Leveraging uncertainty frameworks for groundwater impact assessment in Australia for contaminant risk assessment in Europe

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Uncertainty structure

Type	All possible outcomes identified?	Probabilities can be assigned?	Evidence can be *defined*?	Evidence can be *obtained*?	Uncertainty reducible?
Shallow uncertainty	✅	✅	✅	✅	Practically reducible
Deep uncertainty	✅	❌	✅	❌	Practically irreducible
Recognized ignorance	❌	❌	❌	❌	Irreducible

Janzwood, S. (2022). Confidence deficits and reducibility: Toward a coherent conceptualization of uncertainty level. *Risk Analysis*, *June*, 1–13. https://doi.org/10.1111/risa.14008

Uncertainty structure - examples

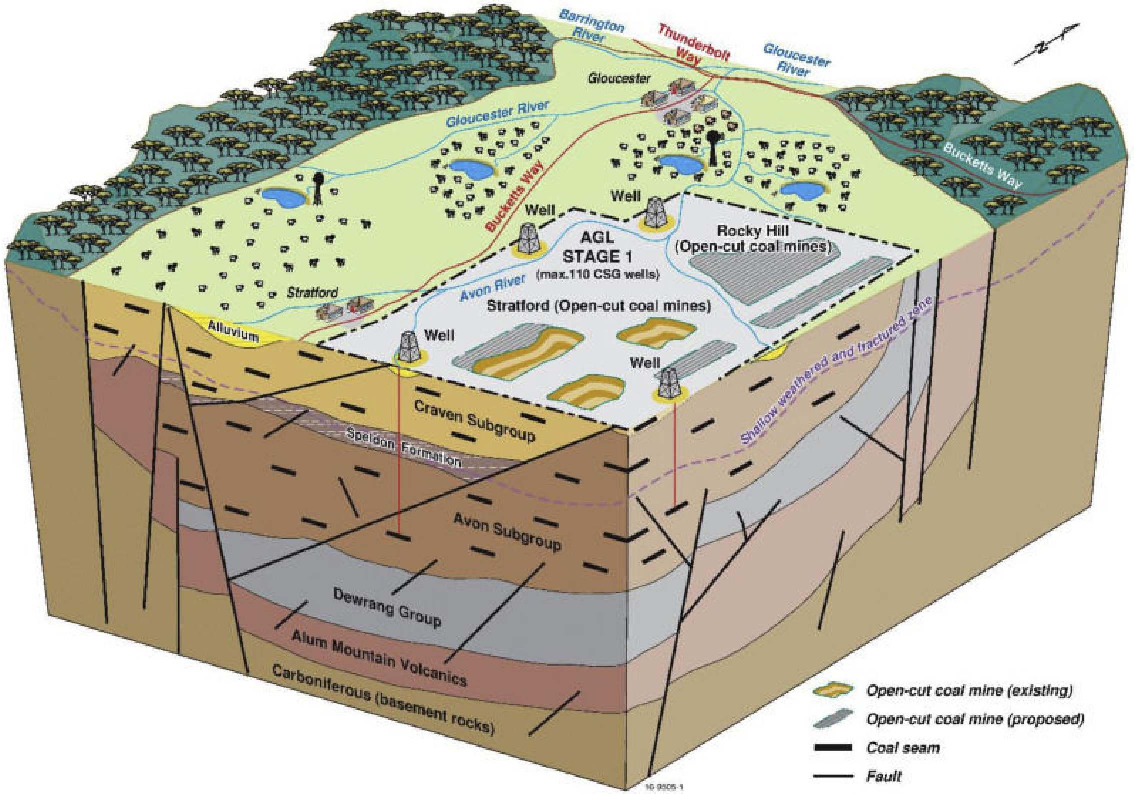
<table>
<tr><th></th><th>Short term weather forecast</th><th>Change in groundwater level from mine development</th><th>Diffuse PFAS</th></tr>
<tr><td>All possible outcomes defined?</td><td>❌--------|-✅</td><td>❌--------|-✅</td><td>❌--|-------✅</td></tr>
<tr><td>Probabilities can be assigned?</td><td>❌-------|--✅</td><td>❌-|--------✅</td><td>❌|---------✅</td></tr>
<tr><td>Evidence can be defined?</td><td>❌---------|✅</td><td>❌--------|-✅</td><td>❌-------|--✅</td></tr>
<tr><td>Evidence can be obtained?</td><td>❌-------|--✅</td><td>❌--|-------✅</td><td>❌--|-------✅</td></tr>
<tr><td>Uncertainty type</td><td>Shallow uncertainty</td><td>Deep uncertainty</td><td>Recognized Ignorance</td></tr>
<tr><td>Uncertainty reducible?</td><td>Yes</td><td>No
(in practice)</td><td>No
(theory & practice)</td></tr>
</table>

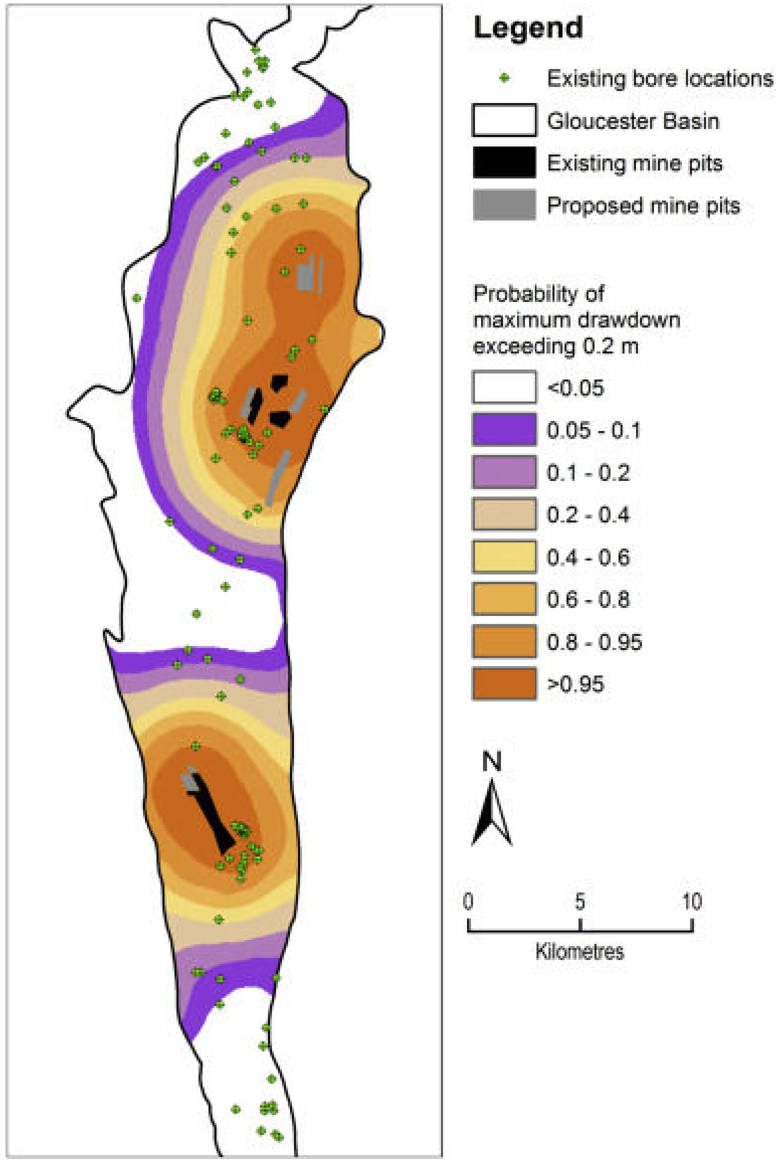
How to use uncertainty in risk assessment?

Uncertainty type	Strategy
Shallow	Quantify probabilities • Data-driven models (ML / AI) • Process-based models
Deep	Quantify probabilities but recognize ignorance • Assumption hunting • *Find assumptions before they find you*
Recognized ignorance	Improve system understanding Robust decision making • Precautionary principle / ALARP • *Bounded by what is known*

Example Deep Uncertainty

Impact coal mining and coal bed methane extraction on water resources





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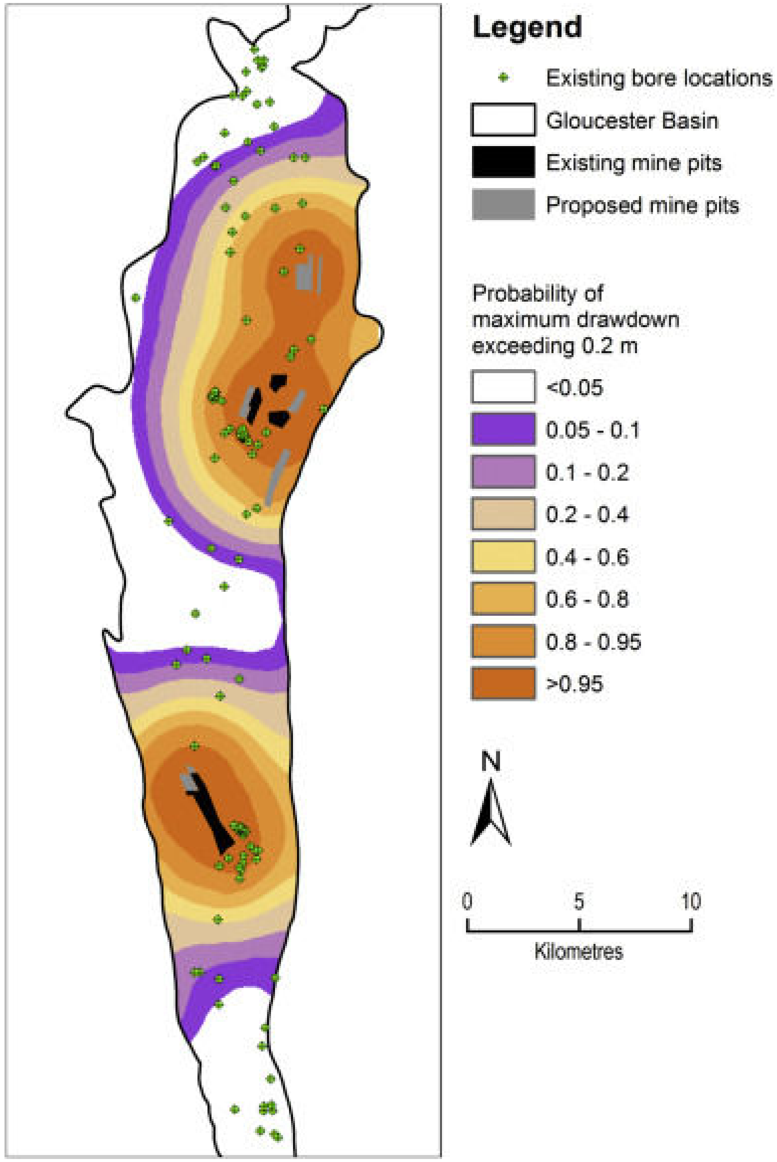
Peeters et al. (2018). Determining the initial spatial extent of an environmental impact assessment with a probabilistic screening methodology. *Environmental Modelling and Software*, *109*(August), 353–367. https://doi.org/10.1016/j.envsoft.2018.08.020

Example Deep Uncertainty

Impact coal mining and coal bed methane extraction on water resources

Assumption / Model choice	Data	Resources	Technical	Effect on predictions
Superposition	M	L	L	L
Uniform properties	H	M	M	L
Stochastic faults	H	L	L	M
Wells as constant head	H	M	H	M
Mines as prescribed Q	H	L	L	H
Prior distributions	H	L	L	M
Flux for calibration	H	L	L	M
Simulation period	L	H	L	L



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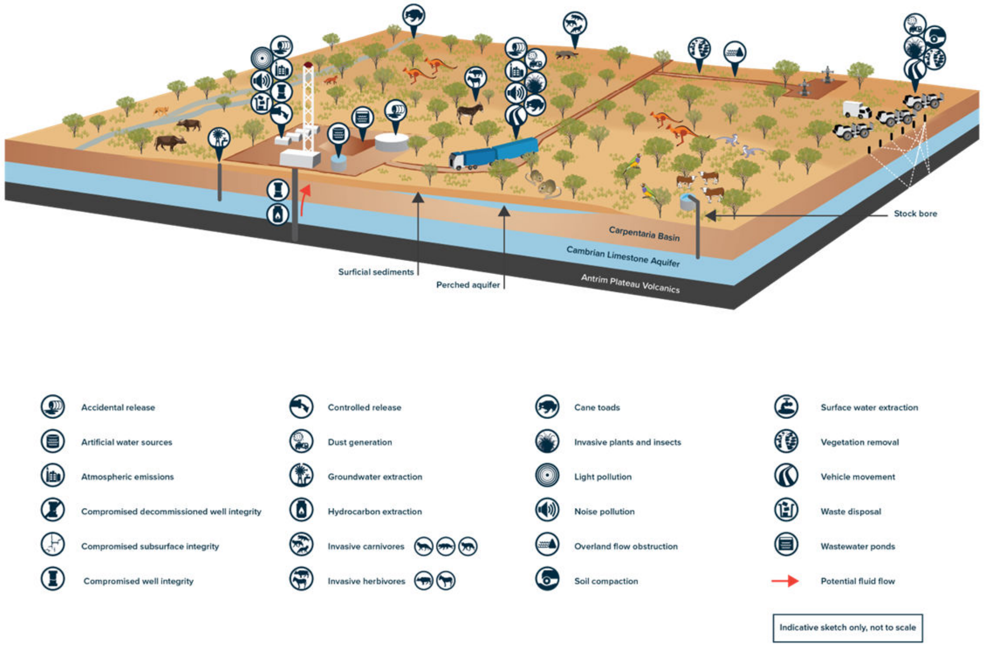
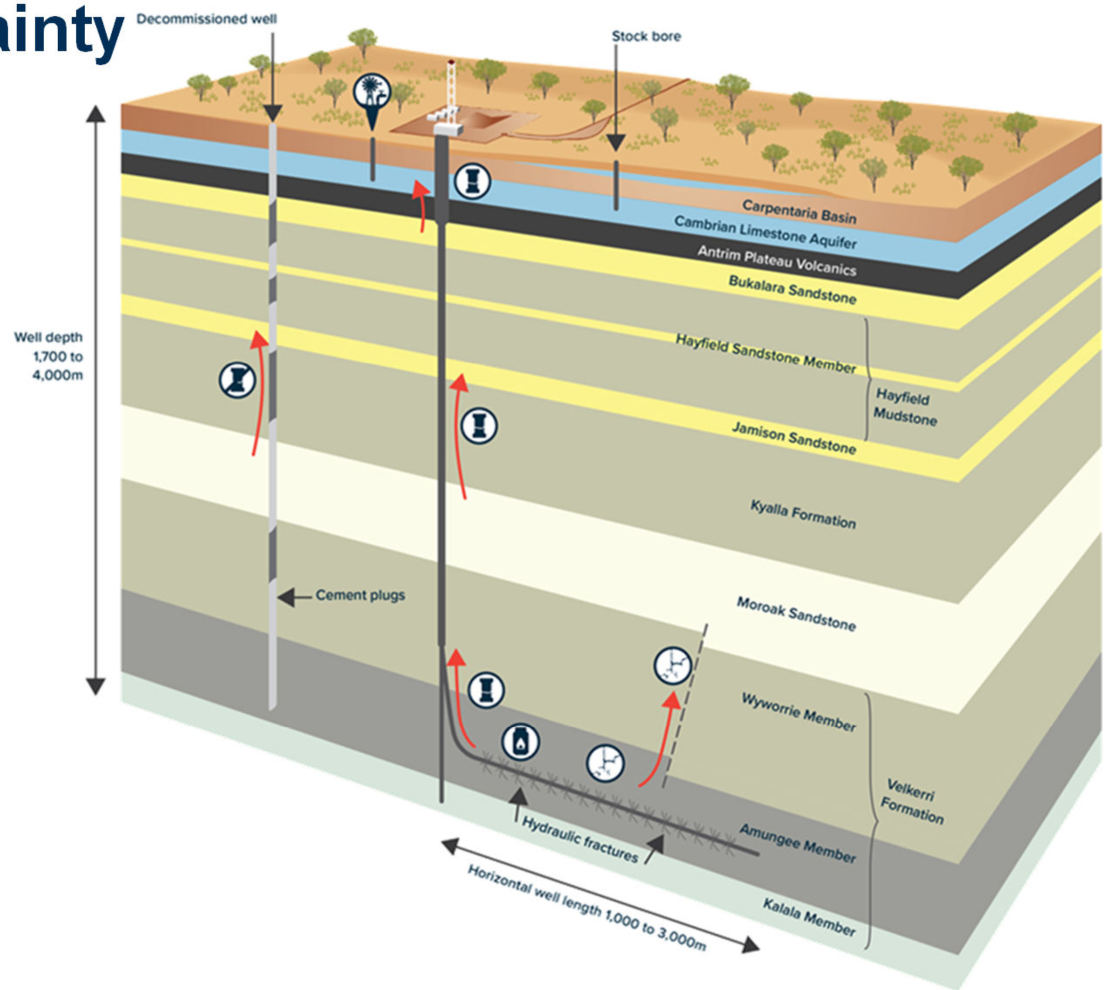
Example Recognised Uncertainty

Greenfield shale gas development

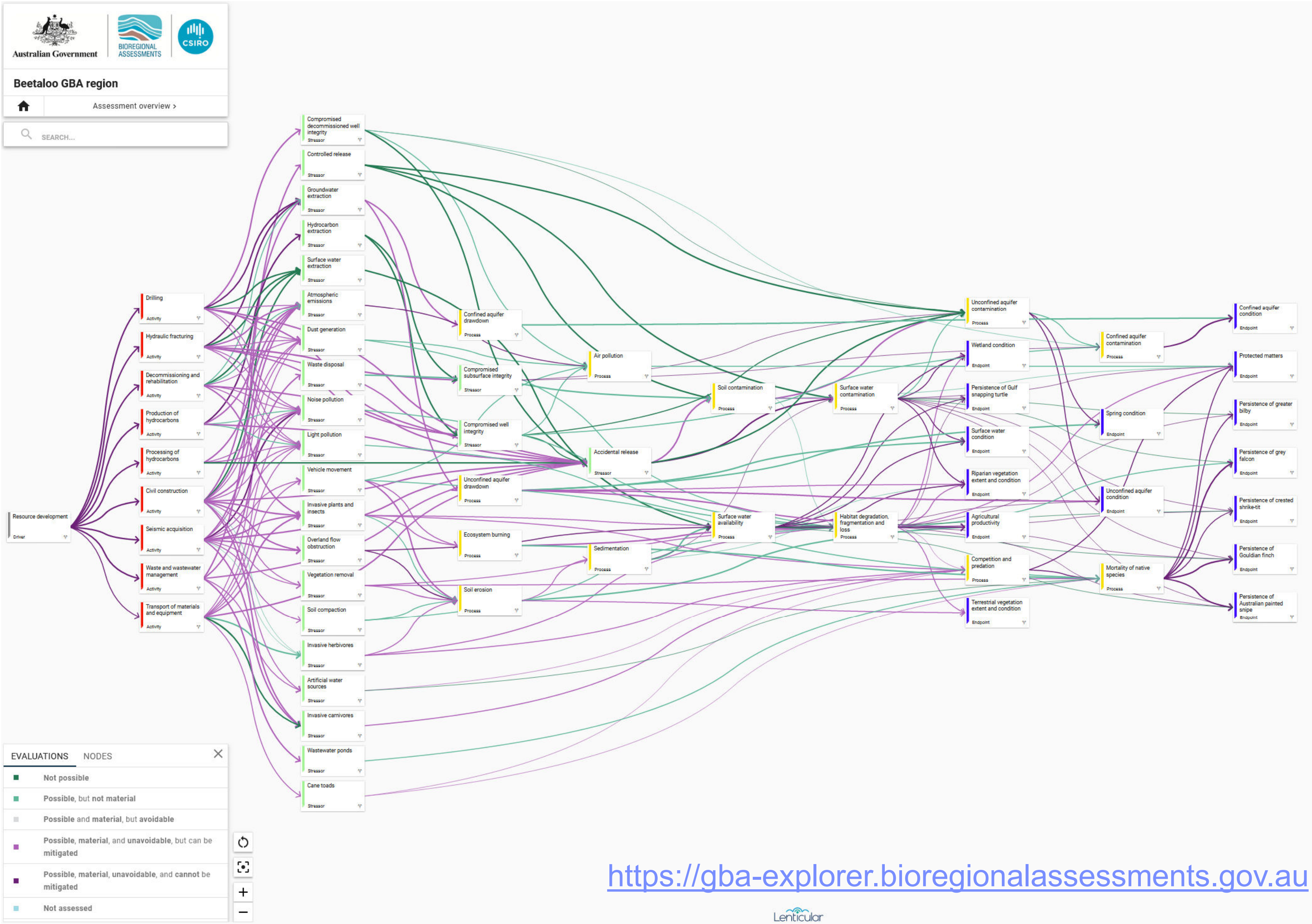




Make what is known explicit

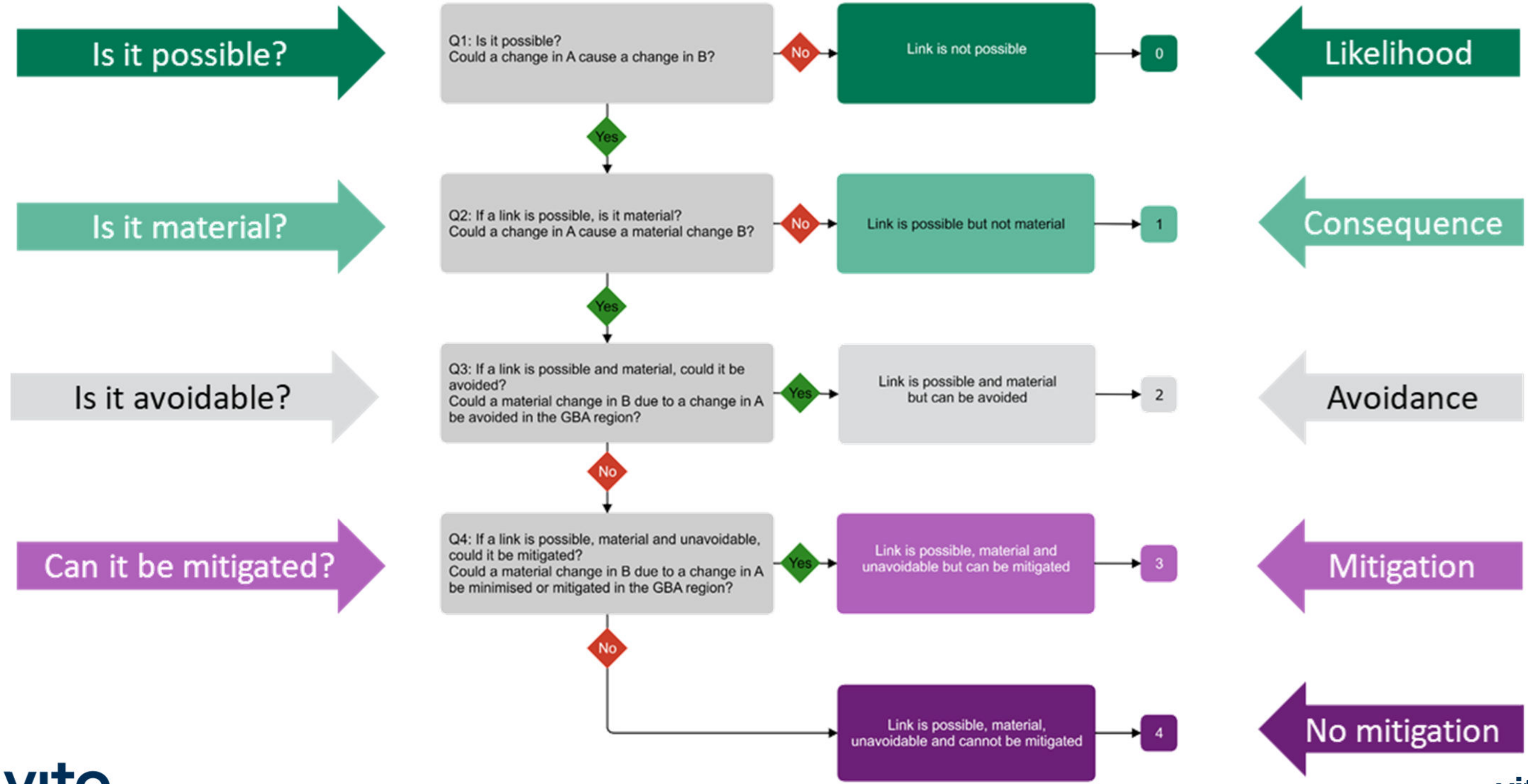
Driver	Activity	Stressor	Process	Endpoint
development of a resource	planned event necessary to develop resource	environmental stress resulting from an activity	natural mechanism by which a stressor impacts an endpoint	something in the region that the community values

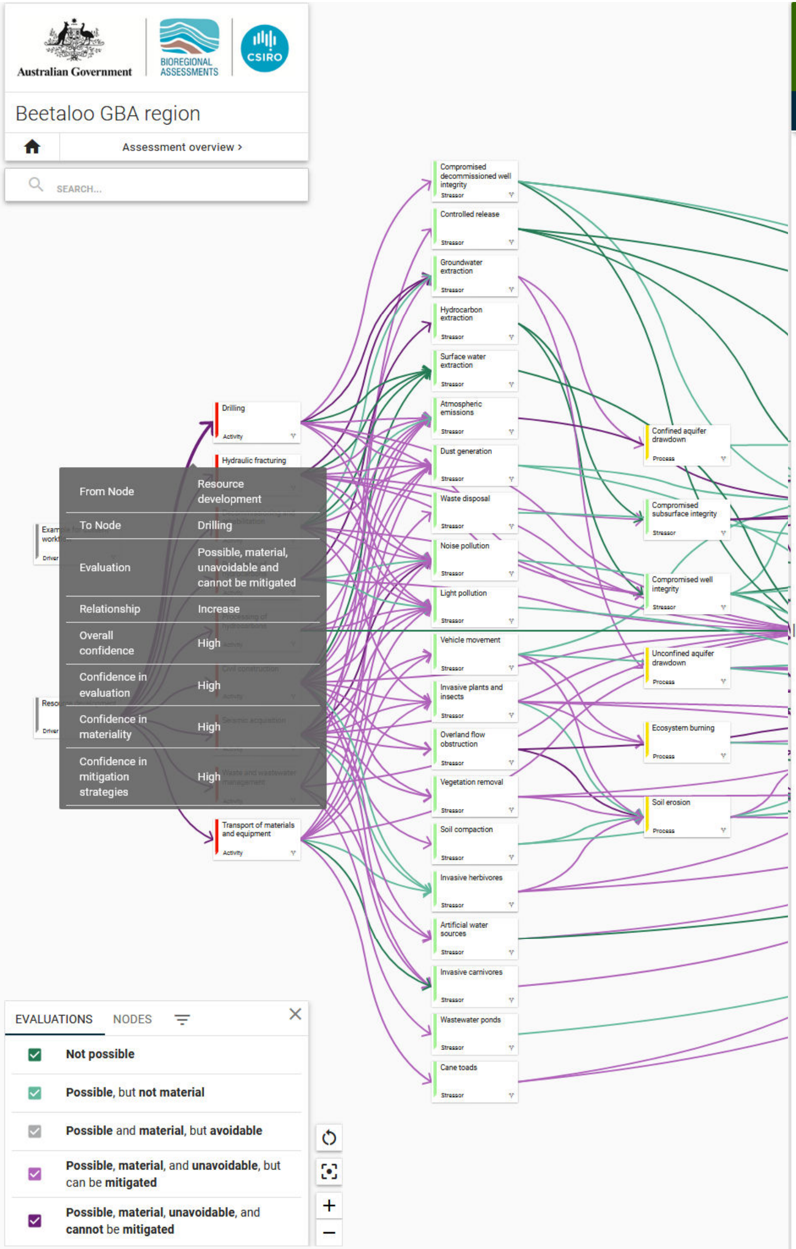
Resource development	Drilling	Vegetation removal	Habitat fragmentation and loss	Grey Grasswren

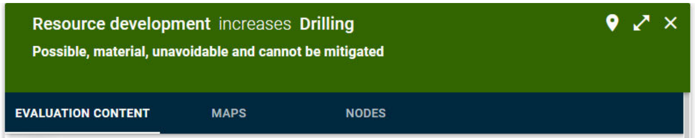


https://gba-explorer.bioregionalassessments.gov.au

Quantitative and qualitative risk assessment







Resource development increases drilling

Drilling of wells is a fundamental component of the development of unconventional hydrocarbon resources.

Will resource development result in an increase in drilling activities within the assessment area?

Link evaluation

The links have been evaluated using the method defined in the impact assessment methodology (Peeters et al., 2021a) and described in the causal network guide (Peeters et al., 2021b). A relationship denoted as 'increases' is a 'direct relationship' where the 'from node' and the 'to node' (the link within a pathway) both increase or decrease together. A relationship denoted as 'decreases' is an 'inverse relationship' where the 'from node' increases and the 'to node' decreases, or vice versa.

Evaluation

Q1: Is it possible? Could an increase in resource development cause an increase in drilling?

Yes. In areas that are prospective for unconventional gas, unconventional gas development requires drilling for exploration and production of hydrocarbons (Huddlestone-Holmes et al., 2020).

In areas where relative prospectivity is equal to zero, it is considered **not possible** for resource development to lead to an increase in drilling, as proponents are assumed not to invest in exploration or production drilling in areas that are not prospective.

Q2: If a link is possible, is it material? Could an increase in resource development cause a material increase in drilling?

Yes. A material increase in drilling due to resource development occurs where and when exploration and production drilling targeting unconventional gas occurs.

Q3: If a link is possible and material, could it be avoided? Could a material increase in drilling due to an increase in resource development be avoided in the Beetaloo GBA region?

No. Drilling is inevitable in prospective areas to produce gas from unconventional plays in the Beetaloo Sub-basin. A material increase in drilling due to resource development is therefore **possible, material and unavoidable**.

Drilling can be avoided where unconventional gas resource exploration and development activities are not allowed (i.e. in reserved blocks).

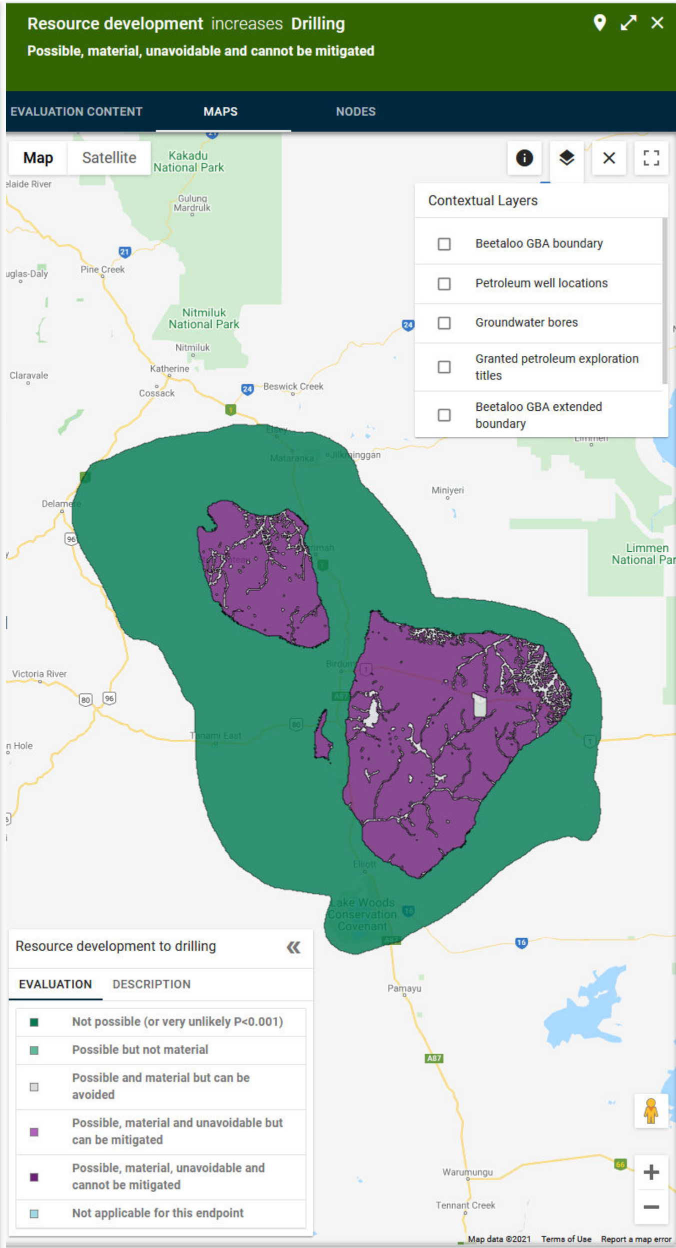
Q4: If a link is possible, material and unavoidable, could it be mitigated? Could a material increase in drilling due to an increase in resource development be mitigated in the Beetaloo GBA region?

No. The number of wells to be drilled depends largely on the characteristics of the unconventional gas resource plays. While the number of wells to be drilled can be optimised, minimising the number of wells drilling will directly affect the amount of gas to be produced.

Evaluation summary

The link 'resource development increases drilling' is evaluated as **possible, material, unavoidable and cannot be mitigated** in prospective areas. Where drilling is not permitted (i.e. in reserved blocks), it is considered **possible and material but can be avoided**. Where prospectivity is equal to zero the link 'resource development increases drilling' is evaluated as **not possible**.

Spatial evaluation



Conclusion

- Not all sources of uncertainty are quantifiable
  - Assumption hunting
  - Clear, transparent and honest reporting
- Source → Receptor causal framework
  - Formalizes what is known
  - Highlights knowledge gaps
- Precautionary principle
  - Rule out areas / pathways of no or low concern
  - Highlights potential pathways of concern

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