Origin Energy

Response to Information Request from the NT Hydraulic Fracturing Inquiry (25 July 2017):

Version	1.0
Submitted	22 August 2017
Presented by	Origin Energy

Contents

Tables

Figures

1 Flooding

Question.

Lock the Gate made the following submission to the Inquiry:

> "In the Northern Territory, Origin Energy has used unlined pits for the storage of waste water, and then has failed to responsibly remove all contaminates, leaving polluted water in areas that have then flooded."

Lock the Gate included a photo in their submission, which purports to show "the state that a shale pad was left in after gas fracking activities stopped in mid-December 2015."

Lock the Gate indicated that water tested at the site had high levels of barium, aluminium, iron and bromine and, further, that the whole area was under water during a flood that stretched from Mataranka to Elliott in late December 2015.

Please comment on these assertions with reference to Origin's submission to the Inquiry.

Response:

Flooding Incident:

An almost identical claim was made to the Lazarus Inquiry in 2016. We provided information to the DME (now DPIR) at that time to provide assurance that there was no overflow of any ponds during the 2015-16 wet season (or at any other time). It should be noted that despite assertions in the Lock the Gate submission that the ponds were associated with "…gas fracking activities…" the ponds had been used to store only fluids and drill cuttings associated with drilling activities and not hydraulic fracturing activities. Hydraulic fracturing activity was not undertaken at Amungee NW-1H until August 2016 and all flow back fluid was stored in above ground, double lined storage tanks.

The surface terrain across the Beetaloo permits is generally flat but not without feature. The Amungee NW-1H well is on a gentle slope dipping slightly to the north and at an elevation of 260 m. 16 km to west along the Carpentaria Highway is the outflow of a large floodplain which is at elevation around 230 m. This floodplain is covered in Coolibah trees which tolerate the few feet of water that covers this area in the wet. The lateritic soils typical of the higher ground in this area and typical around Amungee NW-1H shed water efficiently and remain reasonably firm in heavy rain. The local terrain and variability in elevation across the area (Elliott 226 m, Dunmarra 230 m, Daly Waters 212 m, Mataranka 139 m) make the massive large scale inundation described by Lock the Gate impossible.

During December the rig crew site reports record the sump freeboard as never less than 2 m. The sumps were designed with walls well above the lease and surrounding terrain. The only water which could enter the sumps during this period was due to rain fall directly over the sump area. The highest total annual rainfall recorded at the Daly Waters Airstrip is 1182 mm and the highest recorded monthly rainfall for a December is 635 mm.

Below is a summary of the key points provided to the DME in 2016 in response to the original claim:

1. Origin/Saxon maintained staff in Daly Waters for the duration of the 2015-16 wet season as Saxon Rig 185 remained at the Amungee NW-1 lease over the wet season. These staff made regular trips along the Carpentaria Highway to check the status of the rig and lease site (including the camp and ponds) at Amungee NW-1 and the lease at Kalala S-1.
2. The two well sites are located within approximately 400 m from the Carpentaria Highway at an almost identical elevation, the lack of flood waters over the Carpentaria Highway supports other evidence (discussed subsequently) that the lease sites did not flood and the ponds at no time approached there storage limits.
3. At the Kalala S-1 well site, the mud sump and flare pit were back filled prior to the wet season. No pits were open on site over the wet season. The site was visited semi-regularly by Origin staff and contractors through the wet season and at no point was inaccessible. Origin maintained monitoring equipment on the ground that would have been swept away or damaged by flood waters of the 2-3 metres claimed by one witness to the Lazarus Inquiry. Moreover, the Kalala S-1 well continued to transmit pressure data over the wet season, which would not have been possible if the site was flooded by 2-3 meters of water.
4. At the Amungee NW-1 well site, the mud sump and flare pit were both open. However, the rig was left on site and manned during the wet season. The mud sump and flare pit were constantly monitored with a plan, agreed with the DME, to displace the pits to holding tanks if they were deemed at risk of exceeding the freeboard requirements of our EMP. This plan did not require enacting over the wet season, sumps remained below critical levels. Origin and Saxon maintained records of pit levels over the wet season. This gives Origin confidence that pit levels can be managed in this area even considering the heavy rains that fell over the wet season.

With regard the commentary on the Lock the Gate (LTG) water testing results, the elements reported are anticipated to largely reflect the natural composition of the drill cuttings from the underlying strata. The results presented from LTG are in the “total” form and are likely to be influenced by the level of total suspended solids (TSS) within the pond. The high level of TSS is reflected in the photos submitted by LTG.

The levels of aluminium and iron reported are not unexpected. Aluminium and iron are the most abundant metallic elements in the Earth’s crust, constituting approximately 8% and 5% respectively (World Health Organisation, 2010 and World Health Organisation, 2003). The Barium levels observed are not considered high and are below the World Health Organisations drinking water guideline of 700ug/L (World Health Organisation, 2004). There are no applicable ANZECC freshwater quality guidelines applicable for Barium.

It is important to note that the major toxic effect from metals comes from the “dissolved” fraction, with the comparison of “total” metal levels overestimating the potential risk (ANZECC/ARMCANZ, 2000). All water contained within the sump was disposed of at a licenced offsite facility, which eliminated any long term risk posed by the material.

Origin considers that it is feasible for an onshore gas industry to operate safely year round. Origin has a view that there is no technical, safety or environmental reason why construction or drilling and completion activities could not be undertaken within the

Beetaloo during the NT wet season period. Working in the wet season does present some challenges, however, at the same time also presents opportunities. Origin will expand on full year operations considerations and strategies in a submission to the Inquiry to address the questions from Origin's appearance in the public consultations in Katherine on 9 August 2017.

REFERENCES:

ANZECC/ARMCANZ. (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Canberra: Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

World Health Organisation. (2003). Iron in Drinking-water. World Health Organisation.

World Health Organisation. (2004). Barium in drinking-water. World Health Organisation.

World Health Organisation. (2010). Aluminium in drinking-water. World Health Organisation.

2 Well integrity

Question.

Origin made the following submission to the Inquiry:

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

Origin further submitted that:

> "When a well is no longer required it is permanently plugged and abandoned. These plugs will undergo pressure testing to ensure that they have the integrity required of a long term barrier. As discussed previously, cements used in these applications are specially designed for the conditions and long term isolation. When Origin is satisfied that the abandonment plugs are in place and adequate, the regulator will be notified to provide approval of the abandonment."

The importance of long term well integrity is a key issue for the Inquiry. In this regard, the Inquiry requests that technical references be provided to support the above statements. Further, the Inquiry requests Origin's comments on the potential for groundwater in the Beetaloo Sub-basin to corrode cement and well casings.

Response:

Technical References

Origin agrees that the importance of long term well integrity is not just a key issue for the Inquiry but is a core aspect of responsible operatorship.

The petroleum industry like many other industries (medicine, aeronautics, construction, automotive), routinely use appropriately conditioned (replication of a real system) laboratory testing to categorise changes in the physical properties of a component under the intended operational conditions to ensure components are capable of performing their desired function. Laboratory tests are used to assess progressive changes in a material or component which in turn is used as a tool to forward model the behaviour of an engineered system, in the environment it is designed for, over various timescales. Simulations of material behaviour against the forces that oppose its designed purpose are used as a predictive tool to identify fundamental material issues, operating behaviours and/or conditions that could compromise its engineered purpose. This leads to the design of counteractive measures (material selection, maintenance, service lifespan) that will preserve, extend or improve the engineered structure, component or material in question.

In terms of well integrity, greater than 4 million wells have been drilled in North America over a timespan in excess of a century. The petroleum industry has a strong track record of maintaining well integrity with well failures being exceedingly rare (King, 2015). If there was a systematic or fundamental flaw in well design that consistently led to negative environmental outcomes it would manifest in areas of highest activity. Studies such as the comprehensive EPA (2016) investigation do not report systematic impacts associated with oil and gas activity. Quoting King (2015) the *"Failure rates of wells in a specific time period are artefacts of the period; they should not be reflective of wells designed and completed later. In well construction (and arguably many other engineering professions) the past 15 years have delivered more advancement in well technology then the past 15 decades"*. The principles used to design wells, namely; multiple failsafe principles and redundant systems clearly perform reliably. Inhibited corrosion rates of appropriately designed cement slurries, limited surface area of exposure (in annuli) along with the redundancy of hundreds of meters of cement is a testament to building systems that maintain integrity. While the late 1800's to the early 1900's was an era of poor regulation and pollution, the industry has evolved through time such that the protection of the environment and presence of the petroleum industry are not mutually exclusive.

As requested, the literature supporting the statements made by Origin are detailed below with a brief summary on the content of the references provided for convenience.

<u>**REFERENCES:**</u>

Reference 1

Deandrade, J., and Sangesalnd, S. (2016) Cement Sheath Failure Mechanisms: Numerical Estimates to Design for Long-Term Well Integrity. Journal of Petroleum Science and Engineering (147) pp.682-698

Summary: *Numerical forward modelling of cement properties and their susceptibility to different failure mechanisms over well-life operations. The key findings relate the routinely measured physical properties of cements used to construct a sealing sheath in the wellbore vs. their susceptibility to a particular mode of failure under different operating conditions. Numerical simulations are routinely used to design appropriate slurries as laboratory methods cannot replicate the temporal scale of a well's operational life.*

Reference 2

Bigelow, E.L (1993) Confirmation of a wells mechanical integrity. Offshore Technology Conference. OTC 7344. 25th Annual OTC in Houston Texas. 3-6May 1993.

Summary: *Confirmation of zonal isolation through the use of Cement Bond Logs (CBL) when interpreted correctly, with the proper measurements, is effectively 100% accurate.*

CBL also provide the necessary measurements to pinpoint problem areas in a casing sting and take effective remedial action and/or conduct appropriate plug and abandonment operations.

Reference 3

Boyd, D., Al-Kubti, S., Khedr, O., Khan, N. Al-Nayadi, K., Degouy, D., Elkadi, A., and al-Kindi, Z., (2006) Reliability of Cement Bond Log Interpretations Compared to Physical Communication Tests Between Formations. SPE 101420. Abu-Dhabi International Petroleum Exhibition and Conference

<u>Summary:</u> *A case study on zonal isolation interpreted from CBL logs and then validated through communication testing. Of the 28 wells studied, where CBL logs showed good casing-cement-formation bond, all except two cases had zonal isolation validated through communication testing. The two cases that showed good casing-cement-formation bond on CBL but zonal isolation was invalidated by communication testing occurred not after initial water injection (zonal isolation present), but after injecting acid into the formation.*

Reference 4

Reddy, B., Santra, A., McMechan, D., Gray, D., Brenneis, C., and Dunn, R. (2005) Cement Mechanical-Property Measurements Under Wellbore Conditions. SPE-95921. SPE Annual Technical Conference and Exhibition. Dallas, Texas 9-12October 2005.

<u>Summary:</u> *Discussion centred on the measurements of the physical properties of cement (which control mechanical durability) at wellbore conditions, specifically the downhole pressures and temperatures in the wellbore environment. The paper discusses the laboratory measured (static) physical properties of cement blends and then using compressional and shear acoustic measurements both in the lab and then acquired in the wellbore to confirm the placed cement has achieved the required physical properties. This method is based on elastic theory and provides a means of evaluating cement properties from the time cement is placed and throughout well life operations.*

Reference 5

McDaniel, J., Watters, L., and Shadravan, A. (2014) Cement Sheath Durability: Increasing cement Sheath Integrity to Reduce Gas Migration in the Marcellus Shale Play. SPE 168650. SPE Hydraulic Fracturing Technology Conference. Woodlands, Texas. 4-6 February 2014

<u>Summary:</u> *Investigates the effects of drilling, completion and production operations and the associated cyclic stresses on the cement sheath in an active shale play. Sustained casing pressure observed in the intermediate annulus at surface required a causal explanation as to whether well operations were the cause of the apparent loss in zonal isolation or whether gas migration into the annulus during cement curing was the cause of observed surface pressure. Of the two primary cement blends used in the Marcellus, one blend experienced a higher number of incidences of hydraulic isolation failure. This is related to the stress endurance of that particular blend and its inherent mechanical*

properties were inadequate for the cyclic stress loads applied to the well during drilling, completion and production operations.

Reference 6

Vralstad, T., Todorovic, J., Sassen, A., and Godoy, R. (2016) Long Term Integrity of Well Cements at Downhole Conditions. SPE180058-MS. SPE Bergen One Day Seminar. Bergen, Norway. 20 April 2016.

Summary: *The long term integrity of cement used to plug and abandon wells is crucial in providing long-term zonal isolation. The paper focuses on cement aging tests of different cement blends at the relevant downhole conditions to determine their suitability for long term integrity. The cement blends were tested for physical changes; weight, volume, appearance, mechanical changes; compressive and tensile strength, and transmissibility changes; permeability. The samples were tested using exposure to crude oil, brine and* H_2S *in brine at downhole pressure and temperature. After ageing, the samples exhibit variation in their pre-exposure properties - the magnitude of which varies with respect to the chemicals to which they were aged in. Variance in the cement additives and concentrations in the tested cement blends showed increased resistance to change in the evaluated properties with respect to the fluid they were aged in. The study confirms that the right blend of additives considerably improves the long-term mechanical and chemical durability of cement used in wellbores in corrosive environments.*

Reference 7

Jimenez, W., Pereira, J., and Matzar, L. (2017) Improving Wellbore Economics and Long Term Integrity by Optimizing the Design and Evaluation of Annular Sealants for Hydraulically Fractured Wells: A Case Study. SPE-188112-MS. Presented at SPE Kingdom of Saudi Arabia Technical Symposium and Exhibition. Dammam, Saudi Arabia. 24-27 April 2017.

Summary: *A case study focusing on the cement design and selection process, life-of-well operations and the validation of the modelling efforts. The case study shows that the cement blend selected from the modelling process maintained zonal isolation in a hydraulically fractured, producing wellbore. Zonal isolation was validated through multiple CBL runs both prior to and post hydraulic fracture execution and showed no mechanical integrity loss.*

Reference 8

Vijn,P., and Fraboulet, B. (2001) Improved Cement Formulations for Well Abandonment. OMC-2001-077. Offshore Mediterranean Conference and Exhibition. Ravenna, Italy. 28-30 March 2001.

Summary: *Laboratory based study on the durability of cement blends used in abandonment plugs. The evaluated slurries were tested for bulk property behaviour including; shrinkage, expansion, mechanical strength, bonding strength and permeability under wellbore conditions. The investigation was centred on changes in the evaluated properties of the cements in a variety of downhole scenarios with the results being used* *to determine suitability of the cement blends for well abandonment plug construction. Key areas of focus were on the properties that affect the placement of plugs (thickening time, rheology, fluid loss, and compressive strength development), mechanical strength of the set plugs and the long term stability of plugs. The developed cement slurries showed lower shrinkage under bulk conditions, expansion under influx conditions, better mechanical strength, higher bonding strength and lower permeability. All of these properties improve long term integrity of cements.*

Reference 9

O'Kane, M., (2014) Independent Review of Coal Seam Gas Activities in NSW Information Paper: Abandoned wells. Report Commissioned; NSW Government.

Summary: *In section 2.3 the report reviews well integrity in the 100-1000year time frame. The selection of literature cited is from a corrosive, high pressure, CO_2 injection facility where well integrity affects the core function of the project. The literature cited in the review specifically focuses on the chemical alteration of the cement sheath over a simulated 100yr period. The study found the alteration length (the length over which properties would be different to those of the placed cement) was approximately one meter and that cement would be effective in isolating corrosive fluids and shallow aquifers over 1000 year timeframes. The report concludes that wells designed, constructed and abandoned to best practice, have a low likelihood of causing any environmental damage.*

Reference 10

Bai, M., Song, K., Li, Y., Sun, J., and Reinicle, K. (2015) Development of a Novel Method To Evaluate Well Integrity During CO_2 Underground Storage.SPE-173000-PA.

Summary: *This study focuses on well integrity over a 1000 year timeframe. The numerical processes focus on coupling qualitative features, events and processes (FEP), scenario analysis with quantitative models to simulate well integrity in a corrosive, CO_2 sequestration environment. Mechanical models representing stress distribution of the casing-cement-rock composites and the permeability of the cement sheath are used to identify leakage pathways. Well integrity is evaluated during an operational period of 10-50years and then post- injection integrity is assessed over a time span of 100-10,000 years, with a most likely span of 1000years as recommended by the Intergovernmental Panel on Climate Change (IPCC). The simulated models of wellbore integrity show that when good cement was placed, no leakage or cross contamination of shallow aquifers occurred over the evaluated 1000 year time frame.*

Reference 11

Nygaard, R. (2015) Well Design and Well Integrity; Wabamun Area CO2 Sequestration Project (WASP). University of Calgary, Energy and Environmental Systems Group; Institute for Sustainable Energy, Environment and Economy (ISEEE).

Summary: *This study represents the well design and well integrity chapter of the WASP CO_2 sequestration project. The objective of the sequestration project is to safely store*

CO_2 and prevent it from rising to the surface or cross contaminating formations higher up in geological succession. The author translates this to be representative of well integrity over a 1000 year time frame. Quoting research by Kutchko et al. (2008) on the carbonation processes (cause of cement degradation in CO_2 rich environments), penetration rates of CO_2 into cement are approximately 10mm after 1000years and 100mm after 100,000 years. Separate studies carried out by Barlet-Gouedarad et al. (2008) concluded CO_2 penetration occurs at approximately the same penetration rate as that found by Kutchko et al. (2008). This study shows that for wells designed with hundreds of metres of cement, the system degradation rate is extremely slow.

Reference 12

Guen, Y., Huot, M., Loizzo, M., and Poupard, O. (2011) Well Integrity Risk Assessment of Ketzin Injection Well (ktzi-201) over a prolonged Sequestration Period. Energy Procedia 4. Pp.4076-4083

Summary: *This study evaluates well integrity over a simulated period of 1000years with an objective to demonstrate that a completed wellbore constitutes a safe barrier for CO_2 confinement. Evaluation of well integrity over a 1000 year time frame was performed through extensive data collection and analysis, static model construction - geometry and properties of intended well components and geological formations, dynamic model construction - implementation of time dependant processes including ageing, limits and boundary conditions for the well system. The models were used to construct scenarios and through simulation, verify and quantify risks related to well integrity. The simulations show that in the cases applicable to production (low bottom hole pressure) the well retained integrity over the 1000 year period.*

Reference 13

King, G., King, D. (2013) Environmental Risk arising from Well Construction Failure: Difference Between Barrier and Well Failure, and Estimate of Failure Frequency Across Common Well Types, Locations and Well Age. SPE 166142. SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, USA. 30 Septmebr-2 October 2013.

Summary: *Review of well construction practices and the associated environmental risk based on US data. Data shows that well integrity failures are extremely rare and a testament to the construction quality of wells and redundant barrier designs with nested cemented casing strings. The study focuses on the well construction trends of wells already in service and demonstrates cement and casing integrity for greater than 70+years. The author makes a key observation that failure frequency cannot be treated as reflective of the entire industry but rather needs to be related to similar designs, operations and construction quality. Well age and era of construction are key variables with older wells and surface facilities tending to dominate complaints while newer development areas have fewer confirmed pollution incidents. Well integrity failures on multi-stage hydraulically fractured wells are the lowest risk category for well integrity with data cited from the US EPA (2000) suggesting underground storage tanks and septic systems had the highest groundwater contamination incidents - oil and gas wells did not make the list. Kell (2011) showed in the state of Ohio that no hydraulically fracturing* *related well integrity events were recorded between 1983 and 2007. The author also notes that the potential for downhole leaks to the environment diminish rapidly as the reservoir pressure is drawn down. Low bottom hole pressure in wells (due to production) do not have the driving force to oppose constant hydrostatic pressure of fluids outside the wellbore; hence, if a leak path is formed through the sequence of barriers, the highest potential is for exterior fluids (usually salt water) to leak into a wellbore.*

Reference 14

King, G., Valencia, R. (2014) Environmental Risk and Well Integrity of Plugged and Abandoned Wells. SPE-170949-MS. SPE Annual Technical Conference and Exhibition. Amsterdam, Netherlands. 27-29 October 2014

Summary: *There have been over 4.3 Million oil and gas wells drilled in North America. The author highlights that improperly plugged oil and gas wells inherited from the 1860-1930s oil boom present a pollution pathway and that this pathway is a legacy issue. The author also highlights studies by Davies et al. (2014) and Ingraffea et al. (2013) that project leak claims are misleading. This misrepresentation occurs due to the projected leak claims of the total well population are extrapolated by focusing on a small subset of well populations in areas known for natural hydrocarbon seepage, or mistaking annular pressure existence as total well integrity failures. The author draws attention to the fact the leaks from old wells dominates the reported news and raise estimates of potential risks for uncharted wells which does not give credence to improved well designs. Although eastern USA states of Pennsylvania, New York dominate the reports, 94% of proven oil and gas reserves in the US are centred in; Texas, Alaska, California, North Dakota, Oklahoma, New Mexico, Wyoming, Utah, Colorado and Louisiana. These states all have considerably less well integrity issues. In the authors discussion around groundwater contamination the author highlights that the documented oil and gas well locations are hampered by millions of unmapped, poorly sited residential water wells that are not completed to the same quality as oil and gas wells. These residential water wells provide a path for cross contamination of near surface water aquifer.*

Reference 15

King, G. (2014) 60 Years of Multi-Fractured Vertical, Deviated and Horizontal Wells: What have We Learned? SPE-170952-MS. SPE Annual Technical Conference and Exhibition. Amsterdam, Netherlands. 27-29 October 2014

Summary: *This study highlights that hydraulically fractured wells are exposed to pressure fluctuations over a few days in their early life and that the cement shrinkage, integrity, durability and self-healing abilities are key properties that allow this activity to be safely undertaken. This paper in conjunction with King and King (2013) highlights that hydraulic fracturing when correctly planned for, managed and executed is a low risk activity in terms of well integrity. The paper demonstrates that the cyclic application of pressure in multistage hydraulic fracture treatments does not increase pipe failure incidences and that cement integrity over the long term has been considerably improved by advancements in cement blends and placement techniques.*

Reference 16

Fleckenstein, W., Eustes, A., Stone, C., and Howell, P. (2015) An Assessment of Risk of Migration of Hydrocarbons or Fracturing Fluids to Fresh Water Aquifers: Wattenberg Field, CO. SPE-175401-MS. SPE Kuwait Oil and Gas Show and Conference, Mishref, Kuwait, 11-14 October 2015.

<u>Summary:</u> *This study assesses the risk of aquifer contamination due to hydraulic fracturing operations. The authors demonstrate that in the Wattenberg field, similar to King (2012), that there are no documented cases of fracture fluids migrating to shallower fresh water aquifers or to the surface from hydraulically stimulated formations greater than 2000feet below ground level. The authors show that to gain physical access to shallow aquifers five independent barrier failures must occur. Using higher than observed, deterministic probabilities of 5% the authors show the probability of a five component failure during hydraulic fracturing has a 1 in 3.2million chance of occurrence. Analysis of sustained surface annulus pressure (10 incidences over 17,948 wells) showed that annular casing pressure was solely observed in old wells, where surface casing was set too shallow, and inadequate cement was placed. New wells (<15 years), appropriately constructed using modern standards and techniques show no barrier failure occurrences. The Wattenberg field is an example where well integrity is maintained over 45+ years of operation.*

Reference 17

Stone, C., Eustes, A., and Fleckenstein, W. (2016) A continued Assessment of the Risk of Migration of Hydrocarbons or Fracturing Fluids into Fresh Water Aquifers in the Piceance, Raton and San Juan Basins of Colorado. SPE-181680-MS. SPE Annual Technical Conference and Exhibition, Dubai, UAE. 26-28 September 2016

<u>Summary:</u> Logical, science based framework for evaluating the environmental, economic and social trade-offs between development of natural gas resources and protection of water and air resources. The study focuses on well integrity and the risk of fresh water aquifer contamination in the Piceance, Raton and San Juan basins of Colorado. The review of wellbore construction methods particularly casing and cementing practices are analysed in context of fresh water aquifer contamination. The study confirms that no occurrence of hydraulic fracturing fluid contamination of shallow fresh water aquifers has occurred, no catastrophic barrier failures were detected for any horizontal wells nor any wells with intermediate casing, and that shallow gas occurrences were due to the presence of shallower hydrocarbon bearing units and not the producing intervals within the wells.

Reference 18

King, G. (2015) Are well Construction Practices Safe for the Environment? Journal of Petroleum Technology, SPE-0515-0024-JPT.

As referenced in text above.

<u>Response:</u> The potential for groundwater in the Beetaloo Sub-basin to corrode cement and well casings

Cement is routinely designed and pumped to form a casing-cement-formation seal in a variety of corrosive and challenging environments which include;

- Acidic and/or highly saline formation brines
- H_2S rich gas streams
- CO_2 sequestration (low pH)
- Permafrost affected areas
- Subsiding areas
- Shallow hydrocarbon bearing formations
- Thermally enhanced oil recovery processes
- High Temperature / High Pressure Environments

Ground water in the Beetaloo JV permit area is found in a number of formations and the key properties are summarised in table 2.1 below.

Table 2.1 - Summary of ground water bearing formation fluid properties

Formation[1]	Salinity (ppm)	pH	Mg^{2+} (ppm)	SO_4 (ppm)	Density (psi/ft)	H_2S / CO_2
CLA	160-1500	7.6	11-134	147	0.433	NA
Bukalara*	160-1500	7.4	2-98	228	0.434	NA
Bukalorkmi*	100000-120000	5.1-6.4	4230-4500	22-82	0.48	NA
Moroak*	120000-160000	3.8-5.1	4200-8290	325-343	0.50	NA

*Deeper formation water properties from DST water analysis
[1]Vertical profile shown in figure 5.1

Each of the formation fluids in the Beetaloo have different properties (Table 2.1). The Cambrian Limestone Aquifer (CLA) and Bukalara aquifers are potable and provide little potential for harmful reactivity with casing and cement. The key, manageable hazards associated with well integrity in these shallow aquifers arise primarily when the casing is exposed to surface water with high dissolved oxygen content, low pH, high total dissolved solids and/or large seasonal flux in aquifer levels. Analysis of data from existing water bores and ground water studies (e.g. Knapton and Fulton, 2015), this potential is considered low.

In contrast to the Shallow aquifers the deeper, isolated, and non-artesian Bukalorkmi Formation and Moroak Sandstone contain relatively high saline and sometimes low pH brines (Table 2.1).

Low pH and high magnesium or sulphate brines may require specifically designed cement slurries to ensure that the slurry is both chemically resilient and possesses the required mechanical properties to sustain zonal isolation throughout subsequent well operations. Below is summary of relevant literature that specifically deals with cement sheath design for well operations in potentially corrosive environments.

REFERENCES:

Reference 1

Brandl, A., Cutler, J., Seholm, A., Sansil, M., and Braun, G. (2010) Cementing Solutions for Corrosive Well Environments. SPE 132228. CPS/SPE International Oil and Gas Conference and Exhibition. Beijing, China. 8-10 June 2010.

Summary: *The main environmental factors associated with degradation of the cement sheath in wells are evaluated in this paper. The study focuses on the description of the chemistry, mineralogy and physical properties of the cement blends and the mechanisms of corrosion in the presence of aggressive formation fluids. The cement properties evaluated include; thin section petrography, Young's modulus, Poissons ratio, compressive strength, tensile strength, micro indentation, water permeability, chemical analysis, and quantitative* $CaCO_3$ *determination. The paper shows that increasing pozzolanic material in cements leads to a decrease in the cement sheath permeability, improving the mechanical strength and chemical resilience of the set cement. Cement specimens were prepared and exposed to* CO_2 *in water at* 300^0 *F and 3000psi for a period of six months. Following the aging tests, repeated testing for the aforementioned properties demonstrated considerably less strength retrogression, corrosion and negative impacts using the cement-pozzolan blends. Evaluating literature studies on field operation practices the authors demonstrate that even in the presence of aggressive chemical environments the cement blends utilised in wells over 70 years of operational life showed a chemical alteration zone of 2mm with no signs of any negative impacts on long term integrity. The minute corrosion observed in these ideal cement blends suggests that although it is relatively straight forward to design the cement for environmental conditions the most important factor in well integrity is placement of the cement and obtaining a good initial bond with casing and formation. The authors make the point that lab testing is often of a worst case scenario for exposure as all sides of the cement are exposed to corrosive fluids; however, in the wellbore there is extremely small surface area for these reactions to take place. Numerical modelling of the cement blends shows that both chemical resilience and the necessary mechanical integrity to keep the sheath intact are achievable using readily utilised cement blends.*

Reference 2

Ilesanmi, O., Hilal, B., Gill, S., Brandl, A., Al-Mazrouei, M., and Abdullah, A. (2013) Long Term Wellbore Isolation In a Corrosive Environment. SPE 166769. SPE/IADC Middle East Drilling Technology Conference and Exhibition. Dubai, UAE. 7-9 October.

Summary: *Demonstrated case histories of successful wellbore isolation in corrosive environments. The cement system utilised in the field was developed in the lab to maintain mechanical properties and be chemically resilient to the naturally corrosive environment. Implementation of the designed cement in the field was examined showed that the cement achieved excellent casing and formation bond log results and provided a viable solution for long term zonal isolation in a situation where zonal isolation was paramount to project success. The designed cement was* CO_2 *tolerant, had expanding*

properties at downhole conditions which eliminated shrinkage/micro-annuli issues, and was able to be successfully pumped in field execution.

Reference 3

Crow, W., Williams, B., Carey, W., Celia, M., and Gasda, S. (2009) Wellbore integrity analysis of a natural CO2 producer. Energy Procedia, pp.3561-3569.

<u>Summary:</u> *Detailed study from a 30year old well from a natural CO_2 producing reservoir. The wellbore has been exposed to a gas stream of 96% CO_2 from the time of cement placement. The data set includes 10 sidewall casing-cement-formation cores taken from the reservoir through to the sealing rock. The hydrologic, mineralogical and mechanical properties of this retrieved wellbore cement were evaluated. The study was complimented with vertical communication testing, fluid sampling, as well as pressure and temperature measurements. This allowed a thorough evaluation of the cement integrity from a micro to macro scale to be assessed in a corrosive well environment. The results of the study demonstrate the CBL evidence for good casing-cement-formation bond was validated through the cement sheath recovered from wellbore and by the absence of a pressure response during vertical communication testing. Although some cement alteration was seen on the micro-scale it was of varying degrees with very little alteration of the evaluated properties; permeability, porosity and Young's Modulus over zones of shale and limestone – typically impermeable lithologies. No casing corrosion or casing pressure history was observed on the well which was drilled in 1976 with production operations commencing in 1985.*

Reference 4

Carey, W., Wigand, M., Chipera, S., Woldegabriel, G., Pawar, R., Lichtner, P., Wehner, S., Raines, M., and Gurthrie, G., (2007) Analysis and performance of oil well cement with 30 years of CO2 exposure from the SACROC unit, West Texas, USA. International Journal of Greenhouse Gas Control, pp.75-85

<u>Summary:</u> *Detailed study on well integrity of a 55 year old well, with 30 years of corrosive environment exposure (CO_2). Sidewall cores taken across the casing-cement-formation interfaces show evidence of localised cement sheath de-bonding which resulted in the formation of carbonate precipitates and orange coloured, carbonated cement. The structural integrity of the recovered cement cores was evaluated through; petrographic observations, permeability testing, and cement bond logs, which all indicate that although alteration had occurred, no loss of the system integrity was seen. The results of the study confirm that the localised alteration of cement did not affect the wells capacity to prevent fluid migration in the cement sheath. Numerical modelling of the matched chemical alteration observations of the cement sheath suggest that the actual rates of degradation of cement by diffusive attack are extremely slow and the thick columns of cement used in wellbore annuli retain integrity for significant periods of time. The sealing of micro annular gaps with carbonate precipitates also suggests that with limited flux, the systems exhibit self-sealing behaviour.*

Reference 5

Moroni, N., Repetto, C., and Ravi, K. (2008) Zonal isolation in Reservoir Containing CO_2 and H_2S. IADC/SPE 112703. IADC/SPE Drilling Conference. Orlando, Florida, USA. 4-6 March 2008.

Reference 6

Kutchko, B., Strazisar, B., Dzombak, D., Lowry, G., and Thaulow, N. (2007) Degradation of Well Cement by CO_2 under Geologic Sequestration Conditions. Journal of Environmental Science and Technology (41) pp.4787-4792.

Reference 7

Nelson, E., and Guillot, D. - Editors (2006) Well Cementing – 2nd Edition. Schlumberger.

3 Flowback and produced water

Question.

The Interim Report includes a discussion on the composition of flowback and produced water. As noted in the report, these waters may contain inorganic and organic chemicals of potential environmental significance in addition to those that were originally found in hydraulic fracturing fluid.

The Inquiry understands that interest holders are required to disclose the chemicals used in hydraulic fracturing fluids to the government. However, the identity and concentration of geogenics, that is, chemicals extracted from the shale formation as a result of the hydraulic fracturing process, do not need to be disclosed. The Panel currently has no Australian information on the actual composition of flowback or produced water from shale gas operations.

In that regard, please provide chemical composition data for the flowback and produced water produced from the Amungee NW-1H production test.

The Inquiry's preliminary view is that the regulatory framework should include a requirement for:

(a) a risk assessment of the geogenic components of flowback and produced water; and

(b) disclosure of the chemical composition of flowback and produced water.

Please comment on this proposal.

Response:

Origin supports a framework requiring industry members to complete a risk assessment for geogenic components of flowback at a project level. Origin also understands the concerns of the public regarding flowback water quality and the driver behind the desire for full and open disclosure. Origin, in principle, supports an appropriate disclosure requirement.

Flowback fluid monitoring results:

The following section provides an overview of the quality of the flowback fluid of the Amungee NW-1H well.

The hydraulic fracture stimulation of Amungee NW-1H well involved the injection of 10.6 mega litres (ML) of fluid over a two week period. Upon completion of injection activities, fluid from the well was "flowed back" for a period of 81 days. Approximately 1.9 ML of fluid was returned to surface prior to the suspension of well testing activities.

To provide an understanding of the water chemistry evolution with time, field sampling and laboratory sampling were regularly undertaken throughout the flowback. Field electrical conductivity (EC) samples were collected approximately every hour, additionally

16 water samples were collected by Schlumberger and one by a specialist company, SGS. These samples were submitted to a third party laboratory for analysis.

Laboratory samples were analysed for approximately 100 parameters to characterise the flowback water, including:

- Physical Chemistry (EC, pH, Total Dissolved Solids (TDS), Alkalinity)
- Dissolved metals (Arsenic, Boron, Barium, Beryllium, Cadmium, Cobalt, Chromium, Copper, Manganese, Nickel, Lead, Selenium, Vanadium, zinc)
- Major Ions (Sodium, Magnesium, Calcium, Potassium, Chloride, Carbonate, Bicarbonate, Sulphate, Fluoride)
- Nutrients (Total Nitrogen, Nitrite and Nitrate, Total Kieldhal Nitrogen)
- Polycyclic Aromatic Hydrocarbons
- Phenols
- Total Petroleum Hydrocarbon (BTEX, C6-9, C10-C14, C10-C16, C15-C28, C16-C34, C34-C40,C10-C36 sum, C10-C40 sum
- Radionuclides (Gross Alpha activity and Gross Beta activity)

The additional sample collected by SGS was analysed for Gross Alpha activity, Gross Beta activity, Thorium 228, Thorium 230, Thorium 232, Lead 210, Polonium 210 and Potassium 40.

Results and Discussion

Results of the Amungee NW-1H field and laboratory flowback sampling program are provided in Table 3.1. Summary statistics for all parameters observed during flowback monitoring are provided in Appendix 1. Flowback and produced water quality results from the US Marcellus and Barnett shales (where available) are also provided in Appendix 1 for comparison purposes.

All fluid encountered in the flowback is considered to be introduced from stimulation activities. Any parameters found at concentrations above those in the stimulation fluid are likely to have been mobilised from the formation and are considered “geogenic”.

Parameter	Stimulation Fluid	Flowback	Geogenic?	Treatment required for HFS recycling?
BTEX compounds	Not detected in stimulation fluid	BTEX levels are extremely low. Benzene and toluene reached maximum values of 7 and 6 µg/L respectively. Total BTEX ranged between 2 and 15 µg/L.	Yes - trace levels of BTEX in flowback sourced from formation.	No - Levels insufficient to impact on recycling or re-use.
Boron	Maximum concentration detected at 0.88mg/l. Boron compounds added to stimulation fluid and present in raw bore water.	Maximum boron levels of 54.5mg/l - Boron is commonly associated with sedimentary rocks such as shales	Yes - Boron is common in organic rich sedimentary rocks, such as coal, clays and shales.	No - Boron compounds present in stimulation fluid and recycling unlikely to impact fluid composition. Blending likely sufficient.
Barium	Maximum detection 0.24.	Maximum levels recorded at 80.1mg/l. Barium is commonly associated with shales. Observed levels are substantially lower than Marcellus flowback.	Yes - Barium is a common in flowback from shale formations. Level observed is on the lower end of US shale flowback values.	Potentially - Barium can result in the formation of scale. Treatment using ion exchange or precipitation. Further investigation required.
Total nitrogen (as N)	Maximum value 308mg/l recorded within stimulation fluid.	Maximum value of 62.1mg/l observed within flowback.	No - Levels returned are likely associated with stimulation fluid.	No - levels in flowback unlikely to inhibit recycling.
Salinity (TDS)	Brackish with a maximum of 3240mg/L	Saline with a maximum of 49,00mg/L	Yes - Elevated TDS associated with the dissolution of salts, metals and other ionic compounds from Velkerri B shale.	No - blending believed to be sufficient to reduce TDS levels down to minimise friction in hydraulic fracturing process.

Parameter	Stimulation Fluid	Flowback	Geogenic?	Treatment required for HFS recycling?
pH	Slightly alkaline, with a median value of 8	Slightly acidic with a median value of 6.74	No	No - Blending and normal pH control for stimulation fluid make up sufficient.
Major ions	Predominately Na and Cl. Bicarbonate also present.	Predominately Na and Cl. Bicarbonate present at levels consistent with stimulation fluid.	Yes - Sodium and Chloride dominated formation. Bicarbonate sourced from stimulation fluid.	No - Blending believed to be sufficient.
Dissolved metals	Below LoR Ar, Be, Co, Hg, Se, and V. All detected dissolved metals were present at trace levels except Zn at 0.287mg/L.	Below LoR: Be, Cd, Cu, Pb, Hg, Se, V, Zn. All detected dissolved metal concentrations were consistently low with the exception of Manganese observed at a maximum concentration of 3.09 mg/L.	Yes - low levels of manganese are likely mobilised from formation.	No - metal levels will not impede recycling
Polycyclic Aromatic Hydrocarbons	A single detection of Phenanthrene just above LoR.	All values below LoR.	No - PAH's not detected in flowback	No - Not detected in flowback.
Petroleum Hydrocarbons	All fractions of TPH detected at relatively low levels.	All fractions of TPH were detected; predominantly C16-C34, with a maximum value of 4.16mg/l.	Yes - Shale source rocks contain hydrocarbons. The Velkerri is a dry gas, reflecting low levels of TPH in flowback water.	No - Levels insufficient to impact on recycling or re-use.
Phenolic Compounds	Not Detected in stimulation fluid	Low level of phenolic compounds, with only Phenol (max 4µg/L) and 3-&4-methylphenol (max 11.3ug/L)	Yes - low levels of phenolic compounds present in flowback likely sourced from the formation.	No - Levels insufficient to impact on recycling or re-use.

Parameter	Stimulation Fluid	Flowback	Geogenic?	Treatment required for HFS recycling?
Radionuclides	Not Detected in stimulation fluid	Maximum Gross Alpha Activity and Gross Beta Activity 12.4Bq/L and 18.3Bq/L. The primary component being Radium-226.	Yes - Radionuclides sourced from formation	Potentially - Treatment using ion exchange, activated carbon or other methods may be required periodically. Further investigation required to understand NORMs accumulation in flowback associated with recycling.

Table 3.1 - Summary of laboratory analysis results for the Amungee NW-1H flowback.

Field and Laboratory results indicate that the flowback has the following characteristics:

- Levels of compounds observed are generally at the lower end of results reported from the US Marcellus and Barnett shale plays.
- Field and laboratory measurements of EC show a distinct increase in electrical conductivity with flowback return volume (Figure 3.1). This is as expected as the stimulation fluid retention time will increase the dissolution of compounds from the formation.
- Flowback is saline, with a maximum EC and total dissolved solids levels were recorded at 72ms/cm and 49,200mg/l respectively;
- BTEX compounds observed at trace levels and consistent with flowback from Qld CSG developments of the Surat and Bowen Basins.
- Low levels of C10-C40 hydrocarbons observed: this is expected from a hydrocarbon source rock;
- Sodium chloride was the most dominant salt, with relatively low magnesium, potassium, calcium, bicarbonate, fluoride, sulphate and carbonate levels;
- Absence of semi-volatiles, such as Polycyclic Aromatic Hydrocarbons (PAH's)
- Elevated barium and boron levels which is consistent with shales;
- Low levels of phenolic compounds;
- Low naturally occurring radioactive material (NORMs) levels at the lower end of those observed in selected US shales.

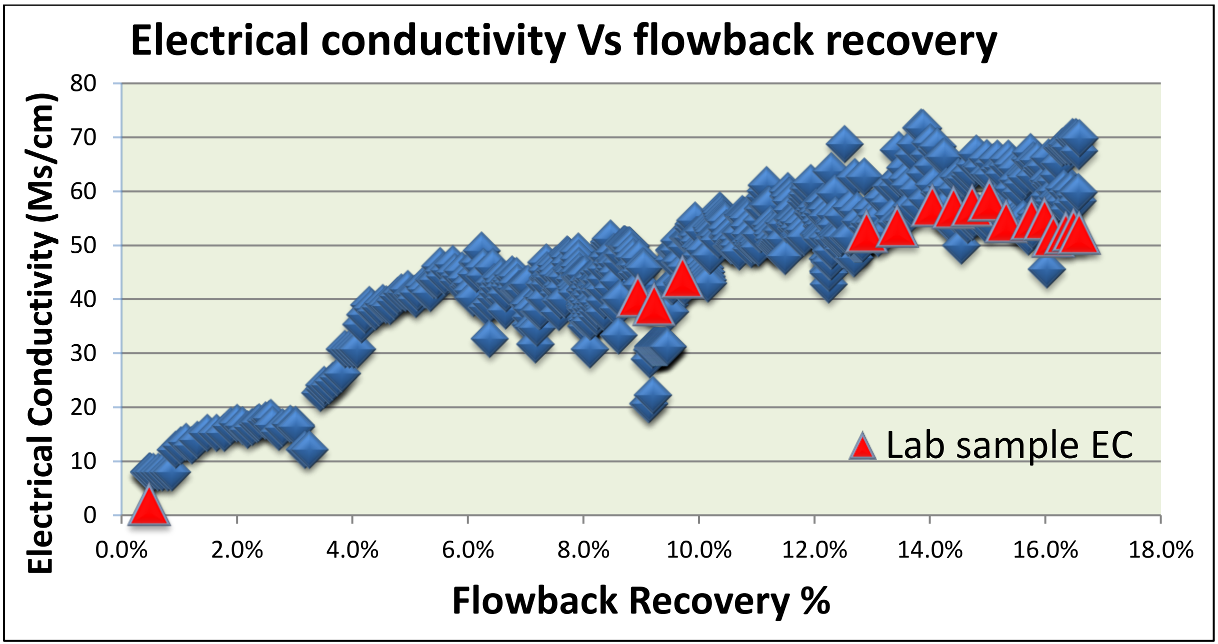


Figure 3.1 - Field EC measurements (blue diamonds) versus flowback recovery. Red triangles indicate laboratory samples.

The results from the Amungee NW-1H flowback sampling program provides confidence that flowback water from the Velkerri B shale formation has a high potential for re-use within further stimulation activities. The majority of the compounds and parameters analysed in the Beetaloo flowback water were at the lower end of the equivalent parameters reported from the US Marcellus and Barnett shale developments.

As these flowback monitoring results are only a single point of data from the Velkerri B shale, ongoing sampling of stimulation activities will be required to fully characterise the spatial variability of flowback quality. It is anticipated that the monitoring suite will be expanded in the future, to increase understanding of trace metals, organics and other geogenic compounds.

4 Spills

Question.

The Inquiry has been provided with submissions to the effect that the likelihood of contaminants in a spill rapidly reaching a surface aquifer prior to any clean up action is low because:

- groundwater aquifers are quite deep (between 50 and 200m below surface in the Beetaloo Sub-basin);
- where appropriate containment facilities are used, spills are unlikely; and
- the interaction with the soil zone reduces the concentrations of many contaminants.

The Panel currently has no specific information regarding the potential for toxic contaminants in flowback and produced water to be removed or diluted when it passes through the soil profile.

In that regard, the Panel requests specific information on the likelihood that on-site surface spills of chemicals or wastewater could reach the groundwater aquifer, and if they do, what could be done to remediate the system. Please make reference to the Beetaloo Sub-basin.

Response:

In the unlikely event of a surface spill migrating to a groundwater aquifer, remediation would be undertaken using a variety of methods that are underpinned by an understanding of human and environmental risks. This process would consist of the following three stages:

- Stage 1 – Detailed site investigation which uses intrusive methods to collect samples from the source and subsurface in accordance with Australian Standards (AS4482). Information obtained from this investigation would be used to optimise remediation design and includes:
  - Delineate the lateral and vertical extent of contamination within soil profile and groundwater
  - Determine maximum and average concentrations of the various contaminants within the vertical and lateral profile,
  - Assess observed contaminant levels against relevant guidelines to determine requirement to remediate
  - Calculate volumes of soil/ groundwater requiring remediation,
- Stage 2 – Health and Environment Risk Assessment performed in accordance with the National Environment Protection (Assessment of Site Contamination) Measure 1999. This process involves quantifying the likelihood of compounds in groundwater affecting human health of the environment. The output would generate a remediation action plan specifying the type of remediation to be implemented and performance standards to determine success.

- Stage 3 – Implementation of the remediation action plan and subsequent adherence to monitoring plans to demonstrate that remediation has been successful.

Individual compounds behave differently in groundwater owing to their physical properties and degradation ability. The remediation of a groundwater contamination event will require the development of a site specific risk-based remediation strategy. As the main risk associated with flowback in the Beetaloo Sub-Basin surrounds salinity, the following remediation options can be considered potentially viable:

- Monitored natural attenuation whereby the contaminants naturally reduce in concentration through diffusion. A monitoring program is implemented to verify that the contaminants are attenuating at predicted rates. This is a suitable approach where there are a lack of groundwater users and high potential for contaminants to be diluted naturally.
- Source removal including installation of pump and treat systems that extract water from the aquifer for treatment onsite to meet water quality criteria before being reinjected back into the aquifer or disposed of offsite.
- In-situ flushing whereby uncontaminated water is pumped into the aquifer which flows down gradient where the solution desorbs, solubilises and/or flushes the contaminants from groundwater. After the contaminants have been solubilised, the solution is pump out via extraction wells.

It should be noted that the exact strategy for remediation will require extensive risk assessment and technical review prior to implementation. The development of a risk based strategy will align with the various technical strategies published by CRC CARE.

5 Deep groundwater systems

Question.

Please advise if there has been any research undertaken in respect of the deep groundwater systems in the Beetaloo Sub-basin or other prospective shale gas regions. Please indicate what is known about them, including their depth, extent, quality, and prospectivity for use in hydraulic fracturing.

If deeper groundwater systems are present, please indicate whether Origin is considering using these resources for hydraulic fracturing rather than the better quality surface aquifer, that is, the Cambrian Limestone Aquifer.

Response:

Within the Beetaloo, from the limited data available, there is a distinct and sharp differentiation between shallow fresh water aquifers and deeper saline aquifers. This boundary coincides with the Base Cambrian unconformity, above which fresh water is typically found and below which saline water or brines occur (Figure 5.1). The regional extent of these aquifers is illustrated schematically through the Beetaloo in Figure 5.2.

Although a large regional data set exists for water quality from fresh water aquifers (specifically the Cambrian Limestone Aquifers) as they are widely used by pastoralists and communities, data for the deeper saline aquifers is sparse. Data for the saline aquifers is available from a limited number of drill stem tests (DST) and air-lifted water samples from petroleum exploration wells. A summary of the water quality for the deep saline aquifers within the Beetaloo Sub-Basin area can be found in

.

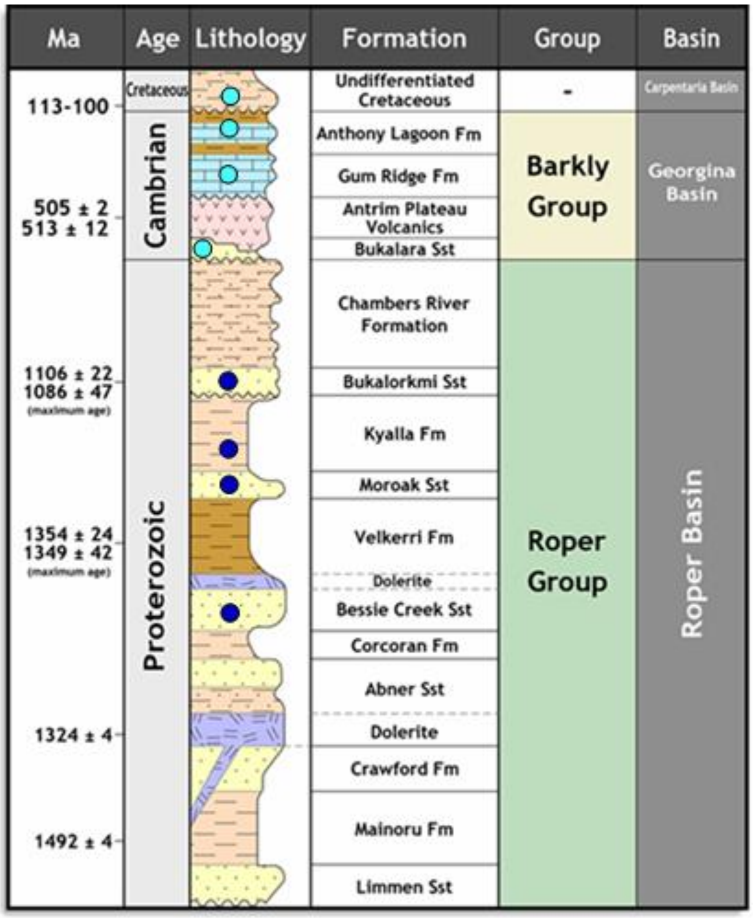


Figure 5.1 - Generalised Beetaloo Sub-Basin Stratigraphy with pore water salinity notated on major identified aquifers. Dark Blue – Saline Water Aquifer, Aqua – Fresh Water Aquifer.

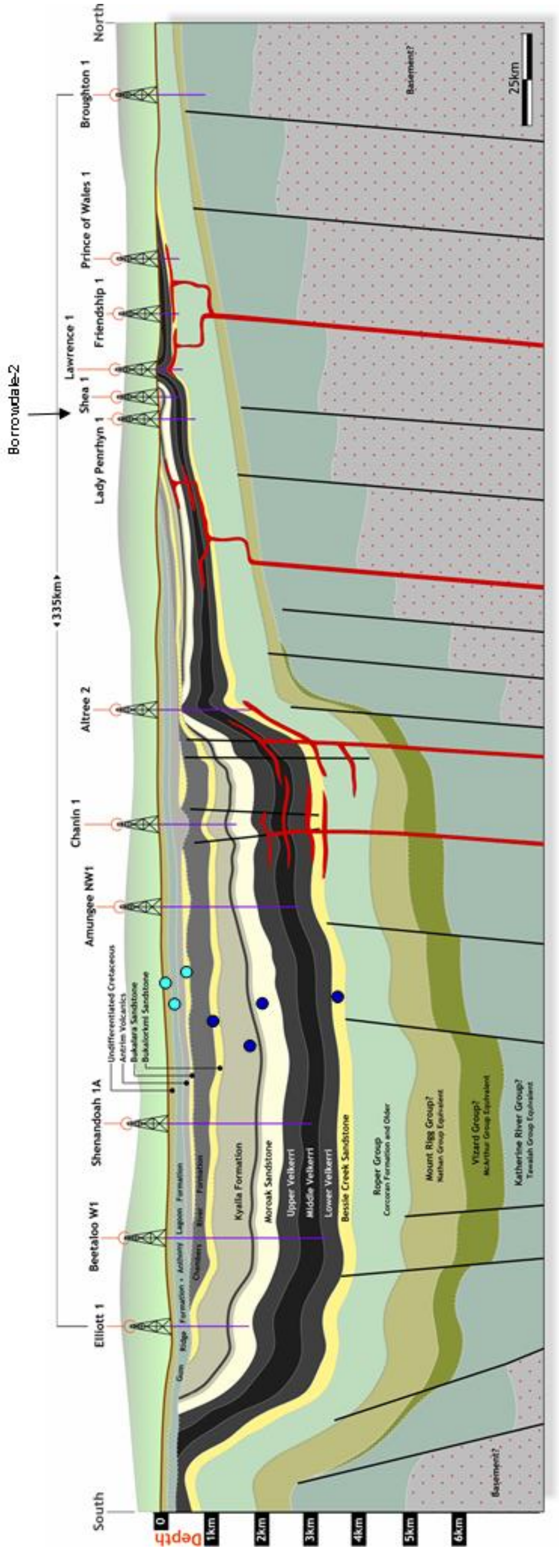


Figure 5.2 - Regional Cross section through the Beetaloo Sub-Basin with general aquifer water sanity noted.

Dark Blue – Saline Water Aquifer
Aqua – Fresh Water Aquifer

Geological Formation		Geological Age / Aquifer Type	Aquifer Yield Range (L/s)	Aquifer Water Quality Summary	Beetaloo Sub-Basin Salinity Measurements (Chlorides mg/L)	Beetaloo Sub-Basin Total Dissolved Solids Measurements (mg/L)
Undifferentiated Cretaceous		Cretaceous / Sandstone	0.3 - 4	Fresh – Potable	-	-
Cambrian Limestone Aquifer (CLA)	**Anthony Lagoon Formation**	Cambrian / Limestone	0 - 10	Fresh – Potable	-	-
	Gum Ridge Limestone	Cambrian / Limestone	0.3 - >20	Fresh – Potable	-	-
Bukalara Sandstone		Cambrian / Sandstone	0.3 - 5	Fresh – Potable	-	-
Bukalorkmi Sandstone		Proterozoic / Sandstone	Not Known	Saline - Non-Potable	**Jamison-1 - 106,000 mg/L** **Balmain-1 - 96,000 mg/L**	**Jamison-1 - 168,000 mg/L** **Balmain-1 - 151,000 mg/L**
Kyalla Sandstone		Proterozoic / Sandstone	Not Known	Saline - Non-Potable	**Chanin-1 - 140,000 mg/L** **Two DST's from Elliott-1 – Neither produced uncontaminated formation water samples**	**Chanin-1 - 226,000 mg/L** **Two DST's from Elliott-1 – Neither produced uncontaminated formation water samples**
Moroak Sandstone		Proterozoic / Sandstone	0.5 - 5	Saline - Non-Potable	**Ronald-1 - 63,000 mg/L** **Elliott-1 - 149,000 mg/L** **Amungee NW-1 - 154,000 mg/L** **Kalala S-1 - 123,000 mg/L** **Burdo-1 - 41,000 mg/L**	**Ronald-1 - 108,000mg/L** **Elliott-1 - 239,000 mg/L** **Amungee NW-1 - 216,000 mg/L** **Kalala S-1 - 178,000 mg/L** **Burdo-1 - 72,000 mg/L**
Bessie Creek Sandstone		Proterozoic / Sandstone	0.5 - 5	Saline - Non-Potable	No DST water samples available from the Bessie Creek Sandstone within 'Core Area' of Beetaloo Sub-Basin. **Friendship-1 - 38,000 mg/L** shallow DST water sample (362-394.7m) **Borrowdale-2 - 19,500 mg/L** shallow DST water sample (519.84-547m)	No DST water samples available from the Bessie Creek Sandstone within 'Core Area' of Beetaloo Sub-Basin. **Friendship-1 - 58,000 mg/L** **Borrowdale-2 - 31,300 mg/L**

*** DST Water Samples**
*** Air Lifted Water Samples**

Table 5.1 - Beetaloo Sub-Basin deep saline aquifer water salinity and total dissolved solids summary.

Origin will consider all potential, suitable water sources for its requirements if a development proceeds. There are insufficient data on the permeability and storage of the deep, saline aquifers at this time to know whether they could be suitable for usage in hydraulic fracturing and other development activities; however, the data that are available are not encouraging regarding the suitability of deeper, saline aquifers.

The Bukalara Sandstone, however, is a fresh water aquifer that in the Beetaloo area is used in a very small number of water bores north of Origin's permits (Figure 5.3) and is not used by landholders in the core area of Origin's permits where a development is considered most likely. The Bukalara Sandstone could be a viable aquifer to locally draw fresh water for hydraulic fracturing in a development without drawing from the regional Cambrian Limestone Aquifer (CLA).

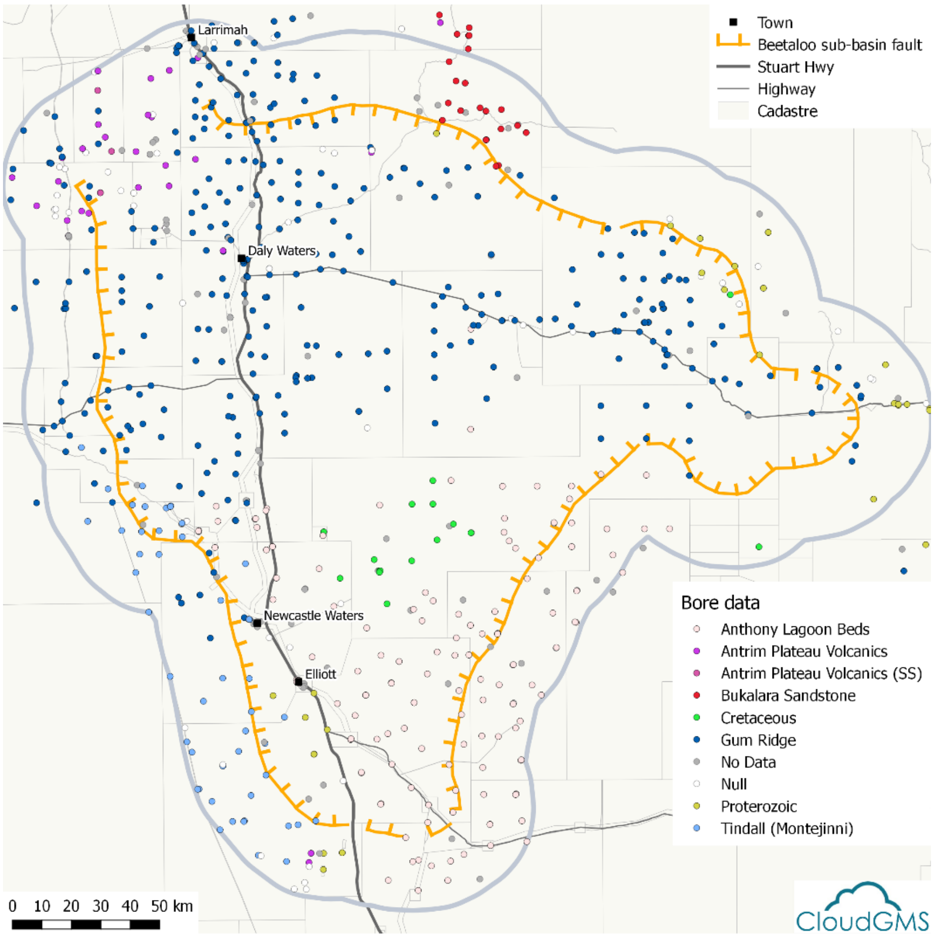


Figure 5.3 - Water bores in the Beetaloo area coloured to represent which aquifer they take water from. The Cambrian Limestone Aquifers (Gum Ridge, Tindall and Anthony Lagoon Beds) provide almost all water in the area, with small contributions from the shallower Cretaceous aquifer and the deeper Bukalara Sandstone aquifer.

The Knapton and Fulton study (2015) also suggests that the CLA can support a sustainable yield sufficient to supply all groundwater usage and the exploration, appraisal and delineation activities in the Beetaloo.

6 Solid waste management

Question.

As noted in the Interim Report, the solids produced by drilling represent a substantial waste stream associated with the production of shale gas.6 In the United States, the disposal of large amounts of drill cuttings produced by a full-scale industry is the cause of concern given the nature of this material and its potential to leach organic and inorganic components into the near surface environment.

A strategic management issue for any potential shale gas industry in the Northern Territory will be the question of whether this solid waste should be contained in a purpose-built and engineered centralised facility, or contained and managed on a per well pad basis as is currently the case for the exploration regime.

Please comment on this matter.

Response:

Origin agrees that purpose built, engineered facilities would be required to safely manage, some solid and liquid waste generated by commercial shale development within the NT. Whether these facilities are located centrally or on each of the lease pads will be assessed as a part of the development concept. It can be stated however, that these facilities will be designed to prevent the seepage of contaminants to the environment.

Several independently owned and operated waste management facilities have successfully serviced the solid waste management needs of the Queensland Coal Seam Gas industry for many years. Examples of facilities established within the Queensland CSG fields that treat solid waste from drilling include:

- The Westrex Jackson facility: http://www.westrex.com.au/
- Nugrow Roma and Kogan facility http://nugrow.com.au/facilities/

It is anticipated that there will be similar opportunities to establish solid waste management facilities in the region, if commercial shale gas development were to proceed.

7 Health assessment

Question.

Origin's submission refers to a:

> "risk assessment, modelled on Queensland requirements, to cover an expanded gas development within the Beetaloo."

Origin advises that the risk assessment is currently underway and is being undertaken in accordance with Australian guidelines for human health and environmental risk assessments. The Inquiry referred to this risk assessment in the Interim Report.8

Origin has indicated that the report containing the risk assessment would be made available to the Inquiry in mid-June. Please indicate when the report will be available and whether it will address the chemicals present in flowback water.

Further, Chapter 10 of the Interim Report includes a proposal that a site specific human health risk assessment should be required for each shale gas project in order to fully inform the impact of the project on public health. Please comment on this proposal.

Response:

Origin engaged third party assessors from AECOM to undertake a human health and environmental chemical risk assessment for the Beetaloo exploration project. The assessment report is undergoing formal review and will be made available by late– August. The report has been extended to include NORMs assessment and does address potential impacts from flowback water. This risk assessment will be updated prior to the development phase to incorporate site specific receptors. The quantitative results will be the same as the current assessment; unless a process or stimulation mixture change occurs.

The risk assessment approach provides for a review of the nature and extent of contamination, identification of issues that may give rise to exposure, and identification of the key chemicals, exposure pathways and receptors that may be relevant. In addition, the assessment utilises site-specific data with assumptions on exposure and toxicity data to enable the quantification of risk to human and environmental health.

Through the assessment methodology it has been qualitatively determined that the chemicals used in hydraulic fracturing fluid systems can be generally characterized as not persistent, bioaccumulative and toxic (PBT) to aquatic and human receptors, however some chemicals (in undiluted form) have been associated with potential risks to aquatic receptors. Of the hydraulic fracturing chemicals, seven of the chemicals fulfilled at least one of the PBT criteria. However, only one substance displayed the potential to fulfil all three, this being Dodecamethylcyclohexasiloxane (D6) and derivatives. Of the flowback chemicals assessed, only the heavier end TPH (C10 to C34) triggered the persistence and bioaccumulative criteria. This stage of the assessment highlights potential chemicals of concern, these are then carried forward for quantitative assessment.

The quantitative risk assessment evaluated the toxicity of the individual chemicals, and characterised the cumulative risks of the total fluid mixture to human receptors and environmental terrestrial and aquatic receptors. The methodology incorporated an assessment of potential exposures to human and environmental receptors, with the following identified as the only potentially complete exposure pathways:

- Incidental ingestion and dermal contact of flowback fluid by human trespassers at the flowback fluid storage ponds; and
- Potential releases of flowback fluid to aquatic environments.

Based on the risk mitigation measures Origin has in place, no potentially complete exposure pathway was identified for hydraulic fracturing chemicals to impact groundwater that is used for beneficial use in the project area.

The assessment of the overall potential for adverse human health effects posed by simultaneous exposure to multiple chemicals the actual uptake of chemicals by ingestion and dermal contact were compared to acceptable risk based intakes to calculate an individual hazard quotient (HQ) and then summed for all constituents into a hazard index (HI).

The assessment conservatively considered a human exposure duration of 6 months at a frequency of half a day for both pure stimulation chemicals (empirical data used) and theoretical tank flowback water quality. On the basis of the risk evaluation, no unacceptable risk to human receptors (trespassers) was identified (HI less than 1) for both scenarios. Conservative risk scenarios assessed included regular access to the uncovered holding ponds, where swimming type activities were undertaken, with exposures to high theoretical concentrations of COPC in the flowback water. Effective operational controls and management implemented by Origin further minimises potential exposures to trespassers.

Site specific human health risk assessment requirements:

The requirement for a project specific human health risk assessment for any development phase in the Beetaloo project is supported by Origin. As the risks from hydraulic fracturing activities are likely to be similar through the broader Macarthur and Beetaloo basins, an industry-wide health risk assessment may be practicable; with site specific conditions of operators addressed where appropriate. These could be undertaken by an independent party in direct consultation with the various industry members.

If individual health assessments were required for each project, we believe a comprehensive health assessment is best undertaken during the completion of an Environmental Impact Assessment for a commercial scale development. This assessment would be underpinned by data collected during the exploration phase to provide greater confidence of the relevance of results obtained.

Further discussion regarding baseline health studies is presented in section 9.

8 Infrastructure requirements

Question.

i) The proposals around infrastructure requirements require careful scrutiny. Experience in the United States has shown that well production and field production typically declines over time, requiring additional wells to be commissioned to meet demand. Shale gas plays in the United States invariably have had "core" areas or "sweet spots", where individual well production is highest and hence the economics are best. Sweet spots are targeted and drilled off early in a play's lifecycle, leaving lesser quality rock to be drilled as the play matures. Therefore, the number of wells required to offset field decline inevitably increases with time. Shale gas plays have high field production declines, typically in the range of 30-45% per year, which must be replaced with more drilling to maintain production levels.

ii) The Inquiry has received submissions to the effect that the potential infrastructure needs of a possible development in the Beetaloo Sub-basin is approximately 200 drill pads and over 1000 wells. In light of the above discussion, please comment on the proposed infrastructure requirements. Please also comment on the figures provided by the Department of Primary Industry and Resources in their submission.

Please also provide details on the expected:

- initial size of well pads;
- size of well pads during the operation phase;
- length and clearing width for collector pipelines; and
- lengths and clearing widths of any access roads that are not contained within pipeline corridors.

iii) If the moratorium is lifted but the number of well pads is limited within a project area (e.g. to 50), please comment on the relative merits of the two scenarios described below:

a. Scenario 1: wider spacing (5-10 km) between well pads, such that the effective project area would be larger (900 – 3,600 km^2), but less-intensively developed; and
b. Scenario 2: narrower spacing (2-3 km) between well pads, such that the effective project area would be smaller (144 – 322 km^2) but more-intensively developed within that footprint.

Response:

i) Infrastructure and well productivity

RFI quote: "*Experience in the United States has shown that well production and field production typically declines over time, requiring additional wells to be commissioned to meet demand*"

Origin comment: Well productivity will, of course, decline over time. If new wells are not drilled to replace the declining production then field decline will of course also follow. To sustain a given production plateau, ongoing development drilling is required. Origin outlined this in detail in our April 30th submission to the Inquiry.

RFI quote: "*Shale gas plays in the United States invariably have had "core" areas or "sweet spots", where individual well production is highest and hence the economics are best. Sweet spots are targeted and drilled off early in a play's lifecycle, leaving lesser quality rock to be drilled as the play matures*"

Origin comment:

- Origin caution the panel not to assume that "sweet spots" or "core areas" comprise only a small portion of a shale play's extent. Drilling trends in the US show that in successful shale play, development extends across maturity windows which have similar production characteristics.
- Being in the correct play (i.e. Marcellus vs. Antrim) is more important than being in the "core area" of a play

Marcellus example

- The Marcellus formation footprint covers about 95,000 square miles with a prospective area of about 72,000 square miles
- Over 13,000 wells have been drilled within the Marcellus play extent. The majority of the wells have been drilled in Pennsylvania and West Virginia
- If the panel assertions were correct then the "sweet spots" or "core areas" should have long been drilled out in the Marcellus and one should observe a decline in production across the field or a substantial increase in well count in order to maintain production. However, this has not been observed. In fact the exact opposite has been.
- The "core areas" or "sweet spots" in the Marcellus corresponds to hydrocarbon maturity windows. As such the "core area" covers a large portion of the play extents and drilling within the gas window occurs almost ubiquitously within it as can be seen in Figure 8.1. The same observation can me made other shale plays for example the Eagle Ford shown in Figure 8.5e.
- Furthermore, despite having drilled over 13,000 wells to date operators are continuing to achieve ever better well results year on year. Improved well results are primarily a function of technological advancements rather than "sweet spot drilling".
- Figure 8.2 shows how the new well gas production per rig has increased between 2008 and 2017. This corresponds with a rapid increase in total Marcellus production (figure 8.3) while at the same time reducing the total number of wells drilled per year.
- EURs correlate strongly to lateral lengths and sand/proppant placement as shown in Figure 8.2 rather than sweet spots as suggested in the Inquiry's RFI.

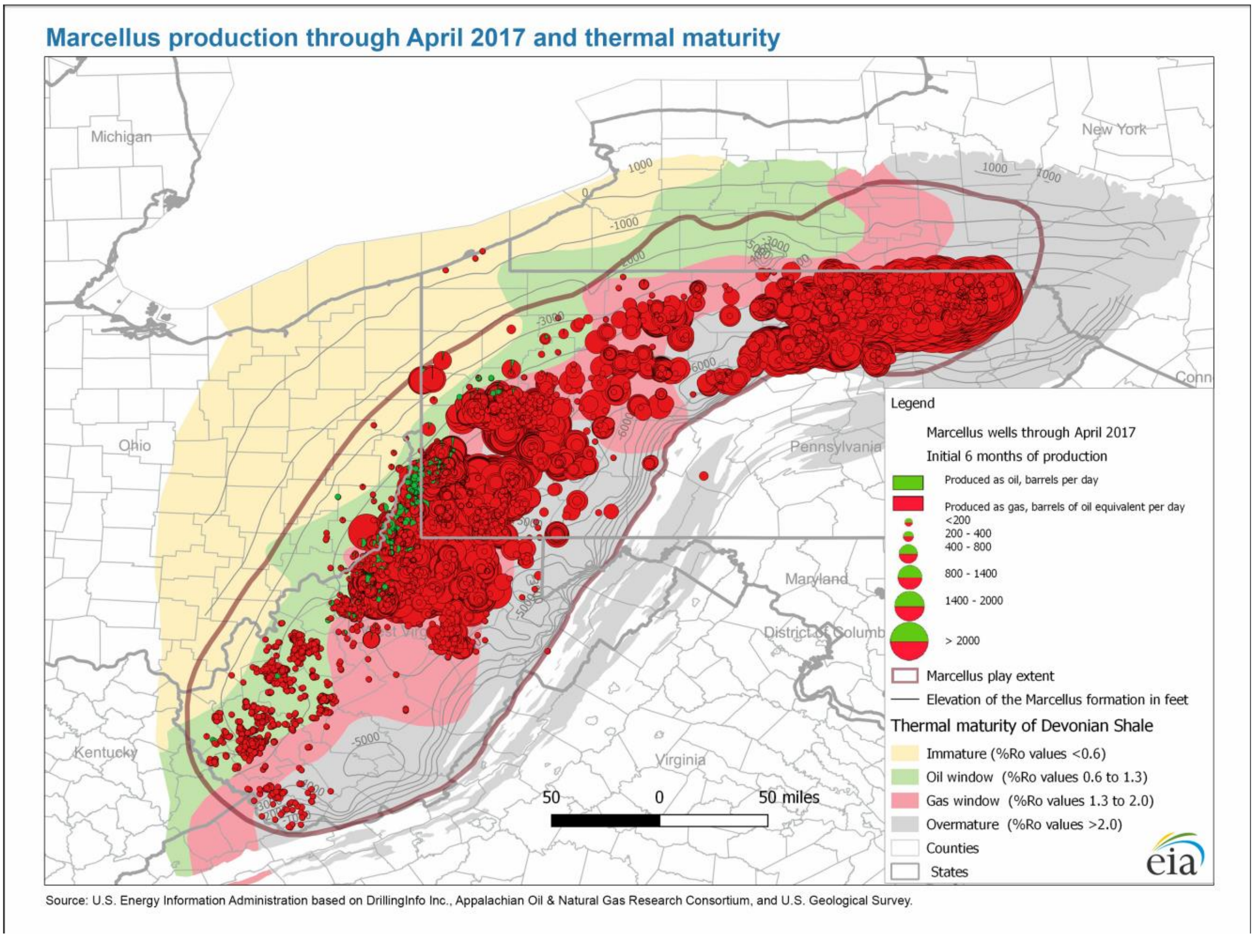


Figure 8.1 - Marcellus EUR per well summary map

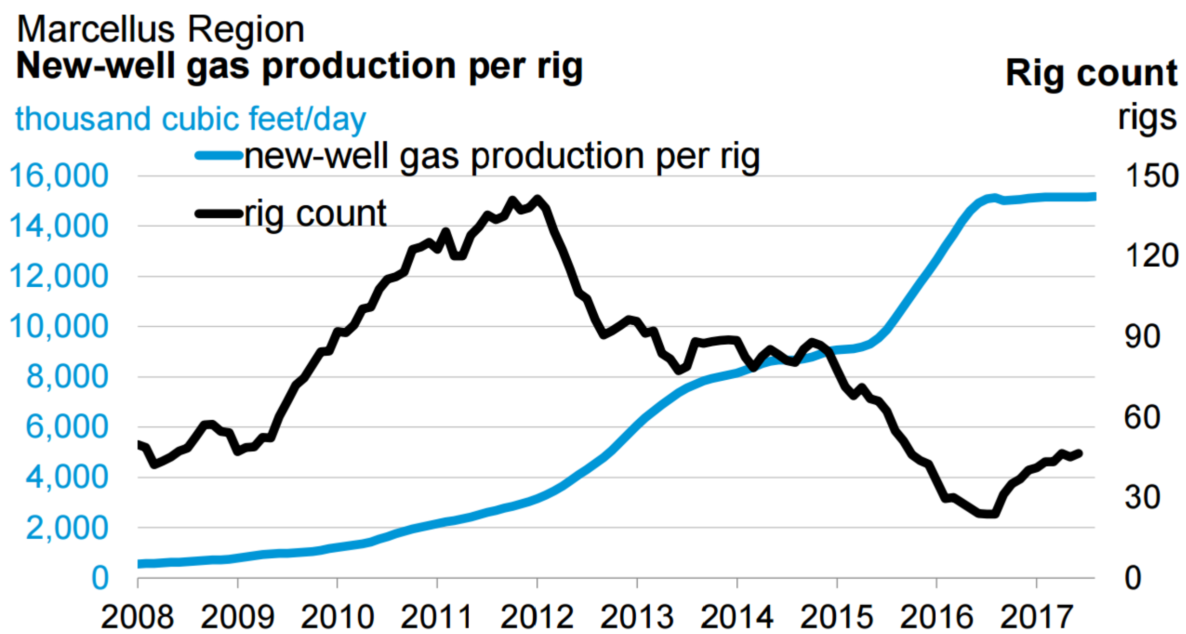


Figure 8.2 – Marcellus new-well production per rig vs rig count

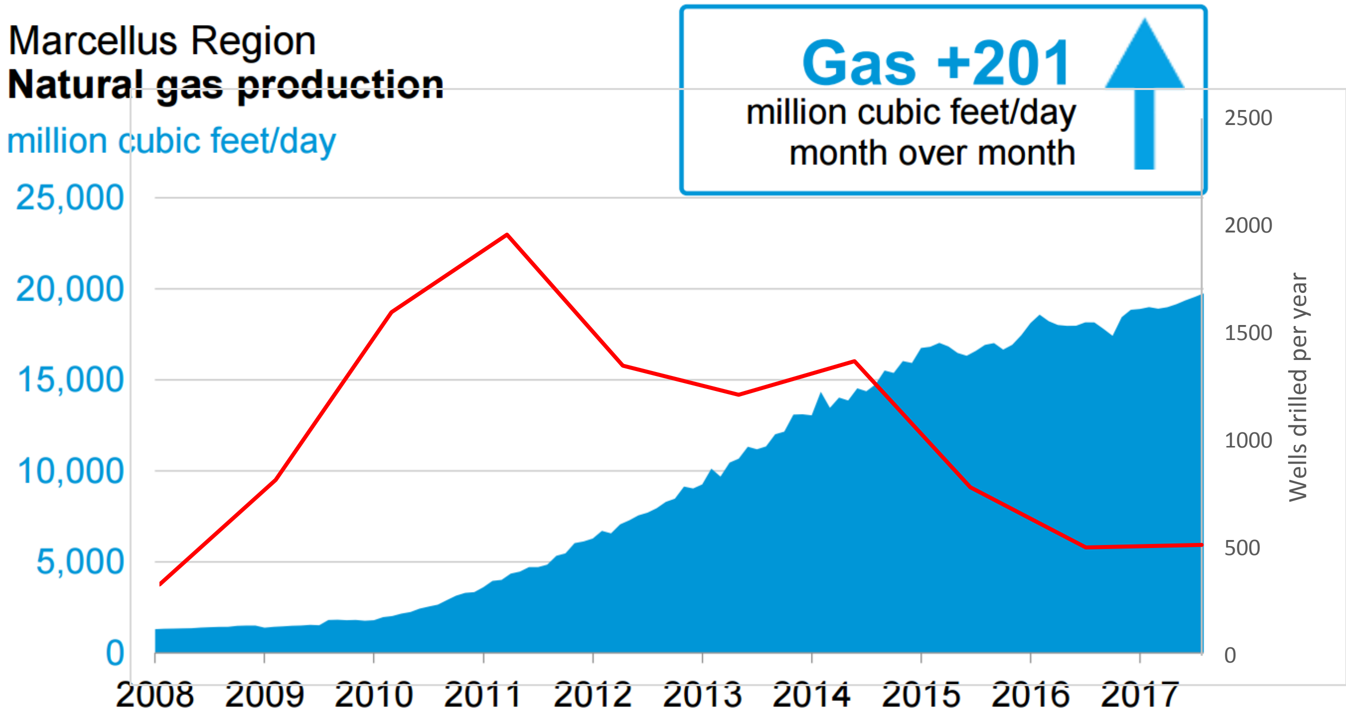


Figure 8.3 - Marcellus region natural gas production (blue) and wells drilled per year (red)

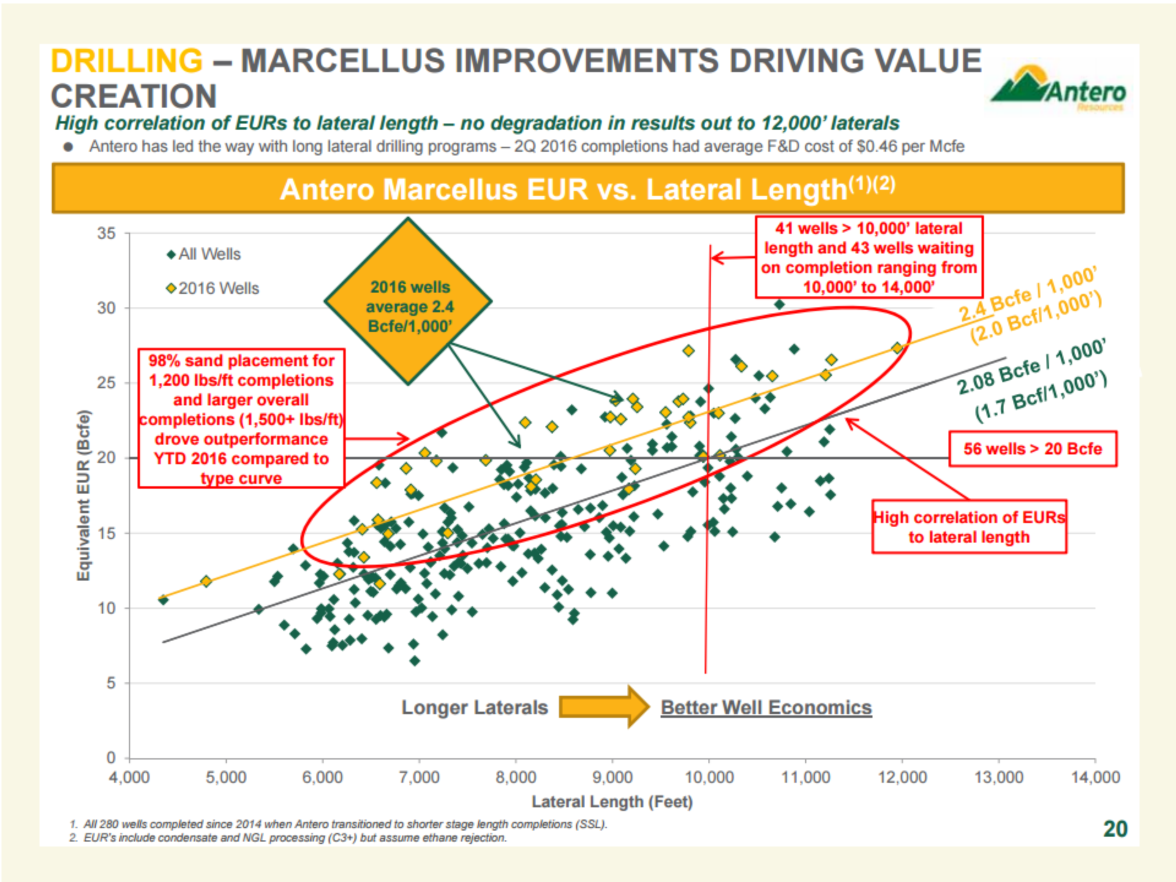
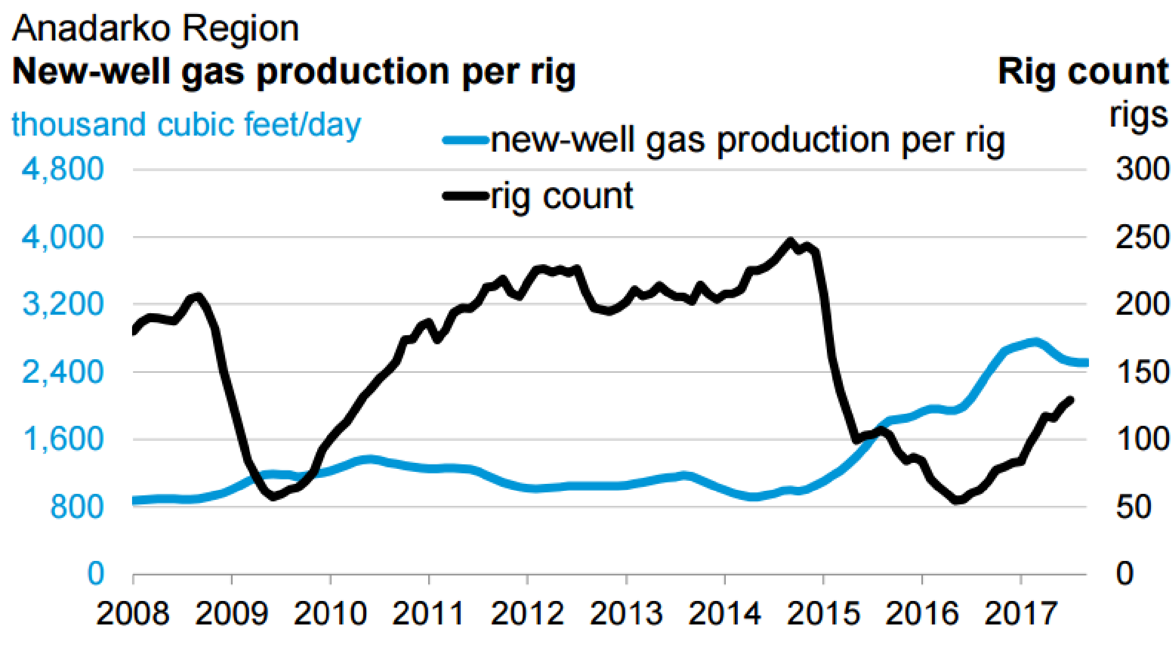
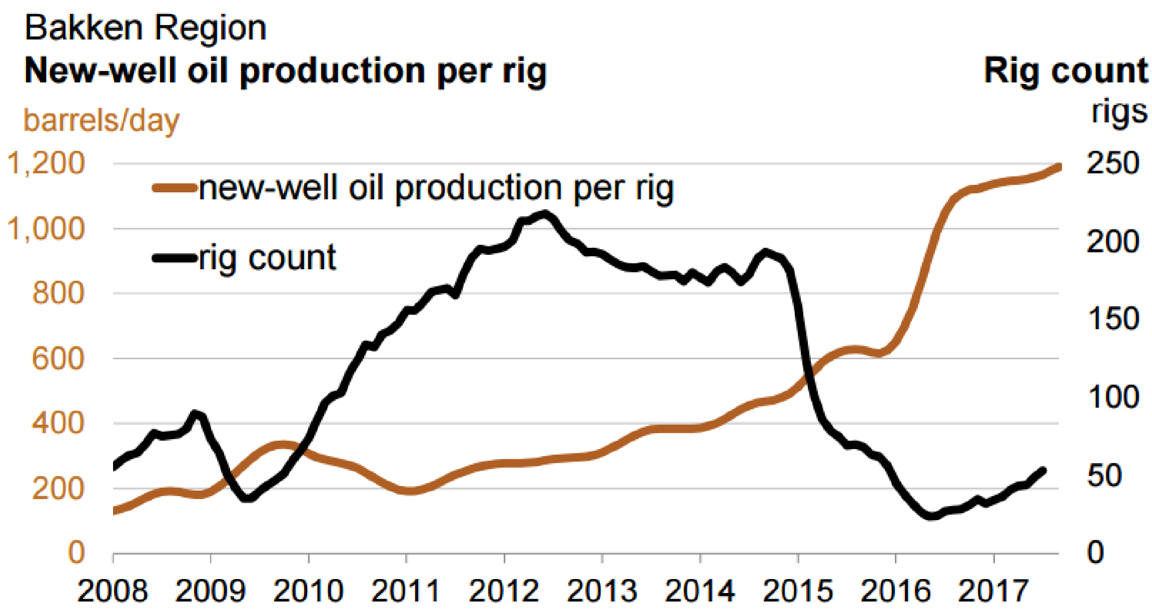


Figure 8.4 - Summary of Antero well lengths vs EUR in their Marcellus acreage

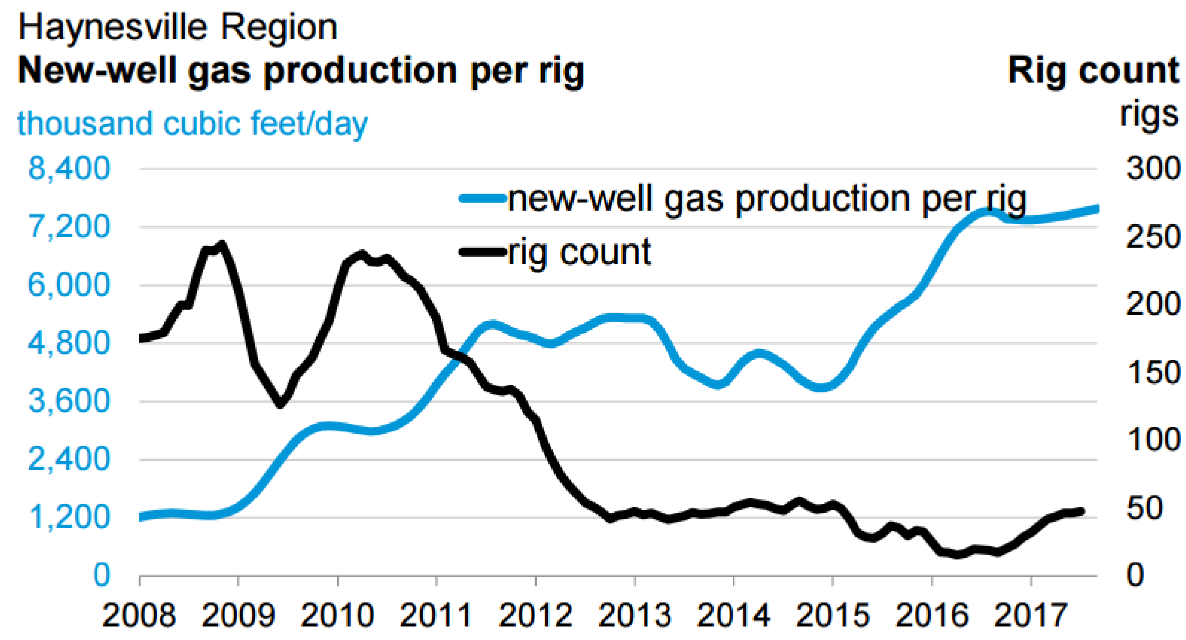
These trends are repeated in all the other major mature shale gas and shale oil plays in the USA which are shown below in Figure 8.5.



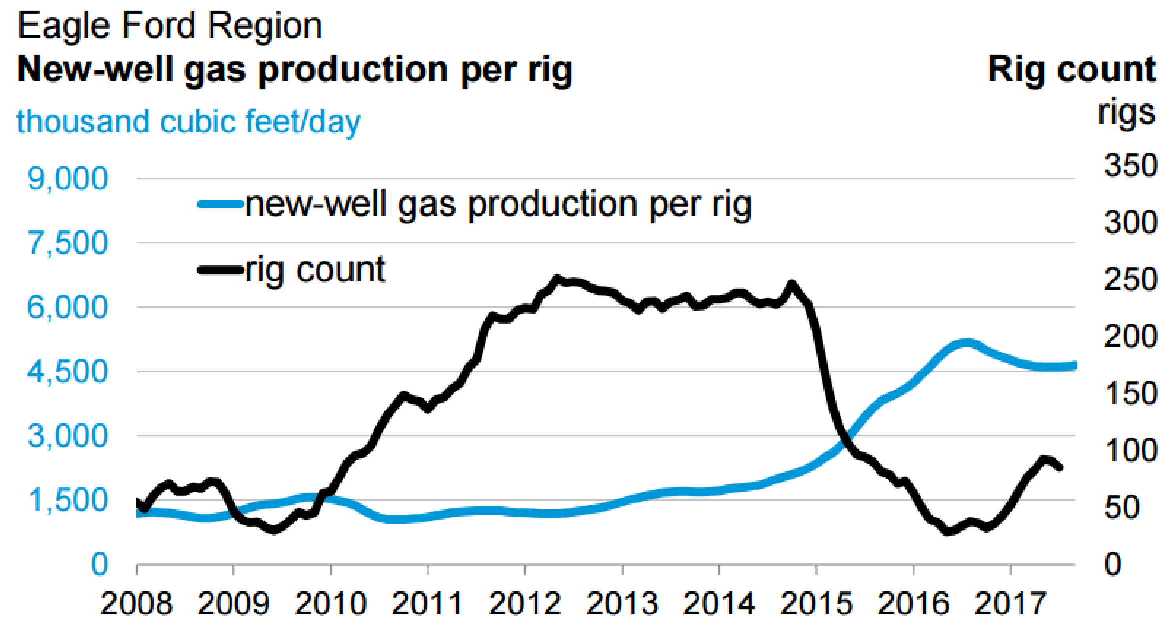
a.



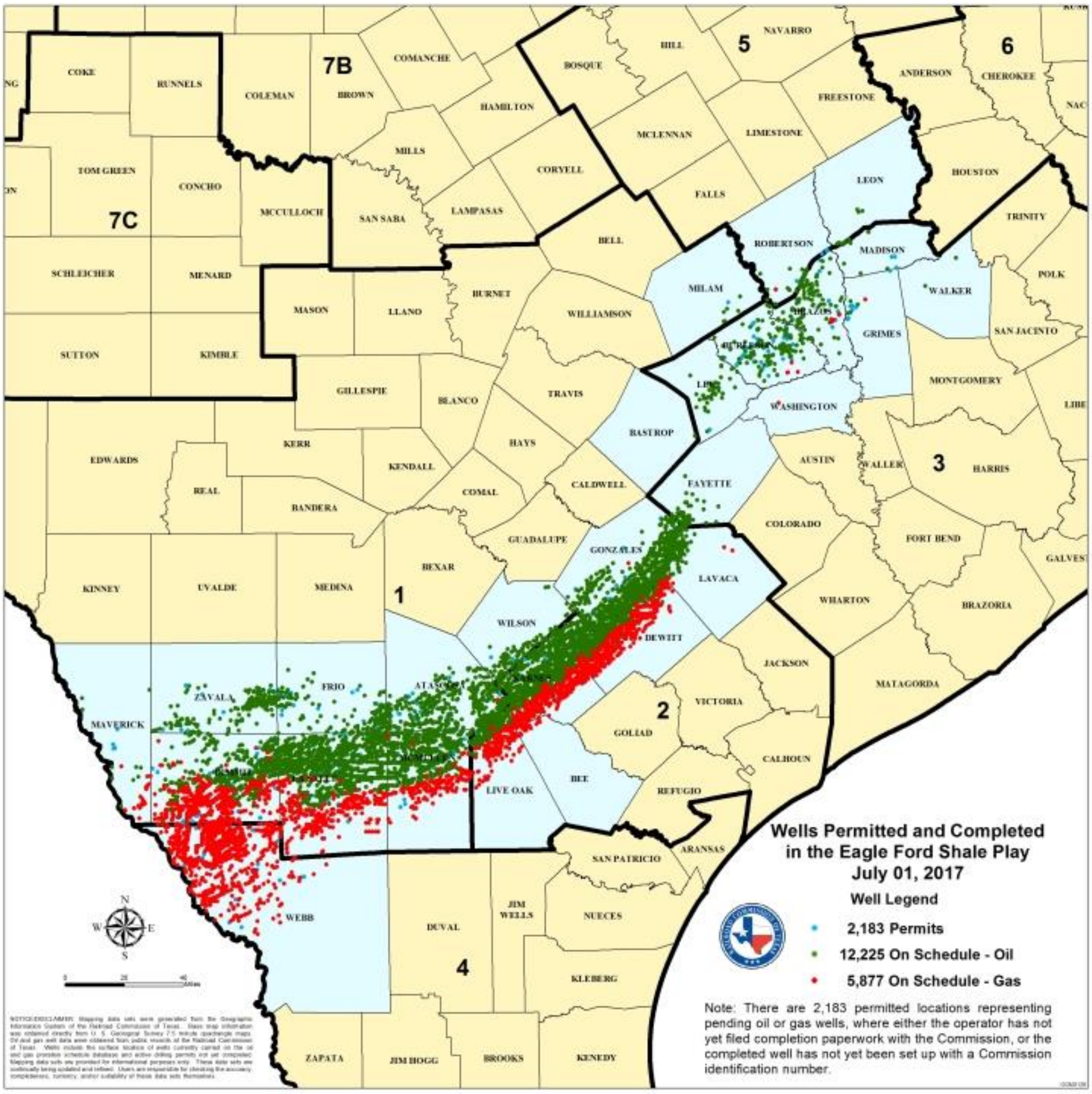
b.


Haynesville Region
New-well gas production per rig
thousand cubic feet/day
Rig count
rigs
new-well gas production per rig
rig count
8,400
7,200
6,000
4,800
3,600
2,400
1,200
0
300
250
200
150
100
50
0
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

c.


Eagle Ford Region
New-well gas production per rig
thousand cubic feet/day
Rig count
rigs
new-well gas production per rig
rig count
9,000
7,500
6,000
4,500
3,000
1,500
0
350
300
250
200
150
100
50
0
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

d.



e.)

Figure 8.5 - Production per rig and rig count for US shale plays, a) Anadarko b) Bakken c) Haynesville and, d) Eagle Ford (Source: EIA) e) Eagle Ford well summary map.

RFI quote: "*Therefore, the number of wells required to offset field decline inevitably increases with time. Shale gas plays have high field production declines, typically in the range of 30-45% per year, which must be replaced with more drilling to maintain production levels.*"

Origin comment: Evidence from North American shale gas plays doesn't support this statement. These assertions are incorrect for two reasons:

1. They do not account for the improvement in well results seen over time (contrary to the panel's sweet spot drilling assertion)
2. They incorrectly assume that a well's production, and therefore a shale play's base production, declines by 30-45% year on year

The evidence is very clear that the number of wells required to offset field decline does not inevitably increase with time. The Marcellus data presented above shows a 75% drop in the number of wells drilled per year between 2011 and 2017 while achieving a 500% gain in production.

The assertion that shale gas fields/wells decline by 30-45% per year is inaccurate. Decades of empirical data, and theoretical and numerical modelling show that the decline rate of individual wells (and therefore fields) decreases with time.

To counter these assertions with empirical data, Origin has analysed the production data for all wells targeting the Montney Formation Play in British Columbia, Canada, with lateral length >1500m (Figures 8.6-8.8, source: IHS Accumap). There are 1532 wells drilled into the Montney with a lateral length >1500 m (the "dataset").

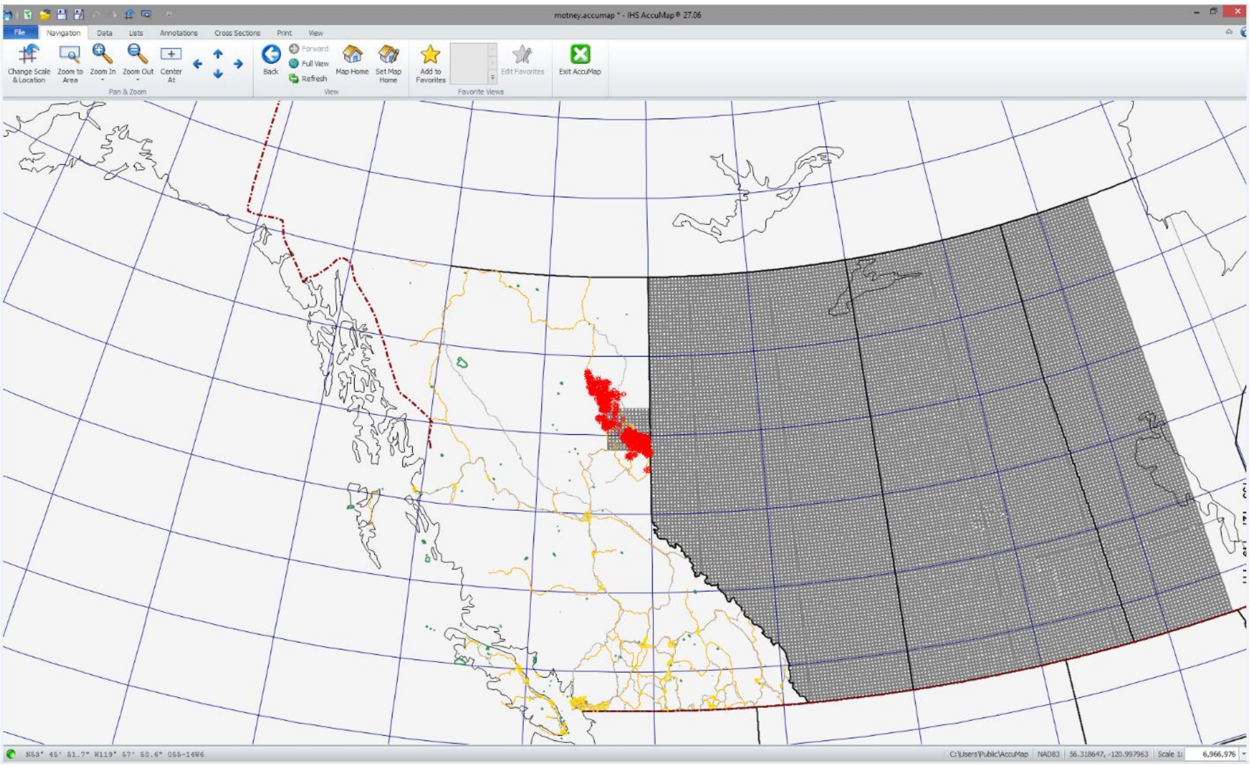


Figure 8.6 – Location of Montney wells in British Columbia, Canada, used in decline analysis. Origin used the production data to create type well decline curves and calculate the P10-P50-P90 production trend vs. producing time. Next, Origin fit a P10-P50-P90 decline curve to the P10-P50-P90 production trends to forecast the EUR distribution.

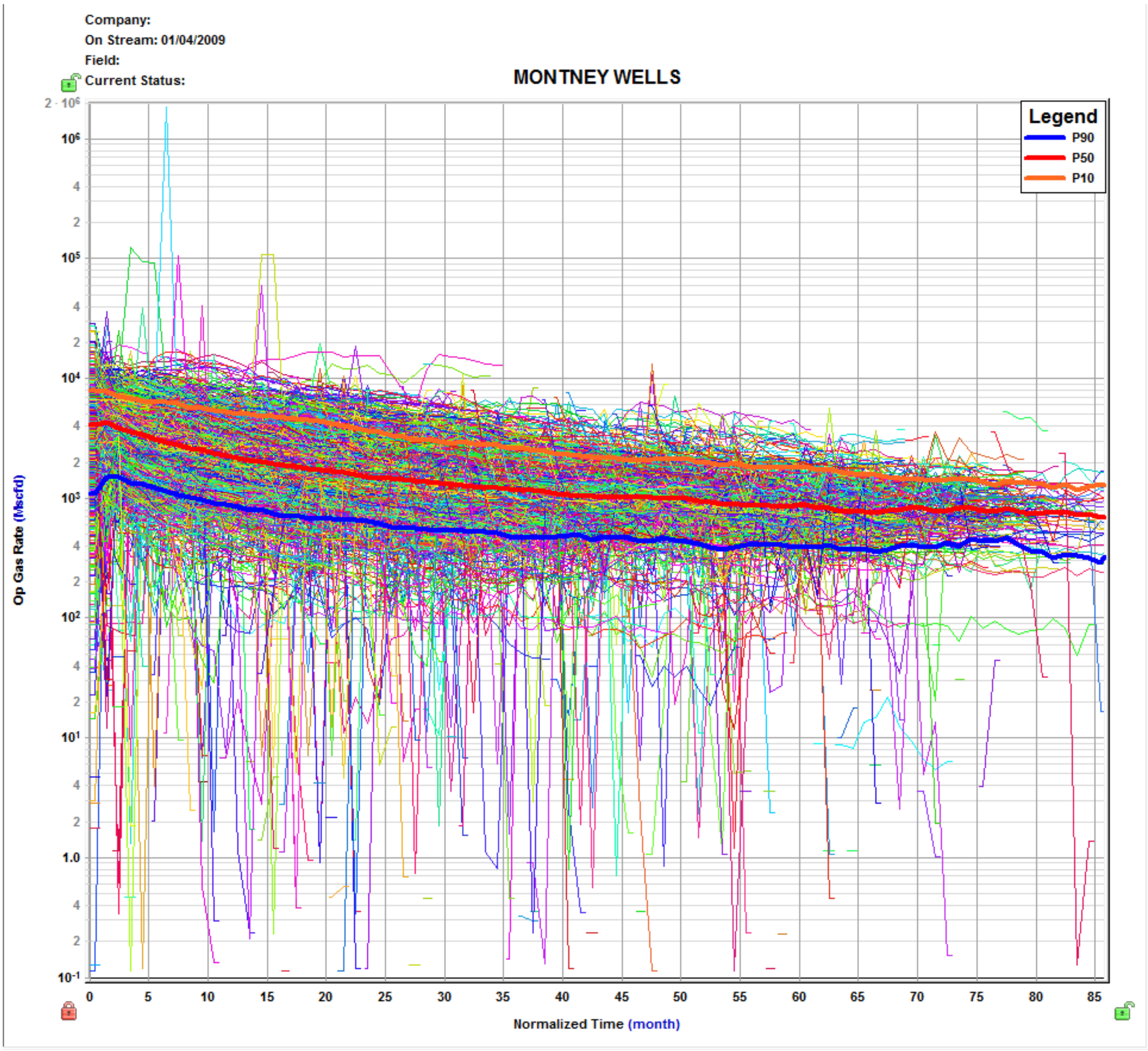


Figure 8.7 - Production rate vs time for the Montney dataset.

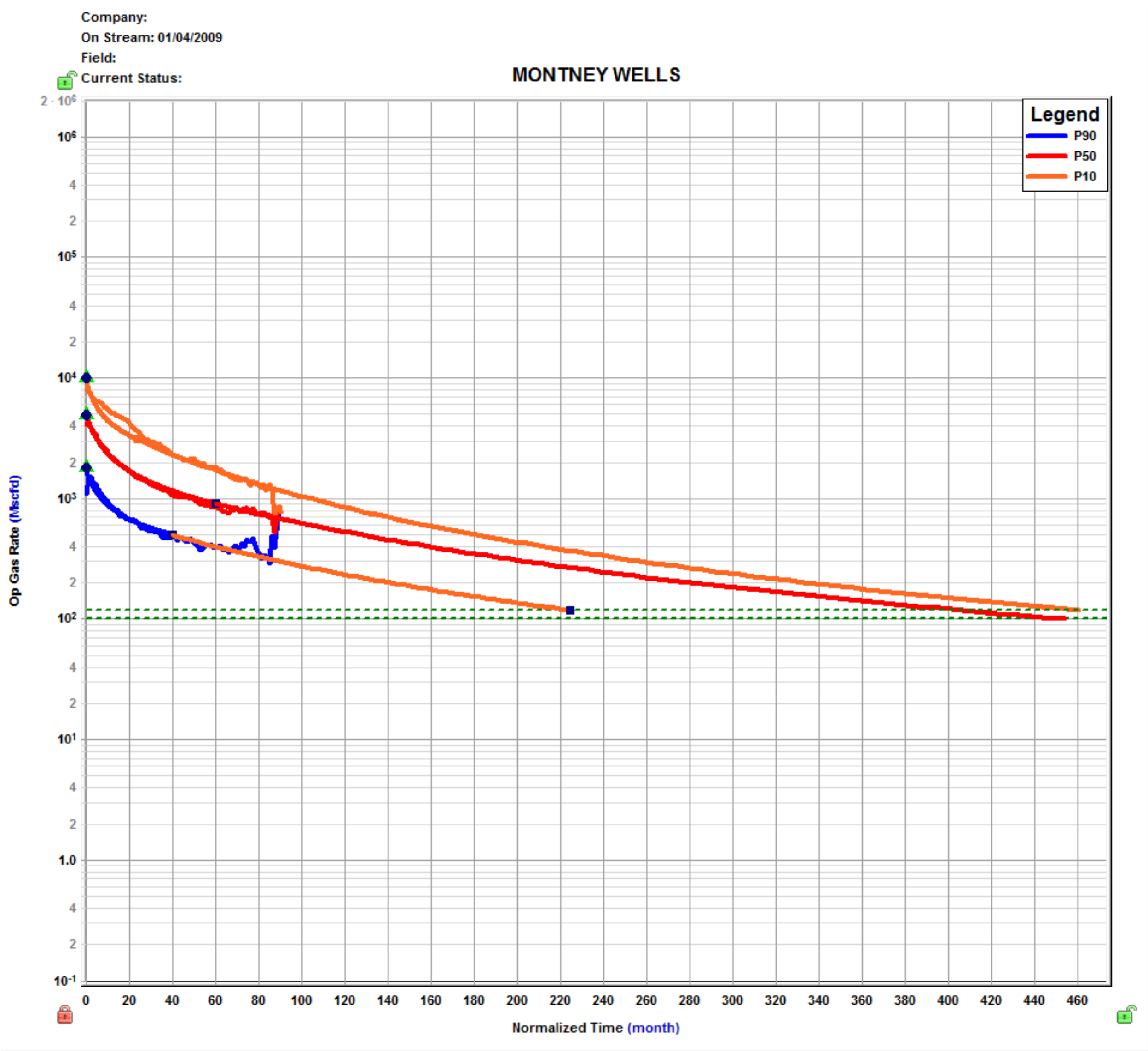


Figure 8.8 - EUR type curves for the Montney dataset.

Origin then compared the decline behaviour of the P50 Montney type well against the 45% per year and 30% per year decline scenarios suggested in the panels RFI - these are shown in Figure 8.9 below. It should be noted that in reality, decline rates are not constant and decrease over time. Over the course of a wells life the 45% per year and 30% per year decline rates would underestimate the P50 type well by 3.7 Bcf and 1.7 Bcf respectively.

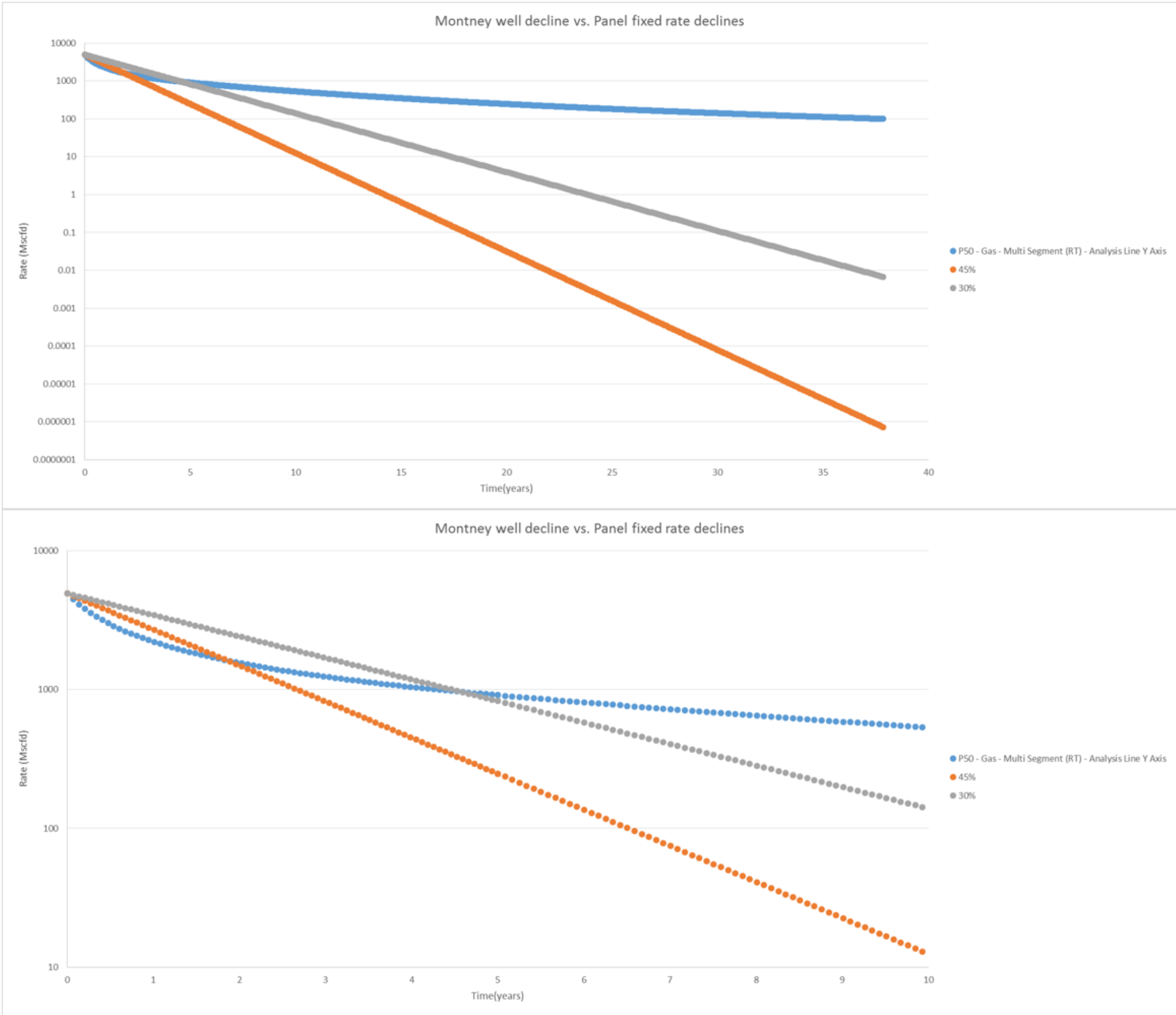


Figure 8.9 - Montney well decline scenarios

Furthermore, if the decline were constant as asserted in the RFI, then the number of wells required to replace a given year's decline in base production would be constant not increasing. However, a well's decline rate decreases over time and therefore so does the decline rate of the base production. In the development scenario submitted by Origin as part of the original submission, the number of wells required to maintain the plateau production decreases over time. This is because the base production average yearly decline also decreases over time.

This can be observed in the Beetaloo development scenario included as part of Origin's April 30 submission. The number of wells to maintain the production plateau decreases overtime (Figure 8.10), this is because the base production is comprised of more wells with ever lower decline rates as time progresses.

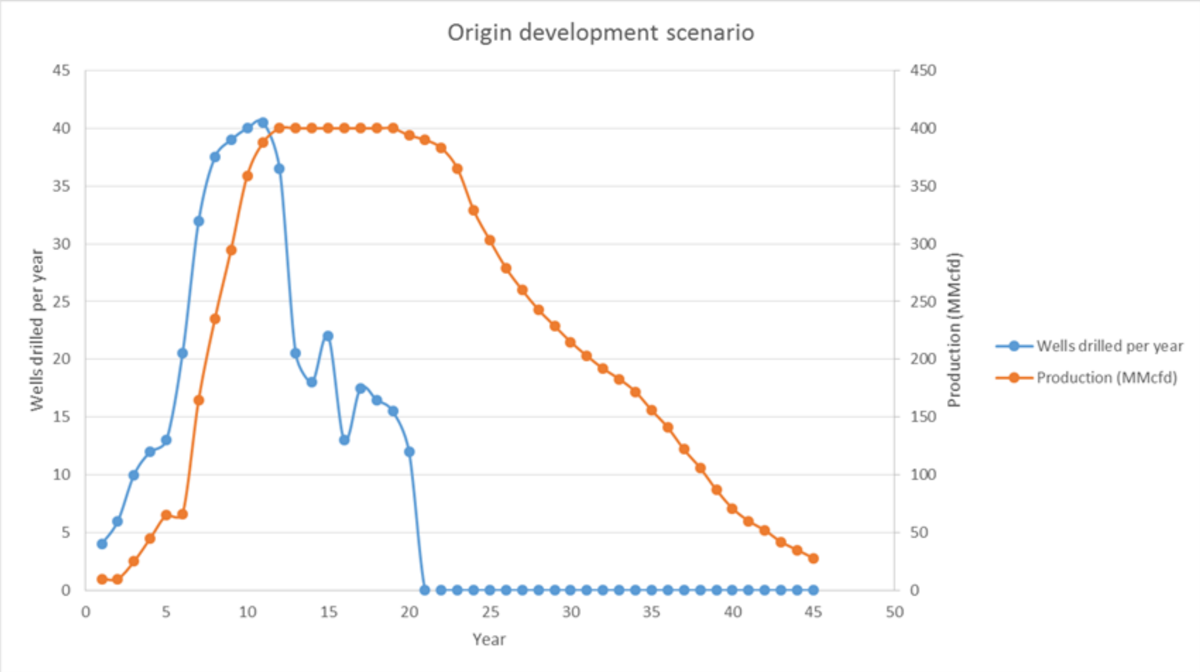


Figure 8.10 – Beetaloo development scenario, production vs wells drilled per year

Another way to assess this is to compare the production profile coming off plateau to the 30-45% year on year decline suggested in the RFI. The panel's 30-45% year on year field decline would suggest that it would only take 4-5 years to go from the peak plateau to field abandonment (Figure 8.11), this is not observed in reality.

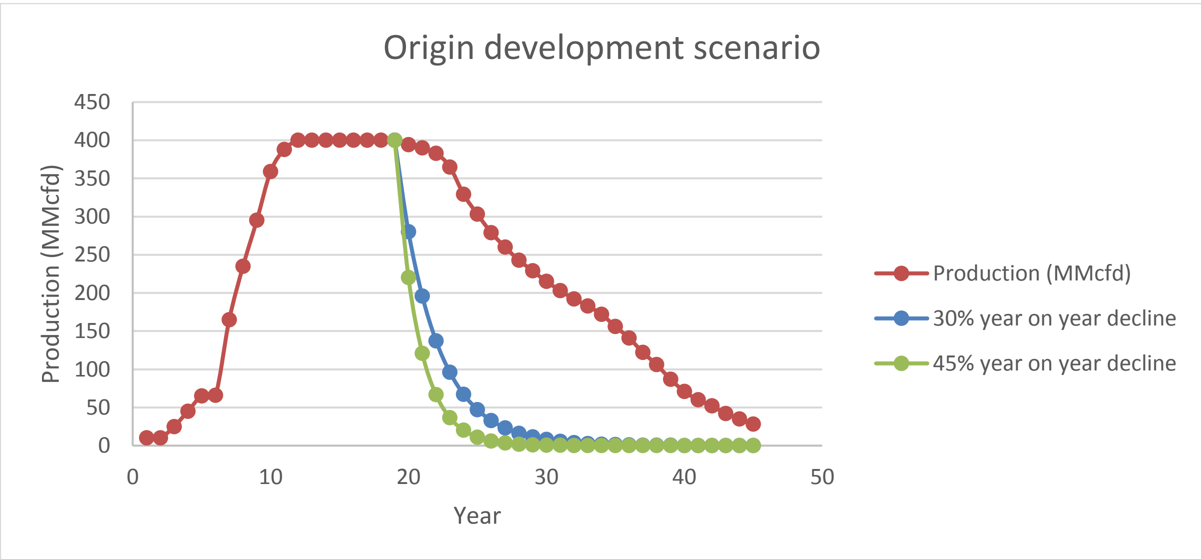


Figure 8.11 – Impact of decline rate on field abandonment for Beetaloo development scenario

<u>ii) Development scenario infrastructure</u>

Origin re-affirms the development scenario(s) that are described in detail in our April 30 submission to the Inquiry. The infrastructure requirements, to the level of detail that can be proposed at this time, are discussed in our submission also.

With regards the DPIR estimates of potential development size, we recognise that development scenarios require assumptions regarding demand and that there are no clear constraints to these assumptions. All proponents, including Origin, are attempting to forecast five to ten years into the future regarding gas prices domestically and internationally, pipeline construction costs and likelihood of construction and then tolls to use these pipelines, policies targeting carbon reduction in energy and manufacturing, the success or otherwise of other plays in eastern Australia, and many other factors in attempting to outline an appropriate size of development in the Northern Territory. Moreover, all proponents are doing so with a total lack of play specific production and cost data. Given the many uncertainties, we are not surprised by the range of outcomes that have been put to the Inquiry.

Estimates for footprint of various surface elements (Figure 8.12):

- Initial size of well pads during D&C phase: 0.02 km^2
- Size of well pad during production phase: 0.01 km^2
- Pipeline length per pad: 2.1 km
- Pipeline right of way width: 10 m
- Road length per pad: 2.1 km
- Road width: 15 m

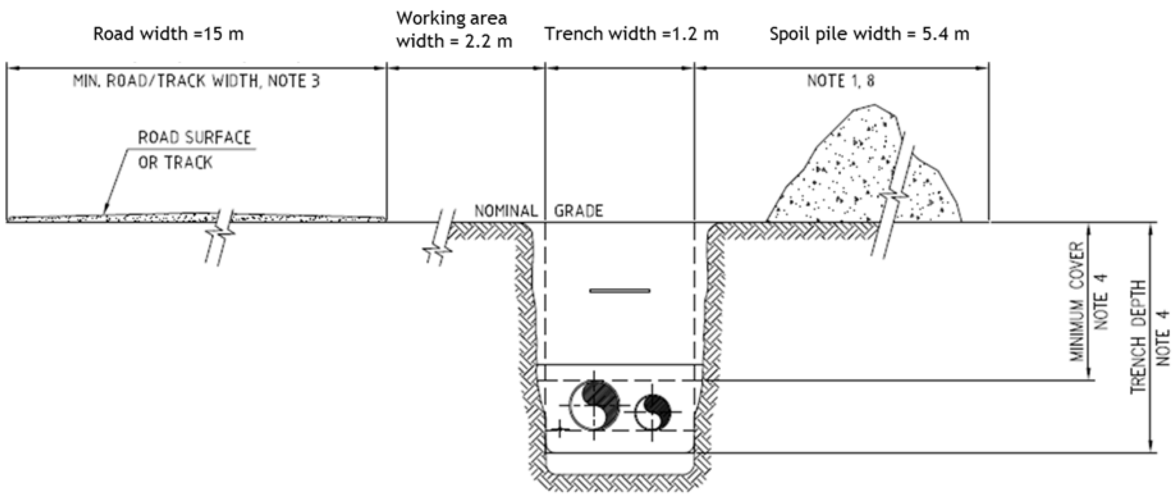


Figure 8.12 – Example pipeline and road right-of-way design

<u>iii) If the moratorium is lifted but the number of well pads is limited within a project area (e.g. to 50), please comment on the relative merits of the two scenarios described below:</u>

c. Scenario 1: wider spacing (5-10 km) between well pads, such that the effective project area would be larger (900 – 3,600 km^2), but less-intensively developed; and
d. Scenario 2: narrower spacing (2-3 km) between well pads, such that the effective project area would be smaller (144 – 322 km^2) but more-intensively developed within that footprint.

- Origin recognise that the intent of the question posed by the panel is to address the concerns that the land scape not be developed as it has been in certain North American jurisdictions.
- Origin does not believe that the scenarios suggested by the panel are necessary to ensure landscapes are not 'over industrialised'. The two scenarios posed in the RFI would result in substantial amounts of sterilised acreage. Origin is unaware of any regulator having ever prescribed measures that would deliberately result in sterilised acreage.

Origin's hypothetical development scenario provided to the panel was based on our expectations of what a success case development may look like. Underpinning this is an assessment of gas in place, recovery factors, and EURs. In order to deliver the scenario provided to the panel without changing the subsurface inputs requires a development area of 500 km^2.

To assess the impact the spacing requirements would have on the development Origin has assumed, as previously submitted to the panel, the following:

- Total subsurface area to underpin development 500 km^2
- 8 wells per pad
- 3 km lateral lengths drilled in the direction of minimum horizontal stress
- 200 meter spacing between wells on a pad

	Original Spacing	Wider Spacing		Narrower Spacing	
		Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b
Pad Spacing (km)	1.6	4.8	10	2	3
Drainage Area (km^2)	499.2	499.2	499.2	499.2	499.2
Sterile Area (km^2)	0	921.6	2419.2	115.2	460.8
Total Development Area (km^2)	**499.2**	**1420.8**	**2918.4**	**614.4**	**960**

Table 8.1 - Impact of imposing pad spacing on the total subsurface development area required to replicate the submitted Beetaloo development scenario.

Table 8.1 shows that imposing pad spacing is inefficient and un-optimized compared to Origin's scenario as the total surface area footprint per area of subsurface developed or per BCF developed will increase. Figure 8.12, which was included in Origin's original submission, shows that roads and pipelines make up the majority of a development's surface footprint requirements. By enforcing these spacings the panel will inadvertently increase the surface footprint of the play as more kilometres of road and pipeline will be required.

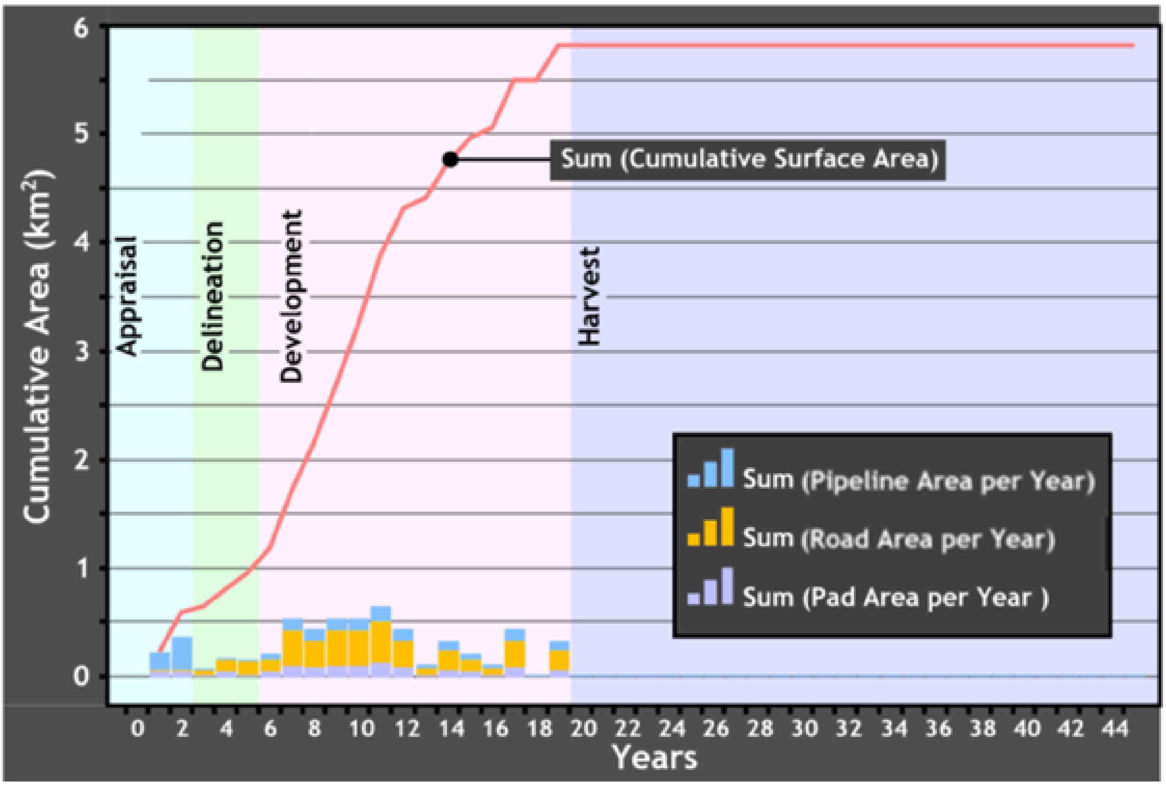


Figure 8.13 - Surface area requirements in a development scenario

Another issue with Scenario 2, is that if a development is restricted to between 144-322 km^2 it will not be able to meet the production requirements of the original scenario.

Other points:

- Should not arbitrarily limit the number of pads – this could be assessed during detailed project approvals and the EIA process
- There is not a need for a prescriptive minimum pad spacing if effective, outcome based regulations are in place that require operator's to show they are minimising their surface impact appropriately

Origin would encourage the Inquiry to review the work completed by the Alberta Energy Regulator with respect to play-based regulation. Origin believe that the outcomes the panel wishes to achieve with respect to minimising the cumulative effects of surface impacts can be better achieved by implementing a holistic development planning framework similar to the being assessed by the AER. Objectives of the AER's play based regulations pilot includes:

Objective 1: Minimize cumulative effects in the pilot area and have industry collaborate on surface development plans.

Objective 2: Enhance engagement by providing affected stakeholders, including First Nations and Métis, with the opportunity to participate in the AER's PBR pilot approach and the proponent's pilot applications.

Objective 3: Establish risk-based, play-based requirements for the pilot area.

Objective 4: Develop and test a single application and decision-making process for energy development projects.

Origin has attached the AER's Evaluation of the Alberta Energy Regulator's Play-Based Regulation Pilot and the Energy Resources Conservation Board's discussion paper on Regulating Unconventional Oil and Gas in Alberta (Appendix 2).

REFERENCES:

US Energy Information Administration - EIA (2017) Marcellus Production through April 2017 and thermal maturity. Online Map - Last Accessed 10th August 2018. https://www.eia.gov/maps/images/Marcellus_Production_April2017.pdf

US Energy Information Administration - EIA (2017) Drilling Productivity Report – For key Tight Oil and Shale Gas Regions. Onlien Report – Last Accessed 10th August 2018. https://www.eia.gov/petroleum/drilling/pdf/dpr-full.pdf

Antero Resources (2017) Company Overview. Accessed Online. Last accessed 10th August 2018. http://s1.q4cdn.com/057781830/files/doc_presentations/2017/08/Company-Website-Presentation-August-2017-(2).pdf

9 Baseline data

Question.

If the moratorium is lifted, describe Origin's annual work program for baseline data acquisition for the first five years. Describe the level of effort that is proposed with regard to water quality and biodiversity.

Response:

The collection of baseline environmental data prior to the commencement of development activities is a core component of obtaining required environmental approvals. The scale and extent of baseline surveys will be determined based on the intensiveness of the proposed activity; with studies expanding if and as the commercial viability of any project is proven.

Origin has been acquiring groundwater data from the project area since 2014, and is expanding the groundwater monitoring in 2017 with CSIRO. Origin's groundwater monitoring program is described in detail in our April 30 submission to the Inquiry and is not commented upon further in this response.

A guide to the type, overview and cost effort of selected baseline surveys is provided in the following section. It should be noted that this list is not exhaustive and that the exact details of baseline programs have yet to be defined.

Surface Water Quality:

Origin's Beetaloo permit area is located within three main drainage basins. These include the Barkly, Roper and Wiso basins. The area is characterised by a lack of permanent surface water, with surface water typically present in the area during the wet season.

Surface water quality in the permit area has previously been investigated as a part of exploration activities within the tenure (HLA, 2006). The program involved the sampling of 21 sites across the Beetaloo exploration area as illustrated in Figure 9.1. The reports concluded that the local surface waters carry calcium, magnesium carbonate and bicarbonate, which is in contrast to generally held views of sodium chloride dominated inland waters.

Future baseline programs are likely to expand upon the existing 2006 surface water monitoring program. The surface water monitoring program is likely to be expanded to include aquatic ecology components 2-3 years prior to any commercial development. A summary of these programs is provided in Table 9.1.

An example of a baseline surface water monitoring program completed for the Queensland APLNG CSG development prior to development is provided in the below links.

https://www.aplng.com.au/content/dam/aplng/compliance/eis/Volume_2/Vol2_Chapter9_AquaticEcology_GasFields.pdf

https://www.aplng.com.au/content/dam/aplng/compliance/eis/Volume_5/Vol5_Att_17_AquaticEcologyWaterQuality_GasFields.pdf

https://www.aplng.com.au/content/dam/aplng/compliance/eis/GasFieldsAquaticEcology.pdf

Component	Commencement	Overview	Parameters	Anticipated Effort/ Cost
Surface Water Quality	Preliminary assessment completed Further Assessment 2-3 years prior to planned commercial development	Collection of baseline data during both wet and dry seasons to characterise water quality and quantity trends within the Beetaloo Exploration area. This will focus on areas identified in the existing HLA (2006) baseline report (Figure 9.1**Error! Reference source not found.**)	Physical Chemistry, Metals and metalloids, Major ions, Hydrocarbons.	$65,000 per yr
Aquatic Ecology	3 years prior to planned commercial development.	Collection of baseline aquatic ecology information to understand both physical and biological values of permanent watercourses of high ecological value within the exploration area. This program will form part of an Environmental Impact Assessment.	Nationally recognised sampling methodology such as AusRIVAS or ANZECC/ ARMCANZ: Water Quality, sediment quality, Macro-invertebrates, zooplankton, invertebrates (fish), in stream and riparian habitat etc.	$300,000/yr

Table 9.1 - Potential baseline surface water quality and ecology monitoring program overview

Landscape and Visual Amenity:

Landscape and visual amenity assessments are important considerations when selecting the placement of infrastructure. Baseline assessments will be undertaken prior to commercial development to determine the visual character of the landscape, as well as visual sensitivity of the various viewing locations. This information will be used to identify potential visual amenity impacts, so that treatments can be applied. Such treatments include:

- Relocation of infrastructure away from sensitive areas (main roads, high points)
- Selection of infrastructure i.e. pit flares versus candle stick flares
- The colour of infrastructure to blend in with surroundings

An overview of the potential landscape and visual amenity baseline program is provided in Table 9.2. An overview of an existing landscape and visual amenity baseline assessment from the Queensland APLNG project is provided in the below link:

https://www.aplng.com.au/content/dam/aplng/compliance/eis/Volume_5/Vol5_Att12-VisualImpactAssessGasFieldsPipeline.pdf

Component	Commencement	Overview	Parameters	Anticipated Effort/ Cost
Landscape and visual amenity	Conducted prior to planned commercial development.	Collection of baseline landscape and visual amenity to determine visual character and sensitivity of landscape.	Landscape setting (vegetation, land use, topography, hydrology etc.), viewing locations etc	Assessment estimate approximately $150,000

Table 9.2 - Potential landscape and visual amenity baseline program

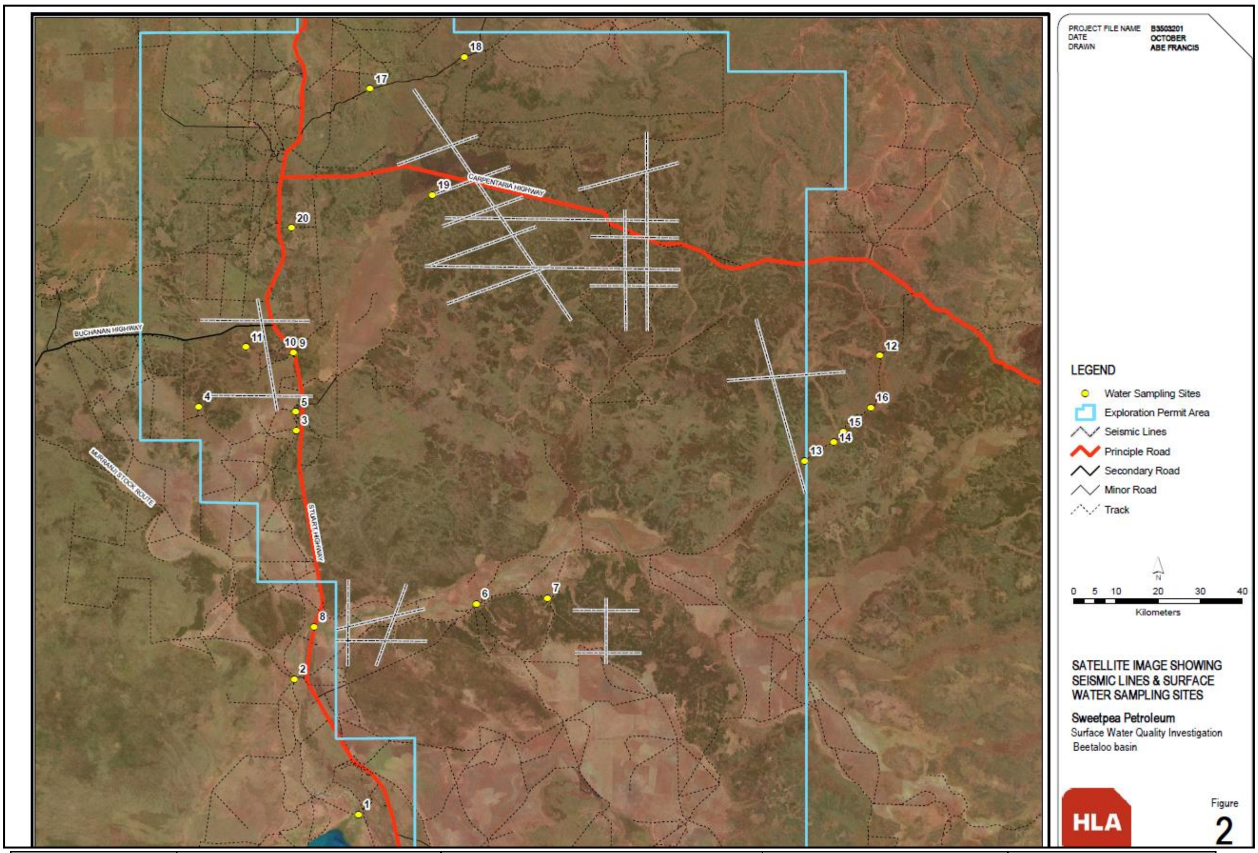


Figure 9.1 - Overview of water sample sites baselined as a part of the HLA 2006 surface water monitoring program.

Terrestrial Ecology:

Terrestrial ecology baseline information will be collected throughout the life of the project. The intensity of the assessment of potential impacts on terrestrial ecosystems will increase as (if) the project transitions from an exploration activity to a commercial scale development.

Terrestrial baseline surveys during the exploration phase are primarily restricted to the proposed footprint. This includes the areas proposed for roads, well pads and ancillary infrastructure (camps, lay down yard etc.) to support exploration activities. Baseline assessments are undertaken in accordance with the NT EPA Guidelines for assessment of impacts on Terrestrial Biodiversity (2013). Such assessments utilise a combination of desktop assessments and field verification to identify and map the following features:

- Vegetation communities
- Presence of threatened flora and fauna under the Territory Parks and Wildlife Conservation Act 2000
- Critical habitat
- Matters of National Environmental Significance
- Presence of weed and pest species

If the project moves from an exploration based activity to a commercial development, the baseline programs will be increased to cover the proposed footprint of a broader development. Such an assessment would include extensive field verification to ground truth existing terrestrial ecology data. A broad overview of a baseline program is provided in Table 9.3. It should be noted that the extent of the baseline assessment can only be known once the project development concept is defined post-exploration and appraisal activities. Costs provided are indicative based upon Origin's experience within QLD.

An example of a terrestrial ecology baseline program completed for the APLBG project in Queensland is provided in the below link:

https://www.aplng.com.au/content/dam/aplng/compliance/eis/Volume_2/Vol2_Chapter8_TerrestrialEcology.pdf

Component	Commencement	Overview	Parameters	Anticipated Effort/ Cost
Terrestrial Ecology	Exploration- activity based assessments required for exploration activities. Detailed expansion of surveys likely 2 years prior to planned commercial development.	Exploration- Targeted terrestrial flora and fauna surveys covering areas of proposed exploration infrastructure Expansion of program to cover the development area prior to EIS.	1.Field verification of existing vegetation types, ecosystems and habitat values; 2. presence or evidence of significant terrestrial flora and fauna species including an assessment of suitable habitat for listed threatened species; 3. presence of weeds and/or	Exploration ~100k,yr. Pre-EIS ~$600k/yr over 3 years

Component	Commencement	Overview	Parameters	Anticipated Effort/ Cost
			feral animals. All surveys undertaken in accordance with : NT Environmental Assessment Guidelines- Terrestrial Biodiversity (2013) NT weed data collection guidelines (2015). Department of the Environment Survey Guidelines for Nationally Threatened Species(2011)	

Table 9.3 – Potential terrestrial ecology baseline overview

Air Quality:

Establishing an appropriate air quality baseline is important when undertaking air impact assessments associated with developments. Baseline assessments provide an understanding of pre-existing pollutant sources, which are necessary to predict cumulative impacts from a proposed development.

An example of and effective baseline air quality monitoring program is the GISERA Surat Basin Ambient Air Quality Monitoring Program (https://gisera.org.au/project/ambient-air-quality-in-the-surat-basin/). This program consists of a mixture of ambient air monitoring stations (Figure 9.2) and approximately 10 passive sampling sites across the Surat Basin. This program monitors over 60 pollutants that are pertinent to public health and the environment.

The majority of instrumented ambient air monitoring stations are located adjacent to gas processing facilities (and associated flares) and surrounding CSG infrastructure. Data from these sites is live streamed to the EHP website and can be viewed by the public real time at https://www.ehp.qld.gov.au/air/data/search.php. Impacts to air quality from flaring in the Surat Basin have not been observed contrary to the claims made by certain individuals and groups.

It is anticipated that an ambient air baseline program would be implemented at least two years prior to any commercial development. An overview of a potential program is provided in Table 9.4.

Figure 9.2 – Example of an air quality monitoring station within the Surat Basin

Component	Commencement	Overview	Parameters	Anticipated Effort/ Cost
Air Quality	Conducted at least 2 years prior to planned commercial development.	Collection of baseline air quality data to underpin air impact assessment for full scale shale gas developments. Data to be collected from a representative location within the Beetaloo development area.	Meteorological components, Combustion Related Gasses (Oxides of Nitrogen, Carbon Monoxide, Carbon Dioxide, Sulphur Dioxide, Ozone), Particulate Matter (Pm 2.5, PM10 and TSP), Total Volatile Organic Compounds (VOC's),Speciated VOC's-(USEPA Method TO17), Aldehydes, Hydrogen Sulphide, Radon Data to be collected using a combination of instrumentation, Radiello's (US EPA TO 17) and Suma Canisters (US EPA TO15) similar to the GISERA Surat basin Ambient Air Monitoring Program	$1.2 Million over 3 years

Table 9.4 - Potential baseline ambient air monitoring program

Greenhouse gas emissions:

Collection of greenhouse gas baseline data is becoming increasingly important for unconventional gas developments. Without baseline data, it is extremely difficult to distinguish the potential contribution of oil and gas activities to the broader regional methane budget. A perfect example of this is the Four Corners hot spot identified by NASA in 2014 (NASA, 2014).

In the Beetaloo, there are a range of large natural GHG emission sources likely to be contributing to the regional methane budget. These include biomass burning, ephemeral wetlands, termites and agriculture. These emissions sources are likely to vary significantly both temporally and spatially, therefore a robust GHG baseline program is required prior to development.

Origin anticipates a Beetaloo GHG baseline program could be implemented that follows the approach of Day et al. (2015) and Day et al. (2016). An overview such a program is provided in Table 9.5 and would likely include the following components:

- 2-3 fixed atmospheric monitoring stations combined with eddy covariance measurements
- Vehicle mounted cavity ring-down spectroscopy (CRDS) methane surveys
- Remote sensing (satellite) measurements (e.g. GHGsat, http://www.ghgsat.com)

Component	Commencement	Overview	Parameters	Anticipated Effort/ Cost
Greenhouse Gas	Conducted at least 2 years prior to planned commercial development.	Baseline regional methane measurements combined with eddy covariance, remote sensing and vehicle based measurements. Designed to understand both regional and local variations in methane fluxes which can be used to develop a regional methane budget	Methane, Carbon Dioxide, Carbon $_{13}$ Isotope,	$2.0 Mil over 3 years

Table 9.5 - Potential Greenhouse Gas baseline study

Soils:

Preliminary soil mapping for the Beetaloo exploration area has been undertaken as a part of the Beetaloo Drilling Environmental Plan (Figure 9.3).

Baseline soil sampling programs are best deployed at the site scale prior to the civil design phase of development of specific activities. This ensures that regional mapping can be validated with site specific information, rather than rely on regional mapping with little ground truthing.

Information collected during baseline assessments can provide insights into:

- Constructability and stability
- Erosion susceptibility and required controls (erosion and sediment control, management of sodicity etc.)
- Determination of topsoil management practice
- Soil nutrient levels for reinstatement

An overview of a potential baseline assessment approach is provided in Table 9.6.

Component	Commencement	Overview	Parameters	Anticipated Effort/ Cost
Soils	Exploration - activity based assessments required for exploration activities. Detailed expansion of surveys likely 2 years prior to planned commercial development.	Exploration - targeted terrestrial flora and fauna surveys covering areas of proposed exploration infrastructure Baseline assessments completed prior to civil construction on a property. Designed to provide information for civil construction, erosion and sediment control and rehabilitation. This will be expanded prior to development to validate soil units across the development area.	1. Field verification of existing vegetation types, ecosystems and habitat values; 2. presence or evidence of significant terrestrial flora and fauna species including an Physical properties (Particle size distribution, dispersivity, texture, etc.), physical chemistry (EC and pH,) major ions, ESP, SAR selected metals, nutrients and total organic carbon.	Exploration ~100k/yr. Pre-EIS expanded to ~$500,000

Table 9.6 – Potential soils baseline assessment approach

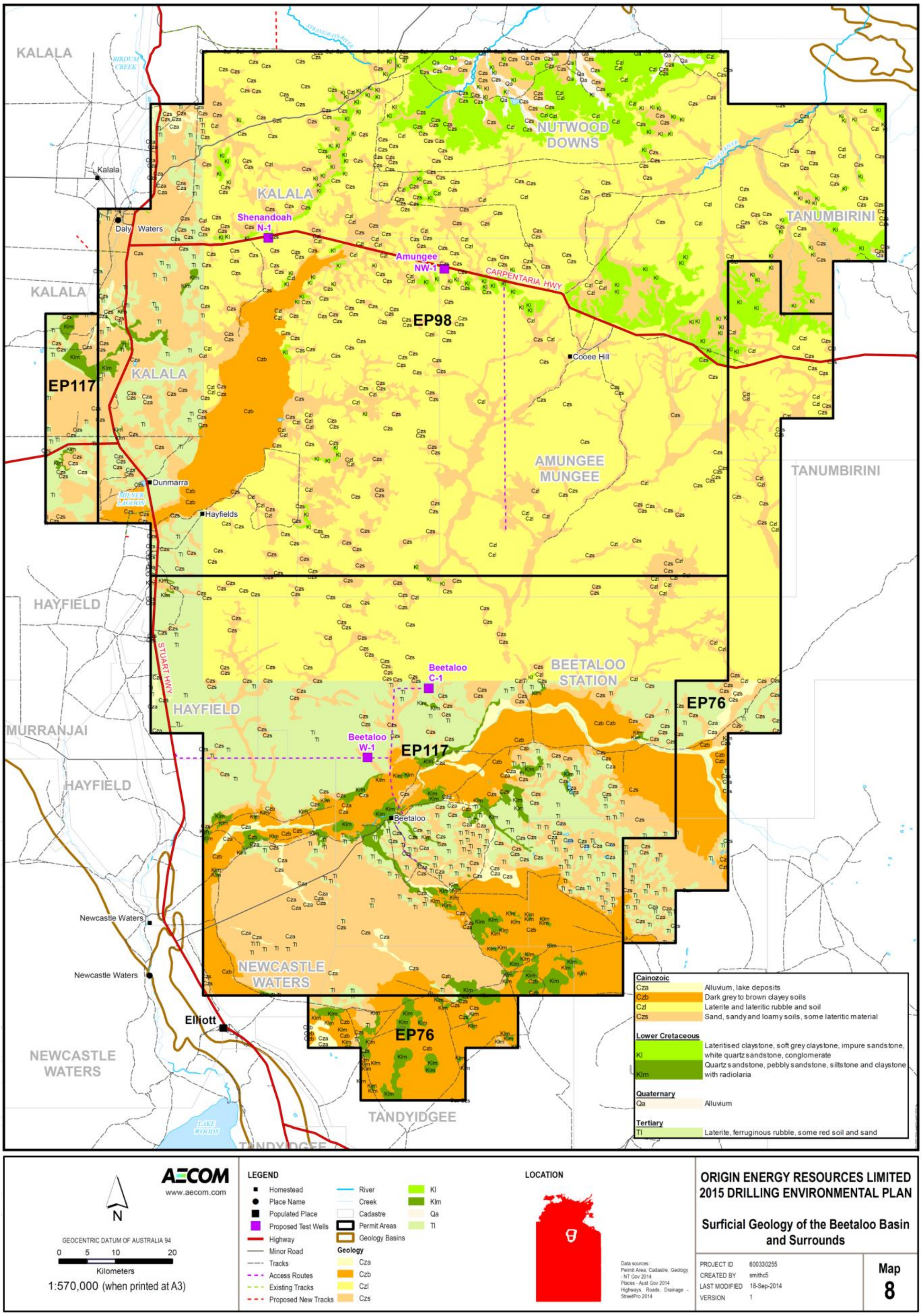


Figure 9.3 – Soil unit distribution across the Beetaloo Sub-Basin (EP98, EP117 and EP76)

Health:

Baseline health statistics for areas are captured by the relevant State or Territory Health departments (https://health.nt.gov.au/professionals/health-gains) and the Australian Bureau of Statistics on an ongoing basis. Contrary to individual claims, health baseline statistics that predate unconventional development do exist in both Queensland and the NT. For example, health statistics utilised by Werner, Cameron, Watt, Vink, Jaggals, & Page (2017), predate major CSG development.

Origin supports the concept of an independent research organisation undertaking a baseline health study for the broader Beetaloo and Macarthur basins. The current study approach being developed by GISERA as part of the assessment of human health effects from coal seam gas is likely to provide a suitable platform for a NT specific study (https://gisera.org.au/project/human-health-effects-of-coal-seam-gas/).

Establishment of baseline should be independent of the industry and undertaken in collaboration with the NT Government.

REFERENCES:

HLA. (2006) Surface Water Quality Investigation, Beetaloo Basin, Northern Territory. NT. Report prepared for Sweetpea Petroleum Pty Ltd.

NASA (2014) U.S. Methane 'Hot Spot" Bigger than Expected. Online article https://science.nasa.gov/science-news/science-at-nasa/2014/09oct_methanehotspot. Last accessed 14th August 2017.

Day, S., Ong, C., Rodger, A., Etheridge, D., Hibberd, M., Gorsel, E., Spencer, D., Krummel, P., Zegelin, S., Fry, R., Dell'Amico, M., Sestak, S., Williams, D., Loh, Z., Barrett, D. (2015) Characterisation of regional fluxes of methane in the Surat Basin, Queensland: Phase 2: A pilot study of methodology to detect and quantify methane sources. CSIRO, Australia.

D. M. Etheridge, S. Day, M. F. Hibberd, A. Luhar, D. A. Spencer, Z. M. Loh, S. Zegelin, P. B. Krummel, E. van Gorsel, D. P. Thornton, R. L. Gregory, C. Ong and D. Barrett (2016). Characterisation of Regional Fluxes of Methane in the Surat Basin, Queensland - Milestone 3.1 GISERA Greenhouse Gas Research – Phase 3. CSIRO, Australia.

10 Traffic

Question.

The Panel notes the community's concern about increased traffic along the Stuart and Carpentaria Highways should the industry be given approval to proceed. This is not just a matter of road safety and increased potential for spills, but also an issue of "amenity" for road users in general, noting that the Stuart highway is a major route for grey nomad traffic during the dry season.

Please indicate the nature and extent of the increase, relative to current conditions, in vehicle movements during each state of development. Please also indicate whether transportation by rail has been considered given the proximity of the rail line corridor to the relevant lease areas in the Beetaloo.

Origin's submission noted that:

> "Detailed modelling of traffic movements would be included in any project proposal and require approval of various agencies."

Please provide additional detail about the proposed modelling. Specifically, please indicate whether modelling has been undertaken for similar projects (for example, in respect of coal seam gas projects in Qld). Please also indicate whether the output from such modelling can be used to infer impacts on accident statistics. This is especially important in relation to the potential for spills of chemicals that are being transported.

Please also identify the legislative approvals that are required as per the above quote, including the legislation under which the approval is given and the Department and/or Minister responsible for giving the approval.

Response:

Equipment volumes have been provided for exploration activities undertaken to date as part of the approval process in the Environment Management Plans (EMP). The equipment volumes provided in these documents are a good representation of future volumes for drilling rigs, hydraulic fracturing spreads and civil works for initial field mobilisation.

The EMP, which is approved by the Department of Primary Industries and Resources and is a requirement for approval as per the Northern Territory Petroleum Regulations (6 July 2016), covers a wide range of potential impacts. Work within a road corridor requires a detailed Traffic Management Plan and this includes permits issued by Department of Infrastructure, Planning and Logistics. The exact permits required depend on the location and nature of the work to be undertaken.

Traffic modelling has been undertaken for Origin's operated CSG project, APLNG, as part of the EIS process. However, the APLNG project is much more dependent on public roads due to the higher spatial intensity of development and the larger number of well leases and thus this modelling is not directly relevant. If a development were to proceed in the Beetaloo, similar modelling would be undertaken which included analysis of traffic incident history of the affected roads and the probability of increasing the incident frequency based on the volume of additional traffic. A copy of the Traffic and Transport chapter of the APLNG EIS is provided in Appendix 3.

In a development scenario, optimally the drilling rig and hydraulic fracturing spreads would work continuously avoiding costly remobilisations. Movement between lease sites would mostly be infield moves not requiring extensive use of public roads. The main source of traffic would be supplies of equipment and consumables. Material such as proppant and the hydraulic fracturing additives would be secured in a location within the field for optimal distribution to the well leases.

Origin is aware that an upgrade of the Carpentaria Highway to dual carriage way from the Stuart Highway to the coast is considered of importance to the local community, regardless of onshore petroleum activity. This road services the McArthur River mine and a significant population on the coast and is a popular tourist destination for both locals and interstate visitors. If this road was to become a supply route for a future development a contribution to an upgrade by the operator would be considered. It should be noted the existing road is high quality being fully sealed and only cut in a couple of locations during heavy rain events.

In 2004 the rail upgrade from Darwin to Adelaide was completed. This has opened this route to both passenger and cargo trains. The rail line roughly runs parallel with the Stuart Highway and is only 60 km to the west of Daly Waters. There are existing cargo facilities at Katherine and Tennant Creek and a passing loop at Newcastle Waters. The operator would investigate the use of rail for delivery of bulk cargo such as pipe, rig tubulars, proppant and other additives along with any other infrastructure which may be required to the region. Rail was used in Queensland to some extent to reduce traffic on the Warrego Highway.

Drilling rigs and hydraulic fracturing spreads are highly controlled work environments and in most areas personnel working at these sites live in co-located camps. This would likely be the case in a development scenario and this will again minimize traffic due to personnel movement. For civil works it will be highly dependent on the location of the work. If work is very isolated, then fly camps will be required to reduce travel times for crews. There will be light vehicle (mine specification 4WD) traffic between accommodation and the work sites.

A potential conflict between *"Grey Nomad"* traffic and industry traffic has been suggested. The Stuart Highway is the major route for all traffic moving north and south between the Northern Territory and the rest of Australia including large volumes of cattle being moved north for live export. The highway already carries a large volume of heavy vehicles, which includes road trains of up to 53.5m long, and therefore the tourist traffic and heavy vehicle traffic already co-exist on the main route through the Beetaloo. It should be noted that the tourist traffic is very predictable and by the nature of the traffic the conflict is reduced. There is almost no tourist traffic in the summer season. During the cooler part of the year the vehicles most likely to conflict are the slow-moving caravans towed by light vehicles and road trains travelling near or at the speed limit. However, the tourists tend to move at a leisurely pace between each night's camp site, usually packing up and moving to the next location between mid-morning and mid-afternoon. This limits the time window when the two types of traffic are simultaneously on the road.

11 Greenhouse gas emissions

Question.

The Panel has formed a preliminary view that, if the industry is given approval to proceed, the following mechanisms will be required to minimise greenhouse gas emissions, and in particular, methane emissions:

- implementation of leading practice standards for emission reduction, such as the United States Environmental Protection Agency's New Source Performance Standards, Permitting Rules for the Oil and Natural Gas Industry;
- baseline measurements of methane levels prior to development; and
- ongoing monitoring of methane levels at key points during exploration, development and production.

The Inquiry invites comments on the above. In addition, please comment on:

1. the technologies that are currently available to obtain baseline measurements of emissions, including the possible use of drones;
2. the scope, including the location, of any emissions monitoring that should occur during the exploration, development and production phases, such as, for example, wellheads during completion, liquids unloading, compressor seals and gathering stations;
3. the use of emission limits that, if exceeded, would trigger an investigation, make-good requirements and/or a penalty;
4. the need for transparency when setting emission limits; and
5. whether or not baseline measurements and on-going monitoring should be undertaken by an independent body.

Response:

Origin supports the introduction of best practice baseline and fugitive emissions reduction requirements for developments within the NT. Origin strongly suggests these requirements be outcome based and have a degree of flexibility in their deployment.

Origin does not support the specification of certain types of emission testing technology; such as Optical Gas Imaging (OGI). The favouring of one particular type of technology is likely to stifle innovation; particularly in a time when gas detection and emissions quantification practices are rapidly evolving. Implementation of detection technology should be based on ensuring the best fit for purpose technology is utilised. Technology forcing often skews innovation leading to sub-standard long term competitive and environmental outcomes.

An example of innovation is the increased use of emission quantification technology. Origin is currently in the process of establishing the use of new vehicle mounted methane survey equipment capable of making estimates of emission rates; not just emissions concentration. A trial of this new technology was completed on one of Origin's CSG development in 2016. The results of this trial were presented at the 2017 APPEA conference in Perth (Appendix 4). Origin has commenced procurement of this technology and it will be rolled out across Origin's CSG developments within Q4 2017.

The technologies that are currently available to obtain baseline measurements of emissions, including the possible use of drones;

Origin supports the collection of baseline methane measurements prior to full scale development. Origin has extensive experience in conducting routine (including baseline) methane surveys and have participated in several fugitive emissions research programs.

The predominate background sources of methane within the Beetaloo are anticipated to be from natural soil respiration processes, termites (Jamali, et al., 2011) ephemeral wetlands (Deutscher, Griffith, Paton-Walsh, & Borah, 2010), agriculture (Cook, Williams, Stokes, Hutley, Ash, & Richards, 2010) and biomass burning (Smith, et al., 2014). These sources are likely to vary both spatially and temporally, particularly between the wet and dry seasons. Any baseline program must be undertaken in a way that enables a sufficient data capture frequency and spatial coverage to adequately characterise the natural GHG emissions from the broader Beetaloo exploration area.

The potential methodologies for establishing baseline GHG levels are mature. The CSIRO have worked on a range of GHG baseline studies for carbon sequestration (Etheridge, et al., 2009 and Berko, et al., 2012) and unconventional gas developments within Australia (Day, et al., 2016 and Day, et al., 2015). A review of available techniques was undertaken by Day, et al. (2015) and provides a good starting point when considering the strengths and weaknesses of various baselining approaches. Further information on this study is available on the GISERA website: https://giser org.au/project/methane-seepage-in-the-surat-basin/

The Surat Basin methane flux characterisation project has adopted a combination of "bottom up" and "top down" monitoring techniques. Bottom up methodologies involve the direct measurement of a potential source at an individual level (well, gas plant etc.). In comparison, top down measurement techniques are used to estimate total emissions from an area or region through upwind-downwind assessments and inverse contaminant transport models (Day, Connel, Etheridge, Norgate, & Sherwood, 2012). Bottom up approaches are useful in characterising the intensity of an individual source, activity or facility; however, they are often criticised due to lack of collective representativeness. Top down techniques measure all sources of emissions from an area, making attribution of emissions levels from individual activities or industries extremely difficult. A combination of approaches is the optimal balance, whereas targeted source characterisation studies are used to cross reference the results of top down studies.

Based on experience with existing programs within the Queensland unconventional gas development areas, a combination of fixed atmospheric monitoring stations, vehicle based surveys and remote sensing technologies are likely to be investigated as a part of a potential Beetaloo baseline program. Field deployment of these technologies within the Surat Basin are shown in **Error! Reference source not found.**.

In regards to the specific question from the panel regarding the use of drones for baseline surveys, this is something that is being looked at by Origin on an ongoing basis. The use of drones is essentially a platform deployment change, rather than a change in sensor capability. It is recognised there are rapid advancements in the use of drones and in methane detection sensors. Origin currently believes that the use of drones is still in the development phase and that there are potential applications of this technology. Like all technological advancements, Origin is closely watching this space and is keen to explore the use of drones once they have proven their accuracy and cost effectiveness.

Figure 11.1 - GISERA Atmospheric GHG concentration monitoring station located on the Greenlea property on Origin's Ironbark tenure (Day, et al., 2015). These stations require access to power.

Figure 11.2 - A Licor Eddy Covariance methane measurement system installed adjacent to an Origin CSG well by Macquarie University. These stations are solar powered and were utilised to estimate the entire life cycle of fugitive emissions from drilling through to production.
https://researchdata.ands.org.au/linkage-projects-grant-id-lp140100460/618640

Figure 11.3 - Methane surveys using high precision cavity ring-down spectroscopy sensors to detect and quantify emissions sources across the Surat Basin (source Picarro)

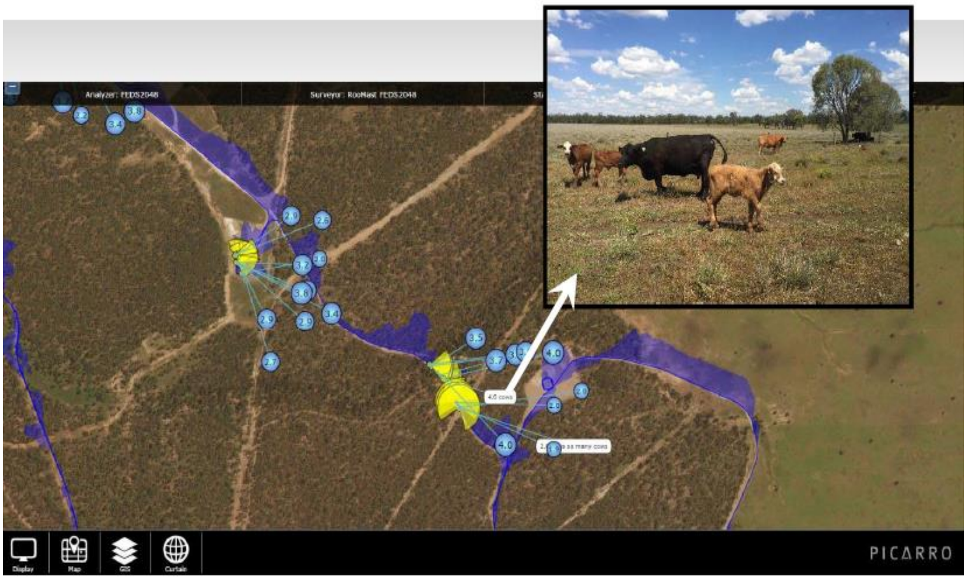


Figure 11.4 - Example of a vehicle methane survey of infrastructure- note the instrument is able extremely sensitive and can detect emission from cows (source Picarro)

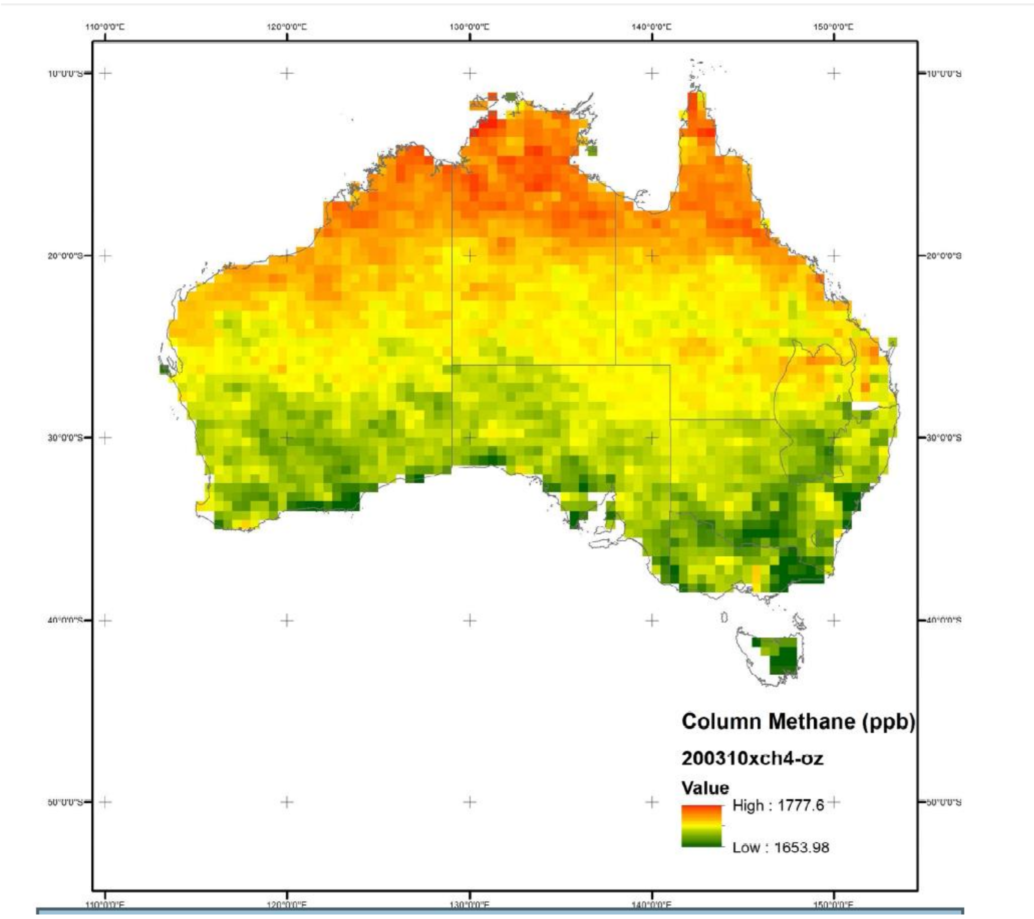


Figure 11.5 - Total column methane measurements produced by CSIRO using a WFM-DOA algorithm (Day, et al., 2015).

The scope, including the location, of any emissions monitoring that should occur during the exploration, development and production phases, such as, for example, wellheads during completion, liquids unloading, compressor seals and gathering stations;

Undertaking leak detection and repair activities within the oil and gas industry is a standard practice. In Queensland, leak detection practices are governed under the Petroleum and Gas (Production and Safety) Regulation 2004 and subsequent codes of practice (Department of Natural Resources and Mines, 2011 and Department of Natural Resources and Mines, 2017). These regulations and codes require operators to take all reasonable and necessary steps to avoid leakage from gas processing infrastructure. A minimum inspection frequency of five years is required for all infrastructure (regardless of exploration or development related); however the regulations require a risk based approach and therefore the inspection frequency employed by operators are typically higher. Origin would recommend the adoption of similar codes of practice for the NT.

The intensity of monitoring should also reflect the age and technology of infrastructure that will be utilised if development within the NT were to progress. Unlike the US where there is a mixture of old and new technology and infrastructure, development within the NT is entirely greenfield and will utilise industry best practice with regard to infrastructure design and fugitive emissions management techniques. The inherent risk associated with fugitive emissions is, therefore, lower than that in the US.

Monitoring emissions resulting from activities would be challenging and impracticable for an operator to complete. Monitoring concentration from activities is also not an accurate method for determining emission rate as demonstrated in Figure 11.6.

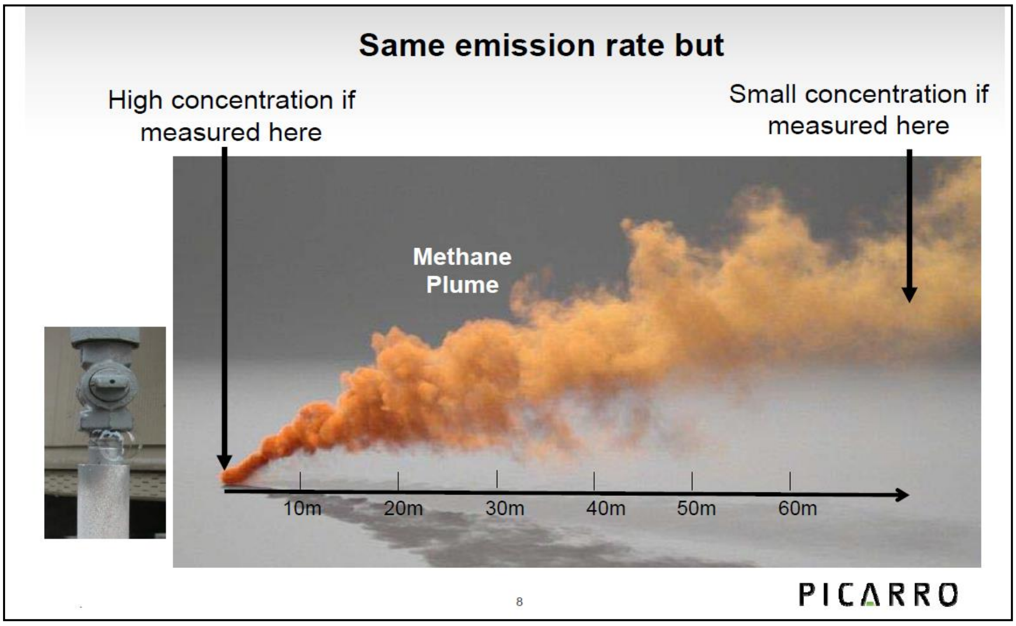


Figure 11.6 - Visualisation of concentration variation at distance away from the emissions source (source: Picarro)

As previously stated Origin supports the use of both top down and bottom up techniques to monitor and assess GHG emissions performance. Top down techniques in place would capture emissions data from all the activity in the field while bottom up can assess specific components (i.e. compressor seals).

Origin also supports a regulatory framework with an objective hierarchy geared at eliminating and reducing flaring, incineration and venting is an effective way to reduce GHG emissions associated with activities. The *AER's Directive 60: Upstream Petroleum Industry Flaring, Incinerating, and Venting* (Appendix 5), requires licensees, operators, and approval holder to evaluate the following three options:

- Can flaring, incineration, and/or venting be eliminated?
- Can flaring, incineration, and/or venting be reduced?
- Will flaring, incineration, and venting meet performance standards?

A high level schematic of the AER's flaring/venting management framework is shown in figure 11.7.

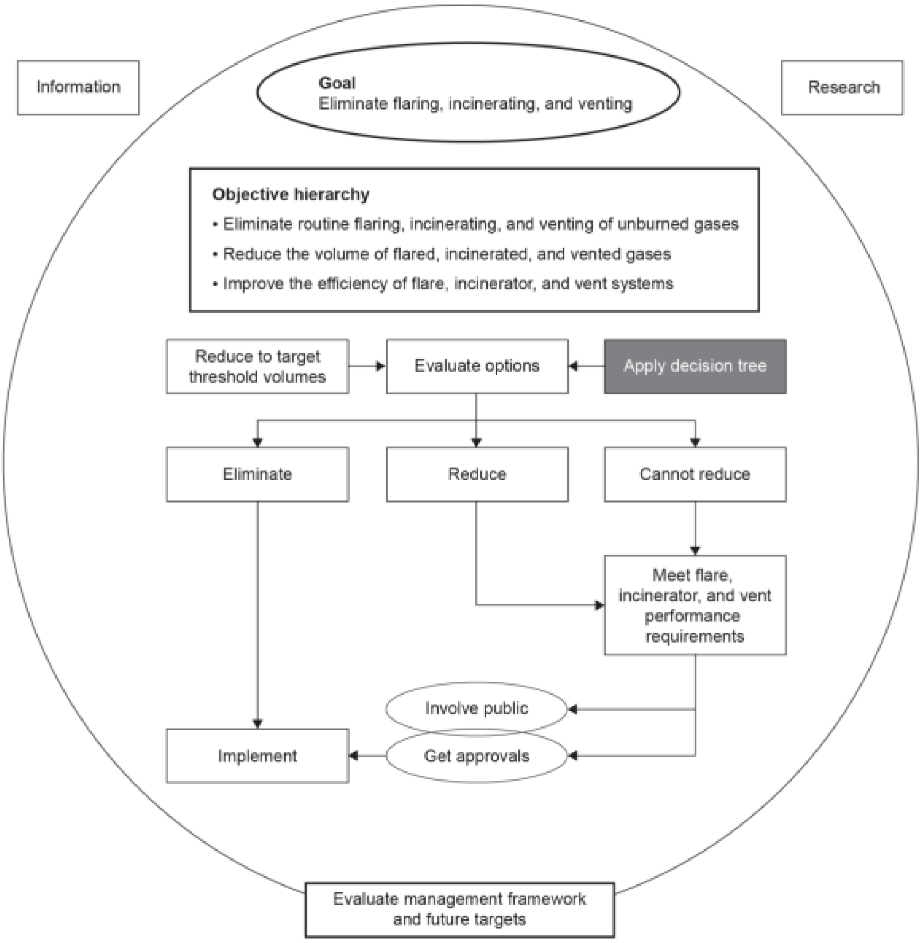


Figure 11.7 – AER flaring/venting management framework

For example, the AER would apply the decision tree in Figure 11.8 to assess an activity that may have the need for temporary flaring such as unloading liquids from a well. The AER does not consider venting an acceptable alternative to flaring or incineration which is why it is not included in the decision tree in Figure 11.8. During the production phase the expectation is that activities such as clean up and unloading of wells will be done in-line. Origin supports a regulatory framework that encourages operators to adopt such practices during all phases of development.

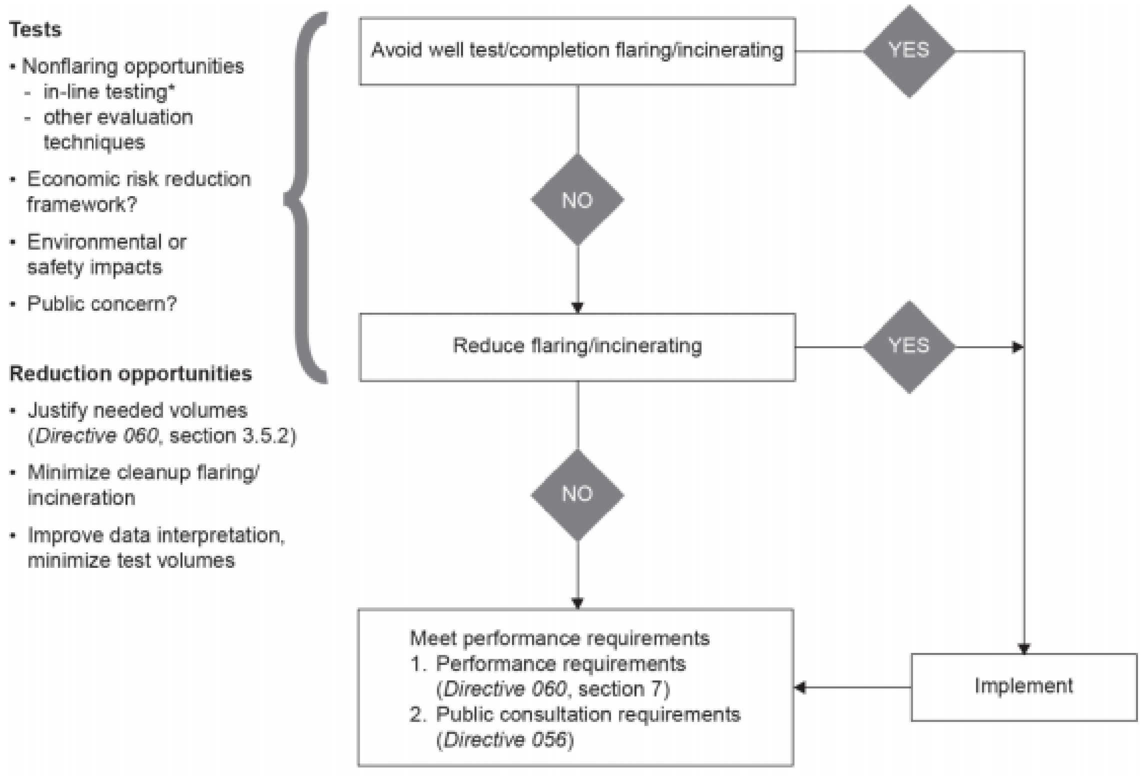


Figure 11.8 – AER temporary flaring and incineration decisions tree

Section 419 of the DPIR Schedule of Onshore Petroleum and Production Requirements 2016 states that except in an emergency, petroleum shall not be flared or vented without approval, either directly or as part of an approved operation or plan. As such, approval from the DPIR is required in order for an operator to vent or flare. Origin supports a more descriptive directive such as the AER's Directive 60 as a sensible way to eliminate and reduce activity based emissions.

The use of emission limits that, if exceeded, would trigger an investigation, make-good requirements and/or a penalty AND the need for transparency when setting emission limits;

Origin supports the adoption of the emission limits aligned with the Queensland Department of Natural Resources Code of practice for leak management, detection and reporting for petroleum production facilities (2017).

Origin does not support the 500 ppm trigger that has been implemented by the US EPA as a part of the New Source Performance Standards, Permitting Rules for the Oil and Natural Gas Industry. The US EPA acknowledge that OGI detection can only be guaranteed to detect a gas plume exceeding 10,000 ppm during all weather conditions and that the adoption of 500 ppm is to ensure that the majority of leaks identified during method 21 surveys are rectified. The use of 500 ppm would mean operators who use the Method 21 survey alternative would be disadvantaged over those who use OGI, as they are required to rectify more leaks. This is essentially a form of market manipulation which favours one approach over a number of other valid approaches. It is Origin's opinion that the Queensland code of practice for leak management, detection and reporting for petroleum production facilities is a far more practicable and outcome based approach.

The justification behind the establishment of emission limits within the Queensland code of practice for leak management is provided within the context of the document.

Whether or not baseline measurements and on-going monitoring should be undertaken by an independent body.

Origin supports the establishment of an independent baselining program modelled upon the GISERA Characterisation of methane fluxes within the Surat basin Program (Day, et al., 2015).

REFERENCES:

Jamali, H., Livesley, S., Grover, S., Dawes, T., Hutley, L., Cook, G., Arndt, S. (2011) The Importance of Termites to the CH Balance of a Tropical Savanna Woodland of Northern Australia. Ecosystems, v.14 (5), pp.698-709.

Deutscher, N., Griffith, D., Paton-Walsh, C., Borah, R (2010) Train-borne measurements of tropical methane enhancements from ephemeral wetlands in Australia. Journal of Geophysical research, v.115 (D15).

Cook, G., Williams, R., Stokes, C., Hutley, L., Ash, A., Richards, A. (2010) Managing Sources and Sinks of Greenhouse Gases in Australia's Rangelands and Tropical Savannas. Rangeland Ecology and Management v.63, pp.137-146.

Smith, T., Paton-Walsh, C., Meyer, C., Cook, G., Maler, S., Russel-Smith, J., Wooster, M., Yates, C. (2014) New emission factors for Australian vegetation fires measured using open-path Fourier Transform Infrared Spectroscopy – Part 2: Australian Tropical Savanna Fires. Atmospheric Chemistry and Physics, vol.12, pp.6311-6360.

Etheridge, D., Luhar, A., Leuning, R., Steele, P., Spencer, D., Allison, C., Zegelin, S., Loh, Z., Krummel, P., Meyer, M., Sharma, S. (2009) Atmospheric Monitoring of the CO2CRC Otway Project. IEA Greenhouse Gas R&D Programme Monitoring Workshop, Tokyo, Japan.

Berko, H., Etheridge, D., Loh, Z., Kuske, T., Allison, C., Gregory, R. (2012) Installation Report for Arcturus (ARA): An inland baseline station for the continuous measurement of atmospheric greenhouse gases. Canberra: Geoscience Australia. csiro:EP126815.

Day, S., Connell, L., Etheridge, D., Norgate, T., Sherwood, N. (2012) Fugitive greenhouse gas emissions from coal seam gas production in Australia. Newcastle, New South Wales: CSIRO. csiro:EP128173. https://doi.org/10.4225/08/584d959a38c7d

12 Groundwater

Question.

Figure 37 of Origin's submission shows the pressure logger data from the Amungee Waterbore 1. The Panel seeks an explanation about how the data shows that there was no impact on the pumping of the bore, which is suggested on page 87 of Origin's submission.

Response:

Figure 37 has been updated and reproduced in Figure 12.1 to more clearly show the rapid recovery of water level in the Cambrian Limestone Aquifer in water bores at the Amungee NW-1 location following a sustained period of extraction. Figure 12.1 shows the water level, as measured by a pressure logger, in Amungee NW-1 Waterbore 1, as it was being pumped to fill storage ponds on site. During the short intervals when the pump rate reduced the level recovered to the original water-level ("No drawdown" line in Figure 12.1) almost immediately.

Figure 12.2 shows the water level in RN5844, approximately 3 km away, which shows no response to the extraction of nearly 10 ML from Waterbore 1 and Waterbore 2 over the course of about five weeks. Figure 12.2 also demonstrates that the water level in Waterbore 1 returns to its natural standing water level effectively immediately when pumping ceases.

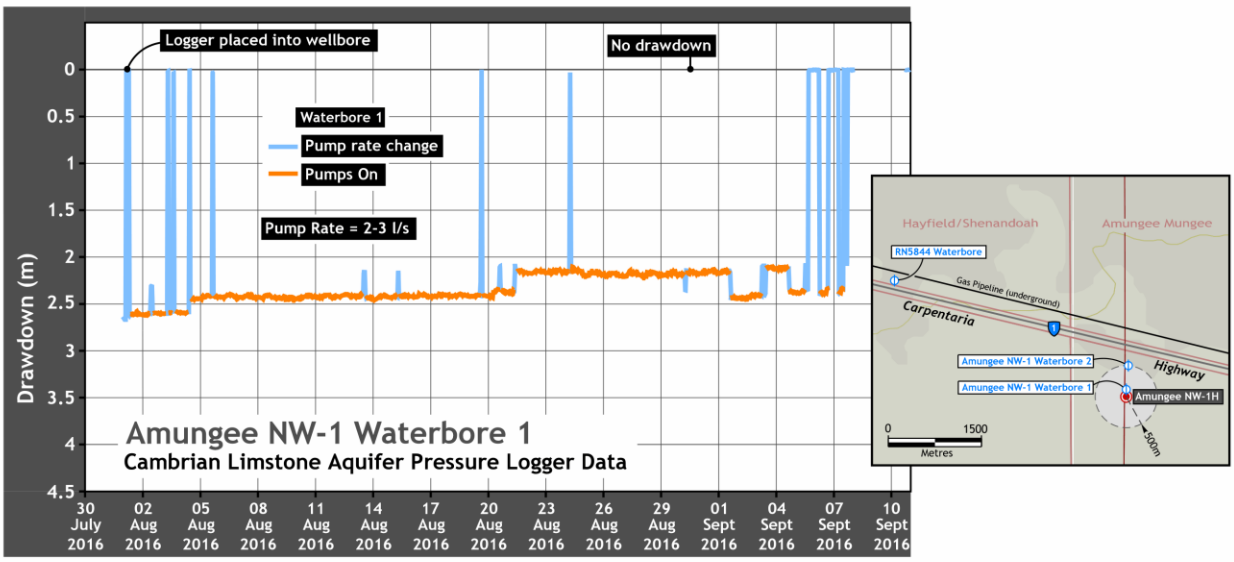


Figure 12.1 – Water levels in Waterbore 1 demonstrate that the Cambrian Limestone Aquifer recovers almost immediately following sustained extraction and that there is no interference with Waterbore 2 despite the relatively short distance.

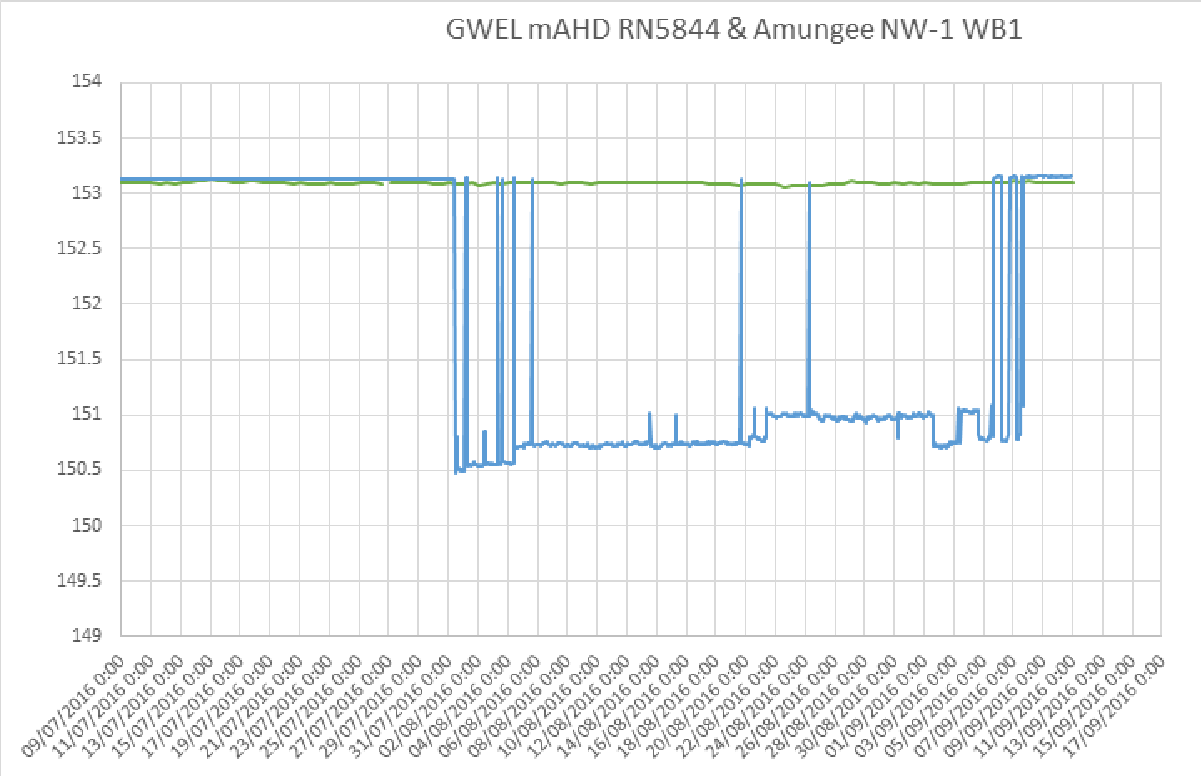


Figure 12.2 - Water levels in monitoring bore RN5844 (green), in the Cambrian Limestone Aquifer, are unchanged during extraction from water bores at Amungee NW-1 approximately 3 km away (drawdown in Amungee NW-1 Waterbore 1 shown in blue).

13 Preliminary risk assessment

Question.

While carbon dioxide emissions dominate the life cycle GHG emissions (because downstream combustion of natural gas generates high amounts of carbon dioxide), methane emissions dominate the upstream GHG emissions. Furthermore, the quantity of methane emissions is more uncertain and they are more amenable to reduction. Accordingly, the focus of the proposed risk assessment is on methane emissions. A framework for an interim risk assessment is given in Table 9.2 for a number of hazards which may prevent lower levels of methane emission performance from being achieved. These levels of methane have been discussed previously.

At this stage, the Panel has insufficient information to make an informed assessment of risk. This risk assessment will be used to identify areas where mitigation of risks is required and to assess strategies to mitigate those risks.

Response:

Origin are supportive of measures to reduce and eliminate fugitive emissions. Fugitive emissions are not just a contributor to greenhouse gas emissions but also impact profitability. Regulations directly and indirectly related to greenhouse gas emissions are already in existence as discussed in Question 11. Origin, however, support improvement to the regulatory framework such as an objective hierarchy geared at eliminating and reducing greenhouse gas emissions through flaring, venting and other fugitive emissions.

14 Concluding remarks

Below is a summary of the responses prepared by Origin in relation to the Inquiry's request for information:

- **Flooding**:
  - The Amungee mud sump and flare pit never overflowed. They were constantly monitored and Origin and Saxon maintained records of water levels over the wet season.
- **Well integrity**:
  - Long term well integrity can be achieved with proper well design and construction. Origin has provided a comprehensive list of technical references to support this assertion.
- **Flowback and produced water:**
  - Origin supports the framework requiring industry members to complete a risk assessment for geogenic components of flowback at a project level and supports an appropriate disclosure requirement.
- **Spills**:
  - In the unlikely event of a surface spill migrating to a groundwater aquifer, remediation would be undertaken using a variety of methods that are underpinned by an understanding of human and environmental risks.
- **Deep groundwater systems**:
  - Origin will consider all potential, suitable water sources for its requirements if a development proceeds.
  - Origin believes the CLA can support a shale gas development in the Beetaloo region and supports the implementation of a holistic water management regime for the Northern Territory whereby all industries and users report their usage.
- **Solid waste management**:
  - Purpose built, engineered facilities would be required to safely manage, some solid and liquid waste generated by a commercial shale development within the NT.
  - The location of these facilities will be assessed as a part of the development concept.
- **Health assessment:**
  - Origin engaged third party assessors from AECOM to undertake a human health and environmental chemical risk assessment for the Beetaloo exploration project. The assessment report is undergoing formal review and will be made available by late-August.
  - The report has been extended to include NORMs assessment and does address potential impacts from flowback water.
  - This risk assessment will be updated prior to the development phase to incorporate site specific receptors. The quantitative results will be the same as the current assessment; unless a process or stimulation mixture change occurs.
- **Infrastructure requirements**:
  - Origin caution the panel not to assume that "sweet spots" or "core areas" comprise only a small portion of a shale play's extent. Drilling trends in the US show that in a successful shale play, development extends across maturity windows which have similar production characteristics.

    - Operators across US shale plays are achieving ever better well productivity results despite having already drilled thousands of wells. Ever fewer wells are required to maintain or grow production at a field level.
    - Evidence from North American shale gas plays doesn't support a 30-45% year on year decline in production
    - Development scenario sizes require assumptions on important factors that are difficult to constrain or forecast such as demand. All proponents, including Origin, are attempting to forecast five to ten years into the future regarding gas prices domestically and internationally, pipeline construction costs and likelihood of construction and then tolls to use these pipelines, policies targeting carbon reduction in energy and manufacturing, the success or otherwise of other plays in eastern Australia, and many other factors in attempting to outline an appropriate size of development in the Northern Territory.
    - Origin does not believe that the scenarios suggested by the panel are necessary to ensure landscapes are not 'over industrialised'. The two scenarios posed in the RFI would result in substantial amounts of sterilised acreage. Origin is unaware of any regulator having ever prescribed measures that would deliberately result in sterilised acreage.
- **Baseline data:**
    - The collection of baseline environmental data prior to the commencement of development activities is a core component of obtaining required environmental approvals. Baseline surveys should be continued and expanded in parallel with ongoing exploration and appraisal activity.
- **Greenhouse gas emissions:**
    - Origin supports the introduction of best practice baseline and fugitive emissions reduction requirements for developments within the NT. Origin strongly suggests these requirements be outcome based and have a degree of flexibility in their deployment.
    - Origin does not support the specification of certain types of emission testing technology.
    - In Queensland, leak detection practices are governed under the Petroleum and Gas (Production and Safety) Regulation 2004 and subsequent codes of practice (Department of Natural Resources and Mines, 2011 and Department of Natural Resources and Mines, 2017). These regulations and codes require operators to take all reasonable and necessary steps to avoid leakage from a gas processing infrastructure. Origin would recommend the adoption of similar codes of practice for the NT.
    - Origin supports a regulatory framework with an objective hierarchy geared at eliminating and reducing flaring, incineration and venting is an effective way to reduce GHG emissions associated with activities.
    - Origin supports the adoption of the emission limits aligned with the Queensland Department of Natural Resources Code of practice for leak management, detection and reporting for petroleum production facilities (2017).

Origin maintains that the Beetaloo could represent a genuine opportunity for economic growth in the NT, one that could coexist successfully with other industries and land users. Further data are required to fully characterise the potential of the Beetaloo, therefore it is critical that exploration and appraisal can continue so that assessments of the opportunity and the design of any necessary legislative reforms can be undertaken based on data and not assumptions. The existing legislative and regulatory framework in the NT continues to serve and be appropriate for current and future exploration activities. However, we do support fit-for-purpose improvements to the existing objective based legislation and regulation which aligns the regulation to the geology and scale of an unconventional gas development in the NT.

15 Appendices

Appendix 1:

Water quality testing results from Amungee NW-1H flowback fluids compared to Marcellus and Barnett flowback

Appendix 2a:

Evaluation of the AERs Play-Based Regulation Pilot

Appendix 2b:

Regulating Unconventional Oil and Gas in Alberta-ERCB Discussion Paper

Appendix 3:

APLNG EIS - Traffic and Transport Impact Assessment

Appendix 4:

Picarro APPEA (2017) Presentation – New System for Detecting, Mapping, Monitoring, Quantifying and reporting fugitive gas emissions

Appendix 5:

AER Directive 060: Upstream Petroleum Industry Flaring, Incinerating, and Venting