	Administered by
Waste Management and Pollution Control Act 1998 **(WMPCA)**	Requirements covering general environmental duty, waste management, including waste management hierarchy, waste transportation and waste disposal requirements.	The storage, transportation and disposal of wastes will comply with the requirements of this Act. The transportation and disposal of listed wastes will only be completed by a licenced contractor and at a licenced disposal facility. Any interstate disposal will be completed with an approved consignment authority.	NT EPA
	S12 General environmental duty: Applies to activities outside of the lease area, or if a spill or leak occurs that leaves the lease area, or 1 km from the centreline of a pipeline.	Origin will conduct all activities outside the approved disturbance area (camp area, lease pad, access tracks authorised in the EMP) in a manner that prevents environmental harm.	
	S14 Duty to notify of incidents causing or threatening to cause pollution: Applies if an incident occurs outside of the lease area, or if a spill or leak occurs that leaves the lease area, or 1 km from the centreline of a pipeline, that causes or threatens to cause material or serious environmental harm.	Origin will report all incidents that causes or threatens to cause pollution beyond the boundary of the authorised activity (beyond the lease or camp pad), in accordance with Section 14 of the WMPCA.	
Water Act 1992 **and Water Regulations 1992**	The Act requires that all groundwater take in the Beetaloo Sub-basin must have obtained a Water Extraction Licence (WEL).	Origin has obtained a Water Extraction Licence GRF 10285 covering water usage required to complete exploration activities. WELs are renewed periodically to support operational activities.	Water Resources Division, Department of Environment, Parks and Water Security (DEPWS)

Legislation	Requirement	How Origin meets the requirement	Administered by
		GRF 10285 can be downloaded from the NT Government website at: Walaps (nt.gov.au).	
	The take of surface water for petroleum activities is prohibited	No surface water take is proposed under this activity.	
	Prohibits wastewater releases to surface water bodies or reinjection	No wastewater release to surface water proposed.	
	The Act requires an interest holder to obtain a permit if activities undertaken under the Act all result in interference with a waterway.	The proposed activities occur on existing EPs with additional clearing to occur on EP98 to expand the well pad. No activities will result in interference with a waterway.	
	The Act requires an interest holder to obtain a bore work permit for any new groundwater bores.	Origin will obtain a bore work permit for any new groundwater bores as required.	
Weeds Management Act 2001	Requires the occupier of the land (in this case Origin) to: • prevent the land being infested with a declared weed • prevent a declared weed or potential weed on the land spreading to other land • notify the weeds officer of the presence of the declared weed • comply with any declared weed management plans	Origin will comply with the requirement of this Act through the implementation of weed prevention, detection and eradication controls through its approved Weed Management Plan (Appendix B).	Weed Management Branch, Department of Environment, Parks and Water Security (DEPWS)

Legislation	Requirement	How Origin meets the requirement	Administered by
Work Health and Safety (National Uniform Legislation) Act 2011	Provides for a nationally consistent framework to secure the health and safety of workers and workplaces. Includes requirements for hazardous chemical assessments, hazardous chemical register, access to safety data sheets, labelling, and the use, handling, generation and storage of hazardous chemicals at a workplace.	Origin has a Safety Management Plan that outlines how the requirements of the Act are achieved. This includes the management of chemical storage dossiers, safety data sheets (SDS) and appropriate procedures and controls to prevent worker exposure to hazards.	NT WorkSafe, Department of the Attorney-General and Justice
Commonwealth[3]			
Environment Protection and Biodiversity Conservation Act 1999	Requires approvals for any activity likely to have an impact on a Matter of National Environmental Significance (MNES).	A self-assessment was completed as a part of this EMP to determine whether a MNES is likely to be impacted by the proposed activities within this EMP. Impacts to MNES are not anticipated to occur.	Department of Climate Change, Energy, the Environment and Water (DCCEEW)
National Greenhouse and Energy Reporting Act 2007	An Act that requires operators who generate emissions over a threshold to report information related to greenhouse gas emissions, greenhouse gas projects, energy consumption and energy productions of corporations.	All energy consumption and greenhouse gas data used/generated form this activity will be reported in accordance with this Act.	DCCEEW
***National Environment Protection Council Act 1994 (*National Environment	This Act provides a nationally consistent approach to the assessment of site contamination to ensure sound	Origin uses the NEPM to assess risk of contamination and for the assessment of the drilling fluids for disposal.	DCCEEW

[3] Revised department names, as per the Administrative Arrangement Order, 23 June 2022: https://www.pmc.gov.au/sites/default/files/publications/administrative-arrangements-order-23-June-2022.pdf.

Legislation	Requirement	How Origin meets the requirement	Administered by
Protection (Assessment of Site Contamination) Measure 1999) (NEPM)	environmental management practices to protect human health and the environment.		
Native Title Act 1993	Legislation that provides for ways in which future dealings affecting native title may proceed and the recognition and protection of native title. The Right to Negotiate requirements are the most relevant provisions applying to Origin's exploration activities.	The Right to Negotiate process was applied to the grant of Origin's permits, resulting in Section 31 Agreements and Exploration (Ancillary) Agreements covering Origin's permits. The Traditional Owners were and continue to be represented by the NLC. Origin continues to implement the Exploration Agreements, in collaboration with the NLC, with all work programs being reviewed and approved by Traditional Owners. Origin has the consent of the Traditional Owners for activities proposed in this EMP, evidenced by the Section 31 Agreements and the implementation of the relevant Exploration Agreement.	Prime Minister and Cabinet (Divisions 6 and 7 of Part 2, and Part 11) Attorney-General's Department (except to the extent administered by the Minister responsible for Indigenous Affairs)

3.1 Alignment with the principles of Ecologically Sustainable Development

The EMP is consistent with the principles of Ecologically Sustainable Development (ESD) through the adoption of responsible practices that are designed to maximise social benefit, while minimising the level of impact on the surrounding ecosystems. [4]

Origin's exploration activities align with the principles of ESD:

- Exploration activities are an essential step in defining a potential future commercial resource which can generate sustainable, long-term benefits to the local community, to the Barkly region generally and more broadly into the rest of the NT (Principles 1 and 5).
- Complying with the Code and industry best practice to reduce the risk to the environment and communities to an acceptable level. Noting the Inquiry Panel's Final Report Statement that "provided that all of the recommendations made in this Report are adopted and implemented in their entirety, not only should the risks associated with an onshore shale gas industry be minimised to an acceptable level, in some instances, they can be avoided altogether." (Scientific Inquiry into Hydraulic Fracturing in the Northern Territory 2018) (all ESD Principles).
- The activities that are the subject of the EMP do not constitute threats of serious or irreversible environmental damage and there is no impact on the conservation of biological diversity and ecological integrity (Principles 4 and 6).
- Beyond royalty payments to the NT Government (as owner of the natural resource), and payments to Native Title Holders (as per Exploration Agreements) and host pastoralists (as per Access and Compensation Agreements), Origin seeks to maximise broad-based local participation in education, training, employment and enterprise opportunities engendered by its presence (Principles 1 and 5).
- Prioritising the use of local employment to deliver exploration activities (Principles 1 and 5).
- Obtaining sacred site clearances from host Traditional Owners through open engagement with custodians, the Statutory Representative body – the NLC and the Aboriginal Area Protection Authority (AAPA) (Principles 1, 4 and 5).
- Obtaining Land Access Agreements with host pastoralists (Principles 1 and 5).

4 Description of regulated activities

This EMP covers the regulated activities required to enable Origin to drill, stimulate, test, maintain and decommission up to 12 horizontal E&A wells at 4 locations on EP 98 (3 wells per pad) and 2D seismic acquisition across EP 98 within the 2022 – 2027 period. To accommodate this scope, the activities summarised in Table 11 are proposed to be executed under this EMP.

In accordance with Clause A.3.1(b)iii of the Code, the following strategies have been considered to minimise the disturbance footprint for infrastructure placement – for example:

- Lease pads: Designed and engineered allow heavy vehicles, drilling rig and associated equipment to manoeuvre and operate safely; wastewater storage and open evaporation tanks.
- Gravel pit(s): Located adjacent to access track(s) to reduce clearing.

[4] Referred to in the NT Petroleum (Environment) Regulations 2016 and the *Petroleum Act 1984* and set out in sections 18 to 24 of the *Environment Protection Act 2019*.

- Access tracks: Use of existing access tracks (where practicable and agreed with pastoralist); including placement parallel to existing cleared fence lines.
- Shared infrastructure: Use of shared infrastructure / facilities across Origin's EPs and regulated activities based on:
    - Number of personnel being deployed across activities at any one time.
    - Capacity of existing infrastructure to absorb additional personnel or waste volumes.
    - Proximity of infrastructure to the regulated activity and whether risks associated with travel between sites (e.g. 10 – 12 hours days, fatigue, etc) is materially higher than using dedicated infrastructure located at each site.
    - Land access authorisation

Table 11: Description of the exploration and appraisal activities in the Amungee Delineation Area

Activity	Parameter	Description
Exploration site civil construction	Lease pad- 7.5 ha per pad	• Construction of four (4) new 7.5ha lease pads at each exploration site, consisting of: - Amungee NW 2, including 2 ha cleared under EMP modification 10-3.1 - Amungee NW 3 - Amungee NW 4 - Amungee NW 5
	Access tracks- 18.9 ha	• Construction/ upgrade of access tracks: - Construction of a 2 km access track from the Carpentaria Highway to Amungee NW 3 - including intersection works - Construction of a 5km access track from the Carpentaria Highway to Amungee NW 4- including intersection works - Construction of a 6.5 km access track from the Carpentaria Highway to Amungee NW 5- including intersection works • Access tracks constructed up to 14 m wide • Use of an existing approved access track to the Amungee NW 2 site (1.5 ha)
	Camp pads- 1.2 ha per site	• Construction of a 1.2 ha camp pad at each exploration site (4 in total) • Camp pad will only be constructed if a centralised camp is not used.
	3 cellars per lease	• Installation of 3 E&A well cellars and conductors on each lease pad to accommodate the proposed wellheads and surface facilities
	1 sump per lease pad	• Construction of a drilling sump on each lease pad to manage drilling fluids, muds and cuttings of up to 5,000 m^3

Activity	Parameter	Description
	1 bund per lease pad	• Construction of a site bund for wastewater storage
	1 stormwater basin per lease pad	• Construction of a sediment basin to manage stormwater during wastewater storage
	4 water extraction bores / monitoring bores per lease pad	• Drilling of up to four additional groundwater monitoring/ extraction bores at each of the proposed E&A sites
	~0.5 ha per exploration site	• Construction of a laydown area at each exploration site
	~0.5 ha per site	• Construction of a helipad at each exploration site
	~4.0 ha per site	• Construction of a 20 m x 2 km fence line and firebreak around each exploration site
	~3.5 ha	• Construction of the new Amungee NW 3 gravel pit.
Site set-up and mobilisation to support the E&A wells	Camps	• The existing Amungee NW camp pad may be used to establish a centralised camp to reduce camp mobilisations/ new disturbance across the Amungee Delineation Area work program. • Where a centralised camp is not used, a temporary main camp will be located on the newly constructed camp pad • Each main camp will typically have a ~70-person capacity. • A drilling mini-camp will also be located on the lease pad during drilling to accommodate 24-hour operations (~8-person capacity).
	Chemical storage areas	• Set-up of chemical and material storage areas.
	Material transportation	• Transportation, handling and storage of bulk chemicals, fuels and wastes
	Drilling rig and equipment	• Set-up of drilling rig, including blow-out preventors, fluid systems and associated equipment such as pipe racks, power generation, offices, ablution blocks and cementing units.
	Frack spread	• Set-up of hydraulic fracture stimulation (HFS) equipment, completions rig and equipment, well testing

Activity	Parameter	Description
		equipment, and other associated equipment at each Amungee NW site.
	Traffic	• Approximately 44 traffic movements per day, per site during site demobilisation.
Camp operation	~70-person camp	• Operation of a main camp – either centralised (existing Amungee NW) or at each site • Operation of drilling camp on each lease pad during drilling
E&A well Drilling	3 E&A wells	• Drilling of 3 horizontal E&A wells at each site, including the vertical pilot well (where required) and collection of reservoir quality data during drilling
Hydraulic fracturing	3 E&A wells per site	• HFS of all 12 wells across 4 sites • 10-30 stages per well depending on horizontal length (typically 15 stages) • Recycling of flowback wastewater for stimulation fluid makeup to reduce raw water use
Well completion	3 E&A wells per site	• Completion of 12 E&A wells across 4 proposed E&A sites
Well testing	90 – 135 days per well (average)	• Extended production testing of 12 wells across 4 sites- average well test duration is anticipated to be 135 days- subject to operational requirements
		• Gas flaring in accordance with Code requirements and as per US EPA 40 CFR 63.11, with a flare tip combustion efficiency of 98%
Well maintenance and monitoring	3 wells per site	• Maintenance and monitoring works on 12 wells across 4 sites (including well workovers) in accordance with approved WOMP
Build up testing	3 wells per site	• Build up testing to monitor the pressure build-up within each E&A well
Well suspension and decommissioning	3 wells per site	• suspension and decommissioning (if required) across 4 sites in accordance with the Code.
Groundwater extraction	107.5 ML per site	• Groundwater extraction under existing groundwater extraction licence (WEL GRF 10285)
Environmental monitoring	4 well sites	• Monitoring activities (including groundwater, stormwater, soils, leak detection, seismicity and all other low impact ancillary data collection programs)
On-site wastewater management to	4 well sites	• On-site wastewater storage and treatment in accordance with Code

Activity	Parameter	Description
support ongoing E&A program		• Use of the drilling sump, enclosed wastewater storage tanks and wastewater treatment tanks to manage drilling and flowback wastewater • Drill cuttings and flowback fluid quality testing in accordance with the Code • Drilling waste storage – including centralised storage of drilling waste from other approved locations • Disposal of drill cuttings subject to the outcomes of chemical analysis in accordance with clause C.4.1.2 of the Code • On-site treatment of wastewater through evaporation or other alternative methods (such as enhanced evaporation or other mechanical water treatment options) • Recycling of flowback wastewater for stimulation fluid makeup to reduce raw water use • Off-site disposal of flowback wastewater in accordance with the Waste Management and Pollution Control Act
Site decommissioning	4 well sites and associated infrastructure (access tracks, gravel pits, seismic lines etc.)	• Decommissioning and removal of all surface infrastructure and wastes from site including the removal of drilling sump, wastewater tanks, cellars, equipment, non-drilling waste, wastewater and all ancillary equipment
Site demobilisation	4 Well sites and 12 wells	• Demobilisation of exploration equipment, including camps, drilling rigs, HFS equipment, completion rigs, well testing equipment, wastewater storage tanks and various service provider equipment • Approximately 44 traffic movements per day during site demobilisation

Seismic acquisition	~60 km
	(31.66 ha)
		• Seismic program to utilise 2 energy sources to evaluate optimal energy source type: vibroseis and seismic charges
		• Civil construction of 10 x 2D seismic lines:
		  ○ Clearing of approximately 60 km of seismic lines with a 5 m cleared track width
		  ○ Seismic lines to be weaved through vegetation to a path of least resistance. Slashing can be used in otherwise untraversable vegetation. Deviations in lines must be constructed in a way that is

Activity	Parameter	Description
		accessible by equipment/vehicles such as heavy-rigid body trucks (minimum 15 m turning radius) ○ A small turning circle to be constructed at the end of each seismic line to allow equipment and vehicles to exit ○ A 250 m buffer /deviation from either side of the centreline pre-plot data where required to avoid any unsuitable terrain or obstacles. ○ Estimated maximum surface disturbance of 31.66 ha, noting that all efforts will be deployed to avoid clearing. ○ Estimated groundwater use ~1 ML. • Construction of 2 fenced areas 12 m(L) x 9 m (W) for explosive storage magazines (AS2187) along cleared lines: ○ Fenced areas to be constructed as per AS1725. ○ Gates minimum 4 m opening. ○ Surface within the magazine storage area to be smooth and free of debris, loose zones and soft spots. ○ Surface compaction ≥ 100 kPa. • Shot hole drilling for 400 x 20 m depth holes @ 80 mm – 100 mm OD at a shot hole interval of 60 m. • Low disturbance node deployment • Seismic acquisition, including vibroseis deployment, charge detonation and data collection • Rehabilitation of cleared lines and shot holes by respreading any windrowed soil and reinstating vegetation from stockpiled area back across the seismic line.
Total disturbance & rehabilitation (approx.)	106.86 ha	• Final rehabilitation activities to return the sites back to a safe, stable and non-polluting form consistent with pre-disturbed condition

4.1 Activity summary

The activities proposed under this EMP within the Amungee Delineation Area are summarised in Table 12. Some figures, such as water use, stimulations stages and proppant usage, are estimates based on previous experience and may be higher or lower depending on operational requirements.

Table 12: Amungee NW site activity summary table

Component	EMP scope
General	
Number of exploration sites	4 well pads: • Amungee NW 2 • Amungee NW 3 • Amungee NW 4 • Amungee NW 5
Number of wells	12 wells- 3 wells per lease pad
Number of stimulations	12 well stimulations
Number of water extraction/monitoring bores	16 (4 per well pad)
Number of gravel pits approved	1 new
Operational workforce	~ 70 persons
Main camp capacity	~70 person
Drilling mini-camp	8 person
Stages per well	10-30 (depending on lateral length)
Proppant use	180 t -250 t of proppant per stage per well (Typically 3000 t per well)
2D Seismic line length	10 lines totally 60 km (31.66 ha of disturbance)
Disturbance	
AAPA certificate	C2022/002
Total area of disturbance	106.86 ha
Traffic	
Peak traffic movements (per day)	44
Average traffic movements first 6-9 months post mobilisation	10-15 (for 6-months)
Average traffic movements for remaining 6 months	3-4 (for 6-months)
Truck load-out: wastewater transport	~20 truck movements

Component	EMP scope
Water use and Stormwater management	
Groundwater extraction licence	WEL GRF 10285
Estimated groundwater usage (ML)	107.5 ML per site
Stormwater retention basin	New 20 m x 20 m sediment retention basin per lease pad
Wastewater management	
Flowback/wastewater volume generated on-site (assumes a maximum of 2 wells stimulated per site concurrently)	15 ML (7.5 ML per well)
Enclosed wastewater tank capacity	Wet season: 16.5 ML (3 x 5.3 ML tanks) Dry season: 5.3 ML (1 x 5.3 ML tanks)
Open treatment tank capacity (including freeboard) (ML)	Wet season: 5.3 ML (1 x 5.3 ML tanks) Dry season: 15.9 ML (3 x 5.3 ML tanks)
Bunded tank pad containment capacity (ML)	6
Flowback/wastewater volume (final predicted for treatment and off-site disposal per site) (ML)	~0.5
Sump capacity (m^3) at each site	~5,000
Total volume of drilling mud and cuttings generated (m^3) per site	~2,250
Total volume of waste drilling and completion fluid per well	1 ML per well
Transfer pumps	6 x 6 inch- up to 23 ML/day
Greenhouse gas emissions	
Flares	Vertical flare
tCO_2-e emissions	522, 172

4.2 Timeframes

The anticipated key activity dates for the drilling, stimulation and well testing program are detailed in Table 13 and illustrated in Figure 5. It should be noted that the below timeframes and order of activities are indicative, with final dates and decision to complete activities dependent on a range of additional considerations, including access, commercial and joint venture constraints. An update on the project will be provided to DEPWS monthly or as otherwise conditioned.

Table 13: Anticipated activity dates

Activity	Estimated dates
Amungee 2D Seismic- line preparation and acquisition	Apr 2023
Amungee NW 2 civil construction. Construction of the lease pad, camp pad, laydown, helipad, access track, sump, cellars, water bores, fence lines and associated infrastructure	Oct 2022
E&A well drilling Amungee NW 2-1H and Amungee NW 2-2H	Nov 2022 – Apr 2023
E&A well stimulation NW 2-1H and Amungee NW 2-2H	Feb 2023
E&A well testing NW 2-1H and Amungee NW 2-2H	Feb 2023 – Jun 2023
E&A well suspension/ build up test NW 2-1H and Amungee NW 2-2H	Jul 2023
Amungee NW3 civil construction of water bores	Jan 2023
Amungee NW 3 civil construction. Construction of the lease pad, camp pad, laydown, helipad, access track, sump, cellars, fence lines and associated infrastructure	Feb 2023
E&A well drilling Amungee NW 3-1H and Amungee NW 3-2H	July 2023
E&A well stimulation NW 3-1H and Amungee NW 3-2H	Sept 2023
E&A well testing NW 3-1H and Amungee NW 3-2H	Oct 2023 – Mar 2024
E&A well suspension NW 3-1H and Amungee NW 3-2H	Apr 2024
Amungee NW 4 civil construction of water bores	Feb 2024
Amungee NW 4 civil construction. Construction of the lease pad, camp pad, laydown, helipad, access track, sump, cellars, fence lines and associated infrastructure	March 2024
E&A well drilling Amungee NW 4-1H and Amungee NW 4-2H	Sep 2024
E&A well stimulation NW 4-1H and Amungee NW 4-2H	Nov 2024
E&A well testing NW 4-1H and Amungee NW 4-2H	Dec 2024 – Jun 2025
E&A well suspension NW 4-1H and Amungee NW 4-2H	Jul 2025
Amungee NW 5 civil construction. Construction of the lease pad, camp pad, laydown, helipad, access track, sump, cellars, water bores, fence lines and associated infrastructure.	Jun 2023
E&A well drilling Amungee NW 5-1H and Amungee NW 5-2H	Mar 2024
E&A well stimulation NW 5-1H and Amungee NW 5-2H	May 2024

Activity	Estimated dates
E&A well testing NW 5-1H and Amungee NW 5-2H	Jun 2024 – Dec 2024
E&A well suspension NW 5-1H and Amungee NW 5-2H	Jan 2025
Well decommissioning (all wells)	2026+ or when each well is no longer required
Rehabilitation of site	2026+ or when each site is no longer required

*worst case assumes 135 day average well test per well calculated by average well test days by E&A wells tested per year

ID	Task Name
1	**2D Seismic**
2	2D seismic: line preparation & acquisition
3	**Amungee NW 2**
4	Civils: Construction of lease pad, camp, control monitoring bore(s), includes all assoc well infrastructure
5	E&A well drilling NW 2-1H & NW 2-2H
6	E&A well stimulation NW 2-1H & NW 2-2H
7	E&A well testing NW 2-1H & NW 2-2H
8	E&A well suspension/ build up test NW 2-1H & NW 2-2H
9	**Amungee NW 3**
10	Civils: Construction of control monitoring bores
11	Civils: Construction of lease pad, camp, includes all assoc well infrastructure
12	E&A well drilling NW 3-1H & NW 3-2H
13	E&A well stimulation NW 3-1H & NW 3-2H
14	E&A well testing NW 3-1H & NW 3-2H
15	E&A well suspension NW 3-1H & NW 3-2H
16	**Amungee NW 4**
17	Civils: Construction of control monitoring bores
18	Civils: Construction of lease pad, camp, includes all assoc well infrastructure
19	E&A well drilling NW 4-1H & NW 4-2H
20	E&A well stimulation NW 4-1H & NW 4-2H
21	E&A well testing NW 4-1H & NW 4-2H
22	E&A well suspension NW 4-1H & NW 4-2H
23	**Amugee NW 5**
24	Civils: Construction of lease pad, camp, control monitoring bore(s), includes all assoc well infrastructure
25	E&A well drilling NW 5-1H & NW 5-2H
26	E&A well stimulation NW 5-1H & NW 5-2H
27	E&A well testing NW 5-1H & NW 5-2H
28	E&A well suspension NW 5-1H & Amungee NW 5-2H
29	**Decommissioning & Rehabilitation**
30	Decommissioining all wells
31	Rehabilitation

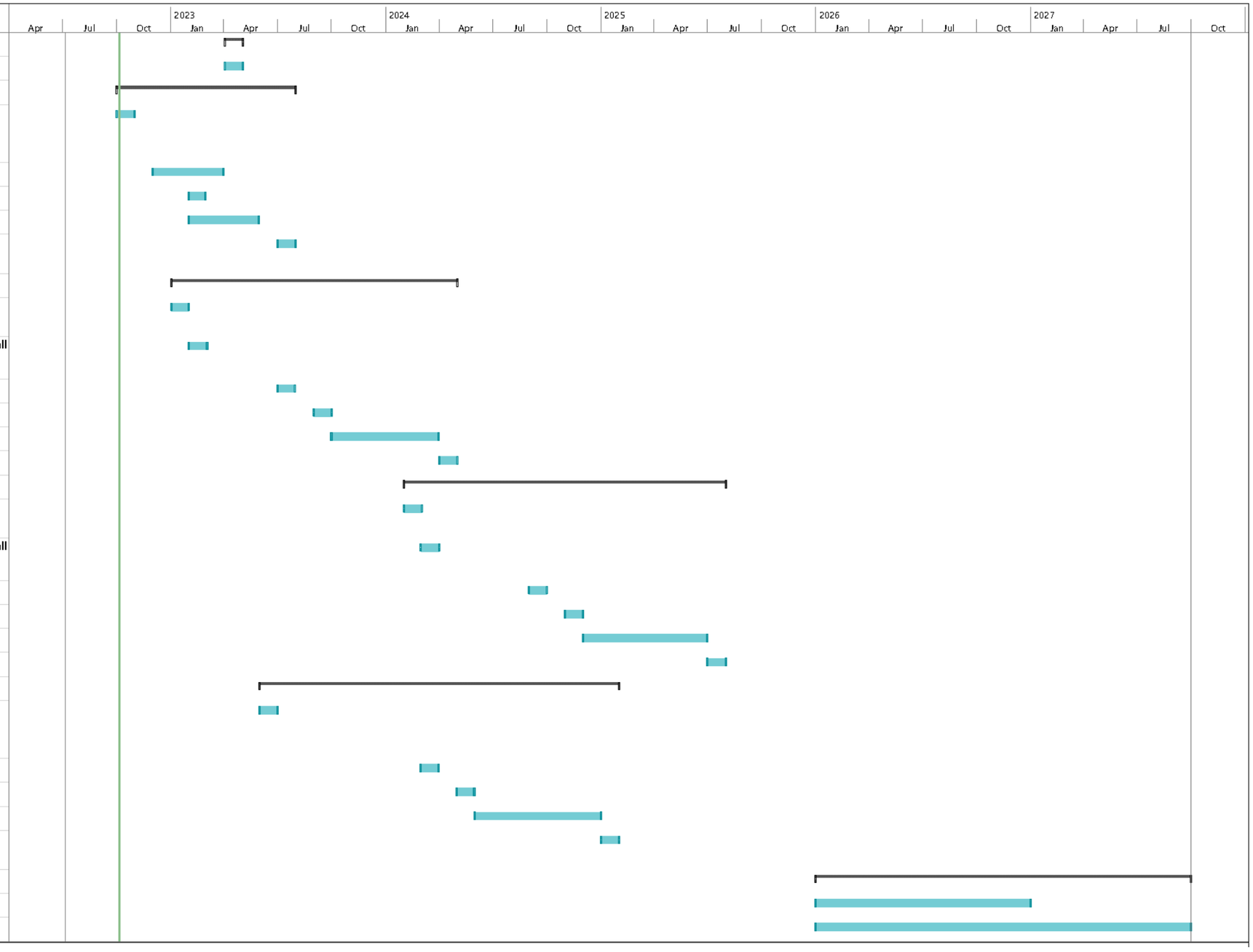


Figure 5: Indicative timeline of the proposed Amungee Delineation Area activities

4.3 Site setting

The proposed exploration sites within the Amungee Delineation Area were chosen using a multi-criteria analysis based on the geological, environmental, cultural and social suitability of the site. Field ecological, cultural heritage and Native Title clearances were obtained to ensure avoidance of the following areas:

- High conservation value
- High habitat value
- Water courses or major overland flow paths
- Areas of cultural significance
- Sensitive receptors (homestead and communities)
- Existing pastoralist groundwater extraction bores
- Major roads

An approximate 1 km buffer has been applied to each exploration site as shown in Figure 1. The buffer zone is necessary to accommodate outcomes of ongoing pastoral engagement and reduce clearing in areas of environmental or cultural heritage sensitivity (e.g. large trees, hollows, dense vegetation or cultural heritage finds). It is also recognised that further changes to infrastructure may be requested by the host pastoralists during the Land Access and Compensation Agreement (LACA) process. Where infrastructure is moved to accommodate a pastoral request or environmental / cultural heritage sensitivity, additional ecological and heritage surveys will be completed prior to undertaking the activity if previous surveys have not adequately covered the new location. If a well site is relocated, the wells will not be located less than 2 km from each other, as per the Code clause A.3.2.2 (a).

A description of the existing environment is provided in section 5.2. The Amungee Delineation Area is characterised by a mixture of in Corymbia woodlands, Bullwaddy and Lancewood, which are all regionally extensive vegetation communities, not threatened and in relatively good condition.

Approximate separation distances to the nearest environmental and community receptors from each well location are illustrated in Figure 6 and with separation distances provided in Table 14.

Table 14: Approximate sensitive receptor separation distances

Receptor	Amungee NW (existing)[5]	Amungee NW 2	Amungee NW 3	Amungee NW 4	Amungee NW 5
Closest pastoralist bore	4 km	4 km	1.2 km	1.1 km	7.5 km
Nearest homestead	27 km	19 km	30 km	16 km	25 km
Nearest community	56 km (Daly Waters)	64 km (Daly Waters)	50 km (Daly Waters)	65 km (Daly Waters)	57 km (Daly Waters)

[5] See Beetaloo Sub-basin Multi-well Drilling, Stimulation and Well Testing Program Exploration Permit (EP) 98 & 76 EMP (ORI10-3), approved 19 May 2022.

Receptor	Amungee NW (existing)[5]	Amungee NW 2	Amungee NW 3	Amungee NW 4	Amungee NW 5
Stuart Highway	56 km	63 km	50 km	64 km	56 km
Carpentaria Highway	1 km	1 km	1 km	3.5 km	5.6 km
Bullwaddy Conservation Reserve	40 km	31 km	44 km	30 km	47 km
Lake Woods	161 km	154 km	154 km	153 km	150 km
Nearest mapped major watercourse	20 km	20 km	15 km	16.5 km	18 km
Sacred site	19 km	9.5 km	14.5 km	9.5 km	15 km

4.3.1 Land clearing

The total approved cumulative land clearing on EP98 from Origin's activities is approximately 125 ha, which represents 0.012% of the total surface area of EP98 (10,300 km^2).

Including clearing proposed under this EMP (106.86 ha), Origin currently has approximately 180 ha of surface disturbance across its three EPs (18,512 km^2). This represents a disturbance footprint of ~0.0097% of the total surface area of Origin's EPs.

To put this into perspective, Table 15 shows the estimated cumulative clearing across Origin's and neighbouring EPs, by other onshore petroleum operators, which is less than 1% of the total surface area of all current operational EPs. This figure (744 ha) is highly conservative, as it indicates approved clearing levels and not actual clearing levels. Clearing for seismic often does not require the clearing of vegetation within open woodlands, thus the estimate is considered conservative.

Also, compared to the approved pastoral clearing (2003 – 2022) on Amungee Mungee Station (4,389 ha) and Tanumbirini Station (1,939 ha), land clearing for onshore petroleum activities is negligible.[6]

Table 15: Cumulative surface disturbance (%) vs EPs (all interest holders)

Interest holder	EP	Exploration permit areas		Clearing	Surface disturbance
		km^2	ha	ha	%
Origin	117 98 76	18,512	1,851,200	180	0.0097
Santos	161	13,350	1,050,000	99	0.0095
Imperial	187	2,998	299,800	252	0.0841
Tamboran	136	4,181	418,100	212	0.0508
TOTAL		**39,041**	**3,619,100**	**744**	**0.0205**

[6] See Pastoral land clearing applications and permits: https://nt.gov.au/property/land-clearing/pastoral-land/pastoral-land-clearing-applications-and-permits.

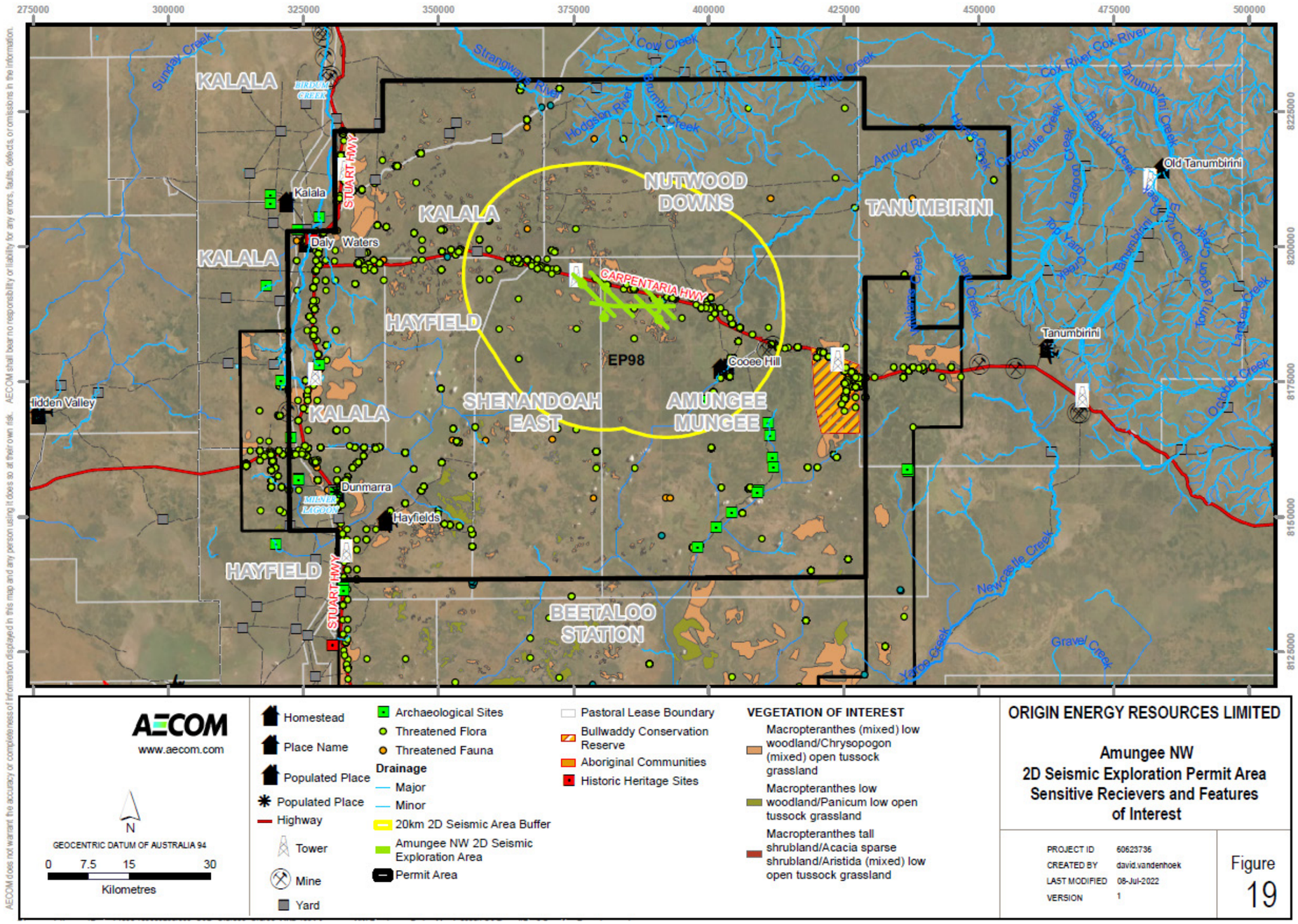


Figure 6: Proximity of active exploration sites (including Amungee Delineation Area) to sensitive receivers and features of interest

4.4 Seismic survey

A 60 km of 2D seismic acquisition will be completed within the Amungee Delineation Area as illustrated in Figure 7 and summarised in Table 9. The seismic survey will involve a maximum ground disturbance of up to 31.66 hectares to support the program, with the actual vegetation clearing level likely to be significantly lower through the deployment of clearance avoidance measures.

Seismic surveys use a sound wave source from an energy source at the surface to propagate sound waves into the earth. The sound waves that reflect off underground rock formations are captured by recording sensors called geophones. Analysing the time sound waves take to return provides valuable information about rock types and an estimate of depth for rock formations. The returning reflections are recorded in a digital format and sent to a seismic data processing centre to produce a cross-section image of the layers of the earth's crust (process seismic image).

The proposed Amungee Delineation Area seismic survey will be undertaken with two different energy sources, seismic charges and vibroseis trucks. The two energy sources proposed for this survey, to determine the most suitable energy source method for future seismic surveys. Seismic charges are specifically being trialled against the use of the standard vibroseis methods, to evaluate whether this survey method could increase data quality, whilst lowering vegetation clearing requirements.

4.4.1 Line preparation

Seismic line preparation will be required so that the vibroseis trucks can drive and operate over the survey area. Survey lines will be installed across the proposed survey area in a SE to NW direction. Seismic lines will be approximately 5 m wide. To reduce disturbance, existing cleared areas will be used where possible. Seismic lines will be located in a manner to avoid any large habitat trees or sensitive flora, with no material vegetation clearance to be undertaken in watercourses or associated riparian vegetation. In areas with low vegetation density (such as open Eucalypt / Corymbia woodland) ground disturbance will be restricted to running a dozer blade over the surface to remove rocks, fallen branches and shrubs to provide effective ground contact of the seismic vibro-source and minimise the risk of fire. Where vegetation clearance in unavoidable, such as within stands of lancewood (*Acacia shirleyi*) and Bullwaddy (*Macropteranthes kekwickii*), vegetation will be cleared with a D8 dozer and grader. Felled vegetation will be pushed to the edge of the line and will be pulled back across the line during rehabilitation.

To reduce the risk of bushfire, a spotter vehicle with a fire tender will be used during clearing activities. Any fires detected will be promptly put out. To further reduce the risk of fire, no vegetation mulching is proposed.

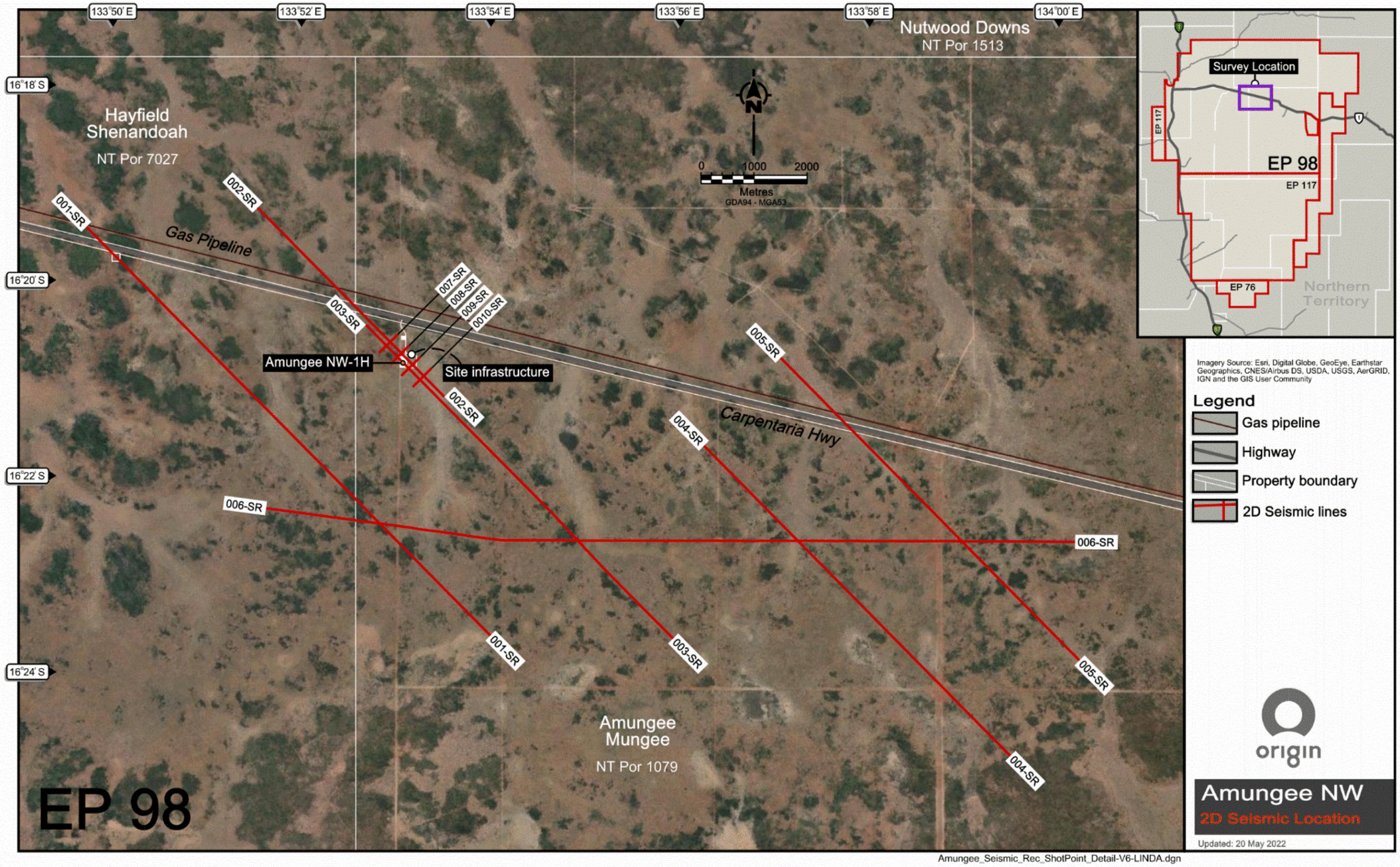


Figure 7: Amungee Delineation Area propsoed 2D seismic acquisition

4.4.2 Shot installation

Seismic acquisition using small dynamite charges reduces the required land clearing substantially (~90% less clearing). Small charges are placed at 15 – 20 m below the ground surface by light 4wd vehicle or equivalent (Figure 8), such as tractor mounted rigs or trailer mounted rigs towed with bobcats. Although not the preferred method, helicopters may also be used to move drilling rigs around. Explosives will be stored on site in a portable magazine which adheres to Australian Standards.

Figure 8: Example of a small rig that could be used for installing dynamite charges during a seismic survey

This approach reduces the need to clear vegetation, with the charges being able to be placed around vegetation to reduce clearing. Small amount of clearing may still be required to access extremely dense vegetation, but this is anticipated to be minimal.

A 1 kg charge of Geoprime dBX high performance pentolite explosive will be utilised. This explosive is specifically designed for seismic surveying. The charges are packed in place within each shot hole, with the blast contained within the subsurface (i.e. no expulsion of earth from the surface). Figure 9 is an example of a typical small seismic charge used during a New Zealand seismic shoot.

Figure 9: Example of loaded charge in hole ready for detonation and example of a charge used in dynamite seismic survey acquisition; charge length is approximately 400 – 500 mm

Millions of freeze-dried microorganisms (along with nutrients for those microorganisms) are cast directly into the GEOPRIME dBX seismic booster during production. When these naturally occurring organisms are submerged in water, they become activated, as designed, and begin to slowly biotransform the undetonated GEOPRIME dBX. When the biotransformation is complete, the compounds are no longer explosive.

All seismic charges have a dual detonation system. Once the charge is placed into a hole, the dual detonation (trigger) is installed so if the first detonator fails, the second detonator sets off the charge. If both detonators were to fail, a bore is drilled beside the detonator to trigger a “sympathetic discharge”. Where the sympathetic discharge failed to destroy the adjacent failed charge, it is anticipated that the charge would start to degrade to an inert substance typically within 6 months.

Charges would be installed 15 m – 20 m below ground level, with no physical access.

Charges will be offset from sensitive sights and infrastructure. Offsetting distances are guided by Australian Standards. When detonation occurs all personnel under the instruction of the shot firer are to observe safe set back distances (20 – 25 m). A short sharp thud will be heard, and potential small level of vibration felt within 1-2 km of charge going off.

In the event of a misfire a drill rig will be on standby to drill and load a new charge offset at approximately 2 m. This will provide replacement data and likely sympathetic detonation or at a minimum break the plastic seal to accelerate bioremediation of the charge.

4.4.3 Geophone installation

The receivers (nodal geophones) will be hand carried along lines and put into the ground, usually deployed with a handheld drill and auger bit light 4WD vehicles or ATVs. The nodal geophones are autonomous units, containing the actual geophone as well as battery and data storage in one unit. These nodes are deployed at regular intervals along the non-cleared lines perpendicular to the source lines, these may be able to be carried through areas of riparian vegetation to avoid any damage to vegetation where access permits. The installation of nodes requires minimal disturbance (Figure 10).

Figure 10: Example of a deployed node

4.4.4 Survey execution and data collection

If the use of dynamite is not feasible, vibroseis trucks will be used for the seismic source. A vibroseis survey involves the establishment of cleared source lines for the vibroseis trucks to operate on. The survey is orientated NW to SE to align with the existing horizontal well Azimuths. Line clearing will be required so that the vibroseis trucks can drive and operate over the survey area (Figure 11). All source lines will be cleared with a dozer of reader to a width of 5 m. However, to reduce disturbance, existing cleared areas will be used where possible. The line position, plus tolerances for weaving the line around vegetation etc are pre-programmed into GPS units.

Seismic lines will be located to avoid any large habitat trees or sensitive flora, with minimal clearance to be undertaken in watercourses and associated riparian vegetation. In areas with low vegetation density (such as open Eucalypt / Corymbia woodland) ground disturbance will be restricted to the removal of rocks and fallen branches and the slashing of grasses and shrubs to provide effective ground contact of the seismic vibro-source and the geophones and minimise the risk of fire (Figure 12).

Figure 11: Example of a vibroseis truck used during seismic acquisition

Figure 12: Data recording van used during seismic acquisition

In relation to potential impacts of seismic on livestock, cattle will be mustered away from the seismic area prior to commencement of the activity, in consultation with pastoralist. From a noise and vibration perspective, the vibroseis does not create an intrusive level of noise and vibration. The vibration is of less intensity than a cattle truck crossing a cattle grid. As discussed above, a short sharp thud will be heard, and potential small level of vibration felt within 1 km of charge going off; however with cattle being mustered away from the activity, this should not result in any significant impact.

4.4.5 Rehabilitation

Upon completion of seismic acquisition, the seismic acquisition area (lines and shot holes) will be rehabilitated. The felled vegetation will be returned across the seismic line upon completion of seismic activities to aid in assist in erosion and sediment control. Root stocks are to be left in place as much as practicable to allow for rapid re-establishment of vegetation.

Drill holes will be progressively remediated after firing. Detonation wires will be pulled out and the hole and remaining cuttings will be returned down the hole. A cap will be emplaced 50 cm down the hole and the hole will be backfilled to ensure load bearing and no surface depression is left that might cause injury to cattle or native fauna.

Based on previous experience in the region, most areas will naturally regenerate following rehabilitation following the wet season. Rehabilitation monitoring will occur on an annual basis until the vegetation has become re-instated, with maintenance on rehabilitated area undertaken as required.

4.4.6 Infrastructure buffer zones

Buffer zones are utilised around infrastructure to minimise the impacts from seismic surveys. These are summarised in Table 15.

Table 16 Seismic survey buffer zones

Infrastructure type	Buffer (m)	
	Seismic charge	Vibroseis
Pipeline	100	50
Water bore	250	100
Carpentaria Highway hard seal	100	Not completed on bitumen seal
Active cattle holding yard	250	100

4.5 Groundwater bore installation

Groundwater monitoring / extraction bores will be installed at each of the proposed new exploration sites to supply water and satisfy the groundwater monitoring requirements. Up to 4 additional groundwater monitoring/production bores are to be installed at each site, totalling 16 new bores (refer Table 8).

The groundwater monitoring bores will be installed on the proposed activity area (either on the lease pad, camp pad or laydown area) at each site, in accordance with the location provisions outlined in the *Preliminary Guideline: Groundwater Monitoring Bores for Exploration Petroleum Wells in the Beetaloo Sub-basin*. The bores will target the Gum Ridge Formation, as the Anthony Lagoon formation is predicted to be absent within the Amungee Delineation Area.

The bores will be drilled and constructed by a licenced water bore driller and in accordance with the current version of the Minimum Construction Requirements for Water Bores in Australia. (4th ed. 2020). A qualified hydrogeologist will supervise the drilling activities and will determine the appropriate screening depth of each bore. Each aquifer intersected will be isolated from overlying aquifers with a cemented casing string. Drilling will be undertaken with air or mud rotary techniques. If mud rotary techniques are employed, the circulation fluid will be water based and will utilised standard water bore drilling polymer or bentonite-based density and viscosity modifying additives.

Each bore will be completed with a self-draining concrete block centred on the bore casing constructed at the surface; 1 m^2 x 75 mm above the final ground surface and 25 mm below final ground surface. This provides further protection of the underlying aquifer from any surface spills.

A bore construction permit will be obtained for each bore, and they will be added to Origin's water extraction licence GRF 10285 if additional production bores are required to meet the water requirements at each site.

A survey of each bore will be undertaken in Australian Height Datum to accurately determine depth to water table. Within 28 days of bore completion, the driller will provide a statement of bore (Form 21) with registered number, which will be provided to DEPWS. All cuttings and drilling mud will be disposed as per the Minimum Construction Requirements for Water Bores in Australia.

4.6 Civil construction activities

The proposed civil construction activities at each exploration site includes:

- Clearing of the lease pad to 7.5 ha. Each lease pad will be engineered to allow heavy vehicles, drilling rig and associated equipment to manoeuvre and operate safely (including the provision of hazardous area zones to accommodate high pressure equipment and flaring). The proposed disturbance area includes the provision for up to 20 m firebreaks to reduce potential fire risks to infrastructure

- Clearing of a camp pad at each lease pad to 1.2 ha
- Construction of a 0.5 ha helipad per lease pad to allow wet season/ emergency access to the site
- Construction of a 0.5 ha laydown yard per lease pad to allow for the storage of equipment and materials
- Construction of new fence line and firebreak around each exploration site (camp pad, lease pad, laydown and helipad), with approximately 4 ha cleared
- Clearing/ upgrading of access tracs, including the construction of up to 3 new intersections with the Carpentaria Highway upgrade

Each proposed disturbance area will be cleared of vegetation. Prior to clearing, the areas will be walked down to identify the presence of fauna prior to clearing activities. Where fauna is encountered, clearing will cease in the immediate area until the fauna has moved on. Felled vegetation will be pushed up along the edges of the lease pad to aid in erosion and sediment control.

Following vegetation clearing, the new disturbance areas will be stripped of up to 150 mm of topsoil, with the topsoil stockpiled around the edge of the lease or on the designated stockpile area. The stockpiled topsoil will be used a growth medium to support vegetation reinstatement. The topsoils will be allowed to germinate with native species from the area to maintain soil condition and seed bank.

The anticipated stockpile depth will typically to be less than 1.5 m to maximise viability of the topsoil for future use. Seed bank viability in the lower half of the stockpile may become compromised, however the upper levels are likely to continue to provide a valid seed bank. Furthermore, the vegetation community in the area are adapted to soils lacking in nutrients, there is low to no rainfall for over 8 months of the year and occur in free draining soils. The vegetation community is adapted to the harsh conditions that occur in a semi-arid area and likely to recover quickly post rehabilitation.

The proposed timeframe for the topsoil to be stockpiled around the lease could be up to 5 years, depending on whether the infrastructure will be required to support future exploration activities.

The topsoil stockpiles around the lease pad will also be used to create a bund to prevent wastewater from leaving the site in the event of a tank failure and prevent overland flow entering the site in the event of a significant regional flood. The bund will be of an appropriate height to contain 110% of the volume of the largest wastewater storage tank on site.

Once the site has been stripped of topsoil, the cleared areas will be grubbed to remove roots and rocks, levelled, compacted and sheeted with gravel to aid forming the working surface. The compacted surface will also minimise the infiltration of any spills and allow for material recovery. The lease pad will be constructed with an approximate 0.2-degree fall terminating at a purpose-built stormwater retention basin to manage rainfall that falls on the lease. The retention basin will only be in operation during stimulation and well testing activities, with the basin being removed at other times. Any stormwater collected will be beneficially used on-site (for dust suppression within the activity area) or tested prior to release outside of the approved activity area (i.e. surrounding area). The site will be fenced with a stock-proof fence to prevent livestock access.

The access track intersection(s) with the Carpentaria Highway will also be upgraded in line with DIPL requirements. This includes installing a turn in lane and construction of a bitumen seal as per DIPL bitumen seal. A road corridor permit and traffic control will mitigate the risk to road users.

Equipment and machinery likely to be used during construction works include:

- Excavators
- Dozers

- Graders
- Rollers
- Water carts
- Haulage trucks
- Bob cats
- Light 4WD vehicles
- Bitumen spray and seal trucks
- Site offices and crib huts

4.7 Drilling sump construction

Each exploration lease pad will have a drilling sump installed to accommodate up to 5,000m^3 of drilling waste and fluids. The sump will either be installed adjacent to the proposed drilling rig or "remotely", in which the sump will be located away from the drilling rig. Where a remote sump is utilised, drilling waste will be stored in tanks/skips adjacent to the rig and transported to the drilling sump as required.

The sump will be excavated to the required depth, lined with an impermeable liner (such as Coletanche or equivalent). The liner will be "welded" in place using a heat gun, with joins tested periodically as per the manufacturers recommended Quality Assurance requirements. An overview of the anticipated sump design is provided in Appendix C.

4.8 Cellar construction

Cellars will be constructed on each lease pad to accommodate the wellhead equipment and blow-out preventer (BOP). Each of the cellars are each approximately 8 m^3, concrete lined and prefabricated off-site (Figure 13). The cellars are transported to the site in one piece and lowered into an excavated pit. A conductor casing is installed within the cellar to approximately 20m using an auger. The conductor casing is designed to prevent the upper sections of the exploration well from caving in when drilling through the unconsolidated sediments. The cellar itself will be fenced to exclude fauna ingress.

Figure 13: Picture of a cellar prior to installation

4.9 Gravel pit construction

Gravel will be required to surface the lease pads, camp pad, laydown area, helipad and access tracks at each location. One new gravel pit (Amungee NW 3 gravel pit) will be constructed and expanded progressively to 3.5 ha. Approximately 5,000 m^3 of gravel will be sourced from the new pit. The typical image of a gravel pit in the Beetaloo is provided in Figure 14. An indicative location of the gravel pit is provided in Table 8 and Figure 1.

The gravel pit will be cleared, with topsoil and subsoil stripped, segregated and stockpiled onsite for future revegetation.

The gravel pit is anticipated to be up to 3 m in depth, with the final depth dependent on the level of gravel present at the site. Gravel pits may be fenced where the pit batters represent a potential fall hazard to livestock and fauna.

Upon cessation of activities, the gravel pit will be recontoured back to a stable, safe and non-polluting form in alignment with Code rehabilitation requirements. Subsoils and topsoil will be reinstated across the gravel pit and natural revegetation used as the primary vegetation reinstatement measure. Gravel pit rehabilitation will commence within 12 months once there is no viable gravel left.

Figure 14: Example of a typical operational gravel pit

4.10 Exploration well drilling

4.10.1 Well design

The well design process is the first step in ensuring the integrity for each proposed well. Origin's sub-surface team, (geologists, geophysicists and petroleum engineers) summarise the key information and data required by the drilling engineers to design each E&A well. It forms the Basis of Well Design (BOWD).

Critical inputs into the BOWD

- Existing geological data available for the site
- Downhole formations that need to be isolated (i.e. freshwater aquifers), hydrocarbon-bearing zones, aquifers and saline units that could be encountered during drilling operations
- The sub-surface well objective (production and/or reservoir evaluation)
- The fracture gradient, which describes how much pressure is required to fracture a specific formation
- The pore pressure, which is the in situ fluid pressure within a reservoir
- The orientation and separation of each vertical and horizontal well
- Other conditions that may affect the integrity of the well (formation fluid composition, stress regime, etc.)

The BOWD is used in combination with the requirements outlined in the Code, the Regulations and Origin's internal standards to develop an appropriate well design that ensures well integrity is maintained throughout the life of the well and addresses all regulatory and risk management requirements.

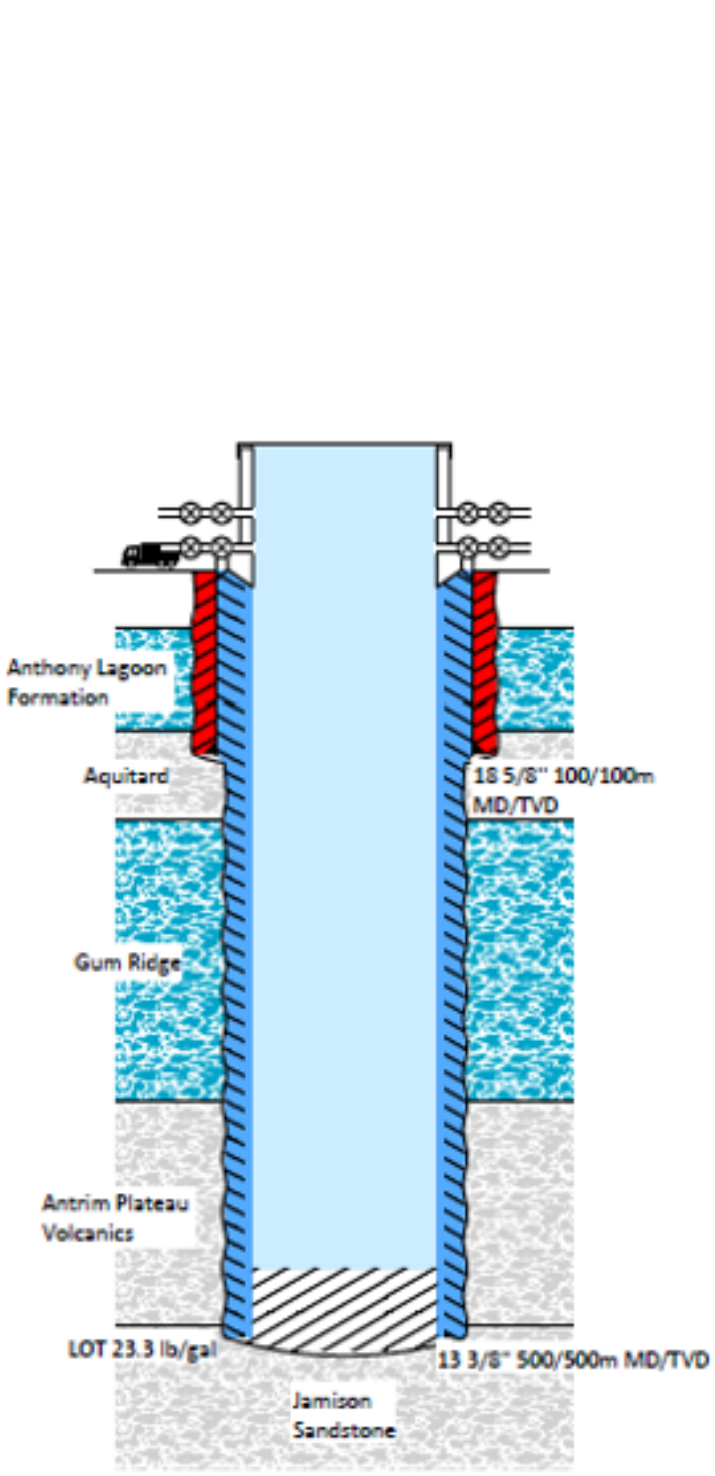
The design process includes the definition of Well Acceptance Criteria (WAC). WAC are critical thresholds that are tested during well construction and typically form components of the well barrier envelope. The barrier envelope is the combination of one or more well barrier elements that are combined to prevent uncontrolled flow of fluids and hydrocarbons into another formation, or to escape at surface. The isolation and protection of aquifers is a critical component of the WAC. The WAC must be met or exceeded to confirm well integrity before proceeding to the next phase of well construction or operation. If a well WAC is not achieved, an approved remedy and/or risk assessment must be in place prior to moving forward with operations.

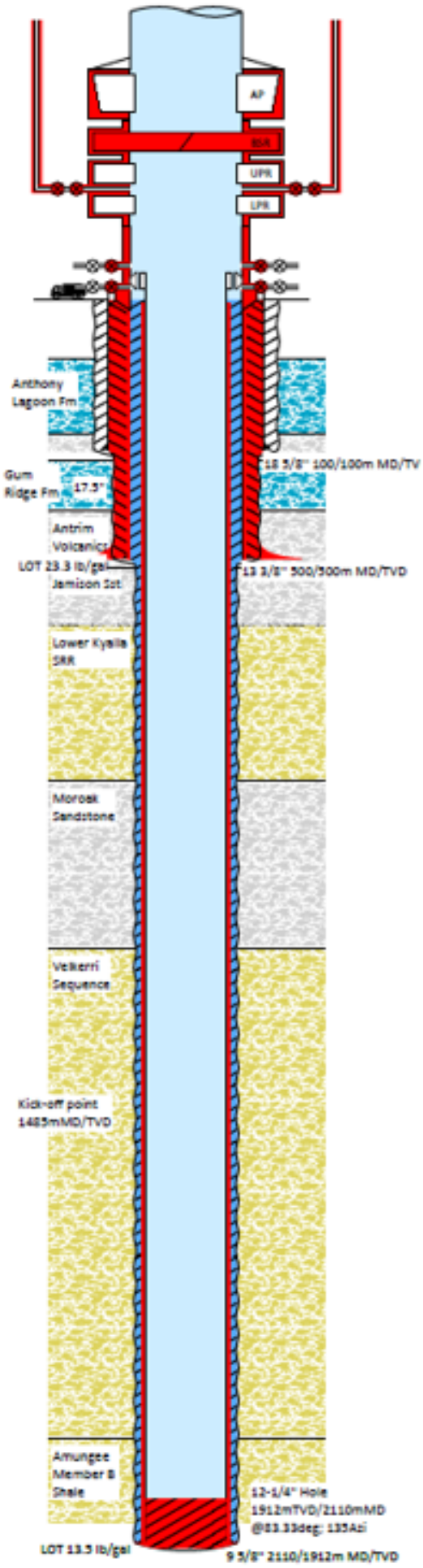
The well design and WAC form a critical part of the Well Operations Management Plan (WOMP), which is a regulatory document that summarises how each well will comply with the required standards from the design to decommissioning of a well. This document is prepared and submitted to DITT for approval prior to the commencement of any drilling and stimulation activities. Where required, any deviation from the approved WOMP will need to be reviewed and approved by DITT prior to proceeding.

To accommodate multiple wells, each well is separated on surface by 10 – 15 m. This separation distance is calculated from the hole centre to hole centre and is selected to accommodate the rig package and future well interventions. Petroleum wells on a multi well pad (both within Australia and internationally) are typically separated by 8 – 10 m but may be closer in proximity where safe to do so (e.g. coal seam gas wells are shallower, need smaller drilling rigs to drill and may be separated by 3 – 5 m). Well deviations from the vertical plane during drilling are monitored using standard survey tools as discussed in section 4.10.3.

Each lateral in a horizontal well on the same pad is drilled at a sub-surface separation distance of at least 200 – 400 m (with the final separation distance determined from the existing well test results and updated mechanical earth model) to ensure the stimulated zones between wells are not connected during stimulation. If two stimulation zones within the target reservoir were connected, this could reduce the productivity of each of the wells. It would not represent an environmental risk, as the stimulated zones are within the Velkerri shale formation.

Indicative well sections and sub-surface layout for the proposed wells sites are shown in Figure 15 and Figure 16.





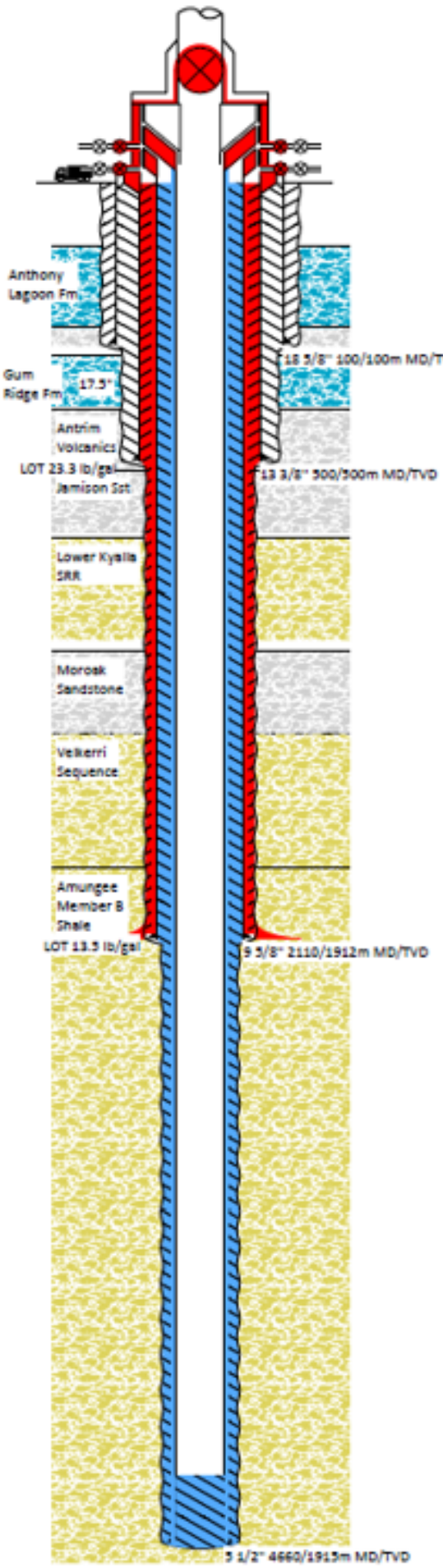


Figure 15: Proposed typical well sections for the Amungee delineation wells – this includes the conductor and surface, intermediate and production casing strings of each exploration well

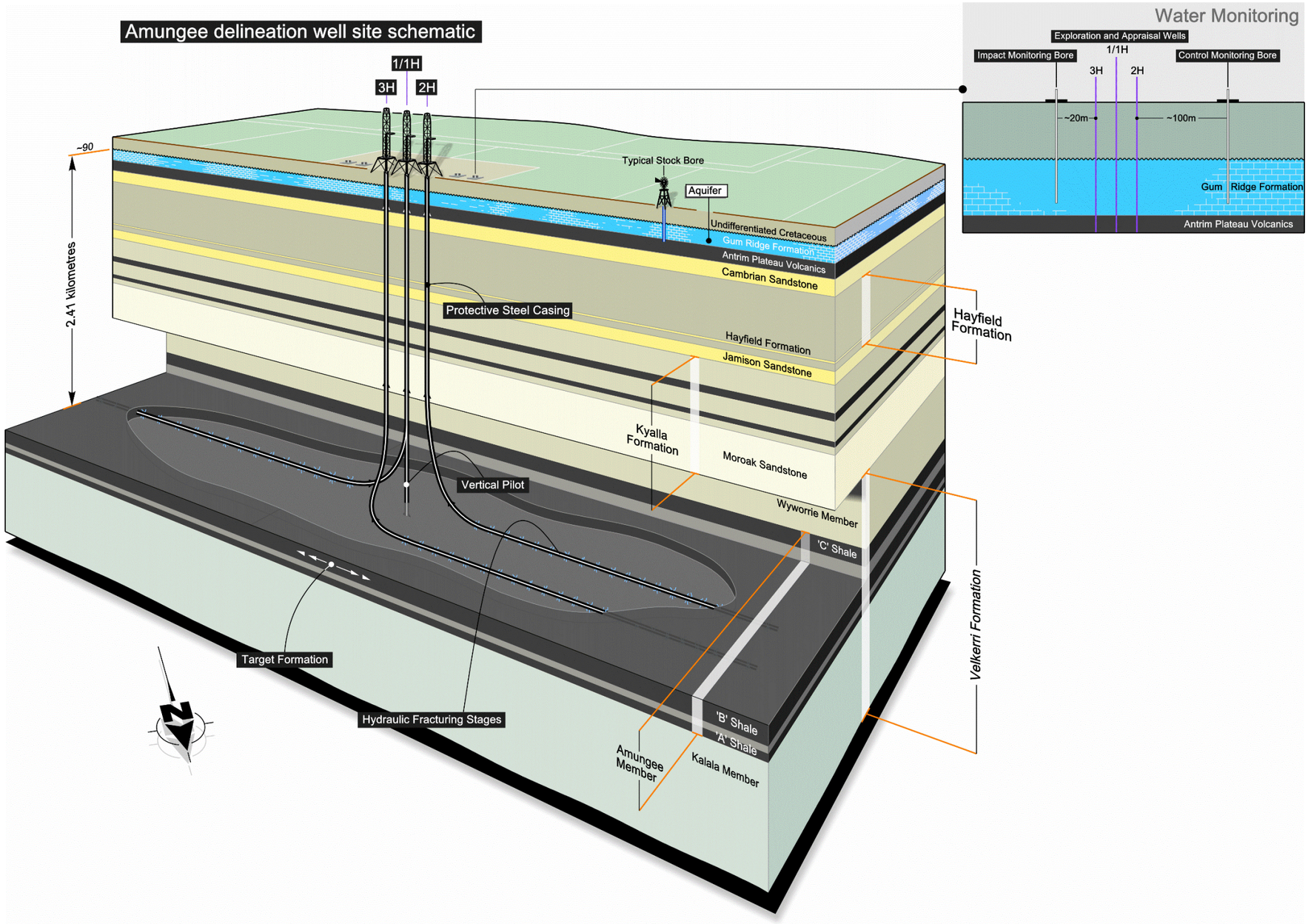


Figure 16: Amungee delineation multi-well site schematic

4.10.2 Site preparation

A drilling rig package will be mobilised to site and constructed to prepare for the commencement of drilling activities. The rig package comprises the main rig, as well as the supporting vehicles, equipment and facilities outlined below:

- Rig mat, an impermeable liner containing all spills from the drilling rig
- Drilling rig, comprising a rig floor, a mast or derrick, rig engine, Blow Out Preventer (BOP) system and catwalk
- Pipe rack for storing drill pipe and casing and potentially a pipe arm, which is a piece of equipment designed to bring the pipe and casing up to the drill floor
- Rig fluid system, including tanks (water and mud), shakers, mud treatment system and pipes for storing and pumping fluids down the drill string
- Storage trailers and racks for equipment
- Bunded chemical storage areas for mud chemicals, diesel and wastes
- A workshop
- Portable on-site offices
- Rig mini-camp, wastewater treatment system and irrigation area
- Temporary accommodation housing approximately 70 people
- Diesel power generators
- Third-party equipment such as cementing trucks, fuel trucks and wireline evaluation units.

Throughout drilling operations there will be ongoing vehicle movements, from the initial rig mobilisation to the interchange of drilling support services or delivery of equipment (a discussion of traffic is provided in section 4.26). Drilling operations are generally a 24-hour per day operation.

An overview example of the drilling rig lease layout is provided in Figure 17 and Figure 18.

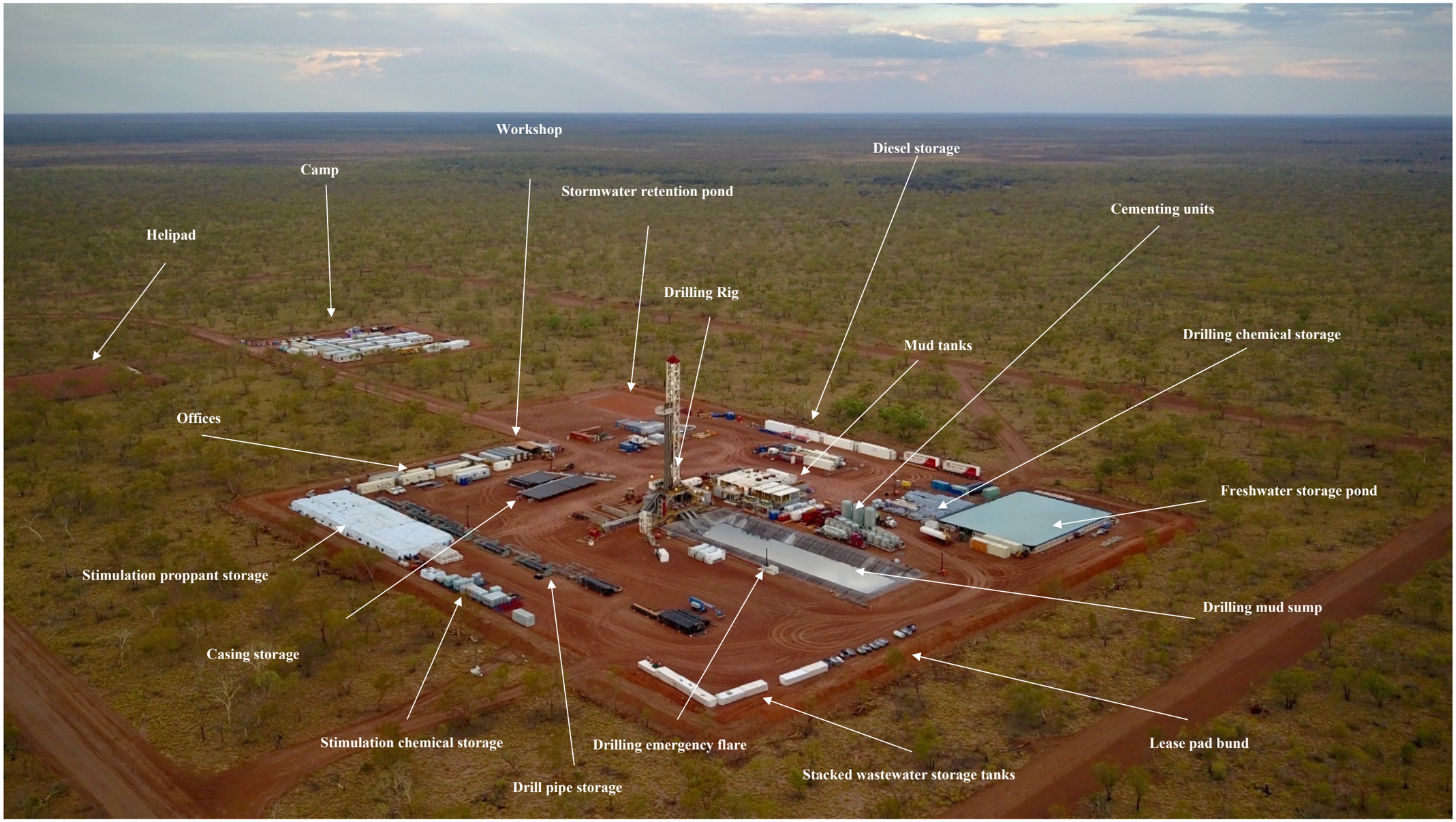


Figure 17: Example of a drilling operation at the Kyalla 117 N2-1H E&A well in November 2019; the well sites within the Amungee Delineation Area are likely to use a similar rig set-up

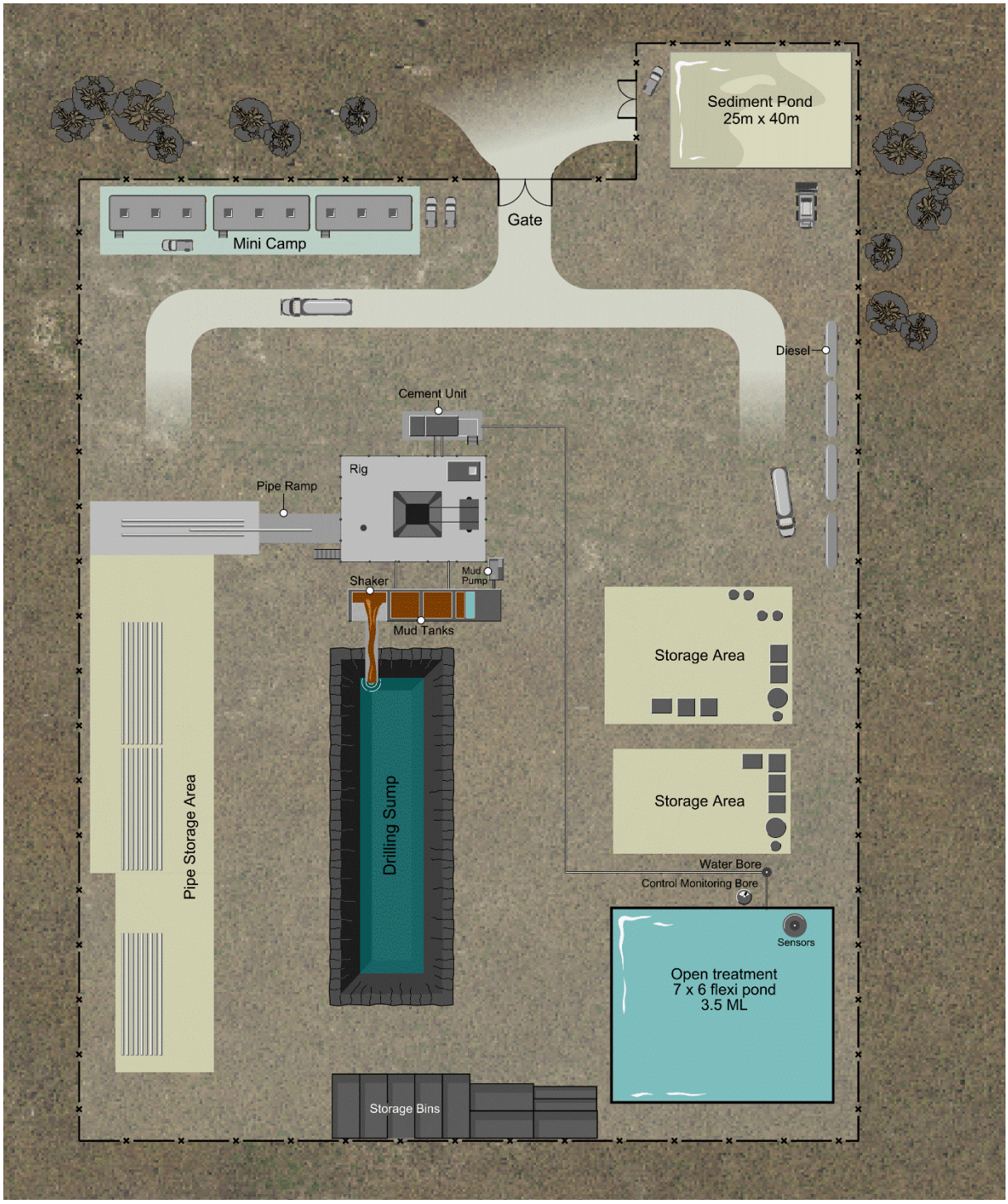


Figure 18: Typical well site layout for well sites within the Amungee Delineation Area

4.10.3 Drilling

Drilling of multiple wells on a pad requires the use of specialised surveying tools to ensure the well path is constructed to design and to eliminate the risk of sub-surface collision with the existing wells on location. These survey tools use drill bit Global Positioning System (GPS) tracking to monitor the downhole position and trajectory of the well when drilling. Safety envelopes are established around each existing well to detect when a well has begun to deviate into the proximity of the adjacent well. This reduces the likelihood of a subsurface collision, which represents a significant well integrity and economic risk to the project through loss of multiple assets. The use of GPS surveying tools is a standard industry control that has been effectively used for multi-well pad drilling within Australia and internationally.

Once the rig is functional, the top-hole sections will be drilled, cased and cemented for each E&A well to depths which will enable isolation of the Gum Ridge Formation, as the Anthony Lagoon formation is absent. Each individual section will be cased and cemented (with specifically engineered cement) to seal the aquifer off from the rest of the wellbore to prevent fluid crossflow between formations. If an aquifer is discovered during drilling that was not identified prior to commencement of drilling, Origin will notify to the Minister as required under the Regulations and the Code.

Defining the contact between the GRF and adjacent formations is critical to ensure the appropriate casing setting points to isolate the two units. Data from the existing wells and control monitoring bores provides a high confidence that the casing setting point will effectively isolate each of the aquifer units.

Commonly during the drilling of the GRF, partial to total losses of drilling fluid have been observed due to high permeability conduits, fractures and cavernous zones expected in karstic formations. Loss of circulation material (LCM) is typically used to respond to fluid losses, with additives used to block fluid pathways to re-establish fluid circulation. LCM is often in the form of viscosity enhancers (such as bentonite and polymers), fibrous material (such as coconut coir, nut hulls etc.) or granular material (such as marble chips) with the type of LCM used dependent on the level of losses and formation type. Where drilling fluid losses cannot be stopped, the drilling fluid systems are reduced back to water to maintain dynamic well control (a continuous supply of water to overcome formation pressures) and to minimise drilling additive losses to the formation. Once the zone of high losses has been drilled through on water, the section is then cased off to regain fluid circulation and allow drilling to continue unimpeded. It is anticipated that LCM will be utilised and there is a potential that casing off high loss zones will be deployed to manage fluid losses for the additional wells proposed under this EMP.

During cement operations, cement may also be lost to the formation resulting in cement slumping or ‘patchy’ cement sections. In the event that cementing of either the conductor casing or the surface casing for a well is unsuccessful (i.e. the cement does not return to surface or slumping is observed) the following practices may be deployed depending on the casing section:

- For the conductor casing: a top up cement job will be undertaken – this process involves spotting cement from surface in the annulus of the conductor casing and formation
- Surface casing: the use of an External Casing Packer (ECP) and a two-stage cement job will be utilised to provide hydraulic isolation between the casing and formation
- A cement evaluation log is performed to analyse the cement quality in the annulus and determine the appropriate corrective actions
- A Leak-Off Test (LOT) or Formation Integrity Test (FIT)is undertaken to confirm cement integrity.

Once the surface casing is cemented in place, the BOP is installed on top of the casing string. A BOP contains a series of rams and elements that may be closed to prevent a release of pressure and isolate the well at surface. Once installed, the BOP is function and pressure tested to confirm its integrity.

Drilling will then progress down to the target 'kick off' point as part of the intermediate hole section, which is anticipated to be around 300 – 500 m above the target shale formation. When the intermediate hole of each E&A well has reached its target depth, intermediate casing is installed and cemented in place.

The design of the well casing strings of each exploration well is illustrated previously in Figure 15.

Prior to each new hole section of an exploration well being drilled, a Formation Integrity Test (FIT) or Leak-off Test (LOT) is performed to validate the integrity of each casing shoe and provide an operating envelope for drilling the next hole section.

Once the kick-off point has been reached, the build section of each E&A well will be drilled into one of the selected Velkerri shale targets. Once in the targeted shale zone, the well will be drilled horizontally for 1,000 – 3000 m laterally, with each horizontal wellbore on the site location separated from each other in the horizontal plane by approximately 400 m.

An open hole Diagnostic Fracture Injection Test (DFIT) may be run to further investigate the local rock properties. This test involves injecting small volumes (<10,000 L) of water, with salts (NaCl) and biocide (assessed in the drilling chemical risk assessment Appendix D), into the formation to create small fractures, allowing the resulting pressure to fall naturally. The fluid contains no proppant; hence the fracture relaxes and closes naturally when the pressure is released. The pressure decline is monitored on-site, and data is analysed to assist reservoir characterisation. This hole section is again cased and cemented in place.

Where a well deviates from the required specification or WAC, a section may need to be plugged and abandoned as per section 4.18. The section of the well may be redrilled (either partially or completely) to ensure compliance with the Code and relevant well acceptance criteria.

Once drilling has been completed, the drill rig will be 'walked' to the next well or will be demobilised from site.

4.10.3.1 Drilling fluids, muds and cuttings

A low toxicity water-based drilling mud is anticipated to be used as the base fluid for drilling, which primarily contain salts and polymers. Drilling mud is required to maintain well control, provide formation stability, lubricate and control the temperature of the drill bit and lift cuttings to the surface. The fluid system consists of water with a sodium or potassium-based salt (to prevent formation swelling) and a viscosifying agent such as bentonite. Other low toxicity chemicals such as barite, citric acid, sodium bicarbonate and loss circulation material may also be used. The chemicals used for drilling are consistent with those used for water bore drilling. The details associated with the chemicals used during drilling have been included in the Chemical Risk Assessment (Appendix D).

To assist in bore-hole stability, synthetic based muds (also known as non-aqueous based muds) may be utilised to drill the horizontal and intermediate section of each of the well (typically commencing from the Shenandoah-East mudstone or below). Drilling using synthetic based muds (SBM) will only occur in section that are below any potable aquifers, with all aquifers protected behind cemented casing.

As per clause B.4.10.2(a) of the Code, the name, type and quantity of each chemical used on each well throughout the well construction process to be recorded. As per clause B.5.1.1 of the Code, the Benzene, Toluene, Ethylbenzene and Xylene (BTEX) of all drilling fluids and muds will not increase the levels of the overall fluid above the BTEX content specified in Table 8 of the Code. Testing of the fluids systems will be carried out to validate BTEX levels.

The main difference between SBM and aqueous based muds (other than chemistry) is that synthetic based muds are recycled through a closed loop process with very little wastage. Typically, these muds are rented from providers and are removed from site and re-used repeatedly at other operations.

Where SBM are utilised, the aqueous drilling fluids in the mud tanks will be discharged to the mud sump and replaced with SBM. A cuttings dryer is utilised to separate the SBM from drill cuttings, with the dried cuttings transferred to a bin via a screw conveyor belt (Figure 19). The cuttings, free of SBM (typically removing >90%) are then transferred to the sump for storage and disposal. The SBM is removed from site by the SBM supply company and is re-used.

All waste drilling fluids, muds and cuttings will be managed in the lined drilling sump on-site. The sump has been designed to support multiple E&A wells. All waste drilling fluids within the sump will be managed and disposed of in accordance with section 4.15.1.

Figure 19: Example of a cuttings dryer used to recover synthetic based drilling fluids

4.11 Hydraulic fracture stimulation activities

Upon completion of drilling operations, each of the horizontal E&A wells will HFS. The hydraulic fracturing process is a series of operations designed to increase the available surface contact area of the shale formation. This enhances the volume of hydrocarbons that migrate into the wellbore and flow to surface.

The process of a hydraulic fracturing completed on each exploration well is conducted in the following sequential stages:

i. Well integrity verification

ii. Site set-up

iii. Stimulation activities

4.11.1 Well integrity validation

Prior to the stimulation of each E&A well, the wellbore will be assessed to ensure that sufficient well integrity is in place to withstand hydraulic fracturing pressures as per the Code (B.4.7.2 and B.4.13.2) and Section 302A of the Schedule of Onshore Petroleum Exploration and Production Requirements.

The assessment will include the following completed for each exploration well:

- Cement evaluation logs are run to ensure that at a minimum 150 mTVD of good quality cement is present from the target reservoir to the nearest aquifer to ensure zonal isolation as per Origin Barriers Standard INT-1000-35-TS-002
- Confirmation of geological barriers and assessment of geological hazards

Mechanical integrity evaluation of the production casing via a pressure test to the Maximum Allowable Operating Pressure (MAOP) of 10,000 psi. The pressure test will consist of (a) 10-minute low pressure (300 psi) leak test and (b) 20-minute high (10,000 psi) pressure strength test.

Origin's pressure test acceptance criteria is a 1% pressure drop per five (5) minutes over a stabilised test duration with a decreasing dP/dT trend as per Origin Barriers Standard INT-1000-35-TS-002.

Pressure tests will be undertaken using fresh water which will be re-used.

Well Barrier Integrity Verification Report (WBIV) certified by an independent and reputable validator must be completed and submitted to DITT before and after hydraulic fracturing.

4.11.2 Site set-up

The hydraulic fracturing operation of each E&A well requires various equipment as illustrated in Figure 20.

Stimulation equipment

- A data van, which is an on-site office to execute stimulation activities
- Water storage – the wastewater tanks will be constructed on-site, capable of managing the total volume of both make-up water and flowback water. Tanks storing flowback will be double lined with leak detection capable of monitoring any leaks between the primary and secondary liner. Specific information on the wastewater tank construction is provided in section 4.11.3
- Proppant trailer which is a large sand storage and delivery trailer that holds the proppant
- Hydration unit which is used to add stimulation additives and viscosifying fluids
- Blender unit which is used to mix proppant and fluid additives prior to its injection into the well
- High pressure pumps which inject the hydraulic fracturing fluid mixtures from the blender unit down the well via the surface lines and hydraulic fracturing wellhead or coiled tubing unit
- Coiled tubing unit – a large length of coiled steel pipe that can be temporarily installed in the well to perform various downhole operations
- Wireline unit for plug and perforation deployment
- Ancillary support buildings including offices, workshop, cranes, chemical storage area, equipment storage, laydowns and all other activities required to support stimulation activities.

The anticipated lease layout for the hydraulic fracture operation is provided in Appendix C.

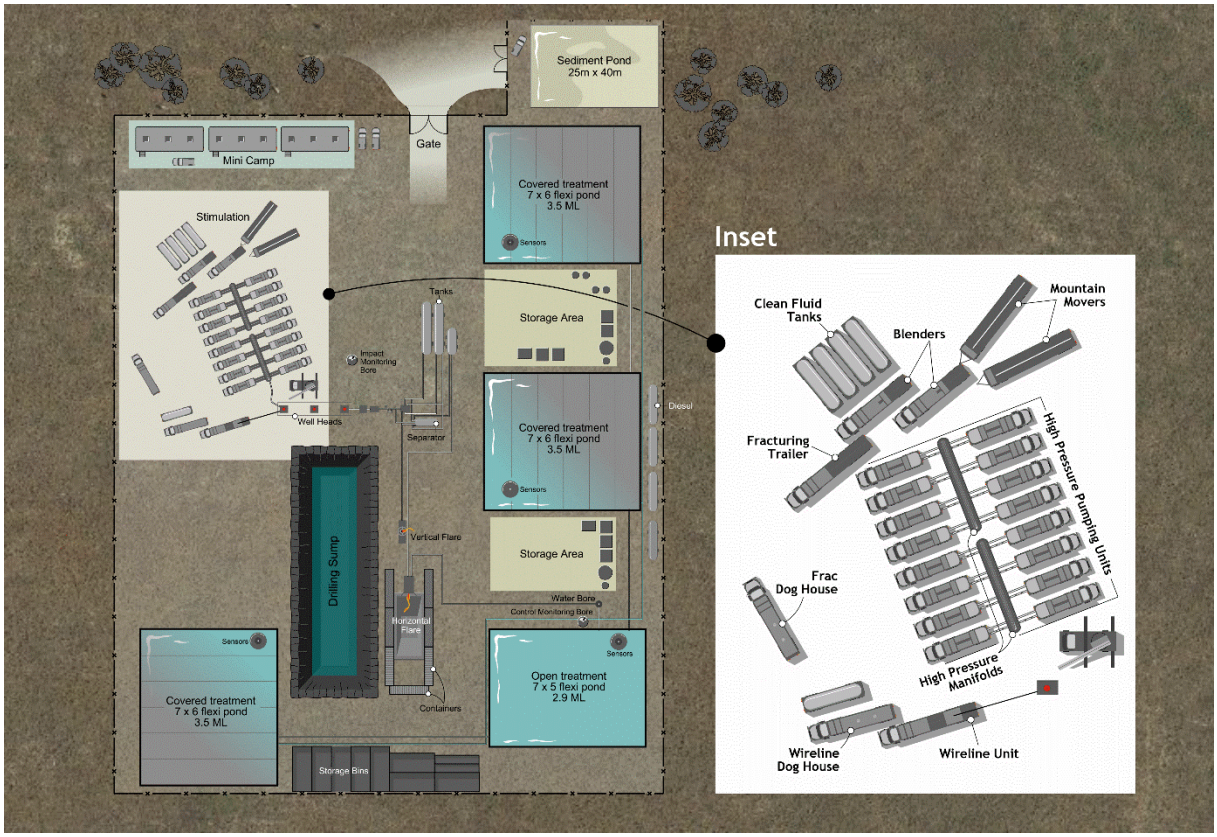


Figure 20: Example hydraulic fracture stimulation spread used for each E&A well (Note: additional tanks will be installed where the frack spread is located during well test)

4.11.3 Wastewater tank set-up

In accordance with section C.4.2.2 of the Code, all flowback must be stored in enclosed tanks unless being treated for disposal or re-use. To comply with this requirement, a series of enclosed and open wastewater tanks will be constructed on-site to store and treat flowback wastewater produced during well testing. The number of enclosed and open tanks utilised on-site will vary depending on the season, as summarised in section 4.15.3.3. Tanks will be periodically brought on and removed from operation to meet wastewater storage requirements.

Each tank will be engineered to meet the Code and site environmental conditions requirements, including:

- Double-lined tank with leak detection in the interstitial space capable of detecting leaks between the primary and secondary liner
- Wastewater tank liners to have an impermeable membrane with coefficient of permeability of less than 10^{-9} m/s permeability, 120N picture resistance and 49N tear resistance
- Tanks are not connected and non-return valves used to prevent uncontrolled discharge from multiple tanks should one fail
- Tanks designed to prevent the risk of build-up of explosive gasses
- Wastewater tanks designed and engineered to Australian Standards (AS3990 Mechanical Equipment – Steel Work, AS 1170.1 Hydrostatic loading, AS1170.2 Wind Rating (cyclonic wind rating)

- Enclosed tanks to have vents and ignition exclusion zones to eliminate the build-up of explosive gasses
- Controls are installed (such as pipe caps and non-return valves) to prevent siphoning of a tank.

Any new wastewater storage tanks will be installed in accordance with the following steps (illustrated in Figure 21):

- Each tank site is flattened to a maximum slope of <0.5% and compacted to above 120kPa- with the lease pad containing a mixture of silt, clay and gravel. Predicted permeability (based on type of material present) exceeds 1 x 10^{-7}m/s
- Each tank panel is transported to the site in flat packs
- Each tank panel is assembled using a simple pin-type set-up, with each tank panel lifted into place using a telehandler. No cranes or suspended overhead loads are required
- Each panel is free standing and capable of withstanding 100 km/hr winds on their own. They are connected to the adjacent panel using engineered steel pins, which increase the wind rating to above the cyclonic wind load requirements. The structure is engineered to a level that can withstand up to 70% erosion of the panel length, without causing any structural damage. This means the risk of water erosion during rainfall events is low
- Geomembranes are installed under each of the tanks to prevent rock/root penetration
- The first 0.5mm HDPE liner is installed and fixed to the structure. Liners are prefabricated, welded and tested off-site, preventing the need for on-site welding
- A moisture and pressure probe are installed between the primary and secondary liner to detect moisture and water pressure
- The second liner is installed and fixed to the structure
- Level sensors are installed within the tanks
- For the enclosed tanks, the covers are installed. The covers have built in vents and rainwater collection system
- Tanks are filled with fresh water and are tested for leaks over a 24-hour period. If moisture and pressure is detected via the leak detection system, the tank is drained to an existing storage tank on-site and leakage point repaired. Leak testing on all tanks will be completed during the well testing to ensure the tanks are free from leaks.

1. Transportation

2. Panel assembly

3. Tank assembly

4. Geomembrane installation

5. Primary liner installation

6. Secondary liner installation

7. Cover installation

8. Tank commissioning

Figure 21: Wastewater tank construction steps

4.11.3.1 Hydrotest water management

Groundwater will be utilised to perform hydrotesting on each of the wastewater tanks to confirm the integrity of the primary liner and rectify any leaks prior to storing flowback wastewater. Hydrotesting involves the filling of each tank to approximately 75% capacity for a period of 24 hours.

Once a tank has been hydrotested, the groundwater in the wastewater tank will be recycled to perform a hydrotest on the adjacent wastewater tank and will also be used for dust suppression. Most of the water will be re-used, with any unused groundwater released through a controlled discharge to the area surrounding the lease pad.

The quality of the hydrotest water is anticipated to be similar to the groundwater, with a pH of between 6.5 to 9, and an electrical conductivity of less than 2000 us/cm. Releases will be undertaken in a manner that prevents erosion or the discharge of groundwater directly to surface waters (which are absent in the immediate vicinity of the Amungee NW 2 – NW 5 locations).

4.11.4 Stimulation activities

Hydraulic fracture stimulation (HFS) will be undertaken upon completion of the drilling of the E&A wells. Stimulation is generally conducted during daylight hours, with wireline and coiled tubing support activities operating on a 24-hour basis.

HFS involves the injection of a slurry, primarily consisting of water (including groundwater and recycled flowback fluid) and sand (proppant), plus a small percentage of chemicals at high pressure into the target section of the horizontal wellbore. Typically, 95% or higher of the total volume in stimulation fluids is a combination of fresh water and sand, with the remainder as fluid-conditioning additives. Chemicals used in HFS are designed to optimise stimulation outcomes and are commonly found in food and other household domestic products. The chemical composition of stimulation fluid is discussed further in section 4.13.

All fluid additives (water and chemicals) and sand are mixed on the surface in the frac spread mixer, which uses a portable containment bund. The mixture and pumping schedule (rates, volume and proppant) are based on modelling which determines the desired fracture attributes. The HFS model is completed prior to the commencement of stimulation activities and is underpinned by a Mechanical Earth Model (MEM). The MEM is generated from data collected during drilling, wireline logging, core analysis and DFIT tests. The stimulation fluid mixture and pumping schedule is continuously updated during and after each stage to ensure optimal outcomes are achieved. An example of the modelled fracture geometry for the Amungee NW-1H well is illustrated in Figure 22.

The stimulation fluid is pressurised by the high-pressure pumping units and directed downhole via a manifold to discrete target intervals along each of the horizontal wellbores (referred to as ‘stages’). It is anticipated that 15 stages are proposed for each exploration well, with the final number of stages determined based upon the horizontal length of the well and commercial considerations. Each stage being isolated and perforated using a plug and perforation gun assembly deployed via wireline. As the pressure is sustained, the fractures propagate radially from the well, through the target rock. Once optimal fracture propagation has been achieved, the proppant (sand) is pumped down the well and into the open fractures. This process is repeated for each stage. The final number of stages pumped in each well is dependent on the useable length of the horizontal wellbore and in situ geological conditions. Once all stages are complete, the well is suspended awaiting completion and well testing activities.

It is anticipated that approximately 1– 1.5 ML of water and 180 – 250 tonnes of proppant (sand) will be used for each stage. This equals an approximate volume of 22.5 ML of water and between 2,700 – 3,750 tonnes of sand per E&A well. Water will be sourced from the Gum Ridge Formation, as described in section 4.14. Proppant will be sourced from locations within Australia (such as South Australia) or imported from international sources.

Wellbore pressures of the E&A well which is being stimulated are monitored during each stimulation to ensure the operations have not compromised the integrity of the production casing or the cement barriers of the well. Pressure monitoring is also completed on each of the casing strings being stimulated and on the adjacent wells to ensure any interference is identified and corrective actions implemented. An example of the monitoring of applied stimulation fluid pressure and annulus pressure monitoring is provided in Figure 23. The risk of a stimulation migrating into an adjacent wellbore is considered low, with conservative well spacing designed to prevent connection. If the stimulation zone of an E&A well were to become connected, the design of each well is sufficient to withstand any likely pressures encountered.

A Maximum Allowable Operating Pressure (MAOP) is an important parameter used to define the safe operating envelope of each E&A well. The Maximum Allowable Pumping Pressure (MAPP) is set below the MAOP to allow for uncertainty and provide an additional safety margin. The anticipated MAPP is 9,200 psi and the MAOP is 10,000 psi.

Two additional safety measures are set in place to ensure treating pressures do not exceed the MAOP of the system:

1. Each HFS pumping unit has an automated high-pressure shut-off control set at the MAPP or lower, and
2. A pressure relief valve will be installed on the surface treating line to instantaneously bleed-down pressures if the pressure exceeds the MAPP.

A coiled tubing unit is on standby, on location, in the event of contingent wellbore intervention operations, such as a wellbore screen-out. A screen-out occurs when the proppant in the stimulation fluid blocks the perforations or fracture network, creating a sudden and significant restriction to fluid flow, resulting in a premature termination of the stimulation operation.

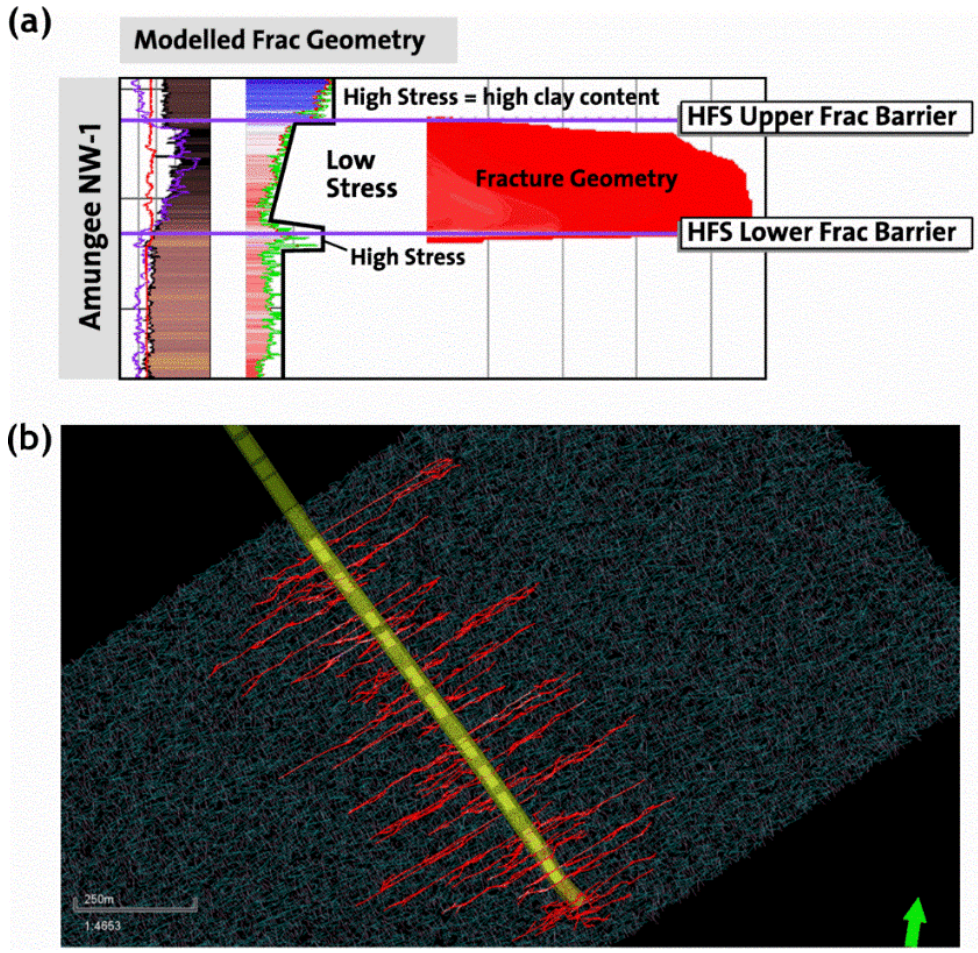


Figure 22: Example of visualised fracture geometry of Amungee NW-1H

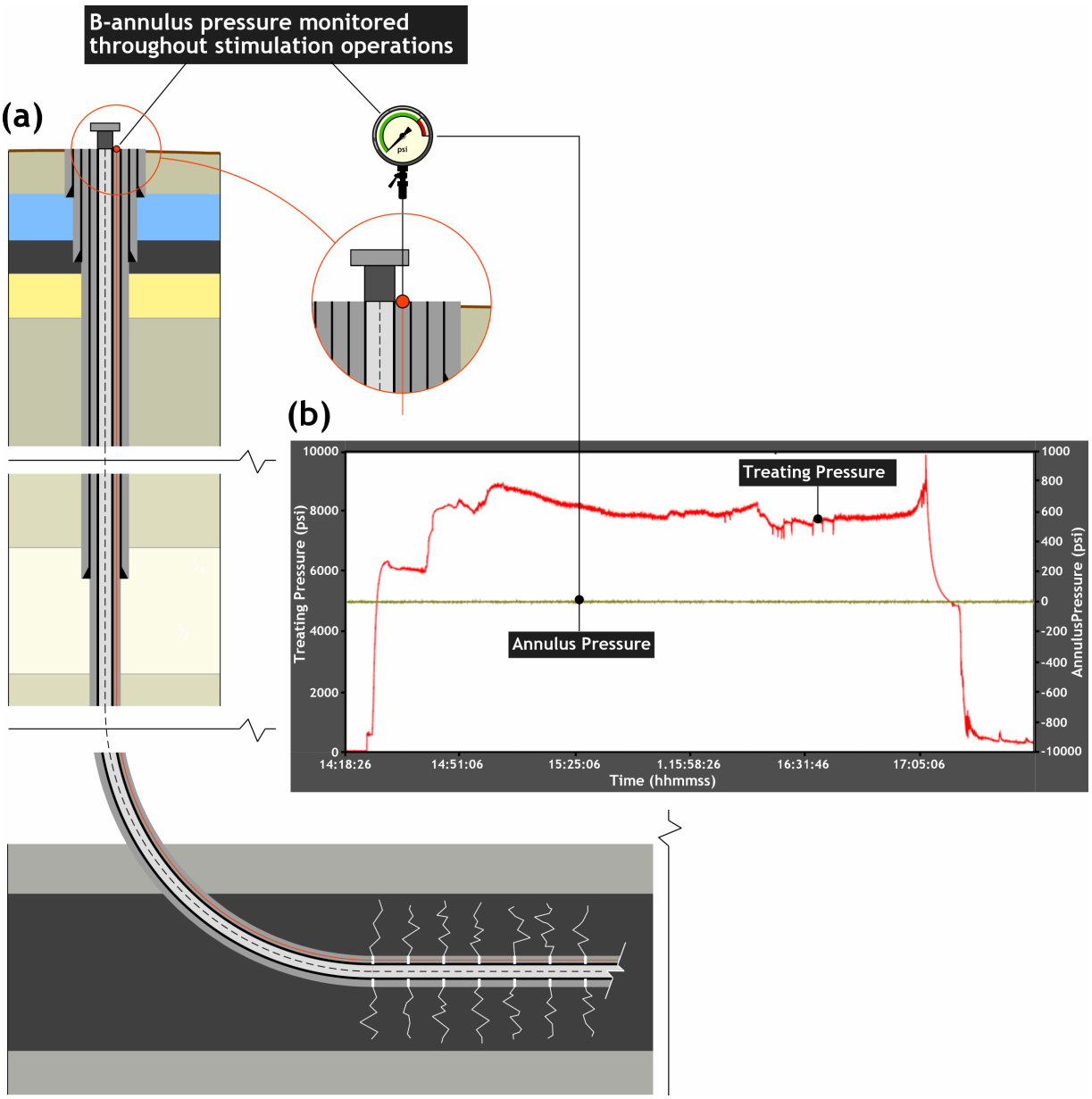


Figure 23: Well and wellhead schematic showing the "B Annulus" monitoring process, and an example from Stage 1 of the observed pressure of the B Annulus (0 psi) while high-pressure HFS operations were underway

4.12 Well completion and test program

Upon finalisation of HFS activities the wells at a site will be completed and the well testing phase initiated. To initiate production, nitrogen lifting using a coil tubing rig is often undertaken to reduce bottom hole pressure and allow gas to flow to surface. As the volume of gas flow increases, the bottom hole pressure will decrease (due to the gas column reducing the hydrostatic head), allowing sustained production.

The well testing program is one of the most critical parts of the program, as information collected during this phase is used to understand the nature, quality, quantity and production performance of the resource. A key outcome of multi-well operations is to understand how the laterals interact with each

other, to optimise lateral spacing and determine the number of wells that can be constructed on a development pad.

The well completion and testing program for each exploration well proposed under this EMP consists of:

- Completion activities for each wellbore include:
  - preparing for downhole completion equipment
  - installation of a production packer and production tubing
  - installation of production wellhead
  - underbalance wellbore to initiate production of hydrocarbons
- Well test activities include:
  - flowback of fluids and hydrocarbons
  - measurement and management of hydrocarbons
  - ongoing sampling of flowback and hydrocarbons
  - disposal of gaseous hydrocarbons via flare
  - disposal of liquid hydrocarbons via flare or off-site transportation (including on-site temporary storage)

4.12.1 Completion and well testing activities

The site will consist of new and existing E&A wells and several associated, temporary facilities that will be brought on to assist with completion and testing activities. The Amungee Delineation Area sites will have the following equipment and infrastructure:

- Completion rig and associated equipment (which installs the production tubing)
- Well testing package, including:
  - Test separator (separates hydrocarbons from flowback fluid)
  - Vertical gas flare, a safe and accepted disposal method of volatile hydrocarbons
  - Surface pipe work and manifolds
  - Emergency Shut Down (ESD) valves
  - Workshops and storerooms
  - Communications and generator shacks
  - Bunded diesel and oil storage areas
  - Wastewater (flowback) fluid storage, open-top and covered
  - Water transfer equipment
  - Condensate storage tanks (where relevant)
  - A camp

Each stimulated well will be completed to enable the flow of hydrocarbons and fluids. Completion activities involve the installation of downhole and surface completion equipment, including production packers and tubing and a wellhead.

To initiate the well testing phase, the well will be underbalanced to allow hydrocarbon and fluid production. To assist in under balancing the well, nitrogen lifting using a coil tube unit is often undertaken. Initially, the flowback will primarily contain HFS fluid. As the fluid and pressure within the reservoir is reduced, it is anticipated that gas rates will increase. To obtain a comprehensive understanding of the fluid recovery and gas production potential of the target reservoir, well testing is anticipated to extend between one and six months for each well. The total time required to test each well will depend on several factors including the success of the well and observed depletion curve. Well testing activities may also be undertaken at multiple times during the activity to accommodate operational requirements (such as well maintenance, COVID-19 constraints or weather). For example, a well may be tested for three months in year one and then three months in year two. Additional time may be required to account for unexpected issues or operational requirements.

All flowback fluids and hydrocarbons will be directed through a fully contained separator on-site. The separator will separate out the gases, fluids and solids so that they can be measured and managed.

Any liquid hydrocarbons will be separated from the flowback fluid, temporarily stored and either combusted in the on-site flare or transported off-site for disposal. Where condensate (or mixture of hydrocarbons greater than 1% by volume) is stored, double skinned enclosed tanks compliant with Australian Standards 1692 Steel Tanks for flammable and combustible liquids will be utilised.

After the well test, the well may be shut-in to complete a pressure build-up test to further characterise the respective reservoirs for a period of up to 24 months. Upon finalisation of the build-up test, the well will be either suspended or plugged and rehabilitated.

An overview of the typical well testing equipment layout is provided in Figure 24.

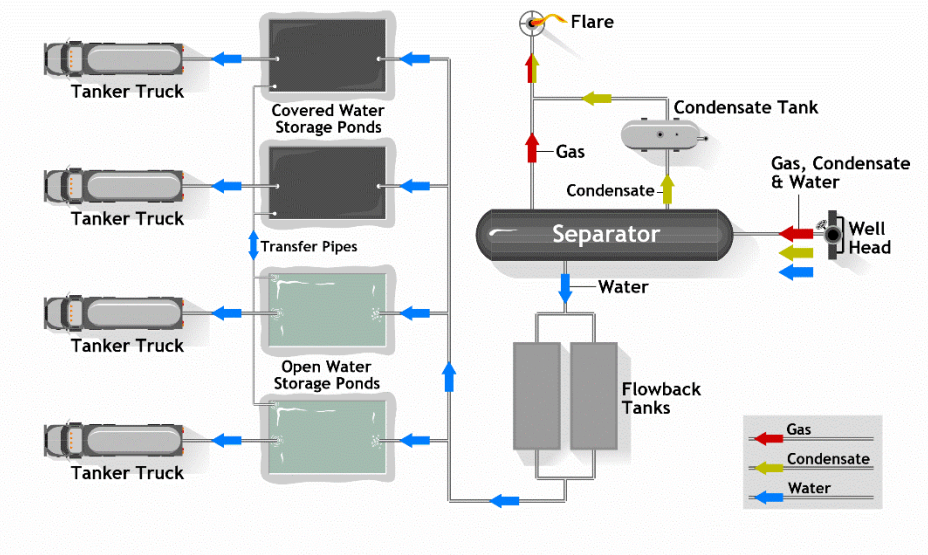


Figure 24: Sample well test schematic

4.12.2 Flaring

During well testing, produced gas and liquids will be separated to split out gas, condensate (if encountered) and flowback fluids. Flowback fluids will be sent to wastewater storage tanks for management as described in section 4.15.3.

To minimise the potential GHG emissions and potential bushfire risk, the following controls will be implemented:

- The flares have been designed and will be operated in compliance with the US EPA 40 CFR § 63.11 control device and work practice requirements to achieve a 98% combustion efficiency
- The vertical flare s will be conservatively designed to manage the maximum anticipated gas production rates likely to be encountered. This is an order of magnitude higher than predicted gas production volumes
- The flare designs have capacity for the anticipated gas/liquid stream composition (net heating value) and maximum tip velocity (V^{max}) to ensure the optimal flare efficiency The flares have been installed with a constant pilot flame and an autoignition system that provides electrical impulses to a spark plug continuously. If the flare were to extinguish, the auto-ignition system has been designed to reignite the flare within 1.3 seconds
- The flares are located at least 45 m from the surrounding vegetation
- A bushfire management plan implemented outlining the controls and communication requirements (Appendix A).

The vertical flare will be an unassisted flare, with the anticipated gas composition likely to achieve the required combustion efficiency without any additional support. The flare will have an autoignition system that provides electrical impulses to a spark plug continuously to generate a spark every 1.3 seconds. If a flare were to go out, the spark would ignite the flare within 1.3 seconds. Refer to Figure 25 for an overview of the vertical flare.

Figure 25: Vertical flare

4.13 Chemical and fuel management

Origin will use a range of chemicals and hydrocarbons to support drilling, stimulation and well testing operations. All chemicals used in Australia must be approved for use by the Federal Government Department of Health and be listed on the Australian Inventory of Chemical Substances (AICS) which is maintained under the National Industrial Chemicals Notification and Assessment Scheme (NICNAS). Origin is also required to disclose all chemicals that are proposed to be used prior to undertaking any drilling and stimulation activities. The CAS number of all chemicals, including proprietary chemicals, is included in a chemical risk assessment which is undertaken by an independent third-party consultant. The final chemical risk assessment report is provided in Appendix D. The proprietary chemical CAS numbers are excluded from the final public submission to protect the intellectual property of chemical manufacturers. This approach ensures that all chemicals can be appropriately assessed, while protecting chemical companies from releasing commercially sensitive information.

4.13.1 Chemical types and quantities

Bulk chemicals and hydrocarbons will be utilised/generated during the drilling, stimulation and well testing activities. These are summarised in Table 16 and include the following chemical types:

- Acids and bases: controls pH and are used to clear perforations of debris prior to stimulation
- Biocides: controls or eliminates bacteria growth in the stimulation fluid to prevent introduction to target formation
- Viscosity regulators: increases or reduces the thickness of a fluid
- Clay control: prevents clays from swelling
- Friction reducers: reduces friction between the stimulation fluid and piping allowing the fluid to be injected further without pressure drop
- Corrosion inhibiters: prevents equipment from rusting
- Chemical inhibitors: such as iron or scale prevention
- Surfactants: reduces surface tension of the hydraulic fracturing fluid
- Bulk diesel: to fuel equipment and generate power
- Drilling muds and weighting agents: used to lubricate the drilling bit, return cuttings to surface, control clay swelling and inhibit formation inflows
- Synthetic based muds: mud used to drill within the intermediate and horizontal sections of a well, which are specifically engineer
- Typical workshop and maintenance chemicals including hydraulic oil, coolant, greases, paints, solvents and engine oils
- Degreasers and domestic cleaning chemicals
- Wastewater (discussed in section 4.15)
- Condensate (discussed in 4.12)
- Camp wastewater (sewage) (discussed in section 4.25)

The maximum chemical storage volume is generally restricted to the materials required for drilling and stimulation of two exploration wells at a time at each site.

Table 17: Anticipated chemical volume and storage used in the drilling and stimulation process at each site

Material name	Typical volume	Maximum volume	Unit	Storage area
Acetic acid - 60% pH control	3,000	6,000L	L	Stimulation chemical storage area
BE-9 biocide	17,000	34,000	L	Stimulation chemical storage area
Caustic soda liquid pH control	15,000	30,000	L	Stimulation chemical storage area
DCA-11001 breaker activator	5,000	10,000	L	Stimulation chemical storage area
DCA-13002 breaker	300	600	kg	Stimulation chemical storage area
DCA-13003 breaker	10,000	20,000	L	Stimulation chemical storage area
DCA-16001 clay stabiliser	42,000	84,000	L	Stimulation chemical storage area
DCA-17001 corrosion inhibitor	1,000	2,000	L	Stimulation chemical storage area
DCA-19001 crosslinker	600	1,200	kg	Stimulation chemical storage area
DCA-19002 crosslinker	10,000	20,000	L	Stimulation chemical storage area
DCA-23001 friction reducer	5,000	10,000	kg	Stimulation chemical storage area
DCA-23003 friction reducer	18,000	36,000	L	Stimulation chemical storage area
DCA-25005 gelling agent	35,000	70,000	kg	Stimulation chemical storage area
DCA-30001 scale inhibitor	15,000	30,000	L	Stimulation chemical storage area
DCA-32002 surfactant	15,000	30,000	L	Stimulation chemical storage area
DCA-32014 surfactant	200	400	L	Stimulation chemical storage area
FE-2 pH buffer	200	400	kg	Stimulation chemical storage area
Hydrochloric acid - 32%	50,000	150,000	L	Stimulation chemical storage area
100 mesh sand	91,000	182,000	kg	Stimulation chemical storage area
40/70 sand	1,650,000	3,300,000	kg	Stimulation chemical storage area
30/50 sand	610,000	1,220,000	kg	Stimulation chemical storage area
Sodium chloride weighting agent	15,000	30,000	kg	Completion chemical storage area
ALDACIDE G biocide	500	1,000	L	Completion chemical storage area
OXYGON oxygen scavenger	100	200	kg	Completion chemical storage area
BARACOR 100 corrosion inhibitor	2,000	4,000	L	Completion chemical storage area
CON-DET wetting agent	50	100	kg	Drilling chemical storage area
SAPP- sodium acid phosphate cement treatment	50	100	kg	Drilling chemical storage area

Material name	Typical volume	Maximum volume	Unit	Storage area
Bentonite- lubricant	3,000	6,000	kg	Drilling chemical storage area
Caustic soda-pH control	1,400	2,800	kg	Drilling chemical storage area
EZ MUD DP or EZ MUD Liquid- drilling mud	2000	4,000	kg	Drilling chemical storage area
ALDACIDE G biocide	336	672	kg	Drilling chemical storage area
STOPPIT loss of circulation material	1,000	2,000	kg	Drilling chemical storage area
Soda ash drill mud conditioner	350	700	kg	Drilling chemical storage area
BARACOR 100 corrosion inhibitor	250	500	kg	Drilling chemical storage area
Sodium chloride (Flossy Salt)- weighting agent and formation inhibitor	96,000	192,000	kg	Drilling chemical storage area
Barite- weighting agent	500	1,000	kg	Drilling chemical storage area
BARACARB loss of circulation material	500	1,000	kg	Drilling chemical storage area
Citric acid pH control	500	1,000	kg	Drilling chemical storage area
BARADEFOAM HP drilling fluid/foam	500	1,000	kg	Drilling chemical storage area
Sodium bicarbonate pH buffer	500	1,000	kg	Drilling chemical storage area
PERFORMATROL polymer fluid system	500	1,000	kg	Drilling chemical storage area
SOURSCAV mud additive treat H_2S contamination	500	1,000	kg	Drilling chemical storage area
DRIL-N-SLIDE casing lubricant	500	1,000	kg	Drilling chemical storage area
STEELSEAL corrosion inhibitor	500	1,000	kg	Drilling chemical storage area
BARAZAN D or BARAZAN D PLUS viscosity increaser	4,150	8,300	kg	Drilling chemical storage area
PAC L loss of circulation material	2,300	4,600	kg	Drilling chemical storage area
Potassium chloride weighting agent and formation inhibitor	22,500	45,000	kg	Drilling chemical storage area
GEM CP/GP shale stabiliser	500	1,000	kg	Drilling chemical storage area
QUIK-FREE drilling additive	500	1,000	kg	Drilling chemical storage area

Material name	Typical volume	Maximum volume	Unit	Storage area
BAROFIBRE, BAROFIBRE Superfine and BAROFIBRE COARSE loss of circulation material	500	1,000	kg	Drilling chemical storage area
BaraBlend-657 loss of circulation material	500	1,000	kg	Drilling chemical storage area
N-DRIL HT PLUS filtration control additive	500	1,000	kg	Drilling chemical storage area
DEXTRID LTE filtration control additive	4,600	13,800	kg	Drilling chemical storage area
BARABUF pH buffer	500	1,000	kg	Drilling chemical storage area
BORE-HIB shale stabiliser	500	1,000	kg	Drilling chemical storage area
BDF 933 or BaraLube W-933 drilling lubricant	864	1,728	kg	Drilling chemical storage area
BAROLIFT sweeping agent	500	1,000	kg	Drilling chemical storage area
OXYGON oxygen scavenger	500	1,000	kg	Drilling chemical storage area
ENVIRO-THIN filtration control additive	500	1,000	kg	Drilling chemical storage area
Lime pH buffer	500	1,000	kg	Drilling chemical storage area
BDF 677 clay stabiliser	4,770	9,540	kg	Drilling chemical storage area
BDF 988 clay stabiliser	3,390	6,780	kg	Drilling chemical storage area
SARALINE 185V- synthetic based mud	299,800	599,600	kg	Drilling chemical storage area
NOVATEC P emulsifier for SBM	13,110	26,220	kg	Drilling chemical storage area
NOVATEC S emulsifier SBM	5700	11,400	kg	Drilling chemical storage area
Calcium chloride weighting agent SBM	37,000	74,000	kg	Drilling chemical storage area
VG SUPREME clay viscosifier SBM	11,350	22,700	kg	Drilling chemical storage area
M-I BAR weighting agent SBM	193,500	169,500	kg	Drilling chemical storage area
NOVATEC F emulsifier SBM	3,610	7,220	kg	Drilling chemical storage area
NOVATEC transferred emulsifier SBM	1770	1770	kg	Drilling chemical storage area
Waste drilling fluids	2,500	2,500	m^3	Drilling mud sump

Material name	Typical volume	Maximum volume	Unit	Storage area
Completion fluids	1.4	1.4	ML	Drilling mud sump/on-site tank
Condensate	160	320	KL	Condensate storage area
Diesel	250	500	KL	Diesel storage tanks
Hydraulic oil	1,000	3,000	L	Workshop
Engine oil	1,000	3,000	L	Workshop
Degreasers	100	300	L	Workshop
Flowback	<10	13.8	ML	Flowback tanks

4.13.2 Chemical risk assessment

A chemical risk assessment was completed to evaluate the potential human health and environmental health effects of all compounds to be used during drilling and stimulation. The chemical risk assessment is provided in Appendix D.

The assessment methodology is based upon the following guidance documents:

- Northern Territory Department of Environment, Parks and Water Security (DEPWS) – Draft Guideline for the Preparation of an EMP under the NT Petroleum (Environment) Regulations, 2019 (herein referred to as NT 2019)
- Department of the Environment and Energy, Exposure Draft – Chemical Risk Assessment Guidance Manual: for chemicals associated with coal seam gas extraction, 2017 (herein referred to as DOE 2017)
- National Industrial Chemicals Notification and Assessment Scheme (NICNAS), National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia, 2017 (herein referred to as NICNAS 2017)
- enHealth "Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards" 2012
- National Environment Protection (Assessment of Site Contamination) Measure 1999 (ASC NEPM); Schedule B4, Site-specific health risk assessment methodology 2013.

The chemical risk assessment comprised the following tasks:

- Hazard assessment: An evaluation of the environmental and human health hazards of the chemical additives in the hydraulic fracturing fluid, based on their environmental persistence, bioaccumulation and aquatic toxicity properties.
- Exposure assessment: The exposure assessment comprises an evaluation of surface and sub-surface exposure pathways and reviews the effectiveness of the proposed controls in preventing a complete pathway.
- Screening and validation processes via Tier 1 and Tier 2 assessments to determine chemicals known to be of low concern and identify chemicals for further risk assessment:
    - Tier 1: Using published information about each chemical proposed to be used in the hydraulic fracturing activity.

— Tier 2: A quantitative evaluation of the risks using toxicity values and quantitative estimates of chemical intake to provide an estimate of potential human health and environmental risk associated with the hydraulic fracturing activities, based on the identification of complete exposure pathways and hazard identification.

4.13.2.1 Results of risk assessment

The results of the chemical hazard and exposure analysis are provided in Appendix D.

A Tier 1 assessment was undertaken on all chemicals except for light petroleum distillate (CAS# 64742-47-8). Certain chemicals (14 from Slick Water, 17 from Hybrid and 15 from High Velocity Friction Reduced) require standard flowback water and wastewater disposal controls to ensure the risk of management is low. These controls are consistent with the requirements outlined in the Code and summarised in section 7.5 of this plan. It must be noted that none of these chemicals were identified to be persistent and bioaccumulative.

An assessment of the potential valid environmental and human health exposure pathways is summarised in Table 17. The exposure pathways assessment considered the:

- properties of the chemicals
- site setting and physical separation distances between receptors (environmental and human) and the activity as outlined in section 4.1
- lack of protected flora and fauna and high conservation value areas in the vicinity of the activity as outlined in section 5.2
- description of the activity and summary of controls as provided in section 4 and section 7.5.

The exposure pathway assessment identified only one partially complete exposure pathway; the on-site release of particulates and vapour during chemical mixing and flowback evaporation. The limited number of valid pathways is consistent with the limited size and duration of the proposed activities.

A Tier 2 assessment was conducted on hydrotreated light petroleum distillate, which was classified as a bioaccumulative and toxic substance. As per NICNAS 2017 and DOE 2017 guidance, the Margin of Exposure (MOE) approach was used to assess the health risk to workers. For each occupational activity scenario (i.e. transport and storage, mixing/blending of hydraulic fracturing chemicals, evaporation of flowback and cleaning and maintenance), an MOE was derived by comparing the point of departure (e.g. No Observed Adverse Effects Level [NOAEL]) for long-term health effects from the critical toxicological study to the estimated total human internal dose from all routes of exposure.

Based on the calculated MOEs, the chemical is of low concern for workers (refer to individual toxicity profile for further detail).

A summary of the Tier 2 risk assessment is provided in Appendix D.

Table 18: Stimulation chemical exposure pathways

Pathway	Controls	Regulatory controls/guidelines	Effectiveness of controls	Scientific certainty	Pathway assessment
Off-lease release via spill – water	As per the Spill Management Plan (Appendix E) 1. All chemical storage and handling areas to have appropriate secondary containment. 2. Lease pad are bunded to contain any major spill of flowback chemicals (capacity of 6 ML) 3. Offset distances from sensitive receptors (groundwater extraction bores, homesteads, culturally sensitive areas and communities). 4. Routine inspections (daily inspections during the wet season and weekly during the dry season) are completed to ensure any leaks or spills from chemical and waste storage are prevented or promptly identified.	**Code** Part A – Surface Activities A.3.1 Site selection and planning A.3.2 Well pad site selection requirements 3.8 Containment of Contaminants C.7.2 Spill Management Plan **American Petroleum Institute Standards** API RP Recommended Practice 100-2 Managing Environmental Aspects Associated with Exploration and Production Operations Including Hydraulic Fracturing Section 13.2: Storage and Management of Fluids and Materials for Hydraulic Fracturing **Australian Standards (AS)** AS/NZS 4452: The storage and handling of toxic substances AS1940: The storage and handling of flammable and combustible liquids AS 3780:2008: The storage and handling of corrosive substances AS/NZS 3833:1998: The storage and handling of mixed classes of dangerous goods	High – The use of secondary containment and bunding reduces the probability of an off-lease release via a spill down to 'remote'.	High – The certainty around the use of secondary containment and bunding to prevent spills is well recognised within international spill containment standards and legislation.	Incomplete – Controls in place unlikely to result in any off-site releases.
On-lease release via spill – water	1. All chemical storage and handling areas to have appropriate secondary containment. 2. Routine inspections (daily during drilling weekly post drilling) are completed to ensure any leaks or spills are prevented, promptly identified and rectified. 3. Spill kits and clean up equipment available on-site.	**Code** Part A – Surface Activities 3.8 Containment of Contaminants C.7.2 Spill Management Plan **American Petroleum Institute Standards** API RP Recommended Practice 100-2 Managing Environmental Aspects Associated with Exploration and production Operations Including Hydraulic Fracturing Section 13.2: Storage and Management of Fluids and Materials for Hydraulic Fracturing **Australian Standards (AS)** AS/NZS 4452: The storage and handling of toxic substances AS1940: The storage and handling of flammable and combustible liquids	High – The use of secondary containment and bunding reduces the probability of releases.	High – The certainty around the use of secondary containment and bunding to prevent spills is well recognised within international spill containment standards and legislation.	Incomplete – Controls in place unlikely to result in any exposure.

Pathway	Controls	Regulatory controls/guidelines	Effectiveness of controls	Scientific certainty	Pathway assessment
		AS 3780:2008: The storage and handling of corrosive substances AS/NZS 3833:1998: The storage and handling of mixed classes of dangerous goods			
Off-lease release via particulate during mixing and flowback evaporation – air	1. All chemical mixing on-site to comply with the Workplace Health and Safety guidelines for handling of chemicals. 2. Chemical transfer and mixing procedures deployed to avoid the generation of dust. 3. Chemical mixing location away from lease boundary, with a separation distance of 50 m and within a portable containment bund. 4. Wind speed and direction sensors deployed with automatic cut-offs to prevent off-site drift from evaporation units.	**Code** Part A – Surface Activities Containment of Contaminants **American Petroleum Institute Standards** API RP Recommended Practice 100-2 Managing Environmental Aspects Associated with Exploration and production Operations Including Hydraulic Fracturing Section 13.2: Storage and Management of Fluids and Materials for Hydraulic Fracturing **Managing risks of hazardous chemicals in the workplace Code of Practices 2013** Section 4— Controlling risk **Australian Standards (AS)** AS/NZS 4452: The storage and handling of toxic substances AS1940: The storage and handling of flammable and combustible liquids AS 3780:2008: The storage and handling of corrosive substances AS/NZS 3833:1998: The storage and handling of mixed classes of dangerous goods	High – Legislation controlling the handling of chemicals is mature and standardised across Australia to limit exposure to employees and surrounding receptors.	High – The certainty around the handling of chemicals is mature and standardised across Australia to limit exposure to employees and surrounding receptors.	Incomplete – The deployment of standard chemical handling procedures to minimise dust, combined with separation distance from the lease boundary, is likely to limit off-site releases.
On-lease release via particulate – air	1. All chemical mixing on-site to comply with the NOHSC guidelines for handling of chemicals. 2. Chemical transfer and mixing procedures deployed to avoid the generation of dust. 3. Chemical mixing location away from lease boundary, with a separation distance of at least 50 m and within a portable containment bund.	**Code** Part A – Surface Activities Containment of Contaminants **American Petroleum Institute Standards** API RP Recommended Practice 100-2 Managing Environmental Aspects Associated with Exploration and production Operations Including Hydraulic Fracturing Section 13.2: Storage and Management of fluids and Materials for Hydraulic Fracturing **Managing risks of hazardous chemicals in the workplace Code of Practices 2013** Section 4 – Controlling risk	High – Legislation controlling the handling of chemicals is mature and standardised across Australia to limit exposure to employees and surrounding receptors.	High – The certainty around the handling of chemicals is mature and standardised across Australia to limit exposure to employees and surrounding receptors.	Partially complete – On-site release of particulate chemicals during handling is potentially complete with human error.

Pathway	Controls	Regulatory controls/guidelines	Effectiveness of controls	Scientific certainty	Pathway assessment
		Australian Standards (AS) AS/NZS 4452: The storage and handling of toxic substances AS1940: The storage and handling of flammable and combustible liquids AS 3780:2008: The storage and handling of corrosive substances AS/NZS 3833:1998: The storage and handling of mixed classes of dangerous goods			
Off-site release via transport accident	1. All chemicals and waste products to be transported by licenced contractors in accordance with the NT Dangerous Goods (Roads and Rail) Regulations and *NT Waste Management and Pollution Control Act 1998*. 2. Legislation, regulations and national standards set out the requirements for the safe transport of chemicals, including for packaging, driver training, safety equipment and vehicle standards. These measures reduce the risk of a spill occurring, or of not being detected and cleaned up if it does occur. 3. Origin has undertaken 100,000s of chemical transport movements without any major accidents causing environmental harm.	**Code** Part A – Surface Activities 3.8 Containment of Contaminants C.7.2 Spill Management Plan **Transport of Dangerous Goods by Road and rail (National Uniform Legislation) Regulations 2011**	High – Legislation controlling the transportation of chemicals and wastes is mature and standardised across Australia.	High – The certainty around the transportation of chemicals and wastes is mature and well understood across Australia. Origin has undertaken 100,000's of chemical transport activities without major incident.	Incomplete – The probability of exposure via a transport accident is limited via the mature legislative framework in place.
Subsurface release of chemicals to aquifer	1.Code requiring multiple strings of casing and cement designed to protect aquifer. 2.Integrity validation of casing and cement barriers prior to completing stimulation. 3. Pressure monitoring during stimulation of both the formation and the B well anulus. 4. Physical separation distance of 1,400 m between aquifer and the target formation prevents any migration of stimulation fluid to aquifer units. 5. >1 km separation distance between exploration well and closest pastoralist extraction bores.	**Code** Part B – Well Operations B.4.2 Aquifer protection B.4.3 Well design and well barriers B.4.6 Casing and tubing B.4.10 Drilling fluids B.4.13 Hydraulic stimulation and flowback operations B.4.7 Primary cementing B.4.17 Groundwater monitoring B.5 BTEX Limit	High – The legislation and guidance notes relating to aquifer protection and well integrity is mature, with extensive industry experience.	High – High certainty around the effectiveness of controls around the protection of aquifers using industry standard practice.	Incomplete – The probability of contamination of an aquifer from release of stimulation fluid during stimulation is remote and therefore incomplete.

Pathway	Controls	Regulatory controls/guidelines	Effectiveness of controls	Scientific certainty	Pathway assessment
Surface release of chemicals to aquifer	1. Secondary containment to be used to manage all chemicals and wastes handled on-site. 2. Code requires double-lined tanks with in-built leak detection. 3. Spill Management Plan and Wastewater Management Plan to be implemented. 4. Routine inspections to identify leaks (daily during drilling weekly post drilling). 5. 70 m vertical separation between surface and underlying aquifer. 6. Closest groundwater extraction bore is >1 km away.	**Code** Part A – Surface Activities 3.8 Containment of Contaminants C.7.2 Spill Management Plan **American Petroleum Institute Standards** API RP Recommended Practice 100-2 Managing Environmental Aspects Associated with Exploration and production Operations Including Hydraulic Fracturing Section 13.2: Storage and Management of Fluids and Materials for Hydraulic Fracturing	High – The controls managing the storage of chemicals and wastes are mature with secondary containment measures limiting potential pathways to receptors.	High – The certainty around the effectiveness of secondary containment in preventing groundwater contamination is mature.	Incomplete – The probability of contamination of an aquifer from release of stimulation fluid is remote and therefore incomplete.

4.14 Water supply and use

The extraction of water for all activities associated with stimulation is approved under the Water Extraction Licence (WEL) number GRF10285. This approval allows for an extraction of up to 175 ML/year from the Gum Ridge Formation to cover all its proposed exploration until December 2024.

Water sourced for the EMP activities will be extracted from the existing Gum Ridge Formation bores at each of the proposed sites. Any new bores constructed to support exploration activities will be registered and added to the WEL.

It is estimated that 107.5 ML of water per site (430 ML total for all sites) will be extracted from the Gum Ridge Formation across the Amungee Delineation Area to support the proposed E&A activities over three years. A water balance for the activity is provided in Table 19, noting that all estimates are estimates and subject to operational changes. The anticipated breakdown of groundwater take for the proposed exploration activities consists of the following breakdown per activity:

- 2.5 ML per E&A well for drilling and completions (total 30 ML)
- 25 ML per well for stimulation (total 300 ML)
- 5 ML for camp activities per site (total 20 ML)
- 20 ML civil construction, groundwater bore drilling, dust suppression, water curtain and general activities per site (total 80 ML)
- 1 ML seismic –for dust suppression and shot installation

All groundwater take is metered with continuous flow meters and reported to DEPWS as per the WEL conditions. Water take records will be kept and updated weekly during operations, to ensure the water take volumes are not exceeded.

Predicted water take by period is provided in Table 18, with peak groundwater usage estimated at 160 ML/year. This demonstrates the available water under the WEL is sufficient to cover the proposed water take. The predicted water take is based upon the drilling, stimulation and testing of 4 wells across 2 locations in a calendar year.

Groundwater will be used to supply potable water, with on-site water treatment used to provide water in accordance with the Australian Drinking Water Guidelines.

To reduce raw water take and minimise the storage and disposal of wastewater, flowback may be reused in the stimulation make up fluid where technically feasible (i.e. due to fluid compatibility). Where flowback is used for make-up fluid, flowback will be managed in accordance with section 4.15.3.

The cumulative impact associated with current and future groundwater takes were addressed in the Water Extraction Licence (WEL) GRF 10285 statement of reason. This WEL covered the anticipated future water take for civil construction, drilling, stimulation and well activities in the near term. The WEL will be periodically renewed and amended to ensure all required take is covered. The WEL statement of reason is available from DEPWS Water Resources website at http://www.ntlis.nt.gov.au/walaps-portal/report/current/gwel.

In relation to groundwater take from the Gum Ridge Formation and cumulative impacts on the resource, the Water Controller's assessment considers the following inputs and assumptions:

1. The availability of water, outside of a water allocation plan area, is assessed in accordance with the NT Water Allocation Planning Framework[7].
2. Advice from the department's hydrogeologists indicating that the area under assessment is complex, however, given the depth, episodic recharge, and predominant geographical area of the water resource, the department's hydrogeologists have advised that application of the Arid Zone principles to this water resource is appropriate.
3. The findings outlined in Tickell and Bruwer (2019)[8] - i.e. the Georgina Basin Report, which estimates that the total aquifer storage of the Gum Ridge Formation is in the range of 1,766,000 GL to 3,532,000 GL. The Arid Zone principle states that the total extraction over 100 years will not exceed 80 per cent of the total aquifer storage at the start of extraction.[9] Applying this to the more conservative storage estimate provides for 1,412,800 GL to be used over 100 years; or averaging use over 100 years, provides for 14,128 GL per year allowable for extraction.
4. The number of groundwater extraction licences authorising take from the Gum Ridge Formation, which is currently a combined maximum entitlement of approximately 1300 ML per year.
5. In addition to licenced use, estimated domestic use is approximately 300 ML per year.
6. An estimated annual volume of water required for maximum stocking capacity of approximately 8.98 GL for stock, per year.

Based on the above inputs and assumptions, Origin's current WEL of 175 ML per annum represents 0.00124% of the current allowable extraction volume (14,128 GL per year) and approximately 14 % of the 1300 ML/year in water licences accessing this formation.

As outlined above, Origin's groundwater extraction cumulative impacts were assessed under the relevant WEL GRF 10285. This includes any adjacent users of groundwater and environmental needs. Origin has committed to annual extraction from all activities withing the WEL annual limit. Therefore there are no anticipated cumulative impacts on the water resource, other users or GDEs.

[7] Northern Territory Water Allocation Planning Framework, available at: https://depws.nt.gov.au/__data/assets/pdf_file/0011/476669/nt-water-allocation-planning-framework.pdf.

[8] Georgina Basin Groundwater Assessment: Daily Water to Tenant Creek by Tickell and Bruwer: https://territorystories.nt.gov.au/100070/304921.

[9] Refer Short, MA and Bond, TW 2021. *Classification of Top End and Arid Zone for Northern Territory Water Resources,* Technical Report 55/2020. Water Resources Division, Northern Territory Department of Environment, Parks and Water Security, Northern Territory Government. Palmerston, Northern Territory

Table 19 Predicted water use by year (ML)

Site	Predicted water use per year			
	2022	2023	2024	2025
Other approved activities				
Amungee multi-well EMP Drilling and stimulation scope	43	2	0	0
This EMP				
Amungee NW 2	20	60		27.5
Amungee NW 3	0	80		27.5
Amungee NW 4	0	0	80	27.5
Amungee NW 5	0	0	80	27.5
Seismic	1	0	0	0
Total	**64**	**142**	**160**	**110**

4.15 Wastewater management

A project-wide Wastewater Management Plan (WWMP) has been developed to manage wastewater generated under this EMP. The WWMP has been developed in accordance with the Code and covers the following wastewater streams:

- drilling fluids, water-based drilling muds and drilling cuttings
- stimulation fluids
- completion and kill fluids
- produced fluids.

The WWMP covers the following information on the management of wastewater during Origin's exploration activities:

- storage, handling and disposal requirements for wastewater, including the requirement for flowback tanks
- spill management and response requirements
- prohibited reinjection or surface disposal of wastewater.

The following section provides an overview of the wastewater management strategy, with further information provided in the Wastewater Management Plan attached in Appendix F.

4.15.1 Site water balance

A water balance has been prepared summarising the anticipated volumes of water to be used and volumes of wastewater that is expected to be generated, stored and disposed of off-site. This balance includes existing wastewater generated from the existing E&A wells and all proposed activities associated with the drilling, stimulation and well testing of under this EMP. Observed average monthly rainfall and evaporation rates for the region are used to calculate the rainfall inputs and evaporation outputs from open tanks.

The water balance includes the make-up water and wastewater generated from the main processes of drilling, stimulation, well testing, dust suppression and camp activity. As per clause B.4.10.2(f) of the Code, Origin will record all source of water used for all well operations (i.e. drilling, workover and hydraulic fracture stimulation).

The water balance uses the following assumptions.

- Evaporation is calculated by using the monthly pan evaporation factor (sourced from the Daly Waters air strip BOM site) and available surface area of each of the proposed tanks. A TDS correction factor was previously applied, but this was removed as it was too unreliable and the influence of the evaporation unit performance/ site specific environmental factors appeared to influence evaporation more. The TDS factor is also influenced by the bulk crystallisation point of the brine, for which is a function of chemistry (such as the ionic balance- the composition of magnesium, calcium and other ions can affect when bulk crystallisation occurs). Not enough information is known on the Velkerri flowback to calculate this point.
- The use of enhanced evaporation units increases the rate of evaporation by 2. Manufacturer data previously reviewed indicates that, depending on the units chosen, the evaporation rates can be increased by 2 – 10 times the normal pan evaporation level. A factor of 2 was applied as a conservative measure, partly to counteract the impacts of salinity.
- Based on experience at Kyalla 117 N2 (flowback from the Kyalla shale), had achieved an 84% reduction in wastewater volume in a 13-month period (August to September and still losing 100 bbl/day (~16,000 L/day)). This reduction was achieved with an EC roughly 5 – 6 times that anticipated to be encountered from the Velkerri shales. (The wells within this EMP are focusing on the Velkerri shales. The Velkerri shales are anticipated to have an EC <50,000 µs/cm, compared to >250,000 µs/cm from the Kyalla shales.)
- The predicted evaporation % over a 12-month period for each well in the Amungee Delineation EMP is approximately 93%. Origin considers this to align with what it has witnessed at Kyalla given EC differences.
- Based on observations at Kyalla, it appears that once the salinity begins to reach the saturation point (~300,00 mg/L) bulk salt crystallisation occurs and salt begins to drop out of solution. This appears to allow evaporation to continue.
- The calculation assumes that during the dry season, maximum available tanks are converted to evaporation tanks to increase evaporation rates (while still maintaining compliance with Code requirements).
- Based on current experience, Origin considers the current estimates reasonable. Even if the evaporation rate achieved was lower, Origin could still achieve the evaporation reduction percentage through longer treatment time (i.e. leaving the wastewater to evaporate longer than the current 12 months proposed).
- A site-specific evaporation rate will be calculated during the Delineation EMP program once longer-term wastewater treatment data is obtained. Long-term evaporation rates have never been calculated for flowback from the Velkerri shale in the vicinity of Origin's tenure (noting differences in water chemistry between Origin's and adjacent tenures).

An overview of on-site water management is provided in Figure 26 and in Table 19.

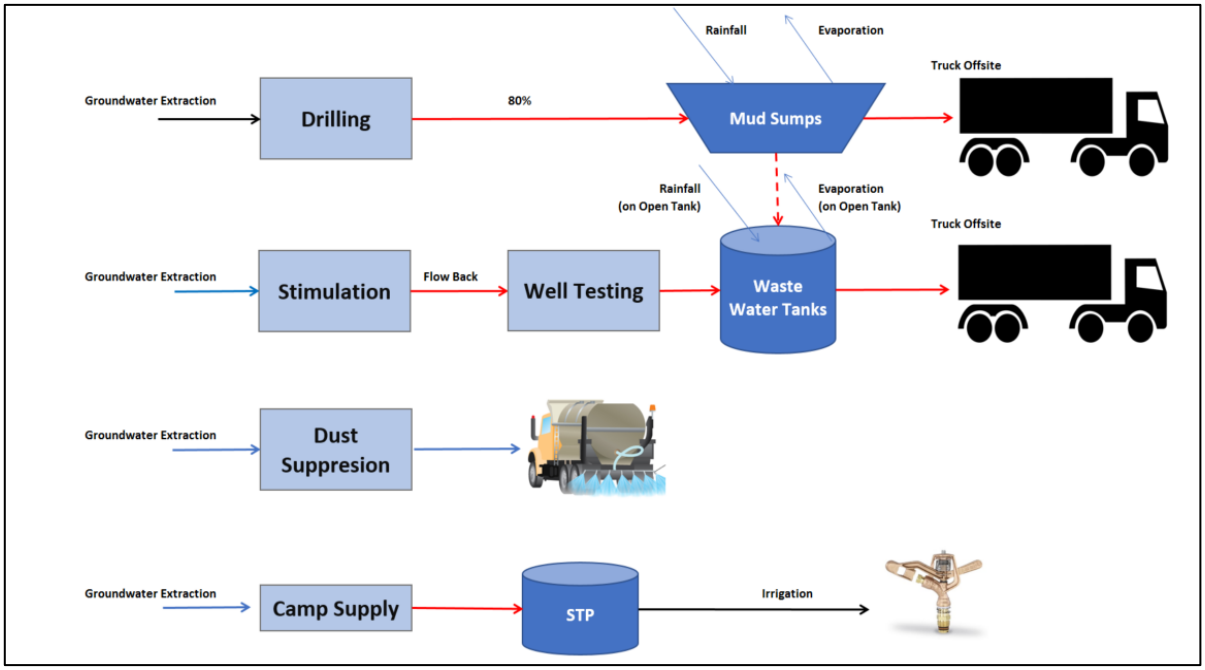


Figure 26: Site water management

Table 20: Typical Amungee NW Delineation Area site process water balance for each site

Summary		Year 1												Year 2										
	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Groundwater water used per month																									
Drilling	ML	0.00	0.00	0.00	0.00	1.25	2.50	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stimulation	ML	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Camp	ML	0.00	0.00	0.00	0.00	0.62	0.60	0.62	0.79	0.18	0.19	0.18	0.19	0.19	0.03	0.03	0.63	0.65	0.63	0.65	0.00	0.00	0.00	0.00	0.00
Dust suppression	ML	0.00	0.00	0.00	0.00	0.16	0.15	0.16	0.16	1.55	0.16	0.15	0.16	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	ML	0.00	0.00	0.00	0.00	2.03	3.25	2.03	50.94	1.73	0.34	0.33	0.34	0.34	0.03	0.03	0.63	0.65	0.63	0.65	0.00	0.00	0.00	0.00	0.00
Wastewater generated per month																									
Drilling	ML	0.00	0.00	0.00	0.00	0.38	0.75	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stimulation	ML	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.00	6.00	0.75	0.75	0.75	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wastewater stored onsite per month																									
Drilling wastewater	ML	0.00	0.00	0.00	0.00	0.38	0.75	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Flowback wastewater onsite	ML	0.20	0.20	0.20	0.20	0.20	0.20	0.20	3.51	6.59	6.34	6.31	7.12	8.48	9.23	9.44	8.83	6.44	4.17	1.87	0.00	0.00	0.00	0.00	0.00
Total wastewater onsite	ML	0.20	0.20	0.20	0.20	0.58	0.95	0.58	3.51	6.59	6.34	6.31	7.12	8.48	9.23	9.44	8.83	6.44	4.17	1.87	0.00	0.00	0.00	0.00	0.00

4.15.2 Drilling fluids, muds, cuttings and cement returns

The following section provides an overview of the management summary associated with waste drilling fluids, muds, cuttings and cement returns.

4.15.2.1 Sump design

Except for synthetic based mud drilling fluid which will be recovered after use and reused, all drilling fluids, including cuttings, muds and cement returns, will be directed to the drilling sump on each site. The drilling sump is designed to accommodate the drilling of multiple wells. Waste drilling fluids may also be transferred and stored on-site in wastewater tanks or to sumps/ tanks on other approved sites to ensure sufficient capacity is always in place to accommodate the freeboard requirements.

An overview of the drilling sump design is provided in Appendix C. The sump surface will be rolled and compacted, with a Coletanche liner (or equivalent). Coletanche is a composite liner consisting of five different layers:

1. A highly resistant anti-root film able to withstand puncturing by vegetation or rough substrates
2. Glass fleece which ensures dimensional stability
3. A non-woven geotextile reinforced structure which is highly resistant to tearing and puncturing
4. An elastomeric bitumen binder ensures that the geotextile is waterproof and resistant to ageing
5. A coating of sand ensures that workers can move on the surface in all weather conditions to carry out maintenance work. It also provides a rough surface which allows coverage of the membrane by soil.

The Coletanche liner product data sheet is provided in Appendix C. Coletanche is anticipated to be utilised based upon the following:

- easily installed and shaped to fit sump geometry
- high resistance to tearing/puncturing and to hydrostatic pressures
- low water permeability, with a 6 x10^{-14} m/s permeability
- can withstand high temperature fluctuations.

In some circumstances, a conventional HDPE liner may be utilised. Where a HDPE liner is utilised, the liner specification shall meet or exceed with the Code.

4.15.2.2 Volume and quality

It is anticipated that approximately 2,250 m^3 (750 m^3 per E&A well) of waste drilling solids (cuttings, muds (water based) and cement returns) and approximately 4.5 ML (1.5 ML of wastewater per E&A well) of drilling and completion fluids will be generated at each of the Amungee Delineation sites. This estimate is based on engineering calculations and observed drilling waste volumes recorded during the existing wells at the sites. Drilling fluids and muds are saline, with sodium and potassium-based salts used as a weighting agent and formation inhibitor. Other compounds, such as barite (barium sulfate) and polymer-based compounds are also utilised during drilling process.

Drill cuttings waste will largely reflect the quality of the rock overburden and target shale formations. Drilling fluids and solids (cuttings, muds and cements returns) may be removed periodically from the sump between wells, or as required to maintain the safe operating level of the sump. Drilling fluids and solids may be transferred to lined tank/ pit (in accordance with section C.4.1.2 of the Code), disposed of in accordance with section 4.15.2.3 of this EMP.

4.15.2.3 Drilling muds, cuttings and cement returns disposal

It is anticipated that drilling material (except for synthetic based muds, which are recovered and reused) may either be disposed of during operations (i.e. between the drilling each E&A well to accommodate storage volume requirements) or upon completion of drilling/well testing operations (with the potential for on-site storage of material in in accordance with section C.4.1.2 of the Code).

Prior to the disposal of drilling waste material, a suitably qualified third-party will test the dried material and determine whether the material is suitable to be disposed of on the lease pad (or within the approved disturbance area) using a 'mix, bury and cover' approach (as per C.4.1.2 of the Code). 'Mix, bury and cover' involves the mixing of dried drilling waste material with the soil located within the drilling sump batters to reduce the concentration of any potential contaminants to an acceptable level. The material is then track-rolled and approximately 300 mm of clean material placed over the top. An additional 150 mm of topsoil is added to the sump upon remediation of the entire lease site. DEPWS will be consulted if on-site disposal is proposed.

If the material is unsuitable for on-site disposal (such as the moisture content is too high or the material is incompatible with surrounding soils or the analysis of the material indicates it is inappropriate for on-site disposal (as per C.4.1.2 of the Code), the material may be left in-situ across the wet season to allow for the material to dry during the subsequent dry season or be transported off-site. Where a site-specific assessment determines a site to not be suitable, (such as underlying geology, soil types, inundation risk, land access approvals etc.) all solid material will be transported off-site to an alternative suitable exploration location for on-site disposal (such as Kyalla 117 N2 which has been deemed appropriate through a site-specific assessment) or a licenced facility. Off-site disposal will be undertaken in accordance with the *NT Waste Management and Pollution Control Act 1998*.

All fluids collected in the sumps will either be evaporated in the sump or transferred to wastewater tanks for storage and evaporation. The use of evaporation is the main mechanism used to reduce the volume down to as low as possible. The residual concentrated liquid waste stream will be disposed of off-site at a licenced facility in accordance with the NT *Waste Management and Pollution Control Act 1998.*

The sumps will be operated with sufficient freeboard available to accommodate the total rainfall anticipated based on a 1:1000-year Average Recurrence Interval (ARI) for the duration the sump is in operation. As per the calculations within the wastewater management plan (WWMP, Appendix F), this equates to a 1.3 m wet season freeboard and a 0.3 m of dry season freeboard. Any rainwater that has come into contact with contaminants in the sump will be collected and disposed of in accordance with the WWMP.

4.15.2.4 Monitoring

Wastewater volumes within the mud sumps will be monitored daily during operations. Once drilling has finished, sump levels will be monitored weekly during the dry season and daily during the wet season. Monitoring may be undertaken via physical inspection, remote cameras or sensor. The wastewater balance and storage curves will be updated weekly to ensure sufficient freeboard in compliance with the Code.

Drilling mud and cuttings will be sampled prior to disposal and characterised in accordance with requirements set out in section 4.29.

4.15.3 Flowback

The anticipated flowback will be composed of formation reservoir hydrocarbons only, with an absence of movable indigenous water from the reservoir. The absence of water is due to a combination of the extremely low reservoir permeabilities and clay adsorption effects.

4.15.3.1 Volume

Origin anticipates that a potential load fluid recovery of 30% of injected stimulation fluid over the testing duration based upon previous Amungee NW-1H results. Origin estimates a flowback wastewater production volume of approximately 7.5 ML per E&A well (assumes 25 ML utilised for stimulation and a 30% recovery rate)). The majority (80% of encountered volume of flowback) is anticipated to be generated in the first 60 days of the well test.

The predicted maximum volume of flowback stored at each of the sites during a specific period is 9.5 ML. This figure includes flowback from 2 wells which is treated via enhanced evaporation.

An overview of the site wastewater balance is provided in section 4.15.1.

4.15.3.2 Quality

The quality of flowback at the 4 sites is expected to be like that encountered during the Amungee NW-1H well test. A summary of the flowback monitoring results is provided in Table 20.

Geogenic chemicals requiring careful management, with salt the main contaminate of concern (predominantly sodium chloride). The flowback is likely to be elevated in some metals (primarily barium) and hydrocarbons. BTEX, phenolic compounds and polycyclic aromatic hydrocarbons (PAHs) are either not anticipated, or likely to be present at low concentrations.

Additional information on flowback quality of the Amungee NW-1H well and other petroleum wells in the Beetaloo are available here: https://depws.nt.gov.au/onshore-gas/onshore-gas-in-the-northern-territory/industry-compliance-and-reporting/flowback-fluid-monitoring-results.

For discussion regarding flowback recycling and disposal, see section 4.15.3.6.

Table 21: Flowback quality based on Amungee NW-1H flowback results

Parameter	Flow back levels
BTEX compounds	Total BTEX levels are anticipated to be low. Total BTEX in the Amungee NW-1 in flowback ranged between 2 and 15 µg/L
Total nitrogen (as N)	Maximum value of 62.1mg/l observed within flowback
Salinity (TDS)	Saline with total dissolved solids level exceeding 49,000 mg/L
pH	Slightly acidic with a median value of 6.74
Major ions	Flowback predominantly Na and Cl dominated
Dissolved metals	All detected dissolved metal concentrations within the flowback were low, except for barium 54.5 mg/L) and boron (80.1 mg/L)
Polycyclic Aromatic Hydrocarbons	All values in the flowback below laboratory Limit of Reporting (LOR),
Petroleum Hydrocarbons	All fractions of TPH are anticipated to be elevated
Phenolic Compounds	Low level of phenolic compounds detected in flowback
Radionuclides	Maximum Gross Alpha Activity and Gross Beta Activity of 12.4 Bq/L and 18.3 Bq/L encountered in the flowback, the anticipated source is likely to be radium-226

4.15.3.3 Flowback storage

On-site wastewater management will be an adaptive process, with enclosed tank and treatment capacity adjusted (added or removed) to meet operational requirements (including meeting mandatory Code requirements). Tanks will be periodically converted to enclosed tanks (have lids installed) and vice versa, as flowback volume increase/decrease. This ensures maximum evaporation potential, whilst ensuring sufficient enclosed tank storage is available at any point in time.

The anticipated tank setup varies depending on season, with the operational strategy summarised in section 4.15.3.4 Total available open and enclosed wet season flowback storage on each site (excluding freeboard) is anticipated to be 13.2 ML, 128% of the predicted flowback generated per site. During the dry season, flowback will be treated in open treatment tanks to reduce the wastewater volume as much as possible.

Enclosed tanks will be constructed on-site with enough capacity to store the 1:1000 ARI dry season freeboard for all open flowback wastewater tanks operating on-site (effectively doubling onsite freeboard). The total available dry season open, and enclosed wastewater tank storage volume per site (accounting for freeboard) is 21.2 ML, double the anticipated 9.5 ML of flowback anticipated to be generated per site.

To manage flowback volume across the basin, longer term (1 – 5 years) centralised storage at one site may be undertaken. This reduces the risk of having multiple sites storing flowback and reduces the need for larger lease pads.

Trucking of wastewater may be undertaken periodically to manage wastewater volumes at a given site. This includes trucking to off-site approved disposal locations and to other approved exploration sites within the Basin (such as between the sites listed in this EMP, Velkerri 76 S2 and Amungee NW and Kyalla 117 N2).

An image of an enclosed tank installed on the Kyalla 117 N2 site is provided as Figure 27.

For additional information regarding wastewater management during the wet season and dry season, refer to section 4.15.3.4.

Table 22: Wet season tank wastewater tank set-up, operating capacity and freeboard levels

Tank type	Tank dimensions (m^2)	Tank maximum operating capacity (ML)	Tank wet season freeboard volume[10] (ML)	Total storage availability (ML) (minus freeboard)
2 x 5.3 ML enclosed tanks (depending on total volume of fluid)	3058	5.3	N/A	10.6
2 x 5.3 ML open treatment tanks	3058	1.3	4	2.6
Total tank storage capacity (minus freeboard)				**13.2 ML**

[10] Freeboard not required for enclosed tanks as these tanks have a cover installed.

Table 23: Dry season wastewater tank set-up, operating capacity and freeboard levels

Tank type	Tank dimensions (m^2)	Tank maximum operating capacity (ML)	Tank dry season freeboard volume (ML)	Total storage availability (ML) (minus freeboard)
Amungee NW				
1x 5.3 ML enclosed tanks (depending on total volume of fluid)	3058	5.3	N/A	5.3
3x 5.3 ML open treatment tanks	3058	4.3	1	15.9
Total tank storage capacity (minus freeboard)				**21.2 (ML)**

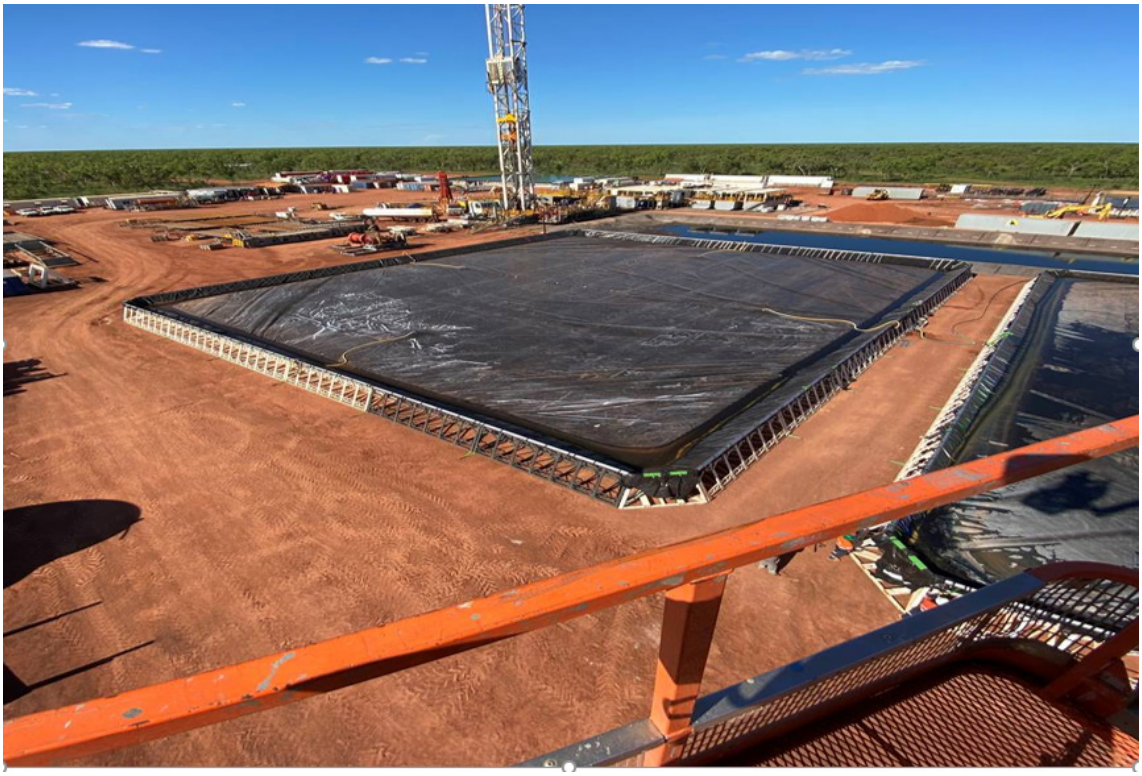


Figure 27 Example of covered water storage tank

4.15.3.4 Wastewater operating strategy

The operating plan for the working evaporation tanks is provided in the WWMP (Appendix F). The wastewater treatment tanks will be operated in accordance with the following philosophy:

- During the dry season, all flowback wastewater will be treated in open tanks to maximise. Sufficient enclosed flowback wastewater storage will be available to manage the sum of all open tank freeboard volume on-site.

- Flowback will be recycled within stimulation make-up water where possible to reduce stored volumes.
- During the wet season, enough covered flowback wastewater storage capacity will be on-site at all times to manage all stored flowback wastewater volumes
- Open tanks will be periodically converted to enclosed tanks as the volume of flowback water on-site increases (i.e. prior to commencement of wet season)
- Flowback wastewater levels and the interstitial space between each of the tank liners are monitored continuously with electric probes to prevent overtopping and leaks
- Where sufficient enclosed tank capacity is unavailable, the well will be shut in to ensure compliance with the Code wastewater management guidelines and prevent overtopping of the tanks. Wastewater levels must be reduced to below the enclosed tank capacity before recommencing operations
- Mechanical enhanced evaporators will be utilised within the evaporation tanks to maximise evaporation rates
- All flowback wastewater stored within open working evaporation tanks will be transferred to enclosed storage at least 8 hours before the onset of a significant rainfall event (defined as a 300 mm rainfall event predicted over four days as per the WWMP)
- All open tanks will be operated with enough freeboard to manage the entire rainfall from of an entire 1:1000 ARI wet or dry season (i.e. the entire seasons rainfall and not just one single event), as specified in the WWMP, this equates to a minimum 1.3 m of freeboard for the wet season and 300 mm for the dry season
- Wastewater may be transferred between approved sites within the basin, which includes wastewater taken to/from the Amungee Delineation Area sites for storage.

Mechanical enhanced evaporators will be utilised in each wastewater treatment tank to enhance natural evaporation. It is anticipated that up to three to five evaporator units will be deployed on each tank, with a combined water treatment rate of up to 1000 L/minute. Based upon the results from the existing Kyalla 117 N2-1 well, evaporation rates above 100 barrels (16000 L) per day have been observed, which aligns with the estimated evaporation rates used in the wastewater balance (Table 18).

The evaporator units have an estimated diesel consumption of 21 L/hour will be required while the units are in operation. To mitigate the drift of wastewater outside of the tank, the units will have an automated wind speed and direction cut-off mechanism to stop operations during periods of moderate wind (11-16 knots as defined by the BOM (refer to http://www.bom.gov.au/marine/knowledge-centre/reference/wind.shtml)). The exact wind speed cut-off will be determined during the installation of the units and tested with fresh water. This proposed approach was used successfully during the flowback operations at the Amungee NW-1H well and Kyalla N2-1H well.

Other technology, such as brine crystallisers and thermal combustion treatment systems may be installed to further reduce wastewater on-site. Such systems will be used to generate solid/ semi solid brines to minimise off-site transportation. These systems will be located on the lease pad, be fully bunded and use either diesel or gas fired (from the on-site wells) power generation. All water treatment systems will either be zero liquid discharge or produce a freshwater compliant with Table 23 that will be irrigated into the surrounding area.

Where a significant rainfall event is predicted, the total volume of flowback stored on-site will be transferred to the covered storage tanks 8 hours prior to the onset of the event. The Bureau of Meteorology's 4-day total rain forecast (http://www.bom.gov.au/jsp/watl/rainfall/pme.jsp) will be

reviewed daily to identify periods of significant rainfall. This forecast provides an 8-day look ahead, which will be able to identify periods of significant rainfall several days before its onset.

Origin will have up to 6 x 6-inch transfer pumps on-site, capable of transferring up to 23 ML/day each. The on-site pumping capacity is significantly more than the total worst-case volume of wastewater that will be stored on-site. Commencement time to begin transferring the flowback fluid will be selected to ensure that it is completed at least eight 8-hours prior to the predicted commencement of the significant rainfall event.

In the event of a catastrophic failure of a tank, all wastewater will be contained within the bunded site. For example, the earthen bund around the Amungee NW site has the capacity to manage approximately 6 ML of wastewater or sufficient to accommodate 110% of the volume of the largest tank on-site if the tank were to fail. Where a tank fails, water will be pumped from the bund into the available waste storage tanks on-site. In such a case, the exploration well would be shut in and the regulator notified as per the SMP. A site assessment and rehabilitation strategy would be developed in alignment with Schedule A of the National Environmental Protection (Assessment of Site Contamination) Measure.

4.15.3.5 Wastewater monitoring

The following wastewater monitoring strategies will be implemented during extended production testing and wastewater storage:

- Each wastewater tank will be equipped with level sensors to monitor the fluid volumes in real time
- Alarms are set below the freeboard level (referred to as the maximum operating water level) to trigger a management response if exceeded
- Automated cut-off sensors will also be deployed to ensure wastewater tank levels do not exceed the safe operating level and 1:1000 ARI freeboard requirements (for open tanks) during operations
- Weekly tracking and storage forecasting will be undertaken to ensure freeboard requirements are not exceeded
- Weekly wastewater tank integrity inspections to identify any liner or tank defects
- Monitoring of flowback quality will be undertaken in accordance with Section 4.29

4.15.3.6 Flowback recycling and disposal

Flowback is anticipated to be disposed of via 2 main methods:

- Evaporation followed by offsite disposal (default disposal method).
- Recycling- where flowback is used as stimulation makeup water.

Enhanced Evaporation and offsite disposal

Enhanced evaporation using mechanical evaporators is the primary wastewater treatment option anticipated to be deployed. It is anticipated that enhanced evaporation will reduce the residual flowback volumes at each site from a peak of approximately 9.5 ML to approximately 0.5 ML within 12 months of well testing commencement. At this point, approximately 20 B-Triples will transport the residual flow back to an approved disposal location. It is anticipated that associated residual solids, brines, sludges and liners will be sent interstate to the Westrex waste facility in Jackson, Queensland as the default location. Options for alternative authorised facilities are under review and if they become available during the disposal of flowback materials they may be used. All interstate transfers of controlled wastes will require an interstate/Territory consignment authority to authorise the movement of waste between administrative boundaries.

Recycling:

Flowback will be preferentially used as stimulation make-up water where practicable. Flowback is saline and will require mixing with raw groundwater in the blenders to reduce the EC of the fluid prior to use. Flowback, raw groundwater and stimulation chemicals will be mixed in the onsite mixers, prior to being injected downhole. This is anticipated to make up approximately 30% of the stimulation fluid volume, which could significantly reduce flowback storage and disposal requirements.

A chemical risk assessment of the use of recycled flowback has been included in Appendix D.2. The assessment was made against observed contaminant levels recorded during the 2016 and 2021 well testing activities. The calculated hazard quotient from potential exposure from recycled flowback in isolation was 0.25, well below the threshold target of 1. When added to the calculated hazard quotient of the proposed slick water and high-volume friction reduction fluid systems (0.26 and 0.28 respectively), the theoretical exposure hazard quotient remains below the low-risk threshold of 1. Therefore, the risks of using recycled flowback water during stimulation is considered of low concern.

From a NORMs perspective, for flowback to breach the NT Radiation Protection Act trigger limit of 1 mSv/year, a person would have to consume greater than 80 litres of flowback fluid. This consumption volume is based on maximum Gross Alpha Activity and Gross Beta Activity of 12.4 Bq/L and 18.3 Bq/L, respectively (see Table 21). Even where the NORMs level in flowback were increased as a result of wastewater recycling/re-use, it is anticipated that a significant volume (10's of litres) of water would need to be consumed in order to trigger the investigation threshold.

It is anticipated that the use of recycled water will potentially increase the final salinity of the flowback, specifically sodium chloride (NaCl) levels. The increase in salinity is expected to reduce the total volume of salt generated by Origin's activities, as higher stimulation fluid salinities will partially reduce the volume of salts exchanging (dissolving) from the target shale into the stimulation fluid (i.e. NaCl is a common formation inhibitor). Other contaminants in the flowback may increase in concentration; however these increases are also likely to be subject to the salinity of the water / saturation level of the chemical within the flowback. All changes in water quality will be monitored, assessed and reported in accordance clause C.5.4. of Code. Given the existing controls around the management of flowback (e.g. the continued use of enclosed tanks, implementation of the wastewater management framework, flowback water quality sampling, etc), regardless of quality, changes in salinity and contaminants of concern will remain ALARP and acceptable.

There is not anticipated to be any additional environmental risk or impacts as the existing well integrity, spill management and wastewater management requirements ensure the protection of the environment regardless of wastewater/ stimulation fluid quality. This includes:

- The well is engineered (including casing and surface facilities) to manage saline fluids
- No potential interaction with the environment as:
    - The management of flowback does not change based on salinity or contaminant level- the default is no environmental release or exposure
    - The stimulation and flowback setup is a fully closed system from flowback tank to blenders, to downhole then back to the flowback tank
    - Multiple casing and cement strings protect aquifers
    - Integrity monitoring completed as per 4.11.4
    - Multiple years of wastewater tank monitoring has not detected any material level of fauna interaction with flowback wastewater, confirming there is limited exposure pathway present.
- All existing spill management requirements treat stimulation fluid identically to flowback fluid – i.e. spills of stimulation fluid are managed identically to flowback

- No change to wastewater management requirements

All returned flowback will be further evaporated and then disposed of offsite at a licenced wastewater disposal facility as described above.

4.15.4 Fauna and bird access

Previous operations at the Amungee NW and Kyalla 117 N2 site have not identified any significant interaction of fauna with open wastewater storages. This is supported by various pieces of literature which highlight the role of the salinity in deterring birds and fauna from consuming/interacting with wastewater (Bartholomew and Cade 1963; Ohmart and Smith, 1970; ANZECC, 1992; Griffiths et al, 2009).

The Amungee NW-1H flowback wastewater is hypersaline, with total dissolved solids (TDS) >50,000 mg/L, and is indicative of the flowback water anticipated under this EMP. It is well documented that birds, insects and mammals are unable to drink hypersaline water >46,000 mg/L TDS (Bartholomew and Cade 1963; Ohmart and Smith, 1970; ANZECC, 1992; Griffiths et al, 2009). The TDS of the wastewater is likely to reduce the palatability of the wastewater, thus reducing the potential exposure of fauna, including birds to wastewater. This has been documented within the gold industry, where studies have identified links between the hyper salinity of wastewater to reduced bird mortality associated with cyanide ecotoxicity (Adams *et al.* 2013, Adams *et al.* 2008, Griffiths *et al.* 2009a and Griffiths *et al.* 2009b*).*

Monitoring of flowback storages and surrounding areas for fauna mortality will be implemented as per section 4.29.

4.15.5 Stormwater

Each of the Amungee Delineation Area sites will be operated in a manger that minimises the contamination of stormwater and overland flow. Stormwater is typically characterised by low electrical conductivity (<100 µs/cm) and will contain sediment sourced from the cleared lease pad surface. The following describes how stormwater is managed on the site:

- the lease pad has been designed to divert stormwater around the lease pad to prevent contamination
- the wastewater storage areas will be bunded from the rest of the well site and designed to divert stormwater to prevent contamination
- a stormwater retention basin within the wastewater storage areas will allow collected stormwater to be tested prior to release/re-use/ disposal in accordance with section 4.29
- clean stormwater that meets the quality outlined in Table 23 will be discharged off-site in controlled manner or re-used for dust suppression
- where the water is visibly turbid, a sediment sock will be used to remove sediment from the release.
- all stormwater above the specified limit will be treated as wastewater and managed accordance with section 4.15.3.6
- once all work on the site has ceased and all contaminant sources have been removed from the lease pad, the site will be left in a stable, non-polluting state with appropriate erosion and sediment controls in place.
- Erosion and sediment control plan (Appendix G) implemented.

Table 24: Stormwater release and re-use limits

Monitoring parameter	Release limit	Limit basis
Off-site release and dust suppression		
Electrical conductivity	1300 µs/cm	Irrigation Salinity values used due to the absence of adjacent watercourses, with the protection of soils the most relevant environmental Value (EV). The Guideline was based on the irrigation water salinity ratings for moderately sensitive crops. sources from Table 9.2.5 of the ANZEC Guidelines (2000) Volume 3, Chapter 9, Primary industries, Sodium adsorption ratio (SAR) of stormwater is anticipated to be low, well below <20. Receiving soils are sandy loam (as described in section 5.1.4), with SAR in irrigation water >20 permissible which will not increase the sodicity of soils (Table 9.2.6 ANZEC Guidelines (2000) Volume 3, Chapter 9, Primary industries.
pH	6.5 – 9.5	Limit based upon the background surface water quality data[11] and Table 8.2.8 of the ANZECC Guidelines 2000 volume 2 Aquatic ecosystems-rationale and background information.

4.16 Routine site maintenance

Civil maintenance will be performed periodically to ensure the site remains functional, safe and non-polluting. Activities to be completed periodically include:

- Vegetation management on the lease pad, camp pad and access tracks
- Firebreak maintenance
- Access track resurfacing and maintenance
- Lease and camp pad resurfacing
- Water extraction bore maintenance
- Erosion and sediment control maintenance and repair
- Weed management

4.17 Ongoing monitoring and well integrity management

The ongoing monitoring and well integrity management of the proposed E&A wells is illustrated in Figure 28. Origin's Operations team manage the ongoing integrity of the well through the Well Integrity Management Plan (WIMP). The WIMP defines monitoring, maintenance and integrity

[11] HLA 2005 report summarising the Beetaloo Basin Surface water quality monitoring completed for Sweetpea Petroleum

testing requirements and frequencies and well integrity assurance activities, this ultimately forms a part of the Well Operation Management Plan (WOMP). The WIMP and WOMP are both designed to satisfy the Code to ensure the integrity of a well throughout its life.

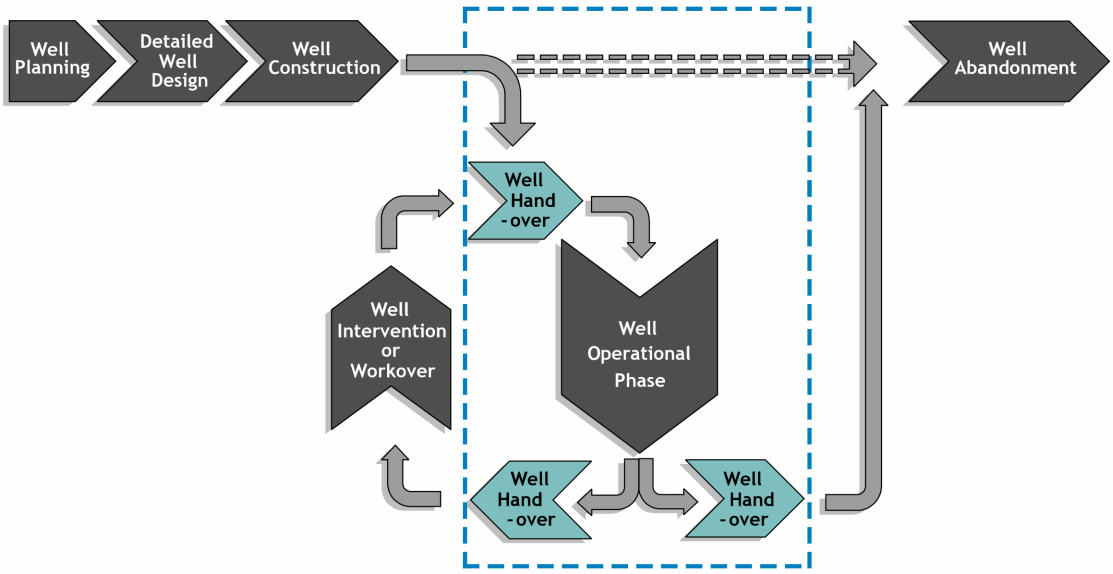


Figure 28: Well lifecycle with operational phase highlighted where well integrity monitoring is a key activity

Information from all Origin wells is gathered and stored in a database and made available to key technical staff via a software tool – 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 data and maintenance. WIMS is used in the identification and assurance of the integrity of each well and outlines the well integrity status for each well.

Well barriers are tested and pressures monitored regularly to ensure their performance over the lifecycle of the well. Remediation of well integrity anomalies could include well integrity barrier replacements, i.e. valves, tubing, and/or barrier remediation, such as casing patches and cement squeezes to ensure pressure isolation. If remediation does not prove to be a feasible option, plugging and decommissioning operations will be considered to ensure well integrity.

Additional routine maintenance and diagnostic testing under this EMP includes:

a. Wellhead Maintenance – Truck and 4WD with about 3 people to do 1-2 days of work on pressure testing, and maintaining the wellhead

b. Completion Rig – a small rig with 6-7 trucks to pull tubing and potential recompleted the well if required

c. Wireline/Slickline – 1 truck to either set a plug downhole or run additional logs

4.18 Well build up testing, suspension and decommissioning

Once all drilling, stimulation and testing has been completed, each E&A well will either be put on build up test, suspended or plugged and decommissioned. The fundamental difference between the three options is as follows:

- **Build up test:** each well or a subset of wells may be shut in at the surface with pressure monitoring undertaken. This may be undertaken for a period of 12 months (or longer) and is used to understand the performance of the reservoir.
- **Well suspension:** the well is suspended with (at a minimum) cemented casing and a wellhead so that it can be re-entered later for further down-hole activities. While the well is suspended, pressures on the well will be continuously monitored as per Origin's Well Integrity Management System (WIMS) to confirm well integrity is intact.
- **Well abandonment:** where a well is to be decommissioned, cement plugs will be installed as permanent barriers to flow prior to cutting off the wellhead. The cement plugs will be set and tested as per Origin Standards and Section B.4.15.2 of the Code. In some circumstances, such as a loss of the bottom hole assembly or hole stability issues, the entire well or a specific section of a well may need to be plugged and abandoned with a new well drilled or the well side-tracked around the affected area. Such an activity is undertaken to ensure the operational integrity of the well and ongoing

4.19 Geohazards and seismicity

Major faults are avoided as they can represent hazards to both drilling and stimulation operations. Risks associated with geohazards are assessed and managed via the following steps:

- **Locating E&A wells:** Origin has more than 9,500 km of 2D data available which is used to screen for large scale, regional faults or structures prior to the finalisation of any exploration well location. The data for Origin's broader Beetaloo exploration area indicates there are very few major faults present and that the strata within the Basin (i.e. away from the steep flanks) are relatively gently dipping.
- **Geohazard assessment post drilling:** Prior to completing stimulation, geological data is analysed to determine the presence of minor and major faults which may pose a hazard to stimulation activities. Where faulting is encountered during the drilling of the horizontal section of the well, a risk assessment is undertaken to determine whether stimulation activities can occur safely. In some instances, location of stimulation stages along the wellbore may need to be moved/removed, to isolate the feature encountered (such as encountered during the original Amungee NW-1H well where a casing deformation occurred).
- **Real-time monitoring of pressure during stimulation:** Pressure data provides a tool to prevent fault activation and fluid/pressure communication out of the target interval. If anomalous pressure behaviour is observed, stimulation operations can be ceased immediately. This prevents any substantial volume of fluid or proppant from being pumped into an open geological structure.

Preliminary drilling results from the existing E&A wells has confirmed the absence of major structural features or faults. A casing deformation event within the Amungee NW-1H horizontal (i.e. within the Velkerri shale) was recorded during stimulation, however this was not considered a major hazard. This event resulted in poor production outcome (i.e. the production casing within the horizontal well installed within the Velkerri shale became damaged) and not an environment risk (i.e. no risk of

interconnectivity with surface aquifers). The risk of induced seismicity is consistent with the current assessment level of low.

Monitoring of seismic events will be undertaken using the Geoscience Australia's Beetaloo seismic array and purpose installed seismic monitoring arrays located adjacent to selected well pads within the Amungee Delineation Area (refer Figure 29). It is likely that any material seismic events will be detected via these arrays if they occur.

An additional traffic light system is currently being developed by the NT in response to the NT Inquiry recommendation. This system is likely to be in place, prior to any full-scale development occurring.

A well plan summary is provided to DITT outlining any known geohazards, structural features or faults prior to stimulation.

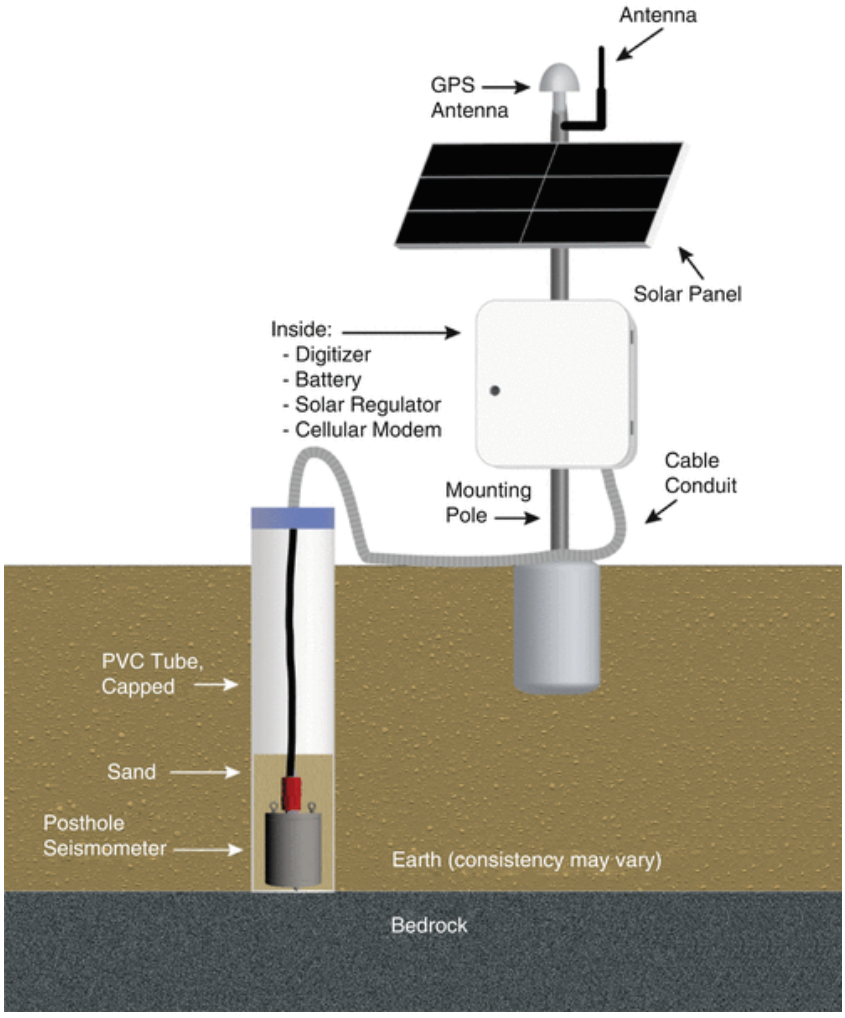


Figure 29: Seismic monitoring array to be set-up adjacent to selected exploration sites to monitor seismic activity

4.20 Greenhouse gas emissions

The anticipated well test emissions associated with the proposed activities will cover the emissions from construction, drilling, stimulation and well testing of 12 E&A wells over a 4-year period.

Emission estimates are conservatively high, assuming that each well is successful (flows hydrocarbons) and observed rates are of commercial quantities. The emissions rates are estimated to be a total predicted maximum of 522,172 tCO_2-e over the 2023 to 2026 period, peaking at 172,815 tCO_2-e in FY 2024. A breakdown of the emission estimates is provided in Table 24 and Table 25.

Over 90% of the anticipated emissions are associated with flaring. Flaring of produced hydrocarbons is required under exploration tenure to evaluate the commercial viability of a resource. Currently, NT legislation does not allow for the beneficial use of gas during exploration (such as 3rd party sale) – i.e. like the approach authorised in other jurisdictions in Australia (such as Queensland and Western Australia), which allow the short-term sale of appraisal hydrocarbons to reduce resource flaring.

Greenhouse gas emissions generation will be mitigated through adoption of the Code and implementation of a Methane Emission Management Plan (MEMP) (Appendix H). Mandatory requirements include:

- Restrictions on venting (D.5.9)
- Use of a Reduced Emissions Completion (REC) (D.5.9)
- Condensate to be beneficially sold where permissible (D.5.1.2)
- Six monthly routine leak detection and repair program to detect, repair and report leaks to be implemented (D.5.3)
- Pressure and gas testing all in service equipment to ensure any leaks are identified and fixed prior to commissioning (D.5.9)
- Flanges, valves and fittings are all API compliant and gas tight (D.5.9)
- Equipment is appropriately sized and regularly maintained to minimise diesel wastage. (D.5.9)

RECs involve the capture and combustion of hydrocarbons in a flare; a standard practice that has been utilised by Origin for all exploration activities. The combustion of gases produced will reduce the emissions generated by flaring by 94% when compared to venting.

In addition to monitoring emissions from drilling, stimulation and well testing activities, baseline assessments have been completed by CSIRO in the vicinity of the lease pad as per the Code.

Table 25 Anticiapted greenhouse gas emissions breakdown per financial year

Emission scenario	FY23	FY 24	FY 25	FY26	Total	Comments
135-day average well test	48,598	172,815	171,517	129,240	**522,172**	12 E&A wells with an average well test duration of 135 days

Table 26: Greenhouse gas calculation for the proposed activities

Activity	Anticipated volume	135-day average well test	Estimate methodology and assumptions
Diesel combustion – transport to cover seismic program	25 KL	68 t	Diesel estimates multiplied by NGERS emission factor from NGER Determination: Division 2.4.2 Method 1 emissions of carbon dioxide, methane and nitrous oxide from liquid fuels other than petroleum-based oils or greases, section 2.41 Method 1—emissions of carbon dioxide, methane and nitrous oxide and Part 3—Fuel combustion—liquid fuels and certain petroleum-based products for stationary energy purposes item 40: Energy Content Factor (GJ/kg) 38.6 CO_2 Factor 69.9 kgCO_2-e/ GJ of diesel CH_4 Factor 0.1 kgO_2-e/ GJ of diesel N_2O Factor 0.2 kgCO_2-e/ GJ of diesel
Diesel combustion – transport to cover drilling/stimulation mobilisation and transport activities (including offsite wastewater transport)	944 KL	2,565 t	Diesel estimates multiplied by NGERS emission factor from NGER Determination: Division 2.4.2 Method 1 emissions of carbon dioxide, methane and nitrous oxide from liquid fuels other than petroleum-based oils or greases, section 2.41 Method 1—emissions of carbon dioxide, methane and nitrous oxide and Part 3—Fuel combustion—liquid fuels and certain petroleum-based products for stationary energy purposes item 40: Energy Content Factor (GJ/kill) 38.6 CO_2 Factor 69.9 kgCO_2-e/ GJ of diesel CH_4 Factor 0.1 kgO_2-e/ GJ of diesel N_2O Factor 0.2 kgCO_2-e/ GJ of diesel

Activity	Anticipated volume	135-day average well test	Estimate methodology and assumptions
Diesel combustion - drilling	5,760 KL	15,608 t	Diesel estimates multiplied by NGERS emission factor from NGER Determination: Division 2.4.2 Method 1 emissions of carbon dioxide, methane and nitrous oxide from liquid fuels other than petroleum-based oils or greases, section 2.41 Method 1—emissions of carbon dioxide, methane and nitrous oxide and Part 3—Fuel combustion—liquid fuels and certain petroleum-based products for stationary energy purposes item 40: Energy Content Factor (GJ/kill) 38.6 CO_2 Factor 69.9 kgCO_2-e/ GJ of diesel CH_4 Factor 0.1 kgO_2-e/ GJ of diesel N_2O Factor 0.2 kgCO_2-e/ GJ of diesel
Diesel combustion- Drilling and stimulation camp	642 KL	1,741 t	Diesel consumption estimates multiplied by NGERS emission factor from NGER Determination: Division 2.4.2 Method 1 emissions of carbon dioxide, methane and nitrous oxide from liquid fuels other than petroleum-based oils or greases, section 2.41 Method 1—emissions of carbon dioxide, methane and nitrous oxide and Part 3—Fuel combustion—liquid fuels and certain petroleum-based products for stationary energy purposes item 40: Energy Content Factor (GJ/kill) 38.6 CO_2 Factor 69.9 kgCO_2-e/ GJ of diesel CH_4 Factor 0.1 kgO_2-e/ GJ of diesel N_2O Factor 0.2 kgCO_2-e/ GJ of diesel

Activity	Anticipated volume	135-day average well test	Estimate methodology and assumptions
Fugitive methane emissions – drill cuttings	10.872 t	304 t	Estimate by engineer based on gas saturation and core volume multiplied by NGERS Global Warming Potential (GWP) of 28 tCO_2-e/tCH_4.
Fugitive emissions – completion (venting)	570 t methane	15,954 t	2 completion days anticipated per well. Table 5-23 Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry; American Petroleum Institute (API), 2009 NGERS completion factor of 25.9 tonnes of methane per day multiple by NGERS Global Warming Potential (GWP) of 28 tCO_2-e/tCH_4
Fugitive emission- wastewater storage	5 t methane	143 t	7.5 ML/ well wastewater (assumes 25 ML stim volume with a recovery of 30%). Emissions multiplied by Table 5-10 produced saltwater tank methane flashing emission factors - Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry; American Petroleum Institute (API), 2009 emission factor of 0.11 tCH_4/ML (assuming 2% salinity, 250 psi separator pressure) multiplied by NGERS Global Warming Potential (GWP) of 28 tCO_2-e/tCH_4.
Well testing- flared natural gas emissions (4.5 TJ/days/well)	7290 TJ of natural gas total	473,870 t	Flared estimate using forecasted P50 success case of 4.5 TJ/day per well. Estimated production rates multiplied by NGER Determination: Subdivision 3.3.2.2—Oil or gas exploration and development (emissions that are flared) section 3.44 Method 1—oil or gas exploration and development item 1: CO_2 Factor 2.8 tCO_2-e/ t unprocessed gas CH_4 Factor 0.933 tCO_2-e/ t unprocessed gas

Activity	Anticipated volume	135-day average well test	Estimate methodology and assumptions
			N_2O Factor 0.026 tCO_2-e/ t unprocessed gas
Well stimulation – stationary sources (diesel combustion)	550 KL	1,490 t	Diesel consumption estimated from historical data and multiplied by NGERS emission factor from NGER Determination: Division 2.4.2 Method 1 emissions of carbon dioxide, methane and nitrous oxide from liquid fuels other than petroleum-based oils or greases, section 2.41 Method 1— emissions of carbon dioxide, methane and nitrous oxide and Part 3—Fuel combustion—liquid fuels and certain petroleum-based products for stationary energy purposes item 40: Energy Content Factor (GJ/kg) 38.6 CO_2 Factor 69.9 $kgCO_2$-e/ GJ of diesel CH_4 Factor 0.1 kgO_2-e/ GJ of diesel N_2O Factor 0.2 $kgCO_2$-e/ GJ of diesel
Well testing- utilised for wastewater management, treatment and internal field transportation (diesel combustion)	810 KL (0.5 KL per day)	2,195 t	Diesel consumption estimated from historical data and multiplied by NGERS emission factor from NGER Determination: Division 2.4.2 Method 1 emissions of carbon dioxide, methane and nitrous oxide from liquid fuels other than petroleum-based oils or greases, section 2.41 Method 1— emissions of carbon dioxide, methane and nitrous oxide and Part 3—Fuel combustion—liquid fuels and certain petroleum-based products for stationary energy purposes item 40: Energy Content Factor (GJ/kill) 38.6 CO_2 Factor 69.9 $kgCO_2$-e/ GJ of diesel

Activity	Anticipated volume	135-day average well test	Estimate methodology and assumptions
			CH_4 Factor 0.1 kgO_2-e/ GJ of diesel N_2O Factor 0.2 $kgCO_2$-e/ GJ of diesel
Land clearing for site preparation and seismic surveys	106.86 ha land clearing (77 tCO_2e/ ha)	8,233 t	TAGG 2013 Appendix I vegetation clearing methodology, Table 6, assumed maximum potential biomass class = 1.
Total over 4 years		**522,172 t**	

^ Based on Global Warming Potential (GWP) of 28 tCO_2-e/tCH_4 (Clean Energy Regulator 2020)

* https://www.api.org/~/media/files/ehs/climate-change/2009_ghg_=11201compendium.ashx

4.20.1 GHG cumulative emissions

The total predicted maximum (135-day average well test at 12 sites) cumulative annual emissions for Origin's current approved, proposed and potential activities are anticipated to be 172,953 tCO_2-e, peaking in 2024 (Table 26). The potential emissions of Origin's activities represent 1% of the total NT GHG emissions for 2020 or 0.029% of Australia's total emission.

Although a full-scale shale development is beyond the scope of this EMP, if a shale development were to occur in the future (post E&A phase), the emissions intensity per well is likely to be significantly lower than during exploration. All development wells will be flowed inline, negating the need to undertake flaring activities at the wellhead. The selection of infrastructure, equipment and operational practices will be specifically focused on eliminating emissions.

Based upon the life cycle assessment analysis of a similar (but different) unconventional gas development in Australia completed by the Gas Industry Social and Environmental Research Alliance (GISERA) (Heinz 2019), the current net climate benefits of using natural gas in replacing coal for electricity generation is up to 50% less emissions (Heinz 2019).

It is anticipated that a future shale gas development will be net zero scope 1 and 2 emissions, through the utilisation of world's best practice emission reduction technology, such as field electrification, flare minimisation strategies, use of renewable energy sources and procurement of emission offsets. The scope 3 emissions from a future shale gas development will also be reduced through investigation into low emission technologies, such as carbon capture and sequestration (CCS), enabled blue ammonia/ hydrogen and electricity export. This would further reduce the emission intensity of a future gas developments and highlights the role of natural gas as a transition or 'firming' fuel to support the roll out of large-scale renewables in the future. This is reflected by Origin's ongoing commitment to invest in both renewable energy sources and firming fuels such as natural gas.

Table 27: Cumulative Origin 2023-2026 financial year predicted greenhouse gas emission assessment by period for approved, proposed and potential future exploration activities

Activity	FY23	FY 24	FY 25	FY26	Comments
Approved EMPs					
Kyalla 117 N2 water bores	0	0	0	0	No material emissions are anticipated
Kyalla 117 N2 civil construction	0	0	0	0	No material emissions are anticipated
Kyalla 117 N2-1H drilling, stimulation and well testing [12]	46	46	46	46	No material emissions are anticipated
Kyalla 117 N2 multi-well EMP	0	0	0	0	No material emissions are anticipated
Amungee NW-1 EMP	46	46	46	46	No material emissions are anticipated

[12] Assumes a total of 9 months of well test

Activity	FY23	FY 24	FY 25	FY26	Comments
Beetaloo W-1 EMP	46	46	46	46	No material emissions are anticipated
Velkerri 76 S2 water bores	0	0	0	0	No material emissions are anticipated
Velkerri 76 S2 civil construction	0	0	0	0	No material emissions are anticipated
Velkerri 76 S2-1H drilling, stimulation and well testing [13]	0	0	0	9,113	Drilling of the Velkerri 76 S2-1H horizontal, stimulation and 90 day well test
Amungee multi-well (Amungee NW-2H and NW-3H; Velkerri 76 S2-2H and S2-3H)	69,415	0	0	0	Drilling, stimulation and 180 day well test of one well on Amungee NW
Maximum proposed under this EMP					
135-day average well test for all 12 E&A wells	48,599	172,815	171,517	129,204	Activities include all those required to construct, drill, stimulate and well test 12 E&A wells over the FY 2023-2026 period
Total annual emissions (tCO_2e)	**118,152**	**172,954**	**171,655**	**138,492**	

4.20.2 Residual emissions offsets

Origin proposes to offset a percentage of residual greenhouse gas emissions to meet net zero by 2050 in alignment with the NT Greenhouse Gas emission target. Origin will offset residual emissions as per the following:

- That residual emissions be offset using credible carbon credit units approved by the Commonwealth Clean Energy Regulator.
- Minimum offset levels shall increase year-on-year by 3.7% (based on a baseline financial year of 2023) to result in a linear decrease in residual emission levels to net zero by 2050 as per the following schedule:
    - Financial year 2023: 3.7% of total emissions offset
    - Financial year 2024: 7.4% of total emissions offset
    - Financial year 2025: 11% of total emission offset
    - Financial year 2026: 14.7% of total emissions offset

[13] The original estimate for Velkerri 76 S2-1H has been reduced from 29,589 to 9,113 tCO_2 based on the revised drilling of a <1000m horizontal and 90 day well test @1 TJ/day.

- Financial year 2027: 18.4% of total emissions offset

- Actual emission levels produced during a financial year must be estimated in accordance with the National Greenhouse and Energy Reporting Scheme (NGERS) reporting methodology.
- Offsets volumes shall be calculated retrospectively, by multiplying the actual emission volumes generated during a financial year with the corresponding financial year offset % requirement level.
- Offsets shall be secured and retired within 6 months of the end of a financial year.
- An appropriately qualified independent person with extensive carbon accounting experience shall verify the actual emission levels generated, the procurement and retirement of the required offset volumes for emission generated in the specified financial year.
- A report from the appropriately qualified independent person shall be provided to DEPWS by January 31 each year verifying the actual emission levels estimated and confirming the required offset for the previous financial year have been acquired and retired.
- That the GGAP is updated annually based on actual emissions from the preceding year to ensure currency.

4.21 Naturally occurring radioactive material

A detailed assessment of Naturally Occurring Radioactive Material (NORM) was undertaken during the Amungee NW-1H well drilling and testing in 2016. The assessment collected data on the drill cuttings, gas and flowback water, with the results considered applicable to the drilling on the 4 Amungee NW sites proposed under this EMP.

The observed radionuclide level within flowback and gas samples observed from Amungee NW-1H are at the lower end of those observed in the USA shale developments (Kibble *et al.* 2013).

The analysis concluded the following:

- **Drill cuttings:** X-Ray Fluorescence (XRF) data was collected at regular intervals (average 5 m), providing an estimate of up to 48 elements (including uranium, thorium and potassium) present in the formations being drilled. This data was analysed by a third-party contractor. Analysis determined that the uranium and thorium (primary sources for mineral contained NORMs) content of the geological formations drilled was well within the ranges of normal geological rocks. In addition, a study commissioned by Origin Energy in 2016 with the company 'Radiation Professionals' analysed drill cuttings samples from four (4) wells drilled by Origin Energy (Kalala S-1, Amungee NW-1, Amungee NW-1H, Beetaloo W-1). Results concluded that none of the samples provided exceeded limits provided in the 'Radiation Protection Regulations, 2012 (NT) Regulations 7' or the 'National Directory for Radiation Protection, Part B, section 3.2'. Given the distribution of the wells across the tenure and the geological continuality of the Roper Group formations, the risk of NORMs is considered low. The assessment of NORMs potential will be able to be accurately assessed and screened using a combination of well site wireline natural gamma and post drilling XRF analysis on cuttings samples to detected analogous samples with high radioactive producing elements such as Uranium and Thorium. If levels approaching the Radiation Protection Regulations are detected, a more thorough evaluation will be conducted. Furthermore, NORMs assessments of drilling muds are required under the Petroleum Code and will be completed as per section 4.15.1.
- **Flowback:** NORMs samples of flowback were collected weekly during the well testing of Amungee NW-1H. An assessment of the results indicated that for the flowback to breach the

regulatory limit of 1 mSv/year, a person would have to consume greater than 80 litres of flowback fluid. Given fluid is strictly managed in accordance with the Code and corresponding Wastewater Management Plan, this scenario is considered highly unlikely.

- **Gas:** Results for the raw gas analysis from Amungee NW 1H indicated that at the observed radon level of 225 Bq/m^3. An exposure above 1 mSv/m^3 from raw natural gas is considered remote, as a person would need to be continuously exposed to raw gas on a long-term basis (years). This exposure scenario is not deemed a credible pathway, as there are stringent requirements in the Code, which prohibit unnecessary venting and require operators to conduct ongoing leak detection and repair program. Furthermore, the observed levels of radon are:
    - well below the maximum radon level limit for natural gas of 600 Bq/m^3. These limits are imposed by the Australian Energy Market Operation (AEMO) and outlined in the Australian Standard AS4564 Specification for general purpose natural gas (AEMO 2017) to protect the safety of the end domestic user of gas.
    - an order of magnitude lower than many shale radon level in the US; including the Marcellus (Cassman *et al.* 2016) which has been deemed safe to use for domestic purposes.
    - consistent with the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) recommendation that radon levels should not exceed 200 Bq/m^3 in households and 1000 Bq/m^3 in workplaces (ARPANSA 2019). The exposure of a pastoralist to unventilated gas is considered remote, based on the separation distance between the well and the inherent controls that limit venting. The potential exposure to workers is also considered a low risk, based upon the radon levels being within the ARPANSA workplace guidelines and Code controls.

Risk controls have been implemented to manage the risk of exposure to personnel, including eliminating raw gas exposure and preventing access to drilling material and wastewater. The risk of exposure from NORMs generated during shale exploration activities is considered low. Testing of the drilling cuttings, gas and flowback water will be undertaken during this campaign, as described in Section 4.29.

Further information on the NORMs level encountered was provided to the Inquiry as part of Origin's submission (https://frackinginquiry.nt.gov.au/?a=424843).

4.22 Wet season operations

Drilling, stimulation, well testing and wastewater storage and treatment operations are anticipated occur over the wet season. Where wet season operations are undertaken, the following risk controls will be implemented to: a) ensure all activities can be undertaken safely and with minimal risk to the environment during the wet season; and b) where necessary, ensure the transport of critical items to/from sites during the wet season:

- All chemicals, fuels, equipment, tanks and materials required for ongoing operations will be (as far as practicable) stored on-site prior to the onset of significant rainfall periods of the wet season (typically December unless credible medium-term forecasts predict earlier/later)
- All equipment required to respond to emergency situations will be on-site; this will be dictated by a pre-wet season risk assessment (based on the nature of activities underway) and include earth moving equipment, vacuum trucks, wireline rigs, cementing equipment etc. and equipment and material to deal with well control issues, spills and other emergency events

- All chemicals storage areas will be bunded, with covers used (where safe and appropriate) to prevent rain ingress and bund overflows
- Enclosed tanks will be utilised as the primary measure to store wastewater with enough enclosed tank capacity to store all wastewater on-site
- Enclosed wastewater storage volume will be sufficient to manage all wastewater stored on-site
- Open working evaporation tanks and mud sumps will have enough freeboard to manage an entire 1:1000 ARI wet season event (not just one rainfall event but an entire season's rainfall total)
- Helicopters will be used to transport people and supplies into and out of the site when access is restricted
- To reduce the risk of transportation of wastewater or chemicals during the wet season to ALARP, transportation will only be undertaken in accordance with the following:
    - Transportation will not occur on tracks where the surface is not safe to allow transportation vehicles to drive upon
    - Wastewater/ chemical transportation will not be undertaken through flooded waterways
    - The transportation of wastewater/ chemicals during rainfall events will be avoided. Data sources considered during logistical planning include:
        - Daily and weekly weather forecasts via the BOM website
        - Review of road conditions after a rain event via Road Report NT
    - Driving on unsealed access tracks will be avoided for 24 hours following a >20 mm rainfall event
    - After a >20mm rain event, or when the integrity of any unsealed road may be compromised due to prolonged rainfall, each unsealed access track proposed to be used for wastewater/ chemical transportation will be inspected to ensure the integrity of the road surface is sufficient to allow the safe passage of the proposed transport vehicle.
    - Chemicals will not be unloaded during rain events.
- Lease pad is bunded, which will prevent all off-site release of chemicals and stormwater
- All stormwater will be retained on-site via the sediment retention pond and tested prior to release
- Overland flow will be diverted around lease pads
- Where wastewater is stored on-site, each sites will either be manned or have remote monitoring within regional manning to respond to any emergencies.

4.23 Helicopter operations

If access to the site is prevented during operations, helicopters will be utilised to move people and supplies into and out of the site. Helicopter activities are an existing, approved activity at the sites. Helicopter activities ensures the site can be manned during all activities, regardless of the season.

The use of helicopters in the NT for transportation is a standard activity and ensures that personnel and material can be moved to and from the site during periods of wet weather or in emergencies.

All helicopter movements will be managed under an aviation journey management plan. This plan addresses the risk associated with vehicle selection, maintenance, flight routes and flight procedures.

Audits are completed prior to the engagement of a helicopter service provider and at least annually. This ensures all aircraft are being appropriately maintained and operated to reduce the risk of accident.

4.24 Waste management

Waste management methods for the proposed exploration program are summarised in Table 27. Waste is managed in accordance with the internationally accepted guide for prioritising waste management practices, with the objective of achieving optimal environmental outcomes. Waste will be managed in accordance with the following hierarchy principals:

1. **Avoid:** eliminate the generation of wastes through design modification
2. **Reduce**: reduce unnecessary resource use or substitute a less resource intensive product or service
3. **Re-use**: reuse a waste without further processing
4. **Recycle**: recover resources from a waste
5. **Treatment**: treat the waste to reduce the hazard of the waste prior to disposal
6. **Disposal**: dispose of waste if there is no viable alternative

Waste transfer certificates will be retained and provided to DEPWS upon completion of the project.

Drilling, stimulation and well testing wastewater is managed in accordance with Section 4.15.

Table 28: Waste and disposal methods

Activity	Disposal method
Sewage, grey and stormwater	**Treatment:** Grey water and sewage treated and disposed of on-site in an approved, portable treatment system accordance with Department of Health Code of Practice for small on-site sewage and sullage treatment systems and disposal for reuse of sewage effluent. Sewage treated will be surface irrigated to a dedicated, fenced area. The area will be left vegetated, with no clearing required. Sludge removed from site and disposed of at an appropriately licenced facility. Uncontaminated stormwater will be tested (refer section 3.11.5) and either released off-site or re-used for dust suppression.
Food waste, paper and plastic	**Disposal:** Collected in dedicated waste bins for back-loading to a licenced landfill under the Waste Management and Pollution Control Act.

Activity	Disposal method
Glass and cans	**Recycled:** Collected in separate waste bins for recycling at an off-site facility.
Chemical bags and cardboard packaging materials	**Recycled:** Compacted and collected at rig site for transport to a licenced recycling centre.
Scrap metals	**Recycled:** Collected in designated skip for recycling at an approved location.
Used chemical and fuel drums	**Recycled:** Collected in designated skip for recycling at an approved location.
Chemical wastes	**Re-use/disposal:** Collected in approved containers for disposal at a licenced landfill under the Waste Management and Pollution Control Act. or returned to supplier or recycled.
Timber pallets (skids)	**Recycled:** Recycled at an approved facility
Vehicle tyres	**Disposal:** Disposed of at a licenced landfill under the Waste Management and Pollution Control Act.
Oily rags, oil-contaminated material, filters and any hydrocarbon material	**Recycled/disposal**: Oil from machinery or encountered during drilling. Collected in suitable containers for disposal at a licenced landfill under the Waste Management and Pollution Control Act. or recycled at an approved recycling facility.
Flowback	**Recycled, treatment and disposal**: Highly saline wastewater collected in a series of open and closed tanks. Where possible, flowback will be utilised as stimulation make up fluid to reduce raw water requirements. Where flowback cannot be recycled, it will be evaporated on-site using mechanical evaporators and then disposed of off-site at a licenced facility interstate. On-site treatment could potentially include other mechanical treatment options, such as brine crystallisers and thermal combustion units.
Exploration well drill cuttings, muds and fluids	**Treatment and disposal:** Saline fluids and solids stored within a lined sump. Fluids segregated from muds and cuttings. Solids dried out, with liquids evaporated. Solids tested and disposed of on-site or off-site depending on hazard. Fluids transported off-site to a licenced facility interstate.
Groundwater extraction bore drilling cutting and muds (cuttings mixed with drilling fluids)	**Disposal:** Freshwater cuttings and drilling muds with low hazard. Disposed of on-site in accordance with the Minimum Construction Requirements for Waters Bores in Australia for water bore drilling practices.
Spill contaminated soils and water	**Disposal:** All contaminated material (solids and liquids) will be disposed of off-site at a licenced facility.

Activity	Disposal method
Stormwater	**Discharged/recycled/disposal:** All stormwater will be collected on-site in a designated sediment retention system. Stormwater will be tested and either released off-site or recovered and either recycled within the drilling process or disposed of at a licenced wastewater treatment facility in accordance with the *NT Waste Management and Pollution Control Act 1998*.
Waste sand	**Re-use/disposal:** Waste and returned sand from stimulation activities will be re-used or disposed of in the drilling sumps with the residual cuttings and muds.

4.25 Camps

Two camps will be used for E&A activities. It is anticipated that a main camp will be located regionally (at Amungee NW), with contingent provisions for the main camp to be located adjacent to each site if required, on-site will be designed to house up to 70 people. The camp will support two crews that will work 12-hour shifts, plus the camp staff, supervisory staff and service company personnel on an as-required basis. The main camp includes:

- accommodation
- ablutions and septic(s) waste treatment and irrigation
- recreation room
- kitchen and mess
- freezer unit
- site office
- generator and diesel storage
- water tank.
- water treatment facility (reverse osmosis plant).

A drilling mini-camp will be set-up on each of the exploration well lease pads during activities. The mini-camp will house up to eight people and will support the 24-hour drilling activities. Mini-camps are temporary 24-hour sites consisting of:

1. A donga for sleeping / rest
2. Portable toilet facilities
3. Diesel generator and diesel storage for power

Each camp has its own sewage treatment plant and wastewater treatment plant. A notification of installation of wastewater management system outside a building control area will be submitted to the Department of Health after the installation of each system with a capacity above 2,000 L/day. Treated water is dispersed via drainage away from the camp to the designated irrigation area. The designated irrigation areas are located adjacent to the camp pad and exploration lease pad. These areas are approximately 50 m x 50 m and are within the broader lease area fence, which will exclude livestock access.

The existing camp infrastructure is temporary and portable and powered by diesel generators. The potable water supply for the camps is sourced from groundwater bores established for drilling activities and treated to the appropriate drinking water standards (2011 NHMRC Australian Drinking Water Guidelines). A temporary reverse osmosis (RO) water treatment plant is used, which produces approximately 10 KL of potable water per day. Approximately 2,000 L of RO reject is likely to be produced per day, which will have an Electrical Conductivity of approximately 1,500-2,000 µs/cm^3. This water will be re-used or blended (diluted) with raw water at a 4:1 ratio and used for dust suppression.

All camp kitchens have been registered under the *NT Food Act 2004* and comply with all food hygiene requirements.

The domestic solid waste generated by camp activities will be removed by a waste contractor in accordance with the NT WMPCA.

4.25.1 Workforce

Origin prioritises the use of local employment to deliver exploration activities where possible. Section 6.7 outlines the range of NT businesses engaged on Origin's activities through information sessions and tender opportunities, covering a range of material supply and support services, which to date has resulted in ~$8M per annum (average) being spent by Origin in the NT. As Origin's exploration activities within the Beetaloo increase, this figure is likely to increase to ~$15-20M in the next 2 – 3 years.

Given the specialty nature of the activities described in this EMP, the majority (~80%) of the drilling, completions and stimulation workforce will be FIFO. The rest will primarily be DIDO from the NT, with some contractors supplying services from Daly Waters and Elliott. Origin has actively looked for local options for all of its exploration activities, which can be seen through the engagement of Silver City (an NT business) for drilling services. Civil construction, camps, water bore drilling, engineering and environmental services and waste management will be 95 – 100% locally sourced from NT businesses.

Presently, Origin directly employs 4 full time equivalent (FTE) personnel based in the NT and estimates an additional 20 – 30 NT based people have been employed indirectly. Due to the short contracting periods; strong competition for services and material in the NT; and, the fact that the majority of activity described in the EMP has not been contracted, it is difficult to provide an accurate forecast of employee numbers.

4.26 Noise

In alignment with Table 3.4 of the NT Noise Management Framework Guideline, a minimum night-time, adverse weather project intrusiveness noise level of 35 LAEQ, 15min dB[A] at a sensitive feature has been adopted. A 35 dB[A] sound level is considered quiet, to very quiet as outlined in Table 28.

Based upon field noise monitoring verification completed for various exploration activities undertaken in Queensland, impacts to sensitive receptors are not anticipated to occur within the following buffers (assuming worst case night-time and adverse weather conditions)[14]:

- Construction activities 1.2 km

[14] Based on noise verification monitoring of the Atlas 1 rig, Ensign 964 rig, Ensign 966 rig, Nitschke Rig 1, Gel HFS completed on Ramyard 30H, Condor frack spread, Schlumberger cementing rig, Envirovibe Minibuggy, and gathering noise construction assessment.

- Seismic operations (vibroseis) 0.75 km
- Drilling- 1.75 km
- Cementing- 2.6 km
- Stimulation- 3.5 km

Given there are no sensitive receptors within 15 km of the site (as outlined in section 57), noise impacts from Origin exploration activities are not anticipated.

Table 29: Subjective evaluation of noise summary table (source SKM 2015 Monitoring of Rig Noise Levels Atlas 1)

Sound Pressure Level (dBA)	Typical Source	Subjective Evaluation
130	Threshold of pain	Intolerable
120	Heavy rock concert	Extremely noisy
110	Grinding on steel	
100	Loud car horn at 3 m	Very noisy
90	Construction site with pneumatic hammering	
80	Kerbside of busy street	Loud
70	Loud radio or television	
60	Department store	Moderate to quiet
50	General Office	
40	Inside private office	Quiet to very quiet
30	Inside bedroom	
20	Recording studio	Almost silent

4.27 Traffic and road impacts

The periods of highest traffic generated from exploration and appraisal activities will generally occur over a short duration and are generally associated with the mobilisation and demobilisation of equipment. The peak maximum anticipated traffic flow increase associated with the activity is conservatively estimated at approximately 44 vehicles per day during the demobilisation of equipment from site.

To assess the potential impact on pastoralist and tourism amenity and experience, a Traffic Impact Assessment (TIA) is discussed below. This assessment includes heavy equipment mobilisation to and from site and is a suitable conservative scenario to assess the potential associated traffic impacts.

The TIA involved the following steps:

- Identification of project traffic movements including approach and departure direction
- Existing traffic levels and road Level of Service
- Assessment of total traffic levels and potential impacts
- Works within the road corridor, including the construction of new intersections and work within the road corridor
- Determine required impact-mitigating treatments.

4.27.1 Identification of project traffic movements

Access to the sites within then Amungee Delineation Area is via the Carpentaria Highway. The Carpentaria Highway is a 110 km/hour posted speed limit in the vicinity of the project two-lane, two-way road with a sealed width of 7 m and unsealed or grassed shoulders varying between 2.5 and 5 m in width.

The peak maximum anticipated traffic flow increase associated with the activity will be approximately 44 vehicles per day, during rig and heavy equipment demobilisation from site.

At each site, peak movements are likely to be restricted to a two-week period during mobilisation and a two-week period during the final rig demobilisation. Average daily traffic additions during the operational phase (drilling, stimulation and well testing) of the period are likely to be 10 – 15 movements per day for the first three-six months, reducing to three-four movements for the remainder of the period. Daily transport volumes have largely been reduced using on-site/regional camps, with busses used to facilitate crew change overs.

4.27.2 Existing traffic levels, road capacity and Level of Service

Existing traffic figures were obtained from the DIPL Annual Traffic Report 2021 showing Average Annual Daily Traffic (AADT) figures for the Carpentaria. The total daily traffic flows on the Carpentaria Highway (2km east of the Stuart Highway) are estimated as 90. The total traffic flows are effectively split evenly between east and west bound (refer Figure 30). Traffic rates during the dry season are likely to be substantially higher than the average figures, with peak dry season traffic observed to be up to 50% higher than the average volumes (GHD 2013). This increases the peak traffic volume to 135 vehicles per day on the Carpentaria Highway and is considered a representative worst-case background traffic volume. To account for an expansion in onshore petroleum exploration including other users (such as road maintenance, mineral exploration etc.) an additional 88 VPD has been added to the assessment. This essentially assumes an additional 2 exploration companies with similar peak vehicle volumes of 44 VPD (VPD total) mobilised at the same time. Therefore, a revised worst case background daily traffic flow of 267 VPD on the Carpentaria Highway is considered a representative worst-case traffic volume.

AUSTROADS guidelines (Austroads 2017) were used to determine the typical capacity that would be expected by traffic on the Carpentaria Highway to maintain a free-flow Level of Service (LOS). The Carpentaria Highway in the project location is a two-lane, two-way road. The capacity of roads is based on the maximum rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of lane or roadway during a given time period. The Level of Service relates to the operating conditions encountered by traffic as defined in the AUSTROADS guidelines (Austroads 2017). This data was then used to determine the capacity of the Carpentaria Highway to maintain a Category A (free flowing) LOS for the site. A conservative 700 – 1,000 vehicle/hr/lane figure was used to determine the vehicle movement capacity.

In an urban situation it can be assumed that the peak hour volumes will be about 10% of the daily traffic volumes. However, the remoteness of this site means that a peak hour is not realistic and has not been considered. Due to the low anticipated volumes that are likely to be spread over the duration of the day, this is considered appropriate.

Rural Primary Count Stations — Year: 2021
Table: 2.1 AADT For Primary Stations - 10 Year Period — Region: Katherine

Road Name / Location	ADT Station	Direction	Units	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Buntine Highway	RKVDP005	Inbound	Veh	35	32	33	33	46	34	32	38	34	34
1km South of Top Springs		Outbound	Veh	35	32	33	32	33	33	32	39	35	32
		Both	Veh	70	64	66	65	79	67	64	77	69	66
Carpentaria Highway	RKVDP008	Inbound	Veh	33	36	34	36	35	34	33	39	34	45
2km East of Stuart Highway		Outbound	Veh	41	37	36	37	33	32	31	37	31	45
		Both	Veh	74	73	70	73	68	66	64	76	65	90

Figure 30: Traffic flows on the Carpentaria Highway near the Daly Waters

4.27.3 Assessment of total traffic levels and reduction to road capacity and Level of Service

The total anticipated peak traffic volume for the Carpentaria Highway has been determined at 267 vehicles per day. This consists of an additional peak project (Origin) vehicle movement level of 44 vehicles per day in addition to the existing peak dry season traffic volumes of 223 vehicles per day (including other potential petroleum and mineral exploration activities).

The total volume of traffic is considerably lower than the capacity of the Carpentaria Highway (700-100 vehicles/hr/lane), with any reduction in LOS from the volume of project traffic considered extremely unlikely.

Traffic LOS may also be impacted through changes in traffic compositions, with the volume of trucks affecting the road capacity greater than light vehicles. To assess the changes in traffic composition, vehicle category data obtained from the DIPL Annual Traffic Report 2021 were assessed against expected total project traffic figures. These figures were increased by 50% to represent peak dry season traffic volumes. The assessment is provided in Table 29.

Table 30: Traffic impact summary for the Carpentaria Highway – existing versus proposed additional

Vehicle category	Existing vehicles per day (vpd) and % (approx.)	Proposed additional Origin vehicles per day (vpd)	Other industry (cumulative-non Origin)	Total vehicles per day (vpd) during activity and % (approx.)
Short (light vehicles)	65 vpd (50%)	12 vpd	24vpd	101 vpd (38%)
Medium (heavy vehicles or short towing)	35 vpd (26%)	0 vpd	0vpd	35 vpd (13%)
Long (heavy vehicles)	7vpd (5%)	5 vpd	10vpd	22 vpd (8%)
Medium combination (heavy vehicles)	8 vpd (6%)	0 vpd	0 vpd	8 vpd (3%)
Large combination (heavy vehicles)	19 vpd (13%)	27 vpd	100 vpd	73 vpd (37%)

The results in Table 29 demonstrate that there will be changes in traffic composition associated with the project, with an additional 24% of large combination vehicles (the vehicle class considered the highest potential risk to local road users) when compared to the total volume composition. Given the small volume of traffic and the conservativeness of the assessment (i.e. use of peak vehicle traffic and conservative cumulative assessment) this percentage is unlikely to significantly impact upon the road's capacity and LOS.

4.27.4 Works within the road corridor

The EMP covers activity within the road corridor relating to the construction of new intersection and collection of seismic.

A total of 3 new intersection with the Carpentaria Highway may be constructed to access the proposed exploration sites. Two (2) of the proposed access points will involve the upgrade of existing pastoral intersections which will improve the safety of these intersection. All new access track intersections will be constructed in accordance with DIPL requirements to minimise the impact on road users. This includes ensuring appropriate sighting of intersections to ensure safe line of site for oncoming traffic, traffic signage, use of traffic management plans during construction, sealing intersections to protect the road surface and minimise gravel on the road and undertaking regular road cleaning (with appropriate traffic management practices in place). Overall, the impact of new intersections on road users is not anticipated to be significant, as the design and location of these is consistent with existing major roads across the NT.

Seismic activities will also be undertaken in the road corridor at 3 proposed locations. Seismic acquisition will be minimal disturbance, involving the deployment of nodes and use of vibroseis trucks. All work within the road corridor shall have the relevant DIPL road corridor permitting prior to the commencement of activities.

4.27.5 Traffic risk management strategies

The management of risks of injury to staff, contractors and the community is a key focus of every Origin activity. To reduce the risks associated transport, all vehicle movements undertaken as a part of Origin activities must comply with the Origin Land Transport Directive. Mandatory controls include:

- Avoiding vehicle movements where possible (such as the use of buses and aircraft)
- Requirement for all vehicles to be fitted with an in-vehicle monitoring systems (IVMS) to monitor speed limits, seat belt usage, harsh breaking and acceleration, and fatigue
- Driving at night to be avoided
- Defensive driver training for all employees and contractors performing work
- Zero alcohol and drug policy – with all staff breath tested when on-site and random drug tests completed
- Fatigue management policy – with mandatory breaks required for every 2 hours and maximum10 hours in a single 24-hour period working hours (unless the driver of a fatigue regulated heavy vehicle, where the driver must then comply with the applicable law for fatigue management where the vehicle is operated)
- Chain of responsibility training for all logistics/supply chain roles to ensure they understand their obligations to ensure the safety of their transport activities under the Heavy Vehicle National Law
- Journey management plan requirements for all remote journeys, with all journeys lodged with Origin's National Response Contact Centre.

- Requirements to comply with the National Transport Code Load Restraint Guide
- Contractor and employee driver performance tracking and reporting, with all breaches investigated, formally documented and disciplinary actions taken

In addition to the above requirements, Origin has also implemented the following additional controls:

- Ongoing engagement with DIPL is underway covering all future exploration activities and interception upgrades.
- Selection of intersection locations to ensure appropriate line of sight with oncoming traffic
- Design of intersections to incorporate bitumen sealing to reduce the risk of gravel being brought onto the road from trucks turning
- Use of appropriate traffic signage to warn oncoming users of turning trucks
- Large loads to have their own journey management plan outlining proposed controls, including fatigue management, route selection. load constraint, speed restrictions, pilot requirements etc.
- Communication with pastoralists when heavy/multiple transports are likely to occur
- Peak transport period to be restricted to the demobilisation of the rig, with most mobilisations occurring via internal access tracks
- The use of camps reduces vehicle movements between the site and local communities

Other potential risks and controls associated with traffic are discussed further in section 7.6.

4.28 Cumulative impact summary

This section provides a summary of the cumulative impacts associated with the proposed activity in accordance with Section 3b of the NT Petroleum (Environment) Regulations 2016. These include cumulative impacts associated with groundwater extraction, flora and fauna, greenhouse gas generation, traffic and social impacts. The assessment of cumulative impacts is summarised in Table 30.

Table 31: Summary of cumulative impacts addressed within the EMP

Aspect	Summary	EMP section
Water	Groundwater extraction cumulative impacts assessed under the Water Extraction Licence GRF 10285. This includes water use for Origin's future exploration program, adjacent petroleum operators and surrounding users. No material impacts on surrounding users expected.	Section 4.14
Flora and fauna	Estimated clearing associated with the regulated activity 107 ha. Impacts associated with weed introduction are managed through the weed management plan. All other petroleum operators and pastoralists required to have a weed management plan.	Section 4.3.1 and Section 5.2

Aspect	Summary	EMP section
Greenhouse gases	Cumulative emissions from all of Origin's FY 2023-2026 activities has been provided. Emission levels are mainly attributed to flaring. In a development scenario, gas production is likely to have 50% less emissions than coal, thus playing an important role as a transition or firming fuel to support large scale renewable energy supply.	Section 4.20
Traffic	Impacts of traffic are anticipated to be minor, with no reduction in level of service of the Carpentaria Highway. Maximum peak traffic level assessment considers cumulative user traffic load, with project movements anticipated to be 44 movements per day during demobilisation. Impacts from the new intersections to be managed through appropriate site selection and design.	Section 4.26
Social	Risk associated with increased competition for labour from exploration activities, including other petroleum operators is low and well within the capacity of existing service providers. Ongoing engagement with local and regional businesses is underway, providing information and updates on the status of any future projects. Increased industrialisation of landscape resulting in a loss of amenity and tourism value considered low due to limited extent of petroleum activities, including from other petroleum or mining operators.	Section 5.4

4.29 Monitoring

A series of monitoring programs has been developed under this EMP to:

- monitor and detect changes in environmental values associated with Origin's activities
- characterise waste streams to understand the nature of the waste and determine the disposal requirements
- characterise the quality of the produced hydrocarbons
- report on rehabilitation progress.

An overview of each of the monitoring programs is provided in Table 31.

4.29.1 Groundwater monitoring

Baseline monitoring data will be collected from the control monitoring bores in accordance with condition B.4.17.2(b) of the Code of Practice and *Preliminary Guideline: Groundwater Monitoring Bores for Exploration Petroleum Wells in the Beetaloo Sub-basin*. Due to land access negotiations delays beyond the control of Origin, it is anticipated that 6 months of baseline prior to drilling may not be achieved for the proposed Amungee NW2-1H well on the Amungee NW2 location. In alignment with B.4.17.2(b) (i) (b) of the Code of Practice, Origin will still comply code by collecting 6 months of monitoring data prior to the commencement of hydraulic fracturing.

Monitoring data collected periodically under this EMP can be accessed via the DEPWS website located at https://depws.nt.gov.au/onshore-gas/onshore-gas-in-the-northern-territory/industry-compliance-and-reporting/groundwater-monitoring-results.

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Table 32: Monitoring program summary

Monitoring program	Purpose	Monitoring points	Parameters	Frequency	Investigation thresholds	Reference document
Stimulation monitoring program	Meet code of Practice Requirements	Post mixer	Total volume of hydraulic fracturing fluid pumped	**Each hydraulic fracturing stage**	N/A	Code B.4.13.1 c)
		Groundwater extraction bore	**Table C.8 of COP including:** **Field Chemistry:** pH, Dissolved Oxygen, temperature and electrical conductivity **Analytical suite:** Appendix I including NORMS	**Prior to stimulation**	N/A	Code B.4.13.1 c)
		Post mixer	Typical and maximum concentrations of chemicals or other substances used	**Each stage**	N/A	Code B.4.13.1 c)
		Pre-injection	**Field Chemistry:** pH, Dissolved Oxygen, temperature and	Each fluid system used during injection (one of each in total)	N/A	Code C.5.4 and C.5.3

Monitoring program	Purpose	Monitoring points	Parameters	Frequency	Investigation thresholds	Reference document
			electrical conductivity **Analytical suite:** Appendix I including NORMS			
Flowback Monitoring	Characterise flowback quality	Post separator before entering flowback tank	**Field Chemistry:** pH, Dissolved Oxygen, temperature and electrical conductivity	**Field Chemistry:** Continuous (at least 1 sample every 24 hours) **Analytical Suite:** Weekly until the EC level stabilises (<10% change over 2 weeks) and then monthly until practical completion of flowback activities	N/A	Code C.5.4
Drill cuttings, fluid and muds characterisation	Characterise the quality of drill cuttings, fluids and muds to determine disposal options	Drilling sump – as determined by a suitably qualified third-party	Table 10 of the Code (NORMs), Particle size distribution, bulk density	Prior to disposal	N/A	Code C.5.2
Gas composition and isotopes	Characterise produced gas	Post-separator	Gas composition (nitrogen, oxygen, carbon dioxide, C1-	Monthly – internal characterisation program	N/A	N/A

Monitoring program	Purpose	Monitoring points	Parameters	Frequency	Investigation thresholds	Reference document
			C10+, H_2S) Isotopes (C^{13} (CO_2 and CH_4) and H^2 (CH_4, C_2H_6 +). Radon and radioactivity.			
Groundwater monitoring	Detect changes in groundwater resulting from drilling and stimulation activities	Amungee NW: RN040894 and newly constructed impact monitoring bores	Level	Quarterly measurements with real-time (continuous) level logging before, during and 1 month after stimulation	+/-1 m water level change observed at the impact monitoring bore	Code B.4.17
			Temperature, electrical conductivity, pH	Upon completion of each monitoring bore and quarterly thereafter commencing 6 months prior (baseline) and three-monthly after stimulation and then annually for 3 years	EC >200 µs/cm change pH >1 unit change	
			Appendix I	Quarterly commencing 6 months prior (baseline) and three-	BTEX and Dissolved Methane - outside of the control bore	

Monitoring program	Purpose	Monitoring points	Parameters	Frequency	Investigation thresholds	Reference document
				monthly after stimulation	and baseline interquartile range	
	Pastoralist bore monitoring	Pastoralist bores within 10km of an exploration well	Level	Baseline collected 3 months prior to stimulation and 12 months after stimulation	1m sustained water level decline against baseline	N/A
			Temperature, electrical conductivity, pH	Baseline collected 3 months prior to stimulation and 12 months after stimulation	+/- 20% compared to pre-stimulation reading	N/A
			Appendix I	Baseline collected 3 months prior to stimulation and 12 months after stimulation	BTEX and Dissolved Methane – outside of baseline interquartile range	N/A
Groundwater take	Groundwater volume	Each groundwater extraction bore	Litres	Continuous flow meter	Total extraction >107.5 ML for a given site	*NT Water Act*
Stormwater	Manage stormwater collected during activities	Sediment basin release point	Field EC and pH	Prior to release and at least every 12 hours during continuous discharges	**Off-site release and dust suppression limits**: • pH 6-9	N/A

Monitoring program	Purpose	Monitoring points	Parameters	Frequency	Investigation thresholds	Reference document
					• EC 1300 µs/cm	
Erosion and sediment control	To detect the presence of erosion and sedimentation from infrastructure	Inspection of all disturbed areas, including lease pads, access tracks, gravel pits, laydown yards, camp pads, etc.	Visual inspection nfrastructure and sion and sediment trols	Visual inspections pre- and post-wet season	Visible erosion or failure of erosion and sediment control	Origin's Approved Erosion and Sediment Control Plan (NT-2050-15-MP-0019)
Fauna - routine inspections	Collect data on fauna interactions with wastewater	Wastewater tank and sump inspections	Inspection records	Daily during operations	>7 per week for two (2) consecutive weeks or >1 threatened fauna species	Field Guide to NT Fauna
Weeds	Identify weeds potentially introduced or spread by Origin's activities	Inspection of all disturbed areas, including lease pads, access tracks, gravel pits, laydown yards, camp pads, seismic lines etc.	Visual inspection	Visual inspections post-wet season	1. Positive confirmation of the detection of a weed of national significance species within Origin's disturbance footprint 2. An increase in existing weed	Origin's Weed Management Plan NT-2050-15-MP-0016

Monitoring program	Purpose	Monitoring points	Parameters	Frequency	Investigation thresholds	Reference document
					density and spatial extent	
Methane emission monitoring program	To identify and remediate gas leaks	Each exploration well	Methane (PPM)	6 monthly	>500 PPM	Methane Emissions Management Plan (Appendix H)
Seismicity monitoring	To identify induced seismic events caused by hydraulic fracturing	Seismometers installed adjacent to selected well sites	Ground motion	2 months before and 2 month safter	Seismic event	Section 4.19
Post rehabilitation	Monitor ongoing rehabilitation success	Inspection of all rehabilitated areas, including lease pads, seismic lines, access tracks, gravel pits and camp pads	Visual inspections of: • Stem count • Vegetation cover % • Species diversity % • Erosion	Annually	Decline in rehabilitation criteria value compared to previous year results	Section 8.5 and Appendix N

4.29.2 Water sampling methodology

Water samples will be collected in accordance with Table 32. All samples will be collected by appropriately qualified personnel, with all meters calibrated in accordance with the manufacturer's instructions before use. Samples will be collected in laboratory-supplied sampling containers and placed in chilled eskies and transported under Chain of Custody (COC) procedures. Analysis will be performed by laboratories with National Association of Testing Authorities (NATA) accredited analysis methodology. Each sample will have a unique identifier that is cross-referenced to the monitoring location and time of sampling. Where there are no NATA accredited laboratories for a specific analyte or substance, then duplicate samples must be sent to at least two separate laboratories for independent testing or evaluation.

Table 33: Monitoring program methodologies

	Methodology
Drilling sump characterisation	• National Environment Protection (Assessment of Site Contamination) Measure • AS4482.1:2005. Guide to the investigation and sampling of sites with potentially contaminated soil
Flowback monitoring	• Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000 (ANZECC Guidelines). • AS/NZ5667.1: 1998. Water Quality Sampling Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples
Groundwater monitoring	• AS/NZ5667.11: 1998. Water Quality Sampling Part 11: Guidance on Sampling of Groundwaters • AS/NZ5667.1: 1998. Water Quality Sampling Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples • Origin Groundwater purging and sampling procedure CDN/ID8212543 • Geoscience Australia 2009: Groundwater Sampling and Analysis

4.29.3 Investigation and response framework

Where an exceedance of a monitoring program investigation trigger is observed from one of the monitoring programs outlined in Table 31, an investigation and response will be implemented as summarised in Figure 31.

The investigation and response process will be divided into the following components:

- Verification – is the result real?
- Evaluation – is the result related to petroleum activities?
- Remediation or management – what is the potential impact?
- Ongoing monitoring

The initial step in the process is *verification* of the measurement. This process begins with a check on integrity of the measurement, including a review of the protocol used to collect the measurement, calibration of equipment and the integrity of the monitoring infrastructure itself (such as the integrity of a monitoring bore). If the original data point is found to be correct, then a risk-based (appropriate to the scale and nature of the exceedances) investigation of the results is conducted, and an evaluation phase is initiated.

The *evaluation* phase will have two major goals; to identify the origin or source of the trigger exceedance and characterise the potential effects on environmental factors in order to reduce or eliminate negative consequences. This phase of investigation is conducted in a manner consistent with the type of threshold exceedance observed. Simple exceedances of water quality triggers during stormwater releases for example, may require simple investigations into the procedures and processes contributing to the event. Groundwater threshold exceedances may require more detailed assessment, whereby a comprehensive set of information is accessed and utilised, including a review of operational activities, the influence of other regional activities (e.g. mining or pastoral activities), changes in climatic conditions etc. Detailed investigation may include the identification of knowledge and/or data gaps and collection of additional data to fill these gaps and bring the issue into proper context.

If the *evaluation* phase of the investigation identifies the issue as being natural or not associated with petroleum activities, then the result is documented and monitoring continues. This may lead to the revision of a trigger or threshold. However, if the results indicate an influence of a petroleum activity, an assessment of risks is undertaken to assess the potential impact on environmental factors. This will involve a more in-depth evaluation or characterisation of the affected area and potential source. Regulatory notification may be required in accordance with section 9.7.

If the *evaluation* phase of the investigation indicates the influence of a petroleum activity, then mitigation measures may need to be implemented to prevent ongoing impacts to an environmental factor. These mitigation measures will be appropriate to the nature of the incident and will be based upon a risk assessment and technical feasibility assessments. Such mitigation measures may include:

- Stopping the activity and/or
- Modifying the activity to directly address the source of harm (i.e. additional procedures, training, ceasing or redesigning an activity) and/or
- Implementation of mitigation measures to reduce the potential effects (i.e. make good agreements, direct removal and treatment of contaminants etc.)

Upon implementation of mitigation measures, further *evaluation* through increased monitoring is undertaken to determine the success of the mitigation measures. If a positive result is observed, and trends begin to stabilise or reverse, then the result is documented and a return to regular monitoring occurs. If not, then the continued operation of the identified activity or activities causing the effected may need to be reviewed and adjusted in consultation with the regulator and other affected parties.

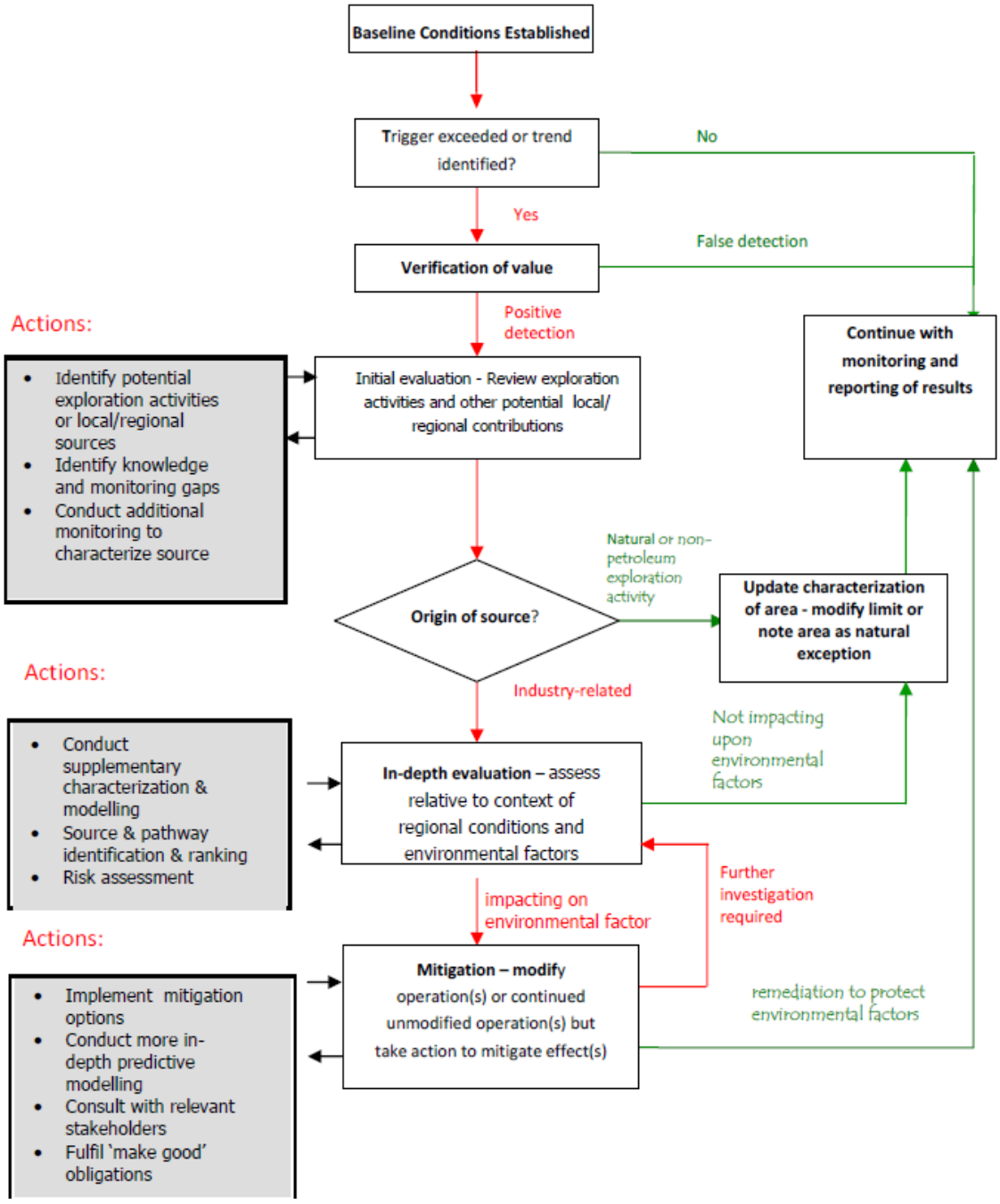


Figure 31: Investigation and response process

5 Description of the existing environment

The full description of the biological environment of the Amungee Delineation Area is provided in the land condition report completed by AECOM (2022) in Appendix J. A summary of the description of the proposed 4 new exploration well locations is provided in section 3. Broader information on the existing environment, including seismic program, are provided in the following sections.

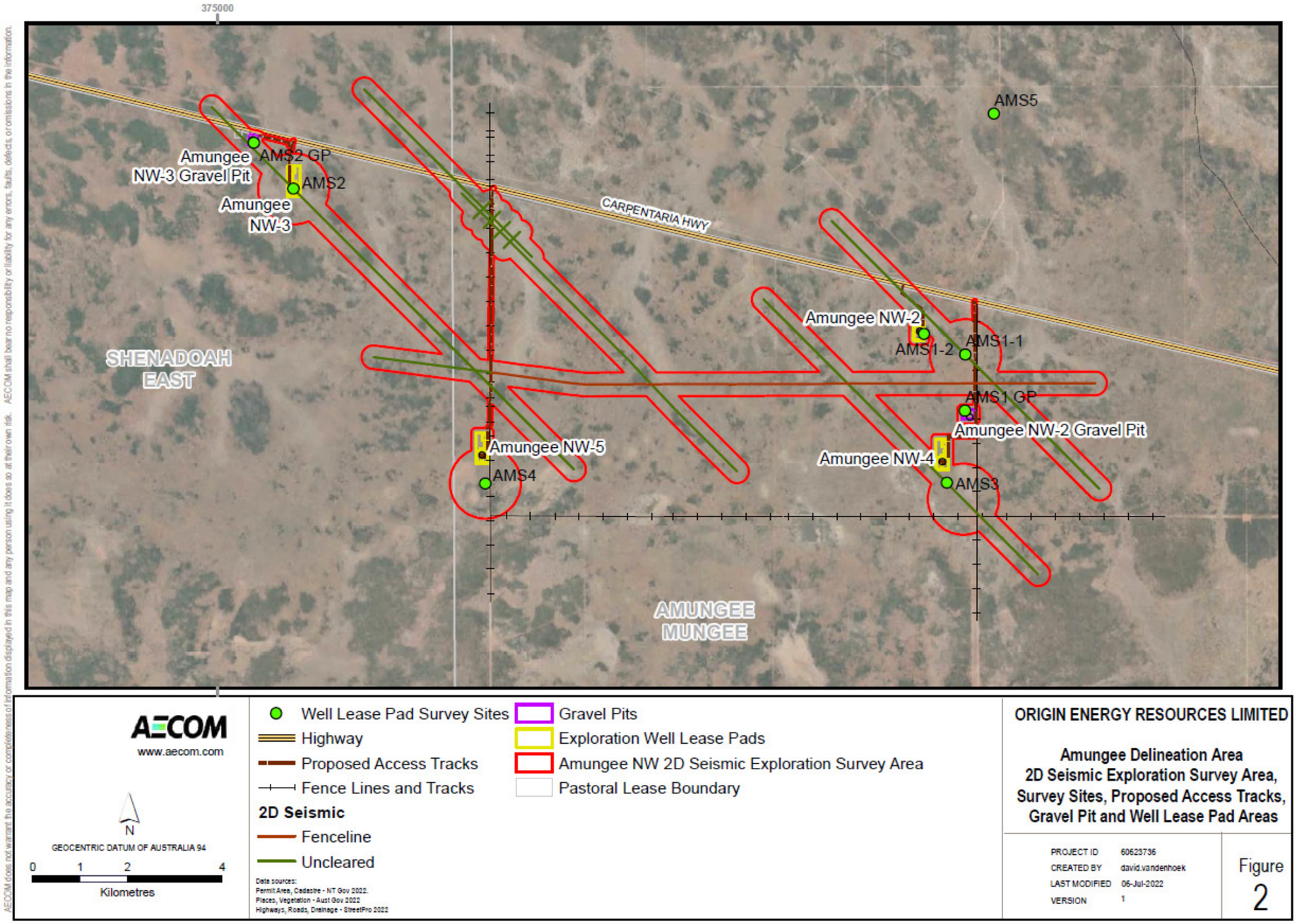


Figure 32: Amungee Delineation Area survey sites

Table 34: Summary of existing environment and surrounds – Amungee NW 2

Amungee NW 2 (AMS1-2)		**Survey photos of the vegetation/habitat of the surrounding environment**	
Location	GDA94, zone 53, 0389927E, 8190027N	   	
Landform and soil	Dark reddish brown sandy loam grading to sandy clay loam material at 0.2 m, well drained on simple slope (1%)		
Vegetation community	*Corymbia dichromophloia* and *Eucalyptus chlorophylla* open woodland		
Vegetation description	*Corymbia dichromophloia* and *Eucalyptus chlorophylla* mid high open woodland, over *Erythrophleum chlorostachys, Acacia difficilis* and *Santalum lanceolatum* mid high open shrubland, over *Chrysopogon fallax and Sorghum plumosum* open tussock grassland		
Dominant flora species	*Eucalyptus chlorophylla*, *Macropteranthes kekwickii*, *Acacia difficilis*, *Corymbia ferruginea*, *Erythrophleum chlorostachys*, *Terminalia canescens*, *Brachychiton paradoxus*, *Bauhinia cunninghamii*		
Habitat condition	Scattered tree hollows, common falling logs. Mistletoe and flowering plants absent. No canopy cover across 68.2%. Tree hollows,	**Potential listed threatened species**	Grey Falcon, Northern Shrike-tit, Plains Death Adder, Gouldian Finch

Amungee NW 2 (AMS1-2)		Survey photos of the vegetation/habitat of the surrounding environment	
	mistletoe and flowering plants absent. Fire damage > 2 years ago. No erosion. Cattle impacts. Termite mounds sparse. Ground cover: 20% vegetation, 10% litter, 70% bare soil	**Weeds**	During the 2022 survey, Hyptis and Sida (*Sida acuta*) were predominantly observed in the upper portion of Amungee Mungee Station, along the Carpentaria Highway corridor, fence lines and areas heavily disturbed by cattle – i.e. at drinking troughs.
		Hydrogeology	Groundwater resources and use is from the Gum Ridge Formation. A seasonal perched shallow alluvium system has also been locally identified by is not a groundwater source. The Anthony Lagoon Formation and undifferentiated Cretaceous are unsaturated.

Table 35: Summary of existing environment and surrounds – Amungee NW 3

Amungee NW 3 (AMS2)		**Survey photos of the vegetation/habitat of the surrounding environment**
Location	GDA94, zone 53, 0376604E, 8193091N	   
Landform and soil	Brown sandy loam grading to silty clay loam at 0.3 m, imperfectly drained on simple slope (1%).	
Vegetation community	*Corymbia dichromophloia* open woodland	
Vegetation description	*Corymbia dichromophloia mid high open woodland, over Terminalia canescens, Petalostigma pubescens and Hakea arborescens mid high sparse shrubland, over Chrysopogon fallax, Schizachyrium fragile open tussock grassland*	
Dominant flora species	*Corymbia dichromophloia, Terminalia canescens, Petalostigma pubescens, Erythrophleum chlorostachys, Hakea arborescens, Grevillea parallela, Ehretia saligna, Erythroxylum ellipticum*	

Amungee NW 3 (AMS2)		Survey photos of the vegetation/habitat of the surrounding environment	
Habitat condition	Common tree hollows and scattered fallen logs. No canopy cover across 66%. Tree hollows, mistletoe and flowering plants absent. Fire damage >2 years ago. No erosion. Cattle impacts. Termite mounds common. Ground cover: 20% vegetation, 5% litter, 35% bare soil, 40% gravel		
		Potential listed threatened species	Grey Falcon, Northern Shrike-tit, Plains Death Adder, Gouldian Finch
		Weeds	Moderate to dense predominantly Hyptis (*Mesophaerum suaveolens*) within the upper portion of Shenandoah East in the Carpentaria Highway corridor. Low number of localised records.[15]
		Hydrogeology	Groundwater resources and use is from the Gum Ridge Formation. A seasonal perched shallow alluvium system has also been locally identified by is not a groundwater source. The Anthony Lagoon Formation and undifferentiated Cretaceous are unsaturated.

[15] NR Maps 2022. Shenandoah East Station Portion 7027 Land Resources (nt.gov.au), viewed online 30 June 2022.

Table 36: Summary of existing environment and surrounds – Amungee NW 4

Amungee NW 4 (AMS3)		**Survey photos of the vegetation/habitat of the surrounding environment**
Location	GDA94, zone 53, 0390418E, 8186954N	   
Landform and soil	Dark reddish brown loamy sand grading to sandy loam at 0.2 m. Well drained over simple slope <1%.	
Vegetation community	*Corymbia dichromophloia* and *Erythrophleum chlorostachys* woodland	
Vegetation description	*Corymbia dichromophloia* and *Erythrophleum chlorostachys* mid high woodland, over *Acacia calligera*, *Grevillea parallela* and *Hakea arborescens* mid high open shrubland, over *Chrysopogon fallax* and *Triodia bitextura* open tussock grassland	
Dominant flora species	*Corymbia dichromophloia*, *Erythrophleum chlorostachys*, *Hakea arborescens*, *Grevillea parallela*, *Terminalia canescens*, *Denhamia cunninghamii*	
Habitat condition	Scattered tree hollows and fallen logs. Mistletoe and flowering plants absent. No canopy cover across 58%. Fire damage >2 years ago. No erosion. Cattle impacts. Termite mounds sparse. Ground cover: 15% vegetation, 65% litter, 5% bare soil, 15% gravel.	
Potential listed	Grey Falcon, Northern Shrike-tit, Plains Death Adder, Gouldian Finch	

Amungee NW 4 (AMS3)		Survey photos of the vegetation/habitat of the surrounding environment	
		threatened species	
		Weeds	During the 2022 survey, Hyptis and Sida (*Sida acuta*) were predominantly observed in the upper portion of Amungee Mungee Station, along the Carpentaria Highway corridor, fence lines and areas heavily disturbed by cattle – i.e. at drinking troughs.
		Hydrogeology	Groundwater resources and use is from the Gum Ridge Formation. A seasonal perched shallow alluvium system has also been locally identified by is not a groundwater source. The Anthony Lagoon Formation and undifferentiated Cretaceous are unsaturated.

Table 37: Summary of existing environment and surrounds – Amungee NW 5

Amungee NW 5 (AMS4)		**Survey photos of the vegetation/habitat of the surrounding environment**
Location	GDA94, zone 53, 0390418E, 8186954N	   
Landform and soil	Dark reddish brown loamy sand grading to sandy loam. Well drained over simple slope 1%.	
Vegetation community	*Corymbia dichromophloia* and *Eucalyptus chlorophylla* open woodland	
Vegetation description	*Corymbia dichromophloia* and *Eucalyptus chlorophylla* mid high open woodland, over *Erythrophleum chlorostachys, Petalostigma pubescens* and *Terminalia volucris* mid high open shrubland, over *Themeda triandra, Chrysopogon fallax* and *Schizachyrium fragile* tussock grassland	
Dominant flora species	*Erythrophleum chlorostachys*, *Corymbia dichromophloia*, *Eucalyptus chlorophylla*, *Terminalia canescens*, *Terminalia volucris*, *Petalostigma pubescens*, *Corymbia polycarpa*, *Acacia shirleyi*, *Macropteranthes kekwickii*, *Grevillea parallela*	
Habitat condition	Scattered tree hollows and fallen logs. Mistletoe and flowering plants absent. No canopy cover across 70.25%. Fire damage >2 years ago. No erosion. Cattle impacts. Termite mounds common. Ground cover: 40% vegetation, 40% bare soil, 20% leaf litter.	

Amungee NW 5 (AMS4)		Survey photos of the vegetation/habitat of the surrounding environment	
		Potential listed threatened species	Grey Falcon, Northern Shrike-tit, Plains Death Adder, Gouldian Finch
		Weeds	During the 2022 survey, Hyptis and Sida (*Sida acuta*) were predominantly observed in the upper portion of Amungee Mungee Station, along the Carpentaria Highway corridor, fence lines and areas heavily disturbed by cattle – i.e. at drinking troughs. One localised occurrence of Annual Mission grass (*Cenchrus pedicellatus*) recorded on the proposed access track to the site.

5.1 Physical environment

5.1.1 Climate

The climate of the permit areas is arid to semi-arid, with rainfall decreasing in frequency and quantity from north to south. The climate is monsoon influenced, with a distinctive wet summer between October and March, and a dry winter season between May and August. September and April are transitional months with occasional rainfall.

Rainfall in the north of the Beetaloo exploration area is recorded at 681 mm at Daly Waters. The southern portion of the permit area records an average annual rainfall of 536 mm at Newcastle Waters and 602 mm at Elliott. Approximately 90% of the rainfall occurs during the wet season.

The area is characterised by a net precipitation deficit of between -1,800 mm and -2,150 mm per year.

5.1.2 1:1000 wet season annual re-occurrence interval calculations

Monthly rainfall totals were analysed from the Scientific Information for Land Owners (SILO) data to interpolate rainfall data from 1900 to the present day. Consistent with industry accepted methodology associated with practices (such as dam risk assessments which calculates the wet season based on your geographical location) 3 months was determined applicable.

The highest 3-month rainfall period during the wet and dry seasons was predicted for every year from 1900 till 2018. These values were then used to fit a Log Pearson III distribution to the data to allow us to extrapolate to the 1,000 year, 3-month duration wet season (Figure 33) and 3-month dry season (Figure 34). This method is consistent with the Australian Rainfall & Runoff methodologies. The median 1 in 1,000-year 3-month wet season is 1,289 mm and 3-month dry season is 300 mm. These figures do not include any evaporation and are therefore considered extremely conservative.

Based on the assessment, a 1,300 mm wet season and 300 mm dry season freeboard will be applied to all open sumps and tanks.

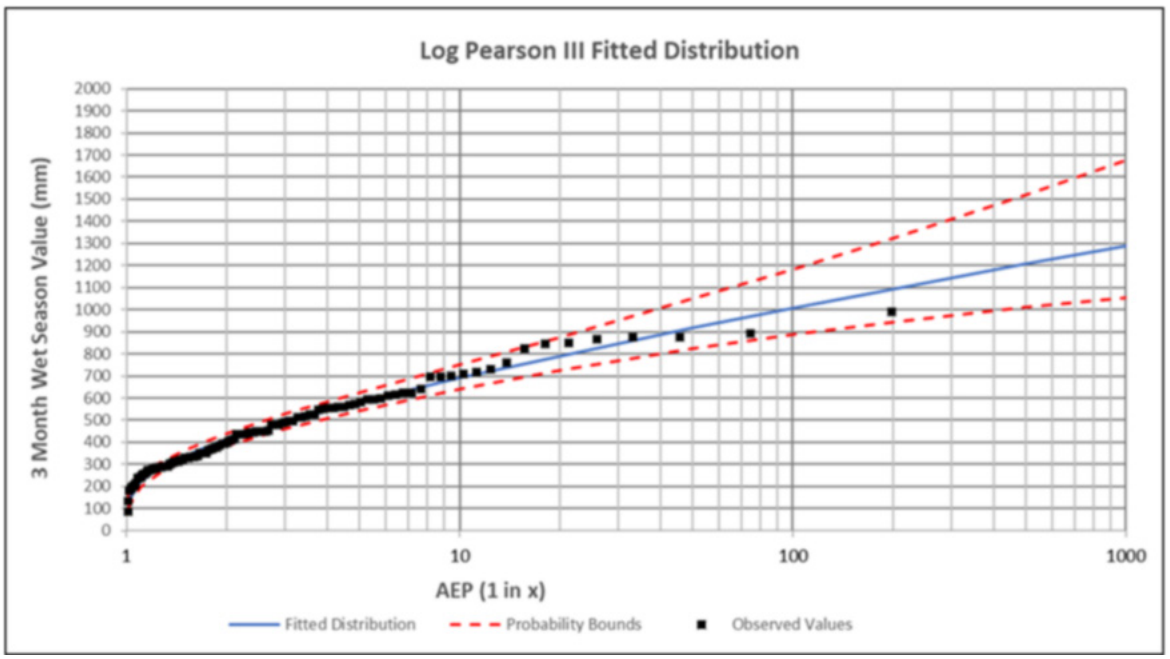


Figure 33: Log Pearson determination of 1:1000 wet season ARI

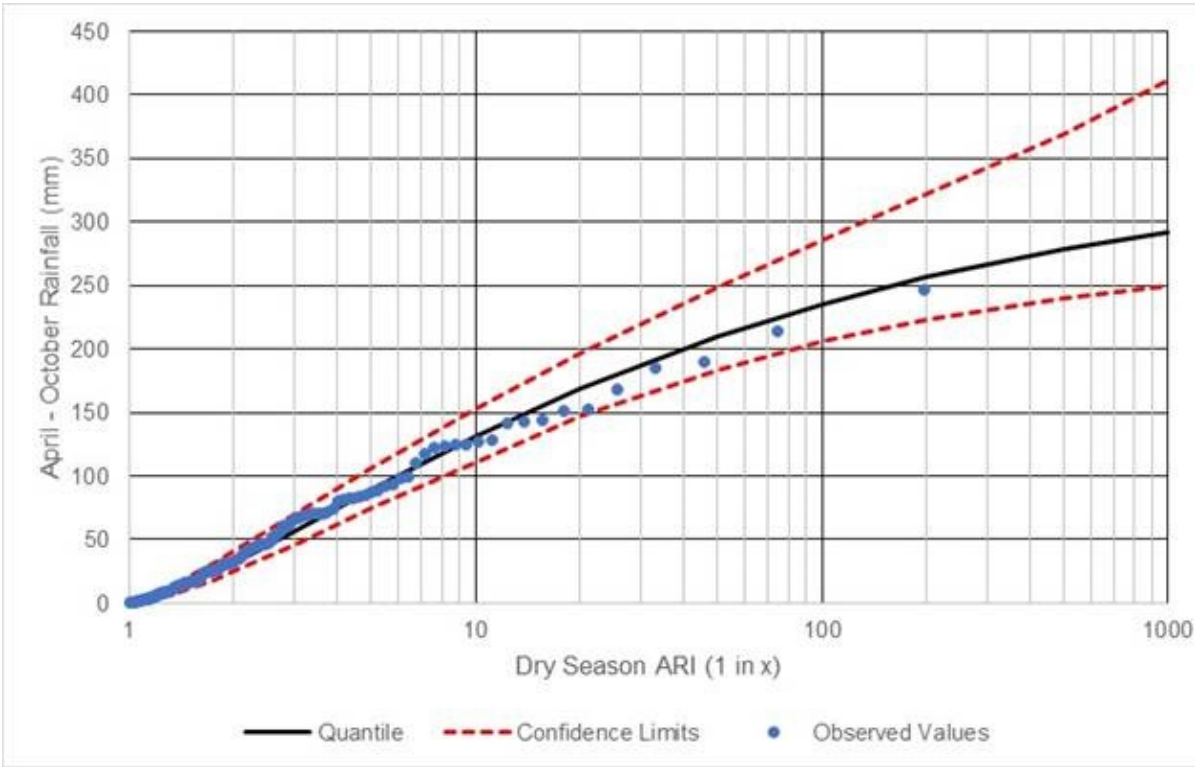


Figure 34: Log Pearson determination of 1:1000 dry season ARI

5.1.3 Geology

The Beetaloo Sub-basin comprises a thick sequence of mudstone and sandstone formations (Roper Group) that were deposited approximately 1,500 – 1,300 million years ago (Ma). The Roper Group is estimated to reach more than 5,000 m in thickness in the centre of the Sub-basin and estimated to be thinner outside the formally defined Beetaloo Sub-basin. The Roper Group is overlain unconformably by the yet to be formally defined Neoproterozoic Group. Unconformably overlying the Neoproterozoic group is the Georgina Basin (Cambrian) sedimentary package, which includes widespread extrusive flood basalts and a thick limestone sequence that forms the Cambrian Limestone Aquifer (CLA), a significant water supply aquifer. The Georgina Basin is capped unconformably by a thin section of Cretaceous mudstone and sandstone (Albian aged ~100-113 Ma) and recent alluvial and laterite deposits.

The proposed wells will be completed in the Velkerri formation. Organic richness within the Velkerri formation is generally confined to three to four main shale intervals, the A, A-B, B and C shales. The existing Amungee NW-1H well has been completed in the Velkerri B shale. The proposed Amungee Delineation Area wells will also likely be located in the Velkerri B Shale, although other shales (A, A-B or C) may be targeted in the future.

The Velkerri Formation Amungee Member is overlain with thick series of low permeability units (mudstone, siltstones, tight sandstone and Volcanic units) which include the Velkerri Formation Wyworrie Member, Kyalla Formation, Shenandoah-East Formation, and Antrim Plateau Volcanics. These formations provide thick and multilayered effective geological barriers, with the Gum Ridge Formation separated from the target formations by >1500 m. The effectiveness of geological barriers to fracture height growth will be assessed prior to stimulation with geomechanical data from core analysis, wireline log data and modelling.

5.1.4 Soils

The Stuart Plateau bioregion covers an area of 103,857 km^2 and comprises undulating plains on sandstones, with mostly neutral sandy red and yellow earth soils (ANRA, 2008).

The soil types located within the plateau range from the very strongly leached lateritic soils of the Tertiary land surface to the calcareous desert soils and desert loams in the southern drier areas.

The lateritic plains, located with the permit area, are classed as very strongly leached soils of the Tertiary land surface. The three main soil types located within the permit area, include:

1. **Tertiary Lateritic Red Earths:** which occur on the gently undulating topography. The soil profile can be described as:
   - **A-Horizon** Grey-brown sandy loam
   - **B-Horizon** Reddish-brown sandy clay loam
   - **C-Horizon** Red-brown to red light clay, overlying heavy ferruginous gravel and massive laterite
2. **Tertiary Lateritic Red Sands:** which occur on gently undulating to undulating topography of the Tertiary Lateritic Plain, formed from sandstones and complex parent materials of the deep sandy soils. The soil profile can be described as

   A-Horizon Grey-brown to brown sand

   B-Horizon Brown sand

   C-Horizon Red-brown to yellow-brown sand overlying pisolitic ferruginous gravel and massive laterite. Altered colouring of highly siliceous parent sandstone is only evident in the mottled and pallid zones

3. **Tertiary Lateritic Podzolic Soils:** formed on the gently undulating topography over a variety of rocks. These soils are located in the northern section of the Barkly Basin. The soil profile can be described as

A-Horizon	Grey sand
B-Horizon	Yellowish-grey sand
C-Horizon	Yellow-grey sandy loam with ferruginous gravel overlying massive laterite, mottled and pallid zones

Table 36 presents the erosion risk rating based on average monthly rainfall using the rating system provided in the IECA (2008) Table 4.4.2 for Daly Waters. All construction activities are anticipated to be undertaken on the lease pad which has a stormwater sediment basin. Limited clearing or major civil construction activities are planned for the wet season. The overall risk of erosion is considered very low.

Table 38: Erosion risk rating based on average monthly rainfall at Daly Waters

Item	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	163.9	185.4	107.5	20.7	6.4	2.8	1.7	0.3	1.9	21.2	48.1	119.1
Erosion Risk*	H	H	H	VL	VL	VL	VL	VL	VL	VL	L	H

** E = Extreme (>225 mm); H = High (100+ to 225 mm); M = Moderate (45+ to 100 mm); L = Low (30+ to 45 mm); VL = Very Low (0 to 30 mm)*

5.1.5 Seismicity

Large earthquakes are relatively rare in Australia with an earthquake exceeding magnitude 7 on the Richter scale occurring somewhere in Australia every 100 years (SRC 2017). Earthquakes are comparably rare in the NT, aside from limited areas around Tenant Creek and west of Alice Springs (refer Figure 35) where several earthquakes with a magnitude of 6.2-6.4 occurred in a 12-hour period. Thousands of aftershocks have occurred since and whilst the rate has decreased, it has not yet returned to its pre-1987 level (McCue 2013).

In the Beetaloo, there have been no earthquakes over magnitude 3 measured since records began. The area is not prone to seismic activity and there is no evidence of recent earthquake activity as most faults and the major subsurface structure are confined to Cambrian or older strata.

The issue of induced seismicity from HFS activities has gained increasing exposure due to some high magnitude events in Oklahoma. However, the United States Geological Survey has stated very clearly that HFS is not causing most of the induced earthquakes and has pointed out that wastewater disposal via reinjection is the primary cause of recent earthquakes in the Central USA (USGS 2017b). Davies *et al.* (2013) illustrates that induced seismicity directly attributed to HFS operations is of such low occurrence that the documented cases are statistical anomalies rather than commonly occurring phenomena.

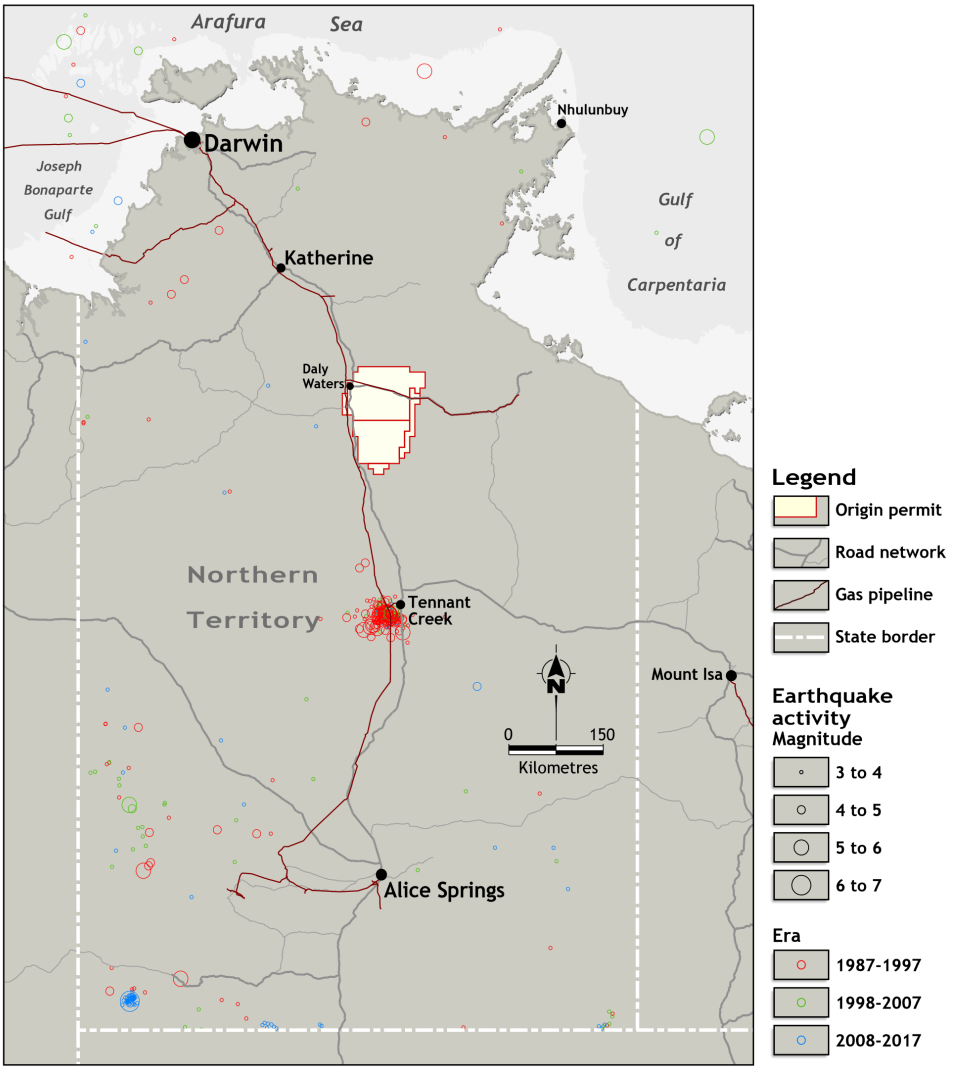


Figure 35: Earthquakes greater than magnitude 3 from 1987 to 2017 across the NT showing an absence of seismic activity in the Beetaloo area

5.1.6 Hydrology

The existing Amungee Delineation Area falls within the Wiso River Basin. The Wiso River Basin covers the southern half of EP98 (south of the Carpentaria Highway) and the majority of EP76 and EP117 and is internally drained by Newcastle Creek and several small ephemeral creeks. Refer to

Newcastle Creek (Stream Order 4) is approximately 85km to the south of the Amungee Delineation Area. Newcastle Creek ultimately flows into Lake Woods, which is located south of the Newcastle Waters Station. Lake Woods covers an area of inundation of approximately 50,000 ha in normal rainfall years, extending to 80,000 ha in exceptionally wet years, after which it can retain water for several years (HLA, 2005). Lake Woods is described as a major quasi-permanent surface water body and is listed on the NT Government Sites of Conservation Significance and on the Directory of Important Wetlands in Australia (HLA, 2006b). Some semi-permanent and many ephemeral waterholes are located across the permit area (HLA, 2006b)

The closest creek to any site is an unnamed branch of Arnold River, which is 15 km from the Amungee NW 4 site. An unnamed tributary of the Newcastle creek is also 15.7 km from Amungee

NW4. The streams are overland flow paths that only flow for a short period during the wet season, with waterholes forming at the beginning of the dry season. Due to the separation distance from the sites to the closest watercourse, these features are unlikely to be directly impacted by the activities proposed under this EMP.

During the wet season, it is likely the broader region could experience widespread periodic surface flooding, to a depth of 30 cm, which has previously been identified by debris being collected on fence lines (HLA, 2005). All sites will be elevated above ground level, fully bunded with flood diversion works undertaken to prevent inundation.

5.1.7 Flood risk assessment

The extent of inundation within the permit area depends on the severity of the wet season and can range from remaining completely dry to widespread flooding. As a part of the Land Condition Assessment (Appendix J), AECOM assessed the 1% Annual Exceedance Probability (AEP) flood depths and levels to determine the risk of flood inundation during the 100-year flood event from a local or regional flooding for each of the Amungee Delineation Area exploration well sites (Table 38).

The greatest risk of flooding to the new exploration well sites is from local catchment sheet-flow (rainfall immediately over the area draining to the site). The site bund is typically <0.5M in height, meaning all sites should be protected from widespread inundation. The local catchment runoff from major storm events will be the considering factor for the establishment of lease pad finish levels and the lease pad designs will take this into consideration for the final placement in the landscape.

Table 39: 1% AEP Results for Each Lease Pad

Lease Pad	SRTM Ground Elevation (m AHD)	Maximum Water Depth (m)	Flood Level at Nearest Channel (m AHD)
Amungee NW-2	286.6	0.4	287.1
Amungee NW-3	253.5	0.1	253.6
Amungee NW-4	295.7	0.3	296.0
Amungee NW-5	284.3	<0.1	282.6

5.1.8 Hydrogeology

Within the Beetaloo exploration area, groundwater use is primarily from the Cambrian Limestone Aquifer (CLA) with minor, localised use from formations where shallower groundwater is intersected, where the CLA is too deep, or where the CLA is absent from erosion. This includes:

- overlying Cretaceous sediments where it is saturated in the central-south of the Beetaloo Sub-basin
- Antrim Plateau Volcanics in the north-west
- Bukalara Sandstone in the north-east.

Table 33 summarises the encountered stratigraphy confirmed during the Amungee NW-1H drilling.

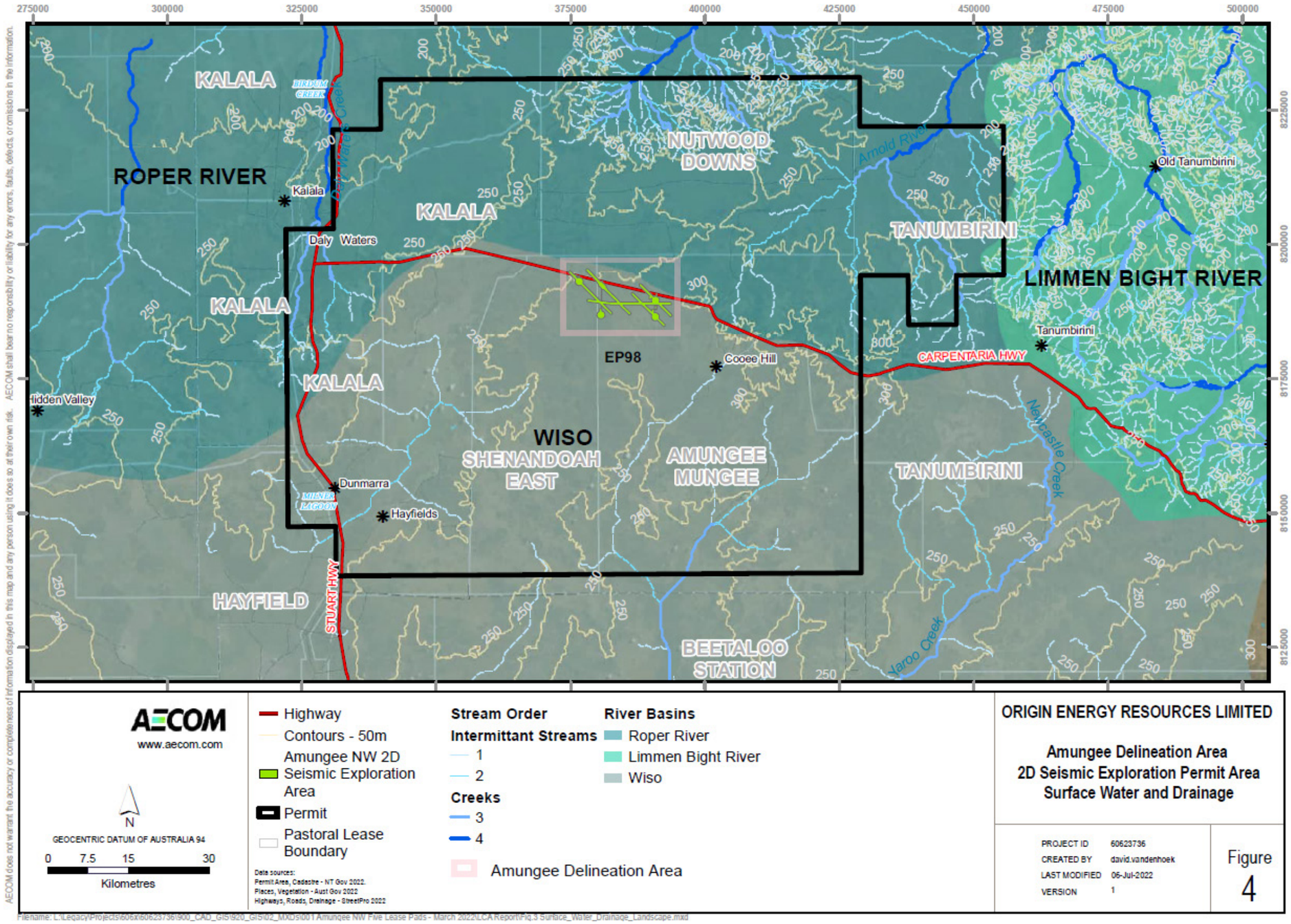


Figure: 36 Surface water and drainage of the Amungee Delineation Area

Table 40: Summary hydrostratigraphy in the Beetaloo Basin at the Amungee Delineation Area sites

Province	Period/Age	Formation		Aquifer status	Encountered Depths (approx. top and bottom) (m)	Regional Yield (L/s)	Avg regional EC (µs/cm
CARPENTARIA BASIN	CRETACEOUS	Undifferentiated		Regional aquifer- Not saturated at location	0 – 87	0.3 – 4	1,800
GEORGINA BASIN	CAMBRIAN	Cambrian Limestone Aquifer (CLA)	Anthony Lagoon Formation	Regional aquifer	Absent		
			Gum Ridge Formation	Regional aquifer	87 – 221	>20	1,180 (Amungee NW1)
		Antrim Plateau Volcanics		Regional aquitard	221 – 306	0.3 – 5	900
		Bukalara Sandstone		Local aquifer	306 – 418	0.3 – 5	1,000
Undefined – Under NTGS Review	NEO PROTEROZOIC	Shenandoah-East Formation		Regional aquitard	418 – 869	ID	32,000
		Jamison Sandstone		Local saline unit	869 – 948	ID	138,000
BEETALOO SUB-BASIN (ROPER GROUP)	MESO PROTEROZOIC 1,300-1,500 Ma	Kyalla Formation		Regional aquitard	948 – 1,349	ID	ID
		Moroak Sandstone		Local saline unit	1,349 – 1,668	0.5 – 5	131,000
		Velkerri Formation		Regional aquitard	1,668 Well TD	-	-
		Bessie Creek Sandstone		Local aquifer (not regionally connected)	Not Penetrated – Inferred to be present from 2D seismic interp.	0.5 – 5	-

ID - insufficient data

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 Sub-basin.

Based on historic monitoring bore and exploration well drilling within the Amungee Delineation Area the Anthony Lagoon Formation is anticipated to be eroded by the Base Cretaceous unconformity. At Amungee NW the Gum Ridge Formation is the upper water bearing aquifer unit with a standing water depth of approximately 106 m below ground level.

The limestone in the Gum Ridge Formation is commonly fractured and cavernous with bore yields of up to 100 L/s having been recorded from this aquifer. At the existing Amungee NW site, yields in excess of 20 L/sec were achieved with minimal (<1m) aquifer losses.

Approximately 80% of groundwater bores drilled in the basin screen the CLA and the aquifer supplies water for the pastoral industry and local communities including Elliott, 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 Sub-basin is estimated at 6,000 ML/year, primarily used for agricultural production (Foulton and Knapton 2015).

The Antrim Plateau Volcanics conformably underlies the CLA in the north and central part of the Beetaloo Sub-basin. Across much of the Basin it consists of sequences of massive basalt flows with negligible primary porosity. In the north-west of the Basin, where the formation is shallow and fractured, it forms a marginal aquifer, however, reported use is primarily from a sandstone sequence at the contact with the Gum Ridge Formation. There is no reported use within the 3 petroleum exploration permits held by Origin.

The Bukalara Sandstone forms a fractured and weathered aquifer where it outcrops beyond the north-east margin of the Beetaloo Sub-basin. The formation consists of quartz sandstone with shale interbeds and probable enhanced permeability in these areas due to jointing within the sandstone. No use is reported from the formation away from the north-east margin of the Beetaloo Sub-basin where it is at considerable depth. This unit, if present, will be protected through intermediate casing and cement.

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 (aquatic, riparian and floodplain) including the Roper River at Elsey National Park and Red Lily/57 Mile Waterhole. These discharge features occur around 100km north-west of the Beetaloo Sub-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 Sub-basin region). 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.

Limited information exists on the hydrogeological characteristics of the deeper Roper Group and undefined Neoproterozoic group sequence is available as it occurs at depth within the Beetaloo Sub-basin. This unit lies below the Georgina Basin which contains the CLA and other important aquifers. The deeper sandstone dominated formations may behave as aquifers, however, drilling results suggest these formations have limited potential as groundwater resources due to their depth and very high salinity. Groundwater in the Roper Group and undefined Neoproterozoic group is highly saline (>100,000 mg/L chlorides) and contrasts with the shallower, utilised aquifers of the Georgina Basin sediments in which groundwater is generally of drinking water quality.

5.1.8.1 Groundwater monitoring results

Groundwater monitoring data has been collected from groundwater bores located at the Amungee NW site since commencing in 2016 until present. A summary of the baseline monitoring data is provided in Table 40. Additionally, data collected during Origin's Beetaloo exploration program can be accessed via the DEPWS website located at: https://depws.nt.gov.au/onshore-gas/onshore-gas-in-the-northern-territory/industry-compliance-and-reporting/groundwater-monitoring-results.

Table 41: Summary of groundwater monitoring results collected at the Amungee NW site, within the Gum Ridge Formation

Analyte	Unit	Reporting limit	RN040894			RN039896			RN038493	
			# of Results	Maximum Conc.	Average Conc.	# of Results	Maximum Conc.	Average Conc.	# of Results	Maximum Conc.
Alkalinity (Bicarbonate) as $CaCO_3$	mg/L	1	5	405	382	8	422	390	1	426
Alkalinity (Total) as $CaCO_3$	mg/L	1	5	405	382	9	432.2	395	1	426
Anions Total	meq/L	0.01	5	13.7	13	8	14.3	13	1	13.8
Calcium						2	119			
Calcium (Filtered)	mg/L	1	5	122	117	7	123	116	1	129
Cations Total	meq/L	0.01	5	13.5	13	8	14.4	13	1	13.7
Chloride	mg/L	1	5	101	87	9	144	103	1	91
Electrical Conductivity (Lab)	µS/cm	1	5	1160	1136	8	1340	1209	1	1170
Fluoride	mg/L	0.1	5	0.6	0.54	5	1.2	0.64	1	0.5
Methane	mg/L	0.01	0	ND	0.005	1	0.002	0.0041	0	<0.001
pH (Lab)	pH	0.01	5	7.45	7.3	7	8.11	7.7		
Potassium						2	12			
Potassium (Filtered)	mg/L	1	5	10	9.8	7	11	10	1	11
Sodium						2	77			
Sodium (Filtered)	mg/L	1	5	72	68	7	103	76	1	67
Sulfate as SO_4						1	127			
Sulfate as SO_4 (Filtered)	mg/L	1	5	139	136	8	142	131	1	132

Analyte	Unit	Reporting limit	RN040894			RN039896			RN038493	
			# of Results	Maximum Conc.	Average Conc.	# of Results	Maximum Conc.	Average Conc.	# of Results	Maximum Conc.
Total Dissolved Solids	mg/L	10	5	728	705	7	848	761	1	759
Barium	mg/L	0.001	5	0.106	0.087	5	0.196	0.11		
Barium (Filtered)	mg/L	0.001	5	0.105	0.079	4	0.1	0.076	1	0.046
Strontium	mg/L	0.001	5	0.706	0.67	1	0.709050667			
Strontium (Filtered)	mg/L	0.001	5	0.683	0.63	1	0.661			

5.2 Biological environment

5.2.1 Bioregions

The Amungee Delineation Area sites fall within the Stuart Plateau Bioregion. The bioregion is characterised by undulating plains on sandstone with predominantly neutral sandy red and yellow earth soils. Dominant vegetation associations included extensive areas of Lancewood (*Acacia shirleyi*), Bullwaddy (*Macropteranthes kekwickii*) vegetation and associated fauna, including the Spectacled Hare-Wallaby (*Lagorchestes conspicillatus*). Land condition in the bioregion is moderate to good but is threatened by impacts from weeds, feral animals, pastoralism and changed fire regimes.

5.2.2 Vegetation communities

Surveys of the vegetation communities of the proposed activity locations within the Amungee Delineation Area were completed in May 2022 by AECOM. Data has also been utilised from previous baseline assessments completed in 2004, 2006 (HLA, 2006; 2006c), 2010, 2014, 2016 ,2018 and 2021 (AECOM, 2011; 2014; 2016, 2018 and 2021).

The proposed activity locations (well sites and seismic lines) of the Amungee Delineation Area have been evaluated through detailed habitat assessments which included identification of vegetation community, dominant flora species at each strata, habitat condition, disturbance factors (fire, weeds, erosion, feral fauna species), and fauna attributes (e.g. tree hollows, logs, grass cover, mistletoe abundance).

The main vegetation communities that will be disturbed by the Amungee Delineation Area for the 2D seismic and well exploration are summarised in Table 41. Community 2a, which is the most widespread vegetation community within the Amungee delineation area will result in only 3.25% of that vegetation being disturbed in the immediate area.

Table 42: Percentage of vegetation community disturbance for 2D seismic and exploration well area

Vegetation community	Area (ha)	% of vegetation community within Amungee Delineation Area
Community 1a - *Acacia shirleyi* ± *Corymbia polycarpa* mid high woodland, over *Macropteranthes kekwickii*, *Terminalia volucris*, *Santalum lanceolatum* mid high shrubland, over *Scleria brownii*, *Chrysopogon fallax*, *Schizachyrium fragile* mid high tussock grassland.	7.1	0.38
Community 2a - *Corymbia dichromophloia*, ± *Erythrophleum chlorostachys*, ± *Eucalyptus chlorophylla* mid high open woodland, over *Terminalia canescens*, *Petalostigma pubescens*, *Erythrophleum chlorostachys* mid high open shrubland, over *Chrysopogon fallax*, ± *Sorghum plumosum*, *Themeda triandra* mid high open tussock grassland.	101.5	3.25
Bare/Disturbed	2.9	-

Potential environmental risks and impacts to the environment have been identified based on environmental conditions observed during the field survey. The overall disturbance footprint for the Amungee delineation area is approximately 107 ha, however with the development of mitigation measures to minimise Origin's impact to the environment Origin could reduce its disturbance area to approximately 97.34 ha.

During the survey the proposed exploration well sites, seismic lines, access tracks and gravel pit were assessed to be in generally good condition with minor evidence of weeds, erosion and disturbance from cattle.

The 6 vegetation communities identified from 41 vegetation sites recorded within the Amungee Delineation Area are shown in Figure 37 and summarised in Figure 38 to Figure 42. These figures provide a holistic view of the vegetation communities associated with the proposed exploration sites and 2D seismic lines.

The vegetation communities are considered regionally extensive and not subjected to extensive clearing.

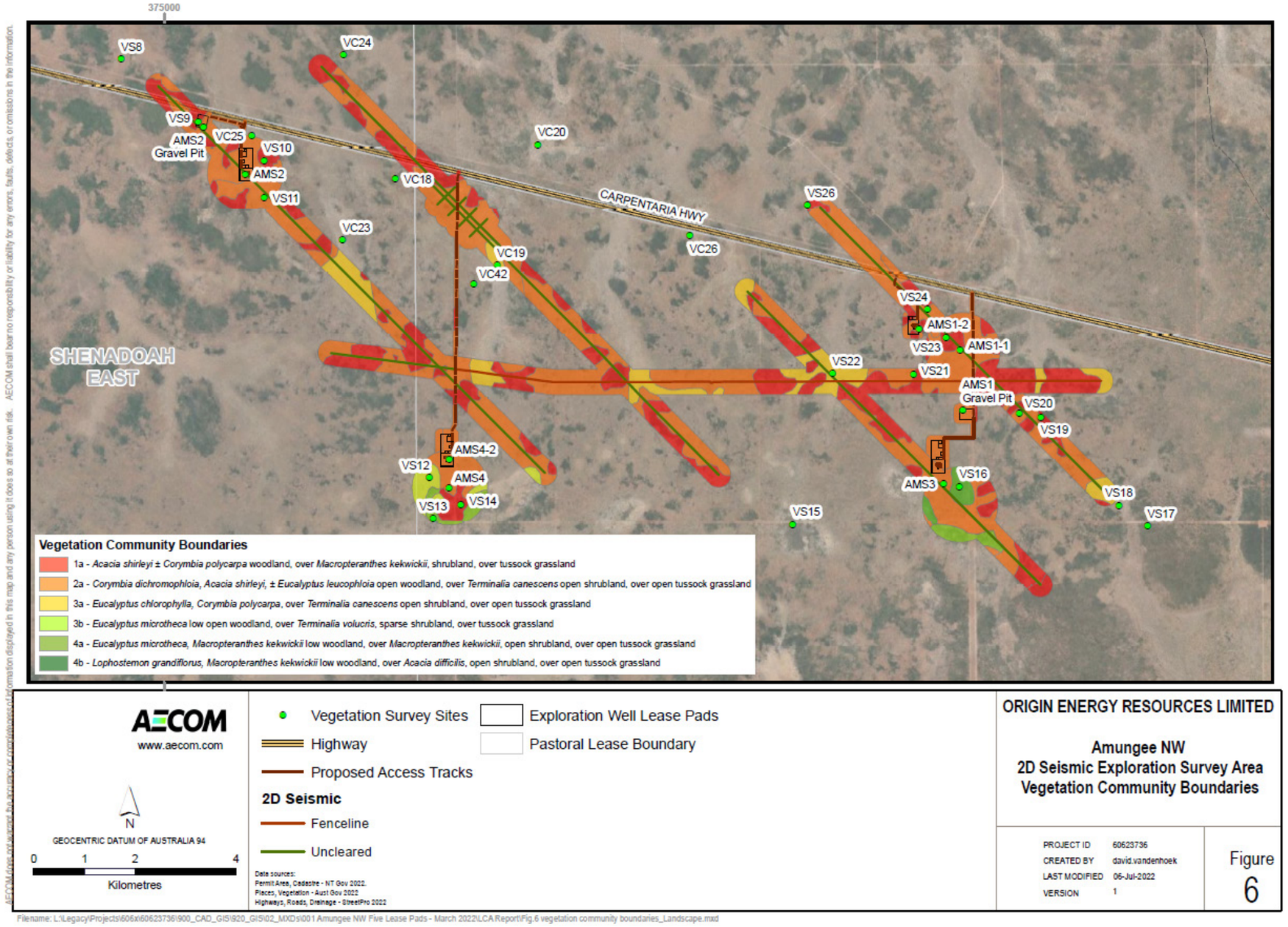


Figure 37: Vegetation communities and scouting locations within the proposed exploration sites within the Amungee Delineation Area

Figure 38: Communtiy 1a

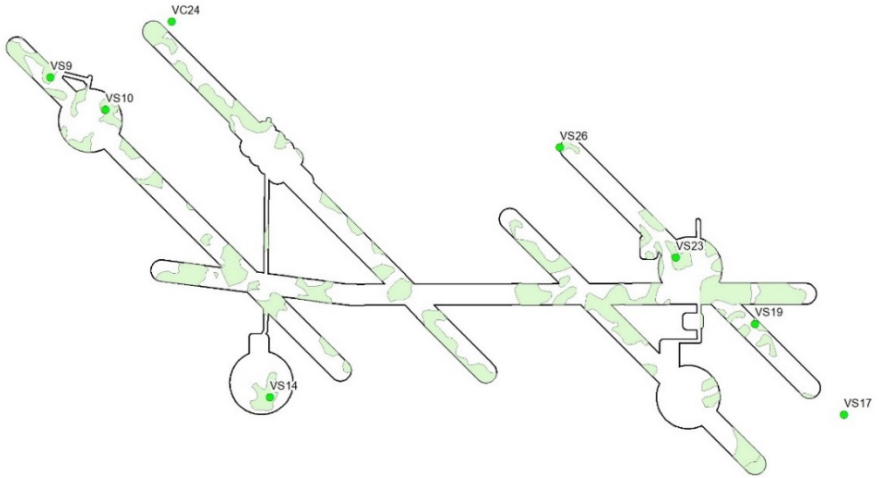
Community 1a (NVIS Code: T7r) - *Acacia shirleyi* ± *Corymbia polycarpa* mid high woodland, over *Macropteranthes kekwickii*, *Terminalia volucris*, *Santalum lanceolatum* mid high shrubland, over *Scleria brownii*, *Chrysopogon fallax*, *Schizachyrium fragile* mid high tussock grassland.					
Upper 1: Mid high open woodland dominated by *Acacia shirleyi* (fq 100%), *Corymbia polycarpa* (fq 20%), *Macropteranthes kekwickii* (20%)					
Mid 1: Mid high shrubland dominated by *Macropteranthes kekwickii* (fq 100%), *Terminalia volucris* (fq 100%), *Santalum lanceolatum* (fq 66%),					
Ground 1: Mid high open tussock grassland dominated by *Scleria brownii* (fq 50%), *Chrysopogon fallax* (fq 20%) *Schizachyrium fragile* (fq 20%)					
					
No. of sites:	(10) VC6, VC7, VC24, VS9, VS10, VS14, VS17, VS19, VS23, VS26				
Other species:	**Upper stratum (U1):** - *Macropteranthes kekwickii*	**Mid stratum (M1):** *Acacia shirleyi (*fq 10%), *Atalaya hemiglauca* (fq 10%)	**Ground stratum (G1):** *Bidens bipinnata* (fq 10%), *Eriachne armitii* (fq 10%), *Waltheria indica* (fq 10%), *Abutilon fraseri* (fq 10%), *Aristida calycina* (fq 10%), *Jasminum molle* (fq 10%)		
Landform:	Lateritic Plains and Rises -associated with deeply weathered profiles (laterite) including sand sheets and other depositional products, sandy and earth soils	**Soils:**	Brown sandy loam kandosol soils.	**Total area of the survey area:**	1857.305 ha (32.8 %)

Figure 39: Community 2a

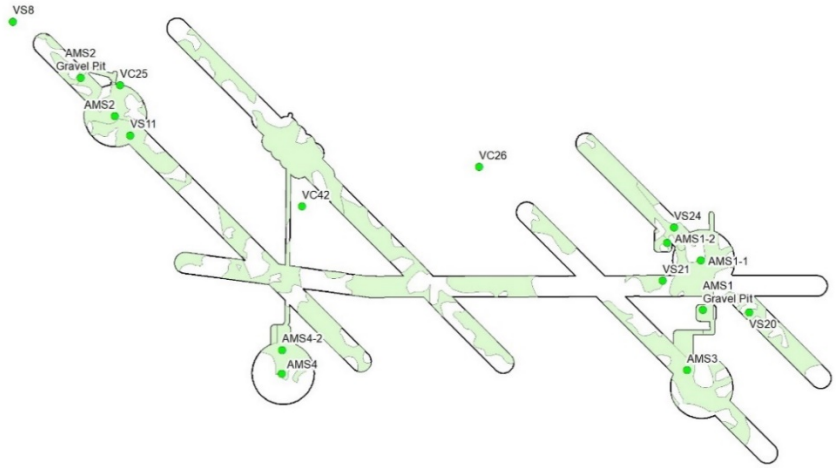
Community 2a (NVIS Code: T7r) - *Corymbia dichromophloia*, ± *Erythrophleum chlorostachys, ± Eucalyptus chlorophylla* mid high open woodland, over *Terminalia canescens, Petalostigma pubescens*, *Erythrophleum chlorostachys* mid high open shrubland, over *Chrysopogon fallax, ± Sorghum plumosum, Themeda triandra* mid high open tussock grassland.					
Upper 1: Mid high open woodland dominated by *Corymbia dichromophloia* (fq 80%), *Erythrophleum chlorostachys* (fq 35%), *Eucalyptus chlorophylla* (fq 30%)					
Mid 1: Mid high open shrubland dominated by *Terminalia canescens* (fq 55%), *Petalostigma pubescens* (fq 45%), *Erythrophleum chlorostachys* (35%)					
Ground 1: Mid high open tussock grassland dominated by *Chrysopogon fallax* (fq 85%), ± *Schizachyrium fragile* (fq 20%), ± *Themeda triandra* (fq 15%)					
					
No. of sites:	(21) VC5, VC8, VC18, VC21, VC25, VC26, VC42, AMS1-1, AMS1-2, AMS1 GravelPit, AMS2, AMS2 GravelPit, AMS3, AMS4, AMS4-2, AMS5, VS8, VS11, VS20, VS21, VS24				
Other species:	**Upper stratum (U1):** *Acacia shirleyi* (20%), *Eucalyptus leucophloia* (fq 10%), *Terminalia canescens* (fq 5%), *Corymbia ferruginea* (fq 5%), *Grevillea parallela* (fq 5%)	**Mid stratum (M1):** *Acacia calligera* (fq 20%), *A. difficilis* (fq 5%), *Alphitonia excelsa* (fq 20%), *Hakea arborescens* (fq 20%), *Corymbia ferruginea* (fq 15%), *Grevillea parallela* (fq 15%), *Terminalia volucris* (fq 15%), *Macropteranthes kekwickii* (fq 10%), *Carissa lanceolata* (fq 5%), *Eucalyptus leucophloia* (fq 5%), *Calytrix exstipulata* (fq 5%), *Bauhinia cunninghamii* (fq 5%), *Santalum lanceolatum* (fq 5%)	**Ground stratum (G1):** *Sorghum plumosum* (15%), *Sehima nervosum* (fq 15%), *Eriachne ciliata* (fq 15%), *Triodia bitextura* (fq 15%), *Sorghum timorense* (fq 5%), *Waltheria indica* (fq 5%), *Aristida inaequiglumis* (fq 5%), *Hakea arborescens* (fq 5%)		
Landform:	Lateritic Plains and Rises - associated with deeply weathered profiles (laterite) including sand sheets and other depositional products, sandy and earth soils.	**Soils:**	Brown sandy loam kandosol soils.	**Total area of the survey area:**	3104.08 ha (54.9%)

Figure 40: Community 3a

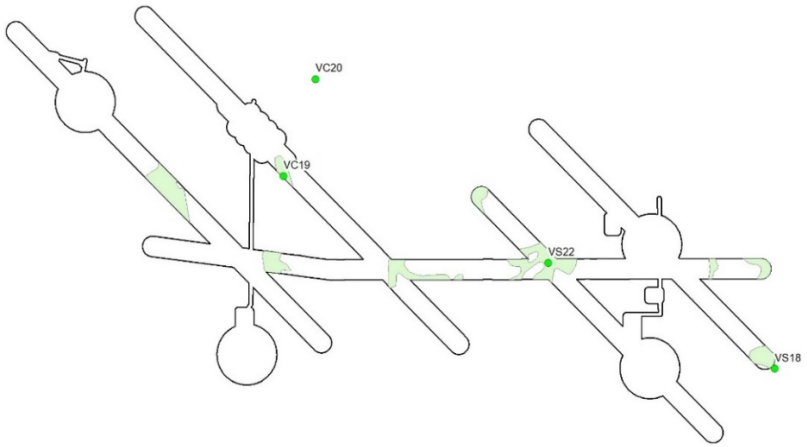
Community 3a (NVIS Code: T6r) - *Eucalyptus chlorophylla*, *Corymbia polycarpa,* ± *Corymbia dichromophloia* mid high open woodland, over *Eucalyptus chlorophylla*, ± *Corymbia ferruginea,* ±*Terminalia canescens*, mid high open shrubland, over *Chrysopogon fallax* mid high open tussock grassland					
Upper 1: Mid high open woodland dominated by *Eucalyptus chlorophylla* (fq 83%), *Corymbia polycarpa* (fq 50%), ± *Corymbia dichromophloia* (fq 33%)					
Mid 1: Mid high open shrubland dominated by *Eucalyptus chlorophylla* (fq 66%), ± *Terminalia canescens* (fq 16%), ± *Corymbia ferruginea* (fq 16%)					
Ground 1: Mid high open tussock grassland dominated by *Chrysopogon fallax* (fq 83%)					
					
No. of sites:	(6) VC19, VC20, VC22, VC23, VS18, VS22				
Other species:	**Upper stratum (U1):** *Erythrophleum chlorostachys* (fq 16%), *Eucalyptus camaldulensis* (fq 16%)	**Mid stratum (M1):** *Acacia pellita* (fq 16%), *Grevillea parallela* (fq 16%), *Petalostigma pubescens* (fq 16%), *Terminalia volucris* (fq 16%), *Acacia difficilis* (fq 16%), *Ehretia saligna* (fq 16%),		**Ground stratum (G1):** - *Dichanthium fecundum* (fq 16%), *Eulalia aurea* (fq 16%), *Themeda triandra* (fq 16%), *Panicum sp* (fq 16%).	
Landform:	Drainage floors and relic drainages associated with clay and alluvial soils	**Soils:**	Reddish brown clay soils	**Total area of the survey area:**	325.32 ha (5.8%)

Figure 41: Community 3b

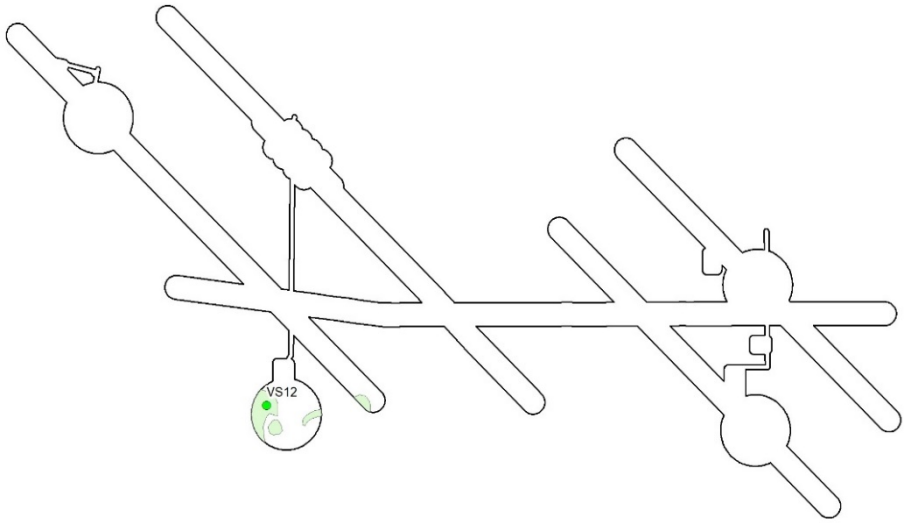
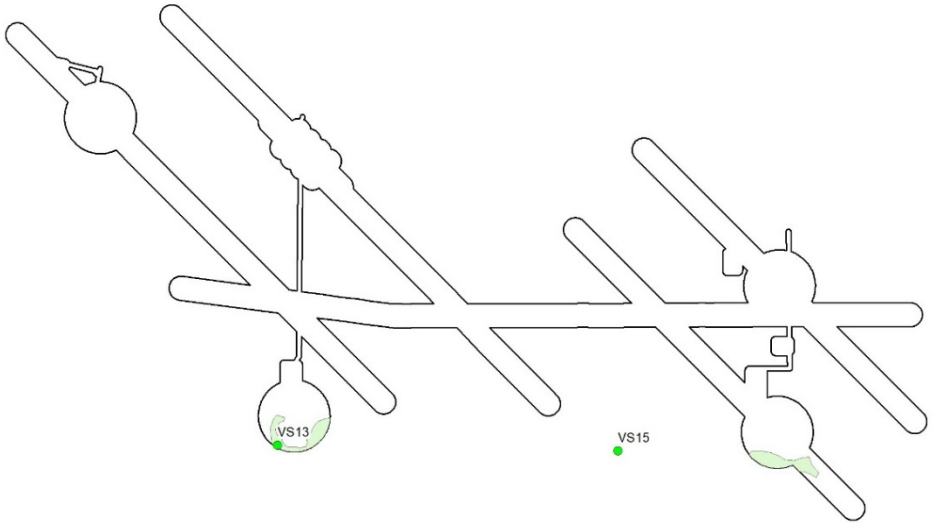
Community 3b (NVIS Code: T6r) - *Eucalyptus microtheca* low open woodland, over *Terminalia volucris, Ehretia saligna*, mid high sparse shrubland, over *Aristida inaequiglumis, Eulalia aurea* mid high tussock grassland.					
Upper 1: Low woodland dominated by *Eucalyptus microtheca* (fq 100%), *Macropteranthes kekwickii* (fq 100%)					
Mid 1: Mid high Open shrubland dominated by *Macropteranthes kekwickii* (fq 100%), *Eucalyptus microtheca* (fq 100%), *Brachychiton diversifolius* (fq 50%).					
Ground 1: Mid high open tussock grassland dominated by *Chrysopogon fallax* (fq 100%), *Sorghum plumosum* (fq 100%).					
					
No. of sites:	(1) VS12			**Other common species:**	None
Landform:	Drainage floors and relic drainages associated with clay and alluvial soils	**Soils:**	Reddish brown clay soils	**Total area of the survey area:**	103.50 ha (1.8%)

Figure 42: Community 4a

Community 4a (NVIS Code: T6i) - *Eucalyptus microtheca*, *Macropteranthes kekwickii* low woodland, over *Macropteranthes kekwickii*, *Eucalyptus microtheca*, *Brachychiton diversifolius* mid high open shrubland, over *Chrysopogon fallax*, *Sorghum plumosum* mid high open tussock grassland.					
Upper 1: Low woodland dominated by *Eucalyptus microtheca* (fq 100%), *Macropteranthes kekwickii* (fq 100%)					
Mid 1: Mid high Open shrubland dominated by *Macropteranthes kekwickii* (fq 100%), *Eucalyptus microtheca* (fq 100%), *Brachychiton diversifolius* (fq 50%).					
Ground 1: Mid high open tussock grassland dominated by *Chrysopogon fallax* (fq 100%), *Sorghum plumosum* (fq 100%).					
					
No. of sites:	(2) VS13, VS15			**Other common species:**	None
Landform:	Closed drainage depression associated with clay and alluvial soils	**Soils:**	Reddish brown clay soils	**Total area of the survey area:**	227.80 ha (4.0%)

5.2.3 Flora

A search of the DCCEEW Protected Matters database of nationally significant fauna (PMST) and the NT Government flora atlas database was undertaken for the exploration area, with a 10 km buffer applied. No threatened vegetation communities are listed as likely to occur within the project area.

A total of 805 plant species have been recorded within the Beetaloo exploration area, and during the most recent May 2022 survey, 73 flora species were identified. No threatened flora were identified during the surveys.

5.2.4 Weeds

Weed surveys were undertaken within the Amungee Delineation Area (proposed well sites and seismic lines) during the October 2020, November 2021 and May 2022 field surveys. Survey areas included the edge of tracks, disturbance areas and along the Carpentaria Highway. The following weeds were recorded during the May 2022 field survey:

- Hyptis (*Mesosphaerum suaveolens*)
- Sida (*Sida acuta*)
- Annual Mission grass (*Cenchrus pedicellatus*) - Environmental weed of concern

The class B weed Hyptis was observed along the Carpentaria Highway and along fence line tracks. Sida was observed predominantly in areas heavily disturbed by cattle, such as where drinking troughs were located. A single occurrence of Annual Mission grass was recorded on the proposed access track to Amungee NW5. A map showing the location, size and density of weed patches located within the Amungee NW 2D seismic exploration lease area is show in Figure 43.

The weed species of high risk of introduction or spread through Origin's activities are listed in section 5.2.4. These high-risk weeds have been determined through consideration of the following criteria:

- Weed species that has been confirmed in the area within the relevant Regional Weed Management Plan (RWMP) or through field surveys
- Weed species listed in a RWMP that are near Origin tenure
- Weed species that is at risk of introduction using machinery sourced from other regions in the NT or from other states

Additional information on the full list of weeds and control measures for the exploration area are provided in Origin's Weed Management Plan (Appendix B).

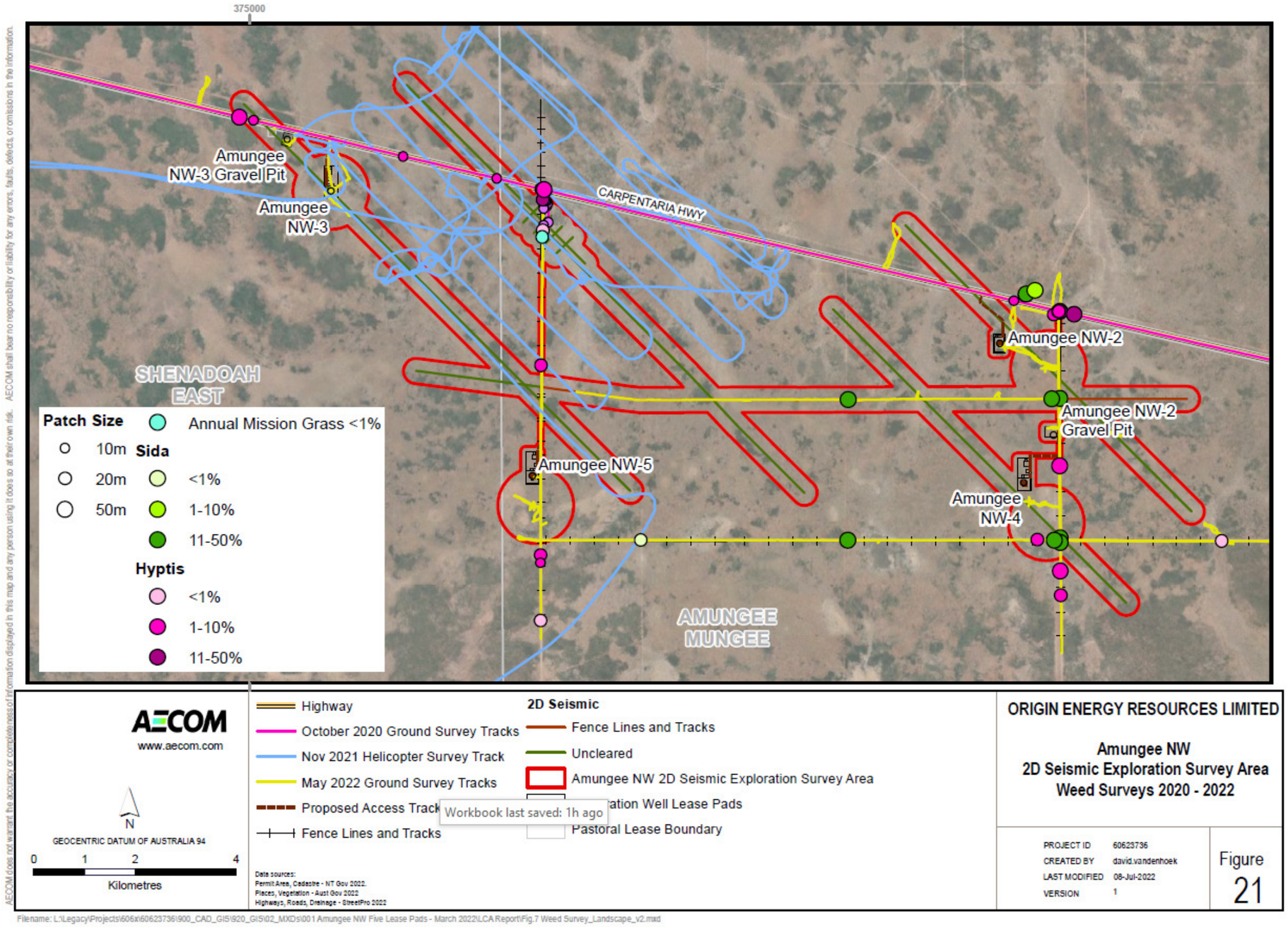


Figure 43: Weed baseline survey for the prospoed exploration sites within the Amungee Delinesation Area

5.2.5 Fauna

A search of the Department of Environment, Parks and Water Security (DEPWS) Natural Resource Maps database reveals that a total of 88 fauna species have been recorded within 5 km of the Amungee Delineation Area comprising 76 species of bird, eight reptiles and four mammals.

The Amungee Delineation Area primarily comprises open woodland consisting of mixed Eucalyptus/Corymbia species with a mixed tussock grass understorey. Often, scattered stands of Bullwaddy/Lancewood communities occur across the proposed sites and individuals of both species are dispersed throughout. In the wider landscape, including proposed access tracks and seismic lines, additional vegetation types include those associated with drainage lines, grasslands/floodplains and Acacia sp. shrublands.
Eucalyptus/Corymbia sp. woodland provides habitat for a range of species. The proposed disturbance areas had high native grass cover and included numerous species suitable for granivorous birds (seed eaters). Dense leaf litter and numerous logs provide suitable refuge and foraging sites for fauna such as reptiles. Although most of the species found in this vegetation type are widespread in the tropical savannas of the Northern Territory, some such as the threatened Crested Shrike-tit (Falcunculus frontatus whitei) are rare and known to utilise this habitat (Ward, 2008). Many of the sites have a high density of hollow-bearing trees that provide important habitat for many fauna species. Avoiding clearing large hollow-bearing trees will reduce the impact to native wildlife within the permit area.
Incidental fauna sightings were recorded within the exploration lease pad scouting during the May 2022 field survey. A total of 15 birds and one reptile were recorded during the field survey as summarised in Table 42.

Table 43: Incidental fauna sightings

Scientific name	Common name	Sites/s
Birds		
Aegotheles cristatus	Owlet Nightjar	Amungee NW 5
Artamus superciliosus	White-browed Woodswallow	VS19
Colluricincla harmonica	Grey Shrike-thrush	Amungee NW 4
Corvus orru	Torresian Crow	Amungee NW 2 GP
Cracticus nigrogularis	Pied Butcherbird	VS8
Falco berigora	Brown falcon	Amungee NW 3 GP
Gavicalis virescens	Singing Honeyeater	VS14, VS18, VS19
Haliastur sphenurus	Whistling Kite	VS17
Malurus melanocephalus	Red-backed Fairy-wren	VS16
Melanodryas cucullata	Hooded Robin	VS20
Pachycephala rufiventris	Rufous Whistler	Amungee NW 3
Pardalotus striatus	Striated Pardalote	VS8, VS18, VS20
Pomatostomus temporalis	Grey-crowned Babbler	VS20
Rhipidura leucophrys	Willie Wagtail	VS20
Smicrornis brevirostris	Weebill	VS13
Reptiles		
Aspidites melanocephalus	Black-headed Python	Amungee NW 5

5.2.6 Threatened fauna

A search of the DCCEEW Protected Matters database of nationally significant fauna (PMST) and records from the NT Government Fauna Atlas database (NR Maps) was undertaken at 10 km and 50 km of the proposed lease areas and access tracks. The search results indicate the potential presence of

15 fauna species listed as threatened under the EPBC Act and/or the TPWC Act. These included eight birds, five mammals and two reptiles.

The likelihood of occurrence assessment is based on the availability of suitable habitat within the permit area, records in the vicinity and distributional data. Therefore, many of the threatened and migratory fauna species indicated in databases as 'occurring' or 'likely to occur' have been assessed as unlikely to occur within the project area. As some areas in the proposed lease area have not been subject to intensive survey and some species are very cryptic, a conservative approach has been taken to assess species presence. A full description of each species, their distribution and habitat associations are outlined in Table 43 below.

No core habitat for threatened fauna was identified at the sites. However, some species may occur and are known to occur in the wider landscape. Threatened species that potentially occur include:

- Gouldian Finch *Erythrura gouldiae* (Endangered EPBC Act, Vulnerable TPWC Act)
- Grey Falcon *Falco hypoleucos* (Vulnerable EPBC Act and TPWC Act)
- Crested Shrike-tit (northern) *Falcunculus frontatus whitei* (Vulnerable EPBC Act)
- Painted Honeyeater *Grantiella picta* (Vulnerable EPBC Act and TPWC Act)
- Pale Field-rat *Rattus tunneyi* (Vulnerable TPWC Act)
- Common Brushtail Possum (northern) *Trichosurus vulpecula arnhemensis* (Vulnerable EPBC Act)
- Yellow-spotted Monitor *Varanus panoptes* (Vulnerable TPWC Act)

Research has shown that critical components of suitable habitat for the Gouldian Finch include suitable nesting trees during the breeding season (particularly *Eucalyptus tintinnans*, *E. brevifolia* or *E. leucophloia*), a water source and a diverse range of favoured annual and perennial grasses (Dostine & Franklin, 2002).

The proposed exploration well sites, gravel pit and seismic line vegetation sites were surveyed for Gouldian Finch. Primary nesting trees were not observed in the area. Corymbia and Eucalyptus trees that are potentially suitable for nesting and perennial grasses suitable for feeding were observed at several sites. Habitat in the Amungee Delineation Area was moderately suitable for Gouldian Finch but core habitat was absent. No Gouldian Finch were observed during the bird surveys and it is unlikely this species breeds in close vicinity to the exploration well sites within the Amungee Delineation Area. During the wet season, Gouldian Finches move from breeding habitat on hillsides with suitable trees down to lower lying areas where they forage on perennial grasses such as *Triodia sp.*, *Alloteropsis semialata*, and *Chrysopogon fallax* (Palmer *et al*. 2012). Some of the perennial grasses were recorded during recent surveys so potential foraging habitat is present; however, there are limited records in the vicinity and the level of available foraging habitat in the region is extensive.

The Crested Shrike-tit lives in dry Eucalypt forests and woodlands where it feeds on insects from the canopy and under bark. It has been recorded in wet Melaleuca open woodlands and woodlands dominated by Nutwood (*Terminalia arostrata*) and Bloodwoods with flaky bark and ironwood (Ward, 2008). In the NT, nesting has been recorded from September through to January and nests are built in terminal branches at the top of trees (Ward *et al*., 2009). The stronghold of this species is north of this location and only one old record exists near Borroloola.

Although it is possible the Crested Shrike-tit may be present in the area, it is unlikely to represent an important area for this species. During the May 2022 field survey targeted call-playback was undertaken for Crested Shrike-tit (northern subspecies) at the exploration well sites and the seismic line vegetation assessment sites. Call-playback was undertaken for approximately 5 minutes at all the proposed exploration well sites (Amungee NW-2, Amungee NW-3, Amungee NW-4 and Amungee

NW-5, and AMS 1-1 and AMS5), two proposed gravel pits[16] and the seismic vegetation survey sites (VS1 to VS28). Following 5 minutes of call playback the area was surveyed for approximately 10 minutes with binoculars. The search area was within 50 m of where call playback was undertaken, covering an approximate 0.8 ha search area. No Crested Shrike-tits were observed during these surveys.

The overall estimated density of the *Corymbia* sp. has previously been recorded for the Amungee NW (AECOM, 2022) at 6 stems/ha, which based on the impact of the proposed activities of 110.96 ha represents 0.03% of the available *Corymbia* open woodland vegetation community within EP98 (estimated from NVIS of 359,950 ha). Based on the recorded stems/ha for Amungee Delineation Area it can also be estimated that within the 1,000 ha directly surrounding the disturbance area there would be up to 6,000 individual stems/ha of *Corymbia* sp.

Clearing for the seismic acquisition is not planned to occur until post wet season 2023. With additional vegetation clearing controls, such as timing of the clearing activities to avoid the preferred breeding and fledging times (October to March) and pre-clearance inspections to minimise impacts to breeding / fledging (October to March), the risk of impact to the Crested Shrike tit is considered low. Impacts to *Eucalyptus* and *Corymbia* species will be avoided – i.e. trees with a trunk diameter greater than 25 cm at 1.3 m above the ground will be avoided, as far as reasonably practicable.

The Grey Falcon (*Falco hypoleucos*) is a widespread species listed as Vulnerable in the NT and considered possibly present in the study area. The species occurs in low densities throughout arid and semi-arid areas of Australia (DEPWS, 2021a). The species is known to nest on repeater towers in the region, including one site located approximately 100 km south-west of the Amungee Delineation Area where the species bred in 2014 (Jonny Schoenjahn, personal communication, 2022). One repeater tower located within the lease area next to the Carpentaria Highway was surveyed for Grey Falcon. The species was not detected. The species is also known to nest in the tallest trees along watercourses, such as Red River Gums (*Eucalyptus camaldulensis*) (TSSC, 2020). Grey Falcon may forage within the Amungee Delineation Area but is unlikely to be impacted by project activities because suitable nesting trees will not be cleared. If a Grey Falcon nest (or suspected nest) is encountered, a minimum buffer of 300 m will be maintained around the active nest to reduce disturbance and potential impacts.

The Painted Honeyeater (*Grantiella picta*) has been known to occur in region, however, given it does not breed in the NT it would only be present intermittently for foraging. Suitable habitat for the species potentially occurs within the Amungee Delineation Area. The area proposed for clearance is relatively small compared to available suitable habitat within the region.

The Yellow-spotted Monitor (*Varanus panoptes*) occurs across northern Australia where it occupies a variety of habitats, including grasslands and woodlands (Ward *et al*., 2012). Most records of this species are from the Top End, though it has been recorded in the Barkly Tablelands. The species likely occurs close to wetlands and riparian habitats within the permit areas; however such habitat will not be impacted by proposed activities.

Recent surveys have detected Common Brushtail Possum (*Trichosurus vulpecula arnhemensis*) on Kalala Station, located approximately 45 km from the Amungee NW exploration lease (NTG Flora & Fauna, personal communication, 2022). Suitable woodland habitat is contiguous through the landscape; therefore the species potentially occurs within the Amungee Delineation Area. Given the large amount of suitable habitat within the region comparative to the project footprint the risk to regional populations of the species is small.

[16] Noting that only 1 gravel pit at NW 3 is proposed under this EMP.

The Pale Field-rat occurs in a wide range of habitats, including tall grasslands and woodlands (Cole & Woinarski, 2002). There are no recent records of the species within the region; however this may reflect a lack of survey effort. Suitable habitat for the species occurs within the Amungee Delineation Area. The proposed area of impact is relatively small compared to available suitable habitat within the region.

As records of species may be limited in remote areas the precautionary principle has been applied. There are some species that have been assessed as possibly occurring even though their primary habitat is not found within the proposed sites or access tracks. These include species that are associated with ephemeral wetlands, low lying areas that may be seasonally inundated and creeks. During the wet and early dry season these areas may sustain threatened species such as wetland birds (including migratory species).

Table 44: Commonwealth EPBC and Terrtiory TPWC listed threatened species and likelihood occurence assessment with the the Amungee Delineation Area

Species	Listed status		Distribution	Habitat	Likelihood
	Cth	NT			
Birds					
Curlew Sandpiper *Calidris ferruginea*	Marine Migratory	VU	In the NT this species occurs around Darwin, north to Melville Island and Cobourg Peninsula, and east and south-east to Gove. It has been recorded inland from Victoria River Downs and around Alice Springs (Higgins & Davies, 1996).	Coastal habitats, inland it has been found around lakes, dams and ephemeral/permanent waterholes.	Unlikely No suitable habitat within project area
Red Goshawk *Erythrotriorchis radiatus*	VU	VU	Found across most of Northern Australia, in the NT most records are from the Top End but there are records from central Australia (Pizzey & Knight, 2012).	Red Goshawks occupy a range of habitats, often at ecotones, including coastal and sub-coastal tall open forest, tropical savannahs crossed by wooded or forested watercourses. In the NT, it inhabits tall open forest/woodland as well as tall riparian woodland (Aumann & Baker-Gabb, 1991).	Unlikely No records and no suitable breeding habitat within the project area
Gouldian Finch *Erythrura gouldiae*	EN	VU	Formerly widespread across northern Australia. In the NT they are found in the Top End south past Daly Waters (Palmer *et al*., 2012).	Gouldian Finches occupy different habitat types in the breeding and non-breeding season. Breeding habitat consists of hillsides with suitable nesting trees. Outside of the breeding season they are found in lowland drainages to feed on	Possible The closest record occurs 75 km east of the project area. Suitable foraging habitat is present

Species	Listed status		Distribution	Habitat	Likelihood
	Cth	NT			
				suitable perennial grasses (Dostine & Franklin, 2002).	
Grey Falcon *Falco hypoleucos*	VU	VU	This species has a widespread distribution and records occur throughout the NT. However, most records are from arid and semi-arid regions (Pizzey & Knight, 2012).	Grey Falcon is typically found on inland drainage systems in lightly treed lowland plains, pastoral lands, timbered watercourses and, occasionally, the driest deserts (DEPWS, 2021a).	Possible The species may forage within the project area but is unlikely to breed
Crested Shrike-tit (northern) *Falcunculus frontatus whitei*	VU	NT	This species has been recorded from widely scattered localities from near Timber Creek to the east Gulf Country, north to Kakadu National Park and in north-eastern Arnhem Land (DEPWS, 2021b).	Occupies wet and semi-arid melaleuca and eucalypt open woodlands. May be associated with bloodwoods with flaky bark and ironwood (Ward, 2008).	Possible No records in the vicinity of the project area. Sub-optimal habitat is present. Call-playback surveys failed to detect the species
Painted Honeyeater *Grantiella picta*	VU	VU	This species is migratory based on seasonal variation in occurrence. They breed on the inland slopes of the Great Dividing Range. After the breeding season they sometimes occur in the north-eastern NT, south of the Roper River (Garnett & Baker, 2021).	Painted Honeyeater inhabits woodlands dominated by Acacia and/or Eucalyptus species and open forests but prefers habitats with abundant mature trees that host mistletoes. The species specialises on the fruit of mistletoes although it may also forage on nectar and insects (Garnett *et al.*, 2011).	Possible No recent records occur close to the project area; however suitable habitat is present

Species	Listed status		Distribution	Habitat	Likelihood
	Cth	NT			
Australian Painted Snipe *Rostratula australis*	CE	VU	Records of the species occur across the NT. More recent records come from McMinns Lagoon near Darwin, Yellow Waters in Kakadu, the Sturt Plateau, the Barkly and the Tanami (DEPWS, 2021c).	Australian Painted Snipe prefers a habitat of recently flooded temporary vegetated wetlands during the non-breeding period and brackish temporary freshwater wetlands with minimum vegetation during breeding periods. Birds usually forage in thick, low vegetated areas during the day (Curtis *et al*, 2012).	Unlikely Suitable habitat does not occur within the project area
Masked Owl (northern) *Tyto novaehollandiae kimberli*	VU	VU	The subspecies occurs in northern Australia, although its distribution is not well known. In the NT, occurs from Cobourg south to Katherine and the VRD and east to the McArthur River (DoE, 2014).	This species inhabits tall open eucalypt forest in the NT, especially those associated with *Eucalyptus miniata* and *E. tetrodonta (*Woinarski, 2007*)*. Also found in riparian and monsoonal forest and rainforest (DoE, 2014).	Unlikely No recent records occur close to the project area and suitable habitat is not present
Mammals					
Northern Quoll *Dasyurus hallucatus*	CE	EN	The species once occurred throughout most of Northern Australia although it is has declined across much of its range (Woinarski & Hill, 2012). In the NT it is found in the Top End as far southeast as Borroloola.	Northern Quolls do not have highly specific habitat requirements although the most suitable appear to be rocky habitats. They occur in a variety of habitats across their range, including open forest and woodland. Daytime den sites provide important shelter. Shelter sites include rocky outcrops, tree hollows, hollow logs, termite mounds, goanna burrows	Unlikely No recent records, occur in the vicinity of the project area and habitat is sub-optimal

Species	Listed status		Distribution	Habitat	Likelihood
	Cth	NT			
				and human dwellings (Woinarski & Hill, 2012).	
Ghost Bat *Macroderma gigas*	VU	NT	The species' range in northern Australia is from relatively arid conditions in the Pilbara region of Western Australia to humid rainforests of northern Queensland. A large colony occurs in a series of gold mine workings at Pine Creek, NT. This species has also been recorded throughout the mainland Top End north of approximately 17° latitude (DEPWS, 2021d).	The distribution of Ghost Bats is influenced by the availability of suitable caves and mines for roost sites. The species often roosts in a deep crack or cave during the day (DEPWS, 2021d).	Unlikely Suitable habitat does not occur within the project area
Greater Bilby *Macrotis lagotis*	VU	VU	This species occurs in south-western Queensland and in arid north-western Australia (Western Australia and Northern Territory). This species was previously widespread in arid and semi-arid Australia (Pavey, 2006). The most northern records are from Newcastle Waters and Wave Hill (Southgate & Paltridge, 1998).	In the NT, this species is found on sandy soils dominated by spinifex. Also hummock grassland associated with low lying drainage systems and alluvial areas (Pavey, 2006). Recent surveys in the Beetaloo region have recorded Greater Bilby in Eucalyptus and Corymbia woodlands mixed tussock and hummock grasses in sandy/loam soils (Davis *et al*., 2021).	Unlikely No recent records, occur in the vicinity of the project area and suitable habitat is not present

Species	Listed status		Distribution	Habitat	Likelihood
	Cth	NT			
Bare-rumped Sheath-Tailed Bat *Saccolaimus saccolaimus nudicluniatus*	CE	DD	Wide distribution from India through south-eastern Asia to the Solomon Islands, including north-eastern Queensland and the NT. Records of the species in the NT are sparsely scattered across the Top End (DEPWS, 2021e).	Previous specimens have been collected from Open *Pandanus* woodland fringing the sedgelands of the South Alligator River in Kakadu National Park, and from eucalypt woodlands and forests from coastal and adjacent inland areas (DEPWS, 2021e).	Unlikely No recent records, occur in the vicinity of the project area and habitat is not suitable
Common Brushtail Possum *Trichosurus vulpecula arnhemensis*	VU	NT	The Common Brushtail Possum (northern subspecies) occurs discontinuously from the Gulf of Carpentaria hinterland near Borroloola, NT westward to the Kimberley, WA (TSSC, 2020b).	The species occurs mainly in tall eucalypt open forests with large hollow-bearing trees, particularly where the understorey includes some shrubs that bear fleshy fruits (TSSC, 2020b).	Possible Recent records of the species occur at nearby Kalala Station and suitable habitat occurs within the project area
Pale Field-rat *Rattus tunneyi*	-	VU	Pale Field-rat inhabits higher rainfall areas of northern and eastern Australia, including the Top End of the NT (Menkhorst & Knight, 2011).	This species favours dense vegetation found along rivers where it occupies burrows in loose colonies (Cole & Woinarski, 2002). Pale Field-rat occurs within a variety of habitats including woodlands if a dense understorey of grasses is present (Menkhorst and Knight, 2011)	Possible One record from 1999 occurs approximately 15 km from the project area. Suitable habitat occurs within the project area
Reptiles					
Gulf Snapping Turtle	-	EN	Gulf Snapping Turtle is restricted to rivers draining into the Gulf of Carpentaria, including the Calvert	The species occurs in deep pools in the upper catchments of permanently flowing spring-fed river systems, particularly in	Unlikely

Species	Listed status		Distribution	Habitat	Likelihood
	Cth	NT			
Elseya lavarackorum			and Nicholson River systems (DEPWS, 2021f)	areas with intact riparian vegetation (DEPWS, 2021f).	No rivers or large permanent water bodies occur within the project area
Yellow-spotted Monitor *Varanus panoptes*	-	VU	Occurs across a broad geographic range across northern Australia. In the NT most records are from the Top End but occurs as far south as Renner Springs (Ward *et al*., 2012).	Occupies a variety of habitats including coastal beaches, floodplains, grasslands and woodlands (Ward *et al*., 2012).	Possible A 2019 record occurs approximately 45 km from the project area and suitable habitat is present

5.2.7 Marine and Listed Species

The EPBC Protected Matters database indicated the potential presence of 20 Migratory and Marine listed species within the Amungee Delineation Area (Table 43). Of these species, three are considered likely to occur, nine possibly occur and eight are unlikely to occur within the Amungee Delineation Area. Several migratory wetland bird would possibly occur within the area in ephemeral wetlands that would fill up following wet season rainfall. The Amungee Delineation Area does not contain critical habitat for any Migratory or Marine listed species.

Table 45: Migratory listed species potentially occurring within the Amungee Delineation Area

Scientific name	Common name	EPBC Act	Likelihood of Occurrence
Actitis hypoleucos	Common Sandpiper	Migratory, Marine	Possible
Anseranas semipalmata	Magpie Goose	Marine	Possible
Apus pacificus	Fork-tailed Swift	Migratory, Marine	Likely
Ardea ibis	Cattle Egret	Marine	Likely
Calidris acuminata	Sharp-tailed Sandpiper	Migratory, Marine	Possible
Calidris ferruginea	Curlew Sandpiper	Migratory, Marine	Possible
Calidris melanotos	Pectoral Sandpiper	Migratory, Marine	Possible
Cecropis daurica (Hirundo daurica)	Red-rumped Swallow	Migratory, Marine	Unlikely
Charadrius veredus	Oriental Plover	Migratory, Marine	Possible
Chalcites osculans (Chrysococcyx osculans)	Black-eared Cuckoo	Marine	Possible
Crocodylus johnstoni	Freshwater Crocodile	Marine	Highly unlikely
Cuculus optatus	Oriental Cuckoo	Migratory	Possible
Glareola maldivarum	Oriental Pratincole	Migratory, Marine	Possible
Haliaeetus leucogaster	White-bellied Sea-eagle	Marine	Unlikely
Hirundo rustica	Barn Swallow	Migratory, Marine	Unlikely
Merops ornatus	Rainbow Bee-eater	Marine	Likely
Motacilla cinerea	Grey Wagtail	Migratory, Marine	Unlikely
Motacilla flava	Yellow Wagtail	Migratory, Marine	Unlikely
Pristis pristis	Freshwater Sawfish	Migratory	Highly unlikely

Scientific name	Common name	EPBC Act	Likelihood of Occurrence
Rostratula benghalensis (*Sensu lato*)	Australian Painted Snipe	Migratory, Marine	Unlikely

5.2.8 Feral and pest animals

Feral animals known to occur within the region include:

- Pig *(Sus scrofa)*
- Wild dog *(Canis lupus familiaris)*
- Feral cat (*Felis catus*)
- Cane toad (*Bufo marinus*)
- Horse *(Equus caballus)*
- Donkey *(Equus asinus)*
- Water buffalo (*Bubalus bubalis*)
- Camel *(Camelus dromedarius)*
- Black rat *(Rattus rattus)*
- Domestic cattle (*Bos Taurus*)

During May 2022 field survey evidence of current cattle grazing or grazing within the last 1 to 2 years was recorded at most assessed sites. Pig damage was also observed at some sites.

Cane Toad is known to be present in the project area and the Commonwealth DCCEEW recognises this species as a 'key threatening process' related to their impacts on biodiversity through predation, competition, land degradation and poisoning. In the NT, the Cane Toad has been implicated in the decline of several species including many reptiles such as the King Brown snake (*Pseudechis australis*) and Varanus monitors (Smith & Phillips, 2006).

Pest predators such as cats likely occur within the project area, though their abundance is difficult to assess due to their cryptic nature. Introduced predators such as cats can impact many vertebrates (Dickman, 1996 & 2009). One of the primary concerns of introduced predators are the impacts on reptiles and ground-dwelling birds. Feral cats are also believed to be one of the factors that have led to the decline of the threatened ground-dwelling Partridge Pigeon (Woinarski et al. 2007).

5.2.9 Fire regime

Fire is a natural occurrence in most Australian ecosystems and plays an important role in their ecology. Fire is generally excluded from Mitchell grasslands by pastoral management to maintain forage throughout the dry season (HLA, 2005), whereas fire is more frequent in the Stuart Plateau.

Land condition assessments undertaken at Amungee NW 2022 recorded low intensity fire events occurring at all assessed sites in the previous 2-3 years, with minor scars on some trees and shrubs. Data acquired from the NAFI site shows increased fire frequency occurring between 1 and 4 years on the western side of the Amungee Delineation Area, reducing to between 1 and 3 years on the eastern side. Fire frequency was highest in areas of woodland and less frequent in areas of dense Lancewood and Bullwaddy shrubland (AECOM, 2022).

A Bushfire Management Plan (BMP) has been developed to manage bushfire risks associated with the Amungee Delineation sites. This plan provides the hazard reduction strategies, resources and response to bushfire emergencies. The BMP is provided in Appendix A.

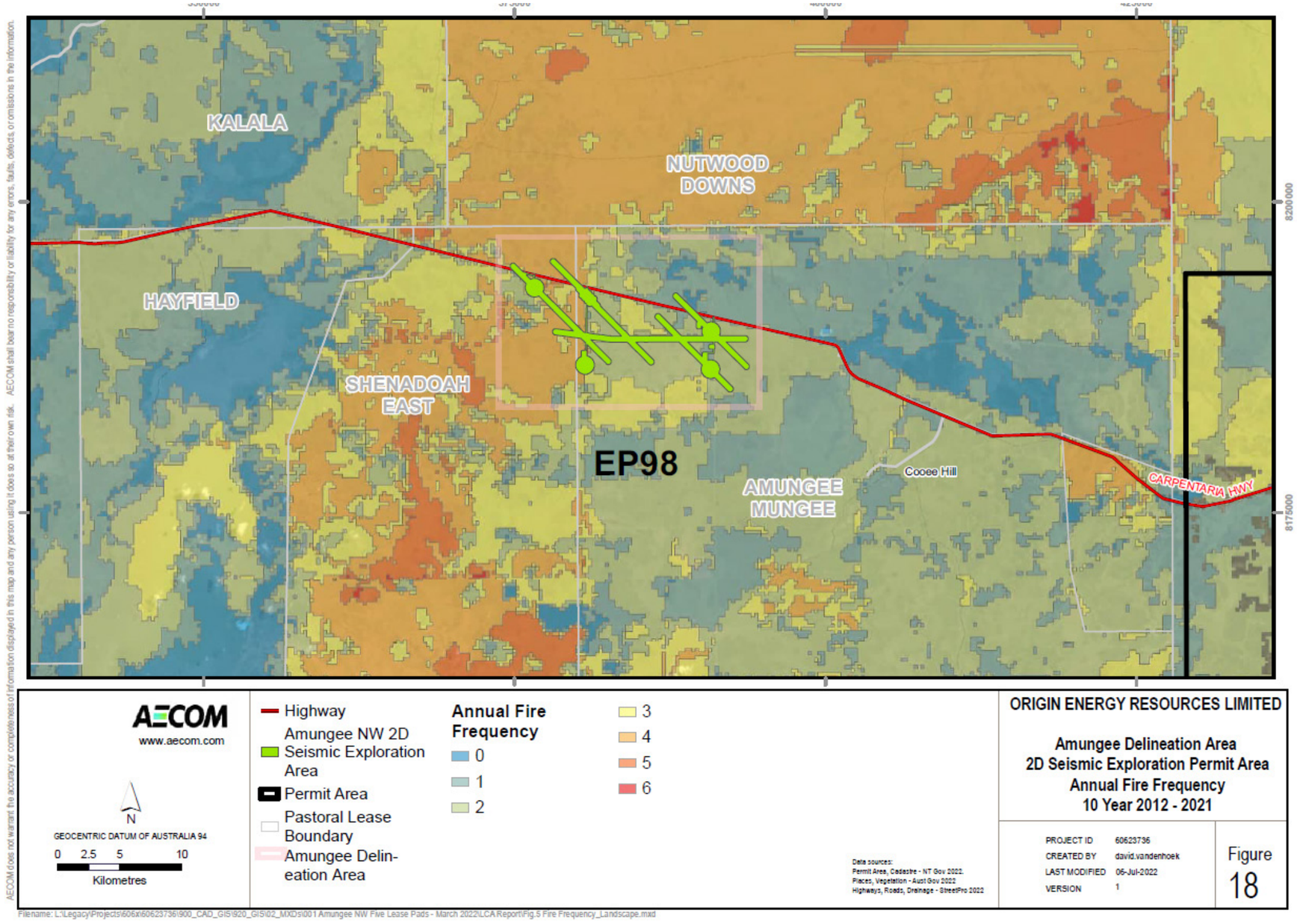


Figure 44: Fire frequency map of Origin's active sites within the Beetaloo Sub-basin

5.2.10 Groundwater dependent ecosystems

A search of the National Groundwater Dependent Ecosystems (GDE) has been conducted for the Amungee NW sites. The dataset expresses the potential for groundwater interaction/use for river/spring/wetland ecosystems across Australia. It shows the ecosystems that rely on groundwater that has been discharged to the surface, such as baseflow or spring flow.

A known aquatic GDE, the Strangways River (a tributary of the Roper River), was identified as occurring within 50 km of the Amungee Delineation sites. Eleven other locations were identified as having moderate aquatic GDE potential, including the Bull Creek, Hogdson River, Red Ochre Creek, Arnold River, Cow Creek and Crumby Creek River systems in the Roper River region.

All known and moderate potential GDE locations occurred at distances >20 km from the vicinity of the proposed Amungee NW sites and seismic acquisition. The impact on these units from Origin's total water extraction across the Beetaloo exploration area was assessed during the granting of WEL GRF 10285.

Stygofauna are a form of GDE that inhabit the interstitial spaces of the cavities of alluvial, sedimentary and karstic aquifers. Data is available that can provide an indication of the likelihood of stygofauna presence, with Hose, GC., et al (2015) outlining the following factors affecting the distribution of stygofauna:

- **Formation type:** Stygofauna are predominantly found in aquifers with large (mm or greater) pore spaces, which a more common for alluvial, karstic and some fractured rock aquifers.
- **Depth below ground level:** The abundance and diversity of stygofauna typically decreases with depth below ground, with fauna are rarely found more than 100 m below ground level (Hose, *et al* 2015).
- **Proximity of exchange and recharge:** Stygofauna are more abundant in areas of surface water-groundwater exchange, compared to deeper areas or those further along the groundwater flow path remote from areas of exchange or recharge

A recent Gas Industry Social and Environment Research Alliance (GISERA) program collected data from 2 locations within the proposed Amungee Delineation Area in 2020 (Rees *et al.,* 2020). The study did not find any stygofauna individuals within the sampling program, however the study did identify eDNA which may indicate stygofauna presence. The results are consistent with Hose *et al* (2015), which indicates stygofauna are likely to be present at lower abundance at the observed groundwater depth within the Amungee Delineation Area (~106 m below ground level).

The depth of the groundwater, likely low abundance of stygofauna and limited extraction draw down observed at Amungee NW extraction bores, concludes that impacts to stygofauna from extraction are considered highly unlikely. Any impacts are likely to be extremely localised, in the vicinity of metres.

Changes in groundwater quality may also result in impacts to stygofauna. Impacts to aquifers are mitigated through the following controls:

- Well design and construction to isolate aquifers
- Low toxicity drilling fluid systems utilised
- Groundwater monitoring bores will be located on each site which will be used to detect changes in groundwater quality, with monitoring around existing wells not identifying any material changes in water quality likely to impact stygofauna

Based upon the above information, the presence of significant assemblages of stygofauna in the area is considered limited and impacts considered unlikely.

5.3 Environmental and cultural sensitivities

5.3.1 Native Title

Two Native Title claims have been determined over the permit areas as summarised in Table 45.

Table 46: Native Title and IULA Agreements current for the permit areas

Type	Site	Name	Summary
Native Title	Amungee Delineation Area	NTD17/2010 Amungee Mungee Pastoral Lease	Native title exists in parts of the determination area and is held by The Karranjini group; the Bamarrngganja group
		NTD21/2010 Shenandoah Pastoral Lease	Native Title exists in parts of the determination area and is held by the Kinbininggu and Bamarrngganja groups

The Native Title Petroleum Exploration Agreement between Origin and the NLC includes clauses for the protection of sacred sites, objects and sensitive areas related to Aboriginal activities in the area, including cultural, hunting and foraging activities. Site clearance will occur prior to any on ground activities. The Native Title Agreement also includes clauses for the protection of the environment and site rehabilitation.

5.3.2 Archaeology assessment

Archaeological assessments of E&A sites have been completed by AECOM in May 2022 for the proposed sites within the Amungee Delineation Area. The assessment involved a desktop review of existing heritage data from the Australian Heritage Database, the NT Heritage Branch and the AAPA, previous archaeological survey reports prepared for the local area, as well as consultation with traditional owners of the study area and a field inspection.

The field surveys of both sites were conducted by EMM Archaeologist, Luke Kirkwood and traditional custodian Ben Ulamari and Jeremy Jackson. The archaeological surveys involved a vehicle and pedestrian survey of the proposed exploration sites.

In addition to well locations, an additional 26 heritage inspection locations in areas of proposed disturbance (Seismic lines and access tracks) were identified during the desktop assessment for further assessment as they had potential to be associated with culturally sensitive landforms (watercourses, gilgai, soaks, elevated locations etc). During the inspection, notes were taken on landform, ground surface visibility and areas of exposure. The aim of the inspection was to identify any surface expressions of Aboriginal archaeological and cultural heritage values within the proposal area. Photographic records were taken at each proposed disturbance location. A copy of the archaeological assessment is provided in Appendix K.

The inspection results of the sites are provided in Table 46, with find locations provided in Figure 45. Three Artefact locations were identified during the survey, all of which have been notified to the NT Heritage Branch. BB-22-AS1 was an artefact scatter that was identified in proximity to the proposed Amungee NW5 location. The proposed exploration site has now been moved to avoid this feature. BB-22-IA1 and BB-22-IA2 are both isolated flake type artefacts. These artefacts were found within the Amungee NW3 and Amungee NW3 gravel pit respectively and have been assessed by the EMM Archaeologist and attending Traditional custodians as being suitable for translocation. It is proposed that both artefacts will be translocated with approval sought by the NT Heritage branch (under the NT

Heritage Act vi a permit) and Traditional custodians (via the NLC in alignment with the Exploration Agreement) or the sites moved to avoid the features.

An unexpected finds procedure has been developed to respond to any potential additional artifact or sacred site finds during Origin's activities, which is appended to the archaeological assessment (Appendix K).

Table 47: Exploration lease area inspection results

Location	Survey date	Artefact ID	Description	Easting (mE)*	Northing (mN)*	Proposed management strategy
Amungee NW 5	May 2022	BB-22-AS1	Artefact Scatter	[redacted]	[redacted]	The proposed Amungee NW 5 location has been moved approximately 500 m to avoid the artefact scatter. No impacts are anticipated.
Amungee NW-3	May 2022	BB-22-IA1	Isolated artefact (proximal chert flake)	[redacted]	[redacted]	The isolated artefact is located approximately 140 m NW of the Amungee NW3 well centre. The artefact will be translocated with approval sought by the NT Heritage branch (under the NT Heritage Act) and Traditional custodians (via NLC in alignment with the Exploration Agreement) or the sites moved to avoid it.
Amungee NW-3 gravel pit	May 2022	BB-22-IA2	Isolated artefact (complete quartzite flake)	[redacted]	[redacted]	The isolated artefact is located within the Amungee NW 3 gravel pit. The artefact will be translocated with approval sought by the NT Heritage branch (under the NT Heritage Act) and Traditional custodians (via NLC in alignment with the Exploration Agreement) or the gravel pit moved to avoid it.

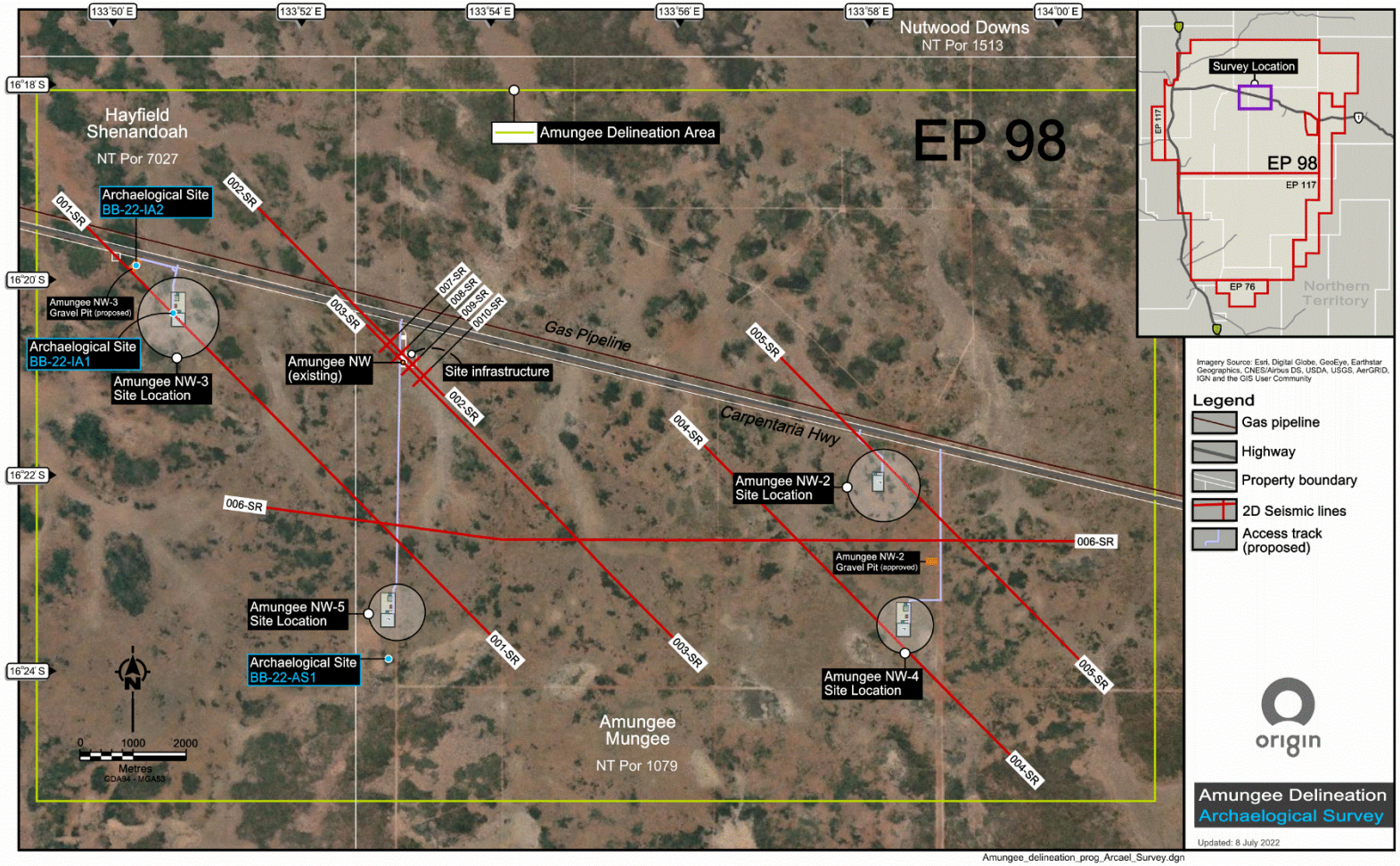


Figure 45: Achaelogical survey find sites

5.3.3 Areas of cultural significance

Recorded sacred sites in the study area are primarily associated with drainage lines; natural landform features and stock routes, but there are also concentrations of sites nearby to old homesteads. The distribution of these sites may reflect historical patterns of Indigenous movements along drainage lines and subsequent development of stock routes on old Indigenous walking trails, or they may merely be indicative of the site clearance work undertaken along roads and tracks in the area. It is suspected that there will be a range of other sites also within the area, either not yet recorded, or known but not reported for cultural reasons.

AAPA certificate C2022/002 has been granted covering all actives covered under this EMP for the Amungee NW drilling & HF sites and ancillary activities, including the 2D seismic. No Restricted Work Area (RWA) are identified within the Amungee Delineation Area; the closest sacred site is located at a waterhole over 8 km from Amungee NW.

5.3.4 Non-Indigenous heritage

In 1860, explorer John McDougall Stuart was the first European to penetrate the area now known as the ‘Centre’. The first written descriptions of the area come from Stuart during his second attempt to cross the continent from south to north (HLA, 2005).

Development in the area began as pastoral lands with an increased interest in land settlement following the completion of the Overland Telegraph Line in 1873. Most attempts were unsuccessful with the Lancewood-Bullwaddy vegetation found to be impenetrable and the lack of surface water making the land unsuitable for cattle. Daly Waters was thus recognised as one of the last watering stops on the Murranji Stock Route.

It was not until the 1930s to 1950s, that the area saw regional economic growth with Daly Waters becoming a significant hub of air and mail services into the Northern Territory. The wartime years saw this role increase with Daly Waters again playing a major role in cross country transport and communication. This role continued until the early 1970s when the airport was closed to commercial traffic. The town and surrounding areas subsequently reverted to a primarily agriculture-based existence following the decline of air travel, but in recent times has seen commercial interest from the exploration for gas in the Beetaloo Sub-basin and the growth of the ‘grey nomad’ tourism market.

5.3.5 Heritage assessment

A search of the Australia Heritage Database identified that no statutory listed heritage places were present within the proposed Amungee Delineation Area.

A search of NT Heritage Register identified a number of historic heritage sites within a 125 km by 125 km search
area that encompasses the Beetaloo Basin. The closest item to the proposed Amungee NW extension area is the Daly Waters Aviation Complex, an airfield that once operated as an international air hub and has the oldest hangar in the Northern Territory dating back to 1930. The Aviation Complex is located 50km to the west of the Amungee NW extension area on the Stuart Highway.

No heritage places or artefacts are registered within the proposed impact areas.

5.3.6 Protected or conservation areas

There are no conservation reserves, national parks, world heritage places, Commonwealth land, heritage places or critical habitat areas listed under the EPBC Act located within or adjacent to the proposed exploration area.

The closest area is the Bullwaddy Conservation Reserve, which is located approximately 30 km from the Amungee NW 4 site. The EPBC Listed Lake Woods is located approximately 150 km from the Amungee NW 5 site and is listed on the National directory of important Wetlands.

The risks to these receptors through aquifer contamination, spills, sediment release, habitat destruction have been addressed in the risk assessment presented in Appendix L. The main mitigation measures/ factors include:

- As the proposed sites are 30 – 40 km away from the Bullwaddy Conservation Reserve and over 150km (direct) from Lake Woods, contamination is not likely to reach the area at any undiluted impactable state.
- Surface water flow is to the south into a tributary of Newcastle Creek which flows into Lake Woods via Newcastle Waters. Any spill would need to exceed the capacity of the site bund and travel over 150 km to reach Lake Woods. A spill cannot impact the Bullwaddy Conservation Area as it lies east of the Amungee Delineation Area and is not in the overland flow path from any of the proposed sites.
- Groundwater depth throughout the Bullwaddy Conservation Reserve is anticipated to be approximately 70m of depth with vegetation not being able to access groundwater at this depth. The flow path (north-west) is not in alignment with the conservation area- meaning a valid contamination pathway does not exist.

5.4 Social environment

5.4.1 Social context

The proposed EMP activities will occur within the Roper Gulf regional Council area, which covers 201,000 km^2. The approximate population is estimated for the Roper Guld region of 5,592 people (Roper Gulf Council regional Plan 2022-23).

The potential social and economic effects associated with the proposed exploration activities are considered to be minor and predominantly positive.

The closest neighbouring regional towns and communities identified as being within proximity to Origin's activities include:

- Dunmarra
- Elliott
- Daly Waters
- Newcastle Waters

5.4.2 Pastoral activity

The proposed Amungee NW 2, NW 4 and NW 5 lease pads are located on the Amungee Mungee Station; Amungee NW 3 lease pad is located on the Shenandoah East Station. The 2D seismic will occur across the Amungee Mungee and Shenandoah East stations. Both stations are used for pastoral activities

Within the Origin's Beetaloo exploration permit area there are nine pastoral properties as shown in Table 47. All the land within the permit area is Leasehold Land. There is one small area of Aboriginal Freehold land known as Jingaloo on EP117, which is located approximately 80km from the Amungee Delineation Area.

Table 48: Pastoral properties in the permit area

Pastoral property	Permit areas			Contact details
	EP76	EP98	EP117	
Amungee Mungee	X	X	X	Adrian and Emma Brown [redacted]
Shenandoah-East/ Shenandoah		X	X	Val Dyer [redacted]
Kalala		X	X	N/A
Tanumbirini	X	X		
Beetaloo	X		X	
Ucharonidge	X		X	
Tandyidgee	X	X		
Nutwood Downs		X		
Newcastle Waters			X	

5.4.3 Other land uses in the area

A range of other land uses exist in the permit area or in the larger region, including a range of public utilities and facilities. These include the following:

- Tourism – Tourism is an important regional industry with the Stuart Highway being a major thoroughfare for tourists travelling in the area during the dry season. The local townships of Daily Waters, Dunmarra and Elliott provide consumables (food, fuel etc.) and accommodation. Several heritage areas of importance to regional tourism are in the broader region, including Elliott, Newcastle Waters and other heritage listed homesteads.
- Road networks – The Stuart Highway and Carpentaria Highway will be used to access the sites. In addition, there are numerous gravel roads connecting properties, and internal property tracks. All properties also have firebreaks on their boundaries and internally.
- Gas pipeline – A gas pipeline runs to the west of the Stuart Highway, along the eastern boundary of EP117 and crosses the boundary of one part of EP98. It also runs parallel with the Carpentaria Highway to the Gulf of Carpentaria, through EP98 and EP76.
- Alice Springs to Darwin Railway – The railway line runs to the west of the gas pipeline and Stuart Highway and does not cross into any of the permit areas.
- Townships – The townships of Daly Waters and Dunmarra neighbour EP98 to the West.
- Conservation areas – including the Bullwaddy Conservation Reserve, which lies within EP98 approximately 30 km east of the proposed activities, and Lake Woods and the Junction Stock Reserve just outside the permit area.

- Heritage – There are seven (7) heritage sites within the exploration permit area and several heritage areas of importance to regional tourism located in the broader region, including Elliott, Newcastle Waters and heritage-listed homesteads.
- Archaeological sites – The permit areas have a long history of Aboriginal association and 41 archaeological sites have previously been recorded within the permit areas, as well as registered sacred sites and areas of significance which are shown in the AAPA Abstract of Record. During the May 2022 cultural heritage surveys on EP 98, a site was identified containing a significant number of archaeological objects adjacent to the proposed Amungee NW-5 site. The find has been communicated to native title holders, NLC and NT Heritage branch. Based on the find, Origin has revised the intended location of the proposed Amungee NW 5 lease pad to avoid the area. A buffer has been implemented around the site with no activity proposed. Origin will continue to work with traditional owners and the NT Heritage branch to protect the objects.

6 Stakeholder engagement

6.1 Purpose and objectives

Origin's stakeholder engagement is focused on building respectful relationships with key stakeholders and developing a positive reputation founded on Origin's core values. Origin's consistent approach to stakeholder engagement has been to ensure that those persons and/or groups directly impacted/ affected and/or influenced by permit commitments have received Origin's full attention. Origin views the social acceptance and informed consent of these primary stakeholders of critical importance and relevance during this stage of low impact and small-scale exploration activities.

A stakeholder engagement plan has been implemented, which guides the way Origin undertakes stakeholder engagement above and beyond the NT Petroleum (Environment) Regulations 2016. This plan has been developed based upon the International Association for Public Participation (IAP2) (2015) Quality Assurance Standard for Community and Stakeholder Engagement.

6.2 Identification of stakeholders

The NT Petroleum (Environment) Regulations 2016 defines stakeholder as meaning:

(a) a person or body whose rights or activities may be directly affected by the environmental impacts or environmental risks of the regulated activity proposed to be carried out; or

(b) an agent or representative of a person or body mentioned in paragraph (a).

Origin's directly affected stakeholders have been, and will continue to be, consulted in a respectful, open and consistent manner. This has been the case since 2014, when Origin assumed operatorship of EP98, EP117 and EP76.

For this EMP, Origin identifies its stakeholders, in compliance with the NT Petroleum (Environment) Regulations 2016 as:

- **Host Traditional Owners** recognised as the Native Title holders and/or claimants and their representative, the NLC, as described in Exploration Agreements between the parties for EP98, EP117 and EP76; and
- **Host pastoralists** recognised as the landholders of the nine Pastoral Lease Stations in Table 47. (With regard to this EMP for the drilling and hydraulic fracturing activities at Amungee NW 2, NW 3, NW 4 and NW 5 and the 2D seismic acquisition, the owners of the pastoral

leases for Amungee Mungee Station and Shenandoah East Station are recognised as the pastoralist stakeholders directly impacted).

- **Gas pipeline operator, OSD Pipelines**, where Origin will require works approval to allow 2D seismic acquisition to occur in the vicinity of the underground pipeline

Stakeholder and community engagement for the proposed work program has been held with host pastoralists and Traditional Owners directly affected by the proposed activities. Activities performed under EP98, EP117 and EP76 will be conducted in a manner consistent with the Code, which Origin considers an appropriate regulatory instrument for ensuring Origin's activities are in line with community expectations and legislative requirements.

Origin also recognises and engages, where appropriate with other interested parties that are not classified as directly affected under the Regulations. These include government agencies, land councils, local and regional suppliers, non-government organisations, councils and peak industry bodies.

6.3 Pastoralist stakeholder engagement

Origin has engaged with the pastoral stakeholders identified in Table 47 on an ongoing basis, including engagement with the leaseholders and/or representatives of the Amungee Mungee Station and Shenandoah East Station, regarding the full range of exploration activities outlined in this EMP. Key engagement efforts Origin has undertaken include:

- Ongoing regular engagement with pastoralist about Origins general activities.
- Providing the landholder with draft copies of a Stakeholder Engagement Pack (SEP) covering exploration activities and providing opportunity for the landholder to comment

Appendix M summarises Origin's engagement with the leaseholders of Amungee Mungee Station and Shenandoah East Station as a relevant stakeholder and provide information in accordance with section 7(2)(a) of the Regulations.

Appendix M provides the specific details of communication between Origin and the pastoralist regarding the proposed activities.

6.4 Host Traditional Owner(s) engagement

Origin has undertaken detailed engagement with the host Traditional Owners through the NLC to facilitate an ongoing relationship between Origin and their host Traditional Owners. Engagement efforts undertaken by Origin include:

- Complying with the Exploration Agreement(s) between Origin, Native Title holders and the NLC for EP117, EP98, EP76.
- Ongoing consultation regarding Origin work programs and proposed exploration activities, including the location(s) of all areas of disturbance and answering any questions or comments on the activity and its related impacts.
- In person consultation between Origin, host Traditional Owners and their statutory representative body, the NLC regarding Origin's proposed exploration activities on 3 September 2018.
- Execution of Sacred Site clearance and avoidance surveys on the specific areas of land (~6 kms in radius) with the relevant Traditional Owners between 10 September and 19 September 2018. A formal NLC Sacred Site Avoidance and Anthropological Report was

provided to the AAPA to assist with the issuing of an Authority Certificate in compliance with the Northern Territory's Aboriginal Sacred Sites Act.

- On country meetings held between NLC, Traditional Owners and Origin in April and May 2019 revisiting Origin's work program submission from July 2018 and field surveys with Traditional Owners in September 2018. The on-country meetings conclude the engagement and consultation necessary with Traditional Owners prior to commencement of each years' activities.
- Kyalla 117 N2-1H NLC, Traditional Owners and Origin site tour in September 2020. The tour provided an overview of the Beetaloo exploration project and answered questions regarding hydraulic fracking activities underway.
- On country meetings held between NLC, Traditional Owners and Origin in late May – June 2022, revisiting Origin's 2021 activities and results, and outlining Origin's activities for 2022/23. The on-country meetings conclude the engagement and consultation necessary with Traditional Owners prior to commencement of each years' activities.
- Ongoing communication between Origin, the NLC and Traditional Owners.
- Consultation and engagement with host Traditional Owners, to ensure their understanding of the nature and purpose of activities, is executed by the NLC in accordance with the Land Rights Act. The approved work program includes the installation of multiple vertical and horizontal E&A wells per lease pad and 2D seismic activities.
- Pursuant to the Sacred Sites Act, Origin applied for, and obtained, an Authority Certificate from AAPA, which provides indemnity against prosecution in respect of the offences under the Sacred Sites Act. Origin holds AAPA Authority Certificate C2022/002 and shall comply with the conditions in the Certificate to ensure compliance to the Sacred Sites Act.

The Traditional Owner stakeholder engagement summary is provided in Appendix M.

The NLC is the contact point for all Native Title holders and can be contacted on (08) 8920 5100.

6.5 Gas pipeline operator engagement

A gas pipeline runs parallel to the Carpentaria Highway (northern side) on Amungee Mungee Station and Shenandoah East Station. The 2D seismic acquisition requires crossing at two locations along the gas pipeline. Origin has engaged with ODS Pipelines, the operator of the gas pipeline regarding the seismic program in the vicinity of the gas pipeline.

Origin will comply with the conditions specified by OSD. Ongoing communication will be required with OSD prior to activities commencing.

6.6 Stakeholder activities

Key considerations when understanding the consequences to pastoral operations and Traditional Owners include:

- Understanding pastoralist operations and determined Native Title holder custodianship of the proposed area to ensure petroleum activities can sustainably co-exist
- Provision of payments and/or benefits to the Pastoral Lessee(s) and Native Title holders for the impact of regulated activities on the proposed activity area in accordance with the relevant agreements.

A summary of the potential consequences of the activity and mitigation controls are summarised in Table 48.

Table 49: Potential consequences of Origin's activities and control measures which are covered in the SEPs sent to stakeholders

Activity	Potential consequence to activities	Consequence mitigations measures
Land and stock		
Well pad (and E&A wells) and associated infrastructure	• Reduction in grazing area • Restricted access to well lease pads and associated infrastructure during activity duration	• Exploration Agreement(s) with NLC and Native Title holders and/or claimants • Aboriginal Areas Protection Authority Certification (including RWAs and Work Instructions) • Short term use • Full fencing and bunding of well pad • Industry-proven coexistence of cattle and petroleum industry • End of life rehabilitation to return land back to pre-existing state • Code of Conduct agreed to by Origin and the pastoralists.
Existing access tracks	• Traffic along access track • Temporary access restrictions during rig mobilisations and heavy transport operations • Interference with stock • Reduced palatability of grasses adjacent to access tracks from dust	• Exploration Agreement(s) with NLC and Native Title holders and/or claimants • Aboriginal Areas Protection Authority Certification (including RWAs and Work Instructions) • Upgrade of the existing road to enable dual carriage • Main traffic movements limited to over a 2-week period 1-2 times per year - • Code of Conduct agreed with pastoral lessee • Origin pastoral lease notification of large movements • Road remains shared use asset of pastoral lessee • Controls to be implemented regarding use of gates- including specific induction requirements, gate monitoring and signage. • Dust suppression utilised where practicable to reduce dust levels.

Activity	Potential consequence to activities	Consequence mitigations measures
Lease pads	• Contamination of soils from activities • Impact to organic certification	• All activities must comply with Code, including spill management, wastewater management and waste management • Site to be rehabilitated back to pre-disturbance level with no harmful contamination permitted. • Sites fully bunded • Activity restricted to a small area, with no contaminates released to surrounding areas • Contaminants affecting organic certification for cattle or crops (agrichemicals, GMO, pesticides etc) are typically not associated with petroleum activities. • Exploration Agreement(s) with NLC and Native Title holders and/or claimants • Aboriginal Areas Protection Authority Certification (including RWAs and Work Instructions)
2D seismic	• Restricted access during 2D seismic acquisition • Impacts to cattle – noise, dust • Erosion on seismic lines	• Origin will work with pastoralists to ensure all cattle in the vicinity of the proposed seismic are mustered prior to undertaking the activities. • Some dust adjacent to access tracks is anticipated and accommodated for as a part of compensation. Current dust levels are anticipated to be similar to existing tracks used for pastoral activities. • Vibroseis vibration is of less intensity than a cattle truck crossing a cattle grid. • Seismic charge noise and vibration consistent with a dull thud • Erosion should be minimized through blade up practices and minimizing clearing to only those areas where detouring is inhibited. • Large trees will be avoided.

Activity	Potential consequence to activities	Consequence mitigations measures
		• Vegetation will be stockpiled adjacent to the lines and pulled back over the line in perpendicular with the topography to reduce overland flow. • Annual monitoring will be undertaken to identify significant erosion that requires rectification. Rectification works will be undertaken periodically as required.
Water		
Groundwater	• Pastoral bores rates and/or quality • Reduction in groundwater availability	• Exploration Agreement(s) with NLC and Native Title holders and/or claimants *(Clause 9.2(n))* • No hydrocarbon wells within 1km of pastoral bore unless other wised agreed • Modelling supported extraction limits set by DEPWS through extraction licence GRF 10285 • Monitoring of control and impact groundwater levels to detect and respond to water level declines >1 m as per section 4.29. • Baseline monitoring of local bores within 10 km of petroleum wells • Ongoing control and impact groundwater water monitoring • Aquifer protected by multiple cement and steel casing barriers • Well integrity validated prior to completing stimulation
Weeds		
Weed control	• Noxious weeds • Impacts to vegetation communities	• Exploration Agreement(s) with NLC and Native Title holders and/or claimants • Baseline weeds survey completed • Ongoing weeds surveys and NTG bi-annual monitoring • Vehicle and equipment to be clean and have valid weed hygiene certificates prior to access

Activity	Potential consequence to activities	Consequence mitigations measures
		• Weed identification training of key personnel • Weed management plans
Air quality		
Dust	• Dust	• Exploration Agreement(s) with NLC and Native Title holders and/or claimants • Short period of high-volume traffic movements • Equipment movements to consider time of day to reduce impacts on traffic • Dust suppression utilised during high volume traffic movements and around sensitive features (homesteads, cattle yards etc.)
Emissions	• Increased emissions from flares and wells	• Exploration Agreement(s) with NLC and Native Title holders and/or claimants • Flares are used to reduce the risk associated with vented hydrocarbons • Short period of operations and testing • Baseline emissions monitoring conducted and is ongoing • Emissions monitoring at all locations • No well pad within 20 km of a residence
Light, noise and visual amenity		
Light and noise	• Interaction with stock • Reduction in amenity of surrounding site	• Exploration Agreement(s) with NLC and Native Title holders and/or claimants • Site location chosen to minimise impacts on pastoralist operations – including appropriate separation distances between sensitive receptors and activities • Short duration of drilling and stimulation activities

Activity	Potential consequence to activities	Consequence mitigations measures
Visual amenity	• Pastoral and Traditional Owner visual amenity	• Exploration Agreement(s) with NLC and Native Title holders and/or claimants • Site location chosen to minimise impacts on pastoralist amenity – including appropriate separation distances between sensitive receptors and activities • Short duration of drilling and stimulation activities • Site not located in major thoroughfare and away from most pastoralist activities

6.7 Northern Territory business engagement

Broader engagement has occurred with local and regional business within the local communities of Daly Waters, Elliott, Katherine and the broader Northern Territory region.

Northern Territory businesses have been engaged on the scope of Origin's activities through information sessions and tender opportunities covering a range of material supply and support services, such as:

- people transport and logistics
- accommodation and food
- provision of temporary camps and camp services
- civil construction work
- freight and transport
- water bore drilling
- water carting and waste management
- site maintenance and inspections
- weed management and control
- equipment and materials storage
- oil country tubular goods
- environmental and civil consulting
- surveying and geotechnical assessments
- general provisions of goods and services (such as personal protective equipment and hire cars).

6.8 Ongoing stakeholder and community engagement

Origin is committed to continuing to engage with stakeholders regarding the exploration activities under EP98, EP117 and EP76 and any associated environmental outcomes prior to, during and after performance of exploration activities.

Origin recognises the growing community interest in ensuring onshore natural gas development takes place in a safe and environmentally sound way and are committed to delivering operational excellence (which encapsulates our health, safety and environmental performance standards). From the perspective of negative impacts to regional tourism, businesses and accommodation, most Origin employees and contractors are predominantly based on site in camps away from major tourism/ business hubs, resulting in minimal competition with existing industries. This is discussed in the EMP and risk assessment (Appendix J). A range of services and supplies are sourced locally, including fuel, food, potable water, laydown yard storage, short term accommodation and office space. These services are provided year-round, giving local businesses an additional income stream during off peak periods.

Origin has further committed to ongoing engagement with the relevant Traditional Owners, including annual work plan meetings and provision of draft work programs for future years of activity.

Detailed community and stakeholder engagement are underway, covering future exploration activities. This includes the following engagement activities:

- Pastoralists:
    - Weekly-monthly engagement with host pastoralists for which activity is proposed within the immediate time period. With the engagement frequency agreed to with the pastoralist
    - Quarterly engagement with future host pastoralists for which activity is proposed within the preceding year time period
    - Annual consultation with all pastoralists, including surrounding pastoralists with no immediate proposed activities
- Native title holders of the area in which the activity is occurring:
    - Ad hoc updates for the NLC when required, informing them of progress of exploration activities underway
    - Quarterly project status updates to the NLC informing them of progress of exploration activities underway
    - Site visits by Traditional Owners during exploration activity so that Traditional Owners can have first-hand observation of key activities
    - Work program surveys conducted by Traditional Owners, with the support of the NLC, to review work programs and ensure protection of sacred sites and objects
    - Annual on country meetings with Native Title Holders to discuss current work program status and future exploration activities
    - Broader community engagement that is in addition to the requirements outlined in section 7 of the Regulations will continue.

7 Environmental risk assessment

7.1 Origin's risk management approach

Origin uses a robust risk management process for all its activities to achieve the following key outcomes:

- Risks are understood, eliminated or reduced and controlled to an acceptable level
- Controls are owned, assured and continuously reviewed for effectiveness
- All activities are compliant with regulatory standards and are guided by best practice
- Origin and its stakeholders are confident in the way activities are conducted to manage risks
- The approach aligns with the findings of the NT Inquiry Final Report and associated recommendations (as implemented via the Code or legislation).

Origin's risk assessment process is undertaken in accordance with section 5.4.3 of ISO 31000. Risk management is mandated through the Origin Risk Management Policy and Directive, which includes a risk rating toolkit that is utilised from the Board through to frontline activity owners (Figure 46).

Assessment of risk is completed using Origin's Risk Matrix (Figure 46) to assess and rate risks by assessing the combination of frequency of occurrence and the severity of the outcome of a potential event, including a worst-case scenario event. This allows quantification of a risk and determination can then be made about whether the risk can be accepted, or whether further mitigation is required.

Origin risk management processes requires regular assessment of unmitigated[17] risk from an activity, the residual risk once controls are applied, the effectiveness of controls (provided in Table 49) and the likelihood and consequence of a risk event. A residual risk is either accepted in accordance with strict delegations of authority or the activity does not proceed.

Origin also includes site specific controls for each identified risk, which further demonstrates how it achieves a residual risk that meets its ALARP and acceptable criteria. When applying the existing controls during the risk analysis (as per ISO 31000), there is very often little material change to most risk profiles identified in the risk register (Appendix L). This is a function of the comprehensive nature of the Code, which was designed to mandate a high level of environmental performance and minimise environmental risk.

Table 50: Risk control effectiveness definition

Rating	Explanation
Effective	• Controls are well designed and address the root cause(s) of the risk. • Controls are recognised industry best practice. • All controls operate at the required level.

[17] Unmitigated" risk ratings include applying existing controls, such as compliance with regulatory requirements which are mandatory (e.g. the Code, Regulations Schedule 1, etc).

Rating	Explanation
	• All controls are within the power of Origin, with few external factors beyond control. • Ongoing monitoring required.
Can Be Improved	• Majority of controls are well designed and address the root cause(s) of the risk. • Majority of controls operate at the required level. • Some controls are outside the power of Origin, with multiple external factors beyond control. • Ongoing monitoring required. • Certain controls can be improved or have elements below industry best practice.
Must Be Improved	• Most controls are not well designed and do not address the root cause(s) of the risk. • Most controls are not operating to the required level. • A large number of controls are outside the power of Origin, with multiple external factors. • The majority of controls require improvement and are well below industry best practice.

Risk Management

Directive

Appendix 1 – Origin Risk Rating Toolkit

Step A – describe the risk
Identify and describe the risk in terms of what could happen, its causes and potential effective/impact on Origin's objectives.

Step B – identify and assess controls
Identify and assess existing controls using the Control Assessment Ratings. Consider any related significant incidents, near miss events and assurance activities when assessing controls.

Step C – assess the level of consequence
Decide on the level of consequence that best represents the risk. Determine the highest credible consequence level in all relevant consequence categories in the Risk Matrix, taking into account current control assessment.

Step D – assess the likelihood
Determine the likelihood level in the Risk Matrix that represents the chance of the risk occurring at each consequence level identified, taking into account current control assessments.

Step E – determine the level of residual risk
Use the Risk Matrix to determine the level of risk

Step F – determine the priority for risk treatment and approval
Using the Risk Treatment and Acceptance Criteria, determine the risk treatment required and who can approve/accept the risk at its current level.

Step G – assess the potential maximum consequence
Estimate the potential maximum consequence (plausible worse case level assuming all current controls fail) using the consequence categories.

Control Assessment Ratings

Rating	Explanation
Effective	▪ Controls are well designed and address the root cause/s of the risk. ▪ Controls operate to the required level. ▪ Ongoing monitoring required.
Can be improved	▪ Majority of controls are well designed and address the root cause/s of the risk. ▪ Majority of controls operate to the required level. ▪ Certain controls can be improved. ▪ Ongoing monitoring required.
Needs to be improved	▪ Majority of controls are not well designed and do not address the root cause/s of the risk. ▪ Majority of controls do not operate to the required level. ▪ Majority of controls require improvement.

Risk Treatment and Acceptance Criteria

Level of risk	Action required	Acceptance authority
VERY HIGH	▪ Risk treatment must be in place immediately ▪ Review risk quarterly at a minimum	ELT member*
HIGH	▪ Risk treatment must be considered (having regard to current business priorities) ▪ Review risk annually at a minimum	General Manager
MEDIUM	▪ Risk treatment may be considered ▪ Review risk two yearly at a minimum	Group/Asset (EM)/ Project Manager/ Manager/Lead (IG)
LOW	▪ No risk treatment required ▪ No ongoing review required unless determined by the relevant Group Manager	Site/Activity Manager/ Manager/Lead (IG)

* CEO acceptance required for risks with a Catastrophic consequence and Likely or above Likelihood

Figure 46: Origin's risk toolkit which describes the approach to identify, assess, control, treat and accept risks

Risk Matrix

CONSEQUENCE	IMPACT ON ORIGIN OPERATIONS – Conduct Business with Due Care: People	IMPACT ON ORIGIN OPERATIONS – Conduct Business with Due Care: Environment and Community	IMPACT ON ORIGIN OPERATIONS – Create Value: EBIT	IMPACT ON ORIGIN OPERATIONS – Create Value: Cash flow	IMPACT ON ORIGIN OPERATIONS – Create Value: NPV	EXTERNAL RESPONSE – Decisions are Subject to Scrutiny: Stakeholder Perceptions	EXTERNAL RESPONSE – Decisions are Subject to Scrutiny: Laws, regulation and civil actions
6 CATASTROPHIC	Multiple fatalities ≥4 or life threatening illness or total permanent disability to a large exposed group (10 or more people)	Extensive permanent damage to endangered species, habitats, ecosystems or area/s of cultural significance Extensive irreversible loss of community livelihood. Long-term social unrest and outrage	>$200m	>$1b	>$1.5b	Multiple stakeholder groups confirming coordinated action, as reflected in media channels with significant reach and influence (eg. scheduled blockade or boycott covered in media for more than 1 week).	Criminal charges against any director or senior executive involving jail or loss of right to manage the company. Public inquiry – requiring considerable resources and Executive Management time. Loss of licence to operate an asset
5 CRITICAL	1 – 3 fatalities or life threatening illness or total permanent disability to a small exposed group (<10 people)	Extensive long term partially reversible damage to vulnerable species, unique habitats, ecosystems or area/s of cultural significance Extensive reversible loss of community livelihood. Prolonged community outrage.	>$50m - $200m	>$250m - $1b	>$375m - $1.5b	Multiple stakeholder groups mobilising and encouraging others to take action, as reflected in media channels with significant reach and influence (eg. social media campaign calling for protest, escalating over several days).	Criminal charges against any director, senior executive or senior manager not involving jail or loss of right to manage the company. Prolonged major litigation – exposure to significant damages / fines / costs. Suspension / restriction to operate an asset.
4 MAJOR	Injury or illness to one or more persons, resulting in permanent partial disability	Long term reversible impacts to listed species, habitats, ecosystems or area of cultural significance Significant impacts to community cost of living, business viability or social wellbeing. High levels of community tension.	>$20m - $50m	>$100m - $250m	>$150m - $375m	More than one stakeholder group's opinion or view influencing other stakeholders, reported through media channels with some reach and influence (eg. government comments in national media or in Parliament).	Criminal charges against any employee (not described above) Major litigation – exposure to damages / fines / costs.
3 SERIOUS	Injury or illness to one or more persons resulting in hospitalisation, 5 or more days lost time or alternative / restricted duties for 1 month or more	Serious medium term reversible impacts to low risk species, habitats, ecosystems or area/s of cultural significance Moderate impacts to community cost of living, business viability or social wellbeing. Moderate levels of community tension.	>$5m - $20m	>$25m - $100m	>$37.5m - $150m	More than one stakeholder group offering an opinion or view, reported through media channels with some reach and influence (eg. state based commentary lasting one 24 hour media cycle across internet, print, television, radio).	Non-compliance with conditions of licence to operate an asset or to conduct an activity. Litigation – exposure to damages / fines / costs.
2 MODERATE	Injury or illness to 1 or more persons resulting in medical treatment, up to 5 days lost time or alternative / restricted duties for up to 1 month	Moderate short term impacts to common regional species, habitats, ecosystems or area of cultural significance Small scale impacts to cost of living, business viability or social wellbeing. Isolated examples of community tension.	>$1m - $5m	>$500k - $25m	>$750k - $37.5m	A single stakeholder group drawing attention to an incident, issue or approach, conveyed though media channels with potential reach and influence (eg. some social media complaints or local media reports).	Moderate non-compliance with external mandatory obligations or breach of contractual or other legal obligations (not described above). Litigation possible.
1 MINOR	Injury or illness requiring first aid to 1 or more persons, or no treatment (record only)	Minor environmental or community impact - readily dealt with	>$100k - $1m	<$500k	<$750k	A person or organisation within stakeholder group signaling an interest in an incident, event or approach, using channels with limited reach or influence (eg. letter of complaint/commendation).	Minor non-compliance with external mandatory obligations or breach of contractual or other legal obligations.

CONSEQUENCE	LIKELIHOOD – 1 REMOTE: <1% chance of occurring within the next year. Only occurs as a '100 year event' or less frequent.	2 HIGHLY UNLIKELY: <10% chance of occurring within the next year. Could occur within decades.	3 UNLIKELY: <30% chance of occurring within the next year. Could occur within the next few years.	4 POSSIBLE: <60% chance of occurring within the next year. Could occur within months to years.	5 LIKELY: <90% chance of occurring within the next year. Could occur within weeks to months.	6 HIGHLY LIKELY: Likely to happen multiple times a year
6 CATASTROPHIC	HIGH	HIGH	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH
5 CRITICAL	MEDIUM	MEDIUM	HIGH	VERY HIGH	VERY HIGH	VERY HIGH
4 MAJOR	MEDIUM	MEDIUM	MEDIUM	HIGH	VERY HIGH	VERY HIGH
3 SERIOUS	LOW	MEDIUM	MEDIUM	MEDIUM	HIGH	HIGH
2 MODERATE	LOW	LOW	MEDIUM	MEDIUM	MEDIUM	MEDIUM
1 MINOR	LOW	LOW	LOW	MEDIUM	MEDIUM	MEDIUM

* Cash Flow - change from expectation over the life of the exposure. EBIT change from expectation over 12 – 18 month period.

Figure 47: Origin's Risk Matrix

7.2 ALARP

Origins risk management process requires risks to be management to ALARP. A risk can be considered to have been reduced to ALARP when all reasonably practicable control measures (both preventative and mitigative) have been identified and implemented to reduce the risk of identified events. A key element of demonstrating ALARP is that good practice is followed, where good practice is defined as the recognised risk management practices and measures that are used by competent organisations to manage well understood hazards arising from their activities. This definition incorporates good practice as defined in codes and standards, and a consensus of good practice within the industry. ALARP is not a final position over the life of an asset or project.

The practicability and the reasonability of control measures can change over time due to changes in technology (that can make measures more readily available), industry standards (that can commoditise once-cutting-edge technology) and the socio-technical landscape (that can modify societal expectations).

In the NT context, ALARP and the definition of acceptable risk levels was a key feature of the NT Inquiry Final Report. For each aspect, acceptability criteria were defined, with recommendations outlined to reduce the potential risk to below the acceptable level. With the adoption of all recommendations by the NTG, the Code and associated regulatory changes provides a high level of inherent protection to ensure activities are undertaken in a safe and consistent manner.

Origin considers ALARP to be achieved where the residual risk is low, whereby any additional control measures applied will not reduce the risk any further.

If the residual risk of low is not achieved, Origin considers ALARP to be achieved where the following criteria have been met:

1. the requirements of the Code have been met
2. all reasonably practicable site-specific controls have been identified and implemented and
3. the cost of further reducing the risk is unreasonable compared to the environmental benefit gained from implementing the control measure.

7.3 Risk acceptability

Origin uses a series of criteria provided in Table 50 to determine the acceptability of a residual risk. Each residual risk event outlined in Appendix L is assessed against these criteria to determine whether Origin believes the residual risk is acceptable. The outcome of the residual risk acceptability assessment and outcome is provided in Appendix L.

Table 51: Residual risk acceptability criteria

#	Criteria	Origin's acceptance threshold
1	Residual risk level	Consistent with Origin's risk acceptance criteria: **Very high risk** – Not acceptable **High risk** – Residual risk may be conditionally accepted where the residual risk is ALARP and the risk is signed off by a General Manager with risk treatment applied to improve, control or further modify risk. Risk reviews are to occur annually with the intent to reduce the risk severity lower.

#	Criteria	Origin's acceptance threshold
		Medium-Low risk – Residual risk is accepted when ALARP is demonstrated
2	Legislative requirements and regional strategies and conservation plans	1. Consistent with legislative requirements, including Code 2. Consistent with regional strategies and conservation/threat abatement plans
3	Stakeholder expectations	Consistent with the commitments made in stakeholder engagement and/or agreements
4	Industry guidelines and best practice	Is consistent with petroleum standards (such as API and the Oil and Gas UK standards), best practice and controls used in other NT industries
5	Scientific uncertainty in the data used to determine the environmental impact or risk	**Low uncertainty:** Accepted Risks are well understood and uncertainty is minimal **Moderate uncertainty:** Accepted using well-established data and assessment methods. Some uncertainty exists, with routine monitoring and performance criteria in place to detect and respond to any impacts arising from a risk. **High**: Conditional acceptance – Significant uncertainty exists with data and assessment methodologies unproven. A precautionary approach will mean that uncertainty is replaced by conservative assumptions that will require additional control measures being implemented to prevent, detect and respond to any impacts arising from a risk.
6	Ecological Sustainable Development Principles	Risk is consistent with the principles of ESD as defined in section 1.1. This also includes weighting to consider the social and economic benefits of the project

7.4 Assessment of scientific uncertainty

The Petroleum (Environment) Regulations requires an assessment of uncertainty as a part of the risk assessment process. The assessment of potential impacts and effectiveness of controls must demonstrate that the activities are carried out in a manner consistent with the Principles of Ecologically Sustainable Development (ESD) and the Precautionary Principle.

Impact and risk identification must include consideration of uncertainty regarding impacts and risks for the activity where a precautionary approach is appropriate. Uncertainty is high where confidence in the available information is low in identifying risk or the effectiveness of a management control. Additional baseline studies or other safeguards may be required to increase the accuracy of an assessment to determine the acceptability of a risk.

As per the Draft EMP Guidelines, scientific certainty is qualitatively assessed using a generic means of ranking the data available in accordance with Table 51. Considerations of uncertainty have been included in the risk assessment discussed in section 7.5.

Table 52: Scoring system for Scientific Uncertainty (DEFRA, 2013)

Ranking Scientific Uncertainty	
Score	**Description**
Low (1)	• Comprehensive data with strong evidence in multiple peer reviewed data • Little disagreement between authors or experts • Considerable and consistent on-ground experience and/or monitoring
Medium (2)	• Some or incomplete data available • Evidence provided based on a small number of references • Authors or experts conclusions vary • Limited on-ground experience and/or monitoring
High (3)	• Scarce or no data available; evidence provided in unpublished reports • Few on-ground observations • Authors and experts conclusions vary considerably

7.5 Risk assessment outcomes

The environmental, heritage and social risks associated with the activities covered under this EMP have been assessed using the Origin risk assessment framework described in section 7.1. The risk assessment presents the range of potential impact-causing activities, corresponding mitigation measures and residual risk ratings based on their assessed worst-case consequence and likelihood of occurrence. The assessment also cross-references the various risk assessment outcomes in the NT Inquiry Final Report, to ensure consistency.

Site specific conditions and cumulative impacts have also been considered during the assessment. Cumulative impacts have included the following:

- A total of 12 future Origin E&A wells for the 2022 - 2027 period as per the current approved tenure work plan.
- Existing land users (predominately pastoralists).

There were no residual risks above a ‘Medium’ risk ranking, with 23 risk scenarios. Within these risk scenarios, the assessment considered 83 risk sources which may potentially result in a risk occurring. Of the 83 risk sources, 12 were ranked as ‘Moderate’ with the remaining ranked as ‘Low’. The medium residual risks sources identified through the risk assessment include:

1. Loss in soil productivity and viability due to soil erosion from cleared areas (existing access tracks, lease pads, camp pads and 2D seismic) – risk ID24

2. Impact to listed threatened habitats and listed threatened flora and fauna, including non-listed fauna and livestock through the introduction and spread of weeds in the area – risk ID 35 and risk ID 43
3. Impact to listed threatened habitats and listed threatened flora and fauna, including non-listed fauna and livestock from exploration activities (drilling, HFS, flaring, general access, 2D seismic) – risk ID 36 and risk ID44
4. Impact to listed threatened habitats and listed threatened flora and fauna from poor rehabilitation of 2D seismic lines – risk ID 45
5. Disturbance of sacred site or culturally sensitive area and decline in environmental value of area used for cultural purposes through the accidental ignition of fire by site activities – risk ID 48 and risk 52
6. Reduction in agriculture productivity through the introduction and spread of weeds in the area – risk ID 60
7. Reduction in agriculture productivity through bushfire from accidental ignition by site activities or site personnel – risk ID 63
8. Increased nuisance from dust emissions associated with the activities – risk ID 72
9. Increased nuisance from dust and particulate emissions due to accidental ignition of bushfire during the site activities – risk ID 73

The 'Medium' risks identified were consistent with standard construction or pastoralist activities carried out across the NT, being the potential spread of weeds, erosion and sediment control, and ignition of bushfires from the proposed activities. The reduced risk profile associated with stimulation activities (such as potential spills and groundwater contamination) is reflective of the stringent regulatory requirements in the Code.

The level of uncertainty for each risk was also assessed. There was no uncertainty level above 'Low', which is consistent with the scale of the activity and the knowledge of impacts associated with shale exploration activities demonstrated in the Inquiry Final Report and through the various reports published by the US EPA (such as USEPA 2016- U.S. EPA. Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States (Final Report)).

Table 52 provides a count of the post-treatment environmental risks associated with this EMP. A copy of the risk assessment is provided in Appendix L.

Table 53: Count of Residual Environmental Risks for the drilling and stimulation program

	Residual Environmental Risk Level			
	Low	**Medium**	**High**	**Very High**
Total 72	71	12	0	0

7.6 Environmental outcomes, performance standards and measurement criteria

The following section provides the environmental outcomes, performance standards and measurement criteria of each environmental aspect, based on the risk assessment presented in Appendix L. Tables 47 to 53 provide the environmental outcomes, performance standards and measurement criteria to demonstrate whether controls have been effective during the activity and that the stated environmental outcomes have been achieved.

7.6.1 Soils

Table 54: Environmental outcomes, performance standards and measurement criteria – Soils

Environmental performance measures- Soil				
Environmental outcome	**Environmental performance standards**		**Measurement criteria**	**Records**
No significant impact to the ecological function and productivity of surrounding soils resulting from Origin's exploration activities	S-1	No releases of contaminants (chemicals, stimulation fluid, hydrocarbon, drilling wastewater or flowback wastewater) outside of Origin's lease pad	Weekly site inspections completed during chemical and wastewater storage, handling, treatment and recycling activities confirm no releases of chemicals, stimulation fluid, recycled flowback wastewater, hydrocarbons and wastewater outside of Origin's lease disturbance area	Weekly records of site inspections retained OCIS incidents of off-site releases retained
	S-2	No reportable spills, including wastewater tank/sump overtopping events or spills from wastewater recycling, resulting from Origin's exploration activities	Weekly site inspections during hydrocarbon, wastewater and chemical storage, handling and recycling activities confirm no reportable spills	Weekly records of site inspections retained OCIS incidents of reportable incidents relating to spills
	S-3		Zero reportable incidents resulting from chemical or waste handling, flowback recycling, treatment and transportation accidents	OCIS incidents of reportable incidents relating to transportation accidents and spills
	S-4	Erosion and sediment control in place and working effectively	6-monthly site stability inspections confirm ESC in place and working effectively. No erosion or sediment releases present that cannot be rectified during routine site maintenance.	ESC inspection records retained

Environmental performance measures- Soil				
Environmental outcome	**Environmental performance standards**		**Measurement criteria**	**Records**
	S-5		Evidence of maintenance performed on all material erosion and sediment control events	Maintenance records retained
	S-6	Seismic line reinstatement and rehabilitation implemented to return vegetation cover	Seismic lines to be reinstated within 4 weeks	Daily seismic activity reports
Risk sources	• Soil compaction from access tracks, leases, camp pads, helipads, 2D seismic lines etc. (Risk ID 23) • Soil erosion from cleared areas (access tracks, lease pad, and camp pads and seismic lines) (Risk ID 24) •Soil erosion and instability from 2D seismic charge detonation (Risk ID 25) • Spills/leaks from the on-site storing and handling of fuels (condensate, hydrocarbons, drilling additives, stimulation additives, drilling fluids, flowback fluid, solid wastes, storage and transportation of wastes) (Risk ID 26) • Drill sump and flowback tank overtopping (Risk ID 27) • Chemical and waste transportation accident (Risk ID 28) • On-site disposal of drill muds and cuttings (Risk ID 29) • Failure of a flowback tank (Risk ID 30) • Wastewater evaporation mist transported off-site during wastewater treatment (Risk ID 31) • Greywater and sewerage disposal (camps) (Risk ID 32)			

7.6.2 Surface water

Table 55: Environmental outcomes, performance standards and measurement criteria – Surface water

Environmental performance measure – Surface water				
Environmental outcome	**Environmental performance standards**		**Measurement criteria**	**Records**
No significant impact on surface water quality resulting from Origin's exploration activities	SW-1	During chemical and wastewater recycling and storage activities, no off-site release of contaminants from chemical, hydrocarbon and waste storage	All stormwater discharges monitored by operators prior to release, with results confirm stormwater is within the approved limits listed in Table 23	Discharge monitoring results retained for each stormwater release
	SW-2	No seismic events over Ml 3.5 attributable to Origin's activities	No seismic events over Ml 3.5 recorded in vicinity of a hydraulic fracture operation measured at the Warramunga seismic monitoring station or adjacent seismometer during period that hydraulic fracture stimulations have occurred resulting in surface subsidence and impacting surface hydrology.	Monitoring results available at https://earthquakes.ga.gov.au/
	SW-3	No reportable spills, including off-site releases of contaminants resulting from Origin's exploration activities	Weekly site inspections completed during chemical and wastewater storage, handling and recycling confirm no releases of chemicals, hydrocarbons and wastewater outside of the project areas	Weekly records of site inspections retained
				OCIS incidents of off-site releases retained

Environmental performance measure – Surface water				
Environmental outcome	**Environmental performance standards**		**Measurement criteria**	**Records**
	SW-4	Erosion and sediment control in place and working effectively	All material erosion and sediment control events are rectified as soon practicable upon identification	OCIS incidents of reportable incidents relating to spills
Risk sources	• Failure of flowback storage tank (Risk ID 14) • Overtopping of drilling sumps and flowback tanks (including wet season operations) (Risk ID 15) • Transportation accident releasing chemical or wastewater (drilling fluid and flowback) (Risk ID 16) • Storage and handling of drilling and stimulation chemicals and hydrocarbons (Risk ID 17) • Release of stormwater from activities to surface water (Risk ID 18) • Runoff from sewage treatment irrigation areas (Risk ID 19) • Infrastructure located on regional flow path resulting in changes to surface water flow (Risk ID 20) • Changes to terrestrial ground surface levels associated with seismic activity (Risk ID 21)			
Instrument calibration	**Management of storm water**: Instrument calibrated before use. pH probe calibrated with a two-point calibration using a pH buffer of 7 and 10. EC meter calibrated with a 1413µs/cm (or similar) standard.			

7.6.3 Groundwater

Table 56: Environmental outcomes, performance standards and measurement criteria – Groundwater

Environmental performance measure – Groundwater				
Environmental outcome	**Environmental performance standards**		**Measurement criteria**	**Records**
Origin's exploration activities do not reduce the environmental values of the underlying groundwater resources	GW-1	All regional aquifers isolated through cement and casing	Isolation of the Gum Ridge Formation and Anthony Lagoons Formation is confirmed through cement bond logs and casing pressure tests.	Well completion report
	GW-2	No failure of wastewater tank secondary liner	All leak detection alarms investigated within 24 hour, with no incidents of secondary liner failure.	Records of leak detection alarms and investigations retained on site
				Incidents of secondary liner failure documented in OCIS and reported to regulator.
	GW-3	No seismic events over Ml 3.5 attributable to Origin's activities	No seismic events over Ml 3.5 recorded in vicinity of a hydraulic fracture operation measured at the Warramunga seismic monitoring station or adjacent site seismometer during period that hydraulic fracture stimulations have occurred.	Monitoring results available at https://earthquakes.ga.gov.au/
	GW-4	No long-term (>12 month) reduction in quality of an impact groundwater monitoring bore that is attributable to Origin's activities. A decline is defined as a change in water chemistry that exceeds the ANZECC guidelines for Livestock (the primary Environmental Value) of groundwater in the region.	Quarterly groundwater monitoring data collected and analysed against baseline data demonstrates no material decline in groundwater quality.	Quarterly groundwater monitoring results retained

Environmental performance measure – Groundwater				
Environmental outcome	**Environmental performance standards**		**Measurement criteria**	**Records**
	GW-5	No long term (>12 month) reduction in groundwater level observed in the impact monitoring bore that results in >1 m decline in groundwater water level	Quarterly groundwater monitoring data collected and analysed against baseline data confirms no material (>1 m) decline in groundwater level	Quarterly groundwater monitoring results retained
	GW-6		Total groundwater extraction volume below the approved water extraction licence take of 175 ML/year	Groundwater take records retained
Risk sources	• Sub-surface loss of drilling fluids during drilling (Risk ID 1) • Sub-surface cross flow of formation through inappropriate well barrier design and construction (Risk ID 2) • Sub-surface crossflow through fracture growth into aquifer from stimulation activities allowing the migration of fluid and gas (Risk ID 3) • Stimulation activity induces seismic activity that enables cross formational flow between shallow aquifers (Risk ID 4) • Sub-surface migration of fluid and gasses via fractures intersecting with offset wells (including the adjacent horizontal wells) or intersecting an existing geohazard (Risk ID 5) • Crossflow/well integrity caused by the deviation of an E&A well into the adjacent well during drilling (Risk ID 6) • Leakage of either flowback, produced water, or hydrocarbons (liquid and gaseous) from suspended or abandoned wells (Risk ID 7) • Surface spills/contamination from the storage and disposal of drilling fluids, additives, muds and cuttings on-site (Risk ID 8) • Surface spills from the storage, handling and transportation of produced hydrocarbons (condensate) (Risk ID 9) • Surface spills from storage, handling and transportation of flowback water (Risk ID 10) • Surface spills from the storage, handling and transportation of chemicals, fuels and wastes (Risk ID 11) • Surface spills from the overtopping of drilling sumps and flowback tanks (including during wet season) (Risk ID 12) • Surface spills from the failure of flowback storage tank (Risk ID 13) • Over extraction of groundwater for exploration activities (Risk ID 22) • Cumulative impact from regional groundwater take exceeds the natural recharge rate of the Basin (Risk ID 68)			
Instrument calibration	**Groundwater volume:** N/A approved DEPWS meter used with no calibration required.			

7.6.4 Ecology – flora, fauna and habitats

Table 57: Environmental outcomes, performance standards and measurement criteria – Ecology

Environmental performance measures – Ecology				
Environmental outcome	**Environmental performance standards**		**Measurement criteria**	**Records**
No significant impact to high valued habitats and listed threatened flora and fauna from Origin's exploration activities	EC-1	No releases of wastewater (drilling fluid and flowback) off the lease into the surrounding vegetation	Weekly site inspections confirm no loss of containment (structural failure, overtopping or major spills from wastewater storage, handling and recycling) resulting in off-site releases of wastewater	Weekly site inspection completed during wastewater storage
	EC-2	<7 individual fauna deaths per week for 2 consecutive weeks caused by flowback water storage	Daily checks of wastewater tanks for fauna mortality during well testing	Fauna interaction log retained
	EC-3		Weekly checks of area immediately surrounding lease pad for fauna deaths	Fauna interaction log retained
	EC-4	No listed threatened fauna deaths caused by flowback storage, handling and recycling	Daily checks of wastewater tanks for fauna mortality during well testing	Fauna interaction log retained
	EC-5		Weekly checks of area immediately surrounding lease pad for fauna deaths	Fauna interaction log retained
	EC-6	No uncontrolled bushfires caused by Origin's exploration activities (including civil construction, seismic and E&A activities)	Zero reported incidents of uncontrolled bushfire caused by Origin's activities	Fire incident data to be retained for all Origin unplanned fires
	EC-7	Weed surveys completed on all Origin disturbed areas	6-monthly pre and post-wet season weed surveys completed on all Origin controlled disturbed areas	Annual weed monitoring and management report
	EC-8	Year-on-year decline in the size and density of all weed infestations introduced as a result of Origin's activities	Annual report demonstrates weed infestation size and density of weed outbreaks introduced by Origin's activities are reducing each year	Annual weed monitoring and management report

Environmental performance measures – Ecology				
Environmental outcome	**Environmental performance standards**		**Measurement criteria**	**Records**
	EC-9	Disturbed seismic lines are reinstated promptly to promote revegetation	Seismic reinstatement commences within 4 weeks upon completion of seismic data acquisition	Daily seismic activity reports
Risk sources	• Activity (vehicle and machinery) noise and lighting on well pads and access tracks (Risk ID 33) • Structural failure and overtopping of flowback storage tanks and drilling sump (Risk ID 34) • Introduction and spread of weeds in the area (Risk ID 35) • Accidental ignition of fire from exploration activities (drilling, stimulation, flaring and general access (Risk ID 36) • Poor rehabilitation of the site reduces regional habitat and promotes weed invasions (Risk ID 37 • Trapping and drowning of fauna in storage tanks and sumps (Risk ID 38) • Contaminants in water and soil pass through the food chain and bioaccumulate in fauna causing detrimental impacts to local species and communities (Risk ID 39) • Vehicle collisions with fauna – fauna mortality results in a localised decline in species abundance (Risk ID 40) • Encouragement of feral animals and other pest species increases leading to competition with native species. This includes the introduction of cane toads (Risk ID 41) • Activity (Vehicle, machinery and seismic activity) noise and vibration during 2D seismic acquisition (Risk ID 42) • Introduction and spread of weeds during 2D seismic (Risk ID 43)			

7.6.5 Air quality and greenhouse gas emissions (GHG)

Table 58: Environmental outcomes, performance standards and measurement criteria – Air quality and GHG emissions

Environmental performance measures – air quality and GHG emissions				
Environmental outcome	**Environmental performance standards**		**Measurement criteria**	**Records**
No significant impact on air quality and no excess greenhouse gas emissions as a result of Origin's exploration activities	AQ-1	Venting to be eliminated as far as reasonably practicable	Daily reports confirm all technically recovered hydrocarbons sent to the flare is metered and recorded	Gas flow volumes recorded
	AQ-2	All greenhouse gases reporting in accordance with NGERS requirements	All emissions related data (fuel use, flaring volumes etc.) reported in accordance with NGERS requirements	Emission related data (fuel use, flare volumes, etc.) retained
	AQ-3	All leaks detected and repaired in accordance with Code	6-monthly leak detection program completed on surface equipment.	Leak detection records retained
	AQ-4		Minor leaks rectified as per Code within 30 days	Leaks and management recorded in OCIS
	AQ-5		A significant leak is repaired as per the Code within 72-hours	Leaks and management recorded in OCIS
Risk sources	• Emissions from the combustion of diesel (Risk ID 68) • Air emissions from gas and condensate flaring (Risk ID 69) • Air emissions from chemical releases during drilling and stimulation activities (Risk ID 70) • Emissions form the combustion of diesel, detonation of charges and dust from clearing (Risk ID 71) • Dust from truck movements, drilling operations, stimulation and well testing (Risk ID 72) • Bushfire from accidental ignition by site activities (civil works, seismic, drilling, flaring, grinding) or personnel (Risk ID 73) • Combustion of diesel for exploration activities, including civil construction, seismic and E&A activities (Risk ID 74) • Avoidable GHG generation through flaring of gas and condensate during well testing (Risk ID 75) • Uncontrolled release of gas encountered during drilling, stimulation, barrier failure, operator error or vehicle collision under a multi-well scenario (Risk ID 76) • Leak of gas from wells (Risk ID77) • Uncontrolled release of gas from well due to sabotage (Risk ID 78)			
Instrument calibration	Identification and remediation of gas leaks: Gas detector calibrated monthly with a 10 ppm (or similar) methane calibration gas.			

7.6.6 Community

Table 59: Environmental outcomes, performance standards and measurement criteria – lighting, noise, vibration and visual amenity

Environmental performance measures – Community				
Environmental outcome	**Environmental performance standards**		**Measurement criteria**	**Records**
No significant negative impacts to the community resulting from Origin's exploration activities	CO-1	All valid community complaints of nuisance investigated and resolved	All valid community complaints responded to within 24 hours with actions to remedy nuisance implemented as soon as practicable (depending on the nature of the complaint)	OCIS records of community complaints and actions completed
	CO-1	>60% of addressable spend[18] to be from NT businesses	Project expenditure data confirms the NT business spend on the Beetaloo exploration project exceeds >60% of addressable spend[18] of the project	Data on NT business spend retained
Risk sources	• Industrialisation of landscape (Risk ID 54) • Increased traffic (Risk ID 55) • Light emissions impact on sensitive receptor (such as pastoralist) (Risk ID 56) • Influx of workers to region (Risk ID 48) • Noise emissions from activities (Risk ID 58) • Noise emissions from activities (Risk ID 59) • Introduction and spread of weeds in the area (Risk ID 60) • Over extraction of groundwater (Risk ID6) • Impact to surface hydrology reduces water capture (Risk ID 62) • Bushfire from accidental ignition by site activities (civil works, seismic, drilling, flaring grinding) or personnel (Risk ID 63) • Poor rehabilitation of exploration infrastructure (Risk ID 64) • Exploration activities compete with agricultural industry for resources (Risk ID 65) • Increased risk of vehicle accident (Risk ID 66) • Exploration activities compete with agricultural industry for resources (Risk ID 67)			

[18] Addressable spend: a service or material that can be reasonably provided by an NT business at similar quality, timeliness and cost.

7.6.7 Cultural heritage

Table 60: Environmental outcomes, performance standards and measurement criteria – cultural heritage

Environmental performance measures – cultural heritage				
Environmental outcome	**Environmental performance standards**		**Measurement criteria**	**Records**
No significant impact on sacred sites and environmental values as a result of Origin's exploration activities	EC-1	No non-compliances with Native Title Holder Exploration Agreements and AAPA certificate conditions	No non-compliances with AAPA certificate conditions including unauthorised work within Restricted Work Areas (RWA)	OCIS incidents retained where unauthorised activities are identified
	EC-2		No breaches of Native Title holders Exploration Agreements	OCIS incidents retained where unauthorised activities are identified
Protection of culture and heritage	EC-3	Native Title holders are actively engaged on Origin's work program, including understanding of Origins current and future exploration activities.	Annual work program update report completed and submitted on time	Records of annual work program update report retained.
	EC-4		On country meetings completed providing status of work program and future activities- including ongoing presentation of story boards and other activity information	Records of on country meetings retained
	EC-5		Engagement and presence of local Cultural Managers during new land disturbance activities	Records of Native title Holders attending disturbance activities
	EC-6		Annual welcome to country smoking ceremonies completed for each year's work program	Records of welcome to country ceremonies retained.
	EC-7		Indigenous business involved in at least 2 environmental monitoring program, such as weed, monitoring, groundwater monitoring and site stability monitoring	Records of environmental programs completed by indigenous contractors retained.

Environmental performance measures – cultural heritage			
Environmental outcome	**Environmental performance standards**	**Measurement criteria**	**Records**
Risk sources	• Sites disturbed directly by exploration activities (Risk ID 47) • Accidental ignition by site activities (civil works, drilling, grinding) or site personnel (Risk ID 48) • Flowback tank structural failure (Risk ID 43) • Personnel unauthorised access to sacred site (Risk ID 44) • Sites disturbed directly by 2D seismic activities (Risk ID 51) • Accidental ignition during 2D seismic activities (Risk ID 52) • Personnel unauthorised access to scared site during 2D seismic (Risk ID 53)		

8 Management plans

The following section provides a high-level summary of the various management plans required to be implemented in accordance with the Code.

8.1 Wastewater management plan

A wastewater management plan (WWMP) has been developed to satisfy the requirements of the Code. The WWMP describes how Origin will store wastewater to minimise risks to the environment. A copy of the WWMP is provided in Appendix F.

8.2 Spill management plan

The use of secondary containment to prevent spills during the activities is a regulatory requirement embedded in national and state chemical handling legislation and guidelines. These requirements have been further covered in the Code.

A spill management plan (SMP) has been developed covering Origin's proposed exploration activities. This SMP is provided in Appendix E.

An example of bunding used for drilling and stimulation activities is provided in Figure 48.

Figure 48: Examples of spill mats used to contain potential wastewater transfer spills

8.3 Methane emissions management plan

A methane emission management plan (MEMP) is required to be developed to demonstrate how methane emissions will be managed (Appendix H). The MEMP describes how Origin:

- Mitigates the generation of methane emissions, such as the minimisation of venting and use of reduced emission completions
- Outlines the required leak detection and repair programs

- Summarises the leak reporting requirements

8.4 Erosion and sediment control plan

An erosion and sediment control plan has been developed to outline how the Amungee NW site will be operated to minimise the risk of erosion and sediment releases to the surrounding environment. The ESCP is provided in Appendix G.

8.5 Rehabilitation plan

Once a determination has been made to decommission an asset, a site-specific rehabilitation strategy will be developed for each disturbed area in accordance with the Code. A specific strategy for each area is required to ensure the operational history of the site is considered during rehabilitation planning (such as spills etc.). As per the Code, rehabilitation will commence within 12 months of determining an asset is no longer required.

Each petroleum well will be plugged and decommissioned in accordance with the Code. All tanks, surface infrastructure and wastes will be removed from site and disposed of in accordance with the *Waste Management and Pollution Control Act 1998*.

All remaining disturbance will be rehabilitated in alignment with the Code and typically include the following aspects (depending on the infrastructure being rehabilitated) to return disturbed areas to a state where they are ecologically integrated with the existing environment:

- Removal of all surface facilities
- Removal of all weeds and contaminated materials/wastes
- Re-spreading of stockpiled topsoil
- Backfilling of all open sumps
- Reshaping the site to as close to natural form as possible
- Ripping or scarifying any compacted surface
- Spreading of stockpiled vegetation to aid in surface water flow control
- Spreading seed of suitable local native species which has been determined through analogue sites representative surrounding vegetation communities
- Any native seed supply and rehabilitation services will be sourced using Indigenous suppliers (where available).
- Yearly monitoring of the rehabilitation success requirements to assess the rehabilitation status of a site and determine where additional remedial works are required

The rehabilitation plan for the Amungee sites is provided in Appendix N.

8.6 Weed management plan

Exploration activities are undertaken in accordance with Origin's Beetaloo Weed Management Plan Appendix B). This plan has been developed in accordance with the *Weed Management Planning Guide: Onshore Shale Gas Developments Project.*

Weed surveys have confirmed the proposed area of activity has an extremely low presence of weeds. Efforts will therefore focus on both eliminating the potential introduction of weeds into the region and preventing the spread of existing weeds.

From a cumulative impact perspective, the risks of increasing weed pressure in the area is reduced through the mandated use of weed hygiene inspections/certification for all equipment and vehicles and routine weed monitoring and maintenance. Any weeds that are introduced into the activity areas will be promptly identified and managed, reducing the potential additional stress to the region.

8.7 Bushfire management plan

A bushfire management plan (BMP) has been developed for each of the sites to outline the controls to prevent, detect and respond to fires associated with Origin's activities (Appendix A). Controls implemented include:

- Implementation and maintenance of firebreaks
- Monitoring during periods of high fire danger
- Flaring controls, including separation distances and cessation of flaring during total fire bans
- Fire response and reporting

8.8 Well operations management plan

A well operations management plan (WOMP) must be developed and submitted to the Minister for Industry, Tourism and Trade (DITT) for approval prior to the commencement of activities. The WOMP is a separate approval from the EMP and provides an operational description of how Origin plans to operate, suspend and decommission the proposed wells in a manner that ensures all risk to the environment are reduced to As Low as Reasonably Practicable (ALARP).

9 Implementation strategy

9.1 Corporate environmental policy

Origin's activities are governed by the Origin Health, Safety and Environment Management System (HSEMS). This system is underpinned by Origin's Health, Safety and Environment (HSE) Policy (Figure 50) which is designed to "Conduct our business in a way that causes no harm to the health and safety of people and has no unforeseen impacts to the environment".

9.2 Environment, health and safety management systems

Origin has a mature HSEMS which contains the policies and procedures that Origin has in place to manage and minimise the impact from its activities. In addition to meeting legal requirements, Origin's activities are also governed by several additional internal directives and risk control directives designed to ensure best practice in environmental risk management.

An overview of the Origin HSEMS and the associated directives is provided in Figure 49.

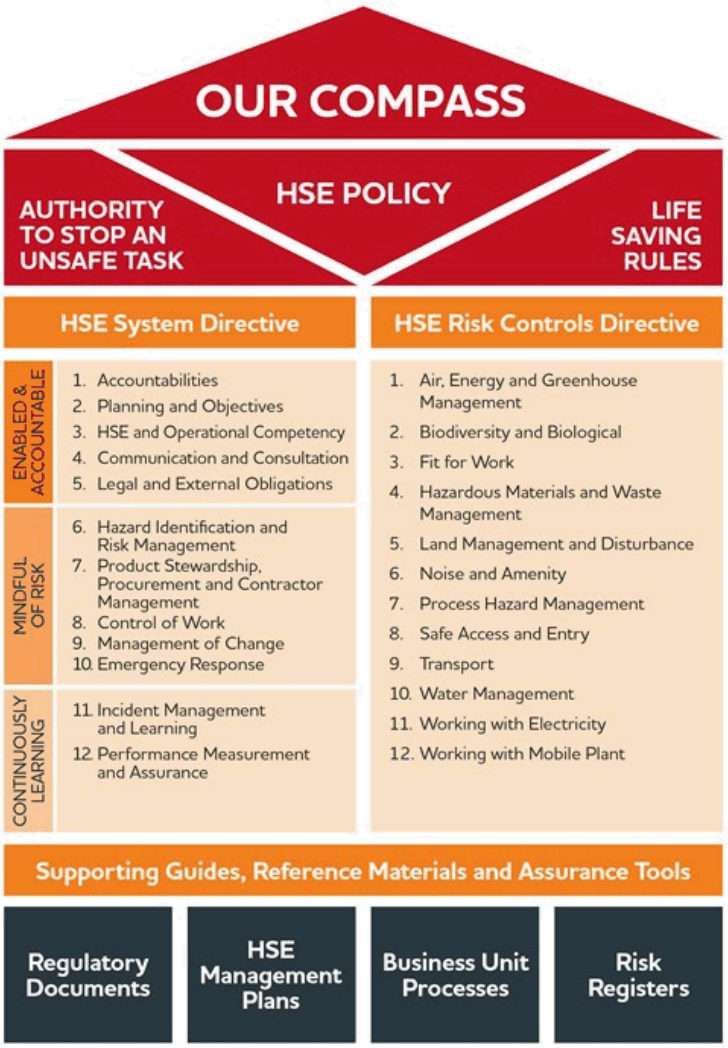

OUR COMPASS
AUTHORITY TO STOP AN UNSAFE TASK
HSE POLICY
LIFE SAVING RULES
HSE System Directive
HSE Risk Controls Directive
ENABLED & ACCOUNTABLE
1. Accountabilities
2. Planning and Objectives
3. HSE and Operational Competency
4. Communication and Consultation
5. Legal and External Obligations
MINDFUL OF RISK
6. Hazard Identification and Risk Management
7. Product Stewardship, Procurement and Contractor Management
8. Control of Work
9. Management of Change
10. Emergency Response
CONTINUOUSLY LEARNING
11. Incident Management and Learning
12. Performance Measurement and Assurance
1. Air, Energy and Greenhouse Management
2. Biodiversity and Biological
3. Fit for Work
4. Hazardous Materials and Waste Management
5. Land Management and Disturbance
6. Noise and Amenity
7. Process Hazard Management
8. Safe Access and Entry
9. Transport
10. Water Management
11. Working with Electricity
12. Working with Mobile Plant
Supporting Guides, Reference Materials and Assurance Tools
Regulatory Documents
HSE Management Plans
Business Unit Processes
Risk Registers

Figure 49: Origins HSEMS structure

OUR HEALTH, SAFETY AND ENVIRONMENT POLICY

OUR PRINCIPLE OF DUE CARE

We care about the wellbeing of our people and our impact on the environment.

OUR HSE ASPIRATION

To conduct our business in a way that causes no harm to the health and safety of people and has no unforeseen impacts to the environment.

OUR HSE ACTIONS

We all believe that our HSE aspiration is achievable and we embrace our responsibility for supporting it by:

Always mindful of risk

Recognising that risk is present in every task we do and taking the time to identify and understand these risks and manage them safely and responsibly.

Enabled and accountable

Taking ownership and using our authority, resources, systems and competencies to manage the risks associated with our work. We stop work when confronted by an unknown hazard and proceed only when satisfied we can continue safely and responsibly.

Continuously learning

Being open and transparent about how well we are doing and relentless in learning from our experience to manage our risks. We work together effectively, welcome any feedback and recognise that we can always do better.

Our Compass and HSE Management System set out how we will implement this policy.

Frank Calabria
CEO
Origin Energy

ORG-HSE-POL-001 November 2016

Figure 50: Origin's Health, Safety and Environment (HSE) Policy

9.3 Roles and responsibilities

The following sections describe, in detail, the management strategies for specific components of the landscape, such as soil, groundwater and vegetation, and the cultural and social environment, in relation to the different impact-causing activities that may occur.

The management hierarchy is illustrated in Figure 51. Each management area has been assigned to specific positions within the exploration team as follows:

- **Asset Manager**: Responsible for the overall operations in the Origin's activities in the exploration permit area.
- **Project Manager**: Oversees the whole planning and execution of the exploration program and is the person ultimately responsible for ensuring all other parties are working within the HSE guidelines. The Project Manager's role is predominantly office-based. The Project Manager will be responsible for notifying the Minister, the occupier of the land on which the activity is to be carried out and the owner of the land on which the activity is to be carried out (unless the owner is also the occupier).
- **Civil Construction Superintendent**: Person based in the field responsible for ensuring all areas of operations and construction are carried out in accordance with the EMP and Origin's HSE Policy. All contractors report to this position, who is responsible to the Project Manager.

  This role will also cover the role of the **Weeds Officer**, who will be responsible for:

  - Planning and execution of weed monitoring requirements, including baseline weed assessments and ongoing monitoring both during periods of gas-related activities as well as during the target identification period of February to May.
  - Facilitate training all workers (including contractors) in weed management requirements, with support from the Northern Territory Government Regional Weed Officer - Onshore Shale Gas Development.
  - Oversight of implementation of weed control mechanisms including but not limited to wash-downs and proactive weed control programs.
  - Ensuring all reporting requirements are met.
  - Act as the designated point of contact for, and rapidly responding to, any civil-related complaints and incidents in accordance with the pre-determined strategies in this EMP or relevant ERP.
  - Review and update of WMPs to remain effective in communication with relevant landholders and Regional Weed Officer - Onshore Shale Gas Development in consideration of monitoring results and emerging weed issues for both gas and pastoral operations.
- **Drilling and Completions Lead**: Person responsible for ensuring the drilling, stimulation and well testing activities are designed and implemented in accordance with the NT legislation and Code.
  - Ensures all drilling, completion and stimulation activities are undertaken in accordance with the NT Petroleum Code.
  - Selection and design of equipment and practices to manage environmental risk.
  - Responsible for selecting and engaging drilling, stimulation and well testing contractors.

- Ensuring all contractors comply with the contract terms including compliance with the EMP requirements.

– **Drilling and Completions Superintendent**: Person responsible for ensuring the drilling, stimulation and well testing activities are executed in accordance with the works program, EMP and Origin's HSE Policy. This role reports to the Growth Assets Drilling and Completions Lead.

- Ensures all drilling, completion and stimulation activities are undertaken in accordance with the Code.
- Selection and design of equipment and practices to manage environmental risk.
- Responsible for selecting and engaging drilling, stimulation and well testing contractors.
- Ensuring all contractors comply with the contract terms including compliance with the EMP requirements.

– **Well Site Representative:** Person based at the well pad responsible for ensuring all areas of drilling, completion and well testing are carried out in accordance with the EMP and Origin's HSE Policy. All drilling, stimulation and well testing contractors report to this position, who reports to the Drilling and Completions Superintendent.

This role reports to the Drilling and Completions Superintendent and is responsible for:

- Planning and execution of the drilling, stimulation and well testing activities when on-site, including understanding and communicating the environmental requirements of this plan.
- Facilitate training of all workers (including contractors) in accordance with the management of weeds, spills, waste, emissions and other aspects.
- Ensuring all reporting requirements are met.
- Act as the designated point of contact for, and rapidly responding to, any drilling, stimulation and well testing environmental incidents and emergencies in accordance with the pre-determined strategies in this EMP or relevant ERP.
- Undertake field inspection and assurance activities.

– **Lead Contractor:** A nominated member within each contracting company (Drilling, Stimulation, Well Testing service providers) that are responsible for delivering the commitments outlined in this plan. The Lead Contractor for each service provider will comply with the nominated contractual terms and work instructions issued under this EMP. The Lead Contractor must ensure all staff are aware of their obligations, are approximately trained and that procedures and controls are fully implemented and complied with.

– **Civil Design Engineer:** An individual or organisation that provides professional or expert advice in the field of civil engineering and design. They determine the best locations, design, materials and construction techniques for undertaking a project to ensure it meets the needs of the end user.

– **Health Safety and Environment Representative (HSE Representative):** Origin representative providing guidance and advice to site personnel on the day-to-day management of the environment. This role will also support the nominated Weeds Officer, specifically in the planning and reporting phases.

– **Field Personnel**: All staff including Origin and contractors that are working in the exploration permit areas. Responsible for day-to-day management and reporting of environmental aspects.

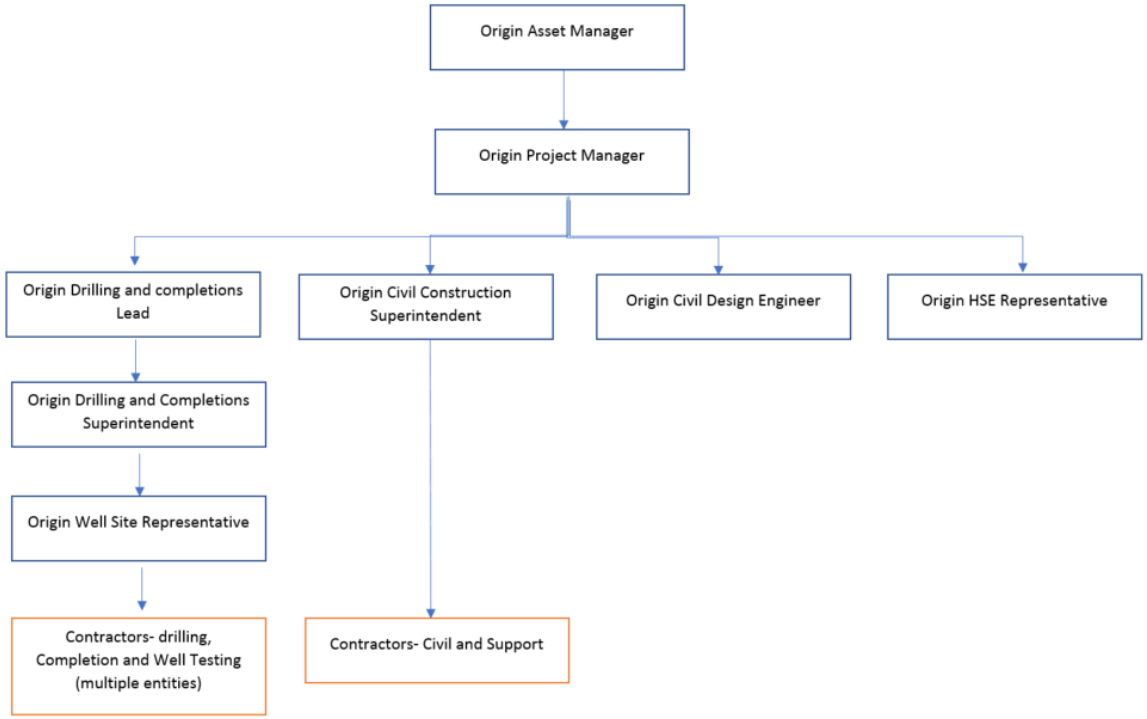


Figure 51: Beetaloo Project Organisation Chart

9.4 Training and awareness

Origin's HSEMS outlines the policies and procedures governing the training and competency of all personnel (staff and contractors) to ensure they can fulfil their obligations under this EMP and the broader Origin HSEMS.

The majority of work undertaken under this will be via contractors under supervision of Origin staff. Assuring the level of training and competency of the selected contractors and supervisors is therefore a major focus of the HSE EMS implementation strategy.

These systems include:

- General Origin HSE induction
- Contractor HSE prequalification process
- Contractor management system
- Site-specific inductions
- Task-specific training, procedures and competency requirements

Contractors will be required to demonstrate they have appropriate systems, procedures and training to manage specific risks covered under this EMP prior to award. The following aspects will be considered during tender award:

- Maturity of HSE systems and process
- Previous HSE performance

- Existing procedures and training:
  - Weed identification and management
  - Refuelling procedures
  - Procedures for avoidance of potential fauna habitat and any identified heritage sites
  - Hazardous material and waste management procedures
  - Spill management
  - Incident notification and management processes
- Internal training programs
- Internal auditing processes

All staff and contractors entering the site will be required to attend a site-specific induction. The induction covers the following aspects:

- Regulatory requirements for the area, including specific conditions on the exploration permits and agreements with the NLC
- Environmental considerations and special procedures to be used for environment protection, as well as protection of archaeological and cultural sites within the permit areas
- Safety procedures covering the safe use of vehicles, equipment and explosives first aid and HSE in remote area operations
- Emergency response training
- Landowner sensitivities, including Aboriginal communities and their specific cultural requirements
- Procedures for handling any culturally or archaeologically sensitive materials that may be discovered
- Provide training in safe storage and handling of flammable and combustible liquids

9.5 Environmental commitment summary

The responsibility for general environmental monitoring rests with all personnel engaged on the project. More specifically, Origin's Drilling Completion Lead and Well Site Representatives are responsible for delivering the relevant components of this plan.

The program environmental commitments outlined in Appendix O are sourced from the risk assessment (Appendix L) and environmental outcomes, performance standards and measurement criteria tables (Tables 47-53). The implementation and compliance against these risk controls will be assessed as part of the annual environmental report (refer in section 9.11).

Specific commitments will be to:

- record information to track performance, including non-conformances and corrective actions
- inspect and monitor operational controls on-site via regular environmental monitoring
- assess the level of conformance with objectives and targets detailed in this EMP

The Operating Company Representative will undertake random site inspections and direct such action as may be considered necessary to protect, minimise or rectify any environmental concerns.

9.6 Work instructions

The work covered under this EMP will be executed by external contractors with Origin oversight. Efforts are therefore focused on effective contractor management, to ensure third parties are compliant with the relevant EMP commitment and contractual requirements. An overview of Origin's EMP implementation strategy is provided in Figure 52.

An instrument referred to as a 'work instruction' is the main mechanism by which Origin cascades the relevant environmental commitments to each contractor. The work instructions are designed to be a contractual document that outlines the minimum compliance requirements for a specific activity. The work instructions contain:

- Key compliance and system documents
- A list of compliance commitments and responsible person for a specific activity
- A list of inspections, procedures and other tools required to implement the content of the EMP
- Monitoring and reporting requirements
- 'Hold Points' which require a deliverable to be completed prior to entry into a new activity phase (i.e. prior to mobilisation, operation and demobilisation)
- Maps illustrating the approved disturbance areas and any restricted work areas

The work instructions form a critical implementation and assurance tool in that an Origin representative must sign off the 'Hold Points' to ensure the various commitments have been achieved. This provides a clear, documented approach to demonstrate compliance which can be audited against.

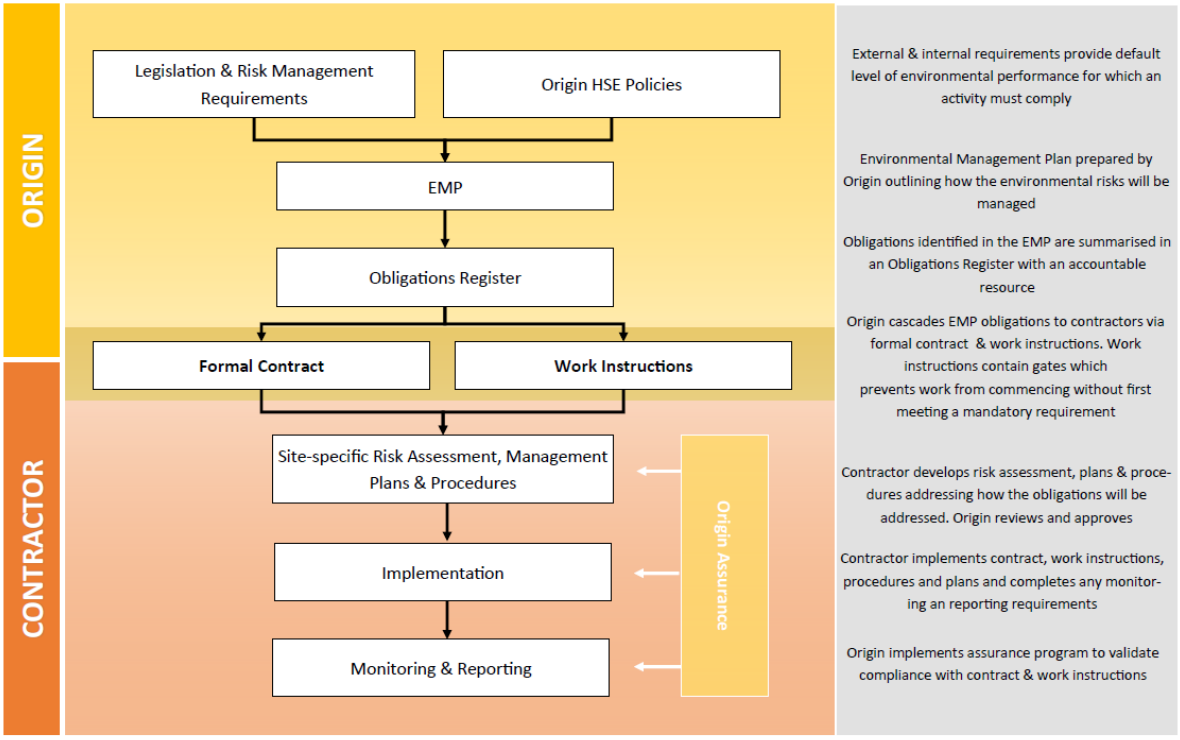


Figure 52: EMP implementation overview flowchart

9.7 Incident reporting

Incident reporting and investigation provides the mechanism to prevent a recurrence. All personnel are required to proactively report all incidents, near-misses and identification of potential hazards.

Origin utilises an online incident management and reporting system. Any environmental incident, near miss or observation is reported through the online incident reporting system. All personnel are encouraged to report minor events to act as an alert to environmental risks and to maintain a program of continual improvement.

9.8 Reportable environmental incident reporting

The NT Petroleum (Environment) Regulations 2016 define a reportable incident as an incident arising from a regulated activity that has caused, or has the potential to cause, material environmental harm or serious environmental harm as defined under the Petroleum Act. This also includes any potential or actual damage to a sacred site.

'Material environmental harm' is defined in section 117AAB(1) of the Petroleum Act to mean environmental harm that:

(a) is not trivial or negligible in nature

(b) consists of an environmental nuisance of a high impact or on a wide scale

(c) results, or is likely to result, in not more than $50,000 or the prescribed amount (whichever is greater) being spent in taking appropriate action to prevent or minimise the environmental harm or rehabilitate the environment; or

(d) results in actual or potential loss or damage to the value of not more than $50,000 or the prescribed amount (whichever is greater).

Origin will identify and assess incidents continuously to determine if they are reportable. Where an incident is reportable, DEPWS will be contacted (this may be verbal or in writing) as soon as practicable but no later than two hours after the first occurrence of the incident or after the time the interest holder becomes aware of the incident.

The NT Petroleum (Environment) Regulations 2016 define a recordable incident as an incident arising from a regulated activity that:

1. Has resulted in an environmental impact or environmental risk not specified in the current plan for the activity; or
2. Has resulted in a contravention of an environmental performance standard specified in the current plan for the activity; or
3. Is inconsistent with an environmental outcome specified in the current plan for the activity; and
4. Is not a reportable incident.

Origin will notify (this may be oral or in writing) DEPWS of a recordable incident as soon as practicable but no later than 15-days after the reporting period (agreed period or each 90-day period after the day on which the EMP is approved).

9.8.1 NT Waste Management and Pollution Control Act 1998 incident reporting

In accordance with the *NT Waste Management and Pollution Control (WMPC) Act 1998,* where contaminants or waste is not confined within the land on which the petroleum activities are undertaken (i.e. the approved disturbance areas where the petroleum activity is occurring), Origin has a duty to notify of incidents causing or threatening to cause pollution as soon as practicable, but no less than 24-hours after becoming aware of the incident.

A notifiable incident is defined as an incident that causes, or is threatening or may threaten to cause, pollution resulting in material environmental harm or serious environmental harm.

A notification must include:

(a) the incident causing or threatening to cause pollution

(b) the place where the incident occurred

(c) the date and time of the incident

(d) how the pollution has occurred, is occurring or may occur

(e) the attempts made to prevent, reduce, control, rectify or clean up the pollution or resultant environmental harm caused or threatening to be caused by the incident

(f) the identity of the person notifying

Origin shall make all notification under the WMPCA via the NT EPA Pollution Hotline 1800 064 567.

9.8.2 Gas leak reporting

Each gas leak shall be classified, repaired and reported in accordance with Table 60.

Table 61: Leak classification and remediation summary

Classification	Threshold	Notification	Comments
Minor Leak	>500ppm measured at the surface of the component	All minor leaks must be documented	A minor leak is an unplanned release that does not occur during commissioning or bringing equipment back into service. These leaks should be corrected immediately as a part of commissioning
Significant Leak	>5000ppm (or 10%of the Lower Explosive Limit) when measured at 150mm above the leak source or A Liquid Petroleum (condensate/oil) loss of containment that exceeds 200L or The leak is too large or not safe to measure.	In the case of an emergency situation, DITT must be notified within 24 hours via the emergency response hotline number 1300 935 250. Notification must include the date of identification, nature and level of the leak, infrastructure name, number and location as well as the initial actions to minimise the risk. The landowner or occupier of the property in which these leaks are occurring must be notified in the following circumstances: i) if the leak cannot be repaired immediately; and ii) if the leak is likely to affect any of the landowner's or occupiers facilities or activities. A written close-out report must be submitted within 5 business days of the remediation of the leak, specifying the date of identification, nature and level of leak, location and name of the operating plant, and the rectification actions taken.	A significant leak is an unplanned release that does not occur during commissioning or bringing equipment back into service. These leaks should be corrected immediately as a part of commissioning

Classification	Threshold	Notification	Comments
		If finalising the remediation is delayed more than 7 business days from the identification of the leak an update must be submitted on that day. The final close out report shall be provided when all work is completed. Where environmental impacts have occurred notification to DEPWS is undertaken as described in section 7.7.1 or 7.7.2 as appropriate.	

9.9 Monitoring, assurance and non-conformance management

In addition to regular monitoring as set out in this document, audits assessing compliance with this EMP and associated work instructions will be undertaken by Origin during the commencement of the activity. System deficiencies, adverse or potentially adverse environmental conditions arising from site activities may be subject to the issue of environmental non-conformances or corrective action requests. These non-conformances or corrective actions shall be logged, and remedial actions identified and implemented. The status of corrective actions will be tracked and reported annual in the annual environmental report.

Audits of implementation of the EMP commitments will be completed for each activity or at least annually. The results will be included in the annual environmental report.

Table 62: EMP audit schedule

Audit Type	Scope of Audit	Frequency	Responsibility
Operational assurance	Operational compliance checks to ensure risk management controls are implemented	Monthly	Origin HSE Representative
Annual Assurance	Compliance against EMP commitments and risk management controls	Annually	Origin HSE Representative

9.10 Emergency response plan

An Emergency Response Plan (ERP) has been developed covering the proposed activities within the EMP (Appendix P). The ERP provides a broad framework for managing potential emergency incidents to minimise the potential risk to human safety and the environment.

The ERP covers the following aspects pertinent to the drilling and stimulation activities and associated infrastructure:

- Spills and loss of containment
- Bushfires
- Medical emergencies
- Flooding
- Emergency incident reporting

The ERP will be reviewed every three years to ensure the content is continually kept up to date.

9.11 Reporting

Internal and government reporting on performance standards will be carried out by the Origin authorised representative, and distributed to Origin management and the DEPWS, in accordance with Section 35 of the NT Petroleum (Environment) Regulations 2016. Quarterly and annual reports will be completed to summarise the compliance with this EMP, whether the environmental outcomes and performance standards in the plan were met and the details of any recordable and reportable incidents.

Table 63: EMP reporting schedule

Frequency	Report detail	Recipient
Prior to the commencement of construction and drilling	A commencement of construction or drilling activity notification	a) The Minister for Environment b) The occupier of the land in which the activity is carried out c) The owner for the land for which the activity is to be carried out
Only if required	Incident report summarising reportable incidents	DEPWS
Monthly	Monthly activity summary report	DEPWS
Quarterly	Quarterly incident report summarising recordable incidents during the period (during operational activities) and groundwater monitoring data	DEPWS
Annually	An annual environmental report will be prepared and submitted to the Minister covering the following: • Summary of the works completed under the EMP during the reporting period • Summary of performance against measurement criteria • A summary of environmental incidents that occurred during the year (i.e. reportable and recordable incidents that occurred) • Any environmental studies or research associated with the activity	Origin management DEPWS

Frequency	Report detail	Recipient
	• Technical improvements • Consultation undertaken • Annual weed management performance reporting against NT-2050-15-MP-0016 • Results of related research or of an ongoing monitoring program • The relevant records outlined with Section 6.6 Environmental Risk Management Summary tables	
Report about flowback fluid and produced water	A report regarding flowback and produced water is required within 6 months of the flowback commencing, in accordance with section 37A and 37B of the NT Petroleum (Environment) Regulations 2016	The Minister for Environment
Geospatial information	As per A.3.5 of the Code, geospatial information must be provided to the Minister	The Minister for Environment

9.12 Record keeping

The following records will be retained within Origin's Document Management system for a period of five years:

- Records linked to measurement criteria, commitments and statutory reporting requirements
- Induction records
- Waste records
- Hazardous goods manifests
- Fuel usage
- Weed inspections
- Non-compliances and corrective action records
- Internal audits and inspection records
- Management of change records.

To the extent these documents are 'prescribed records' for the purpose of the NT Petroleum (Environment) Regulations 2016, they will be kept for the longer of five years following the period during which the petroleum interest is in force and 15-years after the record comes into existence.

9.13 Management of change

A management of change process will be implemented to ensure any changes to activities are appropriately assessed and communicated to ensure no additional un-intended risks or impacts are introduced. This allows adaptive management and the ability to use appropriate technologies.

It should be noted that changes can only be implemented to optimise environmental outcomes or to improve operational efficiency where no new regulated activity, risk (including risk level) or impact is introduced. Where a new regulated activity, risk (including risk level) or impact is introduced, then a Revision of the EMP is required under the Regulations.

9.14 EMP review

Implementation of this EMP will be continually monitored and revised as required based on monitoring and audit results, complaints, employee and stakeholder feedback, change to the proposed work program or a material increase in risk level.

A formal review, update and resubmission of this EMP will be undertaken every five years.

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11 Acronyms and Abbreviations

Acronym	Meaning
°C	Degrees Celsius
%	Percentage
AAPA	Aboriginal Areas Protection Authority
ABS	Australian Bureau of Statistics
AICS	Australian Inventory of Chemical Substances
ALA	Atlas of Living Australia
ALARP	As Low as Reasonably Practicable
ANZECC	Australian and New Zealand Environment Conservation Council
API	American Petroleum Institute
APPEA	Australian Petroleum Production and Exploration Association
AS	Australian Standard
BMP	Bushfire Management Plan
BPESC	Best Practice Erosion and Sediment Control
CAS	Chemical Abstracts Services number
CEEVNT	Critically Endangered, Endangered, Vulnerable and Near Threatened
CLA	Cambrian Limestone Aquifer
Code	Code of Practice: Onshore Petroleum Activities in the Northern Territory
Cth	Commonwealth
CY	calendar year
DAWE	Department of Agriculture, Water and the Environment (Cth); now the Department of Climate Change, Energy, the Environment and Water
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DEPWS	Department of Environment, Parks and Water Security
DITT	Department of Industry, Trade and Tourism
DoH	Department of Health (NT)
EC	Electrical Conductivity
EIS	Environment Impact Statement

Acronym	Meaning
EMP	Environment Management Plan
EP	Exploration Permit (e.g. EP76, EP98 and EP117)
EPA	Environment Protection Authority (NT)
EPBC	*Environment Protection and Biodiversity Conservation Act 1999*
ERS	Emergency Response Plan
ESC	Erosion and sediment controls
ESCP	Erosion and Sediment Control Plan
GDE	Groundwater Dependent Ecosystems
GHG	Greenhouse Gas
GPS	Global Positioning Device
ha	hectare
HFS	Hydraulic Fracture Stimulation
HSE	Health, Safety and Environment
HSEMPs	Health, Safety and Environmental Management Plans
HSEMS	Health, Safety and Environment Management System
IBA	Important Bird Area
IECA	International Erosion Control Association
ILUA	Indigenous Land Use Agreement
ISO	International Organisation for Standardisation
JV	Joint Venture
km	Kilometre
km^2	Square Kilometres
km/hr	Kilometres per hour
LAG	Local Aboriginal Group
LOS	Level of Service
m	metre
Ma	Millions of years ago
MD	Measured Depth

Acronym	Meaning
MEMP	Methane Emission Management Plan
ML	Megalitre
Ml	Local Magnitude
mm	millimetre
mMDRT	Meters measured depth below rotary table
MNES	Matters of National Environmental Significance
SDS	Safety Data Sheet
mTVDGL	metre True Vertical Depth below ground level
NATA	National Association of Testing Authorities
NEPM	National Environmental Protection Measure
NGERS	National Greenhouse and Energy Reporting Scheme
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
NLC	Northern Land Council
NORMs	Naturally Occurring Radioactive Materials
NPI	National Pollutant Inventory
NT	Northern Territory
OHS	Occupational Health and Safety
ppm	parts per million
PER	Public Environment Report
RWA	Restricted Work Area
SPMP	Spill Management Plan
SWL	Standing Water Level
tCO_2e	tonnes of carbon dioxide equivalent
TDS	Total Dissolved Solids
TIA	Traffic Impact Assessment
TJ/day	Terajoules per day
TMP	Traffic Management Plan
TO	Traditional Owner

Acronym	Meaning
TVDSS	True Vertical Depth from Surface Sea level
TPWC Act	*Territory Parks and Wildlife Conservation Act*
TRH	Total Recoverable Hydrocarbons
TSS	Total Suspended Solids
VOCs	Volatile Organic Compounds
WBIV	Well barrier integrity verification
WEL	Water Extraction Licence
WIMP	Well Integrity Management Plan
WMP	Weed management Plan
WOMP	Well Operations Management Plan
WoNS	Weed of National Significance
WWMP	Wastewater Management Plan