Appendix 3 Risk assessment matrix

Chapter 7 Water

Environmental value 1: water quantity

Environmental objective 1: to ensure all surface and groundwater resources are used sustainably

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Excessive extraction from surface water	*Likelihood* - low, lack of permanent surface water in Beetaloo Sub-basin and other semi-arid and arid regions. *Consequence* - medium. *Risk* - low.	Prohibit use of surface water for shale gas hydraulic fracturing in the NT ***(Recommendation 7.5).*** Develop WAPs for the Beetaloo Sub-basin region that specifically exclude use of surface water for onshore shale gas development ***(Recommendations 7.5 and 7.6).***	Low
Excessive extraction from groundwater - regional impacts	**Northern Beetaloo Sub-basin:** *Likelihood* - low. *Consequences* - medium. *Risk* - low. **Southern Beetaloo Sub-basin:** *Risk* - cannot be assessed, lack of detailed knowledge on recharge rates in the region.	Develop and undertake a strategic regional environmental and baseline assessment (**SREBA**), including a regional groundwater model, for any prospective onshore shale gas basin before any production licences are granted for shale gas activities in that basin, commencing with the Beetaloo Sub-basin (***Recommendation 7.4***). Ensure sustainable extraction limits on the basis of the outputs from the regional numerical groundwater model ***(Recommendations 7.6*** and ***7.15***). Develop WAPs for the northern and southern regions of the Beetaloo Sub-basin and determine water allocations once there is better knowledge of the groundwater resources (***Recommendation 7.6***).	Low for northern Beetaloo Sub-basin. Not able to be determined for southern Beetaloo Sub-basin.
Excessive extraction from groundwater - local impacts	*Likelihood* - low of an unacceptable aquifer drawdown further than 1 km from the gas company bore fields. *Consequence* - medium, if aquifers are drawn down excessively this could reduce the effectiveness of bores used by pastoralists and communities. *Risk* - low.	Develop and undertake a SREBA, including a regional groundwater model, for any prospective onshore shale gas basin before any production licences are granted for shale gas activities in that basin, commencing with the Beetaloo Sub-basin (***Recommendations 7.4***). Develop WAPs for the relevant region that include adequate controls over the rate and volume of water extraction by gas companies, and implement a default buffer zone of 1 km between gas company bores and other bores (***Recommendation 7.7***). Require gas companies to monitor local drawdown and 'make good' any excessive drawdown (***Recommendation 7.7)***.	Low
Unacceptable changes to surface or groundwater flows from felt seismic activity caused by hydraulic fracturing	*Likelihood* - low, little evidence for hydraulic fracturing causing felt seismic activity, except in areas of active faults. *Consequence* - low. *Risk* - low.	Require monitoring of the extent of hydraulic fracturing and if needed, reduce the pressure used for fracturing (see discussion at Section 5.10 and ***Recommendation 5.8***). Require monitoring of seismicity during hydraulic fracturing and terminate if induced earth tremors exceed 0.5 on the Richter scale (see discussion at Section 5.10 and ***Recommendation 5.8***).	Low
Unacceptable changes to surface and groundwater flow from seismic activity caused by reinjection of wastewater	*Likelihood* - low, evidence that this practice has cause seismic activity in US but no evidence for flow changes. *Consequence* - low to medium. *Risk* - medium.	Prohibit reinjection of wastewater until comprehensive investigations are undertaken to show that no seismic activity will occur (***Recommendation 7.8***).	Low

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Unacceptable changes to the surface water flow characteristics due to planned or accidental discharge of wastewaters	*Likelihood* - low to medium, based on historical data from the US. *Consequence* - low. *Risk* - low.	Prohibit the discharge of onshore shale gas hydraulic fracturing wastewaters (treated or untreated) to any surface water body (***Recommendation 7.16***).	Low

Environmental value 2: surface and groundwater quality

Environmental objective 2: to maintain acceptable quality of surface and groundwater

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Unacceptable groundwater contamination from leaky production wells	**Wastewater (salts and chemicals)** *Likelihood* - very low, little evidence of faulty contemporary wells. *Consequence* - medium, will depend upon the behaviour of contaminants in the groundwater (dispersion, transport, degradation). *Risk* - medium. **Methane** *Likelihood* - low to medium, methane leakage more likely than leakage from bores of contaminated flowback or produced water. *Consequence* - low, little evidence that methane contamination of groundwater is harmful. Methane in water is considered non-toxic, but a possible explosion risk in drinking water bores or storage tanks if dissolved concentration exceeds 28 mg/L. *Risk* - low.	Ensure that all wells to be hydraulically fractured are constructed to at least Category 9 or equivalent, and tested to ensure well integrity before and after hydraulic fracturing, with the results certified by the regulator (***Recommendation 7.10***). Require all relevant information about hydraulic fracturing fluids, flowback and produced water be publicly disclosed (***Recommendations 5.5*** and ***7.9***). Establish a default 'no go zone' of 1 km between well pads and water supply bores (***Recommendation 7.10***). Require real-time groundwater quality monitoring around each well pad (***Recommendation 7.10*** and ***7.11***). Develop specific guidelines for human and environmental risk assessments for all onshore shale gas developments (***Recommendation 7.3)***. Require monitoring of methane in domestic and stock-watering bores closest to well pads. Require venting if concentration in water exceeds 10 mg/L (see discussion at Section 7.6.1.2 and ***Recommendation 7.10***).	Low (wastewater) Low (methane)
Unacceptable groundwater contamination due to leaky abandoned wells	*Likelihood* - low, likely to be little produced water present and gas pressure will be greatly reduced at end of production life. *Consequence* (wastewater) - low, since very low volumes of wastewater will be involved. *Risk* (wastewater) - low. Consequence (methane) - low. *Risk* (methane) - low.	Ensure world leading practice well integrity construction and decommissioning standards are applied and enforced by the regulator (***Recommendations 5.1, 5.3*** and ***7.10***).	Low (wastewater) Low (methane)

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Unacceptable groundwater contamination due to spills of hydraulic fracturing chemicals and wastewater: on-site spills	*Likelihood* - medium, spills are typically small volume; the likelihood of the contaminants penetrating to the aquifer is low for most of the Beetaloo Sub-basin. *Consequence* - medium, contamination could result in health issues for humans and stock using the aquifer for drinking. *Risk* - medium.	Require the EMP for each well pad to include an enforceable wastewater management plan and spill management plan to be approved prior to the commencement of hydraulic fracturing (***Recommendation 7.11***). Require use of enclosed tanks for wastewater in preference to open ponds, and each well pad to be covered (for example, with a geo-membrane or clay liner) to reduce the infiltration of spills to aquifers (***Recommendation 7.11***). Require real-time monitoring around each well pad (***Recommendations 7.10*** and ***7.11***).	Low
Unacceptable surface and groundwater contamination due to off-site spills of hydraulic fracturing chemicals and wastewater from road and rail transport	*Likelihood* - medium, accidents are likely, particularly for road transport. *Consequence* - medium, contamination of surface waterbodies could occur and result in adverse effects on aquatic ecosystem; in case of groundwater, will depend on where the accident/spill occurs and permeability of overlying soil/rock horizons at that location. *Risk* - medium.	Review adequacy of transportation of hazardous goods regulations (see discussion at Section 7.6.3.2). Conduct a review to determine whether there is a need for restrictions on the transport of hydraulic fracturing chemicals and wastewater during the wet season, particularly on unsealed roads (***Recommendation 7.12***). Review the benefits of rail transport for some or all of the hydraulic fracturing chemicals and other consumables required by the shale gas companies (***Recommendation 7.12***).	Not able to be determined
Unacceptable groundwater contamination due to off-site leaks of hydraulic fracturing chemicals and wastewater from pipelines	*Likelihood* - low, pipelines will be buried. *Consequence* - medium, will depend on volume of the spill, type of wastewater and potential for contamination of groundwater. *Risk* - low.	Ensure adequacy of construction guidelines and their enforcement.	Not able to be determined
Unacceptable contamination of groundwater aquifers due to reinjection of treated or untreated wastewater into other aquifers	*Likelihood* - undetermined, cannot be assessed without detailed site-specific information and computer modelling. *Consequence* - medium, if surface aquifer is contaminated. *Risk* - undetermined.	Prohibit reinjection of wastewater until detailed investigations are undertaken to determine whether or not the risks associated with this practice can be managed to acceptable levels (***Recommendation 7.13***).	Not able to be determined
Unacceptable groundwater contamination due to induced connectivity between hydraulically fractured shale rock formation and overlying aquifers	*Likelihood* - remote to very low, provided that the hydraulic fracturing does not intersect with a fault. *Consequence* - medium. *Risk* - low.	Require submission of details of known fault locations and geomechanical planning for hydraulic fracturing by gas companies to the regulator (***Recommendation 7.14***).	Low

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Unacceptable groundwater contamination due to changed groundwater pressures	*Likelihood* - low due to very large distance between shale formation and aquifers. *Consequence* - medium. *Risk* - low, provided that the fracturing operations avoid the proximity of existing faults.	Require submission of details of known fault locations and geomechanical planning for hydraulic fracturing by gas companies to the regulator (***Recommendation 7.14***).	Low
Unacceptable contamination of surface waters due to the intentional discharge of partially treated or untreated wastewater	*Likelihood* - low, provided that this practice is prohibited. *Consequence* - medium, if during wet season when dilution is available and depending upon the concentrations of contaminants released. *Risk* - low.	Discharge of shale gas hydraulic fracturing wastewater (treated or untreated) to drainage lines, waterways or temporary stream systems should not be permitted (***Recommendation 7.16***).	Low
Adverse effects of linear infrastructure (roads, pipelines) on the quality and distribution of surface water across the landscape	*Likelihood* - medium, unlikely there will be problems with pipelines provided they are buried. *Consequence* - low to medium, depending upon how they are designed and constructed. *Risk* - medium.	Ensure that there is a landscape scale approach to the design of any infrastructure to minimise the possibility of flow disruption or concentration of flows and that all roads and pipeline corridors are constructed to comply with relevant guidelines, such as the International Erosion Control Association's Best Practice for Erosion and Sediment Control and the Australian Pipeline Industry Association Code of Environmental Practice 2009 (***Recommendation 7.17***).	Low

Environmental value 3: aquatic ecosystems and biodiversity

Environmental objective 3: to adequately protect ecosystems and biodiversity that are dependent on surface water or groundwater

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Excessive extraction from surface waters	*Likelihood* - low, given the lack of permanent surface water in Beetaloo Sub-basin and other semi-arid and arid regions. *Consequence* - medium, if volumes and flow regimes are altered. *Risk* - medium.	Prohibit use of surface water for onshore shale gas hydraulic fracturing in the NT (***Recommendation 7.5***). Develop WAPs for the Beetaloo Sub-basin region that specifically exclude use of surface waters for onshore shale gas development (***Recommendations 7.5*** and ***7.6***).	Low
Excessive extraction from groundwaters	*Likelihood* - low, for surface GDEs since none known in Beetaloo Sub-basin, undetermined for subterranean ecosystems (stygofauna). *Consequence* - undetermined for subterranean ecosystems. *Risk* - undetermined, lack of detailed knowledge of impact of subterranean fauna (stygofauna).	Undertake a SREBA of the Beetaloo Sub-basin, including a baseline study of surface and subterranean ecosystems (***Recommendation 7.4***).	Low for surface GDEs but undetermined for subterranean ecosystems
Unacceptable contamination of surface waters (aquatic ecosystems)	*Likelihood* - low. *Consequence* - medium. *Risk* - low.	Discharge of shale gas hydraulic fracturing wastewater (treated or untreated) to drainage lines, waterways or temporary stream systems should not be permitted (***Recommendation 7.16***). Store chemicals and wastewater in lined containment structures or tanks within bunded areas. Effectively manage accidental spills from well pads, road tankers or pipelines (see discussion at Sections 7.6.3.1, 7.6.3.2 and 7.6.7, and ***Recommendations 7.11*** and ***7.12***).	Low
Unacceptable contamination of groundwaters (groundwater-dependent ecosystems)	*Likelihood* (leaky wells) - low, little evidence of faulty contemporary wells leaking solutes. *Likelihood* (spills) - medium. *Consequence* -undetermined, impact of contaminants on surface GDEs and subterranean fauna unknown. *Risk* - undetermined.	Undertake a SREBA of the Beetaloo Sub-basin, including a baseline study of surface and subterranean ecosystems (***Recommendations 7.4, 7.18*** and ***7.19***). Undertake an ecological risk assessment of shale gas hydraulic fracking wastewater toxicity to stygofauna (see discussion at Sections 7.2.3, 7.7.1 and ***Recommendations 7.4, 7.18*** and ***7.19***).	Undetermined

Chapter 8 Land

Environmental value 1: terrestrial biodiversity and ecosystem health

Environmental objective 1: to ensure there is a low risk of impact on the terrestrial biodiversity values of affected bioregions and to ensure that the overall terrestrial ecosystem health, including the provision of ecosystem services, is maintained

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Unacceptable location of shale gas developments within a region	*Likelihood* - high, due to lack of region-wide biodiversity knowledge. *Consequence* - high, significant threat to species that might occupy highly restricted ranges in development area. *Risk* - high.	Undertake a SREBA for all affected bioregions prior to any onshore shale gas production. (***Recommendation 8.1***). Exclude onshore shale gas development from regions identified in the SREBA as having high conservation value (***Recommendation 8.1***).	Low
Unacceptable increase in the spread or impact of weeds	*Likelihood* - high, given experience with onshore gas developments elsewhere. Consequence - high, given severe potential impact on conservation and production values. *Risk* - high.	Undertake baseline assessment of all weeds on a permit area prior to any onshore shale gas exploration (***Recommendation 8.2***). Undertake ongoing weed monitoring to inform any necessary weed management measures (***Recommendation 8.2***). Ensure gas companies have in place prior to entering a petroleum title area, a weed management plan that is consistent with all relevant statutory weed management plans and any relevant threat abatement plans made under the EPBC Act (***Recommendation 8.3***).	Low
Unacceptable increase in the spread or impact of exotic invasive ants	*Likelihood* - medium, given that such species are established elsewhere in northern Australia and are readily spread by vehicles and machinery. *Consequence* - high, major impacts on native species if introduced. *Risk* - high.	Implement hygiene measures for vehicles and machinery (see discussion at Section 8.4.2.2 and ***Recommendation 8.3***).	Low
Unacceptable increase in the impact of feral animals	*Likelihood* - low, because onshore gas development is unlikely to have a significant impact on feral animal populations. *Consequence* - low, as any increased impact of feral animals is likely to be local only. *Risk* - low.	Require gas companies to be aware of regional feral animal management obligations and programs (see discussion at Section 8.4.2.3).	Low
Unacceptable changes to fire regimes	*Likelihood* - medium, increased human activity and hence sources of ignition. *Consequence* - high, given the ecological importance of fire and its role in GHG gas emissions. *Risk* - high.	Establish regional fire management plans, which include requirements for baseline data, monitoring for any increase in fire frequency, and implementation of management actions as appropriate (***Recommendation 8.4***).	Low

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Unacceptable loss of native vegetation	*Likelihood* - high, given that substantial areas will be cleared of vegetation. *Consequence* - low, because only small proportion of the landscape will be cleared, and fragmentation and edge effects are likely to be limited. Risk - medium.	Identify any threatened species likely to be affected by cumulative effects of habitat loss and fragmentation and manage accordingly (***Recommendation 8.5***). Minimise vegetation clearing (***Recommendation 8.6***). Progressively rehabilitate cleared areas (***Recommendation 8.7***). Implement offsets to compensate for local vegetation and habitat losses (***Recommendation 8.8***).	Low
Roads and pipelines as ecological barrier or corridors	*Likelihood* - medium, given impacts of past construction of roads and pipelines. *Consequence* - medium, given ecological importance of run-on/ run-off dynamics in flat, semi-arid landscapes. *Risk* - medium.	Require gas companies to identify critical habitats during corridor construction and select an appropriate mechanism to avoid detrimental impact upon them (***Recommendation 8.10***).	Low
Other impacts on wildlife	*Likelihood* - low, given management procedures already in place. *Consequence* - low, given that any impacts will be local only. *Risk* - low.	Implement existing management procedures (***Recommendation 8.10***).	Low

Environmental value 2: landscape amenity

Environmental objective 2: to ensure that the perception by residents and tourists that the NT is a place of largely unspoiled landscapes is not diminished

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Unacceptable landscape transformation	*Likelihood* - medium, given experiences with onshore gas developments elsewhere. *Consequence* - high, given the extremely high importance of the NT's unspoiled landscapes. *Risk* - high.	Ensure that gas companies minimise the surface footprint of each development and ensure that well pads are at least 2 km apart (***Recommendation 8.15***). Ensure that the infrastructure within development areas is not visible from public roads (***Recommendation 8.15***).	Low
Unacceptable increase in heavy-vehicle traffic	*Likelihood* - cannot be assessed, lack of predicted traffic information. *Consequence* - uncertain. *Risk* - uncertain.	Assess the impact that all heavy-vehicle traffic associated with any onshore shale gas industry will have on the NT's transport system, including: • forecast traffic volume and roads used; • the feasibility of using the existing Adelaide to Darwin railway line to reduce heavy-vehicle road use; and • road upgrades. Develop a management plan to mitigate such impacts (***Recommendation 8.16***).	Low to medium

Chapter 9 Greenhouse gases

Environmental value 3: climate change

Environmental objective: to limit the emissions of methane and greenhouse gases to the atmosphere

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Excessive upstream fugitive emissions of methane	*Likelihood* - high, given that methane emissions occur mostly on a continuous basis but with some episodic releases. *Consequence* - low, given that upstream methane emissions (from any new shale gas field) will contribute a very low proportion of net global methane emissions. *Risk* - medium.	Introduce the US EPA New Source Performance Standards of 2012 and 2016 (***Recommendation 9.1***).	Acceptable[1]
Abnormal fugitive emissions of methane during upstream production and processing	*Likelihood* - high, in the absence of monitoring and appropriate action. *Consequence* - low, given that upstream methane emissions (from any new shale gas field) will contribute a very low proportion of net global methane emissions. *Risk* - medium.	Implement a code of practice or other guideline for the ongoing monitoring, detection and reporting of emissions from gas fields and wells upon production commencing (***Recommendation 9.2***). Implement baseline monitoring of methane concentrations for at least one year in advance of production commencing (***Recommendation 9.3***). Implement baseline and ongoing monitoring by the regulator, to be funded by the industry. Measurements and their interpretation to be undertaken by an independent third party (***Recommendation 9.4***). Monitoring results should be published on a continuous real-time basis (***Recommendation 9.5***). Implement investigation if emission concentration limits are exceeded to identify the source(s) of the excess levels, and 'make good' provisions must be implemented where necessary. Such investigations and implementation must be the responsibility of industry. All methane exceedance events must be reported to the regulator and the information made public (***Recommendations 9.5*** and ***9.6***).	Acceptable
Excessive emissions of lifecycle greenhouse gas	*Likelihood* - high, given that GHG emissions occur mostly on a continuous basis but with some episodic releases. *Consequence* - low, given that GHG emissions (from any new shale gas field) will contribute a very low proportion of net global GHG emissions. *Risk* - medium.	Focus risk reduction on reducing upstream methane emissions as there is little opportunity to reduce GHG from the downstream stage (see discussion at Section 9.6).	Acceptable

1 The Panel assessed all GHG risks as 'medium', making it necessary to consider how these risks can be further mitigated. Given the assessed likelihood and consequence ratings cannot be reduced to a lower category, the assessed risks will remain medium. As the consequences are assessed as 'minor' or 'moderate' (they are not assessed as 'severe' or 'catastrophic'), it is not necessary to formally invoke the precautionary principle as the conditions precedent have not been met (see Chapter 4). Nevertheless, the precautionary principle has been considered and applied where appropriate.

The Panel believes that implementation of the additional mitigation measures specified in the recommendations contained in Chapter 9 will result in lower levels of emissions of methane and GHG and allow any new onshore shale gas field in the NT to achieve an acceptable level of risk for methane and GHG emissions.

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Excessive emissions of methane from abandoned wells	*Likelihood* - high, given that methane emissions from abandoned wells occur mostly on a continuous basis but with some episodic releases. *Consequence* - low, given that methane emissions from abandoned wells will contribute a very low proportion of net global methane emissions. *Risk* - medium.	Mandate a code of practice setting out minimum requirements for the abandonment of all onshore shale gas wells in the NT. The code must be enforceable and include a requirement that: • wells undergo pressure and cement integrity tests prior to abandonment, with any identified defects to be repaired prior to releasing the well for decommissioning; and • testing must be conducted to confirm that the plugs have been properly set in the well. (***Recommendation 5.1***) Provide a bank guarantee or bond to the regulator to ensure necessary funds are available to decommission wells or facilities in the event an operator is no longer a going concern (***Recommendation 14.19***).	Acceptable
Other (supplementary) risks may prevent lower levels of methane emission performance from being achieved	N/A	The action framework in **Table 9.10** to be implemented to manage and/or mitigate any supplementary risks that may prevent the achievement of lower levels of methane emissions (***Recommendation 9.7***).	Acceptable

Chapter 10 Public health

Environmental value 1: to prevent adverse impacts on public health by exposure to chemicals in contaminated water and air

Environmental objective 1: to assess and manage health risks associated with contaminated surface and groundwater

The risk estimates and risk mitigation measures for this objective are identical to those associated with water quality in Chapter 7.

Environmental objective 2: to assess and manage human health risks associated with the specific chemicals used in, or likely to result from, hydraulic fracturing processes

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Unacceptable human health effects caused by hydraulic fracturing and geogenic chemicals in flowback water	*Likelihood* - low, for hydraulic fracturing chemicals, unknown (at this time) for geogenic chemicals. *Consequence* - medium, if inadequate knowledge of the concentration or presence of more toxic chemicals compromises the estimation of health risks via a formal HHRA. *Risk* - low.	Require gas companies to prepare a site-specific HHRA that: • uses contemporary knowledge of the chemicals proposed to be used specifically in formulating fracking fluids for operations in the NT; and • provides further details of the chemical composition of flowback and produced water specific to the geological features of the NT sites proposed for shale gas development, along with the proposed methods of treatment and/or disposal of this water (***Recommendation 10.1*** and ***10.2***).	Low - for hydraulic fracturing chemicals Unknown - (at this time) for geogenic chemicals

Environmental objective 3: to ensure human health risks associated with airborne emissions from gas wells and associated infrastructure are acceptable

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Unacceptable impacts on the health of nearby communities from volatile or gaseous chemicals emitted from well heads, storage ponds, processing facilities or pipelines	*Likelihood* - medium for methane. Low for VOCs but highly dependent on the distance between source and potentially exposed humans. *Consequence* - low for methane (relatively non-toxic gas). Medium for toxic gases and VOCs (such as NOx, BTEX), especially where associated with gas combustion events (flaring). *Risk* - low to medium.	Require a high standard of maintenance to ensure well head assemblies and pipelines are not leaking, coupled with regular monitoring to detect point source leaks. (***Recommendations 5.1*** to ***5.4***). Establish appropriate setback distances to minimise risks identified in HHRA reports, including potential pathways for waterborne and airborne contaminants. In the absence of local information, a default minimum setback distance of 1.6 km (based on US data) should be used (***Recommendation 10.3***).	Low
Unacceptable impacts on the health of nearby communities from dusts and/or diesel exhaust fumes from shale gas site preparation activities	*Likelihood* - medium, but likely to be of relatively short-term impact during the pre-production phase of well head and facility development. *Consequence* - low to medium, depending on controls over equipment movements and/or dust suppression measures. *Risk* - low to medium.	Establish appropriate setback distances (based on scientific evidence) to protect landowners and local communities. In the absence of local information, a default minimum setback distance of 1.6 km (based on US data) should be used (***Recommendation 10.3***).	Low to medium

Environmental objective 4: to ensure the human health risks associated with potential impacts on wellbeing are acceptable

The assessment of this objective is primarily covered in Chapter 9, together with the assessments contained in Chapters 11 and 12.