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The University of Queensland Surat Deep Aquifer Appraisal Project (UQ-SDAAP)

Scoping study for material carbon abatement via carbon capture and storage

Supplementary Detailed Report

Risk register report

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Referenced throughout the UQ-SDAAP reports as **Honari et al. 2019e.**

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1. Executive summary

The University of Queensland Surat Deep Aquifer Appraisal Project (UQ-SDAAP) was formed to conduct an initial scoping study into the feasibility (or otherwise) of establishing an industrial-scale carbon capture and storage (CCS) initiative in Queensland to deliver *material carbon abatement*. An industrial scale CCS project would involve the capture and purification of carbon dioxide (CO_2) post-combustion, transport of the CO_2 to suitable sites, and injection and storage of CO_2 in a deep geological formation.

This report sets out the first risk register version for the exploration and appraisal (E&A) and nominal field development plan (FDP) project arising out of the UQ-SDAAP project. This is an additional risk assessment not related to delivery of the UQ-SDAAP project itself. The purpose of this risk assessment is to generate actions in terms of further exploration, appraisal, studies or social engagement in order to mature or discount the feasibility of the notional CCS FDP produced through the project.

The UQ-SDAAP study has identified around sixty individual risks and opportunities, including technical, environmental, social, legal and regulatory risks related to a notional commercial-scale CCS project in the Surat Basin. Opportunities such as enhanced water recovery, improved regional groundwater management and greenhouse gas mitigation have been documented. In this report, we record the details of "high" and "medium" risks consisting of risk headlines, descriptions and consequences.

2. UQ-SDAAP risk and opportunity register

The risk and opportunity descriptions reported in this document are dynamic in nature and will need updating during the appraisal activities and subsequent life of the project. Thus, these risks can be further expanded to cover more categories and disciplines as required. Similarly, more opportunities may exist that are not captured at this stage, but could be added to the list of opportunities as new information is acquired. This risk/opportunity register was completed as a team exercise (risk identification and assessment) and plans were formulated by risk owners (mitigation/management).

The technical and non-technical risks and opportunities were registered along with their descriptions, consequences, probabilities and possible mitigation actions. The risk matrix described in Figure 1 was used to score the technical and non-technical risks as well as opportunities. The full details of the risk register can be found in Appendix A.

Figure 1 Risk matrix score for UQ-SDAAP

NOTIONAL CCS (Hub) NOTIONAL FDP RISK MATRIX									
		Technical		POLITICAL or SOCIAL	PROBABILITY or LIKELIHOOD SCALE				
		Containment	Injectivity						
					1	2	3	4	5
		Significant loss of containment which causes damages to local environment or other resource users.	10 mln tpa can be sustained for 30 years		**Highly Unlikely** *Only in exceptional circumstances or no previous incidence or in direct control*	**Unlikely** *Could occur at some time. Rarely has. Checks and balances usually suffice. Early indications promising etc*	**Likely** *Material chance, (or out of direct control) treat as if at least 50:50 until reduced*	**Very Likely** *More likely than not to occur. Has happened often before. Or not in direct control*	**Highly Likely** *Treat as if almost certain to occur. A common or reasonably expected occurance*
					0-5%	5-20%	20-50%	50-80%	80-100%
IMPACT or CONSEQUENCE	5	Catestrophic loss to the environment through external or internal blow-out. Or Cronic low rate loss to the atmosphere which causes the CCS solution to underperform in terms of materiality and unit cost compared with alternative technologies.	Rapid close down in injection rate or rise in pressure causing almost complete loss of investment to date.	5 *Has major implications for achieving project outcomes , finance or UQ reputation*					
	4	Loss which causes widespread (in areas for abstraction) acidification of shallower aquifers (or the Precipice aquifer outside the zone of licenced storage) where 3rd party use or allocations exist or are planned or forecast to exist.	Reduction in injection potential which requires sigificant investment in maturing another location (new wells plus diversion of existing pipelines).	4 *Has important, notifiable) implications for achieving best quality project outcomes (finance or UQ reputation)*					
	3	Loss which causes localised acidification of shallower aquifers where 3rd party use or allocations exist.	Reduction in injection potential which requires re-drill of at least one well in a similar location (no major re-investment in facilities or pipelines).	3 *Project outcomes will be achieved but a little compromised*					
	2	Measured loss to subsurface aquifers without measured impact.	Reduction in injection potential which requires significant investment in work-overs.	2 *Project outcomes will be sufficient*					
	1	Minor fugitive emissions from plant or equipment.	Minor degradation in injection performancer over time which requires little additional investment.	1 *Project outcomes are assured*					

2.1 Technical risks

This section outlines the 'high' and 'medium' technical risks which are listed in red and orange boxes in Figure 2. The key technical risks are related to the maturing of site specific measurement assessments, containment (faulting and the Ultimate Seal) and injectivity (permeability).

Figure 2 Technical forward looking risk register

Technical risks

Consequence						
	5					**R51** (maturity of assessment)
	4	R8, 9, 10, 11, 12, 13, 15 & 41	R2, 18 & 43	R20, 45	*R34 (also an opp)*	
	3	R22, 23, 39, 40 & 42	R7, 19 & 21		R3, 50	
	2	R2 & 4	R5, 16 & 24		R17	
	1	R6				
		1	**2**	**3**	**4**	**5**
		Probability or Likelihood				

R51: Technical maturity for social acceptance and regulatory approvals

This is an integrated and compounded risk which needs many detailed questions to be addressed so that a complete story can be told before further decisions can be made on actual injections. Thus, detailed, competent and site specific data and tests are required to convince many stakeholder groups. Failure to gather convincing (probably confirmatory) data will prevent any hub deployment project being defined adequately and will be highly consequential in all technical, economic, social and political domains.

The window of opportunity is limited. Thus, it is essential to commence this immediately as there is a time criteria for both climate abatement and for power plant life.

R34: Legal and regulatory: far-field pressure increase in third party bores

During the CO_2 injection period, there is a risk of pressure increases leading to unwanted flow and or mechanical damage and changes to the water chemistry of third party bores. The likelihood of this risk is considered to be high and it therefore needs local assessments. In addition, the damages from increased water flows or from material damage to third party bores are required to be remedied.

R20: Injectivity: diagenesis leading to drastically reduced permeabilities at depth

There is currently no deep core data available and, as mentioned in Garnett et al. (2019d), the regional model is parameterised by petrophysical properties estimated based on data available in other areas and extrapolated into the deeper section of the Surat Basin. Also, there is some cuttings evidence of the deepest portions of the Blocky Sandstone Reservoir to be partially cemented. Therefore, some risks have been carried over which may result in the possibility of encountering lower permeability values in the Blocky Sandstone Reservoir than estimated in this study. Thus, actual injection performance may be low due to the significant decrease of permeability values with depth.

R3: Containment: pre-existing faults

There is currently not enough seismic data in the notional injection sites proposed by this study and, therefore, there is limited information about any existing faults and their distribution. During the CO_2 injection phase, CO_2 could leak from the Blocky Sandstone Reservoir through the Transition Zone and Ultimate Seal into shallow aquifers, where pre-existing faults provide pathways for CO_2 migration due to sufficiently low capillary forces. Thus, the acquisition of new seismic data will be essential to accurately select the prospective injection site at an adequate distance from faults.

R50: Containment: displaced water and Hutton Sandstone water quality

Pressure increase in the Blocky Sandstone Reservoir causes pressure increases in the Transition Zone and Ultimate Seal. This will change the vertical gradient between the Blocky Sandstone Reservoir and Hutton Sandstone which can then alter the water leakage rate across the intervening Evergreen seal. If the salinity of interstitial water in the Ultimate Seal is higher than water in the Hutton Sandstone, lower quality water (not CO_2) is displaced from the Ultimate Seal into the lower Hutton Sandstone. Depending on the leakage rate, it may degrade Hutton Sandstone water quality therein. The potential water leakage mechanisms may include faults, channels/erosion surfaces, or through simple pressure-matrix phenomenon.

R17: Containment: new third party well drilling through injection zones

This is the risk when third party operators plan to drill wells through the "plume" or inflated zone in the Blocky Sandstone Reservoir (e.g. oil and gas wells into Permian plays) during or after the CO_2 injection period. They may encounter increased pore pressure and/or pH reduction (acidic environment). Even though the current simulations show a low chance of drilling into the plume, there would be a higher chance of drilling wells through high pressure zones. This will increase the cost of drilling as well as risks to third party operators and Simultaneous Operations (SIMOPS). The shut-in of injection operations may be required during the drilling and completions of new wells.

R7: Containment: legacy wells

This is a potential risk of CO_2 leakage from the Blocky Sandstone Reservoir into shallower aquifers through legacy wells (registered and unregistered bores). CO_2 may flow through Transition Zone and Ultimate Seal where sufficiently low capillary pressure exists and lead to acidification of shallower aquifers and pressure increases in overlaying formations in which third party operators have an interest. It may also result in a loss of storage performance, shut down of CO_2 injection operations, or a decrease in water quality such as the potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations.

R2: Containment: the Ultimate Seal eroded by sand channel

There is a risk of CO_2 leakage from the Blocky Sandstone Reservoir through the Transition Zone and Ultimate Seal where the top seal is eroded and down-cut by an overlying permeable (Hutton) sand channel allowing flows into the shallower aquifer. Also, the CO_2 leakage to a shallower aquifer may occur due to an incorrect depositional model, such as if the Transition Zone becomes ‘sandier’ more quickly to the south. Thus, addressing this risk is essential to the ultimate abatement goal of any deployment. Having said that, the Ultimate Seal is present in all wells in the area and the erosion into it by a Hutton sand channel is purely hypothetical.
The outcome of this risk could be aquifer acidification in areas of potential third party interest, loss of storage performance, risk of shut down, or a decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations.

R18: Injectivity: scaling

Near well bore scaling impacts CO_2 injectivity and reduces predicted injection performance. It may result in reduction of CO_2 storage, possible over-investment in CO_2 capture plant and transportation, and the requirement for work-over jobs or the drilling of new wells.

R19: Injectivity: compartmentalisation or baffles (faults and channels)

The presence of baffles or barriers in the far-field decreases CO_2 injectivity during injection operations and ultimately reduction of CO_2 storage. It can also increase the risk of fracturing and containment loss to shallower zones.

R21: Injectivity: far-field precipitation

There is a risk of far-field precipitation of minerals which may cause pressure build up and loss of CO_2 injection performance over the injection period.

R45: Injectivity: poor quality reservoir (depositional)

This risk highlights the possibility of a poor quality Blocky Sandstone Reservoir (i.e. petrophysical properties) to be encountered. It may create a risk of delay in CO_2 injection operations which potentially increase the number of sites and associated costs.

R43: Focus groups: managed aquifer recharge

There will be potential risk/opportunity to impact MAR operations. Thus, those in the community will need to become more aware of the principles of MAR and CCS and their co-existence. This may result in community members to either become concerned about interactions with the Great Artesian Basin (GAB) or see the potential opportunities it can bring to landholders and others.

2.2 Non-technical risks

Figure 3 shows the list of the key legal, social and regulatory risks that were identified within the UQ-SDAAP project. These risks are mainly related to regulatory pathways and community engagement.

Note that the majority of "high" rated risks belong to non-technical risks. These 'high' and 'medium' non-technical risks are described in more detail below.

Figure 3 Non-technical forward-looking risk register

Non-technical risks

Consequence		1	2	3	4	5
	5	R33	R27	R25, 26 & 49	R30, 31 & 37	R28 & 32
	4	R46	R29	R35, 36 & 38	*R34 (also an opp)*	R35
	3	R47 & 48				
	2					
	1					

Probability or Likelihood

R28: Legal and regulatory: Environmental protection regulations prevent injection of waste

Carbon dioxide from power stations looks likely to be classified as waste under the Environmental Protection Act (1994), restricting the ability for injection. There are currently no 'end of waste' codes or approvals which apply to CO_2 and granting approval must consider whether the waste may cause temporary or permanent environmental harm. This risk highlights a significant possible impediment to the project in the current Queensland regulations. Hence, it is considered to be a major risk which will require the clarification of the regulatory roadmap for large-scale CCS investments in Queensland.

Amendments to the regulations or the redefining of CO_2 as an 'end of waste resource' will be required (under the *Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017* – 'GABORA'; and the, *Waste Reduction and Recycling Act 2011* – 'The Waste Act'). The judgement of environmental harm depends on the definition of values. Also, injecting in a GAB aquifer looks likely to raise major issues as it is likely that the endemic value of potable aquifers might be 'protected' as an initial position.

Without an 'end of waste' approval, an application for an EA may be refused by the Department of Environment and Science (DES). End of waste approval may also be problematical under the Waste Act. Thus, an argument is needed to discuss local 'harm' vs. prevention of wider 'harms' from CO_2 emissions.

R32: Legal and regulatory: GABORA (nor EPBC) does not yet consider large scale injection impacts

Water resources are a matter of *national* environmental significance. The Commonwealth, Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) is currently "triggered" when coal seam gas and large mining developments impact water resources. The 2013 EPBC Act Amendments which instantiated this trigger are silent on large scale CCS developments.

The GABORA anticipates a draw-down rather than an increase in hydraulic head which may occur during a large-scale CCS project. Thus, this is considered to be a major risk which could cause significant delays (approvals) or costs (upgrading or monitoring third party infrastructure). This risk requires clarification as to the regulatory roadmap for large-scale CCS projects in order to reduce its impact.

It is noteworthy to mention that the current availability of water in the GABORA is in the Precipice Sandstone and it is therefore expected to see growth for future use or requests for allocations. In addition, the Water Act and GABORA seek to protect groundwater resources which appears to be in direct conflict with large scale injection.

R30: Legal and regulatory: complexity of water allocations impacted under the Water Act

It is noteworthy to mention that GHG licences are not exempt from the Water Act. Since the injection of CO_2 into an aquifer will in effect sterilise an area and allocable volume, a Water Act licence will be required for a large-scale CCS project. Failure to acquire a water licence will prevent any CO_2 injection operations.

R31: Legal and regulatory: CO_2 injection is 'interfering with water'

This is another major legal and regulatory risk which will require clarification of the regulatory roadmap for a large-scale CCS project. As mentioned in R30, injection of CO_2 would likely require a water licence.

The granting of a water licence must take into account the provisions of any water plan. It is also necessary to consider that CO_2 emplaced within an aquifer may not be aligned with the sustainable management principles of the Water Act. Thus, both of these issues are potential impediments to a large-scale CCS investment.

R37: Social: resistance to ultimate development (local)

A key risk identified is that of local resistance (e.g. landholders) to the development of a large-scale CCS project, driven by concerns surrounding groundwater, emissions and the impact of fossil fuel use. Potentially, it may delay the appraisal program or even lead to the failure to secure the necessary permits or EA. This risk could be further exacerbated by political activism at both local and state levels.

This risk is linked to other legal and regulatory risks R25 to R34. To properly address this risk, local communities need to be adequately consulted and informed regarding decarbonisation and climate objectives.

R25: Legal and regulatory: coordination agreement: third party operator objections

GHG exploration activities can only be carried out where the relevant overlapping (not adjacent or proximate) tenement rights holder has not objected to the activity (GHG Act s19) or to the safety management plan (s221).

There is a potential risk that third party overlapping rights holders decide to prevent exploration and development of a storage site (this is subject to ministerial override). Thus, applications must comment on the potential of forming a coordination agreement (if there is no reasonable chance of an agreement, the lease may be refused). To address this risk, a regulatory amendment (which is dependent on R28) may be required.

It is noteworthy to mention that GHG activities post-date most other tenements and are "at the end of the queue" with respect to resource rights permissions and consents.

R26: Legal and regulatory: coordination agreement: third party operator existing activities

GHG exploration activities cannot be undertaken where existing activities on other exploration permits would be adversely affected. Thus, there is a risk that third party overlapping rights holders decide to prevent exploration and development activities related to a CO_2 storage site (this is subject to ministerial override).

As mentioned in R25, GHG activities post-date most other tenements and are "at the end of the queue" with respect to resource rights permissions and consents,

R49: Legal and regulatory: compliance

There is a concern about the regulator's view of the subsurface water resources in the Precipice Sandstone, Hutton Sandstone and other aquifers. A potential contamination of the low salinity water (including within the Blocky Sandstone Reservoir of the site) may impact the regulator's action/decision. That is why an appropriate procedure is required to specify/predict any water contamination in the aquifers.

This risk will be mainly covered in 'high' risks R30 to R32 and it would not be an issue for the appraisal program.

R35: Social: resistance to further appraisal (local)

This is a risk at the appraisal stage of a large-scale CCS project even though the appraisal activities are low impact and involve no CO_2 in order to progress to the next decision stage. The project may face local resistance (e.g. landholders) to an in-field appraisal program which can be driven by concerns on groundwater emissions and the impacts of fossil fuel use. This may cause delays in appraisal activities or failure to secure the necessary permits or EA.

R36: Social: resistance to further appraisal (non-local)

This risk is linked to other legal and regulatory risks (R25 to R34) and considered based on broad social resistance on grounds of groundwater emissions and the impact of fossil fuel use. Even though appraisal activities are low impact and involve no CO_2, not addressing this risk properly may cause delays in appraisal or failure to secure the necessary permits or EA.

R38: Social: resistance to ultimate development (non-local)

The development of a large-scale CCS project may face a broad social resistance on grounds of groundwater emissions and the impact of fossil fuel use. This risk may potentially cause delays in appraisal or failure to secure the necessary permits or EA.

Nevertheless, this is categorised as a low-consequence risk as it requires a wide community acceptance. Currently, broader community attitudes are in line with decarbonisation / climate objectives.

R27: Legal and Regulatory: Environmental impact and authority; water abstraction

A GHG 'authority' requires an EA granted by DES which should allow for water abstraction (the provisions under the *Petroleum and Gas (production and safety) Act*, for associated water do not apply). Water take is needed during the appraisal program for the dynamic pumping test of the Blocky Sandstone Reservoir. The inability to do this increases the long term pressure build-up risk, which may adversely impact on the development of a large-scale CCS project. Reinjection licences may also be required depending on volumes and costs of produced water during the dynamic pumping test.

To address this risk, a regulatory amendment (which is dependent on R28) may be required.

R29: Legal and regulatory: Environmental protection regulations prevent injection of waste - potential for damage to novel fauna

The Queensland Water Quality Guidelines include a cautionary note on the potential to harm novel underground fauna in groundwater systems even though the likelihood of novel fauna is considered low (but local environmental assessments are required). This risk could potentially cause significant delays; specifically the need to establish a lack of deep fauna (which would be unlikely in relatively hot aquifers). This will also impose some costs to investigate the existence of novel fauna and the potential impact of CO_2 injection on them in a deep section of the Surat Basin.

R33: Legal and regulatory: indirect impacts to surface water courses and springs

Injecting CO_2 into the Blocky Sandstone Reservoir may result in subsequent changes to surface water or springs, as well as changes in water chemistry and pressure. Impacts to water in the Precipice Sandstone may be authorised but this does not authorise impacts to near surface or surface features. Impacts such as increased pressure and flow may cause environmental 'harm,' for which serious breaches may entail regulatory penalties (civil and criminal) on operators. The likelihood of this risk is considered low but local environmental assessments will be required.

2.3 Opportunities

Figure 4 highlights the opportunities that were identified within the UQ-SDAAP project at this stage. Opportunities that are rated as 'high' are confident and impactful opportunities whereas the opportunities rated 'medium' are generally of less confidence at this immature stage of the project.

Figure 4 Key opportunities listed in UQ-SDAAP risk register

Key opportunities

Consequence		Probability or Likelihood 1	2	3	4	5
	5				O1, O2, O3	
	4				*R34 (also a risk)* & O6	
	3				O4, O5	O7, O8
	2					
	1					

O1: Enhanced groundwater levels

An opportunity can be created from a large-scale CCS project where CO_2 injection in the basin centre may raise water levels in the far-field and displace basin-centre water. This may support water abstraction from the Precipice Sandstone in areas well away (distal) from the injection sites for third party users (e.g. agriculture).

This opportunity needs to be addressed in an appraisal plan through the acquisition of more data. The associated social impacts of enhanced groundwater levels may also be addressed through consultation.

O2: Enhanced groundwater recovery

Injecting CO_2 in the basin centre may displace basin-centre water to areas where it is more economic to drill and recover water (up dip). This also provides an opportunity to support abstraction from the Precipice Sandstone in areas away from the injection sites for third party users (e.g. agriculture).

Similar to O1, this opportunity requires further investigation during the appraisal activities by acquiring more relevant data. Social impacts of enhanced groundwater recovery may also be addressed through consultation.

O3: Regional development: Retention / extension of existing regional industry and jobs

Successful reduction of carbon intensity of power generation via a large-scale CCS project could prolong the existence of regional jobs and industry in the region (mining and power generation). This would be a great opportunity to enhance sustainable regional employment, continuation of taxes and state royalties. In other words, regional employment is a direct consequence of deployment and details need to be worked up prior to FID.

O4: Regional development: Attraction of new carbon intensive industries to the region

Availability of large CO_2 storage capacity may attract high CO_2 emitters (e.g. cement or gas-fertiliser or gas-plastics) into the region which creates new regional employment, increased taxes and state royalties.

It is likely that there is more injection/storage potential than required by the three power plants studied and therefore more carbon intensive industries could be accommodated in the area. Sufficient appraisal data will be required to increase confidence levels.

O5: National survey results

There is an opportunity to engage the community with the national survey results which in turn builds positive recognition of the project and UQ more widely. Results and methods from UQ-SDAAP show promise in understanding the community response and in better quality engagement.

O6: Message testing focus groups and survey

This is an opportunity to enhance or tailor a message based on specific comments thus far. Message testing focus groups and surveys also provide a good understanding of the clear messages that will help in communication of CCS technology in the future. Similar to O5, results and methods from UQ-SDAAP show promise in understanding community responses and in better quality engagement going foward.

O7: Improved regional groundwater management

The undertaking of appraisal activities and acquisition of data may significantly assist OGIA's regional groundwater efforts. Also, obtaining dynamic data from the deeper portions of the basin (which is not currently available) will improve overall basin groundwater management.

O8: Improved NEM system cost modelling

Total system cost modelling for the NEM decarbonisation is highly dependent on the amount of CCS available. Appraisal work will improve estimates and dynamic data from the deep basin will improve overall NEM system management.

3. Reference

Honari V, Gonzalez S & Garnett A (2019), *Site appraisal plan*, The University of Queensland Surat Deep Aquifer Appraisal Project – Supplementary Detailed Report, The University of Queensland.

4. Appendices

4.1 Appendix A: UQ-SDAAP forward risk register

Project Risk (Opportunity) Register v1.9 (01 April 2019)

Unique ID	Headline	Risk or Opportunity (narrative)	Consequence (narrative)	Classification				Rating when registered								Mitigating Action / Response (narrative) *General form of sub-surface uncertainty and risk management is* *- AVOID/SELECT riskier/least-risky areas and features by maximising distance from key features* *- CHARACTERISE the sub-surface pre-FID and injection and select injection sites to minimise risks* *- ENGINEER wells and completions to minimise pressure build up* *- MONITOR post-FID and injection* *- ENGAGE with key stakeholders* *- DEVELOP messages and programs*	Comments (result of group discusisons)	Responsible Risk Owner	Action Party(s) (plans, dates and deliverables to be addressed elsewhere)
				THSE	EC	O	SPL	Conseq. (1-5)	Probab. (1-5)	Result (CxP)	Rating L	M	H	Assmnt Maturity Low 1 High 5	Time Frame to address Sh-Med-Lng Term				
R1	Containment: the Ultimate Seal flow	Leaks of CO_2 from the Blocky Sandstone Reservoir (BSR) through Transition Zone (TZ) and Ultimate Seal (US) via capillary flow into shallow aquifer.	Aquifer acidification in area of potential third party interest (potential for damages). Loss of storage performance, risk of shut down etc. Decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations (considered less likely than simple acidification).	Y	Y		Y	**2**	**1**	**2**	L			**2**	**Short**	R1.1 Select: deeper areas with likely highest entry pressures. R1.2 Select: areas with lower NTG in transition and seal formations. R1.3 Select: areas with low risk of sand directly above main seal. R1.4 Characterise: CEPs for transition zone and seal for CO_2 through core studies. R1.5 Engineer: for minimum pressure build up at seal. R1.6 Monitor: pressure above seal in higher risk areas (seismic or monitoring wells).	Addressed in appraisal plan. Essential to the ultimate abatement goal of any deployment	AG	ALC, IR, AH (included in res & gaol unc. Analysis)
R2	Containment: the Ultimate Seal eroded by sand channel	Leaks of CO_2 from the BSR through TZ and US where top seal is eroded and down-cut by overlying permeable (Hutton) sand channel causing flows into shallower aquifer. OR ... if depositional model is wrong and TZ becomes "sandier" more quickly to the south.	Note: the ultimate seal is present in ALL wells in the area. The erosion into it by a Hutton sand channel is purely hypothetical. Aquifer acidification in area of potential third party interest (potential for damages). Loss of storage performance, risk of shut down. Decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in place concentrations (considered less likely than simple acidification).	Y	Y		Y	**4**	**2**	**8**		M		**2**	**Short**	R2.1 = R1.3 Select: areas with low risk of sand directly above main seal. R2.2 Characterise: seal and lower Hutton interface with core analysis. R2.3 Characterise: seal and lower Hutton interface with 2D and/or 3D seismic. R2.4 = R1.5 Engineer: for minimum pressure build up at seal. R2.5 = R1.6 Monitor: pressure and water quality above seal in higher risk area (seismic or monitoring wells).	Addressed in appraisal plan. Essential to the ultimate abatement goal of any deployment	AG	ALC, IR, AH (included in res & geol unc. Analysis)
R3	Containment: pre-existing faults	Leaks of CO_2 from the BSR through TZ and US via capillary flow through a **pre-existing fault** into shallow aquifer	Note: there is only evidence from hydrocarbon shows of leakage around "major faults" (e.g. Moonie). The preponderance of evidence is that the TZ & US form a regional seal. Aquifer acidification and pressure increase in area of potential third party interest (potential for damages). Loss of storage performance, risk of shut down or de-selection. Decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations (considered less likely than simple acidification).	Y	Y		Y	**3**	**4**	**12**		M		**1**	**Short**	R3.1 Select: areas with low risk of faults and maximise distance. R3.2 Characterise: faults with 2D or 3D seismic (re-process, in-fill 2D & possible site 3D). R3.3 Characterise: faults through core studies on friction angle and cohesion R3.4 Characterise: faults through juxtaposition and CSP studies. R3.5 = R2.4 = R1.5 Engineer: for minimum pressure build up at seal. R3.6 Monitor: pressure near faults if considered higher risk area.	This is a key play and site specific risk. Addressed in appraisal plan. Essential to the ultimate abatement goal of any deployment	AG	ALC, IR, SG & IA (fault analysis)
R4	Containment: injection operations induced faults and fractures (Stress)	Leakage of CO_2 from the BSR caused by geomechanically induced faults or fractures caused by **induced geomechanical stress differentials from injection operations**	Aquifer acidification and pressure increase in area of potential third party interest (potential for damages). Loss of storage performance, risk of shut down. Decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations (considered less likely than simple acidification).	Y	Y		Y	**2**	**1**	**2**	L			**1**	**Long**	R4.1 Select: areas which are deep with maximum frac-margin. R4.2 Characterise: frac gradient with core studies (CS & UCS). R4.3 Characterise: frac gradient with DFIT or XLOT. R4.4 Characterise: frac distribution with core and image log studies. R4.5 Characterise: stress with seismic studies combined with above. R4.6 = R3.5 = R2.4 = R1.5 Engineer: for minimum pressure build up at seal. R4.7 Possibly monitor: seismicity in higher risk area (if considered more than 'unlikely').	Addressed in appraisal plan by data acquisition which will inform engineering design later.	AG	IR, SG & IA (fault analyses)
R5	Containment: injection operations induced faults and fractures (Temperature)	Leakage of CO_2 from the BSR caused by geomechanically induced faults or fractures caused by combination of reduced temperature and **induced geomechanical stress differentials from injection operations**	Aquifer acidification and pressure increase in area of potential third party interest (potential for damages). Loss of storage performance, risk of shut down. Decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations (considered less likely than simple acidification).	Y	Y		Y	**2**	**2**	**4**	L			**1**	**Long**	R5.1 = R4.1 Select: areas which are deep with maximum frac-margin. R5.2 = R4.2 Characterise: frac gradient with core studies (CS & UCS). R5.3 Characterise: rock thermal properties from core studies. R5.4 Characterise: thermal effects via coupled modelling (with real data). R5.5 Characterise: changes to stress margins. R5.6 = R4.6 = R3.5 = R2.4 = R1.5 Engineer: for minimum pressure build up at seal. R5.7 Possibly monitor: temperature reductions in early field life (if pressure above limit not 'unlikely'). R5.8 = R4.7 Monitor: micro-seismicity.	Addressed in appraisal plan by data acquisition which will inform engineering design later.	AG	IR

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R6	Containment: extraction or CSG operations induced faults and fractures	Leakage of CO_2 from the BSR caused by geomechanically induced faults or fractures caused by **induced geomechanical stress differentials from CSG extraction operation**	Aquifer acidification and pressure increase in area of potential third party interest (potential for damages). Contamination of economic gas asset by leaked CO_2. Loss of storage performance, risk of shut down. Decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations (considered less likely than simple acidification).	Y	Y		Y	**1**	**1**	**1**	L			**3**	**Long**	R6.1 Select: sites well away from areas of extreme and differential draw-down (CSG production areas). R6.2 Estimate areas of future CSG expansion. R6.3 If considered a high risk, monitor: stresses and pressures in intermediate formations at edges of injection areas of influence. R6.4 = 5.8 = R4.7 If considered at high risk, monitor: regional micro-seismicity.	Addressed in appraisal plan by data acquisition which will inform engineering design later.	AG	IR, MS, ASR, IA
R7	Containment: legacy wells	Leakage of CO_2 from the BSR through TZ and US via capillary flow through legacy wells (registered and unregistered bores) into shallow aquifer.	Aquifer acidification and pressure increase in area of potential third party interest (potential for damages). Leaks to atmosphere or vadose zone. Loss of storage performance, risk of shut down. Decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations (considered less likely than simple acidification).	Y	Y		Y	**3**	**2**	**6**		M		**3**	**Med**	R7.1 Select: site to avoid (max distance) from legacy wells through or TD in the BSR. R7.2 Model credible worse case of legacy well leakage or displacement of water between aquifer. R7.3 Characterise: legacy wells for evidence of leakage (if high risk from 7.2) e.g. through Radon or methane sampling.	This is a play and site specific risk. The main approach has been to avoid any sites. Legacy well characterisation may form part of appraisal program Addressed in appraisal plan. Essential to the ultimate abatement goal of any deployment	AG	JU (PhD review- no evidence of poor P&A)
R8	Containment: injection wells cement	Leakage of CO_2 from the BSR through TZ and US via capillary flow through poorly cemented and isolated injection wells into shallow aquifer	Aquifer acidification and pressure increase in area of potential third party interest (potential for damages). Leaks to atmosphere or vadose zone. Loss of injection pressure and out-flow into storage zone. Loss of storage performance, risk of shut down. Decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations (considered less likely than simple acidification).	Y	Y		Y	**4**	**1**	**4**	L			**3**	**Long**	R8.1 Engineer: Drill hole to ensure in-gauge sections. R8.2 Engineer: Cement selection to ensure minimum risk of CO_2 leakage (rheology). R8.3 Engineer: Rotate casing while cementing. R8.4 Engineer: Set cement shoe in siltiest section of "Evergreen". R8.5 Characterise: Pressure test and USIT the cement.	Addressed in appraisal plan by data acquisition which will inform engineering design later.	JU	JU (PhD review- no evidence of poor P&A)
R9	Containment: injection wells materials	Leakage or loss of well integrity occurs through corrosion which causes leak of CO_2 to aquifers or atmosphere.	Aquifer acidification. Loss of injection potential. Possible shut down or failure to licence the project. Decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations (considered less likely than simple acidification).	Y	Y			**4**	**1**	**4**	L			**2**	**Long**	R9.1 Engineer: select CRA tubing, well heads (and casing) for exposure in 'Evergreen' and ' Precipice'. R9.2 Monitor: consider (risk assessment) to periodically for mechanical integrity (MIT? - but could make it worse). R9.3 Engineer: for minimum intervention completion.	Addressed in appraisal plan. Essential to the ultimate abatement goal of any deployment	postpone	
R10	Containment: in-field facilities	Leakage of CO_2 from in-field pipelines, compressors or well-head equipment to atmosphere.	Loss of storage/abatement potential. Potential ponding of CO_2 in "lows" and consequent safety hazard. Loss of storage performance, risk of shut down, failure or loss of licence.	Y	Y	Y	Y	**4**	**1**	**4**	L			**2**	**Long**	R10.1 Engineer: select CRA or coated steel. R10.2 Monitor: for fugitive emissions. R10.3 Monitor: for confined spaces.	Addressed in appraisal plan. Essential to the ultimate abatement goal of any deployment	postpone	
R11	Containment: pipeline fugitives	Leakage of CO_2 from pipeline at booster or LBV positions.	Loss of storage/abatement potential. Potential ponding of CO_2 in "lows" and consequent safety hazard. Loss of storage performance, risk of shut down, Loss of storage performance, risk of shut down, failure or loss of licence.	Y	Y		Y	**4**	**1**	**4**	L			**2**	**Long**	R11.1 Engineer: limit H_2, metals and H_2 content in CO_2. R11.2 Engineer: optimal LBV spacing. R11.3 Engineer: avoid topographic lows. R11.4 Monitor: for fugitive emissions at high risk points. R11.5 Monitor: for confined spaces.	Addressed in appraisal plan or early prefeasibility study. Essential to the ultimate abatement goal of any deployment	postpone	

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Project Risk (Opportunity) Register v1.9 (01 April 2019)

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R12	Containment: pipeline damage	Leakage of CO_2 from pipeline caused by physical damage or breach.	Major loss of storage/abatement potential. Local hazard from high velocity and "freezing" escape. Potential ponding of CO_2 in "lows" and consequent safety hazard. Loss of storage performance, risk of shut down, failure or loss of licence.	Y	Y	Y	Y	4	1	4	L			2	Long	R12.1 Select: Prioritise existing easements (and SOPS). R12.2 Engineer: Pipeline design and burials and LBV spacing (inventory control). R12.3 Monitor: Permits to work, 3rd party interactions.	Addressed in appraisal plan or early prefeasibility study. Essential to the ultimate abatement goal of any deployment	postpone	
R13	Containment; natural migration out of block	Physical migration of CO_2 under injection drive or buoyancy drive outside the "tenement" area.	Breach of licence conditions. Possible consequential risk increases in other leakage forms. Decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations (considered less likely than simple acidification).	Y	Y		Y	4	1	4	L			2	Short	R13.1 Select: site to maximise distance to permit boundary. R13.2: Select: re-negotiate boundaries with State gov to minimise risk. R13.3 Select: site to minimise structural dip along migration pathway. R13.4 Select: injection depth in deeper parts of injection zone. R13.5: Characterise: far field permeability structure to better characterise risk and range of migration scenarios. R13.6 Monitor: pressure vs time and far field plume (or absence of plume) to better history match migration models.	Addressed in appraisal plan. Essential to the ultimate abatement goal of any deployment	AG	IR (included in res scenarios)
R15	Containment; extraction "push" "pull" migration out of block	Physical migration of CO_2 under injection drive or buoyancy drive <u>plus addition extraction</u> "pull" from other users.	Breach of licence conditions. Potential acidification of 3rd party water resource. Possible consequential risk increases in other leakage forms. Decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations (considered less likely than simple acidification).	Y	Y		Y	4	1	4	L			2	Short	R15.2: Characterise: legal position and recourse re consequential losses. Clarify GHG permit 'seniority' wrt future abstraction possibilities. R15.3: Characterise: model credible worse case with current abstraction impacts. R15.4: Characterise: model to set 'exclusion boundaries' for future allowable areas of the BSR abstraction. R15.5: Engineer: scope of simultaneous operations or cooperation agreements R15.6: Monitor: Impact from and to 3rd party operators of abstraction.	Needs to be included in regulatory action theme - how to govern where others drill and pump. Refer to specific scenario testing this - minor or no plume movement even if hypothetical "feedlot" bore is within 5km of plume.	PH	MS (included in res scenarios) & IR
R16	Containment: migration through the BSR "pinch-out"	Physical migration of CO_2 under injection drive or buoyancy drive outside the "play" area to the west (and into others' assets).	Possible breach of licence conditions. Acidification of overlying aquifers. Contamination of gas assets up-dip.	Y	Y		Y	2	2	4	L			1	Med	R16.1: Select: maximise distance from known and likely competing injection points. R16.2: Characterise: legal position and recourse re consequential losses. Clarify GHG permit 'seniority' wrt future large scale injection possibilities. R16.3: Characterise: model credible worse case current injection impacts . R16.4: Characterise: model to set 'exclusion boundaries' for future allowable areas of the BSR injection. R16.5: Engineer: scope of simultaneous operations or cooperation agreements. R16.6: Monitor: Impact from and to 3rd party operators of injection.	Require a condition in the licence agreement for others/3P's not to drill in area. Include discussions in regulator action theme.	PH	IR (included in res scenarios) & ASR
R17	Containment: new 3rd party well drilling through injection zones	Third party operator drilling through "plume" or inflated zone see increased pore pressure and/or pH (e.g. O&G well into Permian plays).	Increase in cost and risk to third party operator. Need for sim-ops during drilling, possible loss, shut-in of injection operations. Need for coordination agreement.	Y	Y	Y	Y	2	4	8		M		2	Long	R17.1 Select: maximise distance from known or likely O&G "drill though" areas. R17.2 (as for 15.2 & 16.2) legal positions or plan - and seniority of rights wrt to future O&G drilling plans. R17.3 Characterise: pressure and pH impacts and scope engineering and cost impacts for 3rd part O&G operators. R17.4 Characterise: preferred "no drill" areas or exclusion zone away from the injection well. R17.5 (as for 15.5 & 16.5) consider scope of a sim-ops or cooperation agreement.	May need an regulatory solution Chance of drilling plume is small. Chance of drilling high pressure zone is high. Review model like conditions.	AG	AG (to be included in regulatory action theme)
R18	Injectivity: scaling	Predicted injection performance is reduced due to near well bore scaling.	Reduction in CO_2 storage, possible venting. Possible over-investment in capture and transport Need for work-over or new well. Site de-selected as unquitable.	Y	Y		Y	4	2	8		M		1	Short	R18.1 Select: site with minimal scaling risk. R18.2 Characterise: site and geochemical reactivity through extensive lab test under representative fluid T&P conditions. R18.3 Engineer: (if a risk) for possible well intervention or for chemical inhibition. R18.4: Consider a contingency plan.	Past work done on the West Wandoan 1 Precipice Sandstone by FEI Digicore showed kaolinite movement; however, changes to permeability through fines migration were not measured. In any case, this again would depend on the nature of the BSR and clays in the deep section to be determined in new cores.	AG	JU, JP

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R19	Injectivity: compartmentalisation or baffles (faults & channels)	Predicted injection performance is reduced over time due to presence of baffles or barriers in the far-field.	Reduction in CO_2 injection rate storage, possible venting. Possible over-investment in capture and transport. Need for new well in location away from barriers. Increased risk of fracturing and containment loss to shallow zones.	Y	Y		Y	**3**	**2**	**6**		M		**2**	**Short**	R19.1 Select: site with maximum distance from known or suspected boundaries or baffles. R19.2 Characterise: far-field flow structure through seismic and dynamic well tests. R19.3 Monitor: pressure build up at injection site and in far-field to better history match impact of baffles and boundaries.	There is no evidence in any LT test on the BSR that there are material baffles and barriers except the major fault system west of the APLNG MAR trial. But the behaviour of deep Basin high angle faults is unappraised	AG	PH, IR, ASR
R20	Injectivity: diagenesis drastically reduced permeabilities at depth	Actual injection performance is LOW due to significant permeability decrease with depth, worse than pre-injection predictions. (There is no deep core data available and there is 'some' cuttings evidence of deepest Precipice being partially cemented).	Possible unsuitability of site for multi-megatonne storage. Over-investment in capture & transport. Site de-selected as unquitable	Y	Y		Y	**4**	**3**	**12**		M		**1**	**Short**	R20.1 Characterise: acquired core, wireline DFIT/MDT and well test data over intended injection zones. R20.2 Monitor: (if risky) flow zones and the proportion of fluid they accept.	No data at this depth. Evidence of water properties also needed. Bringing data from other areas down to existing modelling carries the risk that assumptions could be considered to be poorly constructed.	AG	IR (included in res scenarios)
R21	Injectivity: far-field precipitation	Injection performance is reduced over time due to far-field precipitation of minerals causing pressure build up.	Reduction in CO_2 injection rate storage, possible venting. Possible over-investment in capture and transport. Need for new well in location away from barriers. Increased risk of fracturing and containment loss to shallow zones.	Y	Y		Y	**3**	**2**	**6**		M		**1**	**Short**	R21.1 Characterise: far field flow paths (modelling). R21.2 Characterise: reactivity of formations likely in the flow path. R21.3 Characterise: fracture pressures (including thermal adjustments). R21.4 Characterise: fault reactivation pressures. R21.5 Monitor: near field and far-field pressures (near any at risk features).	No data at this depth. Evidence of water properties also needed. Bringing data from other areas down to existing modelling carries the risk that assumptions could be considered to be poorly constructed.	AG	JU, JP
R22	Injectivity: loss of well availability	Injection wells require work-over or are otherwise impaired or reduced in their injection performance.	Reduction in CO_2 injection rate storage, possible venting. Possible over-investment in capture and transport. Need for new well in location away from barriers. Increased risk of fracturing and containment loss to shallow zones.	Y	Y		Y	**3**	**1**	**3**	L			**2**	**Long**	R22.1 Characterise: formations to assess risks of borehole stability of fines effects (rocks and fluids). R22.2 Engineer: wells and completions for minimum life cycle intervention. R22.3 Engineer: wells' operational windows (pressure and flow) to minimise work-over risk. R22.4 Engineer: include redundant well.	Addressed in appraisal plan or early prefeasibility study. Essential to the ultimate abatement goal of any deployment	AG	will be covered in a post-appraisal FDP revision
R23	Injectivity: high skin	Injection performance reduced due to high completion or formation damage skin	Reduction in CO_2 storage, possible venting. Possible over-investment in capture and transport. Need for work-over or new well. Site de-selected as unquitable.	Y	Y		Y	**3**	**1**	**3**	L			**2**	**Long**	Actions as for R22	Addressed in appraisal plan or early prefeasibility study. Essential to the ultimate abatement goal of any deployment	AG	will be covered in a post-appraisal FDP revision
R24	Injectivity: MAR pressures cause reduction in margin	Injection performance reduced due to increase in far-field pore pressures from MAR (or simular) operations.	Possible need for coordination agreement. Reduction in CO_2 injection rate storage, possible venting. Possible over-investment in capture and transport. Need for new well in location away from MAR pressures. Increased risk of fracturing and containment loss to shallow zones.	Y	Y	Y	Y	**2**	**2**	**4**	L			**2**	**Long**	R24.1 Select: site to maximise distance from MAR sites. R24.2 Characterise: far-field flow properties. R24.3 Monitor: far-field pressures for early signs or issues arising. R24.4 Engage: early with MAR operator on site selection and operating window.	Addressed in appraisal plan or early prefeasibility study. Will need collaboration with other sub-surface operators	PH	PH, IR, MS
R25	Legal & Reg: Coordination agreement: 3rd party operator objections	GHG exploration activities can only be carried out where the relevant overlapping (Not adjacent or proximate) tenement rights holder has not objected to the activity (GHG Act s19) or to the safety management plan (s221).	Third party overlapping rights holders can prevent exploration and development of a storage site (this is subject to ministerial override). Note that GHG activities post date most other tenements are "at the end of the queue". Applications must comment on potential to form a coordination agreement (if no reasonable chance of an agreement, lease may be refused).			Y	Y	**5**	**3**	**15**		M		**1**	**Short**	R25.1 Select: sites without overlapping rights if possible. R25.2 Characterise: additional information and modelling needed to evaluate the likely effect (s197). R25.3 Engage: early with possible applications - provide and co-develop with overlapping rights holders to enable them to make submissions. R25.4 Engage: early with regulator and 3rd part operators - applications must comply with P&G Safety Act. R25.5 Engage: early on potential to form a coordination agreement.	May need regulatory change - is dependent on R28	AG	AG (to be included in regulatory action theme)
R26	Legal & Reg: Coordination agreement: 3rd party operator existing activities	GHG exploration activities cannot be undertaken where existing activities on other exploration permits would be adversely effected.	Third party overlapping rights holders can prevent exploration and development of a storage site (this is subject to ministerial override). Note that GHG activities post date most other tenements are "at the end of the queue".			Y	Y	**5**	**3**	**15**		M		**1**	**Short**	Actions as for R25	May need regulatory change - is dependent on R28	AG	AG (to be included in regulatory action theme)

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R27	Legal & Reg: Environmental Impact & Authority; Water Abstraction	The GHG authority requires an EA granted by DES which should allow for water abstraction (P&G provisions for associated water do not apply).	Water take is needed for dynamic testing. Inability to do this increases the long term pressure build-up risk. Reinjection licences may also be needed depending on volumes and costs of produced water.		Y		Y	5	2	10		M		1	Short	R27.1 Select: sites not covered by water abstraction allocations in the Precipice. R27.2 Select: sites (deep) not likely covered by future allocations due to high costs. R27.3 Characterise: plume and pressure spreads - evaluate impact in any known allocation areas. R27.4 Engage: early with regulator on Water Licence requirements for appraisal and for ultimate development.	May need regulatory change - is dependent on R28	AG	AG (to be included in regulatory action theme)
R28	Legal & Reg: Environmental Protection Regulations prevent injection of Waste	CO_2 from a power station looks likely to be classed as **waste** under the EP Act and cannot be injected. There are no "end of waste" codes or approvals which apply to CO_2. Granting approval must consider whether the waste will have temp or permanent environmental harm.	Significant possible flaw in current Queensland regulations. Regs need changing or CO_2 redefining as '**end of waste resources**' (under Waste Reduction and Recycling Act). The judgement of environmental harm depends on the definition of values and injecting in a GAB aquifer looks likely to raise major issues as it is likely that the endemic value of potable aquifers might be "protected" as an initial position. Without an end of waste approval, an application of an EA would be refused by DES. End of waste approval may be problematics under the Waste Act. An argument is needed to discuss local "harm" vs. prevention of wider "harms" from CO_2 emissions.		Y		Y	5	5	25			H	2	Short	R28.1 Select: sites least attractive (deep) for future use or allocation. R28.2 Engage: early with regulator on classification of CO_2 as "end of waste" resource. R28.3 Engage: early with regulator on local 'harm' vs far-field pressure 'benefits'. R28.4 Engage: early with regulator on local 'harm' vs. global CO_2 reductions.	Major risk - clarification of regulatory roadmap for large-scale CCS	AG	AG (to be included in regulatory action theme)
R29	Legal & Reg: Environmental Protection Regulations prevent injection of waste - potential for damage to "novel fauna".	The Queensland Water Quality Guidelines include a cautionary note on the potential to harm novel underground fauna in groundwater systems.	Significant delays or need to establish lack of deep fauna (unlikely in relatively hot aquifers, though). Some cost impact likely.		Y		Y	4	2	8		M		1	Med	Actions as for R28 R29.1 Select: site with low likelihood or maximum separation from ecosystems (deep). R29.2 Characterise: site for deep faunal potential. R29.3 Characterise: sites of special interest (springs, faults).	Likelihood of "novel fauna" considered low but local environmental assessments needed	AG	AG (to be included in regulatory action theme)
R30	Legal & Reg: Complexity of water allocations impacted under Water Act	GHG licences are not exempt from the Water Act. The injection of CO_2 in the aquifer sterilises an area and allocable volume. A Water Act licence will be required.	Failure to acquire a water licence to interfere will prevent any injection operations.		Y		Y	5	4	20			H	1	Short	R30.1 = 28.1 Select: areas with no and no likely future allocation. R30.2 = R27.4 Engage: early for a Water Licence.	Major risk - clarification of regulatory roadmap for large-scale CCS	AG	AG (to be included in regulatory action theme)
R31	Legal & Reg: CO_2 injection is "interfering with water"	Injection of CO_2 would likely require a water licence.	The granting of a water licence must take into account the provisions of any water plan - CO_2 emplaced within an aquifer may not be aligned with the sustainable management principles of the water act. Either issue might prevent a development.		Y		Y	5	4	20			H	1	Short	R31.1 Characterise: local area water plans. R31.2 Select: area without water plan restrictions or allocations. R31.3 Engage: early with regulator on paradox between GHG & Water Acts.	Major risk - clarification of regulatory roadmap for large-scale CCS	AG	AG (to be included in regulatory action theme)

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R32	Legal & Reg: GABORA (no EPBC) does not yet consider large scale injection impacts	GABORA limits anticipate draw-down rather than increases in hydraulic head which might occur. The possibility could cause major delays (approvals) or costs (upgrading or monitoring 3rd party infrastructure). The current availability of water in the GABORA is in the Precipice - future use or requests for allocations are likely to grow.	Water Act and GABORA seek to protect groundwater resources - this seems in direct conflict with large scale injection. Bore separation distances may be imposed with reducing the area available for injection.		Y		Y	5	5	25			H	1	Short	R32.1 Engage: early with regulator on a 'road map' to permitting / licensing. R32.2 Characterise: GABORA conditions in possible areas for injection and avoid those with most constrains.	Major risk - clarification of regulatory roadmap for large-scale CCS	AG	AG (to be included in regulatory action theme)
R33	Legal & Reg: Indirect impacts to surface water courses and springs	Injection in zone results in subsequent changes to surface water or springs, AP their chemistry and pressure	Impacts to the Precipice may be authorised but this does not authorise impacts to near surface or surface features. Impact such as increased pressure and flow may cause environmental "harm". There are regulatory penalties (Costs / prison) as well as risks of civil remedies.	Y	Y		Y	5	1	5		M		2	Med	R33.1 Select: site away from known springs or faults to surface. R33.2 Characterise: springs for signs of deep connectivity. R33.3 Characterise: flow and quality of water over time (baseline variability).	Likelihood considered low but local environmental assessments needed	AG	AG (to be included in regulatory action theme)
R34	Legal & Reg: Far-field pressure increase in 3rd party bores	Pressure rises cause unwanted flow and or mechanical damage, AP changes to water chemistry to third party bores	Damages from increased water flows or from material damage of bores need to be remedied.	Y	Y		Y	4	4	16		M		2	Med	R34.1 Select: site removed (distance) from Precipice bores. R34.2 Characterise: ranges of far-field impacts (pressure). R34.3 Monitor: 3rd party bores (water levels).	Likelihood considered high (not damaging) but local assessments needed	AG	AG (to be included in regulatory action theme)
R35	Social: resistance to further appraisal (local)	Local resistance (e.g. landholders) to in-field appraisal driven by concerns on groundwater, emissions and impact on fossil fuel use.	Delays in appraisal or failure to secure the necessary permits or EA (note links to legal and reg risks R25 to R34).				Y	4	3	12		M		2	Short	R35.1 Develop a local stakeholder value proposition. R35.2 Characterise: local views (in context). R35.3 Engage: in local outreach activities. R35.4 Consider whether current land access codes and CCAs properly cover GHG activities. R35.5 Engage: and communicate impacts with legal risks R35.6 Develop comms plan of appraisal on context of possible outcomes which would be subject to future additional conditions of approval.	Appraisal activities are low impact and involve no CO2 to get to the next decision.	PA	PA (to be included in community engagement action theme)
R36	Social: resistance to further appraisal (non-local)	Broad social resistance on grounds of groundwater emissions and impact on fossil fuel use.	Delays in appraisal or failure to secure the necessary permits or EA (note links to legal and reg risks R25 to R34).				Y	4	3	12		M		2	Short	R36.1 Develop a wider stakeholder value proposition. R36.2 Characterise: wider views (in context). R36.3 Engage: in wider outreach activities.	Appraisal activities are low impact and involve no CO2 to get to the next decision.	PA	PA (to be included in community engagement action theme)
R37	Social: resistance to ultimate development (local)	Local resistance (e.g. landholders) to large scale driven by concerns on groundwater, emissions and impact on fossil fuel use.	Delays in appraisal or failure to secure the necessary permits or EA (note links to legal and reg risks R25 to R34). Worse case is cross-over influence on politicians (State and Local) - or				Y	5	4	20			H	2	Short	Actions as for R35	Major risk - local community acceptance in line with decarbonisation / climate objectives	PA	PA (to be included in community engagement action theme)
R38	Social: resistance to ultimate development (non-local)	Broad social resistance on grounds of groundwater emissions and impact on fossil fuel use.	Delays in appraisal or failure to secure the necessary permits or EA (note links to legal and reg risks R25 to R34). Worse case is cross-over influence on politicians (State and Local)				Y	4	3	12		M		2	Med	Actions as for R36	Wide community acceptance considered lower consequence (broader community attitudes are in line with decarbonisation / climate objectives)	PA	PA (to be included in community engagement action theme)

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R39	Containment: overpressure	Aquifer contamination and pressure increase in area of potential third party interest (potential for damages).	Leakage of higher salinity groundwater and potentially dissolved metals to overlying aquifers (Hutton) from underlying formations (Evergreen) owing to overpressure. Consequences of R1-R5. Decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations (considered less likely than simple acidification).	Y	Y		Y	3	1	3	L			2	Short	R39.1 Select: deeper areas with likely highest entry pressures. R39.2 Select: areas with lower NTG in TZ and US. R39.3 Characterise: permeabilities for TZ and US for water/brine through core studies. R39.4 Engineer: for minimum pressure build up at US. R39.5 Monitor: pressure above US in higher risk areas (seismic or monitoring wells?).	Addressed by new data acquisition in appraisal program (and later by suitable M&V program IF sites found suitable)	PH	PH (to be studied further post-appraisal)
R40	Containment: migration of saline groundwater out of tenement	Displacement of higher salinity basin-centre groundwater and potentially dissolved metals out of tenement.	Contamination or decrease in water quality in areas of third party interest (e.g. up dip). Decrease in water quality e.g. potential for release (and/or transport) of metals at levels exceeding water quality guidelines and current in situ concentrations (considered less likely than simple acidification).	Y	Y		Y	3	1	3	L			2	Short	R40.1 Sample and Characterise: deep basin-cantered groundwater salinity/chemistry during drilling. R40.2 Model displacement area scenarios. R40.3 Model high/low salinity water mixing if needed.	Addressed by new data acquisition in appraisal program (and later by suitable M&V program IF sites found suitable)	PH	PH (to be studied further post-appraisal)
R41	Containment/social: natural or CSG etc. CO_2 or CH_4 leak to surface	Risk of shut down or delays if CO_2 or CH_4 source unknown.	Leakage of CO_2 or CH_4 from natural or CSG or other source to surface or shallow aquifer (e.g. Hutton). Third party/ social blame placed on CCS storage operation.	Y	Y		Y	4	1	4	L			2	Short	R41.1 Characterise: any natural occurrences of CO_2 or leakage near site. R41.2 Employ potential CO_2 tracer or natural tracer etc. R41.3 Avoid CSG production areas.	Addressed by new data acquisition in appraisal program (and later by suitable M&V program IF sites found suitable)	AG	AG (to be included in regulatory action theme)
R42	Injectivity: pore throat blockage	Blockage of pore throats via clay swelling or fines migration.	Acidification could induce clay or fines migration blocking pore throats. movement of water and changes in salinity can induce clay swelling. Reduction in CO_2 injection rate storage, possible venting. Possible over-investment in capture and transport. Need for new well in location away from barriers. Increased risk of fracturing and containment loss to shallow zones.	Y	Y		Y	3	1	3	L			2	Short	R42.1 Characterise: reservoir clay types - swelling/non swelling, core characterisation and lab tests. R42.2 Characterise: reactivity of formations likely in the flow path. R42.3 Monitor: near field and far-field pressures (near at any risk features).	Addressed by new data acquisition in appraisal program (and later by suitable M&V program IF sites found suitable)	AG	JP (fines tests after appraisal)
R43	Focus Groups: Managed Aquifer Recharge	Potential Risk/Opportunity to impact MAR	Those in community become more aware of the principles of MAR and CCS. Community members either become concerned about interactions with GAB or see the opportunities it presents for landholders and others.	Y	Y		Y	4	2	8		M		1	Short	R43.1 Engage: Focus Groups are being planned and research protocols will be followed.	Closely linked to "High" risk scores R37 and all risks R35 to R38	PA	PA (to be included in community engagement action theme)
R45	Injectivity: poor quality reservoir (depositional)	Poor Quality Reservoir (Porosity/Permeability, Petrophysics)	Risk of delay in injection which may increase number of sites and costings.	Y	Y			4	3	12		M		2	Short	R45.1 Characterise: through core sampling, logging and long term injection tests. R45.2 Characterise: Reprocessing of seismic data / collection of new seismic data. R45.3 Characterise: Collect core from proposed well location and full suite of wireline logs. (refer to consequences R 20)	Essential the same risk as R20	AG	ALC & IR (covered in scenarios - needs data)
R46	Indigenous Land Use Agreement	Resistance to entering into an Indigenous Land Use Agreement	Leading to delays in negotiating and obtaining necessary agreements with Native Title Claimants over the land for the injection site and /pipelines.		Y		Y	4	1	4	L			1	Short	46.1 Avoid: areas over which a Native Title Claim has been registered. 46.2 Engage: in negotiation early, obtaining an experience law firm to help conduct negotiations. This has been taken into account in the site selection (more of an issue with pipelines).	Will be covered in the short term in appraisal phase stakeholder engagement	AG	PA (to be included in community engagement action theme)
R47	Legal & Reg: Areal Migration	Unplanned migration into another jurisdiction (containment), in particular aquifers.	If CO_2 migrates into NSW, out of expected reservoir footprint, then relevant NSW legal and regulatory requirement regarding environment and water may be breached. Complexities in engaging with two different regulator and regulatory systems causing delays.				Y	3	1	3	L			2	Long	47.1 Engage: Mitigating action may be to seek compliance with NSW requirements as well as QLD and drill pressure monitoring bores at the border of NSW /QLD. Engage in Negotiations early. 47.2 Select: location up-dip to QLD.	Considered very low likelihood - include for completeness only. M&V plan to the south would cover this.	AG	AG (to be included in regulatory action theme)

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R48	Legal & Reg: Compliance	Compliance with multiple jurisdictions' regulations for environmental impact	Complexities involved in engaging with two different regulators & regulatory systems causing delay.	Y			Y	3	1	3	L			2	Med	48.1 Engage: Mitigating actions would include engaging in negotiations early. Also see R47.2.	Considered low likelihood - revision of EPBC Act to include CCS would change this risk	AG	AG (to be included in regulatory action theme)
R49	Legal & Reg: Compliance	Regulator's view of the subsurface water resources of the Precipice and Hutton, etc.	Potential contamination of the low salinity water (including within BSR of the site) as needing to be specified/predicted.	Y	Y	Y	Y	5	3	15		M		2	Med	49.1 While a lowered pH in the plume may be ok, the unlikely scenario of releasing metals above stock or agriculture guidelines, or the current in situ concentrations in the water, may or may not be ok. This also relates to R28. Further work on understanding the deep formation water composition, and new rock core (including Hutton) would decrease the uncertainly.	Mainly covered in "high" risks R30 to R32 - not an issue for the appraisal program unless and early ruling is made absent site specific data.	AG	AG (to be included in regulatory action theme)
R50	Containment: Displaced water and Hutton water quality	Pressure in the BSR causes pressure rises in TZ and US. Lower quality water (not CO_2) is displaced from US into the lower Hutton, changing water quality therein. Mechanism could also be faults, channels/erosion or simple pressure through matrix.	Increased salinity in lowermost Hutton (modelling shows relatively low volumes; geology suggests Hutton poorly connected:- little long range effects).	Y	Y		Y	3	4	12		M		2	Short	Refer to mitigation actions and data requirements for other "Containment" classified risks.	Mainly covered in regulatory "high" risks R30 to R32 - not an issue for the appraisal program unless and early ruling is made absent site specific data. Also covered in technical containment risks	PH	PH (to be studied further post-appraisal)
R51	Technical Maturity for Social Acceptance & Regulatory Approvals	Detailed, competent and site specific data and tests are required to convince many stakeholder groups (to address the maturity of this risk assessment).	Many detailed questions need to be addressed so that a complete story can be told before further decisions on actual injections. Failure to gather convincing (probably confirmatory) data will prevent any progress	Y	Y	Y	Y	5	5	25			H	3	Short	Refer to all technical risks and to UQ-SDAAP Supplementary Detailed Report describing the appraisal plan.	Essential to commence this IMMEDIATELY as there is a time criteria for both climate abatement and for power plant life. The window of opportunity is limited.	AG	AG

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CREATE CHANGE

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O1	Enhanced groundwater levels	Injecting in the basin centre may raise water levels in the far-field and displace basin-centre water	This may support Precipice abstraction in areas well removed from the injection sites for 3rd party users (e.g. agriculture).		Y		Y	4	5	20			H	2	Short	Further discussions with community and regulator required (as well as more detailed post-appraisal modelling)	Addressed in appraisal plan through more data acquisition. Social impacts also addressed through consultation.	PH-PA	PH & PA (to be further quantified and discussed with community)
O2	Enhanced groundwater recovery	Injecting in the basin centre may displace basin-centre water to areas where it is more economic to drill and recover (up dip)	This may support Precipice abstraction in areas well removed from the injection sites for 3rd party users (e.g. agriculture).		Y		Y	4	5	20			H	2	Short	Further discussions with community and regulator required (as well as more detailed post-appraisal modelling)	Addressed in appraisal plan through more data acquisition. Social impacts also addressed through consultation.	PH-PA	PH & PA (to be further quantified and discussed with community)
O3	Regional development: Retention / extension of existing regional industry & jobs	Successful reduction of carbon intensity of power generation could prolong the existence of regional jobs and industry in the region (mining and powergen).	Sustained regional employment, continuation of taxes and State royalties		Y		Y	4	5	20			H	2	Med	Further modelling and interaction with DNRME & DSD required	Regional employment is a direct consequence of deployment. Details need to be worked up prior to FID	AG-PA	AG & PA (to be in regulatory and community engagement)
O4	Regional development: Attraction of new carbon intensive industries to the region	Availability of storage may attract high Co2 emitters (e.g. cement or gas-fertiliser or gas-plastics) into the region	New regional employment, increased taxes and State royalties		Y		Y	4	3	12		M		1	Med	Further modelling and interaction with DNRME & DSD required	More industries could be accommodated. It is likely that there is more injection/storage potential than needed by the 3 power plants studied. Appraisal data will increase confidence levels. Details need to be worked up prior to FID	AG	AG (to be included in regulatory action theme)
O5	National Survey Results	Engage Community with the National Survey Results	Builds positive recognition of the project and UQ more widely		Y	Y	Y	4	3	12		M		2	Short	O5.1-Ongoing communication strategy to share the results more widely. These results can be circulated widely across all levels of Government and industry (Local, State, National & International)	Results and methods from UQ-SDAAP show promise in understanding community response and in better quality engagement	PA	PA (to be included in community engagement theme)
O6	Message Testing Focus Groups & Survey	Opportunity to enhance or tailor message to specific comments	An understanding of the clear messages that will help in communication of CCS technology		Y	Y	Y	4	4	16		M		2	Short	O6.1-Ongoing communication strategy to share the results more widely. These results will synthesise findings of ways to inform the community and other stakeholders about the role that CCS may play in decarbonising our energy supply	Results and methods from UQ-SDAAP show promise in understanding community response and in better quality engagement	PA	PA (to be included in community engagement theme)
O7	Improved regional GW management	Data from an appraisal program may significantly assist OGIA's regional GW efforts	Dynamic data from the deep basin will improve overall basin ground water management	Y	Y		Y	3	5	15		M		2	Short	O7-1- Ensure ongoing collaboration with OGIA and with other sub-surface users			
O8	Improved NEM System cost modelling	Total system cost modelling for NEM decarbonisation is highly dependent on the amount of CCS available. Appraisal work will improve estimates	Dynamic data from the deep basin will improve overall NEM system management	Y	Y		Y	3	5	15		M		2	Med	Report complimentary to (but not part of) UQ-SDAAP clearly shows that minimal TCS requires substantial CCS. More confidence in CCS rates will improve optionality for NEM future generation			

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