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

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Emerging contaminants

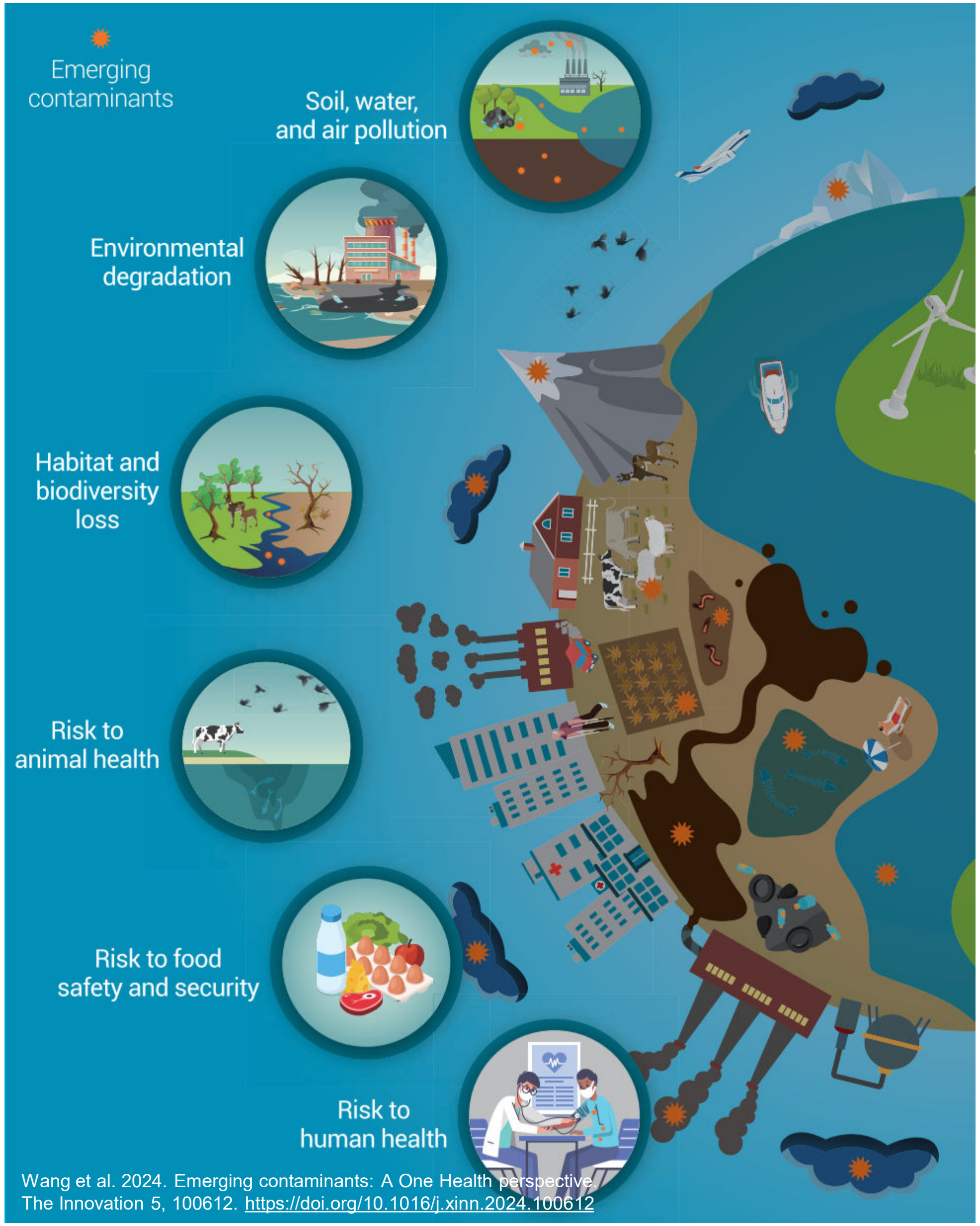
Source

↓

Pathway

↓

Receptor



Wang et al. 2024. Emerging contaminants: A One Health perspective. The Innovation 5, 100612. https://doi.org/10.1016/j.xinn.2024.100612

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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

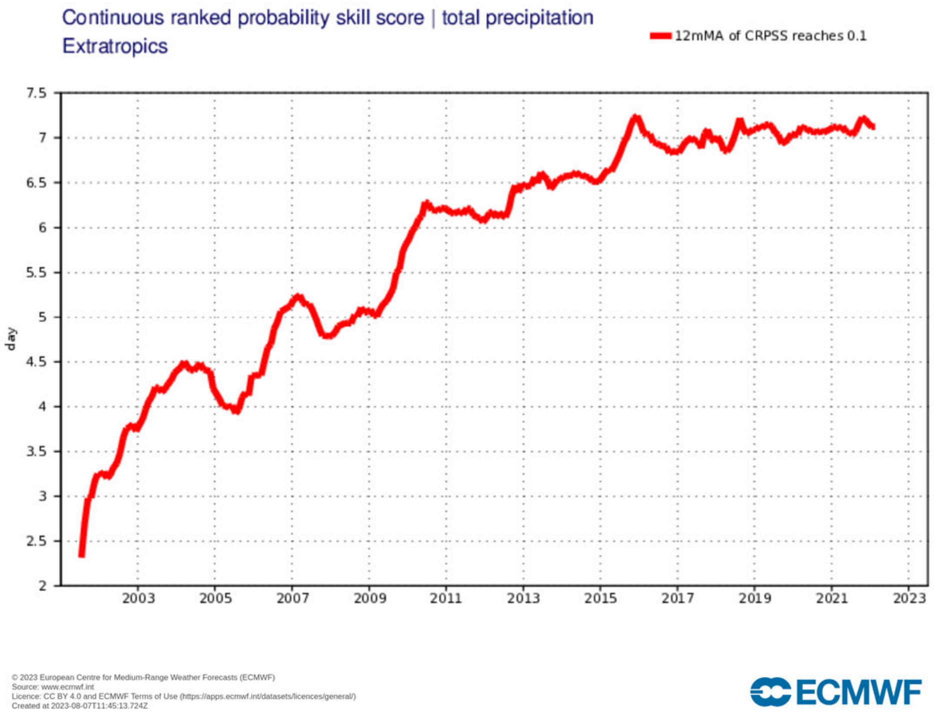
Janzwood, S. (2022). Confidence deficits and reducibility: Toward a coherent conceptualization of uncertainty level. *Risk Analysis*, *June*, 1–13. https://doi.org/10.1111/risa.14008

Uncertainty structure - examples

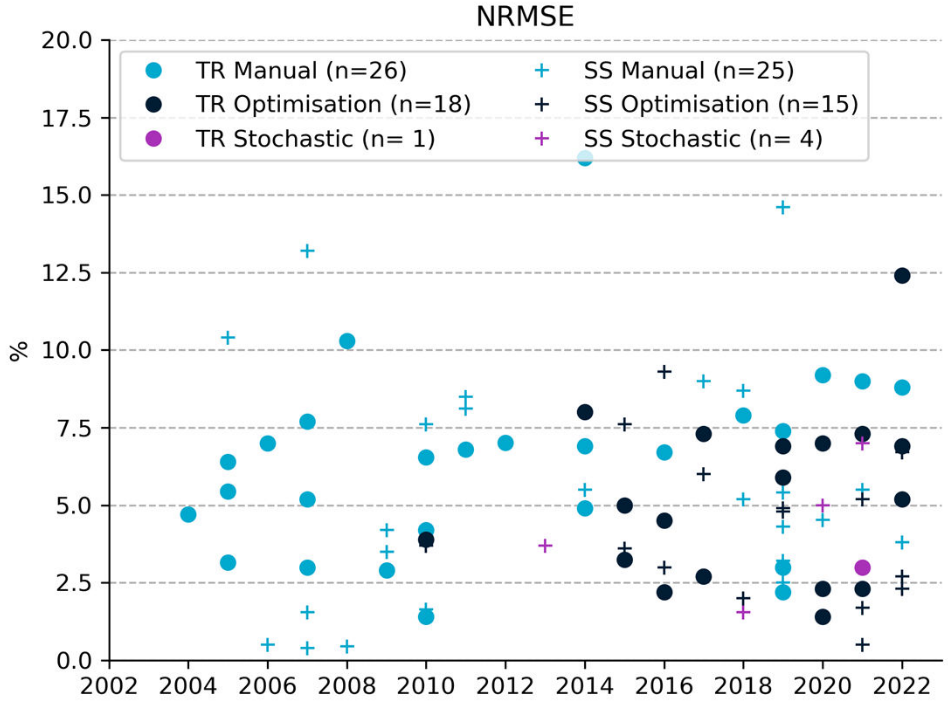
	Short term weather forecast	Change in groundwater level from mine development	Diffuse PFAS
All possible outcomes defined?	❌ --------|- ✅	❌ --------|- ✅	❌ --|------- ✅
Probabilities can be assigned?	❌ -------|-- ✅	❌ -|-------- ✅	❌ |--------- ✅
Evidence can be **defined**?	❌ ---------| ✅	❌ --------|- ✅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

Reality check

Lead time of continuous ranked probability skill score (CRPSS) of 24 hour precipitation forecasts falls to 10%



Accuracy Australian groundwater models



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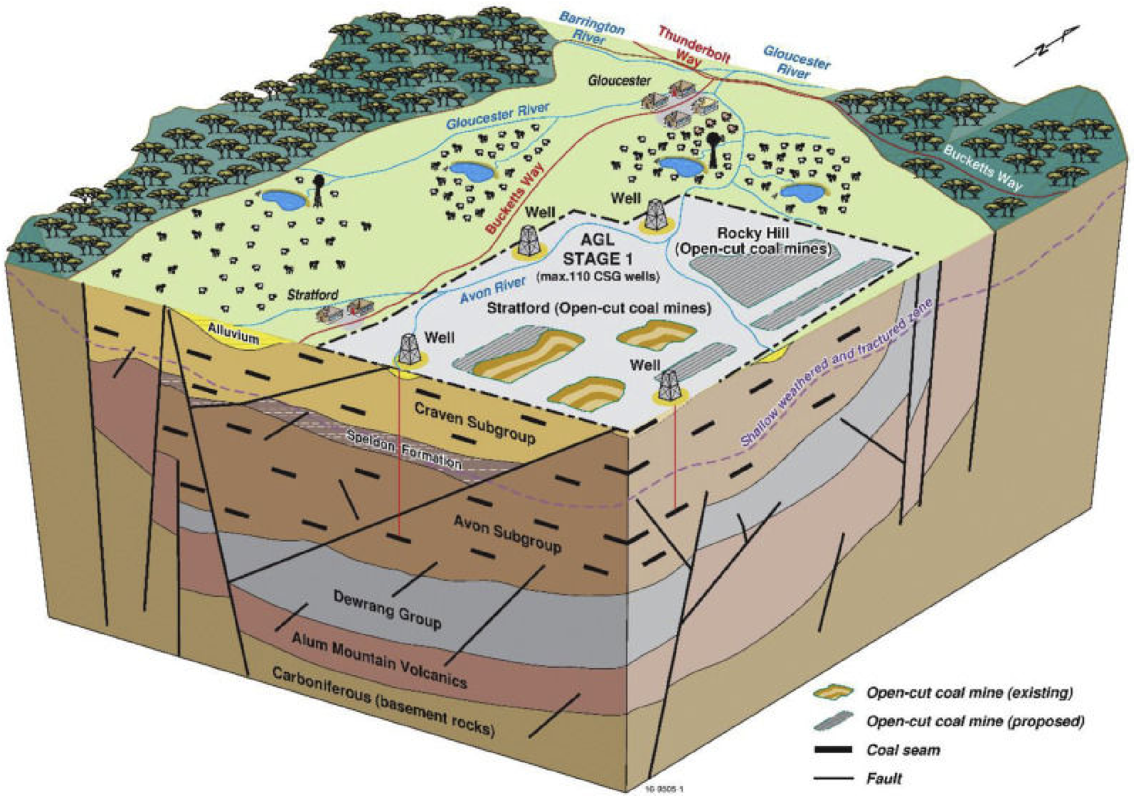
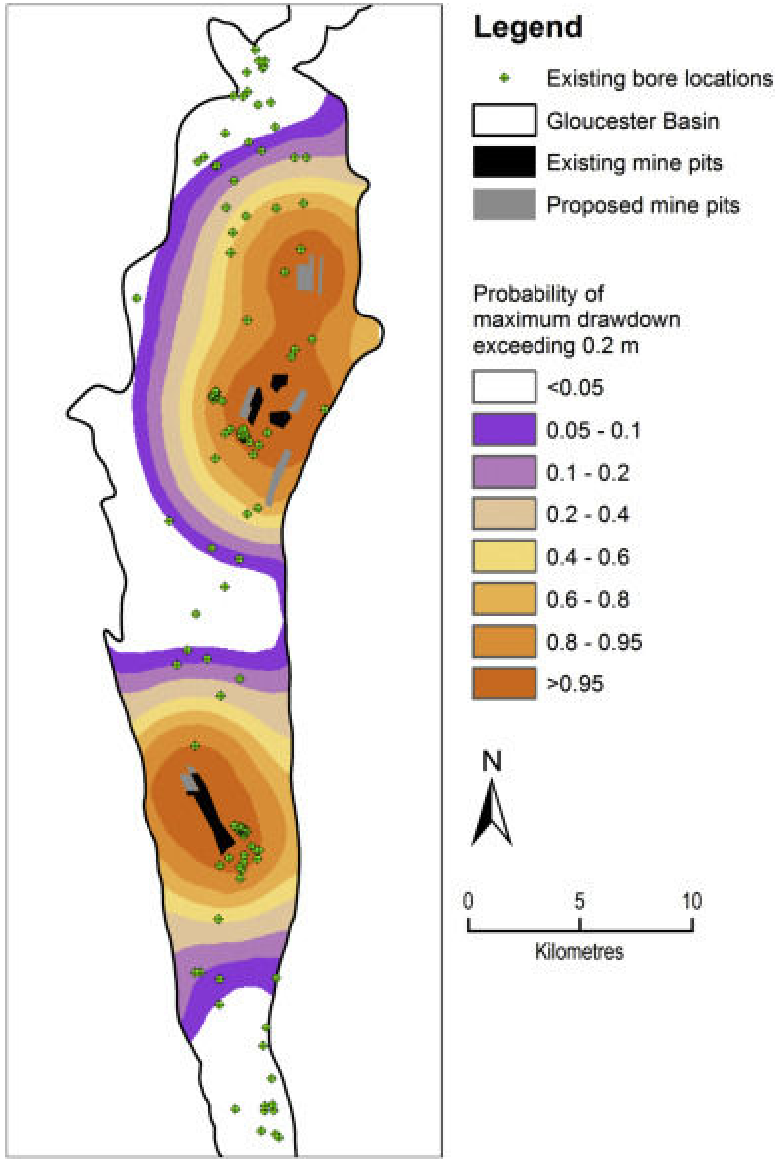
How to use uncertainty in risk assessment?

Uncertainty type	Strategy
Shallow	Quantify probabilities • Data-driven models (ML / AI) • Process-based models
Deep	Quantify probabilities but recognize ignorance • Process-based models • Assumption hunting → *What if the model is wrong?*
Recognized ignorance	Improve system understanding Robust decision making • Precautionary principle • Conservative / “worst” case→ *Bounded by what is known*

Example Deep Uncertainty

Impact coal mining and coal bed methane extraction on water resources





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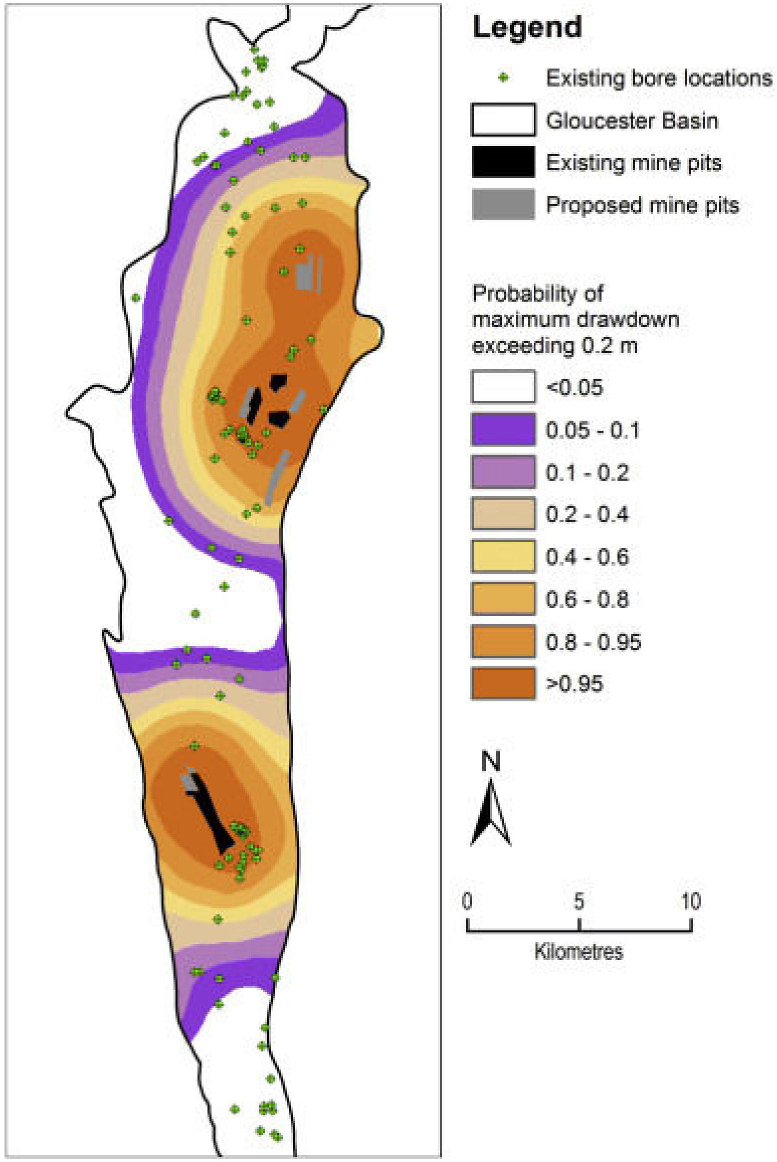
Peeters et al. (2018). Determining the initial spatial extent of an environmental impact assessment with a probabilistic screening methodology. *Environmental Modelling and Software*, *109*(August), 353–367. https://doi.org/10.1016/j.envsoft.2018.08.020

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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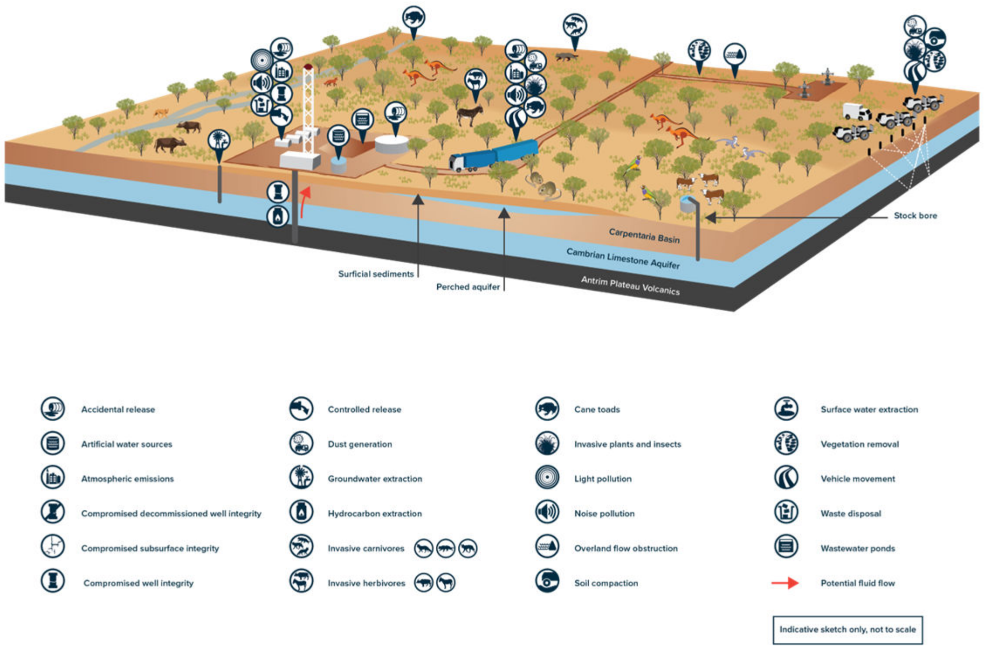
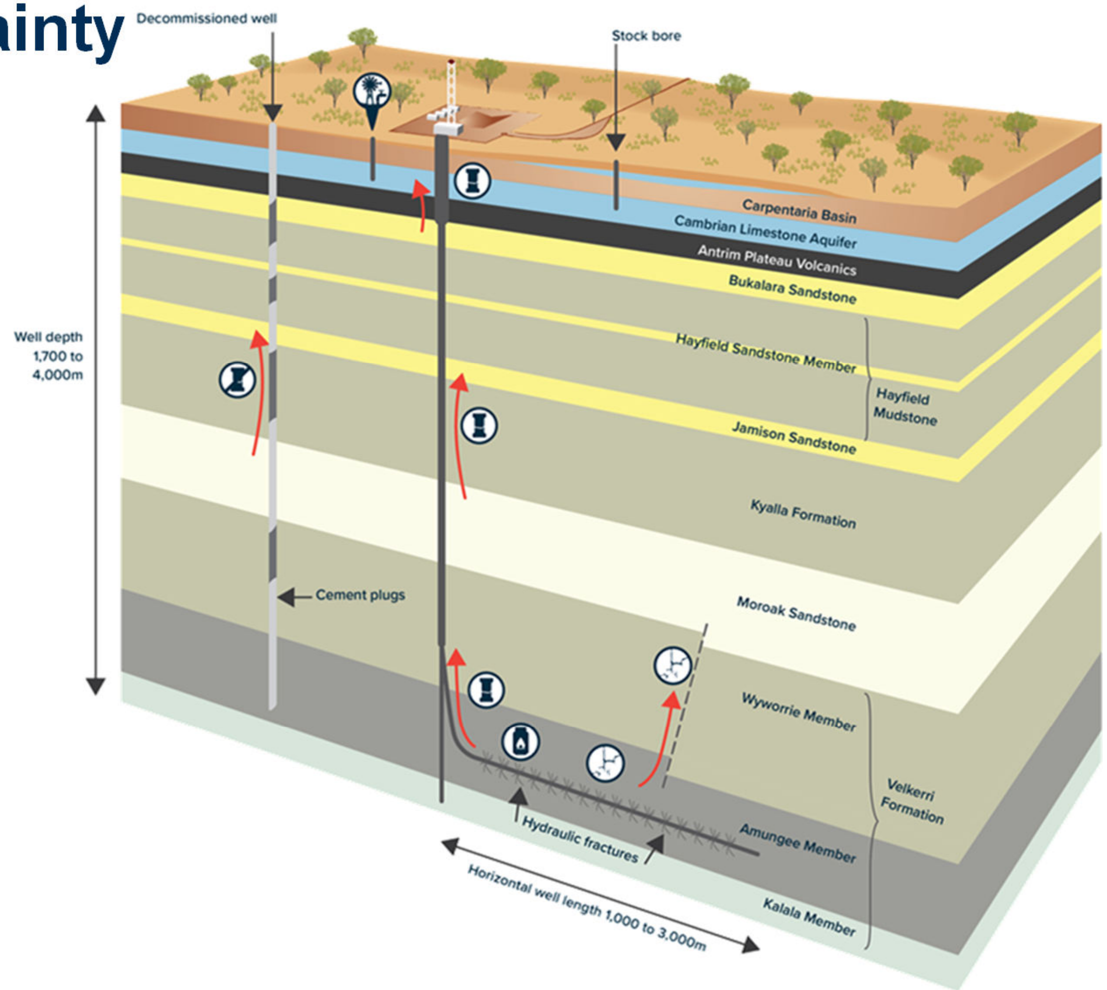
Example Recognised Uncertainty

Greenfield shale gas development





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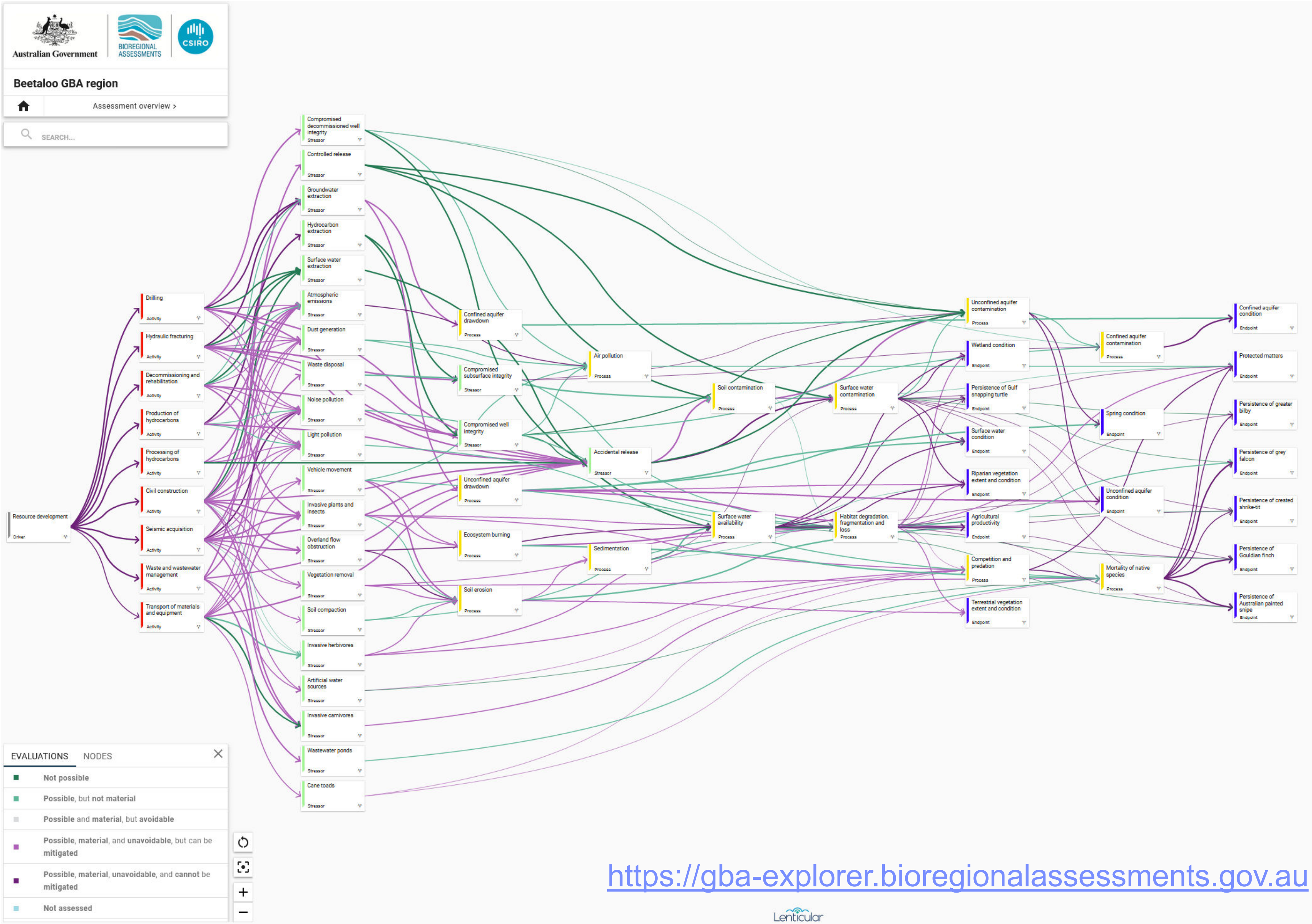
Make what is known explicit

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

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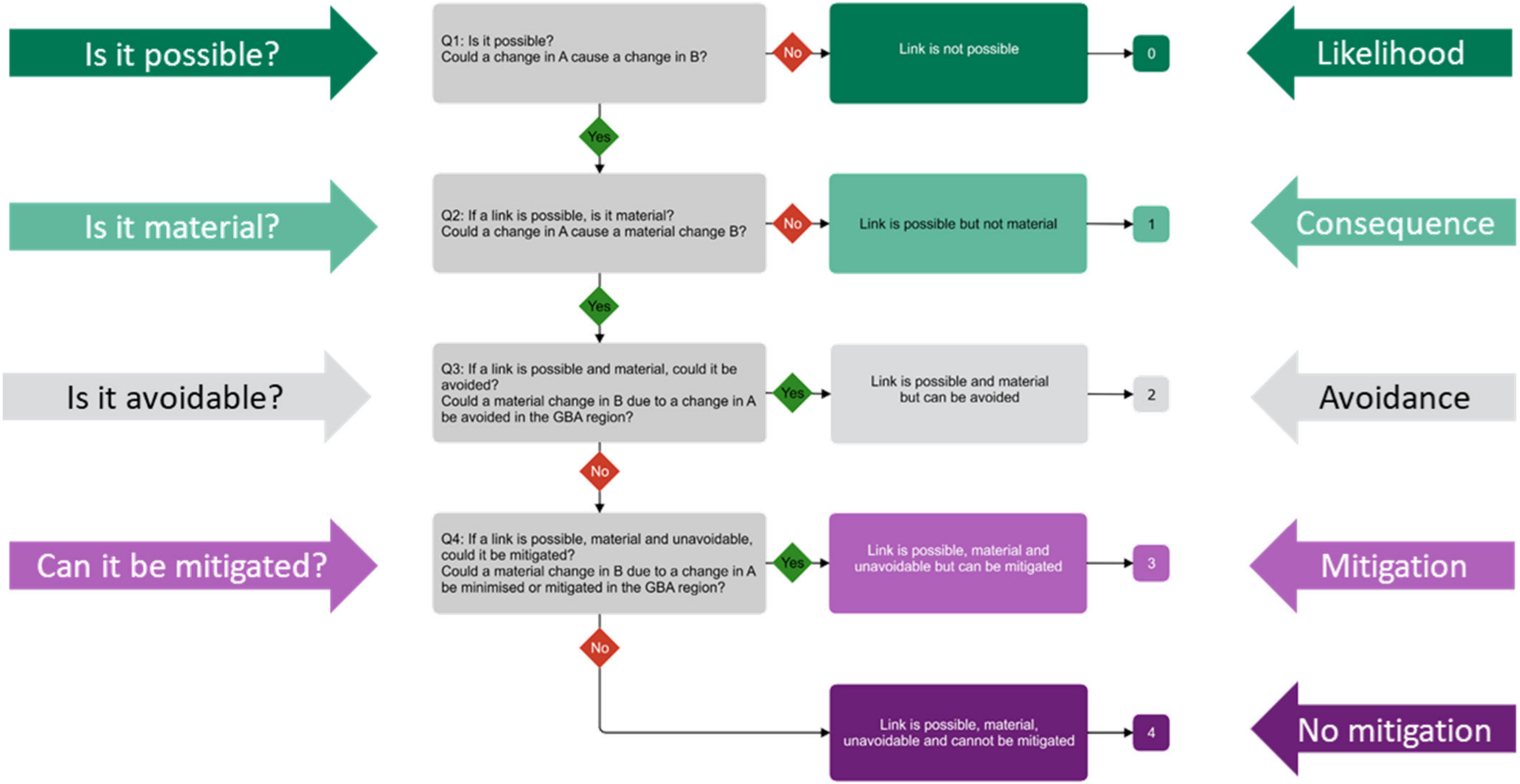


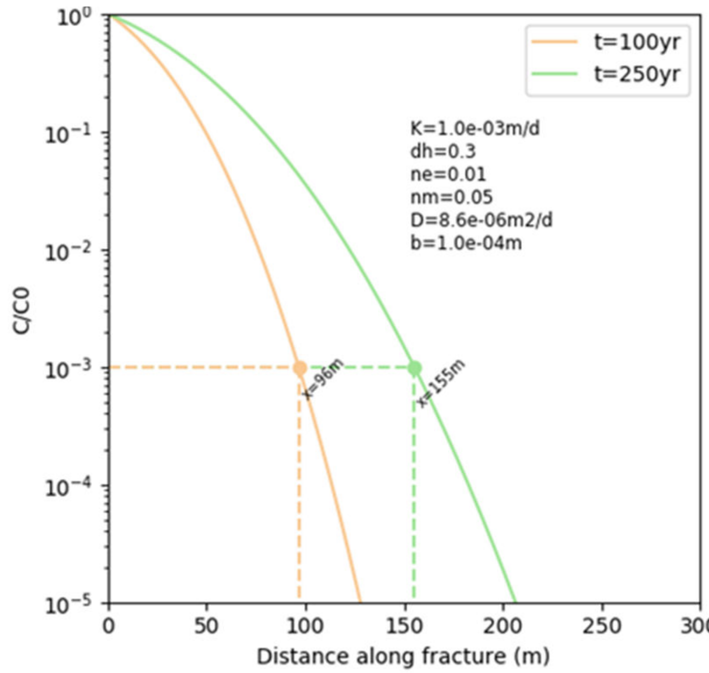
Is it possible?
Is it material?
Is it avoidable?
Can it be mitigated?
Q1: Is it possible?
Could a change in A cause a change in B?
Q2: If a link is possible, is it material?
Could a change in A cause a material change B?
Q3: If a link is possible and material, could it be avoided?
Could a material change in B due to a change in A be avoided in the GBA region?
Q4: If a link is possible, material and unavoidable, could it be mitigated?
Could a material change in B due to a change in A be minimised or mitigated in the GBA region?
Yes
No
Link is not possible
Link is possible but not material
Link is possible and material but can be avoided
Link is possible, material and unavoidable but can be mitigated
Link is possible, material, unavoidable and cannot be mitigated
0
1
2
3
4
Likelihood
Consequence
Avoidance
Mitigation
No mitigation

Precautionary principle risk solute migration vertically along fault

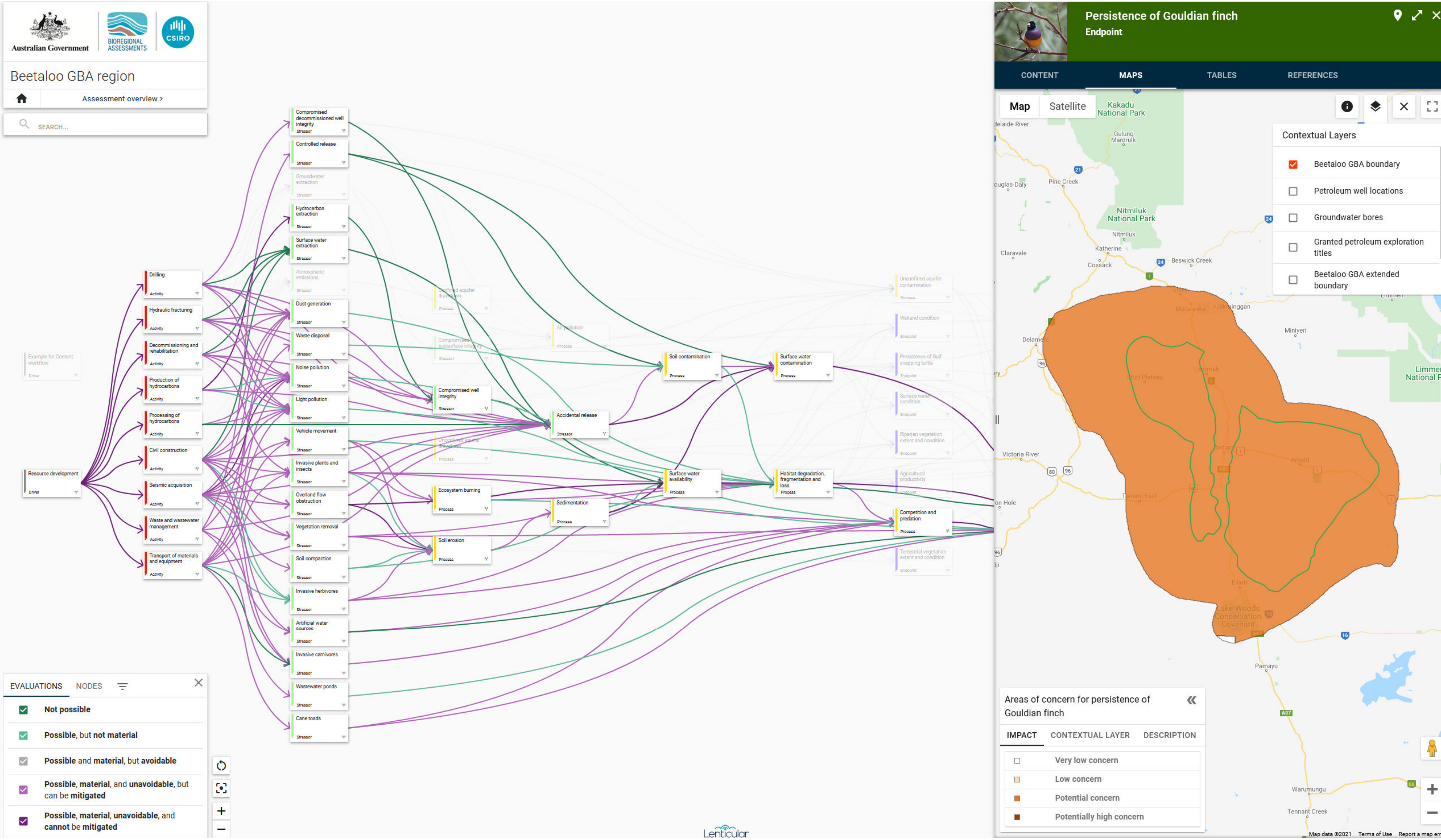
Table 1 Parameter values for solute transport calculations

Symbol	Name	Value	Unit	Comment
K	Hydraulic conductivity fault zone	$1e^{-3}$	m/d	Three orders of magnitude larger than aquitard (Caine et al., 1996)
Δh	Hydraulic gradient across aquitard	0.33	(-)	Corresponds to 100 m of pressure difference over 300 m of aquitard. This is consistent with the upper range of gradients in (Evans et al., 2020)
n_e	Effective porosity fault zone	0.01	(-)	Lower end of plausible range of effective porosities
n_m	Porosity of matrix	0.05	(-)	Lower end of porosity for shale or clay rich sediments
b	Fault or fracture aperture	$1e^{-4}$	m	Lower end of range of fracture apertures at depth
D*	Molecular diffusion coefficient	$8.6e^{-6}$	m^2/d	Lower end of range for shales and clays (e.g. Chen et al., 2018)

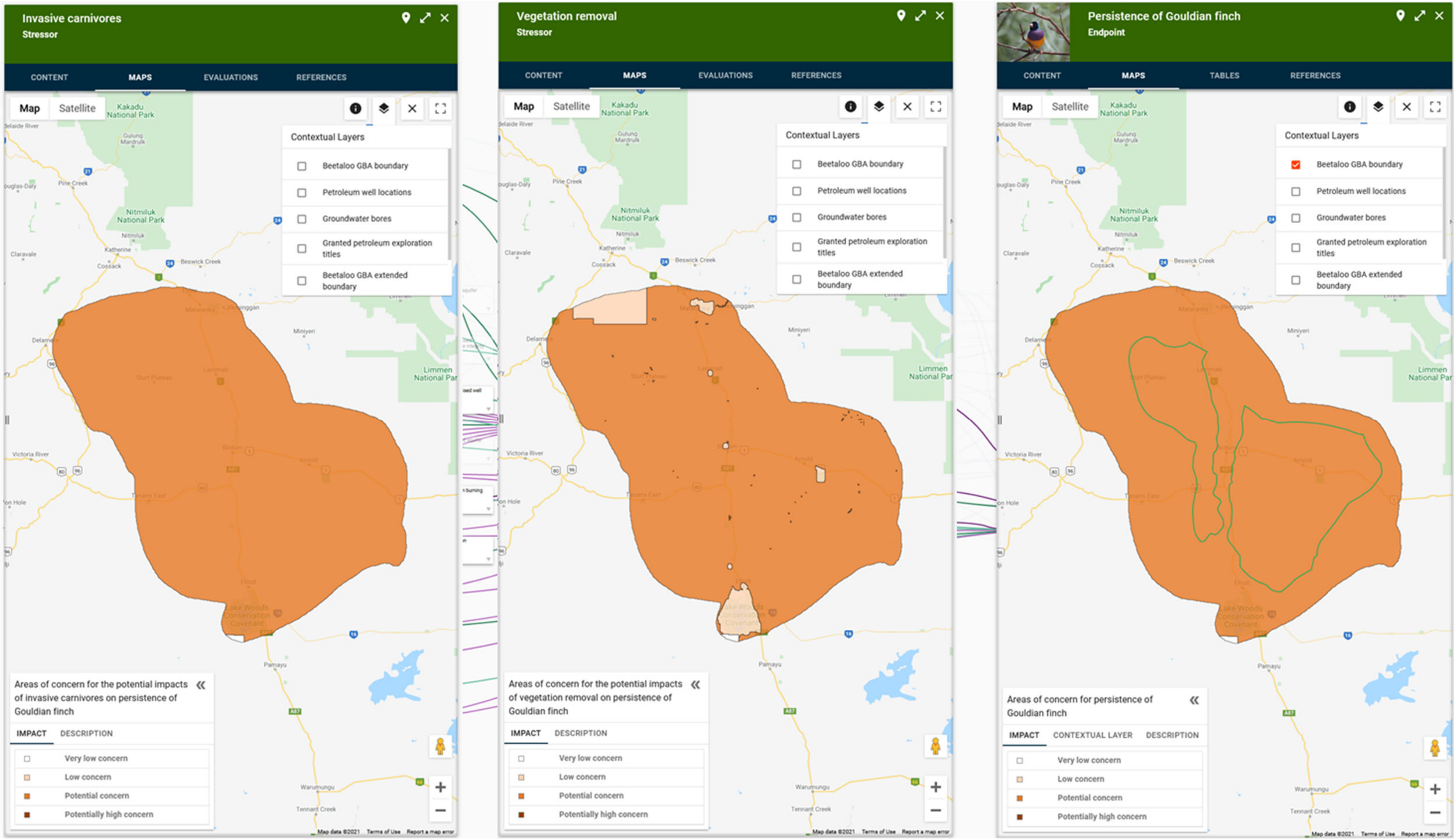
$$C(x,t) = C_0 \operatorname{erfc}\left(\frac{\left(\frac{n_m D}{v_a b}\right) x}{2\sqrt{D^*\left(t - \frac{x}{v_a}\right)}}\right)$$



Geological and Bioregional Assessment Program (2021) Compromised aquitard integrity: Stressor node description for the Cooper GBA region, accessed 07 August 2023.



Australian Government
BIOREGIONAL ASSESSMENTS
CSIRO
Beetaloo GBA region
Assessment overview ›
SEARCH...
Compromised decommissioned well integrity
Controlled release
Groundwater extraction
Hydrocarbon extraction
Surface water extraction
Atmospheric emissions
Dust generation
Waste disposal
Noise pollution
Light pollution
Vehicle movement
Invasive plants and insects
Overland flow obstruction
Vegetation removal
Soil compaction
Invasive herbivores
Artificial water sources
Invasive carnivores
Wastewater ponds
Cane toads
Drilling
Hydraulic fracturing
Decommissioning and rehabilitation
Production of hydrocarbons
Processing of hydrocarbons
Civil construction
Seismic acquisition
Waste and wastewater management
Transport of materials and equipment
Resource development
Compromised well integrity
Ecosystem burning
Soil erosion
Accidental release
Sedimentation
Soil contamination
Surface water availability
Surface water contamination
Habitat degradation, fragmentation and loss
Competition and predation
EVALUATIONS
NODES
Not possible
Possible, but not material
Possible and material, but avoidable
Possible, material, and unavoidable, but can be mitigated
Possible, material, unavoidable, and cannot be mitigated
Lenticular
Persistence of Gouldian finch
Endpoint
CONTENT
MAPS
TABLES
REFERENCES
Map
Satellite
Contextual Layers
Beetaloo GBA boundary
Petroleum well locations
Groundwater bores
Granted petroleum exploration titles
Beetaloo GBA extended boundary
Kakadu National Park
Nitmiluk National Park
Katherine
Mataranka
Victoria River
Pamayu
Warumungu
Tennant Creek
Areas of concern for persistence of Gouldian finch
IMPACT
CONTEXTUAL LAYER
DESCRIPTION
Very low concern
Low concern
Potential concern
Potentially high concern
Map data ©2021
Terms of Use



Invasive carnivores
Stressor
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Areas of concern for the potential impacts of invasive carnivores on persistence of Gouldian finch
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Vegetation removal
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IMPACT
DESCRIPTION
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Low concern
Potential concern
Potentially high concern
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CONTEXTUAL LAYER
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Conclusion

- Uncertainty analysis – technically possible, not only academic / large projects
- Not all sources of uncertainty are quantifiable
  - Assumption hunting
  - Clear, transparent and honest reporting
- Source → Receptor framework
  - Defines quantities of interest for quantitative analysis
  - Formalizes what is known and highlights knowledge gaps
- Precautionary principle
  - Rule out areas / pathways of no or low concern
  - Highlights potential pathways of concern