

21 August 2017

**Santos**

The Honourable Justice Rachel Pepper  
Hydraulic Fracturing Task Force  
GPO Box 4393  
Darwin NT 0801

The Honourable Justice Rachel Pepper

Santos welcomes the opportunity to provide a further written submission to the Northern Territory Government's Scientific Inquiry into Hydraulic Fracturing of Onshore Unconventional Reservoirs and Associated Activities in the Northern Territory.

This submission addresses a range of issues raised in your Interim Report, many of which were discussed at Santos' appearance before the Scientific Panel on 2 August 2017. It includes answers to the questions taken on notice at that appearance as well as answers to questions raised in your correspondence to Santos, dated 25 July 2017.

This submission has been structured into the following components:

- A. Responses to the Information Request date 25 July 2017, across ten headings:
  - 1. Flowback and produced water,
  - 2. Spills,
  - 3. Groundwater systems,
  - 4. Solid waste management,
  - 5. Infrastructure requirements,
  - 6. Baseline data,
  - 7. Traffic,
  - 8. Health assessment,
  - 9. Greenhouse gas emissions,
  - 10. Further information;
- B. Responses to questions Santos took on notice at the public hearing on 2 August 2017; and
- C. Concluding remarks regarding the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory - Interim Report (NT Hydraulic Fracturing Inquiry Scientific Panel, July 2017).

If you require any other information, Santos is happy to assist.

Yours sincerely,



Bill Ovenden

**Executive Vice President – Exploration and Appraisal**

## A. Response to information request

The following provides answers to the questions raised in the correspondence to Santos, dated 25 July 2017.

### 1. Flowback and produced water

Santos provided a proposed scope of work for undertaking human health and ecological risk assessments as part of the initial written submission to the Scientific Panel (Santos Ltd, April 2017; Submission #168, Appendix B).

The scope of work describes how geogenic constituents are presented within the assessment reports and how they are subsequently incorporated into the human health and ecological risk assessments. This includes the incorporation of empirical data when it becomes available following well testing.

Similar chemical risk assessments are currently publically available on the Santos website for other Santos projects as provided by Santos' response to the Scientific Inquiry Chair's request for information dated 26<sup>th</sup> May 2017 (Santos Ltd, June 2017; Submission #280).

Accordingly Santos is supportive of presenting geogenic constituents as a component of such risk assessment reports.

### 2. Spills

The assessment of the potential risks associated with spills to surface water, groundwater and terrestrial systems is evaluated in the human health and ecological risk assessments as provided within the initial written submission to the Scientific Inquiry (Santos Ltd, April 2017; Submission #168, Appendix B).

The human health and ecological risk assessments are supported through the use of a series of models to assess runoff potential for a range of spill scenarios and subsequent potential for leaching to groundwater.

A part of the assessment process, the risk assessments calculate the magnitude of the dilution attenuation factor necessary to mitigate the risk associated with hypothetical release scenarios and potential migration to surface water. This is then used in combination with the attributes of the water (size, flow etc) to determine the potential impact that the hypothetical spill scenarios may have on a receiving water body.

Further, biodegradation, photodegradation, dissociation, cation exchange and other transformation processes in surface water and soils are then evaluated to determine whether the chemical concentrations attenuate over time (or are persistent in the environment), and the nature and toxicity of any by-products.

The output of the assessment and magnitude of the risk is then considered in the engineering design to ensure that the combination of engineering and management controls (commensurate with the risks) are implemented.

As demonstrated in the hydraulic fracturing risk assessments completed for Santos' operations in Queensland (Santos Ltd, June 2017; Submission #280), biological degradation and other processes are shown to very important in attenuating the concentrations of constituents that pose the greatest hazard, such as biocides which have very short degradation half-lives (should a spill occur). In terms of the potential impacts to groundwater, the assessments consider the potential risk associated with surface releases, drilling processes and hydraulic fracturing within the target units.

The assessments conducted in Queensland have demonstrated that:

- the hydraulic properties of the materials (i.e. much of the upper formation / unsaturated zone exhibits low permeability) would limit the vertical movement of water and chemical constituents

and in combination with the capacity of the formation to retain water, any vertical flux is small and the travel times to groundwater long.

- in the unsaturated zone, a range of processes decrease the concentrations over time. These include, biodegradation and sorption processes for the majority of organic constituents and cation exchange and complexation for inorganic constituents.
- In the unlikely event that infiltration did reach shallow groundwater, a combination of dilution with groundwater and advection, dispersion, diffusion, sorption (including ion exchange) and biodecay would all occur in the saturated zone, attenuating groundwater concentrations and that no adverse impact is expected.

### ***Assessment for the prospective area within the Greater Beetaloo Basin, NT***

The prospective area of the Greater Beetaloo Basin is typically characterised by low permeability in the upper near surface formations (surface/near surface aquitard) which serves to limit infiltration to and confine groundwater in the deeper water bearing units (shallow aquifer – typically the Cambrian Limestone aquifer). This therefore limits the potential for surface releases to impact on the underlying groundwater system.

To demonstrate this, the potential for impacts from hypothetical surface spills was modelled (a scenario in which no management, mitigation or containment was implemented, or spill response actions undertaken). The management of drilling materials was also assessed. This methodology is consistent with the assessment methodologies used for Queensland and other Santos projects. The assessment is included as Appendix A.

In summary, this assessment included an evaluation of:

1. The area over which a range of surficial releases would spread before infiltrating into surface soils (with no management controls or spill response implemented);
2. The time period over which releases would remain at surface before infiltrating into surface soils (with no management controls or spill response implemented);
3. The travel time for the released fluids to infiltrate through the unsaturated zone to groundwater (with no management controls or spill response implemented); and
4. The potential leaching of constituents from drilling muds and potential changes in pore water and groundwater concentrations (if constituents leach to sufficient depth).

Three separate hypothetical release scenarios (1,000 litre, 100,000 litre and 1,000,000 litre) were evaluated (with no management controls or spill response implemented). The outcome of this assessment demonstrated that the spill area would range from < 0.1 ha to 24 ha (for 1,000 litre to 1,000,000 litre respectively in silty clays) with the size directly a function of the volume of the spill and infiltration rates. The releases were shown to persist at surface from < 1 hour (sand and 1,000 litre spill) and 6 days (1,000,000 litre spill and silty clay).

The output of the assessment of infiltration demonstrated that (conservatively) the fluids would take approximately 690 years to migrate to groundwater (Cambrian Limestone Aquifer). Further however, given the volume of water that can be retained in the unsaturated zone (from 0 to 52 m bgs) it is unlikely the release would ever make it to the groundwater.

On the basis of these calculations and assessment undertaken and also in consideration of flux dilution and other processes that would occur within the unsaturated and saturated zones, it is considered highly unlikely that any surface release would migrate and result in an adverse impact on groundwater quality (Note: this is even without any management or mitigation controls in place or spill response actions under taken).

A similar assessment was conducted for the drilling muds that may be managed at a well lease such as blended with native soils. Modelling using the USEPA VLeach model demonstrated that the placement of these materials in shallow soils would similarly not pose a risk of adverse impact to groundwater quality (Appendix A).

## **Remedial Technologies**

The United State Environmental Protection Authority (US EPA) reports a variety of technologies that can be used to ensure contaminants are either removed from a site or treated so they no longer pose a risk to human health and the environment (United States Environmental Protection Agency, 2000).

This US EPA report is based on the implementation of over 600 field projects and is supported by a technology screening tool matrix. This tool currently contains 64 soil and groundwater remedial technologies supported by 209 cost and performance reports written by members of the Federal Remediation Technologies Roundtable.

The assessments includes in Appendix B have demonstrated that the proposed activities have limited potential to impact on groundwater quality, with the primary focus (consistent with the risk assessments conducted by Santos) on avoiding and managing the risk of releases.

However, to assist with a response to the information request received, and the unlikely event that impacts were to occur, then remedial efforts would likely be focuses on water soluble constituents. This is because non-water soluble compounds and compounds with high retardation coefficients would not migrate.

A quick screening of remedial alternatives was conducted using the USEPA Remedial Technologies Forum framework and screening tables. Based on the physical properties of the chemicals with the greatest potential for migration and based on the hydrogeological setting (a relatively deep and extensive aquifer system), groundwater extraction and water treatment provides the best means of mass removal, hydraulic containment of groundwater impacts (if needed) and ultimately aquifer restoration.

Considering the physical properties of the constituents with the greatest potential for migration, a broad range of treatment options were identified for the extracted water. These include open air storage to facilitate natural dissociation and photodegradation, biological treatment for alcohols, glycols, glutaraldehyde (they biodegrade rapidly in the presence of oxygen), activated carbon absorption for removal of non-polar organics and ion exchange for removing of metals and inorganics. All of these technologies are readily available and could be quickly implemented.

The long travel times as provided by the infiltration assessment (Appendix A) provide more than ample time for systematic management/monitoring and remediation (if required) program to be implemented to mitigate any potential impacts.

## **3. Groundwater Systems**

Limited data is available regarding deeper groundwater quality or availability within the Greater Beetaloo Basin. Available information suggests that these groundwater(s) are hyper-saline and yields are significantly lower than the Cambrian Limestone Aquifer (CLA). Santos plans to acquire pressure and permeability data through the exploration and appraisal stages that will help assess the feasibility of deeper groundwater systems as a water source.

Given the average and peak industry water demand has been quantified as 2.5GL/year and 5GL/year respectively in the Interim Report, and that the sustainable recharge is estimated at 100 GL to 330GL/year for the shallower aquifer systems, no adverse impact from the take of water can be expected.

While it is acknowledged that there is scientific uncertainty in relation to the actual recharge rates, since the take of water is two orders of magnitude lower than the uncertainty range, Santos agrees with the findings of the Interim Report (NT Hydraulic Fracturing Inquiry Scientific Panel, July 2017)- that modelling and monitoring can effectively manage the risk of adverse impact to water availability.

#### **4. Solid waste management**

In onshore Australian drilling operations it is typical to dig a pit on the drill site to collect drill cuttings. The spoil material dug from the pit is retained nearby ready to back-fill the pit.

Drilling pits are designed as turkey- nest structures that is, they only capture incidental rainfall. The depth and size of the pit is designed to allow for the drill cuttings, drilling fluids and incidental rain water that may occur during the drilling operation.

When operating continuously during the development phase, the volume of drilling fluid can be minimised by recycling on the next well or storing in separate tanks for future use.

The water based drilling fluids currently proposed for drilling shale wells, consist mainly of water that evaporates from the pit, and specific additives like clay stabilisers (potassium chloride), bentonite and barite and traces of biodegradable additives such as guar, biocides, cellulose and polymers.

After the drilling has been completed, in dry weather the water is evaporated and the drill cuttings back filled with the original material dug from the pit. After back-fill, the pit will contain a layer of rock drilled from the well, consisting of shale, sandstone and limestone covered with the native material from the area.

Alternative options for the management of drilled cuttings may also be considered. Cuttings dryers can be used to centrifuge out the fluid from the cuttings, the dry cuttings can then be collected in skips for beneficial re-use such as for road fill material or fill material in concrete, bricks or block manufacturing. Should organic constituents such as petroleum hydrocarbons be present, then the material may be land farmed (biodegradation) prior to beneficial re-use.

At this stage, it is assumed that drill cuttings will be collected in cuttings pits and backfilled after evaporation of fluids.

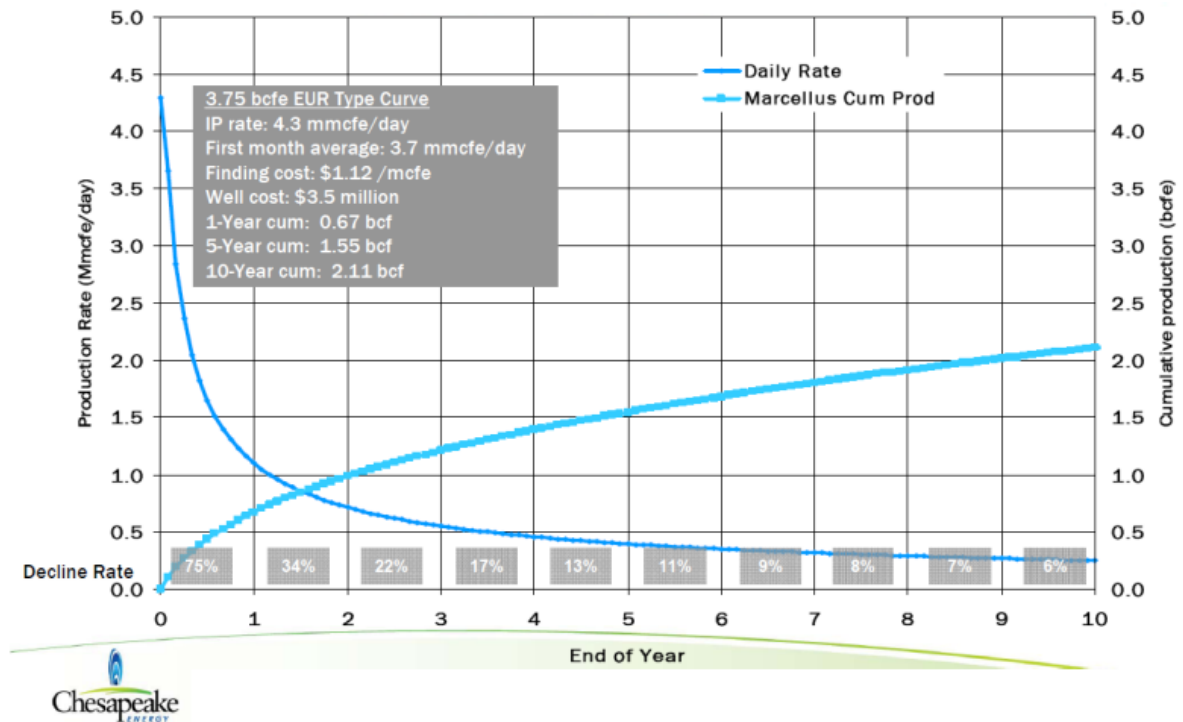
Regardless of whether localised management or a centralised options is adopted, management of solid waste will be supported by human health and environmental risk assessments as described in items 1 & 2 in this response and supported by Appendix A of this response. As detailed in Appendix B of Santos initial written submission (Santos Ltd, April 2017), these assessments are supported by a series of tools and models to assess the potential for leaching and migration through the unsaturated zone.

The outputs of these assessments will inform location selection, engineering design and other management controls and options. Examples of such outputs were provided in the Santos submission #280 (Santos Ltd, June 2017).

#### **5. Infrastructure requirements**

The experience of shale gas development in the United States provides a reference for gas development in the Northern Territory and Australia. It is important for the Scientific Panel to carefully compare and contrast the US experience to that of Australia. Production from shales in the US began in the 1820s, but as technology has developed there has been significant step-up in shale gas development from the late 1970's culminating in a large increase in activity from 2000 (King, 2010). Shale gas in Australia is relatively new, however the advantage is that Australia can learn from the US experience.

Shale gas plays can be characterised by well and field production decline over time and wells are drilled to meet the required production capacity. Shale gas well rates decline substantially early in life, with rate of decline reducing over time. Figure 1, taken from King (2010) illustrates the typical behaviour of a shale gas well in the Marcellus Shale.

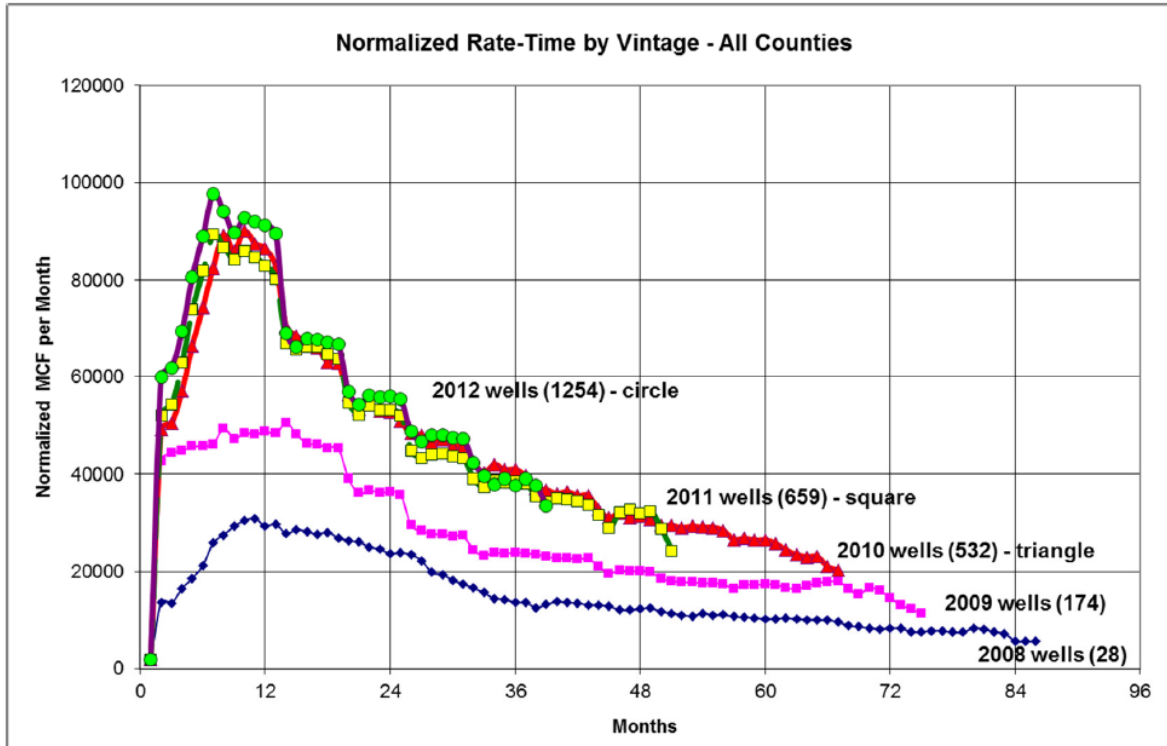


**Figure 1 – Model curve of a shale gas decline showing very large initial production rate in early time. The decline rate is 75% in the first year and decreases over time. (King, 2010)**

An ideal economic scenario for any resource development would focus on an area of optimum geology, where the economic return is maximised. In many basins in the US an extensive database from previous drilling assisted in identifying trends that were potentially prospective for shale plays. At this early exploration stage for the McArthur and Greater Beetaloo Basin, there is a very low level of understanding around the character and variables of the shales to understand their production behaviour. Optimisation of a shale gas development is not possible until many wells have been drilled and supported with years of production. The areal variability of the shale play in the Greater Beetaloo is also poorly understood at this time.

Santos provided in its initial written submission a graphical representation of the annual drilling rate for its conceptual development scenario in Figure 21 (Santos Ltd, April 2017). This figure shows the number of wells drilled hits a peak of 35 wells in Year 5 and stabilises to between 10 and 11 wells per annum from Year 8 to sustain a production plateau of 400 terajoules per day. In this case production plateau is maintained by a stable annual drilling rate.

If an optimal development (or core) area is identified through the better understanding of the geology or improvements in technology and engineering, the annual drilling rate to maintain plateau may decrease as observed in US production data. This is presented graphically for Marcellus Basin well production where decline profiles group by vintage (Figure 2) show a significant improvement in production performance through time as technology improved.



**Figure 2 - Marcellus Basin Normalised rate vs time by well vintage illustrating improvement from 2008 to 2010. Taken from Swindell (2015)**

The scale of development taken from submission the Energy Division of the NT Department of Primary Industry and Resources estimates 15,506 wells for the McArthur Basin and 6,250 wells for the Greater Beetaloo Basin will be drilled (Energy Division Department of Primary Industry and Resources Northern Territory, April 2017, p. 51). The assumptions and context around these well figures need to be highlighted. These figures are taken from the Australian Council of Learned Academies (ACOLA) Report titled 'Potential Geological Risks Associated with Shale Gas Production in Australia' (Australian Council of Learned Academies, 2013). This report provides a hypothetical estimate to the potential water needed to hydraulically fracture wells.

The calculation of wells in the ACOLA Report assumes 5% of each basin is developed ('fairways') over 25 years and wells have spacing of 800m. The accessed area of each well is therefore 0.64 km<sup>2</sup> (0.8km x 0.8km), which is around half the area provided by three petroleum companies which range from 1-1.33 km<sup>2</sup> accessed per well (e.g. 300 wells over 400km<sup>2</sup> area in the Santos case = 1.33km<sup>2</sup> accessed). This would then imply that only half as many wells would be required.

The total number of wells estimated by ACOLA is also highly sensitive to the area that provides the fairway. In the report a basic assumption of 5% of the basin area is taken to be the basin fairway. The Greater Beetaloo is still in the exploration phase so making an assessment as to the area of the basin that provides a developable area is difficult to predict.

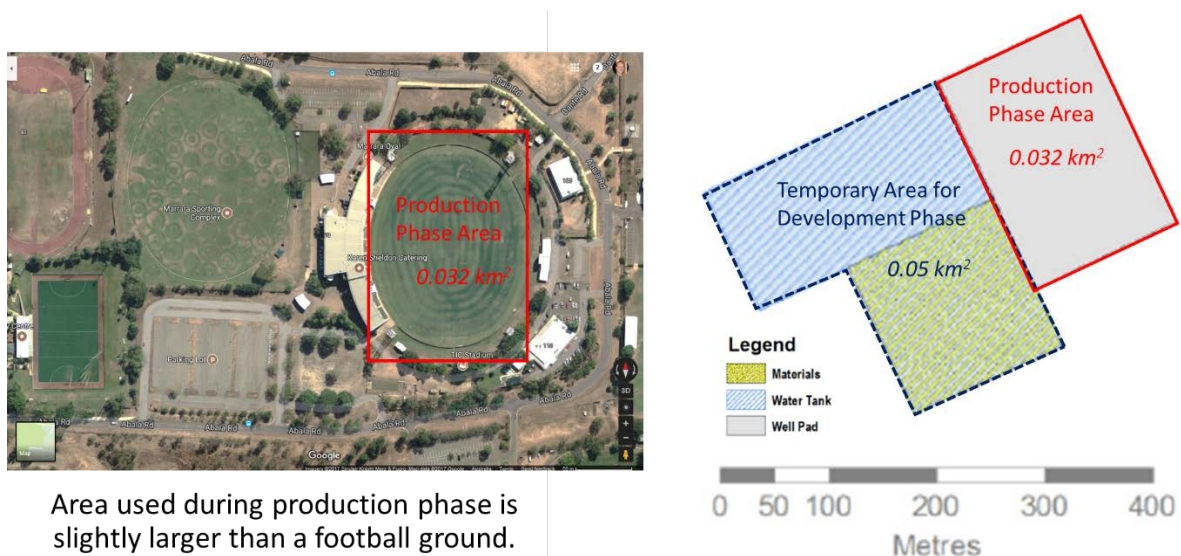
The estimates for accessed area per well pad provided in the submissions by the three petroleum companies (Origin, Santos and Pangaea) are relatively consistent in assessment of between 8.3 – 12.1 km<sup>2</sup> per well pad (e.g. 500km<sup>2</sup> for 50 well pads equates to 10 km<sup>2</sup> per well pad). The ACOLA Report (Australian Council of Learned Academies, 2013) did not consider the use of well pads for the drilling of horizontal wells. Using the data from Origin, Santos and Pangaea and assuming isotropic (equal) spacing of well pads, the centre of each pad would be approximately 2.9km – 3.5km from the centre of an adjacent well pad. This degree of well pad spacing is consistent with Scenario 2 described in the Scientific Panel's Information Request dated 25<sup>th</sup> July 2017. There is however, greater subsurface complexity that affects the development plan that must be considered prior to any regulatory limitation on well pad spacing.

The optimal development plan for a shale gas project will need to consider the anisotropic (non-equal) nature of the subsurface, particularly in regard to subsurface stress. Subsurface stresses will have impact on horizontal well and well pad design and placement. The optimal development plan for spacing and design of well pads given the current state of exploration is highly uncertain. Therefore both Scenarios 1 and 2, if implemented on an isotropic grid, could result in the sub-optimal recovery of hydrocarbons through an increase to well count, well pad count and the total surface area being used. Santos, therefore strongly supports an objective based regulatory framework for petroleum development where surface impact of a development project area is minimised.

Technology development will be the key driver to reducing overall surface infrastructure requirements. Based on US shale gas development studies, such as that provided by Swindell (2015), Expected Ultimate Recovery (EUR) per well has increased with improvement in subsurface understanding and drilling technology to drill and hydraulically fracture longer horizontal wells. This improvement in horizontal well length reduces the number of wells and well pads and reduces surface infrastructure including roads and pipelines.

Santos provided development scenarios in its initial written submission (Santos Ltd, April 2017). The area of land use for the well pad associated with the ten-well lease scenario is illustrated in Figure 3. During the Development Phase (or Initial phase as referred to in the Information Request of 25<sup>th</sup> July 2017) the area of well pads totals 0.082 km<sup>2</sup>. This includes area for the well pad for drilling and fracture stimulation activities (0.032 km<sup>2</sup>), as well as a temporary area for storage of water and materials (0.05 km<sup>2</sup>). During the Production Phase, the water and materials areas are revegetated and the remaining (operational) area is 0.032 km<sup>2</sup>, an area slightly larger than a football ground (Figure 3).

In Santos' initial written submission (Santos Ltd, April 2017) the Middle Velkerri Shale Prospect Area of Interest of 1800km<sup>2</sup> was quoted, however the potential development area within this AOI is 630km<sup>2</sup>. The total land use during the development phase, including well pads, flowlines, processing facilities and access roads is 9km<sup>2</sup>. This excludes the land requirements for trunklines, for the transport of processed gas to market, which are almost entirely outside the potential development area. Therefore the total proportion of land use during the construction phase within the development area is 1.4%, which is consistent with Table 8.1 of the Interim Report (NT Hydraulic Fracturing Inquiry Scientific Panel, July 2017). In the production phase, when temporary areas are rehabilitated, the total land use within the potential development area reduces to 7.3 km<sup>2</sup> (1.2% of the total development area).



Area used during production phase is slightly larger than a football ground.

**Figure 3 - Land use for 10-well pad scenario during Development and Production Phases and comparison to Darwin's TIO Stadium**

Infrastructure was described in Santos submission and further details are provided herein. To address the specific information request regarding pipeline infrastructure, please refer to Figure 22 in Santos' initial written submission (Santos Ltd, April 2017) and the table below.

Pipeline Type	Right of Way / clearing width (metres)	Total Length (kilometres)
8" Pipeline	20	67.3
10" Trunkline	30	90
Export Pipeline	40	TBD

To address the specific information request regarding road infrastructure, please refer to the table below.

Pipeline Type	Right of Way / clearing width (metres)	Total Length (kilometres)
Road for upstream development phase (suitable for trucks)	7.5	15
Access tracks associated with Export Pipeline (suitable for 4WD)	5	192

The Interim Report (NT Hydraulic Fracturing Inquiry Scientific Panel, July 2017) correctly points out that the scale of development is difficult to establish at the current time. In the lifecycle of exploration to production, the purpose of the appraisal phase is to assess the optimal development plan through the acquisition of information. In the case of shale gas appraisal, the key information will be on the spacing of wells to deliver optimal hydrocarbon recovery.

Following this phase of appraisal, a development plan will be defined that will provide the basis for the application for a production licence as required under Division 4, Section 45 of the NT Petroleum Act (2016).

## 6. Baseline data

Santos is in the early planning phase of exploration within the Greater Beetaloo Basin. A considerable amount of data is required from exploration and well testing prior to any commercial decisions on larger scale development and planning.

An indicative lifecycle of a potential development is shown in Figure 4. This includes key company decision points, namely the decision to continue exploration and well testing, through the appraisal phase followed by a commercial investment decision that leads to construction and operations.

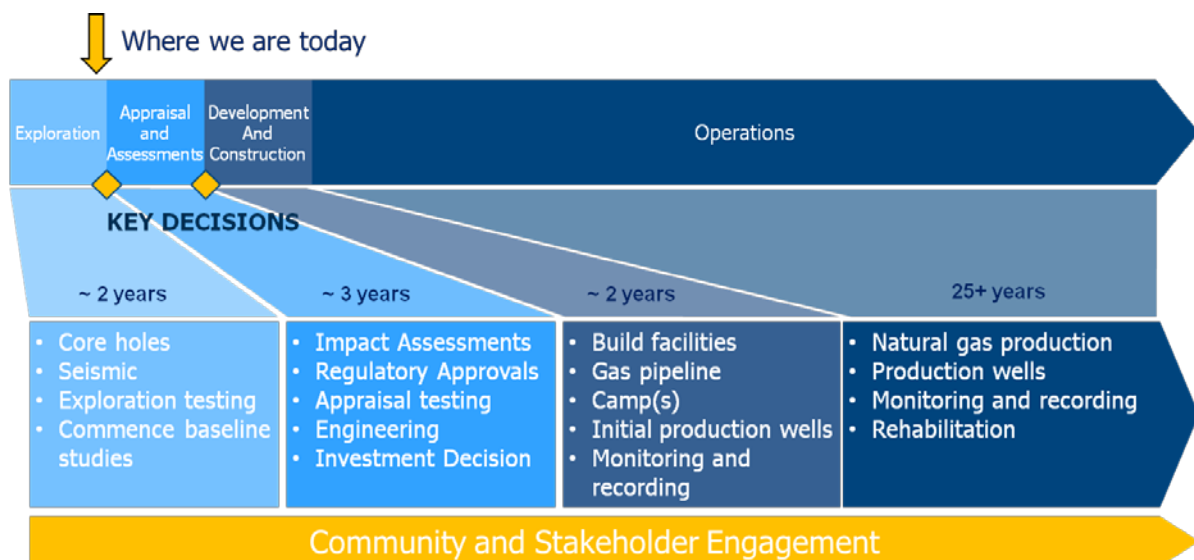


Figure 4 - High-level Exploration to Production lifecycle activities for a shale gas development project

During the exploration and well testing phase, baseline environmental data acquisition can commence. Typically, aspects that require multi-year or seasonal assessments are commenced earlier in the exploration phase. Other aspects may be undertaken later in the exploration phase, especially when additional subsurface, conceptual development or location specific data is available.

In addition, and again in parallel to exploration and well testing, baseline data will be used to inform impact assessments and to support future applications for regulatory approvals. The output of impact assessment and regulatory approvals is then used to inform development planning. This includes location selection, engineering design and management and mitigation controls.

A conceptual 5 year baseline program composition is provided in Figure 5. In addition, studies and impact assessments that utilise baseline information are also shown. The actual timing of studies will be dependent on the status of the moratorium and the outcomes of exploration testing and other commercial and regulatory considerations, or may be subject to seasonal or intermittent measurement, as determined by relative risk exposure.

<b>Baseline / Identification of Environmental Values</b>	<b>Year 1</b>	<b>Year 2</b>	<b>Year 3</b>	<b>Year 4</b>	<b>Year 5</b>
Passive Seismicity					
Groundwater characterisation					
Groundwater bores (existing)					
Surface Water					
Aquatic Ecology					
Terrestrial Ecology					
Air Quality / Near Surface Methane					
Fire Regime					
Landscape and visual amenity					
Traffic and Transport					
Land resources (soils)					
Cultural Heritage					
<b>Assessments / Planning</b>					
Waste characterisation (cuttings and flowback)					
Flood Assessment / Modelling					
Air Quality Modelling					
Noise Modelling					
Fire Regime / Natural hazards					
Waste Management					
Groundwater modelling (extraction)					
Chemical Risk Assessment					
Environmental Impact assessments					
Social Impact assessments					
Economic impact assessments					
<b>Community / Stakeholder Engagement</b>					

Figure 5 – Conceptual 5 year baseline data acquisition and studies program

### Groundwater Characterisation Baseline

As stated in the Interim Report (NT Hydraulic Fracturing Inquiry Scientific Panel, July 2017), Santos and Origin have engaged the CSIRO to quantify the groundwater baseline characteristics for the Greater Beetaloo Basin. This scope comprises:

- Characterisation of the groundwater environment
- Assessment of flow mechanisms on the Cambrian Limestone Aquifer

- Assessment of groundwater recharge and age for the Cambrian Limestone Aquifer

This groundwater study builds upon groundwater studies and monitoring and localised baselines studies already undertaken by Santos and Origin in 2014 and 2015.

### **Groundwater Bore Baseline**

Santos has also commissioned a groundwater bore baseline study. The purpose of this study is to locate and survey all existing groundwater bores within proximity of the prospective portion Santos' tenement in the Greater Beetaloo Basin. In summary, this scope comprises:

- Collation of registered bore records:
  - Bore location, age, construction, geophysical logs and records
  - Historical water level, quality and source aquifer
- Acquisition of bore coordinates and elevation
- Assessment of casing / headworks and bore infrastructure
- Determining feasibility / suitability for future monitoring
- Acquiring groundwater level and depth measurements
- Undertaking groundwater sampling

## **7. Traffic and Transport**

Santos is in the early planning phase of exploration; while highly preliminary conceptual development modelling and evaluation has been conducted, no associated operational activities are being undertaken. The use of rail to support supply line and logistics has been scoped at a very preliminary level. Santos will however consider the use of rail for transportation where technically and economically feasible, should development activities proceed.

Similarly, location of supply hubs, or local materials supply or traffic movements to support development have not been quantified nor potential impacts assessed beyond some highly preliminary scoping considerations. Road / traffic impact assessments for developments however are readily undertaken.

Road / traffic assessments typically comprise the following:

- Acquisition and characterisation baseline / background traffic and road use data
- Quantification of number and type of project vehicle movements – in consideration of starting location and timing of traffic movements.
- Assessment of safety risks
- Assessment of pavement impacts
- Assessment traffic impacts – trip duration, speed impairment and amenity
- Identification of potential upgrades – such as pavements, lane widening, overtaking lanes, turning lanes etc.
- Identification of impact management and maintenance

To assist the Scientific Inquiry in assessing potential risks, links are provided below to publically available road use and traffic impact assessments for other Santos developments.

- Santos GLNG Gas Field Development Project - [Traffic and transport assessment report](#)
- Santos Narrabri Gas Project – [Traffic Impact Assessment](#)

These assessments indicatively show the nature and quantum of vehicles, including duration of movements. It is important to note that the majority of vehicle movements is during the early construction phase or a development (years 1 to 3). This traffic is associated with the movement of modular compression, equipment and facilities as well and drilling and completion equipment and materials, and their corresponding workforce.

Following construction (years 4 to 25+), vehicle movements are reduced to operations and maintenance activities and their associated workforce as well as on-going well drilling and completion activities.

## 8. Health assessment

As per the Santos submission (Santos Ltd, April 2017), Santos supports the use of HHRAs. Santos provided a proposed scope of work for completing such HHRAs and included links and references to actual examples of assessment completed for other Santos projects.

The Interim Report notes a concern regarding the potential for volatile organic constituents to be present in produced waters. A range of techniques are available to assess the potential volatilization of volatile organic constituents (i.e. BTEX) within flow back or produced water associated as stored within tanks or open top water storage structures. The US EPA has developed a series of models for the assessment of volatile constituent losses from tanks and open structures and more simply, fundamental principles, for example use of Henry's Law Coefficients, can be used to assess the flux of volatile constituents from the aqueous phase into the vapour phase.

Where concentrations are low, simple mass partitioning (assuming 100% of the mass dissolved in water partitions into air) can be used to estimate vapour concentrations and assess potential risks. This simple assessment methodology has been provided at an assumed concentration of BTEX constituents (see Appendix B) and demonstrated the absence of risk. Similarly calculations using the California Department of Toxic Substances and Control and California Regional Water Quality Control Board empirical partitioning equations (used to assess risk to recreational receptors above pools or ponds) indicated orders of magnitude lower concentrations than that calculated from the conservative partitioning model.

Once operational, air monitoring can be conducted to verify and validate the modelling outputs, if required. However, given the conservative nature of the assessments, monitoring data will generally show concentrations considerably lower (and typically one order of magnitude lower) than that estimated by models.

## 9. Greenhouse gas emissions

Since exploration is a small, one-off activity and does not comprise production of natural gas (only data acquisition and testing), emissions monitoring is not justified. During exploration however, baseline assessment should be undertaken to support future development and production activities, should they occur.

Santos is supportive of acquiring baseline data prior to development. As per the Santos initial written submission (Santos Ltd, April 2017), Santos envisages that CSIRO scientists (or other suitable qualified experts) will undertake these assessment with our support.

The CSIRO led Gas Industry and Social Environmental Research Alliance (GISERA), have commenced a project to detect and measure methane seepage in the Surat Basin of Queensland. A range of technologies and techniques to detect and measure methane, to quantify methane sources and the fluxes across a region was reviewed by Day, et al., (2015) in Phase 1 of the Surat Basin project. An interim report describing the progress and results of the Surat Basin project has just been published by Etheridge, et al., (2017). Further information on baseline studies and technologies being applied in Queensland is available through the GISERA website: <https://giser.org.au/project/methane-seepage-in-the-surat-basin/>.

Santos again reiterates the importance of objective based regulation rather than prescriptive regulation. Accordingly, should development occur, then Santos proposes that any emissions reduction program be aligned with, or developed in consideration of the Queensland Government's Code of Practice for Leak Management, Detection and Reporting for Petroleum facilities (Department of Natural Resources and Mines - Queensland Gov't, 2017). This code of practices defines emission limits with justification for their adoption.

As examples, two technologies currently available for the implementation of leak detection and repair program include a FLIR GF 320 infrared camera to detect leaks and an Eagle portable gas monitor to quantify leaks. Additional details of these instruments are provided in Appendix C.

Santos however does not support the prescription or limitation of individual pieces of equipment or technologies. This is important as emissions monitoring is an area of significant development and innovation and the potential for future advancement must be considered.

#### **10. Further information**

The reference made in Santos' submission to the Exploration Environmental Plan – Beetaloo Basin Northern Territory is incorrectly referenced. We refer the Scientific Panel to the following correct reference:

Origin Energy (2016), 2016 Hydraulic Stimulation and Well Testing EP.

This document is publically available from the following link:

[https://dpir.nt.gov.au/\\_data/assets/pdf\\_file/0004/428575/Amungee-nw-1h-hydraulic-fracture-stimulation-and-well-testing-full.pdf](https://dpir.nt.gov.au/_data/assets/pdf_file/0004/428575/Amungee-nw-1h-hydraulic-fracture-stimulation-and-well-testing-full.pdf)

## B. Responses to questions on notice

### Relationship with Pastoralists

At the public hearing in August, the Scientific Panel was advised of Santos' position around the relationship with pastoralists. Santos encourages the Scientific Panel to consider the recently published report by the GasFields Commission Queensland entitled 'On New Ground: Lessons from the development of the world's first export coal seam gas industry.'

The Scientific Panel asked for a description of the types of compensation paid to landholders. In our Santos Cooper Basin operations the following items are the main areas covered by compensation;

- Loss of land i.e. wells, borrow pits and roads
- Pipeline construction & rehabilitation
- 3D and 2D seismic surveys
- Livestock management impacts
- Management time
- Extraordinary disturbances

Queensland's land access laws set out a process for negotiating conduct and compensation agreements (the 'statutory' process). Parties do not need to follow the statutory process and can follow their own negotiation process if they choose. However, it is negotiated, and agreement must be in place before a resource company can enter a landholder's land to conduct advanced activities.

To begin negotiations under the statutory process, the resource company may give the owner or occupier a negotiation notice. There is a minimum negotiation period of 20 business days, followed by a conference and alternative dispute resolution process of 20 business days. Following that, if agreement hasn't been reached, either the resource company or the landholder can apply to the Land Court for a determination.

The GasFields Commission Queensland report indicates that some landholders are intimidated by a process that leads to adjudication by the Land Court, whilst others feel empowered by it. Santos' position is always to try to reach agreement, and that's what we've been able to do, to date, without exception.

Since January 2011, Santos in Queensland has secured about 1650 agreements with about 650 landholders for long-term gas infrastructure alongside their farming businesses; including temporary activities such as exploration and pipeline easements, the number of agreements is more than 2000. This is the result of a proven approach based on respect and openness at all times. Santos engages early and extensively throughout the working relationship with landholders, as evidenced by the 15,000 discrete interactions with landholders that Santos has recorded since January 2011, when the GLNG project in Queensland was formally sanctioned. This includes group briefings, one-on-one meetings, phone calls, SMS messages and emails.

### Decommissioning, Well Abandonment and Legacy Liabilities

At the public hearing in August, we advised we would detail Santos' position regarding long term decommissioning and well abandonment risks.

All onshore petroleum and mineral resources in Australia are owned by the State (or Territory) in which they occur. By issuing a licence under the relevant resource legislation, the State has decided not to develop its gas resource but allow a non-government owned entity to explore and produce the resource for the benefit of the State. In return, the State receives a 10% royalty payment on production. While monetising that resource for the State, the licensee and operator is regulated and is required to comply with the terms of the licence, the guiding resource legislation, the secondary approvals that are activity specific, environmental and safety legislation as well as environmental policies and guidelines and industry codes and standards.

For petroleum operations, onshore operators provide financial security to the State for each step or phase of the resource recovery process. The security aligns with the environmental impact proposed by the operator, which is approved by the State. The security may take the form of a bank guarantee, bond or cash but in each case the amount required to be provided is determined by a specially developed calculator that correlates impact with the cost of rehabilitation should the State need to step in to rehabilitate.

In the event of an incident occurs that causes unauthorised environmental impact, the State may rely on certain powers it has under relevant legislation to penalise the operator and require that any impact is managed and rehabilitated at the cost of the operator.

Legacy environmental liabilities from historic resource activities have occurred where a regulator has allowed operators to relinquish licences without adequate rehabilitation and remediation of their impact. Various models are now being developed and implemented by State governments to manage these legacy impacts but all are being funded by current operators that, in most instances, have no relationship or connection to those legacy impacts. Examples of the models being used by government to fund legacy impacts include the WA Mining Rehabilitation Fund and the Queensland Government's proposal to amend the Financial Assurance model to facilitate the remediation of legacy environmental impacts by current operators. To expand on this point, the Queensland Government manages over 15,000 legacy sites as part of its Abandoned Mines Program. It is important to note that none of these 15,000 sites are the result of petroleum development including natural gas. This fact highlights the low risk of petroleum developments when compared to other extractive resources developments such as mining.

At the end of life of operations, an operator is required to remediate and rehabilitate the environment to a standard prescribed by the regulator. While some negligible alteration to the land will remain, for example, a plugged and abandoned well or a buried pipeline, the government is able to manage this risk by prescribing how decommissioning and abandonment is to occur. This is typically done by developing or adopting and implementing a code which is based on best practice well construction and design, and decommissioning / abandonment principles that ensures the outcome is safe, stable and non-polluting, and meets international standards, legislative requirements and stakeholder expectations.

It is important to note that unlike other resource development projects, petroleum developments do not leave legacy issues to manage into the future such as voids from open pits or long term subsidence issues from underground mining. It is Santos' position that by adopting existing best practice operational and decommissioning / abandonment practices and environmental remediation impacts, the NT Government stands to receive safe, stable and non-polluting assets that do not have an ongoing unacceptable risk of failure. It is at this point that the NT Government should rescind the petroleum licence and release the security to the operator.

Through appropriate management of the security provided to the NT Government and utilising NT Government developed or adopted best-practice engineering standards and abandonment and decommissioning practices, the NT Government should be satisfied that future risk of failure is negligible and there is adequate funding in place to rehabilitate minor unforeseen legacy impacts should they ever occur.

### **Social Licence to Operate**

Also, during the Santos appearance in August, there was the inference that the industry (Santos) did not have a social licence to operate (as evidenced by various industry moratoria across multiple Australian jurisdictions). Santos argues strongly that wherever we have activities, we work tirelessly to secure legitimacy, credibility and trust through early engagement with relevant stakeholders and by building relationships on a foundation of respect and openness. We aim to ensure that those stakeholders are fully informed of our proposed activities, and that we properly understand and manage their interests and concerns. However, where our social licence is under threat, as an industry, is those

areas where we do not have activities. It is here the industry must do more to engage and inform to gain broader public acceptance.

With regard to a social licence relating to our exploration activities in the Northern Territory, specifically, we have focussed our initial engagement through the early exploration phase on our local stakeholders (pastoralists, traditional owners, local communities, the regulators and the government). There is a clear inference from the Scientific Panel that we need a much broader acceptance with immediate effect. But it should be acknowledged that we cannot invite ourselves onto land, in particular native title and Aboriginal Land, where we have no activities, and this makes telling our story and sharing information about our industry more challenging. We are unlikely to change the perspective of the anti-fossil fuel lobby, who have been vocal participants in this local debate. However, we will, in the event of commercial success and a viable project, actively work to extend our social licence to a broader community. We commit to this.

## C. Concluding remarks

A recurring theme in the Interim Report is the requirement for a robust regulatory regime and Santos strongly supports this position.

The exploration and appraisal phase of a project is aimed at acquiring data and removing uncertainty. Santos is concerned that the regulatory response to this uncertainty, both in the subsurface and surface aspects of a prospective shale gas industry, combined with significant misinformation from a number of groups, will be a proscriptive management of risk rather than objective risk management. There are some areas where it makes sense to be prescriptive (e.g. well integrity code of practice) but proscriptive over-regulation could make any exploration, development and production opportunity in the McArthur and Greater Beetaloo Basins cost-prohibitive and stifle innovation. Innovation may include projects that harvest surface water for a sustainable water supply, capturing water that would otherwise be lost to evaporation from the large volume of precipitation in the wet season.

Sustainability is an integral part of Santos. Santos is committed to managing environmental impact, working in partnership with communities and focussing on the health, safety and wellbeing of all stakeholders across all of our business operations. Our operations in Queensland demonstrate our commitment to work and invest in the local communities in which we operate.

Uncertainty can only be addressed through the acquisition of new data to improve understanding of the areas of perceived risk. Through the exploration and appraisal phases in the Greater Beetaloo, Santos is committed to gathering the necessary data to assess environmental, social and economic impact. Data acquisition for subsurface data and surface baseline data can proceed in parallel, best supported by an objective based regulatory framework. The output from the baseline data and impact assessment studies can then be used to inform development planning and engineering design that ultimately provide the basis for applications for development and regulatory approvals.

The Northern Territory presents a unique environment and Santos appreciates the community sensitivity for disturbance over the short and long term. Santos has integrated systems and procedures to manage our activities responsibly and find new ways to further reduce our environmental impacts. Santos has processes for decommissioning, including the abandonment of wells, relinquishment of leases, demolition and removal of facilities and remediation of environment once the asset has come to the end of its operating life.

In summary, Santos has over 60 years of experience in exploring, developing and operating some of Australia's most important oil and gas resources, working alongside traditional owners, agriculture and other land users for everyone's benefit, and we will continue to operate safely and sustainably in the NT should the moratorium be lifted.

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Appendix A. Preliminary groundwater impact assessment for a potential spill of fluids or burial of drilling muds

15 August, 2017

Santos Ltd  
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Brisbane QLD 4000

EHS Support Pty Ltd  
PO Box 297  
Port Melbourne,  
Victoria, 3207

Please find attached, EHS Support Pty Ltd technical memorandum for the assessment of potential risk to groundwater associated with hypothetical shale gas activities in the Northern Territory.

Should you have any questions or require additional information, please feel free to contact me at

Sincerely,  
EHS Support Pty Ltd



Chris Smitt  
Principal Hydrogeologist



Nigel Goulding  
Chief Technical Officer

## 1. INTRODUCTION

The following memorandum provides an assessment of the potential for impacts on groundwater associated with hypothetical shale gas activities in the Northern Territory. For the purpose of this assessment two primary modes of potential impact were identified (releases to the land surface and the strategic burial of drilling mud) and technical assessment and modelling is provided in the sections below.

### 1.1. OBJECTIVE

The objective of this assessment is to define the potential extent of the area impacted by a release or “spill” of fluids. Specifically, the following questions were addressed:

1. Using three spill scenarios (1,000L; 100,000L and 1ML), determine the maximum pooled area in which a spill would inundate;
2. Over the size of the pooled area, determine infiltration rates to gain an understanding of vertical groundwater movement and associated travel times;
3. Evaluate the potential impacts on groundwater from burial/management of drilling muds at the well sites (where muds are blended and buried with soils); and.
4. Provide a description of what remedial actions could be implemented if impacts to groundwater were observed.

### 1.2. SCOPE OF WORK

To meet the objectives described above, the following work tasks were undertaken:

1. Establishment of applicable soil/aquifer characteristics within the area of interest based on a literature review and geological log from Santos exploration bore Tanumbirini-1;
2. Assessment of the water pooling area on a flat surface using the formulae proposed by Grimaz et al. (2007);
3. Assessment of the infiltration capacity of surface soils and ponding time using the analytical Green and Ampt infiltration equation;
4. Evaluation of potential migration and attenuation of common drilling fluid constituents if materials were buried below surface as part of the management of drilling muds; and
5. Discuss the remedial technologies that would be employed if impacts to groundwater occurred due to surficial releases and associated infiltration.

## 2. OVERVIEW OF HYDROGEOLOGY/GEOLOGY

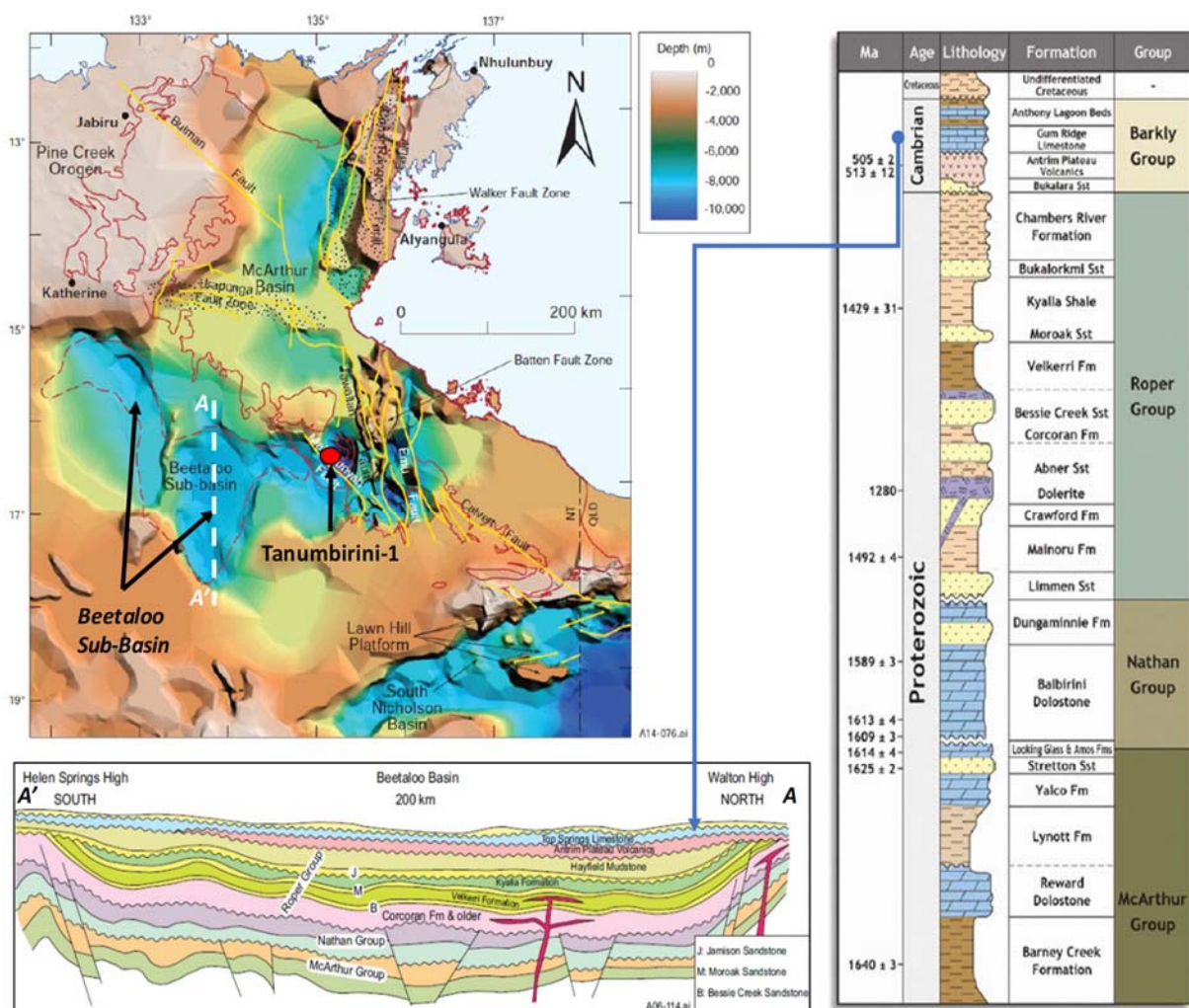
The area of interest where this assessment will occur is within Santos exploration areas of the Beetaloo Sub-Basin (refer **Figure 1**).

The hydrogeological unit of interest is the Cambrian Limestone Aquifer (CLA) defined as the Top Springs Limestone (also commonly referred to as the Tindal Limestone or Gum Ridge Formation) depending on which part of the basin you are in. The unit comprises massive and commonly dolomitised (and often fractured and karstic) limestone beds with minor siliclastic mudstone. Results from Santos exploration bore Tanumbirini-1 (refer **Figure 1** for location and **Figure 2** for stratigraphy), reveal that the Top Springs Limestone can be found at a depth of 52mbgl with a thickness of 150m. For detailed broad scale geological interpretation of the regions geology refer to Fulton, 2009; Kruse et al, 2013.

In the vicinity of exploration bore, Tanumbirini-1, the CLA is confined by Cretaceous siltstones mudstones. The permeability of the CLA is highly dependent on the development of dissolution and fracture features

(Fulton and Knapton, 2015). A review of water bores that intersect cavities or record circulation loss during drilling suggests that the karst development is widespread across the Beetaloo Sub-Basin and that aquifer permeability is generally not spatially correlated. Within the broader basin over 415 operational and abandoned water bores screen the CLA, with bore depths ranging from 34 – 221 m (average 105 m) (*ibid*).

Fulton and Knapton, (2015), reported airlift yields range from 0.3 – 20 l/s (average 3.5 l/s), with the standing water level (SWL) in the Gum Ridge Formation ranging from 23 to 155 metres below ground level (mBGL). Water levels along the Carpentaria Highway on Amungee Mungee and Tanumbirini stations are reported to be (125 mBGL) (*ibid*). Results from 21 pumping tests undertaken by WRD report a Transmissivity (T) range of 3 – 3377 m<sup>2</sup>/d. The lowest T values (<50 m<sup>2</sup>/d) occur in the northwest of the basin where the CLA has limited saturated thickness and aquifer development is restricted to the unconformity with the underlying Antrim Plateau Volcanics (Yin Foo, 2002).



**Figure 1. Location of the Beetaloo Basin along with Santos assets, stratigraphy and a north-south section. Reference used to create Figure 1: Silverman et al. (2008) [geological cross-section], and Close et al: 2016 [SEEBASE™ depth-to-basin image & stratigraphic column]**

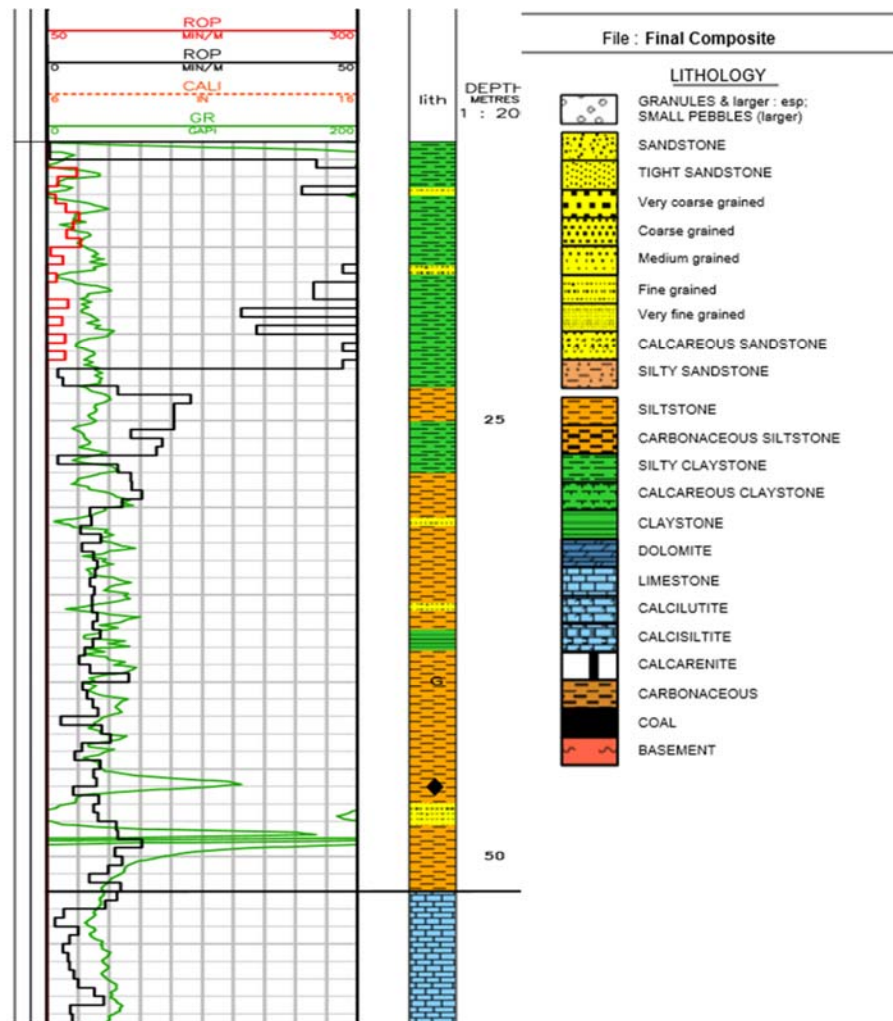


Figure 2 Shallow Lithology from Santos well "Tanumbirini-1"

### 3. ANALYTICAL ASSESSMENT (METHODOLOGY)

#### 3.1. WATER POOLING ON FLAT SURFACES

For instantaneous releases on flat surfaces, the formulae (**Equation 1**) proposed by Grimaz et al. (2007) was used to estimate the area of the pool of liquid on flat ground. This method is used for oil spills but can allow for water by varying the liquid properties (primarily viscosity and permeability).

$$A_{pool} \cong 2.3782 \frac{Q^{4/5}}{(k_i k_r)^{1/5}} \quad (1)$$

Where:  $A_{pool}$  is the area of the pool of liquid on the surface [ $m^2$ ];  $q$  is the flow rate of release [ $m^3 s^{-1}$ ];  $Q$  is the total amount of liquid released [ $m^3$ ];  $\vartheta$  is the kinematic viscosity of the liquid [ $m^2 s^{-1}$ ];  $g$  is the gravitational acceleration [ $ms^{-2}$ ];  $k_i$  is the intrinsic permeability of soil [ $m^2$ ];  $k_r$  is the relative permeability of the liquid [-]

### 3.2. TIME FOR WATER TO REMAIN ON SURFACE

Equation (2) taken from Grimaz et al. (2007), can be used to estimate the duration of the pool on the surface  $t_{ep}$ . and can be considered equal to the time of complete infiltration of the fluid into the porous medium. The method (Equation 2) is based on Darcy's Law and considers a theoretical depth of water pool and the seepage velocity at complete saturation:

$$t_{ep} = \frac{h_{tp}}{v_{p,s}} = \frac{V_{spill}}{A_{pool}} \frac{\theta}{K_w K} \frac{\phi_{fluid}}{\phi_{water}} \quad (2)$$

where;  $t_{ep}$  is the estimated duration of the liquid pool on the surface [s];  $h_{tp}$  is the depth of the liquid pool [m];  $v_{p,s}$  is the velocity of penetration of the liquid into soil in saturated conditions [ms<sup>-1</sup>];  $V_{spill}$  is the volume of the liquid spilt [m<sup>3</sup>];  $K$  is the soil hydraulic conductivity [ms<sup>-1</sup>];  $\theta$  is the porosity of soil [-],  $\phi$  the kinematic viscosity [m<sup>2</sup> s<sup>-1</sup>]; and  $K_w$  is the relative permeability of the liquid [-].

Then, in order to estimate the percentage of fluid evaporated from the pool in  $t_{ep}$  the daily pan evaporation rate can be applied. (Fulton and Knaption, 2015) report pan evaporation ranges between 5 and 11 mm/d (average about 7-8 mm/d) in the region.

### 3.3. INFILTRATION INTO UNSATURATED ZONE

The spilt fluid will not only tend to spread out over the surface of the soil and evaporate, but will also penetrate into the ground (unless it is impermeable). Infiltration to the unsaturated zone, and in particular infiltration capacity and time for ponding to occur can be determined using the infiltration equation of Green and Ampt (1911).

The infiltration rate actually experienced in a given soil depends on the amount and distribution of soil moisture and on the availability of water at the surface with a maximum rate at which the soil in a given condition can absorb water. This upper limit is called the infiltration capacity,  $f_c$  and is a limitation on the rate at which water can move into the ground. If surface water input is less than infiltration capacity, the infiltration rate will be equal to the surface water input rate ( $w$ ). If irrigation (analogous to a release) intensity exceeds the ability of the soil to absorb moisture, infiltration occurs at the infiltration capacity rate until the soil is saturated and ponding and associated runoff occurs. Infiltration capacity declines over time until a steady state is reached.

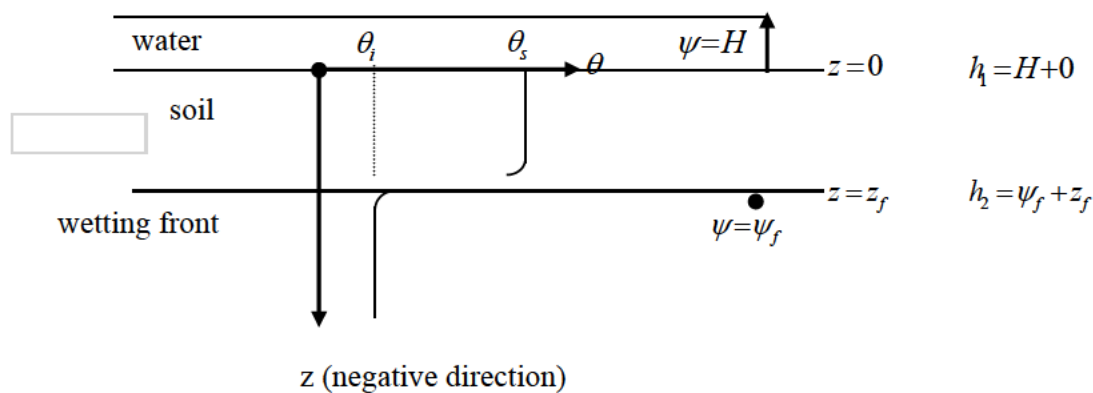
Several processes combine to reduce the infiltration capacity. The filling of fine pores with water reduces capillary forces drawing water into pores reducing the storage potential of the soil. Clay swells as it becomes wetter and the size of pores is reduced. Coarse-textured soils such as sands have large pores down which water can easily drain, while the fine pores in clays retard drainage. If the soil particles are held together in aggregates by organic matter or a small amount of clay, the soil will have a loose, friable structure that will allow rapid infiltration and drainage.

The calculation of infiltration at a point combines the physical conservation of mass (water) principle expressed through the continuity equation with quantification of unsaturated flow through soils, expressed by Darcy's equation. The downward hydraulic gradient inducing infiltration is from a combination of the effect of gravity, quantified by the elevation head, and capillary surface tension forces, quantified by the pressure head (negative due to suction) being lower at depth due to lower moisture content. If the water input rate is greater than the saturated hydraulic conductivity (i.e.  $w > K_{sat}$ ), at some point in time the water content at the surface will reach saturation. At this time, the infiltration capacity drops below the surface

water input rate and runoff is generated. This time is referred to as the ponding time. After ponding occurs, water continues to infiltrate and a zone of saturation begins to propagate downward into the soil as the wetting front. After ponding, the infiltration rate is less than the water input rate and the excess water accumulates at the surface and becomes infiltration excess runoff. As time progresses and the depth of the zone of saturation increases, the contribution of the suction head to the gradient inducing infiltration is reduced, so infiltration capacity is reduced. Once the soil profile is completely saturated no further water can infiltrate.

### 3.3.1. GREEN AND AMPT INFILTRATION MODEL

The Green – Ampt (1911) model (Equation 3) is an approximation of the infiltration process described above and was utilised to assess infiltration capacity and time for ponding for various soils.



$$q = -K_s \frac{dh}{dz} = -K_s \frac{h_2 - h_1}{z_2 - z_1} = -K_s \frac{(\psi_f + z_f) - (H + 0)}{z_f - 0} = -K_s \frac{\psi_f + z_f - H}{z_f} \quad (3)$$

Where:  $H$  = the depth of ponding, cm,  $K_s$  = saturated hydraulic conductivity (cm/s),  $q$  = flux at the surface (cm/h) and is negative,  $f$  = suction at wetting front (negative pressure head),  $\theta_i$  = initial moisture content (dimensionless) and  $\theta_s$  = saturated moisture content (dimensionless).

The following assumptions are implicit in the Green and Ampt equation:

1. As water infiltrates, the wetting front advances at the same rate with depth, which produces a well-defined wetting front;
2. The volumetric water content remains constant above and below the wetting front as it advances; and
3. The soil-water suction immediately below the wetting front remains constant with both time and location as the wetting front advances.

As described in the results discussion (Section 4), the travel times for surface releases to reach groundwater are very long and therefore the potential for impacts to groundwater are low

### 3.4. ASSESSMENT OF LEACHING TO GROUNDWATER

The potential risk associated with the leaching of constituents from drilling muds over time was evaluated using the VLEACH model. This model determines vertical contaminant transport from materials placed in the unsaturated zone and its response to recharge over time. VLEACH was developed by the United States Geological Service for the United States Environmental Protection Agency (USEPA) and is an industry recognised model. This model allows for very conservative modelling of organic constituents moving through the unsaturated zone towards groundwater systems.

## 4. ANALYTICAL ASSESSMENT (RESULTS)

### 4.1. WATER POOLING ON FLAT SURFACES

The “pooled area” for the instantaneous releases of fluid was determined for the following release volumes:

- 1000L (1m<sup>3</sup>);
- 100,000 L (100m<sup>3</sup>); and
- 1,000,000 L (1000m<sup>3</sup>).

Shallow lithology obtained from exploration well Tanumbirini-1 (Figure 2), summarized in Table 1: reveals two main hydrogeological units; a relatively impermeable siltstone/claystone followed by limestone which has been reported to have highly variable hydrogeological properties (see Section 2).

As a result, and for the purposes of assessing surface water pooling, soil properties reflective of a clay have been applied to Equation 1. These are presented in Table 2. Therefore using, Equation 1, and the information presented in Table 2, the theoretical area of pooled water over Clay is presented in Table 3. For the purpose of providing comparison, a more permeable sandier soils is also presented.

**Table 1 Shallow lithology at Tanumbirini-1**

Depth From (mbgl)	Depth to (mbgl)	Lithology (Figure 2)	Hydrogeological Unit
0	20	Silty Claystone	Anthony Lagoon Beds?
20	52	Siltstone	
52		Limestone	Tops Springs Formation / Tindal - Gum Ridge Limestone

**Table 2 Modelling Input Parameters**

Parameter	Clay / Claystone / Siltstone	Permeable Sandstone / Limestone	Literature Source
Porosity	0.482*	0.4**	* Dingman, 1994 **Knapton 2009
Saturated Hydraulic Conductivity (Ksat) (cm/s)	0.0007	0.038**	**Knapton 2006 (based on relevant aquifer transmissivity and thickness)
Air-Entry Tension (cm)	40.5	12.1	Dingman, 1994
Saturated Tension (cm)	30.78	9.2	Dingman, 1994
Intrinsic permeability (m <sup>2</sup> )	1x10 <sup>-13</sup>	1x10 <sup>-8</sup>	Dingman, 1994

**Table 3 Model Results - Pooled Water Area**

	Volume Released (m3)	Area (m2)	Radius (m)
Clay / Claystone / Siltstone	1	947	17
	100,000	37691	110
	1,000,000	237820	275
Permeable Sandstone / Limestone	1	95	6
	100,000	3770	35
	1,000,000	23782	87

## 4.2. TIME FOR WATER TO REMAIN ON SURFACE

Using **Equation 2**, the results presented in **Table 3** and assuming the kinematic viscosity of the fluid is  $1 \times 10^{-6} \text{ m}^2/\text{s}$  and a Kh:Kv of 1:100, the time it will take for a 5cm deep pool over the 1ML spill area is ~6 days. For a smaller spill of 1,000L, infiltration time is less than 1 day (~2 hours).

### 4.2.1. GREEN AND AMPT INFILTRATION MODEL

The results of the Green and Ampt Infiltration equation are present in **Table 4**.

As there are two distinct hydrogeological units (siltstone to a depth of ~50m followed by karstic limestone). The time it takes for water to infiltrate 50m through the siltstone (to the top of the limestone) and the time to migrate through an additional 50 m (to a depth of 100 m) and 150 m of limestone (to a depth of 200m) has been calculated to enable evaluation of travel times based on the potential variable depth to groundwater within the limestone across the field.

Previous studies have indicated the CLA (limestone) can be highly fractured and karstic (refer **Section 2**), a sensitivity analysis assuming k is 100 times greater in this limestone has been undertaken. This has also been applied to the overlying siltstone.

The results indicate that any spill will take ~690 years to move through the initial 50m before rapidly moving through the more permeable limestone. To provide a comparative / conservative case where permeability of the sub surface is increased by 2 orders of magnitude, travel times to the top of the CLA reduce to ~7 years. Furthermore, under each spill scenario, the release rate exceeds the infiltration capacity of the subsurface, therefore as the area increases with each spill (refer **Table 3**), the driving force on the wetting front remains the same and is constrained by the permeability.

It should be noted that the assessment is highly conservative. Due to CLA aquifer anisotropy, bulk basin scale hydraulic conductivities are likely to be lower than those modelled. Further the higher hydraulic conductivities used in the sensitivity analysis for the siltstone are considered improbable based on literature information for this unit.

**Table 4 Green and Ampt Modelling Results**

	Time for wetting front to reach 50 mbgs (days)	Time for wetting front to reach 100 mbgs (days)	Time for wetting front to reach 200 mbgs (days)
Siltstone (K = 0.000007 cm/s; 0.01 m/d)			
Run 1	252267 (690 yrs)		
Run 2	252267 (690 yrs)	-	-
Run 3	252267 (690 yrs)		
Karstic Limestone (K = 0.005 cm/s; 4.3 m/d)			
Run 1	-	252271 (~690 yrs)	252275 (~690 yrs)
Run 2		252271 (~690 yrs)	252275 (~690 yrs)
Run 3		252271 (~690 yrs)	252275 (~690 yrs)

Run 1 = 1,000L spill;  
 Run 2 = 100,000L spill  
 Run 3 = 1,000,000 L spill

**Table 5 Green and Ampt Modelling Results (Sensitivity Analysis K = 100x Increase)**

	Time for wetting front to reach 50 mbgs (days)	Time for wetting front to reach 100 mbgs (days)	Time for wetting front to reach 200 mbgs (days)
Clay (K = 0.0007 cm/s; 0.6 m/d)			
Run 1	2522 (~7 yrs)	-	-
Run 2	2522 (~7 yrs)	-	-
Run 3	2522 (~7 yrs)	-	-
Karstic Limestone (K = 0.5 cm/s; 432 m/d)			
Run 1	-	2523 (~7 yrs)	2523 (~7 yrs)
Run 2	-	2523 (~7 yrs)	2523 (~7 yrs)
Run 3	-	2523 (~7 yrs)	2523 (~7 yrs)

Run 1 = 1,000L spill;  
 Run 2 = 100,000L spill  
 Run 3 = 1,000,000 L spill

#### 4.3. ASSESSMENT OF BURIAL/MANAGEMENT OF DRILLING MUDS

Based on the chemistry for example drilling muds (refer **Table 6**), leaching assessments were conducted on a scenario where drilling muds were stabilized (by blending with native soils to manage residual moisture) and compacted and placed below ground surface. The blend of drilling muds and cuttings produces a low permeability material with a high cation exchange capacity (CEC). This typically results in metals and metalloids being strongly bound within the muds and the mud and cuttings exhibiting very low permeabilities. Drilling muds by design typically exhibit permeabilities between  $1 \times 10^{-8}$  m/s and  $1 \times 10^{-10}$  m/s.

For the purposes of this assessment it has been assumed that the hydraulic conductivity of the blended materials it is assumed that the combined material will have a hydraulic conductivity no lower than  $1 \times 10^{-6}$  m/s. Typically the drilling muds are buried 1-2 m below ground surface to ensure the materials are below the rooting depth of crops and plants and the area graded to prevent ponding and preferential infiltration of water.

For the purposes of the modelling, only water soluble organic compounds were assessed (insoluble organic compounds like starch and polymers would have no mobility in the formation) and Sodium from Sodium Chloride was evaluated conservatively by assuming no attenuation (although cation exchange with the dominant calcium ions would impede vertical migration of sodium and potassium). Furthermore, as the lithology is likely to be rich in clay, a sensitivity analysis was undertaken on Sodium to increase its “retardation factor” or Distribution Coefficient by 2 orders of magnitude.

The VLEACH model results for each chemical constituent (**BOLDED**, in **Table 6**) are presented in **Figure 3**.

The results indicate that the modelled constituents take a very long time to move through the subsurface and contain immeasurable concentrations once below several meters depth even before dilution and without taking into account biodegradation.

**Table 6                  Drilling Mud Chemistry (BOLD values indicate those subject to VLEACH Modelling)**

<b>Chemical Name</b>	<b>Concentration in Drilling Mud Solids (mg/kg)</b>
Ethylene oxide/propylene oxide copolymer	24
Polyalkylene	22260
Polypropylene glycol	48
Silicic acid, potassium salt	22200
<b>Sodium Chloride</b>	<b>45600</b>
Sodium polyacrylate	1092
Copolymer of acrylamide and sodium acrylate	702
<b>Glutaraldehyde</b>	<b>300</b>
Glyoxal	31

<b>Chemical Name</b>	<b>Concentration in Drilling Mud Solids (mg/kg)</b>
<b>Methanol</b>	<b>3</b>
Potassium Chloride	41520
Sodium Carbonate	78
Sodium carboxymethyl cellulose	3117
Sodium Hydroxide	300
Starch	3058
Xanthan Gum	3060
Methylisothiocyanate (MITC)	30

**Table 7      Constituent Properties**

	<b>Concentration in drilling (mg/L)</b>	<b>Organic Distribution Coefficient (ml/g)</b>	<b>Henry's Law Constant (atm-m<sup>3</sup>/mol)</b>	<b>Water Solubility (mg/L)</b>	<b>Free Air Diffusion Coefficient (m<sup>2</sup>/day)</b>	<b>Source</b>
Methanol	3000	0.014	0.0001937	1000000	1.296	GSI Chemical Properties Database ( <a href="http://www.gsi-net.com/en/publications/gsi-chemical-database.html">http://www.gsi-net.com/en/publications/gsi-chemical-database.html</a> )
Glutaraldehyde	300,000	0.07	0.0000108	85500000	0.096	GSI Chemical Properties Database ( <a href="http://www.gsi-net.com/en/publications/gsi-chemical-database.html">http://www.gsi-net.com/en/publications/gsi-chemical-database.html</a> )
Sodium Chloride	29,900,000** (converted from <b>Table 6</b> )	1930* / 19.3	1E-20	360000**	0	*Bencala (1985) ** <a href="http://srdata.nist.gov/solubility/index.aspx">http://srdata.nist.gov/solubility/index.aspx</a>

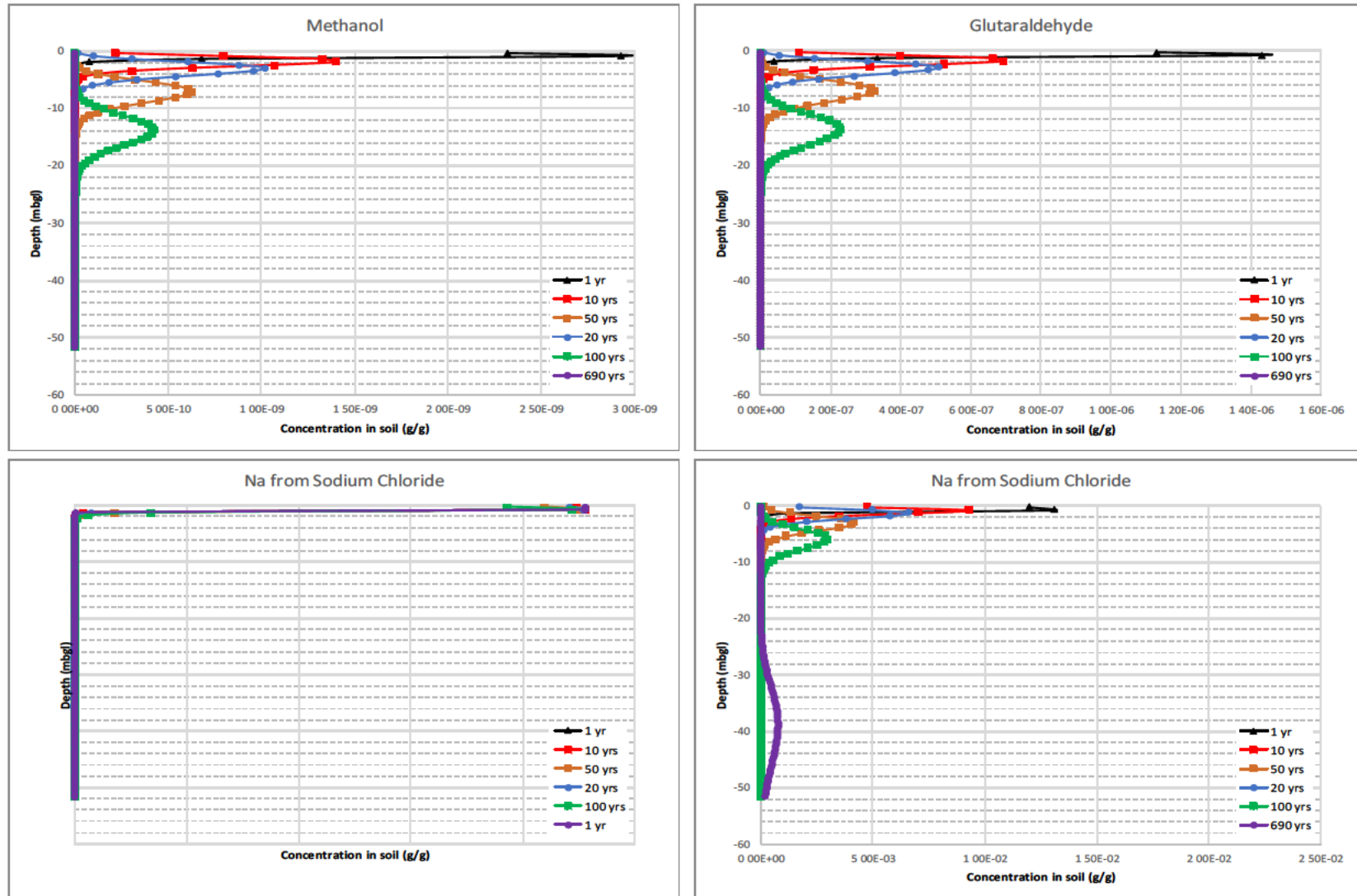


Figure 3 VLEACH Results. [Note: Bottom left Na assumes a Distribution Coefficient 2 orders of magnitude higher than bottom right results].

## 5. REMEDIAL OPTIONS OF GROUNDWATER

Based on the modelling provided above and considering the retardation processes in the formation, only water soluble constituents have the potential to migrate to and impact on groundwater. As demonstrated in the assessment above, the potential for impact on groundwater is considered limited and travel times are sufficient slow (>500 yrs to travel 50m) that management/monitoring and remediation (if required) could be implemented.

In the context of this hydrogeologic system, which has deep and prolific aquifer systems and considering the constituents of potential concern are soluble compounds, groundwater extraction and water treatment provides the best remedial option (if needed).

Based on the drilling fluid constituents that may impact on groundwater a range of treatment options are available including open air storage to facilitate natural dissociation, photodegradation, etc, biological treatment for alcohols, glycols, glutaraldehyde (they biodegrade rapidly in the presence of oxygen), activated carbon absorption (non-polar organics) and ion exchange. All of these technologies are readily available and could be quickly implemented.

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## Appendix B. Hypothetical Vapour Health Assessment

## Focus of Analysis

This document seeks to understand and evaluate potential risks based on the potential that benzene may be present in the shale gas production water. It should be noted that in addition to benzene, other volatile organic compounds may be present including toluene, ethylbenzene and xylene however; these constituents are less toxic than benzene and therefore pose lesser risks.

This assessment has hypothetically but conservatively estimated benzene feed loadings in produced water. It is likely that the concentrations of benzene in the water will be lower than estimated and potentially not present.

A source water characterisation and mass balance calculation were performed to estimate a hypothetical benzene feed concentration entering into a storage tank or pond. This output was used as the basis for a Human Health and Environmental Screening Assessment to determine if there was a potential unacceptable risk to operators or other human receptors such as trespassers from the inhalation of vapour.

## Methodology

To support an assessment of potential risks associated with the revised water management strategy, a quantitative screening level risk assessment was completed against applicable criteria. This risk assessment involved the following key assessment steps which are summarised below and discussed in further detail in the following sections:

Step 1 – Identification of Constituents of Potential Concern

Step 2 – Development of Conceptual Exposure Model

Step 3 – Calculation of Exposure Point Concentrations

Step 4 - Identification of Relevant and Applicable Criteria

Step 5 – Screening Assessment

### Step 1: Identification of Constituents of Potential Concern.

The primary constituent of concern is benzene with an adopted hypothetical concentration of 50 ppb (for the purpose of undertaking this assessment).

### Step 2: Development of Conceptual Exposure Model

In order to assess potential exposures, the physiochemical properties of benzene must be considered. Select attributes on benzene are discussed below:

- Henry's Law constant for benzene is  $5.5 \times 10^{-3} \text{ atm} - \text{m}^3/\text{mole}$  at 25C indicating that benzene partitions readily to the atmosphere. .
- Log  $K_{ow}$  (octanol – water partition coefficient) value for benzene indicates that it will preferentially bind to organic matter (carbon in soils and biomass) limiting its movement in environment.
- Benzene undergoes indirect photolysis in open sunlight especially in the presence of photosensitisers like humic and fulvic acids which are likely present in produced waters. Photodegradation half-lives are estimated at 16.9 days with degradation occurring within the open top storage tanks (residence time of up to 11 days)
- Benzene is easily degraded in water in aerobic conditions. Biodegradation half-lives of 16 days have been reported under aerobic conditions and 120 weeks under anaerobic conditions. Degradation within the storage tank will likely be limited (due to anaerobic conditions).

Based on the physiochemical properties of benzene described above, likely modes of transport within the environment from the storage of produced water is limited to ambient air, with volatilization into the atmosphere from the storage tank and from the application of water for beneficial uses. Potential exposure points for ambient air include the spatial area above the tank or pond. Potential exposure routes include inhalation by workers and trespassers.

The assessment is conservative as the potentially complete exposure pathways are limited by a combination of management and operational controls. These controls include:

- Occupational controls to prevent entry into confined spaces (including the water storage tank)
- Occupational exposure controls including use of PPE (for example gloves) to prevent incidental dermal contact with produced water.
- Occupational exposure monitoring and testing to assess long term exposures to workers.
- Signage and security to prevent entry of trespassers into irrigation areas

### Step 3 – Calculation of Exposure Point Concentrations

#### Exposure Point Concentrations in Air

As described above operational controls limit potential exposures within the tank or pond area and potential exposures are limited to fugitive emissions. To be conservative a work area (and area in which a worker may be present in an average work day has been assumed to be 30 ha. The following key assumptions were used in the calculation to estimate the theoretical concentration of benzene in an air volume 1m high above the 30ha exposure area during the flow of production water to the tank or pond:

1. 100% benzene volatilisation in produced water each day (this is highly conservative as the Henry Law and surface area of the water/air contact will constrain benzene flux into the air)
2. Application of 12g benzene per day (based on producing 240KL per day of water to a tank or pond at 50 µg/L)
3. The vapours are dispersed throughout entire workers exposure area (assumed to be a 30 ha worker exposure area in which the benzene vapours are dispersed)
4. No photodegradation or biodegradation of benzene occurred in the storage tank or pond
5. No air exchanges within the area and outside area (air movement is likely to decrease concentrations 1 order of magnitude)

The calculation output indicated a benzene concentration of **0.44 mg/m<sup>3</sup>**.

As an alternative methodology the Department of Toxic Substances and Control (DTSC) in California developed a methodology to assess the volatilization of benzene from an open pond or pool. In this calculation, the air concentration of constituents of potential concern above the pool or pond was calculated to evaluate swimmer inhalation of VOCs. Given the assumed half-life of 3.5 days for VOC volatilization from a pond or pool water, and considering the Henry's Law partition coefficients for a wide range of VOCs, the average emission rate of VOCs from a pool containing 1 ug/L of VOC is calculated as 0.0127 ug/s with an adjusted concentration of 0.000977 ug/m<sup>3</sup> (considering temperature and air movement) above the water body.

Based on a 50 ug/L benzene and the assumptions contained within the model (air flow of 4 m/s etc) the calculated concentration is **0.05 ug/m<sup>3</sup>** or **0.00005 mg/m<sup>3</sup>** which is orders of magnitude below the conservative calculation methodology provided above.

### Step 4 - Identification of Relevant and Applicable Criteria for Air

To assess the potential risks to workers from occupational exposures, the applicable OSHA standards were selected for screening. The Time Weight Average (TWA) exposure limit for benzene is 3.2 mg/M<sup>3</sup>

or 1 ppm as stated in “*Exposure Standards for Atmospheric Contaminants in the Occupational Environment*’ May 1995 and gazetted updates. A TWA limit applies to an exposed worker over an eight-hour workday, five days a week, over an entire working life. This limit is also endorsed by USEPA and the World Health Organisation (WHO).

The TWA benzene exposure limit has been reduced to **0.5 ppm** or **1.6 mg/m<sup>3</sup>** using the ‘Brief and Scala Method’ in order to compensate for the 12 hour work operator shifts . Other potentially applicable regulatory standards are summarised in Figure 1 below.

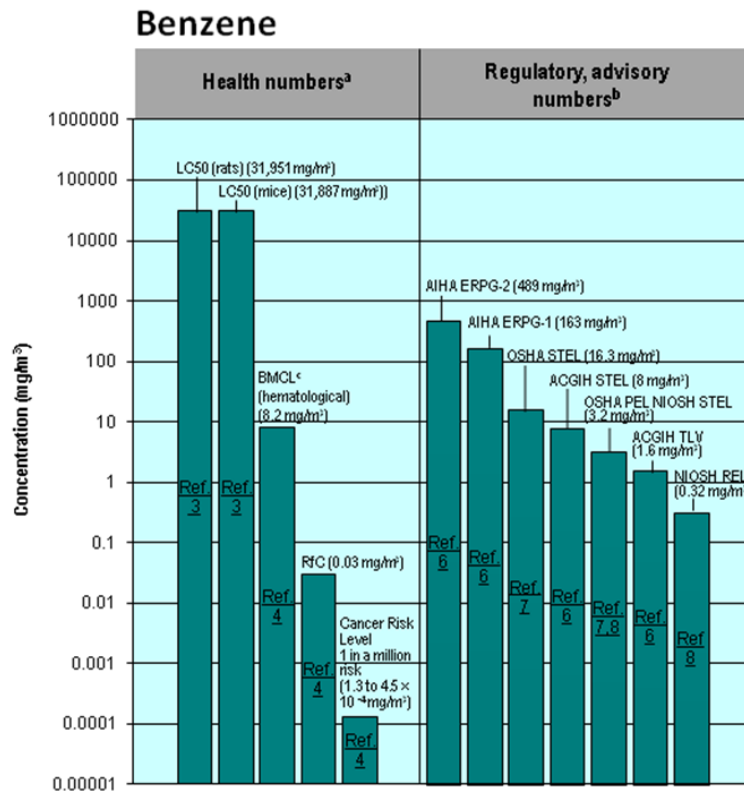


Figure 1 USEPA Exposure Standard Summary

### Step 5: Screening Assessment

On the basis of the site setting, exposure model and screening level assessment no unacceptable risks were associated with the hypothetical scenario of associated with storage and handling of production water containing up to 50 ppb Benzene.

Considering the highly conservative nature of the assessment and multiple mechanisms of degradation in the environment including volatilisation, biodegradation and photolytic degradation the majority of the BTEX mass will be attenuated.

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## Appendix C. Greenhouse Gas (Methane) Monitoring Technology

# FLIR GF320

Infrared camera for gas leak detection and electrical inspections

The new FLIR GF320 is a revolutionary infrared camera capable of finding Methane emissions or other Volatile Organic Compounds (VOC). It is unbeatable for detecting even the smallest gas leaks.

- Real-time visualization of even very small gas leaks thanks to the Excellent High Sensitivity Mode (<25mK)
- Measures temperatures from -40 °C to +350 °C with ±1 °C accuracy
- Built-in Video Recording, Digital Camera, Laser pointer
- Embedded GPS Data helps to identify the precise locations of non-compliance
- High performance LCD & Tilttable high resolution viewfinder delivers bright and vivid image in poor lighting environment or under sunlight
- Lightweight (2,4 kg) and robust design
- User-Inspired Ergonomics: Rotating Handle, Direct Access Buttons
- Dual use, detects gas leaks and carries out electrical inspections (radiometric image data)



### Visualizes gas leaks in real time

FLIR GF320 can scan large areas rapidly and pinpoint leaks in real time. It is ideal for monitoring plants that is difficult to reach with contact measurement tools. Literally thousands of components can be scanned per shift without the need to interrupt the process. It reduces repair downtime and provides verification of the process. And above all it is exceptionally safe, allowing potentially dangerous leaks to be monitored from several meters away.

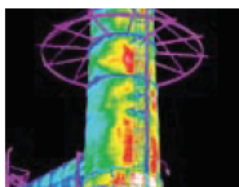
### Protect the environment

FLIR GF320 will significantly improve your work safety, environmental and regulatory compliance, not to mention helping to improve the bottom line by finding leaks that essentially decrease profits.

Detects the following gases:

- Benzene
- Ethanol
- Ethylbenzene
- Heptane
- Hexane
- Isoprene
- Methanol
- MEK
- MIBK
- Octane
- Pentane
- 1-Pentene
- Toluene
- Xylene
- Butane
- Ethane
- Methane
- Propane
- Ethylene
- Propylene

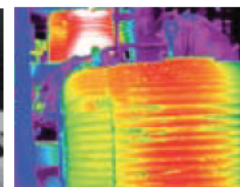
### Applications:



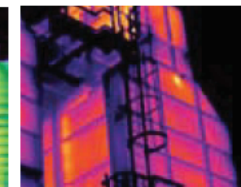
Oil refineries



Natural gas



Power generation



Petrochemical & chemical industries



The sniffer is detecting gas but is unable to trace its source, whereas this thermal image shows the leak source clearly on the left.



Tilttable, flip-out 4.3" High Contrast Color LCD allows you to view targets more safely from any angle.



Automatic (one Touch) and Manual Focus w/ 8 to 1 Continuous Digital Zoom helps you to deliver the perfect picture at ease.

# FLIR GF320 Technical Specifications

Imaging and optical data	
Field of view (FOV) / Minimum focus distance	24° x 18° / 0.3 m
Lens identification	Automatic
F-number	1.5
Thermal sensitivity/NETD	<25 mK @ +30°C
Focus	Automatic (one touch) or manual (electric or on the lens)
Zoom	1–8x continuous, digital zoom
Digital image enhancement	Noise reduction filter, scene based NUC, High Sensitivity Mode (HSM)
Focal Plane Array (FPA) / Spectral range	Cooled InSb / 3–5 µm
IR resolution	320 x 240 pixels
Detector pitch	30 µm
Sensor cooling	Stirling Microcooler (FLIR MC-3)
Electronics and data rate	
Full frame rate	60 Hz
Image presentation	
Display	Built-in widescreen, 4.3 in. LCD, 800 x 480 pixels
Viewfinder	Built-in, tiltable OLED, 800 x 480 pixels
Automatic image adjustment	Continuous/manual; linear or histogram based
Manual image adjustment	Level/span
Image modes	IR-image, visual image, High Sensitivity Mode (HSM)
Measurement	
Temperature range	-40 to +350°C
Accuracy	±1°C for temperature range (0-100 °C) or ±2% of reading for temperature range (> +100 °C)
Measurement analysis	
Spotmeter	10
Area	5 boxes with max/min/average
Profile	1 live line (horizontal or vertical)
Difference temperature	Delta temperature between measurement functions or reference temperature
Reference temperature	Manually set or captured from any measurement function
Emissivity correction	Variable from 0.01 to 1.0 or selected from editable materials list
Reflected apparent temperature correction	Automatic, based on input of reflected temperature
Measurement corrections	Reflected temperature, distance, atmospheric transmission, humidity, external optics
Set-up	
Menu commands	Level, span Auto adjust continuous/manual/semi-automatic Zoom Palette Start/stop recording Store image Playback/recall image
Set-up commands	1 programmable button, local adaptation of units, language, date and time formats
Web interface	Admin camera setup and viewing IR images
Storage of images	
Image storage type	Removable SD or SDHC Memory Card, two card slots
Image storage capacity	> 1200 images (JPEG) with post process capability per GB on memory card
Image storage mode	IR/visual images. Visual image is automatically associated with corresponding IR image.
File formats	Standard JPEG, 14 bit measurement data included
GPS	Location data automatically added to every image from built-in GPS
Video recording and streaming	
Non radiometric IR-video recording	MPEG4/H.264 (60 minutes/clip) to memory card. Visual image can automatically be associated with corresponding recording of non radiometric IR-video.
Digital camera video recording	MPEG4/H.264 (25 minutes/clip) to memory card
Non radiometric IR-video streaming	RTP/H.264
Digital camera	
Built-in digital camera	3.2 Mpixel, auto focus, and two video lamps
Laser pointer	
Laser	Activated by dedicated button
Data communication interfaces	
USB	USB-A: Connect external USB device (e.g. memory stick) USB Mini-B: Data transfer to and from PC
USB, standard	USB Mini-B: 2.0 High Speed
Video	HDMI
Power system	
Battery type	Rechargeable Li Ion battery
Battery voltage	7.2 V
Battery operating time	> 3 hours at 25°C and typical use
Charging system	In camera (AC adapter or 12 V from a vehicle) or 2 bay charger
Start-up time	< 5 min. @ 25°C

Environmental data	
Operating temperature range	-20°C to +50°C
Storage temperature range	-30°C to +60°C
Humidity (operating and storage)	IEC 68-2-30/24 h 95% relative humidity +25°C to +40°C (2 cycle)
Directives	73/23EEC, 89/336/EEC, 2002/ 95/EC, 2002/96/EC
EMC	EN61000-6-3 (Emission) EN61000-6-2 (Immunity) FCC 47 CFR Part 15 class B (Emission) EN 61 000-4-8, L5 EN/UL/CSA 60950-1
Encapsulation	IP 54 (IEC 60529)
Bump	25 g (IEC 60068-2-29)
Vibration	2 g (IEC 60068-2-6)
Physical data	
Camera weight, incl. lens and battery	2,48 kg
Battery weight	0,24 kg
Cameras size, incl. lens (L x W x H)	305 x 169 x 161 mm
Tripod mounting	Standard, 1/4"-20
Housing material	Aluminium, Magnesium
Grip material	TPE Thermoplastic Elastomers

Scope of delivery	
Packaging, contents	Infrared camera
	Standard Lens, 24° (Si)
	Shipping case
	Lens cap (mounted on lens)
	Lens cap (2 ea., backside of lens and opening on camera body)
	Lens cap strap, 2 ea.
	Shoulder strap
	Batteries 2 ea. (1 of the batteries inside camera)
	Charger
	Power supply
	Power supply cord
	HDMI-DVI + HDMI-HDMI cable
	USB cable
	SD card
	SD card adapter (connects via USB to PC)
	Getting Started Guide (printed)
	Manual for GF-series on CD
	FLIR Quick report on CD
	Video Report 1.0 with manual on CD
	System Calibration Certificate



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# ONE TO SIX GAS PORTABLE MONITOR

## LEADERS IN GAS DETECTION

Since 1977

## Eagle 2 Model



### Features:

- Monitor up to 6 different autoranging gases
- PPM / LEL hydrocarbon detection
- PID (Photo Ionization Detector) low and high range for VOC detection
- Infrared Sensors available for CO<sub>2</sub>, % LEL CH<sub>4</sub>, % Vol. CH<sub>4</sub>, % LEL HC, % Vol. HC
- TC (Thermal Conductivity) sensor available for % Vol. H<sub>2</sub> or % Vol. CH<sub>4</sub>
- Plug and play, smart toxic sensors
- Hundreds of configurations
- Displays in 5 languages
- Powerful long-life pump up to 38m range
- Low flow pump shut off and alarm
- Methane elimination for environmental use
- Alkaline 16 hours or Ni-MH 20 hours capability
- Password protection
- Datalogging standard
- IrDA communications port
- Autocalibration
- Internal hydrophobic dust filter
- External probe with hydrophobic filter
- Ergonomic RFI / EMI / chemical / weather resistant enclosure
- Intrinsically safe design, CSA approval

The popular EAGLE 2 portable gas detector is a powerful instrument that does more than just offer the standard confined space protection for LEL, O<sub>2</sub>, H<sub>2</sub>S and CO. The EAGLE 2 portable gas detector is equipped with features that are not available on competitive units.

The EAGLE 2 features include a PID sensor for detecting low and high ppm levels (0-50ppm & 0-2,000ppm) of VOC gases; % volume capability for CH<sub>4</sub> and H<sub>2</sub> using a TC (thermal conductivity) sensor; PPM or LEL hydrocarbon detection at the push of a button; infrared sensors for CO<sub>2</sub>, methane or hydrocarbons in LEL and % volume ranges; methane elimination feature for environmental applications; and a variety of super toxic gases and measurable ranges.

The EAGLE 2 has a strong internal pump with a low flow auto pump shut off and alarm, which can draw samples from up to 38 metres. This allows for quick response and recovery from distant sampling locations. The EAGLE 2 will continuously operate for over 16 hours on alkaline batteries or 20 hours on Ni-MH. A variety of accessories are also available to help satisfy almost any application such as long sample hoses, special float probes for tank testing, and dilution fittings, to name a few. Datalogging is a standard feature for all sensors on all versions. With its ergonomic design and large glove friendly buttons, the EAGLE 2 offers easy access to controls such as autocalibration, alarm silence, demand zero, peak hold, methane elimination, and a wide variety of other features.

Each channel has two alarm levels plus TWA and STEL alarms for toxic channels. The two alarm levels are adjustable and can be latching or self resetting. Rugged, reliable, easy to operate and maintain, the EAGLE 2 is the solution for just about any portable gas monitoring situation.



OIL & GAS



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Melbourne	Auckland
Adelaide	Wellington
Perth	Christchurch

<b>Enclosure</b>	Weatherproof, chemical resistant, RFI/EMI coated high impact polycarbonate-polyester blend. Can operate within 5cm of water without leakage. Ergonomically balanced with rugged top mounted handle. Water & dust resistant equivalent to IP65.
<b>Dimensions</b>	24cm x 13.3cm x 14.9cm (L x W x H)
<b>Weight</b>	1.7 kg (standard 4 gas with batteries)
<b>Detection Principle</b>	Catalytic combustion, electrochemical cell, galvanic cell, infrared, photo ionization detector and thermal conductivity.
<b>Sensor Life</b>	Two (2) years under normal conditions.
<b>Sampling Method</b>	Powerful, long-life pump (over 6000 hours) can draw samples over 38 metres. Flow rate approximately 2.0 SCFH (standard cubic feet / hour)
<b>Display</b>	3 display modes: display all gases, large font-autoscroll or large font-manual scroll. Polyurethane protected overlay. Backlight, illuminates for alarms and by demand with adjustable time.
<b>Language</b>	Readout can display in 5 languages (English, French, German, Italian or Spanish)
<b>Alarms</b>	Two (2) alarms per channel plus TWA and STEL alarms for toxics. Fully adjustable for levels, latching or self reset and silenceable.
<b>Alarm Method</b>	Buzzer 90 dB at 30cm, four high intensity LED's.
<b>Controls</b>	Four (4) external glove friendly push buttons for operation, demand zero, and autocalibration. Buttons also access LEL/ppm, alarm silence, peak hold, TWA/STEL values, battery status, conversion factors and many other features.
<b>Continuous Operating Hours</b>	At 21°C, 16 hours using alkaline batteries, or 20 hours using NiMH.
<b>Power Source</b>	4 alkaline or NiMH, size C batteries (Charger has alkaline recognition to prevent battery damage if charging is attempted with a kalines)
<b>Operating Temp &amp; Humidity</b>	-20°C to 50°, 0 to 95% RH, non-condensing.
<b>Indication Accuracy</b>	Maximum variance $\pm$ 5% of full scale.
<b>Response Time</b>	30 seconds to 90% (for most gases) using standard 1.5 metre hose
<b>Safety Design</b>	Intrinsically safe, Class I, Division 1, Groups A, B, C and D. Approvals: CSA / CE
<b>Standard Accessories</b>	Shoulder strap, alkaline batteries, hydrophobic probe and 1.5m hose, internal hydrophobic filter
<b>Special Features</b>	<ul style="list-style-type: none"> <li>• Low Flow alarm shuts pump off to avoid damage to instrument</li> <li>• Hydrophobic filter disc in probe</li> <li>• Internal hydrophobic filter</li> <li>• Single gas calibration capability</li> <li>• Methane elimination switch for environmental applications</li> <li>• Security Password protected</li> <li>• Meets EPA Method 21 protocol for fugitive emissions testing (most applications)</li> <li>• Plug and play toxic sensors</li> <li>• Datalogging available for all configurations</li> <li>• Transformer gas testing version available</li> </ul>
<b>Optional Accessories</b>	<ul style="list-style-type: none"> <li>• Dilution fitting (50/50)</li> <li>• NiMH Batteries</li> <li>• Battery charger, 220 VAC or 12 VDC (charge time 4 hours)</li> <li>• Continuous Operation Adaptor, 12 VDC</li> <li>• Extension Hoses</li> <li>• Stand Alone Docking Station</li> </ul>
<b>Warranty</b>	Two year material and workmanship, one year for PID sensor

## Gases & Detectable Ranges

### Standard Confined Space Gases

Hydrocarbons (CH <sub>4</sub> std)	0 – 100% LEL 0 – 50,000 ppm
Oxygen (O <sub>2</sub> )	0 – 40% vol
Carbon Monoxide (CO)	0 – 500 ppm
Hydrogen Sulphide (H <sub>2</sub> S)	0 – 100 ppm

### Toxics

Ammonia (NH <sub>3</sub> )	0 – 75 ppm
Arsine (AsH <sub>3</sub> )	0 – 1 ppm
Hydrogen Cyanide (HCN)	0 – 30 ppm
Phosphine (PH <sub>3</sub> )	0 – 1 ppm
Sulphur Dioxide (SO <sub>2</sub> )	0 – 30 ppm

### IR Sensors

Carbon Dioxide (CO <sub>2</sub> )	0 - 10,000 ppm 0 - 5% Vol 0 - 60% Vol
Methane (CH <sub>4</sub> )	0 - 100% LEL 0 - 100% Vol
Hydrocarbons	0 - 100% LEL 0 - 30% Vol

### PID Sensors

VOC	0 - 2,000 ppm 0 - 50 ppm
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### TC Sensors

Methane (CH <sub>4</sub> )	0 - 100% Vol
Hydrogen	0 - 100% Vol 0 - 10% Vol

*The Eagle 2 can be configured with up to 6 gas sensors from the above list*



OIL & GAS



CONFINED SPACE



HVAC



MINING



LABORATORIES



COUNCILS



DEFENCE



SHIPPING



FUMIGATION



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