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ASSESSMENTS

PROVIDING SCIENTIFIC WATER RESOURCE
INFORMATION ASSOCIATED WITH COAL
SEAM GAS AND LARGE COAL MINES

DRAFT - Systematic analysis of water-related hazards associated with coal seam gas in the Clarence-Moreton region

July 31, 2015



A scientific collaboration between the Department of the Environment,
Bureau of Meteorology, CSIRO and Geoscience Australia

The Bioregional Assessment Programme

The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated with coal seam gas and large coal mines. A bioregional assessment is a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and large coal mining development on water resources. This Programme draws on the best available scientific information and knowledge from many sources, including government, industry and regional communities, to produce bioregional assessments that are independent, scientifically robust, and relevant and meaningful at a regional scale.

The Programme is funded by the Australian Government Department of the Environment. The Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia are collaborating to undertake bioregional assessments. For more information, visit <http://www.bioregionalassessments.gov.au>.

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Executive Summary

This report is taken from the Bioregional Assessments programme. The report describes the hazard analysis completed for the Clarence-Moreton region, which built on previous work completed for the Bioregional Assessments programme. This is a draft, the final report will be available as part of the Bioregional Assessments Product 2.3.

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Contributors to the Technical Programme

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1 Background

Virtually all risk assessment frameworks include a separate hazard identification and analysis stage that starts once the stakeholders and assessment and measurement endpoints have been identified, and the temporal and spatial scope of the assessment has been determined. The hazard analysis stage serves several roles:

- It is the point in the risk assessment that asks the question ‘what can go wrong’ - i.e. it identifies the hazards associated with the activity in question.
- It may rank the hazards according to the extent to which they meet certain criteria. These criteria may be risk related - such as the likelihood of the hazard occurring and its consequences - but they may be much broader and reflect a wider range of issues - such as the likelihood that the hazard will be detected if it occurs, or the extent to which the hazard is managed by current legislative controls.
- It is the point in the risk assessment where the potential risks that will be addressed by the assessment, are separated from those that will not be addressed for whatever reason. The rationale for excluding certain hazards is typically unique to each assessment, and may sometimes be reflected in a set of screening criteria that are applied to each hazard to determine whether or not it is ‘within scope’.

The hazard identification and analysis stage of a risk assessment is arguably the most important step of any risk assessment. Hazards that are not identified in the early stages of a risk assessment will not be carried through the assessment, and this can ultimately lead to surprises and underestimates of risk.

Hazard identification techniques also play two other important roles within a risk assessment. First they are an effective and appropriate way to involve stakeholders and other interested parties in the risk assessment - indeed the views and opinions of these groups can provide a deeper and richer appreciation of the problem in hand (Stern and Fineberg, 1996). Second, they can help in the design of statistically valid monitoring strategies by highlighting where and when to look for potential adverse events – it is much easier to monitor a situation when you know what to look out for.

Methods for identifying and ranking hazards vary according to application and novelty of the risk-generating activity. Simple check lists, for example, are sometimes used to list hazards and ensure risk mitigation strategies have been applied to activities that have a long history of successful operation – i.e. to activities where the long operation history provides assurance that the risks are well understood, or have been successfully managed in the past.

Hazard identification for novel technologies, with which we have little if any history of operation, is more demanding. Without the hindsight that a long operating experience provides, the analyst

36 must try to identify all the possible ways things may go wrong in a careful and systematic manner.
37 In complex systems this is difficult so over the years scientists and engineers have developed
38 techniques to assist the analyst in this task. Examples of these techniques include Fault Tree
39 analysis, Hazard and Operability studies, Hierarchical Holographic Modelling and Failure Modes
40 and Effects Analysis (Vesely et al., 1981; Haimes, 1981; Ozog and Bendixen, 1987; Kletz, 1999).

41 In this report we demonstrate the application of Failure Modes and Effects Analysis (FMEA), to
42 the hazards associated with CSG operations in the CLM region. We restrict our attention to
43 water-borne hazards - i.e. hazards that might lead directly or indirectly to impacts on ground or
44 surface water related assets. All other hazards, for example effects of air quality, are explicitly
45 excluded from this analysis.

2 Methods

2.1 Failure Modes and Effects Analysis

Failure Modes and Effects Analysis (FMEA) is a structured process for identifying hazards in complex systems that are composed of many components. It was originally developed by the US military in 1949 to determine the effect of equipment and system failures, and was subsequently developed in the mid-1960s to improve safety in the aerospace industry (Ericson, 2005; McDermott et al., 1996). It has since been widely adopted for other industries that operate complex plants, such as the petro-chemical industry and the automotive industry, and has also been previously applied to mining operations, in relation to mine equipment safety (Daling and Geffen, 1983; Dhillon, 2009), and the construction and operation of a tailings dam (Correia dos Santos et al., 2012).

FMEA is a 'bottom-up' hazard-analysis tool. It begins with a thorough description of the overall system, its sub-systems and individual components. It then identifies all the possible ways in which each component can fail (the 'failure modes') and assesses the severity of the effects of these failures on other components and the overall functioning of the system (Ozog and Bendixen, 1987). It then continues to consider both the likelihood of the failure modes and likelihood of their detection given current controls. In industrial systems, the process is usually formalised as a six-step procedure:

1. Identify and list all components;
2. Identify all failure modes, considering all possible operating modes;
3. List the potential effects of each failure mode and score their severity;
4. List the potential causes of each failure mode and score their likelihood;
5. List the current controls to prevent the failure mode and score the likelihood of detection;
6. Calculate the risk priority number.

The severity, likelihood and detection ratings are usually scored from 1 (lowest rating) to 10 (highest). The Risk Priority Number (RPN) is the product of the three scores, and is the traditional measure used to rank failure modes.

A team of four to six people usually conducts an FMEA, with a coordinating team leader. Each member of the team must be familiar with one or more aspects of the system in question. For example, an industrial FMEA team might consist of a team leader, design engineers, process engineers, plant operatives and their supervisors.

The main advantages of FMEA is that it is systematic, thorough and transparent, and does not require specialised training (but it does require a detailed knowledge of the system under examination). The main disadvantages of FMEA are that it can be time consuming to complete, and does not normally consider the effects of multiple failure modes occurring simultaneously

⁸¹ within the system. It has nonetheless proven to be an effective hazard analysis tool, when
⁸² implemented correctly.

83 2.2 Impact Modes and Effects Analysis

84 In a traditional FMEA, the failure of an industrial system's components is defined as a deviation
85 from the function for which it has been designed, or a deviation from its intended operation. In the
86 application of FMEA to bioregional assessments, however, we are concerned not only with
87 deviations from intended design but also in water-borne hazards associated with the intended CSG
88 and open-cut mining operations. In this context hazards can arise as part of the normal operation
89 of the mine or CSG plant. The use of the term 'failure' is therefore inappropriate and potentially
90 misleading, so we have renamed the process we employ here Impact Modes and Effects Analysis
91 (IMEA) to reflect the reporting of impacts, rather than failures.

92 In this IMEA the 'components' of the system under study are the whole-of-life-cycle activities and
93 operations associated with CSG and open-cut mining operations in Australia. Hence we replace
94 reference to 'component failures modes' with 'activity impact modes'. These activities are both
95 planned (deliberate) and unplanned (accidental).

96 The IMEA reported here was specifically designed to meet the risk identification requirements of
97 the BRAM. The IMEA begins by identifying all of the activities and processes that take place
98 through-out the entire life-cycle of CSG and open-cut mining operations. The analysis then
99 considers how each of these activities may potentially impact on water-dependent assets. Each of
100 the impact modes are then scored for severity, likelihood and probability of detection under a set of
101 control measures that might reasonably be assumed to be in place as part of standard Australian
102 industry operating procedures (see Figure 1).

103 The IMEA for the Namoi region was completed during a one day face-to-face workshop. The
104 relatively rapid completion of the assessment was made possible by a substantial body of work
105 done previously for the Gloucester and Galilee bioregions during which all the activities associated
106 with the entire life-cycle – exploration and appraisal through to decommissioning – of CSG,
107 open-cut mining and underground mining operations were listed and scored according to the IMEA
108 procedure. The completion of the analysis for the Namoi required only that the scores be adjusted
109 for the Namoi-specific conditions.

110 IMEA is an expert-driven approach to hazard identification, mitigation and prioritization. It's value
111 depends on having the appropriate knowledge and expertise in the room when identifying and
112 scoring impact modes. For this reason, and due to the focus on ground and surface water effects,
113 the workshop included participants with expertise in geology, hydrology, and expertise in mine
114 operation and performance.

115 It is important to emphasise that the focus here is on hazard identification and relative ranking not
116 absolute risk estimation. **The likelihood and severity scores elicited here should not be
117 used as an absolute measure of risk.** Expert judgements about the likelihood of uncertain
118 events are known to be prone to a number of biases and errors that occur because humans tend to
119 rely on simple rules of thumb ('heuristics') to solve complex problems quickly (Kahneman and
120 Tversky, 1982; Tversky and Kahneman, 1974; Kynn, 2008).

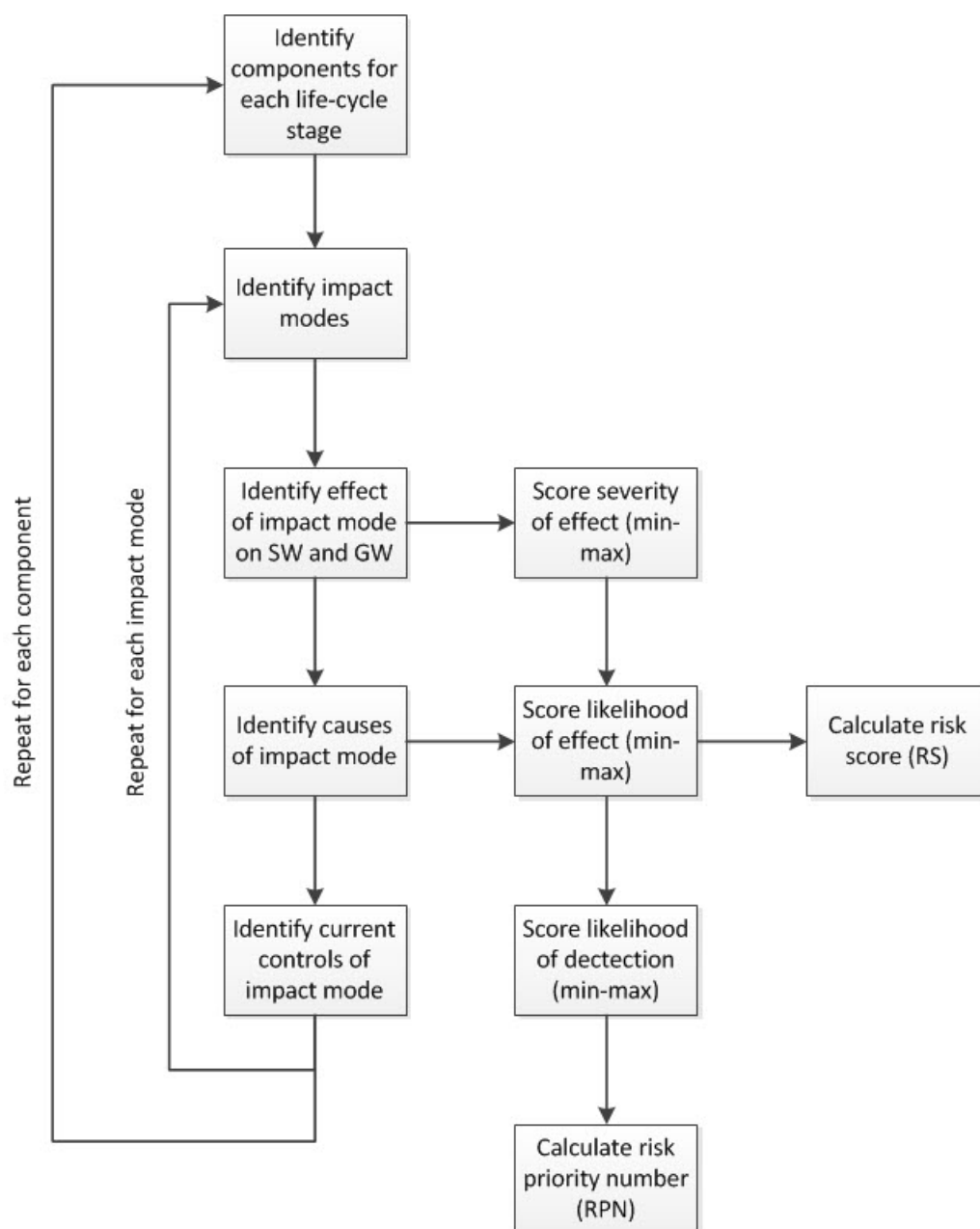


Figure 1 Flow chart showing the steps in a Impact Modes and Effects Analysis (IMEA). IMEA is a structured hazard analysis methodology that identifies all the components of a system and the ways in which these components may have impact on ground water and surface water. It then identifies the effects and causes of each impact, and scores the severity and the likelihood of this effect on an interval (min-max). Finally it identifies current control systems that are in place and scores the likelihood of detecting an impact under these controls. This process is repeated for all of a component's impact modes and for all the components of the system under study. At each iteration the sum of the three scores (on a logarithmic scale) is used to rank hazards via the Risk Priority Number (or two scores in the case of Risk Score).

121 Good risk elicitation exercises employ a series of techniques that are designed to try and avoid the
 122 biases and systematic errors that these heuristics induce. These techniques were deliberately not
 123 employed when the IMEA scores were elicited because they are time-consuming, and the objective
 124 of the IMEA scores is to provide a relative measure of each hazard's importance - i.e. a hazard
 125 score where the rank is important not its absolute value.

126 2.3 Impact Modes and Effects Analysis structure

127 2.3.1 Components, life-cycle and activities

128 IMEA attempts to identify all the ways in which all the parts of a complex system may potentially
129 impact on water-dependent assets. Here the 'parts' of the system are the activities associated with
130 the major components of a CSG and mine operation. In the case of a CSG development the system
131 activities were sub-divided into those associated with the wells, processing facilities, pipelines, roads
132 and associated infrastructure. For open and underground mines the activities were sub-divided into
133 those associated with the open pit, underground mining, surface facilities and infrastructure.

134 Prior to identifying the activities that occur under each of these headings, each sub-system was
135 further expanded into five life-cycle stages. For CSG these comprised: (i) exploration and appraisal;
136 (ii) construction; (iii) production; (iv) work-over; and, (v) decommissioning. The open-cut mining
137 life-cycle stages are similar, comprising: (i) exploration and appraisal; (ii) development; (iii)
138 production; (iv) mine closure; and, (v) rehabilitation. It is important to allocate activities to their
139 appropriate life-cycle stage because the scale and duration of similar activities can be quite
140 different across the different life-stages, and this is often reflected in the scores for consequence
141 and/or likelihood of the impact modes associated with these activities.

142 2.3.2 Impact modes, effects and stressors

143 The IMEA progresses by identifying all possible ways in which the activities (as described above)
144 may have an impact on ground water or surface water. The impact modes may arise through
145 various mechanisms, for example:

- 146 • anthropogenic activities that are deliberate and expected to occur with open-cut or
147 underground mining, such as clearing the vegetation along a pipeline corridor;
- 148 • accidental events due to human error, failures in infrastructure or poor implementation of the
149 operating procedures associated with an activity, such as pipe-line containment loss due to
150 accidental rupture or spillage of petrol around refuelling facilities;
- 151 • abnormal natural events such as heavy rainfall or floods that may compound the impacts of
152 deliberate events or lead to accidental events such as the collapse of a containment pond wall.

153 The participants in the IMEA workshops were invited to identify all plausible impact modes on an
154 activity by activity basis, together with the potential effects of these impact modes on ground
155 and/or surface water assets. Effects represent potentially undesirable changes in the characteristics
156 of these assets, for example, changes in the pressure, quality or volume of a groundwater or surface
157 water resource.

158 2.3.3 Scoring severity, likelihood and detection

159 Traditionally FMEA elicits from experts a single score for the severity, likelihood and probability of,
160 or equivalently time to, detection given current controls. The potential effects (hazards) are then

ranked (high to low) according to the product of these scores, known as the 'Risk Priority Number' (Figure 1).

In our experience, however, the elicitation of scores proceeds far more efficiently if experts are allowed to provide an interval for each score, where the range between the lower and upper bound of this interval represents their uncertainty. Allowing for a range via the interval also provides a quick and efficient way to envelope and thereby reconcile the opinions of multiple experts in a single elicitation. This avoids forcing the experts to agree on a single most appropriate value, which often they are reluctant to do.

In this analysis we also amend the traditional approach to FMEA scoring by adopting the logarithmic scale recommended by Lin et al. (2013). In this approach scores are provided on a base-ten logarithmic scale. This has two notable advantages over other traditional scoring methods. Firstly, the magnitude of change is a constant multiple ($\times 10$) from one score to the next, thereby assisting with the elicitation and interpretation of the scores. Secondly the logarithmic scale creates the opportunity to compare the expert's scores for the likelihood and detection of events with actual known outcomes, and thereby provide a means to calibrate their scores against actual outcomes.

The IMEA severity score is used to measure the severity of the effect of an activity's impact mode. Table 1 shows the definitions of effect and corresponding score adapted from Lin et al. (2013) and Springsure Creek Coal Pty Ltd (2013) to score impacts on environmental assets. The IMEA elicits an interval (upper and lower score) for each impact mode that all participants were able to agree upon. Here a one unit increase, for example from 'Tiny' to 'Minimal' corresponds (roughly) to a ten-fold increase in environmental impact.

Table 1 Environmental consequence (severity) levels and their corresponding scores (adapted from Lin et al. (2013) and Springsure Creek Coal Pty Ltd (2013))

Impact level	Environment	Score
None	No impact	3
Tiny	Minimal impact on ecosystem; contained on mining lease, reversible in 1 year	4
Minimal	Moderate impact on ecosystem; contained on mining lease, reversible in 1-5 years	5
Minor	Moderate impact on ecosystem; contained on mining lease, reversible in 5 – 10 years	6
Moderate	Significant impact on ecosystem; impact at level of exploration lease, reversible in ~ 10 years	7
Major	Significant harm or irreversible impact to World Heritage area, species; widespread, catchment area, long term, > 10 years	8
Catastrophic	Incident(s) due to unforeseen circumstances causing significant harm or irreversible impact to World Heritage area, species; widespread, long term	9

It is theoretically possible to calibrate the impact scores against actual environmental outcomes. In practise, however, this would be a much more difficult task due to the ambiguity associated with terms used to define the impact scores, despite the guidance provided by the definitions in Table 1. The magnitude of direct impacts associated with mining operations are quantified in much more formal, carefully structured, elicitation procedure at a later stage in the bioregional assessment

188 process. Again the role of the impact scores at this stage is to develop an overall hazard ranking,
189 not an absolute measure of risk.

190 The likelihood of a impact mode occurring was scored in a similar fashion, so that a one step
191 change in score indicates a 10-fold increase/decrease in the probability of occurrence (Table 2).

192 The scores indicate a rate per year, so that

$$\text{Annual occurrence rate} = 10^{\text{Likelihood score}} \quad (1)$$

193 Hence a likelihood score of -2 (Rare) equates to a predicted annual occurrence probability (or
194 annual frequency) of $10^{-2} = 1/100 = 0.01$. Note that the likelihood of an event can be readily
195 defined in a much more precise manner than the impact of an event. It is therefore easier to
196 compare the likelihood scores with actual outcomes and thereby calibrate the experts' opinions if
197 data on the impact mode (e.g. incomplete well casing) are available.

198 The probability of detection, or time to detection, is scored in the same fashion as the likelihood
199 score but on a scale specifically developed for the IMEA (Table 3). Again these definitions are
200 readily defined in a precise manner, hence these scores can also be calibrated against real-world
201 outcomes given appropriate data sets.

202 2.3.4 Hazard ranking

203 Hazards identified by the IMEA can be ranked according to the Risk Priority Number (RPN) (see
204 equation 2) or the Risk Score (RS) (see equation 3). The first is the traditional or 'reactive'
205 approach to prioritise management actions. The RS approach is referred to as the 'proactive'
206 approach because it aims to reduce the likelihood and severity of impact modes before allocating
207 resources to improve detection (Palady, 1995).

$$\text{Risk Priority Number} = \text{Severity} + \text{Likelihood} + \text{Detection} \quad (2)$$

$$\text{Risk Score} = \text{Severity} + \text{Likelihood} \quad (3)$$

208 As noted in Section 2.3.3, IMEA scores are normally based on a single elicited value. In this
209 analysis, however, experts were allowed to provide an interval for the reasons outlined above. The
210 additional information provided by the interval provides a number of alternative options for
211 calculating the overall score of any given impact mode. Several potential alternatives were
212 considered, including ranking by:

- 213 1. lowest, mid or highest RS or RPN
- 214 2. lowest, mid or highest RS or RPN weighted according to the inverse of the range of the score

215 The range of the RS or RPN were interpreted as a measure of the expert's certainty, hence
216 weighting by the inverse of the range places greater emphasis on this impact modes that the
217 expert's are more certain of - i.e. those that have a smaller range. Ranking hazards in this manner,
218 however, over-emphasised a large number of relatively trivial hazards and was in our opinion
219 misleading. As such this was not therefore pursued further.

Table 2 Likelihood score. Likelihood, indicative recurrence, and associated likelihood score.

Likelihood	Indicative recurrence	Likelihood score
Extremely rare	One event in 1000 years	-3
Very rare	One event in 333 years	-2.5
Rare	One event in 100 years	-2
Very unlikely	One event in 33 years	-1.5
Unlikely	One event in 10 years	-1
Possible	One event in 3 years	-0.5
Likely	One event in 1 year	0
Almost certain	Three events in 1 year	0.5
Most certain	Ten events in 1 year	1
Frequently	33 events in 1 year	1.5
Very frequently	100 events in 1 year	2
Every day	365 events in 1 year	2.5

Table 3 Detection score. Detection, indicative days to detect, and associated detection score.

Detection	Indicative days to detect	Detection score
Almost impossible	33333 days	4.5
Extremely hard	10000 days	4
Very hard	3333 days	3.5
Hard	1000 days	3
Quite hard	333 days	2.5
Easy	100 days	2
Quite easy	33 days	1.5
Very easy	10 days	1
Almost same day	3 days	0.5
Same day	1 day (within 24 hours)	0
Less than a day	0.3 of a day (<8 hours)	-0.5

220 A high RPN may result from an average severity and likelihood, and high detection score (difficult
 221 to detect), whereas a lower ranking may occur from a high severity and likelihood, but low
 222 detection score (easy to detect). Although this is entirely within the scope of the hazard analysis,
 223 the RPN can mask the potential importance of some of the impact modes with high severity and
 224 likelihood. Comparing the RPN with the RS, which focuses only on the severity and likelihood of
 225 the impact modes, helps avoid this. We therefore elected to rank hazards by the mid-point of the
 226 RS and RPN range. The range of the scores are also presented, showing the lowest RS and highest
 227 RPN.

228 3 Results - Clarence-Moreton

229 3.1 Coal seam gas

230 3.1.1 Effects and stressors and failure causes

231 All unique effects and stressors identified during the IMEA process. Note: each impact may have
 232 multiple effects and stressors, and thus total count of unique effects and stressors will differ with
 233 unique impacts/current controls. The potential impacts of CSG on water-dependent assets in the
 234 CLM region were grouped into 10 unique effect categories, including impacts on surface water and
 235 groundwater quality; surface water volume, direction, and flow; and groundwater quantity,
 236 pressure, direction and composition; and aquifer properties (Table 4). Of these, impacts on surface
 237 water quality were the most frequently identified impact (118) followed by groundwater quality
 238 (47), and surface water volume (20). Table 5 lists the unique stressors identified during the IMEA
 239 process for coal seam gas, together with the frequency with which they were identified during the
 240 analysis. The two most frequently cited stressors are Total Suspended Solids (TSS) and pollutants
 241 (including metals, trace elements, sulfides and phosphorus). Following these, the next most
 242 common stressors are salts (expressed as Total Dissolved Solids, TDS), hydrocarbons, and changes
 243 to surface water flow.

Table 4 Unique effects (for coal seam gas) identified during the Impact Modes Effects Analysis process.
SW = surface water; GW = ground water; SW flow = change in surface water flow volume; GW
composition = mixing groundwaters of different composition (in terms of natural dissolved solids).

Effect	Frequency
SW quality	118
GW quality	47
SW volume	20
change in GW pressure	12
SW directional characteristics	10
GW composition	6
SW flow	6
GW quantity	4
Aquifer properties	2
GW flow (reduction)	1

Table 5 Unique stressors (for coal seam gas) identified during the Impact Modes Effects Analysis process. SW = surface water; GW = ground water; TSS = total suspended solids; TDS = total dissolved solids, salts; SW/GW flow = change in surface water/ groundwater flow volume; GW/SW composition = mixing waters of different composition (in terms of natural dissolved solids); Pollutants = anthropogenic contaminants.

Stressor	Frequency
TSS	71
Pollutants (e.g. metals/trace elements/sulfides/phosphorous)	41
Hydrocarbons	35
TDS	33
SW flow	25
Drilling mud products	17
change in GW pressure	12
GW composition	7
Chemicals	6
pH	6
GW flow	4
Hydraulic fracturing chemicals	4
Organic pollutants	3
Aquifer properties	2
Drilling fluids	2
Cement	1
Subsidence	1
SW composition	1

Table 6 lists the unique impact causes, together with their citation frequency, that were identified during the IMEA for CSG in the CLM region. The most frequently cited impact causes are:

- litter and spills associated with ground support operations are a potential source of hazards in many contexts, but these hazard were deemed to be of a very low priority and well managed given current controls;
- a good proportion of the hazards associated with CSG operations were attributed to inevitable, deliberate or accidental incidents;
- removal of vegetation and diversion of site drain lines are cited relatively frequently in the list of potential impact causes. Their potential impacts are not deemed negligible (due to the potential for weed invasion, habitat fragmentation and soil erosion) but neither do they rank in the top hazards (see below). By virtue of their frequency these types of impacts may warrant additional attention in relation to the potential for cumulative effects.

These results have implications for the scope of the Bioregional Assessments. For example, if their scope is limited to those impacts that are anticipated to occur during the normal operations of CSG activities ('deliberate' impacts) then these accidental hazards will be excluded. Conversely if accidental events are included within the assessments then there will need to be capacity to estimate the likelihood of these events, beyond the approach developed here. Similarly, the relatively high frequency of site vegetation removal, which was also commonly associated with TSS threats to neighbouring surface water bodies, may warrant further examination. If upon re-examination the potential (absolute rather than relative) magnitude of impact is deemed important then this implies that the Bioregional Assessments may need the capacity to model soil erosion and the consequent increase in TSS loads.

Table 6 All unique Impact Causes (for coal seam gas) identified during the Impact Modes Effects Analysis process.

Unique Impact Causes	Frequency
Human error, accident (e.g. containment loss, digging, ignition, logging machine fault, formation variation)	32
Litter, spills	24
Corridor/site vegetation removal	20
Diverting site/corridor drain line	17
Containment failure/leaching/flooding (e.g. lining material failure, loss of holding capacity, pipe failure, dam failure)	10
Inevitable, Deliberate	10
Number of drilling control issues	5
Poor design, construction, implementation, management (e.g. Abandonment practice, bore location, lack of knowledge, historical data records, sealing practices, geological characterisation); Containment failure/leaching/flooding (e.g. lining material failure, loss of holding capacity, pipe failure, dam failure)	5
Ignition following pipe failure; Natural disaster (e.g. bushfire, flooding, earthquake)	4

Inappropriate disposal; Containment failure/leaching/flooding (e.g. lining material failure, loss of holding capacity, pipe failure, dam failure)	4
Human error, accident (e.g. containment loss, digging, ignition, logging machine fault, formation variation); Containment failure/leaching/flooding (e.g. lining material failure, loss of holding capacity, pipe failure, dam failure)	3
Poor design, construction, implementation, management (e.g. Abandonment practice, bore location, lack of knowledge, historical data records, sealing practices, geological characterisation); Natural disaster (e.g. bushfire, flooding, earthquake)	3
Human error, accident (e.g. containment loss, digging, ignition, logging machine fault, formation variation); Natural disaster (e.g. bushfire, flooding, earthquake)	2
Incidental to vegetation removal and compaction in pipeline corridor	2
Incomplete grouting	2
Aquitard leaks	1
Containment failure/leaching/flooding (e.g. lining material failure, loss of holding capacity, pipe failure, dam failure); Natural disaster (e.g. bushfire, flooding, earthquake)	1
Depressurisation	1
Fault open or opening	1
Inappropriate disposal	1
Incomplete reservoir knowledge, too much pressure	1
Interrupting ephemeral water courses	1
Production of water	1

3.1.2 High priority hazards

Table 7 and table 8 list the 30 highest ranked hazards, by RS and RPN respectively, together with their associated stressors and citation frequency (multiple impact modes occurring several times). When ranked by Risk Score, the analysis identifies disruption of natural surface drainage as the most frequent hazard associated with coal seam gas in the CLM region, occurring ten times in the top 30. This impact mode occurred through multiple activities during the construction phase, the top three associated activities were gas and water gathering pipeline networks (well to processing plant); gas-gathering pipeline networks; and trunk gas pipelines and associated easements (processing plant to town). Soil erosion following heavy rain fall occurred six times in the top 30, due to the topography of the CLM bioregion. The top three activities for this impact mode were: pump and well head installation, gas and water-gathering pipeline networks (well to processing plant); and trunk gas pipelines and associated easements (processing plant to town). These two impact modes were most frequent when ranked by Risk Priority Number. Following these were multiple impact modes with difficult detection (e.g. Leaking, Aquifer depressurisation).

Table 7 Top 30 Impact modes for coal seam gas (ranked by high Risk Score), associated stressors and frequency in the top 30.

Impact Mode	Stressors	Freq in top 30
Disruption of natural surface drainage	TSS, SW flow, GW flow	10
Soil erosion following heavy rainfall	TSS	6
Overflow and/or loss of containment	TSS, Drilling mud products, TDS	2
Aquifer depressurisation	change in GW pressure	1
Aquifer depressurisation (coal seam)	change in GW pressure	1
Aquifer depressurisation (fault-mediated)	change in GW pressure	1
Aquifer depressurisation (non-target, non-reservoir)	change in GW pressure	1
Containment failure	TSS, TDS, pH, Pollutants (e.g. metals/trace ele- ments/sulfides/phosphorous)	1
Contaminate non-target aquifer (chemical)	Hydraulic fracturing chemicals	1
Contaminate target aquifer (chemical)	Hydraulic fracturing chemicals	1
Disruption to natural surface water course (e.g. creek crossing)	SW flow	1
Imbalance of mud pressure between well and aquifer	TSS, Drilling mud products, TDS	1
Incomplete seal	TDS, Hydrocarbons, change in GW pressure	1
Incomplete/compromised cementing/casing (linking aquifers)	GW composition, Hydrocarbons	1
Leaching from storage ponds	TDS, Chemicals	1

Table 8 Top 30 Impact modes for coal seam gas (ranked by high Risk Priority Number), associated stressors and frequency in the top 30.

Impact Mode	Stressors	Freq in top 30
Disruption of natural surface drainage	TSS, SW flow, GW flow	9
Soil erosion following heavy rainfall	TSS	3
Incomplete/compromised cementing/casing (linking aquifers)	GW composition, Hydrocarbons	2
Leaking	TSS, TDS, pH, Pollutants (e.g. metals/trace elements/sulphides/phosphorous)	2
Aquifer depressurisation	change in GW pressure	1
Aquifer depressurisation (coal seam)	change in GW pressure	1
Aquifer depressurisation (fault-mediated)	change in GW pressure	1
Aquifer depressurisation (non-target, non-reservoir)	change in GW pressure	1
Bore leakage between aquifers	GW composition, Hydrocarbons	1
Bore leakage to surface	SW composition, Hydrocarbons	1
Connecting aquifers	GW composition, Hydrocarbons	1
Contaminate non-target aquifer (chemical)	Hydraulic fracturing chemicals	1
Incomplete seal	TDS, Hydrocarbons, change in GW pressure	1
Incomplete/compromised cementing/casing (gas leakage)	TDS, Hydrocarbons	1
Leaching from storage ponds	TDS, Chemicals	1
Miss perforation target and depressurise aquifers	change in GW pressure	1
Seal integrity loss	TDS, Hydrocarbons, change in GW pressure	1
Subsidence	Subsidence	1

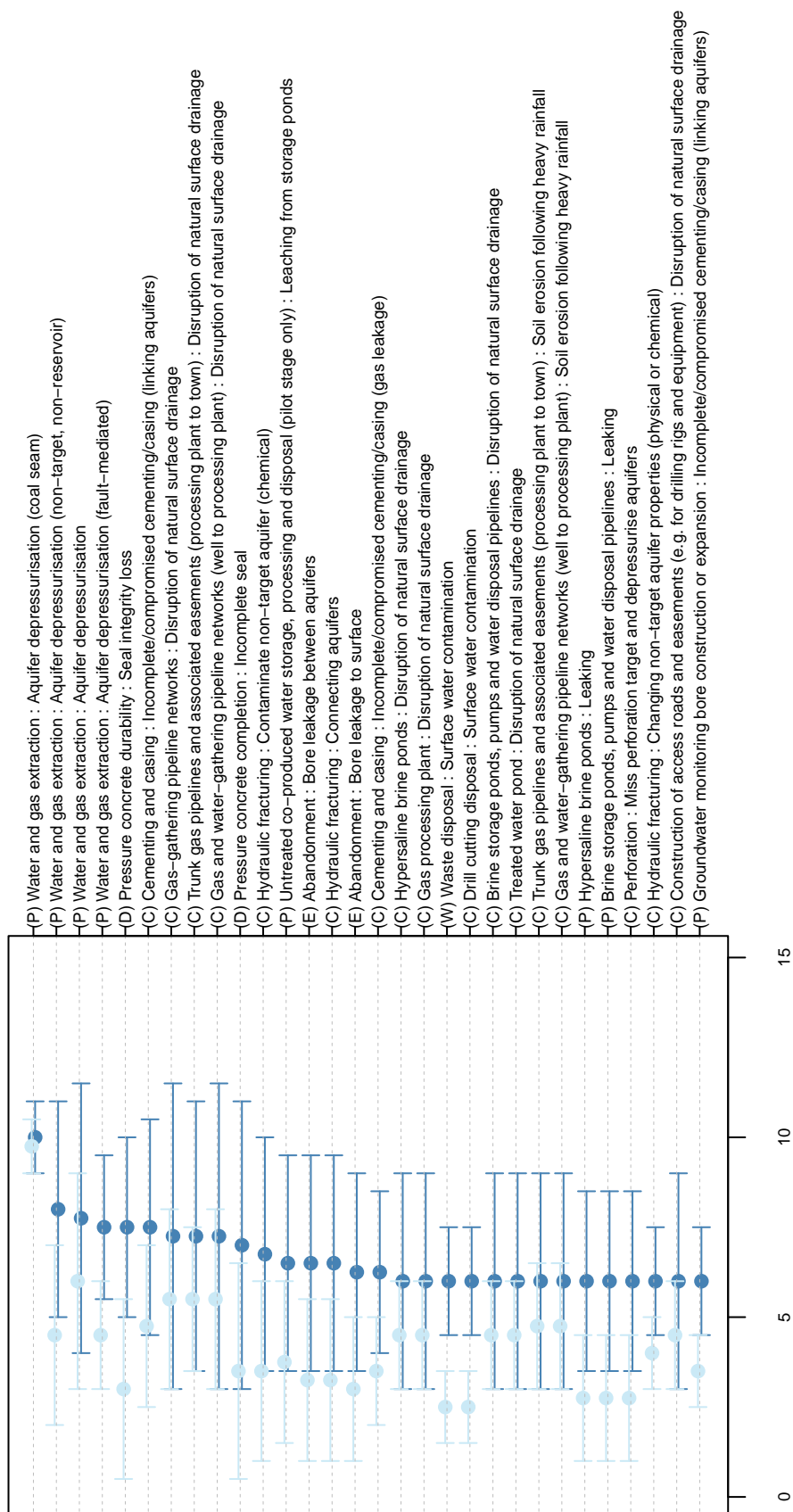


Figure 2 Highest ranked hazards for coal seam gas operations ranked by Risk Priority Number mid-point. The x-axis shows the Risk Priority Number and Risk Score. The interval between the highest and lowest Risk Priority Number are shown in dark blue, and the Risk Score intervals are shown in light blue. The same hazard may appear multiple times, as it may arise from a number of different Life cycle and Activities. Life cycle stages are indicated by (E) for exploration and appraisal, (P) for production, (D) for decommissioning, and (W) for work over.

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A Appendix A: Coal seam gas life-cycles and activities

Table A.1 Unique activities during exploration phase.

Activity
Accommodation, administration, workshop, depots, service facilities
Brine storage ponds, pumps and water disposal pipelines
Fuel and oil
Fuel and oil storage facilities
Gas-gathering pipeline networks
Gas and water-gathering pipeline networks (well to processing plant)
Gas compression stations
Gas processing plant
Groundwater monitoring bore construction or expansion
Hypersaline brine ponds
Materials delivery and storage
Operation access roads and easements (e.g. for drilling rigs and equipment)
Power and communications
Power generation facility (for processing plant)
Sewage treatment and disposal
Staff movement and activities
Treated water pond
Trunk gas pipelines and associated easements (processing plant to town)
Untreated co-produced water storage, processing and disposal (pilot stage only)
Water and gas extraction

Table A.2 Unique activities during construction phase.

Activity
Accommodation, administration, workshop, depots, service facilities
Brine storage ponds, pumps and water disposal pipelines
Cementing and casing
Construction of access roads and easements (e.g. for drilling rigs and equipment)
Drill cutting disposal
Drill stem testing (extraction)
Drilling and logging
Fuel and oil
Fuel and oil storage facilities
Gas-gathering pipeline networks
Gas and water-gathering pipeline networks (well to processing plant)
Gas compression stations
Gas processing plant
Groundwater monitoring bore construction
Horizontal drilling
Hydraulic fracturing
Hydraulic fracturing concentrate delivery
Hydraulic fracturing fluid injection and disposal
Hypersaline brine ponds
Materials delivery and storage
Perforation
Power and communications
Power generation facility (for processing plant)
Pump and well head installation
Remediation
Sewage treatment and disposal
Site preparation
Surface water and mud storage and evaporation
Treated water pond
Trunk gas pipelines and associated easements (processing plant to town)
Water treatment plant (RO, fixed resin, fixed disc, electrochemical, etc)

Table A.3 Unique activities during production phase.

Activity
Abandonment
Construction of access roads and easements (e.g. for drilling rigs and equipment)
Drill cutting disposal
Drill stem testing (extraction)
Drilling and coring
Fuel and oil
Ground-based geophysics
Materials delivery and storage
Power and communications
Pump testing
Site clean-up and rehabilitation
Site preparation
Slug testing (injection)
Surface core testing
Surface water and mud storage and evaporation
Temporary Accommodation, administration, workshop, depots, service facilities

Table A.4 Unique activities during decommissioning phase.

Activity
Fuel and oil
Materials delivery and storage
Pressure concrete completion
Pressure concrete durability
Process production plant
Sewage treatment and disposal

B Appendix B: Coal seam gas unique impact modes

All unique impact modes identified during the IMEA process are listed in Table B.1.

Table B.1 All unique Impact Modes (for coal seam gas) identified during the Impact Modes Effects Analysis process.

Unique Impact Modes
Accidental intersection of aquifer
Accidental intersection of fault
Aquifer depressurisation
Aquifer depressurisation (coal seam)
Aquifer depressurisation (fault-mediated)
Aquifer depressurisation (non-target, non-reservoir)
Bore leakage between aquifers
Bore leakage to surface
Changing non-target aquifer properties (physical or chemical)
Changing target aquifer properties (physical or chemical)
Connecting aquifers
Containment failure
Contaminate non-target aquifer (chemical)
Contaminate target aquifer (chemical)
Cuttings disposal
Dam failure
Disruption of natural surface drainage
Disruption to natural surface water course (e.g. creek crossing)
Fire
Fluid loss to aquifer
Imbalance of mud pressure between well and aquifer
Impacts of ground support staff
Incomplete seal
Incomplete/compromised cementing/casing (gas leakage)
Incomplete/compromised cementing/casing (linking aquifers)
Interruption of natural surface drainage
Leaching from storage ponds
Leaking
Localised watertable reduction
Miss perforation target and connect aquifers through the well
Miss perforation target and depressurise aquifers
Mud and drill cutting spillage
Mud spillage and poor rubbish disposal
Overflow and/or loss of containment
Pipe failure
Pipeline failure
Recovered fluid disposal
Reduction in pressure head
Seal integrity loss
Soil erosion following heavy rainfall
Spillage

Spillage and/or inappropriate disposal
Spillage: e.g. diesel
Spillage: e.g. of sewage
Spillage: on site
Spillage: prior to dilution on site
Subsidence
Surface water contamination
Temporary disruption to natural surface water course (e.g. sandbagging a creek to lay pipe)
Very localised watertable reduction

C Appendix C: Coal seam gas unique current controls

Current controls include potential mitigation measures/management plans. All unique current methods of control which were identified by the experts are listed in Table C.1.

Table C.1 All unique Current Controls (for coal seam gas) identified during the Impact Modes Effects Analysis process.

Unique Current Controls
Australian standard; Good design, monitoring, management (e.g. site selection, erosion control, engineering works, formation knowledge, monitor temp and water, pipe inspection, staff training)
Careful handling; Good design, monitoring, management (e.g. site selection, erosion control, engineering works, formation knowledge, monitor temp and water, pipe inspection, staff training)
Deliberate
Good design, monitoring, management (e.g. site selection, erosion control, engineering works, formation knowledge, monitor temp and water, pipe inspection, staff training)
Regulations (e.g. abandonment practice, irrigation management practice, logging practice, disposal practice, waste disposal, bore construction standards and post-cement logging, guidelines for slug testing planning)
Regulations (e.g. abandonment practice, irrigation management practice, logging practice, disposal practice, waste disposal, bore construction standards and post-cement logging, guidelines for slug testing planning); Good design/monitoring/management (e.g. staff training)
Use existing tracks where possible

³²⁶ **D Appendix D: Listings coal seam gas**

³²⁷ Listings of unique combinations of components, life-cycle and activities are listed in Table D.1.

Table D.1 Unique list of all combinations of component, life-cycle and activities (for CSG impacts) identified during the Impact Modes Effects Analysis process.

Component	Life-cycle	Activity
Pipelines	Construction	Gas and water-gathering pipeline networks (well to processing plant)
Pipelines	Construction	Trunk gas pipelines and associated easements (processing plant to town)
Pipelines	Production	Gas and water-gathering pipeline networks (well to processing plant)
Pipelines	Production	Trunk gas pipelines and associated easements (processing plant to town)
Processing	Construction	Brine storage ponds, pumps and water disposal pipelines
Processing	Construction	Fuel and oil storage facilities
Processing	Construction	Gas-gathering pipeline networks
Processing	Construction	Gas compression stations
Processing	Construction	Gas processing plant
Processing	Construction	Hypersaline brine ponds
Processing	Construction	Power generation facility (for processing plant)
Processing	Construction	Treated water pond
Processing	Construction	Water treatment plant (RO, fixed resin, fixed disc, electrochemical, etc)
Processing	Decomissioning	Process production plant
Processing	Production	Brine storage ponds, pumps and water disposal pipelines
Processing	Production	Fuel and oil storage facilities
Processing	Production	Gas-gathering pipeline networks
Processing	Production	Gas compression stations
Processing	Production	Gas processing plant
Processing	Production	Hypersaline brine ponds
Processing	Production	Materials delivery and storage
Processing	Production	Power generation facility (for processing plant)

Processing	Production	Staff movement and activities
Processing	Production	Treated water pond
Roads and infrastructure	Construction	Accommodation, administration, workshop, depots, service facilities
Roads and infrastructure	Construction	Construction of access roads and easements (e.g. for drilling rigs and equipment)
Roads and infrastructure	Construction	Fuel and oil
Roads and infrastructure	Construction	Power and communications
Roads and infrastructure	Construction	Sewage treatment and disposal
Roads and infrastructure	Decommissioning	Fuel and oil
Roads and infrastructure	Decommissioning	Sewage treatment and disposal
Roads and infrastructure	Exploration and appraisal	Construction of access roads and easements (e.g. for drilling rigs and equipment)
Roads and infrastructure	Exploration and appraisal	Fuel and oil
Roads and infrastructure	Exploration and appraisal	Power and communications
Roads and infrastructure	Exploration and appraisal	Temporary Accommodation, administration, workshop, depots, service facilities
Roads and infrastructure	Production	Accommodation, administration, workshop, depots, service facilities
Roads and infrastructure	Production	Fuel and oil
Roads and infrastructure	Production	Operation access roads and easements (e.g. for drilling rigs and equipment)
Roads and infrastructure	Production	Power and communications
Roads and infrastructure	Production	Sewage treatment and disposal
Wells	Construction	Cementing and casing
Wells	Construction	Drill cutting disposal
Wells	Construction	Drill stem testing (extraction)
Wells	Construction	Drilling and logging
Wells	Construction	Groundwater monitoring bore construction
Wells	Construction	Horizontal drilling

Wells	Construction	Hydraulic fracturing
Wells	Construction	Hydraulic fracturing concentrate delivery
Wells	Construction	Hydraulic fracturing fluid injection and disposal
Wells	Construction	Materials delivery and storage
Wells	Construction	Perforation
Wells	Construction	Pump and well head installation
Wells	Construction	Remediation
Wells	Construction	Site preparation
Wells	Construction	Surface water and mud storage and evaporation
Wells	Decommissioning	Materials delivery and storage
Wells	Decommissioning	Pressure concrete completion
Wells	Decommissioning	Pressure concrete durability
Wells	Exploration and appraisal	Abandonment
Wells	Exploration and appraisal	Drill cutting disposal
Wells	Exploration and appraisal	Drill stem testing (extraction)
Wells	Exploration and appraisal	Drilling and coring
Wells	Exploration and appraisal	Ground-based geophysics
Wells	Exploration and appraisal	Materials delivery and storage
Wells	Exploration and appraisal	Pump testing
Wells	Exploration and appraisal	Site clean-up and rehabilitation
Wells	Exploration and appraisal	Site preparation
Wells	Exploration and appraisal	Slug testing (injection)
Wells	Exploration and appraisal	Surface core testing
Wells	Exploration and appraisal	Surface water and mud storage and evaporation
Wells	Production	Groundwater monitoring bore construction or expansion
Wells	Production	Untreated co-produced water storage, processing and disposal (pilot stage only)
Wells	Production	Water and gas extraction
Wells	Work-over	Materials delivery and storage
Wells	Work-over	Waste disposal

Wells	Work over	Site preparation
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328 **E Appendix E: Listings coal seam gas**

329 Listings of unique combinations of components, life-cycle, activities and impact modes, ranked by
330 risk score are listed in Table E.1.

Table E.1 Unique list of all combinations of component, life-cycle, activities and impact modes (for CSG impacts) ranked by Risk Score identified during the Impact Modes Effects Analysis process.

Component	Life-cycle	Activity	Impact Mode
Wells	Production	Water and gas extraction	Aquifer depressurisation (coal seam)
Wells	Production	Water and gas extraction	Aquifer depressurisation
Pipelines	Construction	Gas and water-gathering pipeline networks (well to processing plant)	Disruption of natural surface drainage
Processing	Construction	Gas-gathering pipeline networks	Disruption of natural surface drainage
Pipelines	Construction	Trunk gas pipelines and associated easements (processing plant to town)	Disruption of natural surface drainage
Wells	Construction	Pump and well head installation	Soil erosion following heavy rainfall
Roads and infrastructure	Construction	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Disruption to natural surface water course (e.g. creek crossing)
Wells	Construction	Cementing and casing	Incomplete/compromised cementing/casing (linking aquifers)
Wells	Production	Water and gas extraction	Aquifer depressurisation (non-target, non-reservoir)
Processing	Production	Hypersaline brine ponds	Containment failure
Wells	Construction	Hydraulic fracturing	Contaminate target aquifer (chemical)
Pipelines	Construction	Gas and water-gathering pipeline networks (well to processing plant)	Soil erosion following heavy rainfall
Pipelines	Construction	Trunk gas pipelines and associated easements (processing plant to town)	Soil erosion following heavy rainfall
Wells	Decomissioning	Pressure concrete completion	Incomplete seal
Roads and infrastructure	Construction	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Disruption of natural surface drainage
Processing	Construction	Hypersaline brine ponds	Soil erosion following heavy rainfall

Processing	Construction	Treated water pond	Disruption of natural surface drainage
Processing	Construction	Brine storage ponds, pumps and water disposal pipelines	Disruption of natural surface drainage
Processing	Construction	Brine storage ponds, pumps and water disposal pipelines	Soil erosion following heavy rainfall
Processing	Construction	Treated water pond	Soil erosion following heavy rainfall
Processing	Construction	Gas processing plant	Disruption of natural surface drainage
Processing	Construction	Hypersaline brine ponds	Disruption of natural surface drainage
Processing	Construction	Water treatment plant (RO, fixed resin, fixed disc, electrochemical, etc)	Disruption of natural surface drainage
Wells	Production	Water and gas extraction	Aquifer depressurisation (fault-mediated)
Wells	Construction	Surface water and mud storage and evaporation	Overflow and/or loss of containment
Wells	Construction	Site preparation	Disruption of natural surface drainage
Wells	Exploration and appraisal	Drilling and coring	Imbalance of mud pressure between well and aquifer
Wells	Production	Untreated co-produced water storage, processing and disposal (pilot stage only)	Leaching from storage ponds
Wells	Exploration and appraisal	Surface water and mud storage and evaporation	Overflow and/or loss of containment
Wells	Construction	Hydraulic fracturing	Contaminate non-target aquifer (chemical)
Roads and infrastructure	Construction	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Soil erosion following heavy rainfall

Wells	Construction	Hydraulic fracturing	Changing target aquifer properties (physical or chemical)
Wells	Construction	Hydraulic fracturing	Connecting aquifers
Wells	Exploration and appraisal	Abandonment	Bore leakage between aquifers
Wells	Decommissioning	Pressure concrete durability	Seal integrity loss
Wells	Production	Water and gas extraction	Subsidence
Wells	Exploration and appraisal	Slug testing (injection)	Fluid loss to aquifer
Roads and infrastructure	Exploration and appraisal	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Disruption to natural surface water course (e.g. creek crossing)
Roads and infrastructure	Exploration and appraisal	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Disruption of natural surface drainage
Processing	Construction	Gas compression stations	Soil erosion following heavy rainfall
Processing	Construction	Gas-gathering pipeline networks	Soil erosion following heavy rainfall
Processing	Construction	Power generation facility (for processing plant)	Soil erosion following heavy rainfall
Wells	Construction	Hydraulic fracturing	Changing non-target aquifer properties (physical or chemical)
Wells	Construction	Cementing and casing	Incomplete/compromised cementing/casing (gas leakage)
Wells	Construction	Hydraulic fracturing concentrate delivery	Spillage: prior to dilution on site
Roads and infrastructure	Production	Operation access roads and easements (e.g. for drilling rigs and equipment)	Disruption to natural surface water course (e.g. creek crossing)
Processing	Construction	Gas processing plant	Soil erosion following heavy rainfall
Wells	Construction	Drilling and logging	Imbalance of mud pressure between well and aquifer
Wells	Construction	Perforation	Miss perforation target and connect aquifers through the well
Wells	Exploration and appraisal	Abandonment	Bore leakage to surface
Processing	Production	Brine storage ponds, pumps and water disposal pipelines	Containment failure

Wells	Production	Groundwater monitoring bore construction or expansion	Incomplete/compromised cementing/casing (linking aquifers)
Wells	Construction	Materials delivery and storage	Spillage: on site
Roads and infrastructure	Production	Operation access roads and easements (e.g. for drilling rigs and equipment)	Soil erosion following heavy rainfall
Wells	Exploration and appraisal	Materials delivery and storage	Spillage
Processing	Production	Materials delivery and storage	Spillage
Wells	Exploration and appraisal	Pump testing	Reduction in pressure head
Wells	Construction	Groundwater monitoring bore construction	Soil erosion following heavy rainfall
Processing	Production	Fuel and oil storage facilities	Spillage
Wells	Construction	Perforation	Miss perforation target and depressurise aquifers
Processing	Production	Brine storage ponds, pumps and water disposal pipelines	Leaking
Processing	Production	Hypersaline brine ponds	Leaking
Wells	Exploration and appraisal	Ground-based geophysics	Soil erosion following heavy rainfall
Wells	Construction	Groundwater monitoring bore construction	Incomplete/compromised cementing/casing (linking aquifers)
Roads and infrastructure	Construction	Accommodation, administration, workshop, depots, service facilities	Soil erosion following heavy rainfall
Wells	Construction	Site preparation	Soil erosion following heavy rainfall
Wells	Exploration and appraisal	Site preparation	Soil erosion following heavy rainfall
Roads and infrastructure	Exploration and appraisal	Temporary Accommodation, administration, workshop, depots, service facilities	Soil erosion following heavy rainfall
Wells	Construction	Horizontal drilling	Accidental intersection of aquifer
Wells	Construction	Horizontal drilling	Accidental intersection of fault
Wells	Construction	Groundwater monitoring bore construction	Spillage
Wells	Construction	Pump and well head installation	Spillage
Wells	Production	Untreated co-produced water storage, processing and disposal (pilot stage only)	Dam failure

Processing	Production	Gas-gathering pipeline networks	Pipeline failure
Pipelines	Production	Trunk gas pipelines and associated easements (processing plant to town)	Pipe failure
Pipelines	Production	Gas and water-gathering pipeline networks (well to processing plant)	Pipe failure
Pipelines	Production	Gas and water-gathering pipeline networks (well to processing plant)	Fire
Processing	Production	Gas processing plant	Fire
Pipelines	Production	Trunk gas pipelines and associated easements (processing plant to town)	Fire
Processing	Production	Treated water pond	Containment failure
Wells	Decommissioning	Materials delivery and storage	Spillage: on site
Wells	Work-over	Materials delivery and storage	Spillage: on site
Wells	Construction	Hydraulic fracturing fluid injection and disposal	Spillage and/or inappropriate disposal
Pipelines	Construction	Gas and water-gathering pipeline networks (well to processing plant)	Temporary disruption to natural surface water course (e.g. sandbagging a creek to lay pipe)
Pipelines	Construction	Trunk gas pipelines and associated easements (processing plant to town)	Temporary disruption to natural surface water course (e.g. sandbagging a creek to lay pipe)
Roads and infrastructure	Production	Operation access roads and easements (e.g. for drilling rigs and equipment)	Disruption of natural surface drainage
Processing	Decommissioning	Process production plant	Spillage
Wells	Construction	Remediation	Mud spillage and poor rubbish disposal
Wells	Exploration and appraisal	Site clean-up and rehabilitation	Mud and drill cutting spillage
Wells	Construction	Drill cutting disposal	Surface water contamination
Wells	Work-over	Waste disposal	Surface water contamination

Roads and infrastructure	Construction	Accommodation, administration, workshop, depots, service facilities	Disruption of natural surface drainage
Wells	Exploration and appraisal	Site preparation	Disruption of natural surface drainage
Roads and infrastructure	Production	Accommodation, administration, workshop, depots, service facilities	Disruption of natural surface drainage
Processing	Construction	Gas compression stations	Disruption of natural surface drainage
Processing	Construction	Power generation facility (for processing plant)	Disruption of natural surface drainage
Processing	Production	Treated water pond	Leaking
Wells	Construction	Groundwater monitoring bore construction	Cuttings disposal
Wells	Construction	Drill stem testing (extraction)	Recovered fluid disposal
Processing	Production	Fuel and oil storage facilities	Fire
Roads and infrastructure	Exploration and appraisal	Fuel and oil	Spillage: e.g. diesel
Roads and infrastructure	Exploration and appraisal	Power and communications	Spillage: e.g. diesel
Roads and infrastructure	Exploration and appraisal	Temporary Accommodation, administration, workshop, depots, service facilities	Spillage: e.g. diesel
Roads and infrastructure	Construction	Accommodation, administration, workshop, depots, service facilities	Spillage: e.g. diesel
Roads and infrastructure	Construction	Fuel and oil	Spillage: e.g. diesel
Roads and infrastructure	Construction	Power and communications	Spillage: e.g. diesel
Roads and infrastructure	Decomissioning	Fuel and oil	Spillage: e.g. diesel
Roads and infrastructure	Production	Accommodation, administration, workshop, depots, service facilities	Spillage: e.g. diesel
Roads and infrastructure	Production	Fuel and oil	Spillage: e.g. diesel
Roads and infrastructure	Production	Power and communications	Spillage: e.g. diesel
Roads and infrastructure	Production	Accommodation, administration, workshop, depots, service facilities	Soil erosion following heavy rainfall

Roads and infrastructure	Exploration and appraisal	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Soil erosion following heavy rainfall
Wells	Exploration and appraisal	Drill cutting disposal	Surface water contamination
Wells	Exploration and appraisal	Drill stem testing (extraction)	Recovered fluid disposal
Wells	Exploration and appraisal	Slug testing (injection)	Recovered fluid disposal
Processing	Decomissioning	Process production plant	Fire
Processing	Production	Gas compression stations	Fire
Processing	Construction	Brine storage ponds, pumps and water disposal pipelines	Impacts of ground support staff
Pipelines	Construction	Gas and water-gathering pipeline networks (well to processing plant)	Impacts of ground support staff
Processing	Construction	Gas processing plant	Impacts of ground support staff
Processing	Construction	Hypersaline brine ponds	Impacts of ground support staff
Processing	Construction	Treated water pond	Impacts of ground support staff
Pipelines	Construction	Trunk gas pipelines and associated easements (processing plant to town)	Impacts of ground support staff
Processing	Construction	Water treatment plant (RO, fixed resin, fixed disc, electrochemical, etc)	Impacts of ground support staff
Processing	Decomissioning	Process production plant	Impacts of ground support staff
Roads and infrastructure	Exploration and appraisal	Temporary Accommodation, administration, workshop, depots, service facilities	Disruption of natural surface drainage
Processing	Construction	Fuel and oil storage facilities	Disruption of natural surface drainage
Processing	Production	Power generation facility (for processing plant)	Fire
Roads and infrastructure	Construction	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Impacts of ground support staff
Processing	Construction	Gas compression stations	Impacts of ground support staff
Processing	Construction	Gas-gathering pipeline networks	Impacts of ground support staff
Processing	Construction	Power generation facility (for processing plant)	Impacts of ground support staff
Wells	Construction	Site preparation	Impacts of ground support staff

Roads and infrastructure	Exploration and appraisal	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Impacts of ground support staff
Wells	Exploration and appraisal	Ground-based geophysics	Impacts of ground support staff
Wells	Exploration and appraisal	Site preparation	Impacts of ground support staff
Wells	Work over	Site preparation	Impacts of ground support staff
Roads and infrastructure	Construction	Sewage treatment and disposal	Spillage: e.g. of sewage
Roads and infrastructure	Decommissioning	Sewage treatment and disposal	Spillage: e.g. of sewage
Roads and infrastructure	Production	Sewage treatment and disposal	Spillage: e.g. of sewage
Processing	Production	Staff movement and activities	Impacts of ground support staff
Processing	Production	Gas-gathering pipeline networks	Fire
Wells	Exploration and appraisal	Ground-based geophysics	Interruption of natural surface drainage
Wells	Exploration and appraisal	Drilling and coring	Very localised watertable reduction
Wells	Construction	Drilling and logging	Localised watertable reduction
Roads and infrastructure	Construction	Accommodation, administration, workshop, depots, service facilities	Impacts of ground support staff
Processing	Construction	Fuel and oil storage facilities	Impacts of ground support staff
Wells	Exploration and appraisal	Surface core testing	Impacts of ground support staff
Roads and infrastructure	Exploration and appraisal	Temporary Accommodation, administration, workshop, depots, service facilities	Impacts of ground support staff
Roads and infrastructure	Production	Accommodation, administration, workshop, depots, service facilities	Impacts of ground support staff
Roads and infrastructure	Production	Operation access roads and easements (e.g. for drilling rigs and equipment)	Impacts of ground support staff

331 **F Appendix F: Listings coal seam gas**

332 Listings of unique combinations of components, life-cycle, activities and impact modes, ranked by
333 risk priority number are listed in Table F.1.

Table F.1 Unique list of all combinations of component, life-cycle, activities and impact modes (for CSG impacts) ranked by Risk Priority Number identified during the Impact Modes Effects Analysis process.

Component	Life-cycle	Activity	Impact Mode
Wells	Production	Water and gas extraction	Aquifer depressurisation
Pipelines	Construction	Gas and water-gathering pipeline networks (well to processing plant)	Disruption of natural surface drainage
Processing	Construction	Gas-gathering pipeline networks	Disruption of natural surface drainage
Wells	Production	Water and gas extraction	Aquifer depressurisation (coal seam)
Pipelines	Construction	Trunk gas pipelines and associated easements (processing plant to town)	Disruption of natural surface drainage
Wells	Production	Water and gas extraction	Aquifer depressurisation (non-target, non-reservoir)
Wells	Decomissioning	Pressure concrete completion	Incomplete seal
Wells	Construction	Cementing and casing	Incomplete/compromised cementing/casing (linking aquifers)
Wells	Construction	Hydraulic fracturing	Contaminate non-target aquifer (chemical)
Wells	Decomissioning	Pressure concrete durability	Seal integrity loss
Wells	Production	Water and gas extraction	Aquifer depressurisation (fault-mediated)
Wells	Production	Untreated co-produced water storage, processing and disposal (pilot stage only)	Leaching from storage ponds
Wells	Construction	Hydraulic fracturing	Connecting aquifers
Wells	Exploration and appraisal	Abandonment	Bore leakage between aquifers
Pipelines	Construction	Gas and water-gathering pipeline networks (well to processing plant)	Soil erosion following heavy rainfall
Pipelines	Construction	Trunk gas pipelines and associated easements (processing plant to town)	Soil erosion following heavy rainfall

Roads and infrastructure	Construction	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Disruption of natural surface drainage
Processing	Construction	Treated water pond	Disruption of natural surface drainage
Processing	Construction	Brine storage ponds, pumps and water disposal pipelines	Disruption of natural surface drainage
Processing	Construction	Gas processing plant	Disruption of natural surface drainage
Processing	Construction	Hypersaline brine ponds	Disruption of natural surface drainage
Processing	Construction	Water treatment plant (RO, fixed resin, fixed disc, electrochemical, etc)	Disruption of natural surface drainage
Wells	Exploration and appraisal	Abandonment	Bore leakage to surface
Wells	Construction	Cementing and casing	Incomplete/compromised cementing/casing (gas leakage)
Wells	Production	Water and gas extraction	Subsidence
Wells	Construction	Perforation	Miss perforation target and depressurise aquifers
Processing	Production	Brine storage ponds, pumps and water disposal pipelines	Leaking
Processing	Production	Hypersaline brine ponds	Leaking
Roads and infrastructure	Construction	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Soil erosion following heavy rainfall
Wells	Construction	Hydraulic fracturing	Contaminate target aquifer (chemical)
Wells	Construction	Pump and well head installation	Soil erosion following heavy rainfall
Wells	Construction	Hydraulic fracturing	Changing non-target aquifer properties (physical or chemical)
Wells	Production	Groundwater monitoring bore construction or expansion	Incomplete/compromised cementing/casing (linking aquifers)

Wells	Construction	Horizontal drilling	Accidental intersection of fault
Wells	Construction	Drill cutting disposal	Surface water contamination
Wells	Work-over	Waste disposal	Surface water contamination
Processing	Production	Treated water pond	Leaking
Roads and infrastructure	Construction	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Disruption to natural surface water course (e.g. creek crossing)
Roads and infrastructure	Production	Operation access roads and easements (e.g. for drilling rigs and equipment)	Soil erosion following heavy rainfall
Wells	Construction	Groundwater monitoring bore construction	Incomplete/compromised cementing/casing (linking aquifers)
Wells	Exploration and appraisal	Drill cutting disposal	Surface water contamination
Roads and infrastructure	Exploration and appraisal	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Disruption of natural surface drainage
Wells	Construction	Hydraulic fracturing	Changing target aquifer properties (physical or chemical)
Wells	Exploration and appraisal	Drilling and coring	Imbalance of mud pressure between well and aquifer
Processing	Production	Hypersaline brine ponds	Containment failure
Roads and infrastructure	Exploration and appraisal	Temporary Accommodation, administration, workshop, depots, service facilities	Soil erosion following heavy rainfall
Roads and infrastructure	Production	Operation access roads and easements (e.g. for drilling rigs and equipment)	Disruption of natural surface drainage
Processing	Production	Gas-gathering pipeline networks	Pipeline failure
Pipelines	Production	Trunk gas pipelines and associated easements (processing plant to town)	Pipe failure
Pipelines	Production	Gas and water-gathering pipeline networks (well to processing plant)	Pipe failure
Processing	Construction	Gas compression stations	Disruption of natural surface drainage

Processing	Construction	Power generation facility (for processing plant)	Disruption of natural surface drainage
Processing	Construction	Hypersaline brine ponds	Soil erosion following heavy rainfall
Processing	Construction	Brine storage ponds, pumps and water disposal pipelines	Soil erosion following heavy rainfall
Processing	Construction	Treated water pond	Soil erosion following heavy rainfall
Wells	Construction	Surface water and mud storage and evaporation	Overflow and/or loss of containment
Wells	Construction	Site preparation	Disruption of natural surface drainage
Wells	Exploration and appraisal	Surface water and mud storage and evaporation	Overflow and/or loss of containment
Wells	Exploration and appraisal	Pump testing	Reduction in pressure head
Wells	Construction	Drilling and logging	Imbalance of mud pressure between well and aquifer
Wells	Construction	Perforation	Miss perforation target and connect aquifers through the well
Processing	Construction	Fuel and oil storage facilities	Disruption of natural surface drainage
Roads and infrastructure	Exploration and appraisal	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Disruption to natural surface water course (e.g. creek crossing)
Processing	Construction	Gas compression stations	Soil erosion following heavy rainfall
Processing	Construction	Gas-gathering pipeline networks	Soil erosion following heavy rainfall
Processing	Construction	Power generation facility (for processing plant)	Soil erosion following heavy rainfall
Wells	Construction	Hydraulic fracturing concentrate delivery	Spillage: prior to dilution on site
Roads and infrastructure	Production	Operation access roads and easements (e.g. for drilling rigs and equipment)	Disruption to natural surface water course (e.g. creek crossing)
Processing	Construction	Gas processing plant	Soil erosion following heavy rainfall
Wells	Construction	Horizontal drilling	Accidental intersection of aquifer

Wells	Exploration and appraisal	Ground-based geophysics	Interruption of natural surface drainage
Wells	Exploration and appraisal	Slug testing (injection)	Fluid loss to aquifer
Wells	Construction	Materials delivery and storage	Spillage: on site
Wells	Exploration and appraisal	Materials delivery and storage	Spillage
Processing	Production	Materials delivery and storage	Spillage
Wells	Construction	Groundwater monitoring bore construction	Soil erosion following heavy rainfall
Processing	Production	Fuel and oil storage facilities	Spillage
Processing	Production	Brine storage ponds, pumps and water disposal pipelines	Containment failure
Wells	Exploration and appraisal	Ground-based geophysics	Soil erosion following heavy rainfall
Wells	Exploration and appraisal	Drilling and coring	Very localised watertable reduction
Roads and infrastructure	Construction	Accommodation, administration, workshop, depots, service facilities	Soil erosion following heavy rainfall
Wells	Construction	Site preparation	Soil erosion following heavy rainfall
Wells	Exploration and appraisal	Site preparation	Soil erosion following heavy rainfall
Wells	Construction	Groundwater monitoring bore construction	Spillage
Wells	Construction	Pump and well head installation	Spillage
Wells	Production	Untreated co-produced water storage, processing and disposal (pilot stage only)	Dam failure
Pipelines	Production	Gas and water-gathering pipeline networks (well to processing plant)	Fire
Processing	Production	Gas processing plant	Fire
Pipelines	Production	Trunk gas pipelines and associated easements (processing plant to town)	Fire
Wells	Decommissioning	Materials delivery and storage	Spillage: on site
Wells	Work-over	Materials delivery and storage	Spillage: on site
Wells	Construction	Hydraulic fracturing fluid injection and disposal	Spillage and/or inappropriate disposal

Pipelines	Construction	Gas and water-gathering pipeline networks (well to processing plant)	Temporary disruption to natural surface water course (e.g. sandbagging a creek to lay pipe)
Pipelines	Construction	Trunk gas pipelines and associated easements (processing plant to town)	Temporary disruption to natural surface water course (e.g. sandbagging a creek to lay pipe)
Processing	Decomissioning	Process production plant	Spillage
Roads and infrastructure	Construction	Accommodation, administration, workshop, depots, service facilities	Disruption of natural surface drainage
Wells	Exploration and appraisal	Site preparation	Disruption of natural surface drainage
Roads and infrastructure	Production	Accommodation, administration, workshop, depots, service facilities	Disruption of natural surface drainage
Processing	Production	Treated water pond	Containment failure
Wells	Construction	Groundwater monitoring bore construction	Cuttings disposal
Wells	Construction	Drill stem testing (extraction)	Recovered fluid disposal
Processing	Production	Fuel and oil storage facilities	Fire
Roads and infrastructure	Exploration and appraisal	Fuel and oil	Spillage: e.g. diesel
Roads and infrastructure	Exploration and appraisal	Power and communications	Spillage: e.g. diesel
Roads and infrastructure	Exploration and appraisal	Temporary Accommodation, administration, workshop, depots, service facilities	Spillage: e.g. diesel
Roads and infrastructure	Construction	Accommodation, administration, workshop, depots, service facilities	Spillage: e.g. diesel
Roads and infrastructure	Construction	Fuel and oil	Spillage: e.g. diesel
Roads and infrastructure	Construction	Power and communications	Spillage: e.g. diesel
Roads and infrastructure	Decomissioning	Fuel and oil	Spillage: e.g. diesel
Roads and infrastructure	Production	Accommodation, administration, workshop, depots, service facilities	Spillage: e.g. diesel
Roads and infrastructure	Production	Fuel and oil	Spillage: e.g. diesel
Roads and infrastructure	Production	Power and communications	Spillage: e.g. diesel

Roads and infrastructure	Production	Accommodation, administration, workshop, depots, service facilities	Soil erosion following heavy rainfall
Wells	Construction	Remediation	Mud spillage and poor rubbish disposal
Wells	Exploration and appraisal	Site clean-up and rehabilitation	Mud and drill cutting spillage
Roads and infrastructure	Exploration and appraisal	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Soil erosion following heavy rainfall
Wells	Exploration and appraisal	Drill stem testing (extraction)	Recovered fluid disposal
Wells	Exploration and appraisal	Slug testing (injection)	Recovered fluid disposal
Processing	Decomissioning	Process production plant	Fire
Processing	Production	Gas compression stations	Fire
Processing	Construction	Brine storage ponds, pumps and water disposal pipelines	Impacts of ground support staff
Pipelines	Construction	Gas and water-gathering pipeline networks (well to processing plant)	Impacts of ground support staff
Processing	Construction	Gas processing plant	Impacts of ground support staff
Processing	Construction	Hypersaline brine ponds	Impacts of ground support staff
Processing	Construction	Treated water pond	Impacts of ground support staff
Pipelines	Construction	Trunk gas pipelines and associated easements (processing plant to town)	Impacts of ground support staff
Processing	Construction	Water treatment plant (RO, fixed resin, fixed disc, electrochemical, etc)	Impacts of ground support staff
Processing	Decomissioning	Process production plant	Impacts of ground support staff
Roads and infrastructure	Exploration and appraisal	Temporary Accommodation, administration, workshop, depots, service facilities	Disruption of natural surface drainage
Processing	Production	Power generation facility (for processing plant)	Fire
Roads and infrastructure	Construction	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Impacts of ground support staff
Processing	Construction	Gas compression stations	Impacts of ground support staff
Processing	Construction	Gas-gathering pipeline networks	Impacts of ground support staff

Processing	Construction	Power generation facility (for processing plant)	Impacts of ground support staff
Wells	Construction	Site preparation	Impacts of ground support staff
Roads and infrastructure	Exploration and appraisal	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Impacts of ground support staff
Wells	Exploration and appraisal	Ground-based geophysics	Impacts of ground support staff
Wells	Exploration and appraisal	Site preparation	Impacts of ground support staff
Wells	Work over	Site preparation	Impacts of ground support staff
Wells	Construction	Drilling and logging	Localised watertable reduction
Roads and infrastructure	Construction	Sewage treatment and disposal	Spillage: e.g. of sewage
Roads and infrastructure	Decomissioning	Sewage treatment and disposal	Spillage: e.g. of sewage
Roads and infrastructure	Production	Sewage treatment and disposal	Spillage: e.g. of sewage
Processing	Production	Staff movement and activities	Impacts of ground support staff
Processing	Production	Gas-gathering pipeline networks	Fire
Roads and infrastructure	Construction	Accommodation, administration, workshop, depots, service facilities	Impacts of ground support staff
Processing	Construction	Fuel and oil storage facilities	Impacts of ground support staff
Wells	Exploration and appraisal	Surface core testing	Impacts of ground support staff
Roads and infrastructure	Exploration and appraisal	Temporary Accommodation, administration, workshop, depots, service facilities	Impacts of ground support staff
Roads and infrastructure	Production	Accommodation, administration, workshop, depots, service facilities	Impacts of ground support staff
Roads and infrastructure	Production	Operation access roads and easements (e.g. for drilling rigs and equipment)	Impacts of ground support staff

G Appendix G: Additional listings coal seam gas- top 30

Table G.1 Top 30 list, ranked by Risk Priority Number (mid point), of component, life-cycle, activities, impact modes and effects (for CSG impacts) identified during the Impact Modes Effects Analysis process.

Component	Life-cycle	Activity	Impact Mode	Effects
Wells	Production	Water and gas extraction	Aquifer depressurisation (coal seam)	change in GW pressure
Wells	Production	Water and gas extraction	Aquifer depressurisation (non-target, non-reservoir)	change in GW pressure
Wells	Production	Water and gas extraction	Aquifer depressurisation	GW flow (reduction)
Wells	Production	Water and gas extraction	Aquifer depressurisation (fault-mediated)	change in GW pressure
Wells	Decomissioning	Pressure concrete durability	Seal integrity loss	GW quality
Wells	Construction	Cementing and casing	Incomplete/compromised cementing/casing (linking aquifers)	GW quality
Processing	Construction	Gas-gathering pipeline networks	Disruption of natural surface drainage	SW volume, SW quality
Pipelines	Construction	Trunk gas pipelines and associated easements (processing plant to town)	Disruption of natural surface drainage	SW volume, SW quality, GW quantity
Pipelines	Construction	Gas and water-gathering pipeline networks (well to processing plant)	Disruption of natural surface drainage	SW volume, SW quality, GW quantity
Wells	Decomissioning	Pressure concrete completion	Incomplete seal	GW quality, change in GW pressure
Wells	Construction	Hydraulic fracturing	Contaminate non-target aquifer (chemical)	GW quality
Wells	Production	Untreated co-produced water storage, processing and disposal (pilot stage only)	Leaching from storage ponds	GW quality
Wells	Exploration and appraisal	Abandonment	Bore leakage between aquifers	GW composition, GW quality, change in GW pressure

Wells	Construction	Hydraulic fracturing	Connecting aquifers	GW composition, GW quality, change in GW pressure
Wells	Exploration and appraisal	Abandonment	Bore leakage to surface	SW quality
Wells	Construction	Cementing and casing	Incomplete/compromised cementing/casing (gas leakage)	GW quality
Wells	Work-over	Waste disposal	Surface water contamination	SW quality
Wells	Production	Groundwater monitoring bore construction or expansion	Incomplete/compromised cementing/casing (linking aquifers)	GW composition, GW quality
Wells	Construction	Perforation	Miss perforation target and depressurise aquifers	change in GW pressure, GW quality
Wells	Construction	Hydraulic fracturing	Changing non-target aquifer properties (physical or chemical)	Aquifer properties
Wells	Construction	Drill cutting disposal	Surface water contamination	SW quality
Roads and infrastructure	Construction	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Disruption of natural surface drainage	SW directional characteristics, SW volume, SW quality
Processing	Production	Hypersaline brine ponds	Leaking	SW quality, GW quality
Processing	Production	Brine storage ponds, pumps and water disposal pipelines	Leaking	SW quality, GW quality
Processing	Construction	Water treatment plant (RO, fixed resin, fixed disc, electrochemical, etc)	Disruption of natural surface drainage	SW volume, SW quality
Processing	Construction	Treated water pond	Disruption of natural surface drainage	SW volume, SW quality
Processing	Construction	Hypersaline brine ponds	Disruption of natural surface drainage	SW volume, SW quality
Processing	Construction	Gas processing plant	Disruption of natural surface drainage	SW volume, SW quality

Processing	Construction	Brine storage ponds, pumps and water disposal pipelines	Disruption of natural surface drainage	SW volume, SW quality, GW quantity
Pipelines	Construction	Trunk gas pipelines and associated easements (processing plant to town)	Soil erosion following heavy rainfall	SW quality

Table G.2 Top 30 list, ranked by Risk Score (mid point), of component, life-cycle, activities, impact modes and effects (for CSG impacts) identified during the Impact Modes Effects Analysis process.

Component	Life-cycle	Activity	Impact Mode	Effects
Wells	Production	Water and gas extraction	Aquifer depressurisation (coal seam)	change in GW pressure
Wells	Production	Water and gas extraction	Aquifer depressurisation	GW flow (reduction)
Processing	Construction	Gas-gathering pipeline networks	Disruption of natural surface drainage	SW volume, SW quality
Pipelines	Construction	Trunk gas pipelines and associated easements (processing plant to town)	Disruption of natural surface drainage	SW volume, SW quality, GW quantity
Pipelines	Construction	Gas and water-gathering pipeline networks (well to processing plant)	Disruption of natural surface drainage	SW volume, SW quality, GW quantity
Wells	Construction	Hydraulic fracturing	Contaminate target aquifer (chemical)	GW quality
Roads and infrastructure	Construction	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Disruption to natural surface water course (e.g. creek crossing)	SW flow
Wells	Exploration and appraisal	Slug testing (injection)	Fluid loss to aquifer	GW composition
Wells	Construction	Cementing and casing	Incomplete/compromised cementing/casing (linking aquifers)	GW quality
Pipelines	Construction	Trunk gas pipelines and associated easements (processing plant to town)	Soil erosion following heavy rainfall	SW quality
Pipelines	Construction	Gas and water-gathering pipeline networks (well to processing plant)	Soil erosion following heavy rainfall	SW quality
Wells	Production	Water and gas extraction	Aquifer depressurisation (non-target, non-reservoir)	change in GW pressure

Wells	Production	Water and gas extraction	Aquifer depressurisation (fault-mediated)	change in GW pressure
Wells	Construction	Pump and well head installation	Soil erosion following heavy rainfall	SW quality
Roads and infrastructure	Construction	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Soil erosion following heavy rainfall	SW quality
Roads and infrastructure	Construction	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Disruption of natural surface drainage	SW directional characteristics, SW volume, SW quality
Processing	Construction	Water treatment plant (RO, fixed resin, fixed disc, electrochemical, etc)	Disruption of natural surface drainage	SW volume, SW quality
Processing	Construction	Treated water pond	Soil erosion following heavy rainfall	SW quality
Processing	Construction	Treated water pond	Disruption of natural surface drainage	SW volume, SW quality
Processing	Construction	Hypersaline brine ponds	Soil erosion following heavy rainfall	SW quality
Processing	Construction	Hypersaline brine ponds	Disruption of natural surface drainage	SW volume, SW quality
Processing	Construction	Gas processing plant	Disruption of natural surface drainage	SW volume, SW quality
Processing	Construction	Brine storage ponds, pumps and water disposal pipelines	Soil erosion following heavy rainfall	SW quality
Processing	Construction	Brine storage ponds, pumps and water disposal pipelines	Disruption of natural surface drainage	SW volume, SW quality, GW quantity
Wells	Construction	Surface water and mud storage and evaporation	Overflow and/or loss of containment	SW quality, GW quality
Wells	Construction	Site preparation	Disruption of natural surface drainage	SW directional characteristics, SW volume, SW quality

Wells	Construction	Hydraulic fracturing	Changing target aquifer properties (physical or chemical)	Aquifer properties
Wells	Construction	Hydraulic fracturing	Changing non-target aquifer properties (physical or chemical)	Aquifer properties
Roads and infrastructure	Exploration and appraisal	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Disruption to natural surface water course (e.g. creek crossing)	SW flow
Roads and infrastructure	Exploration and appraisal	Construction of access roads and easements (e.g. for drilling rigs and equipment)	Disruption of natural surface drainage	SW directional characteristics, SW volume, SW quality

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