Preliminary Guideline: Groundwater Monitoring Bores for Exploration Petroleum Wells in the Beetaloo Sub-basin

1. Purpose and Scope

This preliminary guidance provides information on the expectations of the Department of Environment and Natural Resources (DENR) in relation to the layout, construction and operation of "multi-level observation bores" associated with onshore petroleum wells during the exploration phase of onshore gas development in the Beetaloo Sub-basin.

It is expected that principles in this preliminary guideline will be incorporated into Codes of Practice for the Northern Territory Onshore Petroleum Industry currently being developed by the Northern Territory Government. The requirements in this initial guidance, and subsequently under the Codes, may evolve following a period of operational experience during the exploration phase of the industry and as baseline understanding of the hydrogeological systems improves.

This preliminary guidance will be revised prior to any application to production-level activity.

This preliminary guidance was developed for the Beetaloo Sub-basin and additional guidance will be developed as required to account for different hydrogeology and environmental conditions in other gas basins. Additional guidance will also be developed for conventional petroleum activities.

The guideline relates specifically to monitoring bores established for the purpose of meeting recommendations 7.11 and 7.13 of the *Final Report of the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory, 2018* (the Report), noting that water bores may be established for a range of other purposes.

2. Background

Groundwater monitoring bores must be established to detect any contamination of groundwater as a result of leaky gas wells or onsite spills, in order to meet the recommendations of the Report, specifically:

> *Recommendation 7.11* (in part)
>
> *That prior to the grant of any further exploration approvals, in order to minimise the risk of groundwater contamination from leaky gas wells:*
>
> - *Where a well is hydraulically fractured, monitoring of groundwater be undertaken around each well pad to detect any groundwater contamination using multi-level observation bores to ensure full coverage of the horizon, of any aquifer(s) containing water of sufficient quality to be of value for environmental or consumptive use;*
> - *All existing well pads are to be equipped with multilevel observation bores;*
> - *As a minimum, electrical conductivity data from each level of the monitor bore array should be measured and results electronically transmitted from the well pad site to the regulator as soon as they are available.*
> - *Other water quality indicators, as determined by the regulator, should be measured quarterly, with the results publicly disclosed online a soon as reasonably practical from the date of sampling.*

Recommendation 7.13

Upon a gas company undertaking any exploration activity or production activity, monitoring of the groundwater must be implemented around each well pad to detect any groundwater contamination, adopting the monitoring outlined in Recommendation 7.11. If contamination is detected, remediation must commence immediately.

The rationale for these recommendations is further described in the Report (sections 7.6.1 and 7.6.3) and this detail has informed the guideline, notably:

The Panel's view is that monitoring of key water quality indicators in the groundwater in close proximity (that is within 10-20 m) to each planned well or well pad is essential, and that this monitoring should commence prior to any well drilling, with subsequent monitoring being particularly focussed on the hydraulic fracturing stages. To this end, multi-level monitoring bores must be installed in advance (at least six months) prior to the drilling of a gas well and designed to ensure full vertical coverage of any aquifer(s) currently supplying, or potentially being able to supply, water for environmental or consumptive (stock or domestic) uses. The bore array must have a level of vertical resolution at least sufficient to be able to identify whether a leak of fluid or gas is occurring in the top, middle or bottom zones of an aquifer. At a minimum, electrical conductivity should be measured in real-time as an indicator providing 'early warning' of contamination, with the results telemetered from the site to the regulator and made available to the public. The use of telemetry for other parameters should be reviewed every five years or as technological improvements become available. Additionally, other water quality indicators determined by the regulator must be measured quarterly, with the results made publicly available within one month of sampling. The combination of continuous and randomised spot monitoring should continue for three years, after which time its fitness for purpose should be reviewed by the regulator.

If the electrical conductivity or other measurements suggest that a leak has occurred, or is occurring, more detailed investigations must commence immediately, with remediation to be initiated as soon as practicable. Parameter values for setting action thresholds should be determined from the data collected during the SREBA, and reviewed periodically by the regulator.

The text above specifically refers to the installation and monitoring of all new exploration wells. However, there are already a number of explorations wells (including the Amungee NW-1H well) that exist. The Panel recommends that these wells also require the installation of multilevel bores prior to the approval of either first time or repeat hydraulic fracturing activity.

In developing the guidance, a precautionary approach has been applied at this early stage of shale gas exploration in the Northern Territory, which reflects the Inquiry Report and is appropriate given the lack of comprehensive scientific knowledge and extensive data regarding the stratigraphy and water quality of the Cambrian limestone aquifers across the Beetaloo Sub-basin. The guideline has been developed to ensure that scientific information on the stratigraphy and water quality of aquifer units that may be present at each petroleum exploration well site is established prior to the drilling of petroleum wells. This information will further inform the design of petroleum wells to ensure application of best available techniques to isolate and protect identified aquifer units at each site. Implementation of the guideline will also provide a large amount of spatial information about water quality of these important regional aquifers over time. It has also been developed to ensure that a robust groundwater monitoring system is developed to meet the recommendations and intent of the Inquiry, without being excessively onerous for industry in the exploration phase.

The primary water quality indicator recommended by the Inquiry Panel is electrical conductivity (E.C.). A review of ground water quality data across the Beetaloo Sub-basin from data sets with a broad spatial distribution and spanning several years indicates that E.C. is highly variable spatially, and

perhaps temporally depending on location. Consequently, monitoring of E.C., and its constituents (e.g. Total Dissolved Solids and Chloride) needs to be site-specific to provide a meaningful baseline.

3. Summary of aquifer unit monitoring requirements

Three main configurations of CLA (Cambrian limestone aquifers) are recognised overlying the Beetaloo Sub-Basin (Figure 1). These can be used as a preliminary guide for planning groundwater monitoring at well sites.

Each configuration is described below.

1. Aquifers in both the Anthony Lagoon and Gum Ridge Formations (or equivalents) are present: The depth to the base of the CLA sequence should be greatest in this zone. Each formation should be monitored with separate monitoring bores. Along the margins of this zone the Anthony Lagoon Formation may lie above the water table and so will not contain any aquifers. In such cases only the Gum Ridge Formation needs to be monitored.
2. Only the Gum Ridge Formation (or equivalent) is present: This formation should be monitored.
3. No aquifers present: This occurs mainly west of Larrimah where the Tindall Limestone (a Gum Ridge Fm. equivalent) lies above the water table. In such situations the uppermost aquifer in the Kalkarindiji Suite should be monitored. This formation occurs directly beneath the Tindall Limestone.

The water supply bore for the exploration well should be drilled to the base of the Gum Ridge Formation (or equivalent). Together with down-hole logs such as gamma and caliper this will enable more accurate identification of aquifers in the CLA sequence. The detailed design of the monitoring program at each well site is likely to be specific to that site, so consultation with DENR Water Assessment Branch is recommended following the drilling of the water supply bore.

The guide above indicates that a minimum of one and a maximum of two aquifer units would be monitored at each site, unless site-specific data clearly indicates no groundwater is present.

Where no groundwater is encountered at the proposed well pad site during the drilling of the water supply bore, the results should be provided to DENR Water Assessment Branch. In this circumstance, an exemption for the requirement to install groundwater monitoring bores at the proposed exploration well pad will be considered by DENR providing there has been an adequate attempt to locate groundwater.

Table 1 below provides a summary of requirements which are detailed in sections 4 to 6.

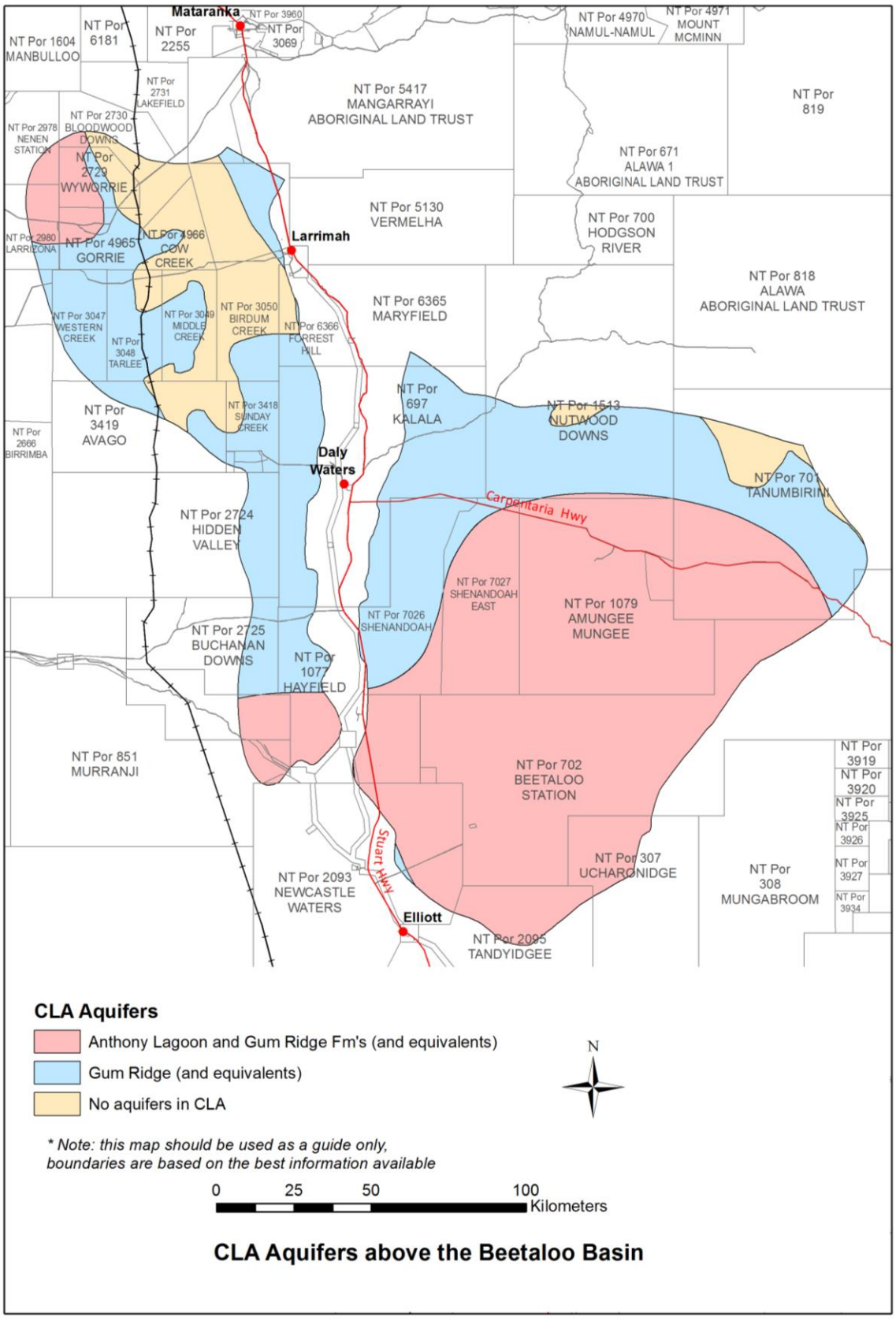

Figure 1 Indicative spatial location of Cambrian Limestone Aquifer units above the Beetaloo Basin

Table 1 – Monitoring bore requirements summary for petroleum exploration wells in the Beetaloo sub-Basin (see sections 4 to 6 for more detail)

Monitoring bore array type	Bore levels required	Possible Beetaloo solution	Location	When required
Control monitoring bore array. *Note this may include the production bore if water is to be sourced at the well site location.*	1 bore for each discrete aquifer unit, which is screened near the top, middle and bottom of the vertical extent of that unit	1 bore screened near the top, middle and bottom of the Anthony Lagoon formation at well sites where it is determined to occur; **and** 1 bore screened near the top, middle and bottom of the Gum Ridge formation; **or** 1 bore screened in the uppermost aquifer in the Kalkarindiji Suite where the Tindall limestone lies above the water table (ref. Sec. 2.3)	Within 100m up-gradient of the well pad	6 months prior to drilling, and preferably to include both wet season and dry season samples. In circumstances, which lie outside of the control of the operator, where six months monitoring data from the control bore is not achievable before drilling, it must at minimum provide six months of data prior to hydraulic fracturing activities
Impact monitoring bore array	1 bore for each discrete aquifer unit, which is screened near the top, middle and bottom of the vertical extent of that unit	As above	Within 20m down-gradient of the petroleum well. Where multiple exploration wells on a well pad are proposed then a single array, 20m down-gradient of the well head-series	At completion of well drilling and prior to hydraulic fracturing of the well. *It is acknowledged that installing this bore array prior to drilling the well may not be possible due to safety reasons.*

4. Layout of groundwater monitoring bores

The minimum requirements for monitoring bores in relation to detecting “leaky wells” is based on Before-After-Control-Impact (BACI) environmental monitoring design. BACI designs are an effective method to evaluate natural and human-induced perturbations of environmental variables (e.g. groundwater quality) when treatment sites cannot be randomly chosen, as is the case in this application. Groundwater monitoring bores to detect potential Impact from “leaky wells” should be located so that any contamination is detected as soon as possible, in a time frame that allows an effective remediation response. Groundwater flow gradients in the Cambrian Limestone Aquifer (CLA) are likely to be low in most parts of the Beetaloo Basin, and DENR believes that monitoring in close proximity (20m) of each well is essential for this purpose. If multiple exploration wells are planned for a single pad, DENR believes that monitoring within 20m downstream of the most proximate well in the series is sufficient.

An appropriate BACI design has been determined to be as follows (also see Figure 2 for a diagrammatic representation):

1. A **Control monitoring bore array** (one or two depending on the discrete aquifer units present at the site), located up-gradient and within 100m of the planned or existing location of the petroleum well pad. This should be installed at least six months prior to drilling of the well and will provide site-specific, baseline ground water quality information. Wherever possible, pre-drilling data should include both wet season and dry season sampling. In circumstances, which lie outside of the control of the operator, where six months monitoring data from the control bore is not achievable before drilling, it **must** provide at minimum six months of data prior to hydraulic fracturing activities. The site-specific aquifer system information derived from drilling the Control monitoring bore array will also inform the subsequent design of the Impact monitoring bore array. It will also provide a basis for understanding natural trends that may occur at the site and therefore help differentiate between background and project-attributable changes over extended timeframes. The control array may also provide useful information about the spatial extent of impacts if a severe perturbation is detected in the impact array.
2. An **Impact monitoring bore array**, screened at similar depths to the **Control monitoring bore array,** 20m down-gradient of the location of the petroleum well. It is acknowledged that installing this bore array prior to drilling the well may not be possible due to safety reasons. Therefore the array may be installed after completion of drilling the petroleum well but must be installed and sampled prior to hydraulic fracturing. Where multiple exploration wells are proposed on a single well pad, either as part of a single drilling campaign or a later infill campaign, then a **single impact monitoring bore array** must be installed and sampled prior to hydraulic fracturing of any well in the series. This bore array must be located within 20m down gradient of the first well in the proposed **series.** and wherever possible this should be at the downgradient end of the series

   Where subsurface geohazards are encountered during the drilling of the exploration petroleum well that may present elevated risks to the installation of an Impact monitoring bore array within 20m of the well, the location of the impact monitoring bore array may be varied on a case-by-case basis with approval from DENR.

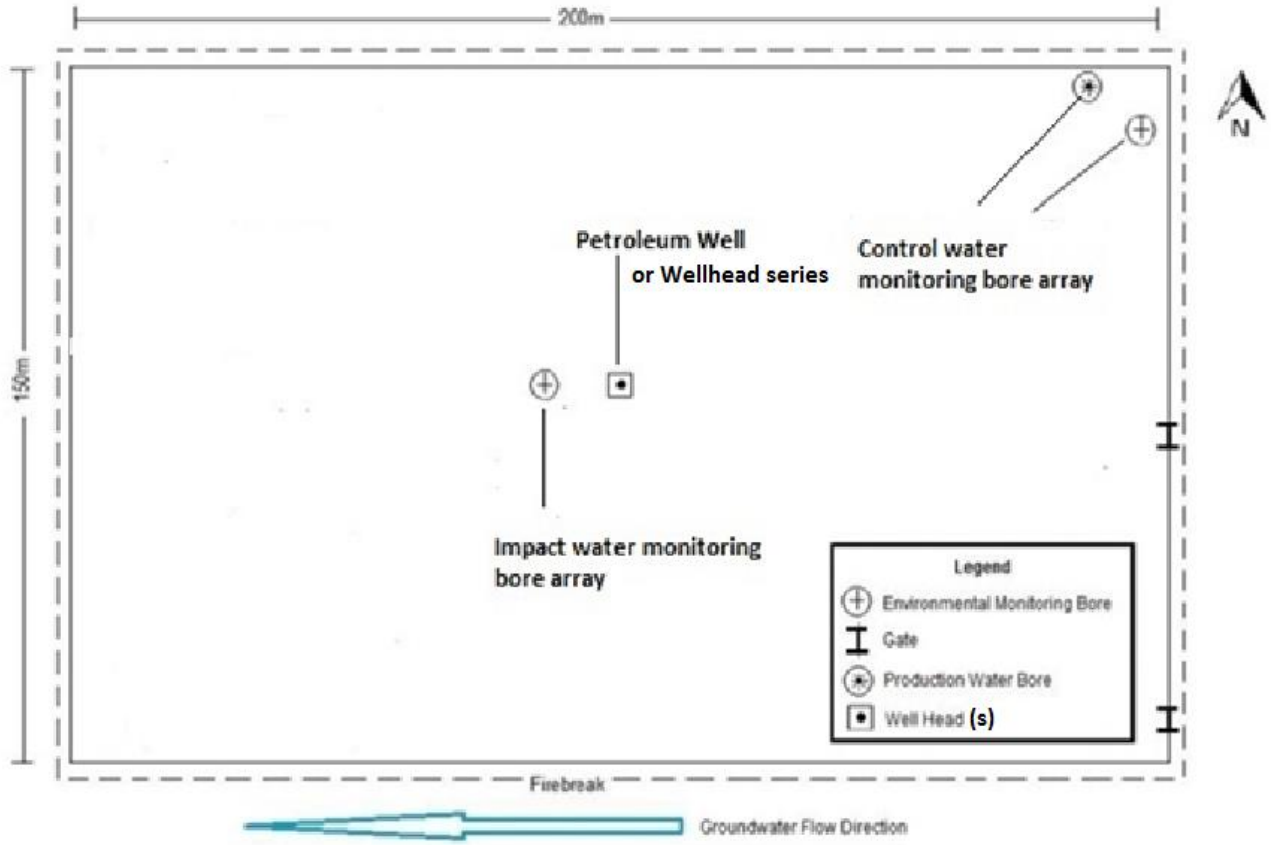

Figure 2: Indicative environmental groundwater monitoring bore layout on a petroleum well pad. Groundwater flow (gradient) direction in this example is from R-L of layout.

5. Design of monitoring bores

Monitoring bores should be established and screened to sample water in each aquifer unit (i.e. each non-interconnected formation) “currently supplying, or potentially being able to supply, water for environmental or consumptive (stock or domestic) uses”. The spatial variability of presently recognised aquifer units above the Beetaloo Sub-Basin are outlined in Figure 1. The design of the monitoring program at each well site is likely to be specific to that site, so consultation with DENR Water Assessment Branch regarding number of aquifer units and suitable screening depths is recommended following the drilling of the water supply bore. If water is not to be sourced at the well site, the first Control monitoring bore should be drilled to the base of the deepest recognised aquifer unit to provide the required stratigraphy data.

The appropriate number of bores and screening depths for each monitoring bore array will be site-dependent. Each Control monitoring bore and corresponding Impact monitoring bore should be screened at similar depths in the distinct aquifer units at that site. To provide vertical coverage of the aquifer unit that it samples, each monitoring bore should be screened near the top, middle and bottom of the vertical extent of that aquifer unit (or continuously as appropriate). DENR recognises that is overly onerous, and increases environmental risks, to require separate monitoring bores to be established at each sampling depth within each aquifer unit. Rather, an integrated sample should be collected from each Control monitoring bore and Impact monitoring bore for each aquifer unit in a way that maximises the probability of detecting any leak. Should a leak be detected, other techniques will be applied to determine the source level within the aquifer unit.

Where two monitoring bores are required in a monitoring bore array, the bores should be placed approximately 10m apart in a line approximately perpendicular to the flow gradient. In the unlikely event that three monitoring bores were required in a monitoring bore array, two bores should be placed as per the two-bore scenario, with an additional bore placed downgradient and 10m from the

other two bores. It is acknowledged that this will result in the third bore being approximately 28m from the petroleum well.

Bores must be constructed in accordance with Minimum Construction Requirements for Water Bores in Australia, 2012 (https://www.adia.com.au/documents/item/290).

An accurate drilling and lithological log of rock strata should be kept for all operations on the drill site. A clean representative sample of the rock formations intersected should be collected at all changes of strata and at a maximum drill depth intervals of three metres. Samples should be laid out in an orderly sequence for inspection and a report log provided to DENR for each bore hole. It should be noted that r11 of the *Water Regulation* also provides information regarding samples required to be taken and shared by licensed water bore drillers. Results of any down-hole logs such as gamma and caliper should also be provided to DENR, as discussed in Sec. 2.

It is recommended that where possible, bores should be fitted with locks, to minimise risk of malicious interference with the monitoring program.

6. Sampling frequency

As baseline levels of some analytes are likely to vary seasonally it is important that baseline groundwater monitoring is conducted throughout the year, noting that there may be access constraints for periods during the wet season. It is suggested that sampling frequency is initially high (e.g. every 4 weeks) until the extent of natural variation is determined at the **Control monitoring bore array** shown in Figure 2, and statistically robust confidence intervals for the suite of analytes to be measured at that site and within the aquifer zone(s) of interest are established. The Report requires quarterly sampling for parameters other than E.C. for at least three years.

DENR considers that in this preliminary stage of exploration, and to meet the intent of the Report, a **Control monitoring bore array** should be established in time to allow at least six months of sampling prior to the drilling of the gas well, and that sampling should encompass the likely major extent of natural variation between late dry season and late wet season periods.

The **Impact monitoring bore array** must be installed and sampled prior to stimulating the well, noting that more than one pre-impact sample period is desirable.

7. Sampling methodology

Samples should generally be taken in accordance with protocols detailed in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality field sampling program (www.waterquality.gov.au/anz-guidelines/monitoring/field-sampling-program). It is expected that sampling protocols would be detailed in the relevant Environment Management Plan (EMP) and made available to DENR for review.

The EMP must include water sampling procedures including the following components:

1. Water sampling must be undertaken by suitably qualified and trained personnel
2. Prior to sampling a water bore, wherever practicable, the volume of stagnant water within the bore casing must be calculated. Water quality samples must only be collected after:
    a) three times the volume of stagnant water in the bore casing and the discharge piping (including a sufficient additional volume to account for any error in volume calculations) have been discharged; and
    b) when the field water quality parameters (e.g. E.C.) have stabilised, indicating the bore is producing formation water.
3. Water quality samples must have a unique identification number that can be cross-referenced to the monitoring location and time of sampling.

4. Sample preservation measures are to be documented and comply with analytical laboratory requirements and relevant standards (e.g. AS/NZS 5667.1:1998).
5. Sample integrity must be maintained through the use of chain of custody procedures and documentation in accordance with section 3.7 of *Monitoring and Sampling Manual 2009 — Environmental Protection (Water) Policy 2009 (Department of Environment and Heritage Protection, 2013).*
6. Sample analysis should be undertaken by a laboratory that is NATA approved for that analysis.

A survey benchmark relative to Australian Height Datum (AHD) should be established at each well pad monitoring bore, accurate to ±10 cm, to accurately determine depth to water table during each sampling event.

The Analytical Suite to be assessed is listed below in Table 2. A review of the suite of analytes to be tested may be requested by the seline has been established for the monitoring bores.

Analytes of particular interest include **Total Dissolved Solids**, **Chloride**, and **Electrical Conductivity** (E.C.) as a proxy, because drilling fluids, hydraulic fracturing fluids, well suspension fluids and produced formation fluids may have orders of magnitude (100s~1000s) higher concentrations of Chloride than background values in potable waters. In addition, Strontium and Barium are typically elevated in produced water from unconventional shale gas reservoirs and serve among others as additional useful tracers. Dissolved methane is important to monitor as a baseline and over the longer term.

Groundwater pressure monitoring on a continuous basis also provides an indicator of well-integrity failure, particularly during the well-stimulation phase when the differential pressure between the aquifer and well annulus is extremely high, and thus a breach of well-integrity would be instantaneously detected. The use of this parameter as a useful reactive monitoring tool will be examined with industry during this exploration phase.

Table 2 – Required analytes

General	Anions	Cations and Metals		Petroleum
pH	**Chloride**	Calcium	Arsenic	TRH
Electrical conductivity*	Fluoride	Chromium	**Barium**	PAH Suite
Total Dissolved Solids	Sulphate	Copper	Boron	BTEX
Total Suspended Solids	Nitrate	Iron	Cadmium	Diss. Methane
Alkalinity	Nitrite	Lead	Lithium	Diss. Ethane
Gross Alpha		Magnesium	Selenium	Diss. Propane
Gross Beta		Manganese	Silica	
Water level**		Mercury	**Strontium**	
Groundwater pressure***		Potassium	Sodium	
		Silver	Zinc	

*Recommendation 7.11 requires that electrical conductivity (E.C.) should be measured in real-time as an indicator providing 'early warning' of contamination, with the results telemetered from the site to the regulator and made available to the public. It is recognised by DENR that this may be difficult to implement in the first stages of exploration, but proponents should provide a plan and timetable to meet this requirement, preferable before hydraulic fracturing occurs.

**A survey benchmark relative to Australian Height Datum (AHD) should be established at each well pad monitoring bore, accurate to ±10 cm or better, to accurately determine water table elevation.

***This indicator has been suggested by industry and collection of this data is encouraged in order to test validity and applicability.

8. Data Management

Laboratory reports should be provided to the regulator as soon as practicable after each sampling occasion. Sampling, chain of custody and results data should also be provided in ESdat format (or another format if previously agreed with the regulator).

Further detail regarding reporting and publication mechanisms will be developed in consultation with industry, including appropriate units, file formats and data transfer protocols. This will encompass the detailed recommendations of the Report such as real time data transfer, data portals and public release of data.