# Ecohydrological Conceptual Models and Impact Pathway Diagrams for the Braemar, Stuart Shelf and Northern Eyre

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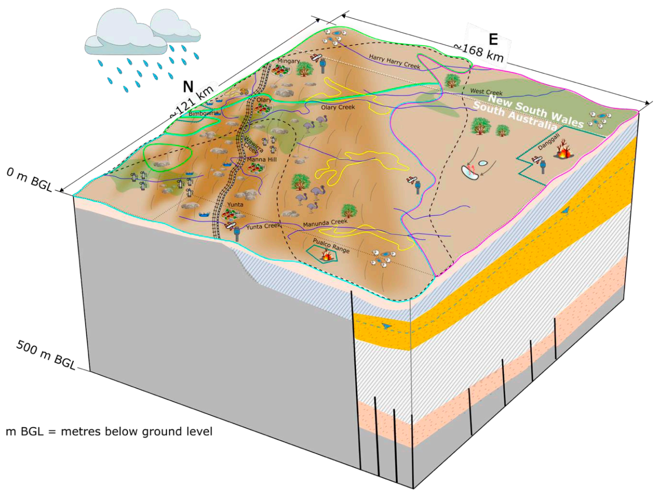
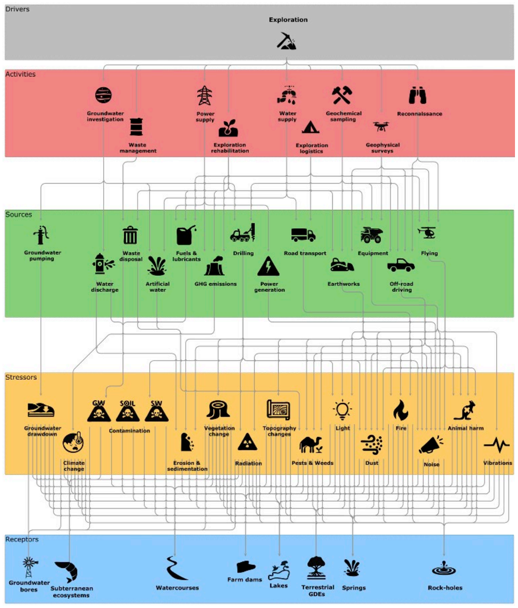
## Summary and methodology report




**Ecohydrological conceptual models**

**Impact pathway diagrams**

Goyder Institute for Water Research
Technical Report Series No. 2024/04.

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## Disclaimer

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# Respect and reconciliation

Aboriginal people are the First Peoples and Nations of South Australia. The Goyder Institute for Water Research acknowledges the range of First Nations' rights, interests and obligations as well as the cultural connections that exist between First Nations and Aboriginal peoples across South Australia and seeks to support their equitable engagement.

Aboriginal peoples' spiritual, social, cultural and economic practices come from their lands and waters, and they continue to maintain their cultural heritage, economies, languages and laws which are of ongoing importance.

# Executive summary

Ecohydrological conceptual models (ECMs) represent and integrate data and other information on hydrological components with ecological ones to understand their interactions. They form the starting point for impact pathway diagrams (IPDs) that outline how resource development can affect the ecological, cultural and economic values supported by ecosystems.

This study is a pilot in developing ECMs and IPDs in the context of regional development of mineral resources and large infrastructure in the Braemar, Stuart Shelf and Northern Eyre regions in the north of South Australia.

Depending on the audience, this project and its outputs aims to fulfill different purposes:

- **General public**: Identify the types of activities required for developing mineral resources and large infrastructure, how these activities are source of stress in the environment and how they can impact the valued aspects of the landscape (receptors).
- **Regulators**: a systematic and comprehensive regional-scale hazard identification of mineral resource and large infrastructure development, aiding the review of environmental impact assessments prepared by proponents
- **Industry and consultants**: a structured framework to assist the transparent organisation of information, data and modelling for impact assessments.

This document presents the methodology underpinning the development of ECMs and IPDs and provides a high-level overview and discussion of the results. The detailed information is captured in a series of fact sheets, which include:

- regional conceptual models for the Braemar, Stuart Shelf and Northern Eyre regions
- overviews of the potential for resource development in the Braemar, Stuart Shelf and Northern Eyre regions
- regional assessment of current climate and expected trends in precipitation and maximum temperatures across the 3 regions
- overviews of the activities and sources of stress on ecosystems associated with exploration, open-pit, underground and in situ mining and the post-mining landscape
- overviews of the various stages of mining and potential stressors on the environment and how they can affect receptors
- overviews of the receptors in the regions, including a definition and general overview of each receptor, followed by a discussion of each receptor in each region.
- impact pathway diagrams.

The ECMs consist of a pictorial model, complemented by a narrative table, summarising the key information on geology, hydrology, land use and ecology of the region. A similar approach is used to present the activities associated with the different kinds of development. The IPDs are box-and-arrow diagrams in which the cause-and-effect relationships are systematically described as a sequence from driver to activity, source, stressor and finally to receptor. The combination of these cause-and-effect relationship form a Directed Acyclic Graph (DAG), which allows to comprehensively and systematically identify causal pathways between drivers and receptors.

The result of the project is a comprehensive, regional-scale hazard identification that forms the basis of a spatial risk assessment by evaluating likelihood, consequence and options for mitigation. The IPDs are necessarily complex and intricate models that are challenging to visualise. The project provides different visualisations, balancing complexity with tractability.

# Acknowledgments

This project is funded by the South Australian Department for Environment and Water and by the South Australian Department for Energy and Mining. The project team wants to thank the support from the South Australian Arid Lands and Eyre Peninsula Landscape Board and acknowledge the advice received from the Project Advisory Committee:

- Peter Baker (DEW, chair)
- Nathan Zeeman (DEM)
- Aaron Smith (SAAL)
- Michelle Clanahan (EP)
- Dr Andrew Boulton (Adjunct Professor, University of New England)

The project team wants to thank everyone who participated in the Port Augusta workshop and dialled in to the webinars. The project team wants to also thank Dr Kerri Muller for facilitating the workshop.

# 1 Introduction

Proponents of large developments prepare environmental impact assessments (EIAs) to outline potential environment impacts of the development and how these impacts will be mitigated and managed. These EIA documents are multi-disciplinary as they necessarily cover hydrogeological, hydrological, ecological and social impacts. They present an enormous amount of information, data and modelling, which can be challenging to integrate in a transparent and clear way. This makes it challenging for readers to navigate the information present and find answers to some of the key questions:

- How can this development affect what we care about?
- What can be done about it?
- What are the key knowledge gaps?

This project is a pilot study to implement ECMs and IPDs in the context of environmental impact assessments, as introduced in Commonwealth of Australia (2024). An ecohydrological conceptual model describes how the landscape works and what the roles of water in the landscape are. It captures the various interactions between geology, soils, hydrology, flora and fauna. ECMs are formally defined in Commonwealth of Australia (2024) as:

*A type of conceptual model that represents and integrates data and other information on hydrological (surface water and groundwater) components with ecological ones (e.g. specific taxa, communities and ecosystems) to understand and communicate their interactions.*

An impact pathway diagram complements an ecohydrological conceptual model as it captures how a development (such as a mine, windfarm or pipeline) can affect water resources[1] and the landscape. It is formally defined in Commonwealth of Australia (2024) as:

*Conceptual models, often box-and-arrow types, used specifically to understand and communicate potential impact pathways between sources and receptors in an environmental impact assessment.*

The project team developed ecohydrological conceptual models (ECMs) and impact pathway diagrams (IPDs) for the Braemar, Stuart Shelf and Northern Eyre region to explore potential hydro-ecological impacts of mining and large infrastructure development. The work complements hydrogeological framework reports for the Braemar (Currie and Richardson, 2022), Stuart Shelf (Currie et al., 2023) and Northern Eyre (Currie, 2023).

The goal of this project is to start developing a common understanding of the environmental issues associated with resource development between government, industry and the community in the regions being studied. The focus of the project is on transparent and clear integration and communication of existing knowledge, rather than on generating new knowledge. The ECMs and IPDs are regional and not specific to a particular development. They provide a structure for information relevant to an EIS to be organised and presented through a combination of visuals and narratives.

Depending on the audience, this project and its outputs aims to fulfill different purposes:

- **General public**: Identify the types of activities required for developing mineral resources and large infrastructure, how these activities are source of stress in the environment and how they can impact the valued aspects of the landscape (receptors).
- **Regulators**: a systematic and comprehensive regional-scale hazard identification of mineral resource and large infrastructure development, aiding the review of environmental impact assessments prepared by proponents

[1] A water resource is defined by the *Water Act 2007 (Cth)* as (a) surface water or ground water; or (b)a water course, lake, wetland or aquifer (whether or not it currently has water in it); and includes all aspects of the water resource (including water, organisms and other components and ecosystems that contribute to the physical state and environmental value of the resource).

- **Industry and consultants**: a structured framework to assist the transparent organisation of information, data and modelling for impact assessments.

The project team chose to deliver the project through a series of short fact sheets, similar to the data guides produced by the Trusted Environmental and Geological Information (TEGI) project by Geoscience Australia and CSIRO. Figure 1 provides an overview of the different fact sheets.

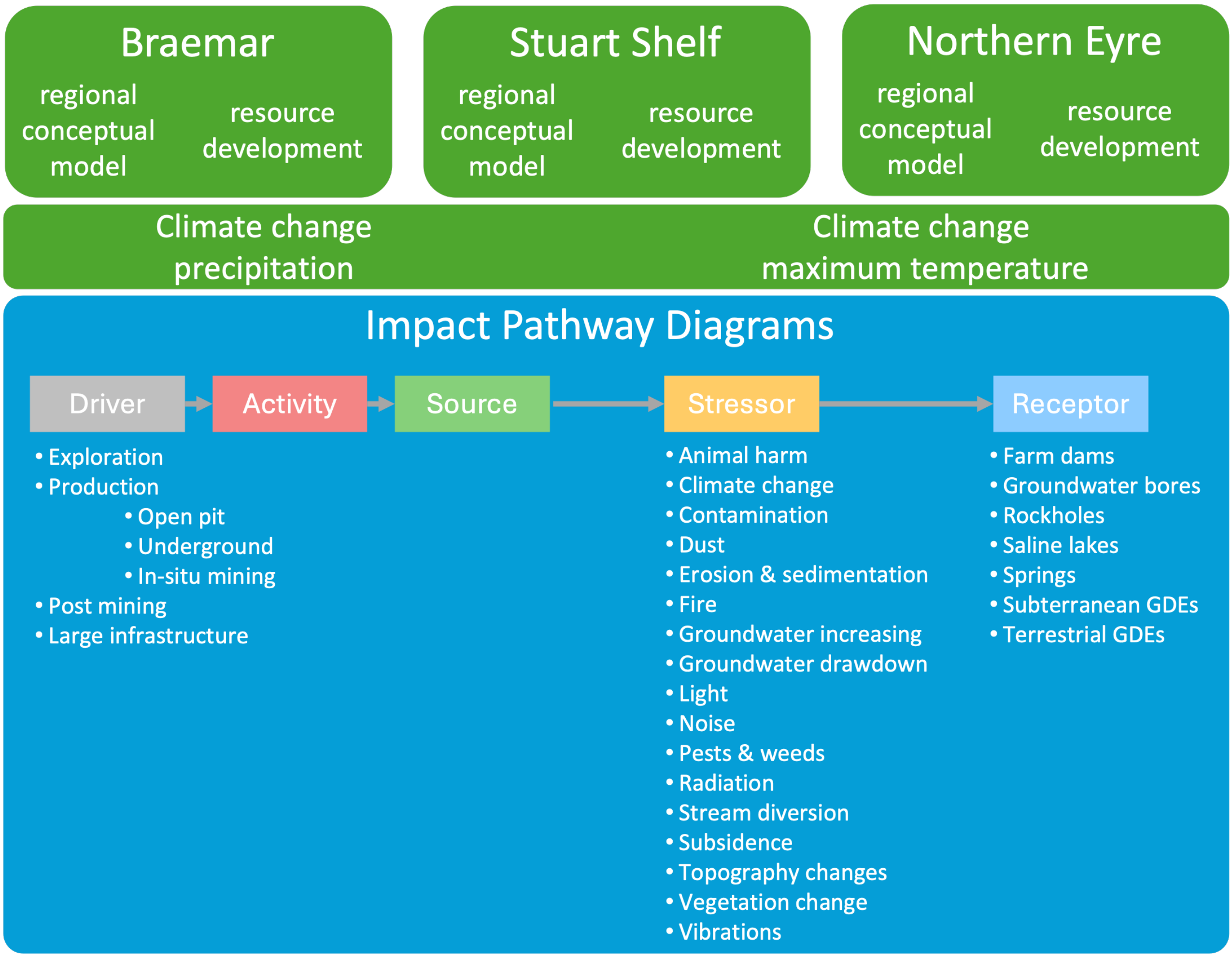


**Figure 1. Overview of fact sheets**

The green boxes are fact sheets describing the regions. There are fact sheets on the regional ecohydrological conceptual model and the current and planned resource development for each region. There are two fact sheets on climate change, describing the current and expected trends in precipitation and maximum temperature. The blue box captures the fact sheets related to the impact pathway diagrams. The impact pathway diagram fact sheet shows the IPDs for exploration, production and post-mining. The activities and sources fact sheets describe in general terms what is involved in the development of open-pit, underground and in situ recovery mining as well as large infrastructure. The stressor fact sheets describe, for each stressor, the processes that can cause exploration, production and post-mining to affect the listed receptors, their materiality and mitigation strategies. Each receptor fact sheet describes what the receptor is, its occurrence and importance in each region and how it can be impacted by stressors.

While the impact pathway diagrams aim to provide a comprehensive body of work, integrating available data and knowledge, different audiences of the project output may want to focus on or start exploring the output with different factsheets:

- **General public**: Factsheets describing the regions (regional conceptual models, resource development, climate change) and the factsheets describing activities and sources. This focus allows to contribute to the understanding of what development activities are possible in the region.
- **Regulators**: Factsheets describing stressors and endpoints. These factsheets capture how development can affect features in the landscape.
- **Industry and consultants**: Factsheets describing activities and sources and factsheets describing stressors. These factsheets provide a high-level of overview of the various aspects of resource

development and how they can affect the landscape. Proponents and consultants can focus on the activities relevant to their development and how they can affect the landscape in the vicinity of their development.

The methods section presents the approach that the project team has taken in developing the ECMs and IPDs. The results section summarises the main findings across the fact sheets, followed by a discussion section on the approach for hazard identification and risk assessment and strengths and weaknesses of the approach.

# 2 Methods

## 2.1 Introduction

Depictions of conceptual models have been widely used for decades to succinctly capture and communicate complex interactions between components in a landscape (Suter II, 1999). Conceptual models can vary from box-and-arrow diagrams (e.g. Norton et al. 2017) to rich, cartoon-style pictures (e.g. Fandel et al. 2018). Such graphics are more captivating than text alone and more efficient at disseminating information as they, when designed well, reduce the cognitive load (Perra and Brinkman, 2021). A conceptual model visualisation can be an important part of storytelling in science communication (Green et al. 2018; Borowiec 2023).

Norton et al. (2017) recommend the following principles in creating box-and-arrow diagrams:

- Group related concepts.
- Use a hierarchical structure.
- Use simple lines to suggest that concepts are related.
- Break up complex diagrams.
- Include a narrative and discuss it.

Fandel et al. (2018) similarly provide guidance for the development of cartoon-style conceptual models:

- consider the value of developing a figure specific to the audience and concept of interest, based on key findings from the literature, rather than beginning with modification of an existing figure,
- do not include decorative images; adding irrelevant images to text decreases learning,
- obtain feedback from the target audience to identify possible misinterpretations,
- include cues in the main text to guide the reader in knowing when and how to look at the figure,
- use high contrast (between tones or colours) to draw attention to key elements,
- use consistent visual cues (colour, texture, size, shape) to indicate conceptually related objects; viewers tend to conceptually group objects with similar visual characteristics,
- include a clearly labelled key and scale,
- to convey change over time, use a series or step-by-step images. Also, consider using an animation instead of an illustration (animations are sometimes more effective),
- minimize the visual elements that are not central to the main concept of the illustration. A simple line drawing is more effective than a realistic drawing or a photograph,
- use colour; colour increases comprehension in university-level students. Choose colours that reproduce well and are distinguishable to colourblind people,
- limit the number of concepts per figure. Use visual subdivisions such as grouping, multiple panels, and zooms for concepts that are too complex to be explained in a single panel,
- use parallel structure (e.g. if the x-axis is the same for 3 panels, they should be aligned horizontally; only change the component of the figure that is the focus of the change being highlighted),
- use a consistent, simple font with minimal acronyms or abbreviations.

The project team chose to use pictorial models for ECMs and box-and-arrow style diagrams for IPDs. ECMs are descriptive, illustrating the functioning of the landscape. The pictorial style lends itself well to this as it provides an intuitive, visual context for the processes in the landscape. Pictorial models are also used to illustrate the activities associated with the different kinds of development. IPDs focus on causal pathways underpinning how development can affect what we care about in the landscape. An illustration using boxes connected with arrows allows for an intuitive visualisation of such pathways and allows the user to trace causality from development to receptor.

## 2.2 Ecohydrological conceptual models

Pictorial ecohydrological models are widely used in Australia. A prime example is the Queensland Wetlands Program that has developed a suite of pictorial conceptual models for wetlands, available from https://wetlandinfo.des.qld.gov.au/. They provide an extensive report on the use and development of such conceptual models (DEHP 2012).

The conceptual diagrams in the South Australian Arid Landscape Boards Districts and Bioregions report (SAAL, 2022) illustrate boom and bust conditions (Figure 2). They demonstrate many of the features of recommended practice. The focus is on the surface aspects however, with very limited representation of the subsurface geology and hydrogeology.

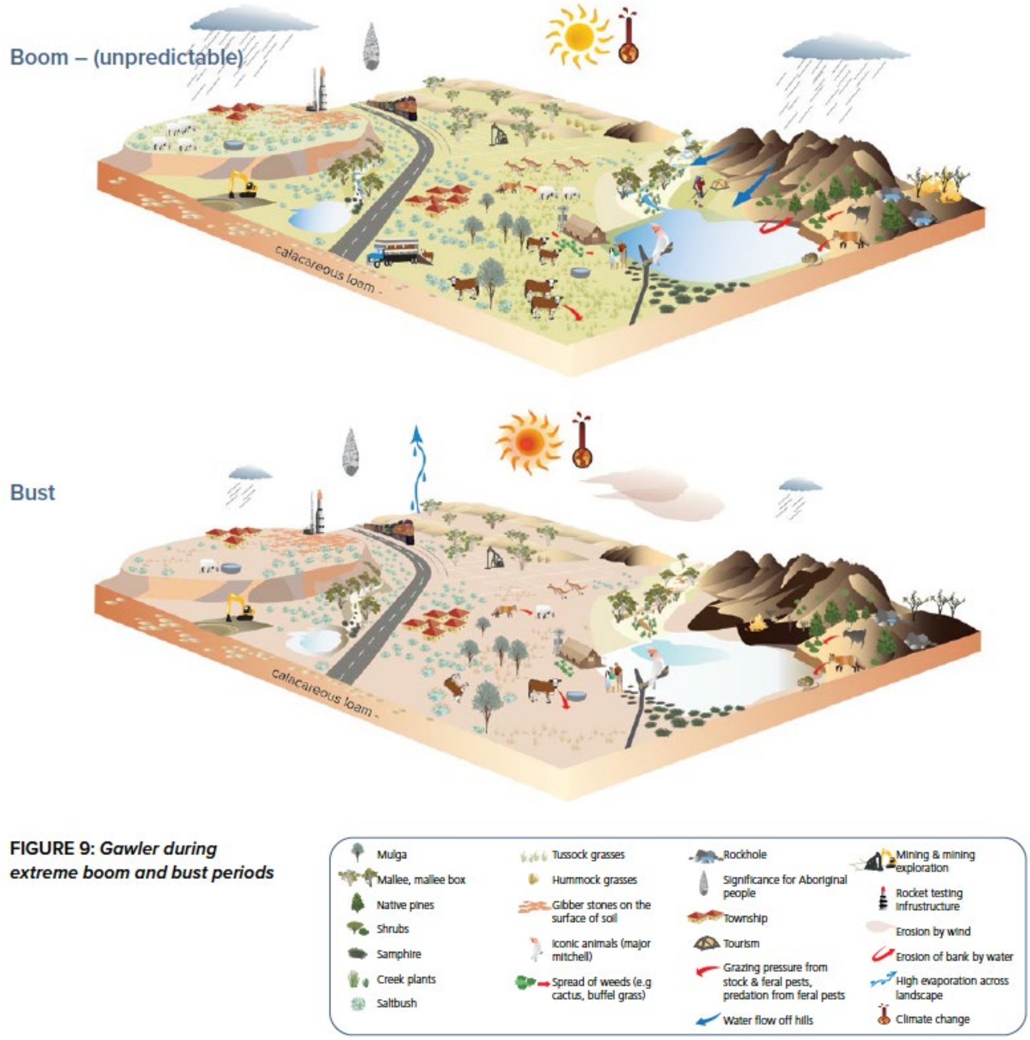


**Figure 2. Example pictorial conceptual model for the Gawler bioregion in the south-west of the SA Arid Lands region. It covers most of the Stuart Shelf region and parts of the Northern Eyre region (from SAAL 2022).**

The project team developed regional ecohydrological conceptual models for the Braemar region (Jazayeri and Werner, 2024a), Stuart Shelf region (Jazayeri et al. 2024) and Northern Eyre region (Jazayeri and Werner, 2024b) as block diagrams. Each block diagram is a simplified representation of the region's geology, hydrogeology, hydrology and topography, biodiversity and land use.

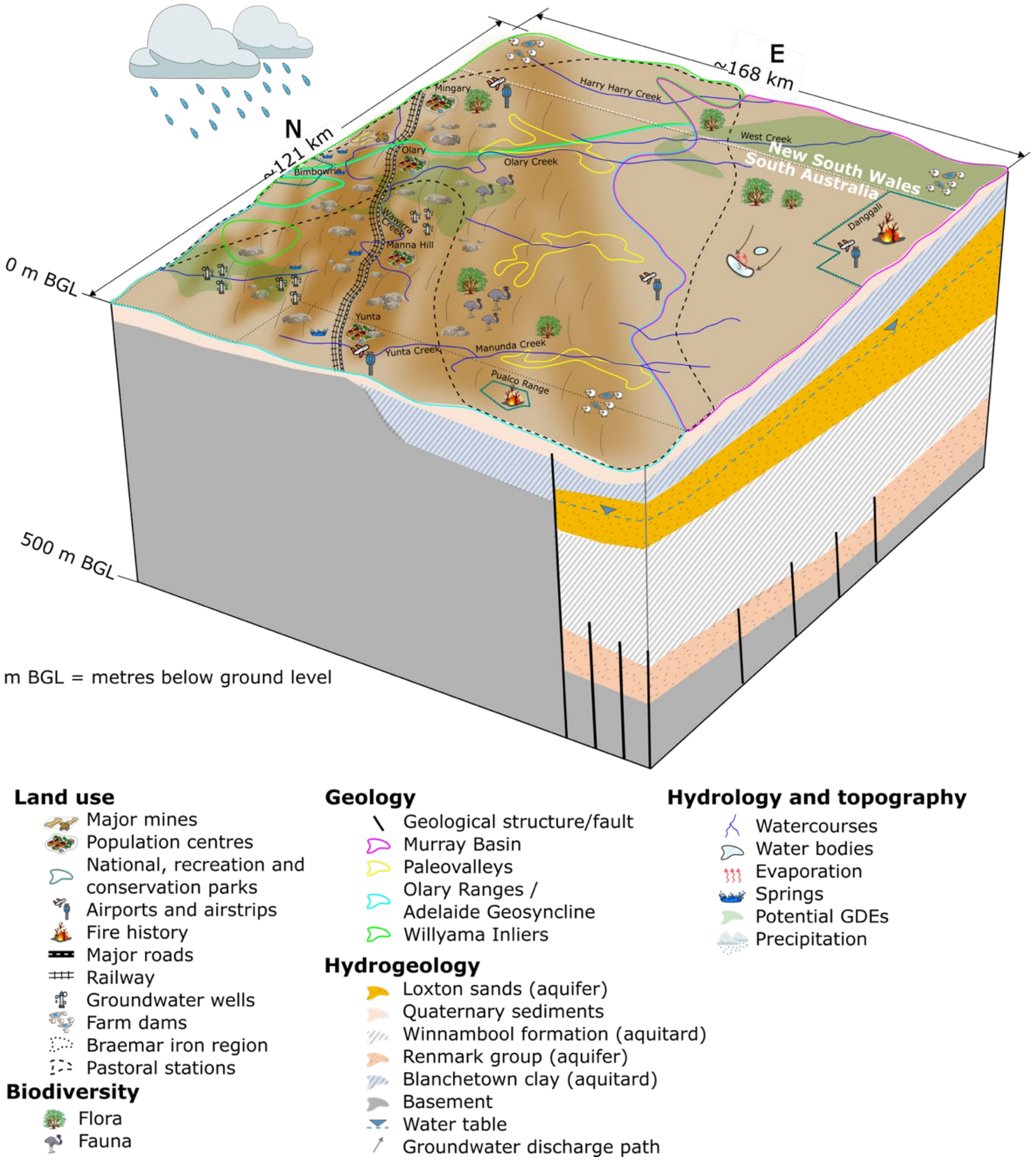


**Figure 3. Ecohydrological Conceptualisation Model  for the Braemar region (Jazayeri and Werner, 2024a)**

Figure 3 shows the ecohydrological conceptual model for the Braemar region as an example. The diagram is accompanied in the fact sheet with a narrative table that provides a short description of each of the features. The diagram aims to be a stylised yet accurate depiction of the landscape. The narrative table contains more information than what can be displayed in the block diagram. The main landscape components such as towns, roads, railways, national parks, watercourses and saline lakes are close in location and shape to their actual position. The geological cross-sections are based on available regional cross-sections and aim to highlight the main geological features in each region. This sometimes requires a trade-off between the accuracy of geological cross-section and the visualisation of the main geological features. This means that these regional scale block models can miss the finer detail of faulting or thin colluvial deposits or weathering zones that are often important in characterising mine sites.

The conceptual block diagram provides a high-level overview of each of the regions. To complement these, the fact sheets on resource development (Draganic et al. 2024a,b & c) describe for each region the existing resource development and the potential development, as well as current land use and their trends. The climate change fact sheets on precipitation (Guan and Pan, 2024a) and maximum temperature (Guan and

Pan, 2024b) describe the current climate and the expected trends based on the most recent climate change models.

## 2.3 Impact Pathway Diagrams

The impact pathway diagrams in this project are an adaptation of the causal networks used for environmental impact assessments developed in Peeters et al. (2022). A causal network shows cause-and-effect relationships as directed arrows between nodes. The types of nodes (Table 1) in the IPDs are based on the classic Source – Stressor – Receptor model (US EPA, 1998). In the context of this project, the definition of driver is intentionally chosen to be very narrow and restricted to regional-scale development of natural resources.

**Table 1. Impact Pathway Diagram structure. Bold categories are nodes in the diagram.**

| Category | Description | Example |
|---|---|---|
| **Driver** | Resource development. | *Open-pit mining* |
| **Activity** | Activities required to develop resource. High-level, not necessarily location-bound | *Water supply* |
| **Source** | Aspects of activities that can cause change in the environment. Location-bound, can be shared between activities | *Groundwater pumping* |
| **Stressor** | Any physical, chemical, or biological entity that can induce an adverse response | *Groundwater drawdown* |
| Process | Any environmental process that provides a pathway to release, disperse, or transform a stressor from a source | *Uptake of water by vegetation* |
| **Receptor** | The ecological entity exposed to the stressor. This term may refer to tissues, organisms, populations, communities, and ecosystems | *Groundwater-dependent ecosystems* |

Figure 4 shows an example IPD for the exploration phase of mining. The driver, exploration, is at the top of the diagram and links to various activities, such as geochemical sampling and reconnaissance. The activities in turn link to sources, such as drilling and off-road transport. The sources cause changes in the environment, which are illustrated with the links to the stressors, such as pests and weeds and contamination. Finally, the stressors can affect the receptors, the features in the landscape we care about, such as watercourses and springs. Stressors can affect receptors via one or more processes.

The project team created impact pathway diagrams for the exploration, production and post-mining phases of mining. The production phase includes 3 drivers: open-pit, underground and in situ recovery mining. The activities and sources associated with each driver are described in fact sheets (Thomas and Peeters, 2024a-f). There is an additional fact sheet describing large infrastructure development. It is, however, not represented as a separate driver as the activities associated with this development are already represented as part of the off-site infrastructure activity in the production IPD.

The landscape features chosen to be represented as receptors are watercourses, saline lakes, farm dams, groundwater bores, springs, rock-holes, terrestrial groundwater-dependent ecosystems and subterranean ecosystems. The list of receptors and their definition was refined during a workshop in Port August in April 2024 (Peeters et al. 2024) Each of these receptors is described in a separate fact sheet (Guan 2024; Guan and Peeters, 2024; Guan and Thomas, 2024; Solórzano-Rivas et al. 2024; Shanafield 2024a-d). As this project focused on ecohydrological impacts, the receptors all have a clear link to hydrology. The receptors include the hydrology, chemistry and ecosystems they support. This allows to include causal pathways in the analysis that are not strictly water-mediated, such as the effects of noise and light pollution.

The fact sheets on stressors (Peeters 2024a) not only describe each of the stressors, but more importantly how the sources can cause the stressor and how the stressor in turn can affect the receptors via processes.

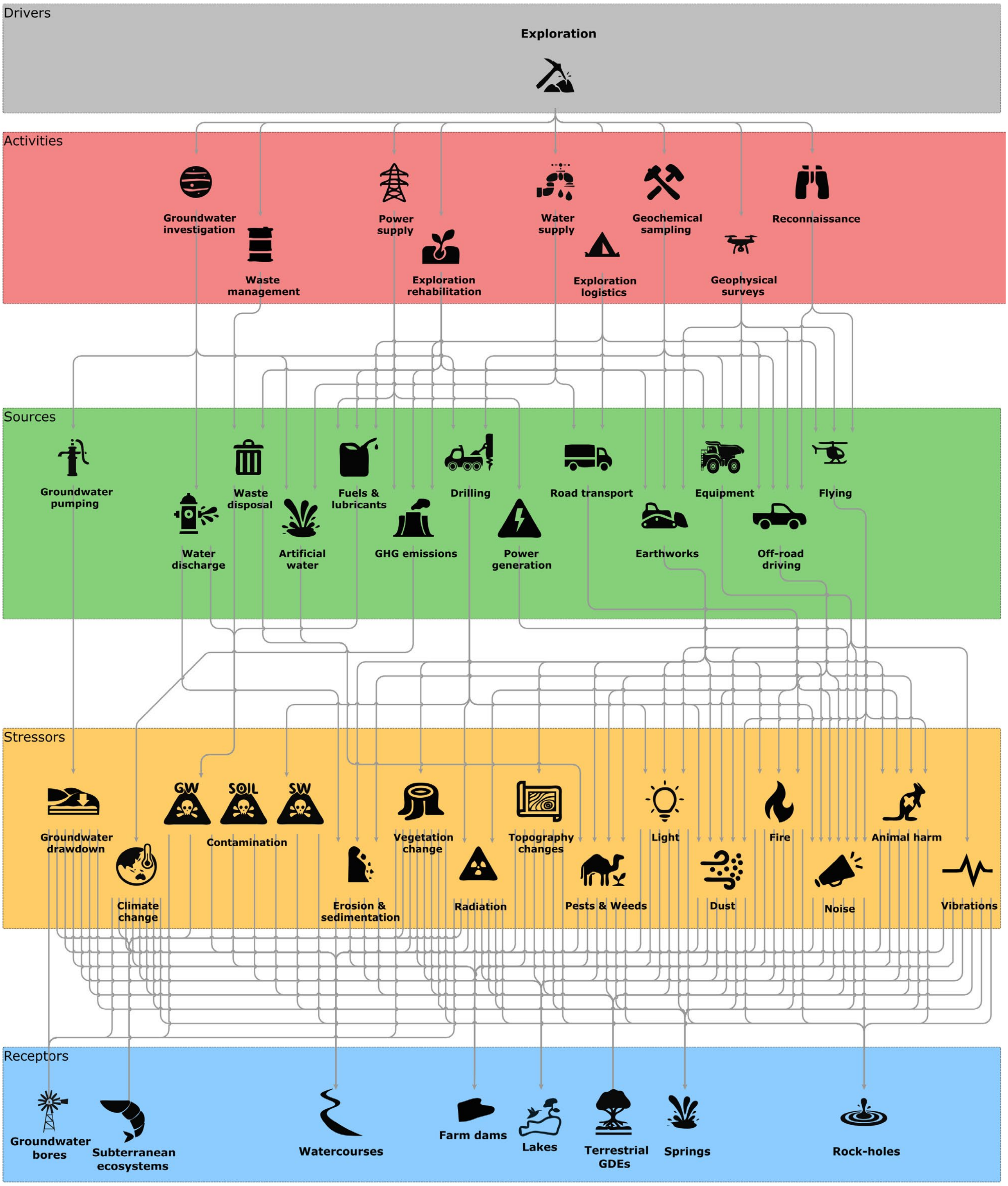


**Figure 4. Impact Pathway Diagram for exploration (Peeters 2024b).**
GDEs: Groundwater Dependent Ecosystems, GW: groundwater, SW: surface water

The analysis of causal pathways through each stressor is possible because the structured representation of the IPD is a directed acyclic graph (DAG, VanderWeele and Robins, 2010). Directed means that each link has a direction; it shows a causal relationship from the parent or starting node to the child or ending node. For instance, groundwater pumping (parent node) causes groundwater drawdown (child node). Acyclic means that there are no closed loops or feedback loops represented in the network. This allows the causal pathways to be unambiguously traced through the diagram (Dambacher et al. 2002). Feedback loops and interactions are, however, important in describing functioning of ecosystems. Every natural ecosystem has feedback loops that maintain its integrity and provide resilience and resistance to disturbance. The IPD represents only direct causal relationships. Indirect causal relationships or feedback loops are discussed in receptor and stressor fact sheets. An example is grazing by invasive herbivores, which is part of the node pests and weeds. The grazing causes both direct and indirect impacts on ecosystems (Waters et al. 2019). A direct impact is a change in plant community structure and composition through herbivory. An indirect impact is an increase in erosion and sedimentation as the groundcover changes. There is no link from pest and weeds to sediment and erosion, but the process is described in the description of the stressor pest and weeds.

Identification of hazards as shown in the impact pathway diagram (Figure 4) is only a first step in an environmental risk assessment. The next step in an environmental risk assessment is to assess the likelihood, consequence and mitigation options for each hazard. It is important to note that this project is not considering a specific development scenario or project proposal, but rather an initial screening of hazards that are possible within a region should the driver (development) occur. Proponents will still need to evaluate likelihood and consequences, and where these pose risks to valued assets, assess mitigation strategies for each hazard within the context and plans of their proposed development.

The stressor fact sheet (Peeters 2024a) does provide information on potential materiality and mitigation options for each stressor. Following the approach in natural capital accounting, something is material if *'it has reasonable potential to significantly alter the decisions being taken by a user of the information being reported'* (Smith et al. 2021). A causal pathway in the IPD is material when it has the potential to cause environmental harm such that a regulator would make approval conditional to effective mitigation of the environmental harm. In assessing the materiality of a causal pathway, we developed the decision tree shown in Figure 5.

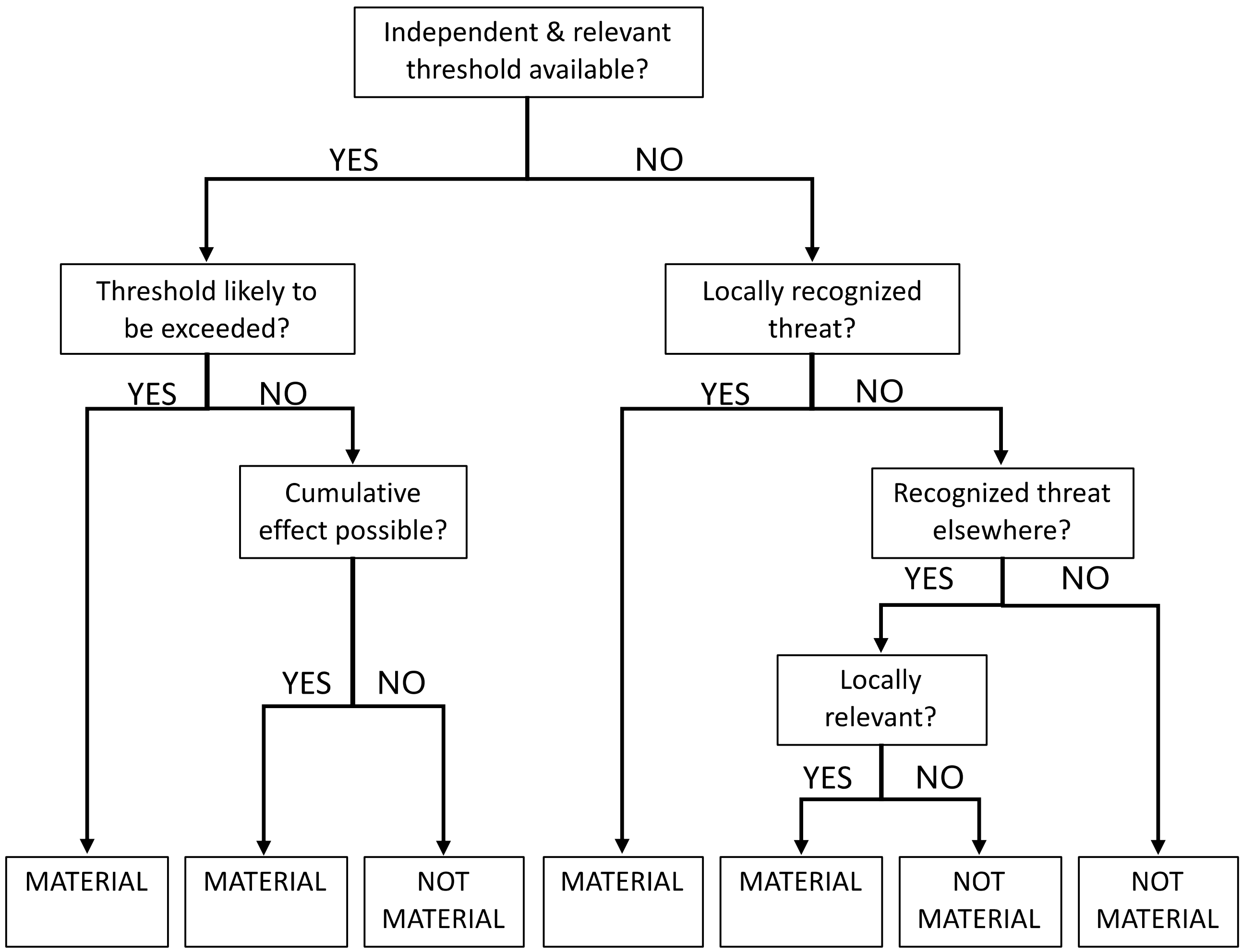


**Figure 5. Decision tree for materiality assessment**

The decision tree starts with the availability of independently established and credible thresholds, relevant to the stressor. The fact that thresholds have been established usually demonstrates that it is an issue that has the potential to cause harm. A causal pathway is material if there is a non-negligible likelihood for the threshold to be exceeded. Even if the threshold is not likely to be exceeded, the pathway can be considered material if there is potential for a cumulative effect. There are several stressors for which independently established and relevant thresholds are not available. In that case, we assess whether the causal pathway is considered a threat or issue locally. If the stressor is not explicitly mentioned as a priority issue in the region, we examine whether it is recognised as a threat or issue elsewhere and if so, if it is locally relevant.

An example of independently established and credible thresholds are the criteria for human health and ecological receptors used by the Environmental Protection Authority to assess site contamination (EPA 2019). Most thresholds are primarily designed to avoid harm to humans. The Australian and New Zealand guidelines for fresh and marine water quality (ANZG 2018) outline a framework to derive species-specific and site-specific threshold values for water quality. For other processes, such as dust, noise or light, there is much less guidance available. Where no specific guidance or thresholds are available, we assume that animals are affected by the same processes as humans and that they are at least as sensitive.

An example of an individually not material but cumulatively material causal pathway would be greenhouse gas emissions leading to climate change. The reporting threshold for atmospheric emissions under the *National Greenhouse and Energy Reporting Act 2007* is 25,000 tonnes of $CO_2$ per year. Even if a proponent does not exceed the threshold, greenhouse gas emissions leading to climate change is material due to the cumulative effect of emissions.

For locally recognized threats, we relied in this project mainly on the Regional Landscape Plans of the SA Arid Lands (SAAL, 2021) and Eyre Peninsula (EP, 2021) Landscape Boards. An example is the spread of pest and weeds, which is recognised as a key priority in all 3 regions. For example, vegetation removal is not explicitly listed as a key priority in the regional plans, but the federal *Environment Protection and Biodiversity Conservation Act 1999* lists land clearing as key threatening process and South Australia's *Native Vegetation Act 1991* outlines the conditions under which vegetation clearance is not allowed. Both legislations are applicable and relevant in the study regions, making vegetation removal a material issue. An example of a threat that is an issue elsewhere, but not relevant locally is methane emissions from mining operations. This is a considerable issue in coal mining, but as there are no coal deposits or coal mining operations in the study areas, it is not a material issue.

For each stressor, the stressor fact sheet lists the available strategies for mitigation. This can refer to legal documents and policies that make an activity subject to a permit. An example is the activities considered as Water Affecting Activities under the *Landscape Act 2019* (e.g. SAAL, 2021a). Other mitigation strategies refer to best practice guidance documents.

# 3 Results

The Impact pathway diagram fact sheet (Peeters et al. 2024) shows the IPDs for the exploration, production and post-mining phases of open-pit, underground and in situ mining. These include the impact pathways for large scale infrastructure, as they are covered under the off-site infrastructure activity.

In the next sections, we provide an overview of each IPD, starting with the exploration IPD, followed by the production and post-mining IPDs. The causal pathways are discussed in more detail in the stressor fact sheet (Peeters 2024a). The project team also produced a spreadsheet that, for each IPD diagram, includes:

- the nodes with their definitions
- the links between nodes and a short description of the linking process
- an exhaustive list of all causal pathways
- summary tables for the number of causal pathways.

Judicious use of the filter function on the exhaustive list of causal pathways allows users to interactively explore the network.

As the IPDs are underpinned by a DAG, it is possible to list all the possible pathways and, for each node, summarise the number of pathways that contain that node. The number of pathways per node is not a proxy for its importance in an environmental impact assessment. A single causal pathway that is not mitigated can still cause enormous environmental harm.

The structure of the IPD and the number of causal pathways per node can be useful in developing mitigation and monitoring strategies. Mitigation measures that are associated with a source or stressor node that is included in many causal pathways, will be able to avoid or minimise the impact on many receptors from different activities. For example, the source node earthworks and stressor node vegetation change. These 2 nodes are associated with all activities that require infrastructure and are also linked to all receptors that represent an ecosystem. A strategy to avoid sensitive vegetation in planning and designing earthworks will therefore mitigate the impact from many activities on almost all ecological receptors. Similarly, the structure of the IPD can be used to guide monitoring design. Monitoring vegetation condition will provide a baseline for the receptors linked to vegetation change and will be useful to monitor effectiveness of mitigation strategies, such as avoiding sensitive vegetation. The structure of the IPD not only provides a starting point to identify opportunities for mitigation, it also allows to check if they are comprehensive. Using the mitigation strategy of avoiding sensitive vegetation as an example, the structure of the network allows to verify that this strategy is applied to all activities that require earthworks, from pit excavation to road construction as part of off-site infrastructure development.

## 3.1 Exploration

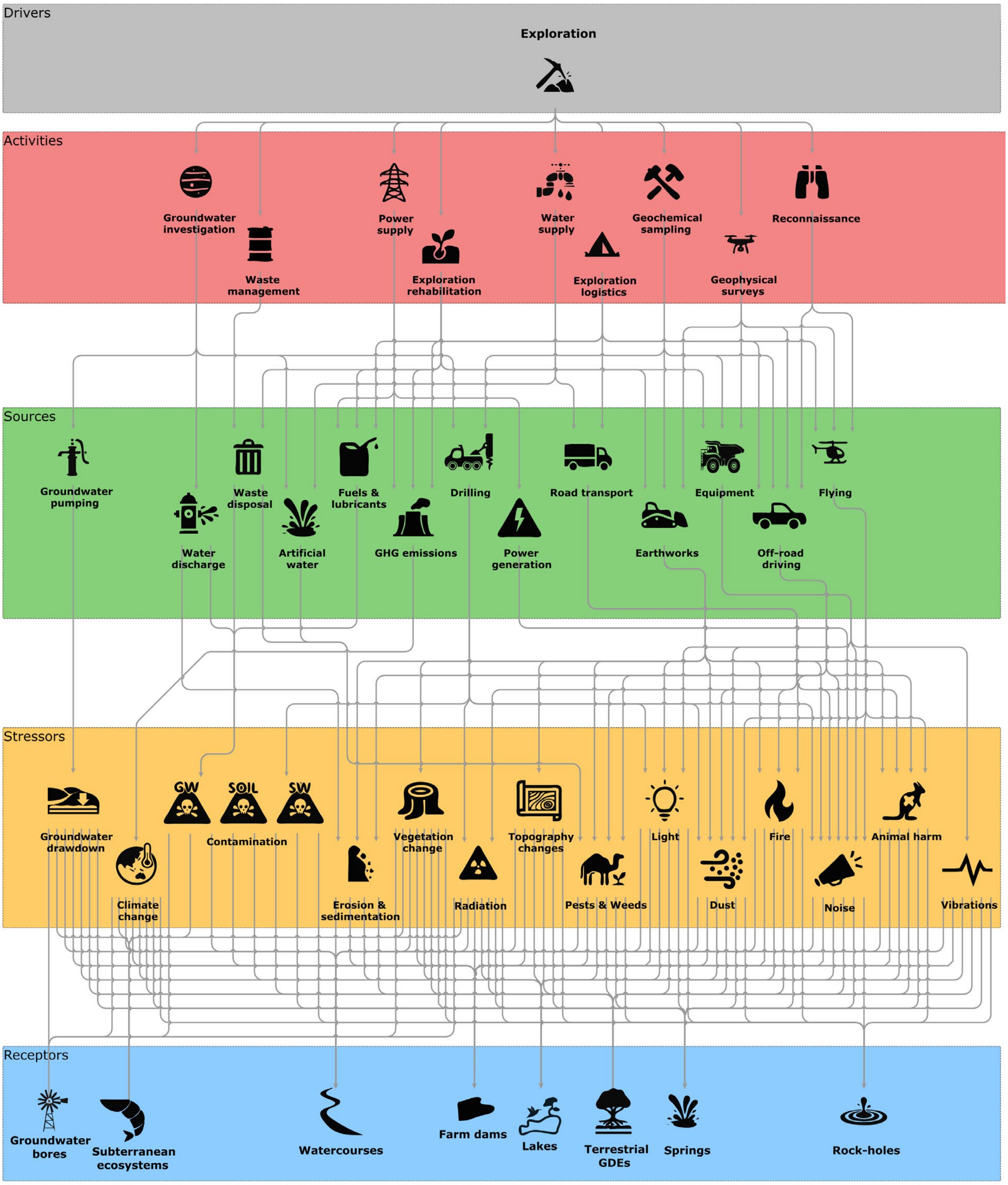


**Figure 6. Impact Pathway Diagram for the exploration phase of open-pit, underground and in situ recovery mining. The graphic is designed to be printed on A3.**

GDE: Groundwater Dependent Ecosystem, GW: groundwater, SW: surface water

**Table 2. Number of causal pathways in the exploration IPD.**
The green-yellow-red colour shading is proportional to the number of causal pathways

| Type | Node name | Terrestrial GDEs | Watercourses | Lakes | Farm dams | Springs | Rock-holes | Groundwater bores | Subterranean ecosystems | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Driver | Exploration | 106 | 106 | 106 | 106 | 98 | 97 | 19 | 19 | **657** |
| | | | | | | | | | | |
| Activities | Geochemical sampling | 23 | 23 | 23 | 23 | 21 | 21 | 3 | 3 | **140** |
| | Geophysical surveys | 21 | 21 | 21 | 21 | 19 | 19 | 1 | 1 | **124** |
| | Exploration rehabilitation | 17 | 17 | 17 | 17 | 16 | 16 | 4 | 4 | **108** |
| | Exploration logistics | 16 | 16 | 16 | 16 | 15 | 15 | 3 | 3 | **100** |
| | Groundwater investigation | 9 | 9 | 9 | 9 | 8 | 7 | 4 | 4 | **59** |
| | Reconnaissance | 8 | 8 | 8 | 8 | 7 | 7 | | | **46** |
| | Water supply | 7 | 7 | 7 | 7 | 7 | 7 | 1 | 1 | **44** |
| | Power supply | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | **22** |
| | Waste management | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | **14** |
| | | | | | | | | | | |
| Sources | Earthworks | 27 | 27 | 27 | 27 | 24 | 24 | 3 | 3 | **162** |
| | Off-road driving | 20 | 20 | 20 | 20 | 16 | 16 | | | **112** |
| | Road transport | 12 | 12 | 12 | 12 | 12 | 12 | 2 | 2 | **76** |
| | Equipment | 12 | 12 | 12 | 12 | 12 | 12 | | | **72** |
| | Drilling | 10 | 10 | 10 | 10 | 10 | 10 | 4 | 4 | **68** |
| | Flying | 9 | 9 | 9 | 9 | 9 | 9 | | | **54** |
| | Waste disposal | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 | **28** |
| | Fuels & lubricants | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | **24** |
| | GHG emissions | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | **24** |
| | Artificial water | 2 | 2 | 2 | 2 | 2 | 2 | | | **12** |
| | Water discharge | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | **12** |
| | Groundwater pumping | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | **7** |
| | Power generation | 1 | 1 | 1 | 1 | 1 | 1 | | | **6** |
| | | | | | | | | | | |
| Stressor | Noise | 18 | 18 | 18 | 18 | 18 | 18 | | | **108** |
| | Dust | 13 | 13 | 13 | 13 | 13 | 13 | | | **78** |
| | Pests & Weeds | 13 | 13 | 13 | 13 | 13 | 13 | | | **78** |
| | Animal harm | 12 | 12 | 12 | 12 | 12 | 12 | | | **72** |
| | Contamination | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | **64** |
| | Fire | 9 | 9 | 9 | 9 | 9 | 9 | | | **54** |
| | Light | 8 | 8 | 8 | 8 | 8 | 8 | | | **48** |
| | Erosion & sedimentation | 8 | 8 | 8 | 8 | | | | | **32** |
| | Radiation | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | **32** |
| | Climate change | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | **24** |
| | Vegetation change | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | **24** |
| | Topography changes | 3 | 3 | 3 | 3 | 3 | 3 | | | **18** |
| | Vibrations | 3 | 3 | 3 | 3 | 3 | 3 | | | **18** |
| | Groundwater drawdown | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | **7** |
| | **Grand Total** | **106** | **106** | **106** | **106** | **98** | **97** | **19** | **19** | **657** |

In total there are 657 individual pathways in the exploration IPD (Figure 6, Table 2). The receptors **terrestrial GDEs**, **watercourses**, **lakes** and **farm dams** each have 106 causal pathways. These receptors are affected by the same set of stressors. They support ecosystems at the surface and rely wholly or partly on groundwater. These receptors may be therefore affected by all stressors that affect flora and fauna as well as the stressors that affect hydrology and hydrogeology. **Springs** are very similar, but they are not affected in the study regions by stream diversion or erosion or sedimentation. **Rock-holes** share many causal pathways with the surface water features, but they are not affected by changes in groundwater or by stream diversion or erosion and sedimentation. The **groundwater bores** and **subterranean GDEs** have the fewest impact pathways, 19. They are not affected by stressors that harm flora and fauna at the surface or changes in surface hydrology. **Climate change** and **vegetation change** may however affect recharge, or surface water groundwater interactions in general, and therefore alter groundwater related receptors. Other causal pathways associated with groundwater receptors include pathways that directly affect groundwater quantity, such as pumping for **groundwater investigations**, or **contamination** or **radiation** of aquifers during drilling or sampling*.*

Most of the causal pathways in Figure 6 are associated with **geochemical sampling** and **geophysical surveys***.* These activities can require ***earthworks*** and ***drilling***, as well as **Off-road driving** and **Road transport**. These in turn lead to stressors like **noise**, **dust**, **animal harm** and the spread of **pests and weeds**. There are few causal pathways that contain the **contamination** stressor. They include pathways that capture the hazard of accidental spillage of **fuel and lubricants** and incorrect disposal of drill cuttings.

## 3.2 Production

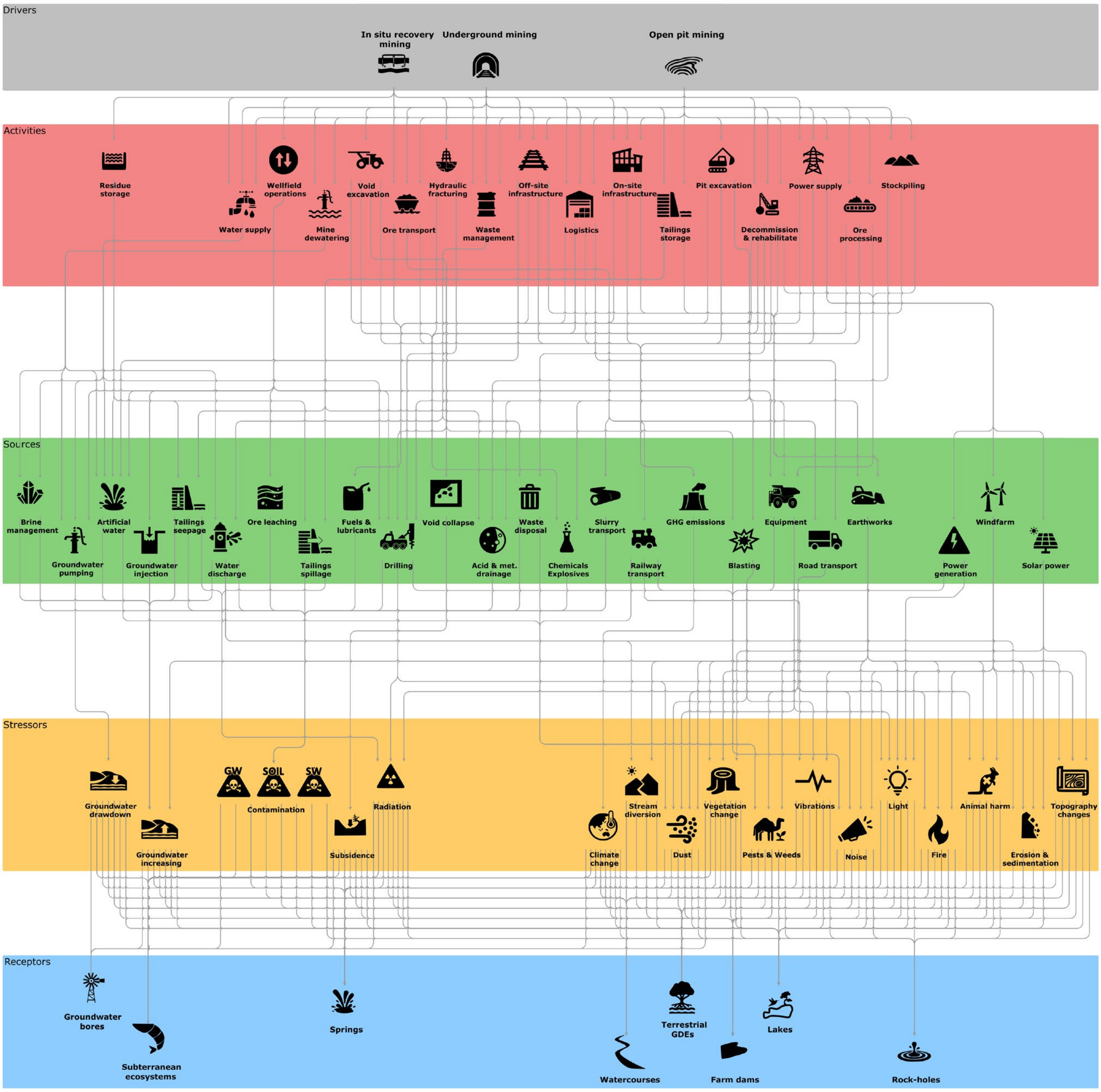


**Figure 7. Impact Pathway Diagram for the production phase of open-pit, underground and in situ recovery mining. The graphic is designed to be printed on A3.**

GDE: Groundwater Dependent Ecosystem, GW: groundwater, SW: surface water

**Table 3. Number of causal pathways in the production IPD.**

The green-yellow-red colour shading is proportional to the number of causal pathways

| Type | Node | Terrestrial GDEs | Watercourses | Lakes | Farm dams | Springs | Rock-holes | Groundwater bores | Subterranean ecosystems | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | Open pit mining | 171 | 171 | 171 | 171 | 153 | 137 | 63 | 63 | 1100 |
| Driver | Underground mining | 157 | 157 | 157 | 157 | 141 | 125 | 61 | 61 | 1016 |
| | In situ recovery mining | 125 | 125 | 125 | 125 | 115 | 102 | 51 | 51 | 819 |
| | Decommission & rehabilitate | 57 | 57 | 57 | 57 | 51 | 48 | 18 | 18 | 363 |
| | Off-site infrastructure | 45 | 45 | 45 | 45 | 39 | 33 | 15 | 15 | 282 |
| | Power supply | 45 | 45 | 45 | 45 | 39 | 39 | 12 | 12 | 282 |
| | On-site infrastructure | 39 | 39 | 39 | 39 | 33 | 30 | 12 | 12 | 243 |
| | Ore transport | 36 | 36 | 36 | 36 | 36 | 36 | 12 | 12 | 240 |
| | Tailings storage | 34 | 34 | 34 | 34 | 30 | 26 | 16 | 16 | 224 |
| | Water supply | 30 | 30 | 30 | 30 | 30 | 21 | 18 | 18 | 207 |
| | Logistics | 27 | 27 | 27 | 27 | 27 | 27 | 12 | 12 | 186 |
| Activity | Stockpiling | 30 | 30 | 30 | 30 | 26 | 24 | 6 | 6 | 182 |
| | Pit excavation | 26 | 26 | 26 | 26 | 24 | 23 | 8 | 8 | 167 |
| | Mine dewatering | 18 | 18 | 18 | 18 | 14 | 6 | 12 | 12 | 116 |
| | Waste management | 18 | 18 | 18 | 18 | 12 | 9 | 9 | 9 | 111 |
| | Wellfield operations | 13 | 13 | 13 | 13 | 13 | 10 | 6 | 6 | 87 |
| | Void excavation | 12 | 12 | 12 | 12 | 12 | 11 | 6 | 6 | 83 |
| | Ore processing | 10 | 10 | 10 | 10 | 10 | 10 | 4 | 4 | 68 |
| | Residue storage | 7 | 7 | 7 | 7 | 7 | 5 | 6 | 6 | 52 |
| | Hydraulic fracturing | 6 | 6 | 6 | 6 | 6 | 6 | 3 | 3 | 42 |
| | Earthworks | 154 | 154 | 154 | 154 | 126 | 112 | 28 | 28 | 910 |
| | Drilling | 35 | 35 | 35 | 35 | 35 | 35 | 14 | 14 | 238 |
| | Road transport | 36 | 36 | 36 | 36 | 36 | 36 | 6 | 6 | 228 |
| | GHG emissions | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 176 |
| | Equipment | 27 | 27 | 27 | 27 | 27 | 27 | | | 162 |
| | Fuels & lubricants | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 160 |
| | Windfarm | 24 | 24 | 24 | 24 | 21 | 21 | 3 | 3 | 144 |
| | Artificial water | 20 | 20 | 20 | 20 | 20 | 10 | 10 | 10 | 130 |
| | Water discharge | 20 | 20 | 20 | 20 | 10 | 5 | 10 | 10 | 115 |
| | Chemicals Explosives | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 88 |
| | Waste disposal | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 6 | 84 |
| Source | Brine management | 10 | 10 | 10 | 10 | 10 | 5 | 10 | 10 | 75 |
| | Tailings seepage | 9 | 9 | 9 | 9 | 9 | 6 | 9 | 9 | 69 |
| | Railway transport | 9 | 9 | 9 | 9 | 9 | 9 | | | 54 |
| | Solar power | 9 | 9 | 9 | 9 | 6 | 6 | 3 | 3 | 54 |
| | Tailings spillage | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 48 |
| | Groundwater pumping | 6 | 6 | 6 | 6 | 6 | | 6 | 6 | 42 |
| | Acid & met. drainage | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 40 |
| | Blasting | 6 | 6 | 6 | 6 | 6 | 6 | | | 36 |
| | Power generation | 6 | 6 | 6 | 6 | 6 | 6 | | | 36 |
| | Slurry transport | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 24 |
| | Ore leaching | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 8 |
| | Groundwater injection | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 7 |
| | Void collapse | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 7 |
| | Contamination | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 552 |
| | Noise | 47 | 47 | 47 | 47 | 47 | 47 | | | 282 |
| | Groundwater increasing | 38 | 38 | 38 | 38 | 38 | | 38 | 38 | 266 |
| | Pests & Weeds | 39 | 39 | 39 | 39 | 39 | 39 | | | 234 |
| | Dust | 38 | 38 | 38 | 38 | 38 | 38 | | | 228 |
| | Light | 36 | 36 | 36 | 36 | 36 | 36 | | | 216 |
| | Climate change | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 176 |
| | Vegetation change | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 160 |
| Stressor | Radiation | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 152 |
| | Animal harm | 23 | 23 | 23 | 23 | 23 | 23 | | | 138 |
| | Fire | 23 | 23 | 23 | 23 | 23 | 23 | | | 138 |
| | Topography changes | 20 | 20 | 20 | 20 | 20 | 20 | | | 120 |
| | Erosion & sedimentation | 25 | 25 | 25 | 25 | | | | | 100 |
| | Stream diversion | 19 | 19 | 19 | 19 | | | | | 76 |
| | Vibrations | 8 | 8 | 8 | 8 | 8 | 8 | | | 48 |
| | Groundwater drawdown | 6 | 6 | 6 | 6 | 6 | | 6 | 6 | 42 |
| | Subsidence | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 7 |
| | **Grand Total** | 453 | 453 | 453 | 453 | 409 | 364 | 175 | 175 | 2935 |

Figure 7 shows the impact pathway diagram for the production phase for open-pit, underground and in situ recovery mining. Table 3 summarises the number of pathways.

In total, there are 2935 individual causal pathways in the production IPD, reflecting that the production IPD is more complex than the exploration IPD, including 3 drivers and many more activities and sources. The stressors however are largely the same.

There are more causal pathways that start from **open-pit mining** than from **underground mining** or from **in situ recovery**. The difference in number of pathways is mostly due to the footprint at the surface. **Open-pit mining** has the largest footprint due to pit excavation, while the footprint at the surface for both **underground mining** and **in situ mining** is smaller. **In situ** mining has the fewest causal pathways starting from it as it is the least invasive and no rocks are brought to the surface.

Table 3 shows that the activities associated with the construction or decommissioning of infrastructure have the most causal pathways. The **decommission and rehabilitate** node has more causal pathways than other infrastructure construction activity nodes as there is a greater component of handling chemicals and explosives, with the associated contamination risks. Decommissioning and rehabilitation is however of shorter duration, reducing likelihood of spills occurring. The activities that have fewest causal pathways are those that are predominantly underground and where the main hazard is related to contamination. To reiterate, the number of causal pathways is not a proxy for risk of environmental harm. A single unmitigated contamination pathway can cause considerable environmental harm.

The table of pathways organised by source (Table 3) is dominated by **earthworks**. **Earthworks** clear vegetation, change the landscape and hydrology, can cause contamination as well as sound and light pollution and can facilitate the spread of pests and weeds. It is important to note that **earthworks**, like transport for **logistics**, **water supply** and **power supply**, are not limited to the mine site footprint and can occur throughout the region.

**Contamination** is the stressor with the most causal pathways. There are many activities and sources that can cause contamination, directly by **tailings spillage** or accidentally spilling **chemicals and explosives**, **fuels and lubricants**, or indirectly by **acid metalliferous drainage**, **tailings seepage** or **waste disposal**, or from **water discharge** that is not compatible with the surrounding environment. **Groundwater increasing** features in 38 causal pathways, while **groundwater drawdown** is only on 6 pathways. This is because there are more sources that can cause groundwater levels to rise (including **groundwater injection**, **water discharge**, **tailings seepage**, **artificial water**, **brine management** and vegetation clearing associated with **earthworks**), while **groundwater drawdown** is only caused by **groundwater pumping**. Especially for ecosystems that evolved in a very dry, water-restricted environment, increased availability of water can drastically change dynamics.

## 3.3 Post-mining

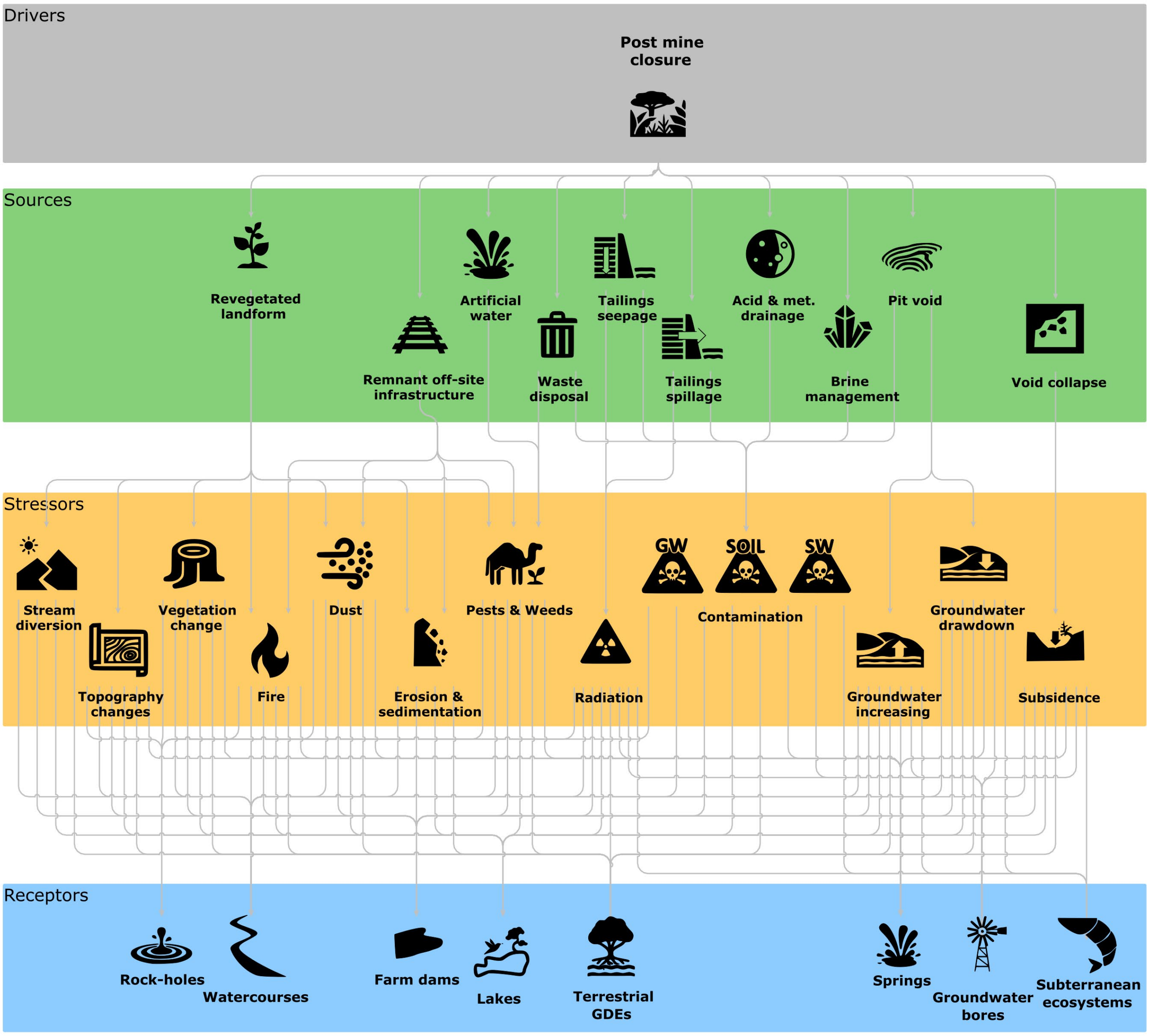


**Figure 8. Impact Pathway Diagram for the post-mining phase. The graphic is designed to be printed on A3**

GDE: Groundwater Dependent Ecosystem, GW: groundwater, SW: surface water

**Table 4. Number of causal pathways in the post mine closure IPD.**
The green-yellow-red colour shading is proportional to the number of causal pathways

| Type | Node | Terrestrial GDEs | Watercourses | Lakes | Farm dams | Springs | Rock-holes | Groundwater bores | Subterranean ecosystems | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Driver | Post mine closure | 21 | 21 | 21 | 21 | 18 | 15 | 10 | 10 | **136** |
| | | | | | | | | | | |
| Source | Revegetated landform | 5 | 5 | 5 | 5 | 3 | 3 | | | **26** |
| | Pit void | 3 | 3 | 3 | 3 | 3 | 1 | 3 | 3 | **22** |
| | Tailings spillage | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | **21** |
| | Tailings seepage | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | **16** |
| | Waste disposal | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | **14** |
| | Remnant off-site infrastructure | 2 | 2 | 2 | 2 | 1 | 1 | | | **10** |
| | Acid & met. drainage | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | **8** |
| | Brine management | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | **8** |
| | Artificial water | 1 | 1 | 1 | 1 | 1 | 1 | | | **6** |
| | Void collapse | 1 | 1 | 1 | 1 | 1 | | | | **5** |
| | | | | | | | | | | |
| Stressor | Contamination | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | **48** |
| | Pests & Weeds | 4 | 4 | 4 | 4 | 4 | 4 | | | **24** |
| | Radiation | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | **16** |
| | Erosion & sedimentation | 2 | 2 | 2 | 2 | | | | | **8** |
| | Groundwater drawdown | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | **7** |
| | Groundwater increasing | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | **7** |
| | Topography changes | 1 | 1 | 1 | 1 | 1 | 1 | | | **6** |
| | Vegetation change | 1 | 1 | 1 | 1 | 1 | 1 | | | **6** |
| | Animal harm | 1 | 1 | 1 | 1 | 1 | 1 | | | **5** |
| | Subsidence | 1 | 1 | 1 | 1 | 1 | | | | **5** |
| | Stream diversion | 1 | 1 | 1 | 1 | | | | | **4** |
| | **Grand Total** | **21** | **21** | **21** | **21** | **18** | **15** | **10** | **10** | **137** |

Figure 8 shows the impact pathway diagram for the post-mining phase. This captures the causal pathways after the mine site has been relinquished. The diagram therefore does not include any activities, but focuses on the sources of environmental stress that remain post-closure, after decommissioning and rehabilitation are finished.

Table 4 summarises the number of causal pathways for each type of stressor. There are 137 individual causal pathways. Most causal pathways contain the **revegetated landform** as it can be a continuous source of runoff, **erosion & sedimentation** and **contamination** as well as facilitating the spread of **pests & weeds**. The main sources of **contamination**, however, are the decommissioned tailings storage facilities and pit void. **Groundwater increasing** occurs after mine dewatering stops and groundwater levels recover. Groundwater levels may not recover to pre-mining conditions and the **pit void** potentially creates a permanent **groundwater drawdown** feature in the landscape.

# 4 Discussion

The series of fact sheets produced for this project capture the:

- geology, hydrogeology, hydrology and ecology of the study regions (Jazayeri and Werner 2024a,b; Jazayeri et al. 2024))
- existing and planned resource developments, as well as current land use and native title agreement (Draganic et al. 2024a-c)
- activities and sources associated with exploration, open-pit mining, underground mining, *in situ* mining, post-mining and large infrastructure corridors (Thomas and Peeters 2024a-f)
- receptors, how they function, where they occur in the landscape, how they can be affected by development and knowledge gaps (Guan 2024; Guan and Peeters, 2024; Guan and Thomas, 2024; Solórzano-Rivas et al. 2024; Shanafield 2024a-d)
- various sources that can cause stressors and how they can affect receptors (Peeters 2024a)
- impact pathway diagrams for exploration, production and post-mining (Peeters 2024b).

## 4.1 Hazard identification

The combined output of this project provides a regional-scale hazard identification for mining and associated infrastructure projects. The pictorial models (regional ECM and activity diagrams) are valuable tools in communicating and discussing the various hazards. The impact pathway diagrams allow users to trace the cause-and-effect relationships for each individual hazard from the resource development to receptor. IPDs also put each individual hazard in the context of all other hazards. The formal structure of an IPD as a DAG allows users to analyse and summarise the causal pathways, such as in Table 2, Table 3 and Table 4.

Box-and-arrow diagrams rapidly become very complex which makes it difficult to trace causal pathways. The team has been experimenting with different visualisation approaches, such as shown in Figure 9. This graphic represents the IPD by a series of interlinked matrices, where a dot represents a causal connection. It is less intuitive than a box-and arrow diagram, but allows to more clearly track which nodes are linked.

Fully exploiting the structure of the impact pathway diagrams however, requires an interactive interface, for instance like the interface of the Geological and Bioregional Assessments project (https://gba-explorer.bioregionalassessments.gov.au). Developing such interactive web portals is beyond the scope of the current project.

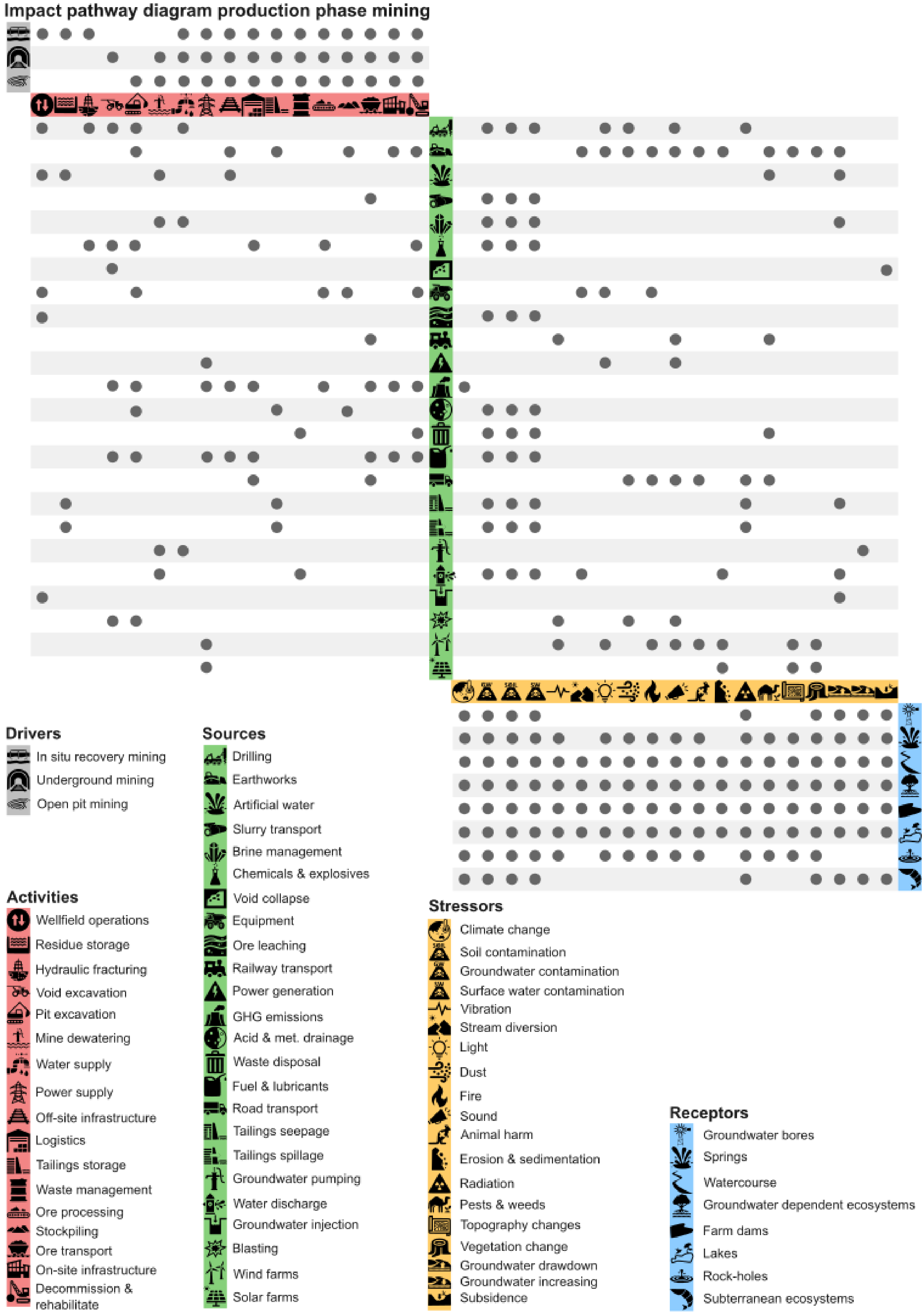


**Figure 9 Alternative IPD visualisation. A dot represents a link between nodes (either vertical or horizontal). Causal pathways can be traced from the top-left to the bottom-right.**

## 4.2 Spatial risk evaluation

The hazards captured in impact pathway diagram are a precursor to a risk assessment. In a risk assessment, each hazard is evaluated in terms of likelihood, consequence and capacity for its mitigation. Such an evaluation requires detailed information on the proposed development.

In the absence of such detailed information, it is at least possible to infer a generic spatial rule. The section below outlines an example. Consider the following causal pathway:

Open-pit mining → Water supply → Groundwater pumping → Groundwater drawdown → Terrestrial GDEs

Table 5 summarises a spatial evaluation for each link. The evaluation lists the conditions that need to be satisfied for the link to eventuate.

**Table 5. Example of spatial evaluation of the causal pathway: Open-pit mining → Water supply → Groundwater pumping → Groundwater drawdown → Terrestrial GDEs**

| Link | Spatial evaluation |
|---|---|
| Open-pit mining<br>→<br>Water supply | Open–pit mining requires water for operational use. Water can be sourced away from the mine site, provided the transport of water is economically and technically feasible. |
| Water supply<br>→<br>Groundwater pumping | Water supply can be sourced from groundwater, provided<br>(1) an aquifer is present with sufficient yield and quality to satisfy (part of) the operational water demand<br>(2) it is technically and economically viable to pipe water from the borefield to the mine site<br>(3) groundwater pumping is allowed from the aquifer |
| Groundwater pumping<br>→<br>Groundwater drawdown | Groundwater pumping will result in local groundwater drawdown, called the cone of depression. |
| Groundwater drawdown<br>→<br>Terrestrial GDEs | A terrestrial GDE will be affected by groundwater drawdown if the groundwater drawdown reduces the groundwater level in the aquifer that the GDE takes water from in periods the GDE is only sustained by groundwater. |

These spatial evaluations can be combined into a single statement:

It is possible for terrestrial GDEs to be affected by groundwater drawdown caused by groundwater pumping for water supply for open-pit mining:

- within a technically and economically feasible water transport distance from where the subsurface is prospective for open-pit mining, AND
- where an aquifer is present with sufficient yield and quality to provide at least part of the operational water demand, AND
- where groundwater pumping for operational water use is allowed, AND
- where there is a terrestrial GDE present in the area of drawdown in the terrestrial GDE's source aquifer due to pumping for operational water use, and that exceeds a predefined threshold in terms of level or rate of decline.

For regional planning purposes, this statement can be inverted so it can be used to identify areas where this causal pathway is **not** possible (difference with previous statement are in ***bold***):

It is **not possible** for terrestrial GDEs to be affected by groundwater drawdown caused by groundwater pumping for water supply for open-pit mining:

- **beyond** a technically and economically feasible water transport distance from where the subsurface is prospective for open-pit mining, OR
- where **no** aquifer is present with sufficient yield and quality to provide at least part of the operational water demand, OR
- where groundwater pumping for operational water use is **not** allowed, OR
- where there is **no** terrestrial GDE present OR
- where a terrestrial GDE is present but the drawdown in the terrestrial GDE's source aquifer due to pumping for operational water use is **below** a predefined threshold in terms of level or rate of decline.

Parts of these statements can be mapped without specific information of the development, such as identifying areas where groundwater pumping is not allowed under South Australian legislation or policies, or where terrestrial GDEs are potentially present. The presence of aquifers suitable to supply mining water can also be mapped, at least to an extent. It is, for instance, unlikely that fractured rock aquifers or small alluvial aquifers will be able to satisfy the operational water demand for a typical mining operation.

Other parts of the statement need project-specific information or data, such as the mineral prospectivity, the distance over which water transport is deemed technically and economically feasible, the requirements of operational water use in terms of quantity and quality and the potential drawdown such pumping would create. Similarly, the mapping of terrestrial GDEs would require ground-truthing and their dependence on groundwater confirmed.

The structure of the impact pathway diagrams can be used to generate statements like in the example on groundwater pumping in a systematic and consistent way. It requires a spatial evaluation to be recorded for each link in the network, which then can be combined along individual causal pathways. This also allows a user to create spatial rules or even maps of where in the landscape specific nodes can have an impact. The example above, for instance, can be broadened to a spatial evaluation of where groundwater pumping associated with water supply for open-pit mining can affect terrestrial GDEs, groundwater bores and subterranean ecosystems. Alternatively, a spatial evaluation can be created that examines the potential impact of groundwater pumping on terrestrial GDEs from both mine dewatering and water supply. An example of this in the context of unconventional gas development is the Geological Bioregional Assessment project for the Cooper and Beetaloo basin, where potential impact from, among other activities, water extraction for unconventional gas development, was examined spatially (https://bioregionalassessments.gov.au/gba)

## 4.3 Resolution

The Ecohydrological Conceptual Models are an abstraction of reality with a prime focus to integrate a large amount of information in a concise way. An impact pathway diagram is also an abstraction of reality in which cause-and-effect relationships are codified in a DAG with a strict schema of Driver → Activity→ Source → Stressor → Receptor. This allows for systematic and structured analysis of hazards, as outlined above.

Defining the nodes and establishing links between them is not trivial (Peeters et al. 2023), nor is developing an ECM. The ECMs and IPDs presented in this project were developed iteratively. The initial IPDs were based on existing causal networks developed in the context of unconventional gas development (Huddlestone-Holmes et al., 2021) and green hydrogen development (Malakar et al. 2023). They were subsequently modified based on relevant guidance information, such as the guidelines for preparation of a Program for Environmental Protection and Rehabilitation (PEPR; DEM, 2023). The ECMs and IPDs were presented at a stakeholder workshop in Port Augusta in March 2024 and revised based on the feedback from workshop participants, which included representatives for First Nations, government and consultants (Peeters et al. 2024).

The abstraction of reality that is needed to create ECMs and IPDs necessitates trade-offs between resolution and communication. The higher the resolution, that is the greater the level of detail with which cause-and-effect relationships are represented, the more complex the diagram or network becomes. Visualising very complex networks is challenging, especially as static, printed diagrams. Diagrams with many nodes and links are hard to navigate, which hinders the clear and transparent communication of causal pathways. For example, in the IPDs developed for this project, surface water, groundwater and soil contamination are represented as a single stressor. Alternatively, these could all be represented as individual stressors as they each consider a specific type of contamination or a specific way in which stressors can be affected. Adding these as individual stressors would, however, create a large number of causal pathways, making the diagram more complex to visualise and understand. The project team chose to represent contamination as a single node because of the complex interactions between these sources of contamination. Soil contamination can directly affect receptors that support ecosystems, but also indirectly by leading to groundwater and surface water contamination. Likewise, groundwater contamination affects groundwater-related stressors directly, but it can also lead to impact on ecosystem receptors if groundwater contamination leads to surface water contamination.

The choices and trade-offs made by the project team aimed to deliver ECMs and IPDs that are fit-for-purpose (Hamilton et al. 2022), balancing reliability (resolution) with usability (communication) and feasibility (display graphic in A3 format). These choices and trade-offs should be revisited if the ECMs and IPDs are considered to be used in another context, such as assessment of an individual project or in a different region.

The regional ECMs were used to identify a set of receptors. The definitions of receptors where chosen pragmatically to be relevant at the regional scale, such as lakes and groundwater dependent ecosystems. For a local study, more resolution can be required. For instance, an inland salt lake functions differently ecologically than an intertidal salt marsh or a flood-out area. While the hazard identification in this project is valid at a regional scale, a local IPD may need to split out these receptors, i.e. increase resolution, to adequately capture the local ecological function.

# Conclusion

This project developed regional ecohydrological conceptual models for the Braemar, Stuart Shelf and Northern Eyre regions in the context of mining and large infrastructure development. These ECMs formed the basis for impact pathway diagrams to systematically explore the hazards associated with resource development, to outline the potential cause-and-effect relationships between drivers and what we care about in the landscape, the receptors. The main output of the project is a series of fact sheets aimed to communicate the ECMs and hazards associated with development, through pictorial models, maps and box-and-arrow diagrams.

The result of the project is a comprehensive, regional-scale hazard identification that can form the basis of a spatial risk assessment by evaluating likelihood, consequence and options for mitigation. To facilitate this, the stressor fact sheet includes a materiality assessment and mitigation options for each stressor.

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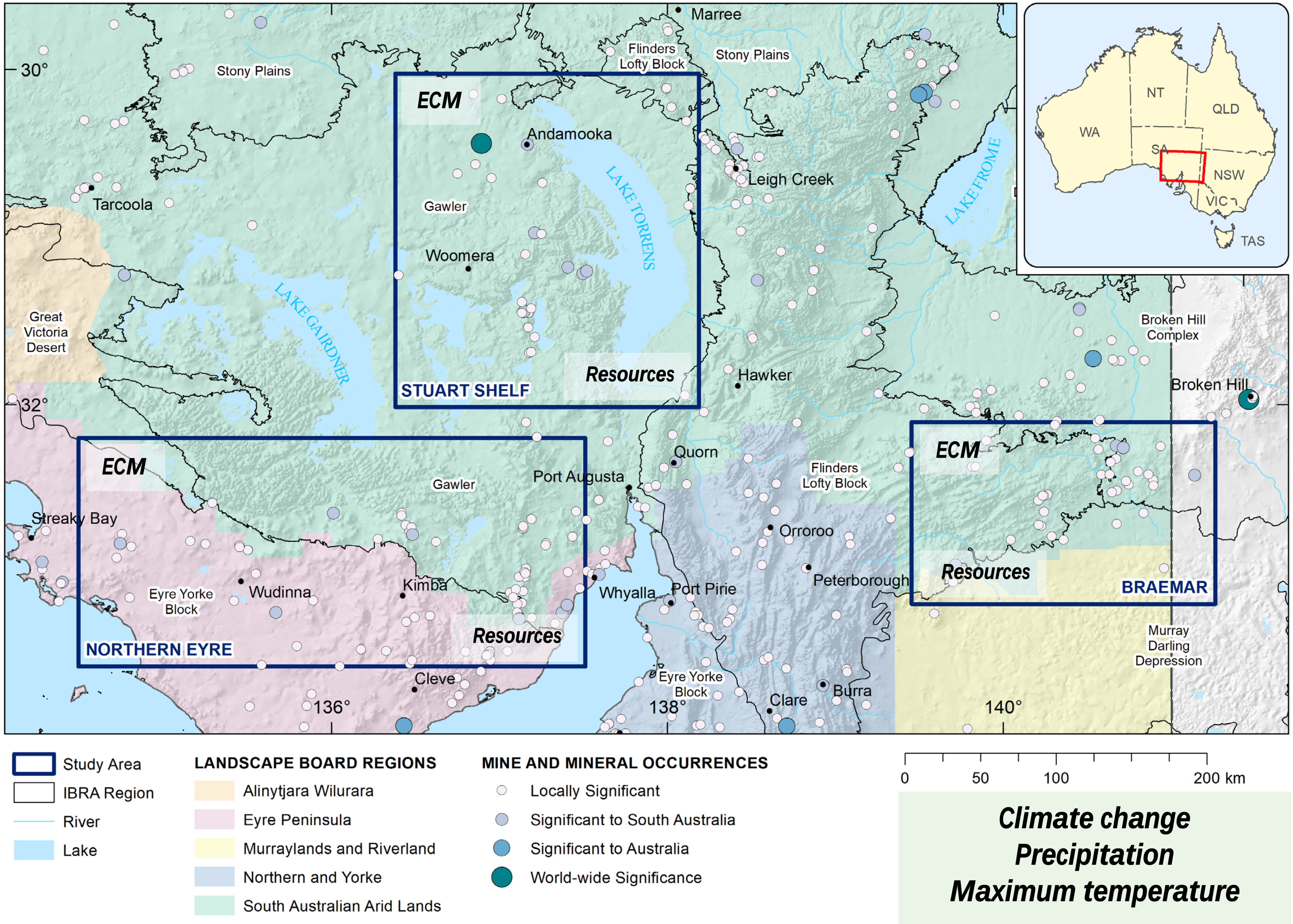
# Ecohydrological conceptual models for the Braemar, Stuart Shelf and Northern Eyre




**Climate change**
**Precipitation**
**Maximum temperature**

Fact Sheet

# Regional ecohydrological conceptual model – Braemar

## HIGHLIGHTS

- The ecohydrological conceptual model (ECM) of the Braemar region captures key components of the groundwater, surface water and hydro-ecological systems of the region.
- Despite the arid climate, the Braemar region has significant infrastructure to access groundwater and large areas of protected ecosystems.

## BACKGROUND

This fact sheet presents a conceptual pictorial block diagram of an ECM of the Braemar region. The ECM shows the key features of the landscape and subsurface that are important to assess the impacts of development. ECMs are commonly adopted in the initial stages of visualising and understanding how a system interacts and lead to more detailed analysis of individual components, including climate drivers, catchment runoff, groundwater flow and contaminant movements as well as ecological responses to these driving forces. ECMs establish a shared understanding among government entities, prospective companies, and landscape boards regarding the potential environmental impacts of resource development activities. They outline the necessary information and data required to evaluate the likelihood, consequences, and mitigation strategies associated with these impacts. The conceptual models that are used to develop numerical models need more detailed investigations that quantify the system parameters and the natural and human-induced stresses on the landscape (Commonwealth of Australia, 2024).

## PROJECT TEAM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The project was conducted with support from the South Australian government through the Department for Environment and Water and Department for Energy and Mining, South Australian Arid Lands Landscape Board and Eyre Peninsula Landscape Board.

## STUDY AREA

The Braemar region was selected as an area of interest as it has a notable concentration of valuable mineral resources, particularly magnetite, within a region constrained by limited water availability. Despite limited water availability, there are important ecosystems and other water users in the region that need to be considered when managing the effects of current and future mining activities. This is particularly important given the significant volumes of water required to process magnetite ore (Currie and Richardson, 2023).

## CONCEPTUAL PICTORIAL BLOCK DIAGRAM

Figure 1 shows a conceptual pictorial block diagram of the Braemar region's relevant landscape and subsurface processes. Detailed descriptions of each component are outlined in Table 1.

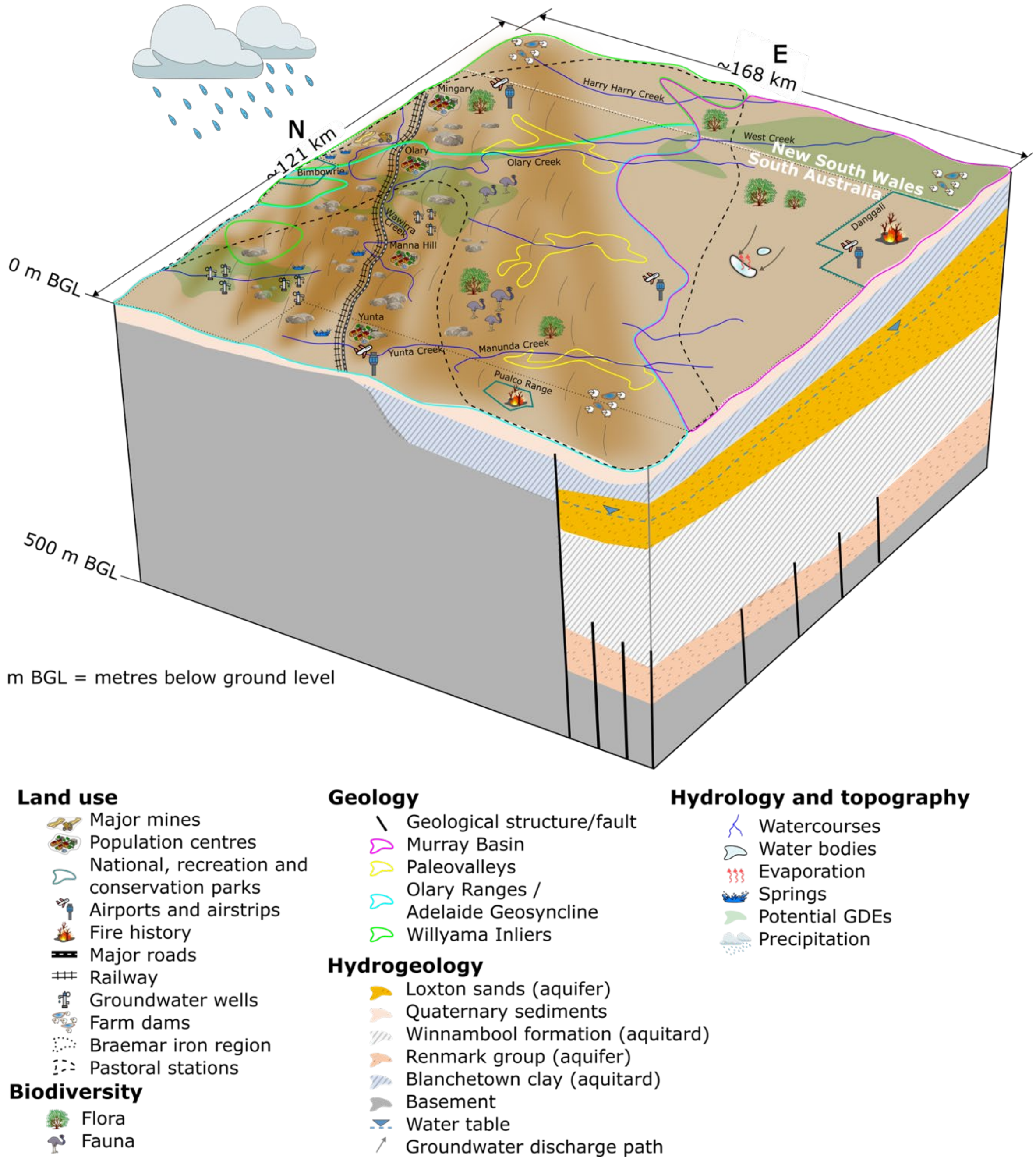


*Figure 1. Conceptual pictorial block diagram for the Braemar region. Hydrostratigraphic cross sections based on Mule et al (2022) and Currie and Richardson (2023)*

*Table 1. Components, descriptions, and information sources of the Braemar region conceptual pictorial block diagram.*

| ITEM | DESCRIPTION |
|---|---|
| **Land use** | Land use in this region includes major mines, population centres, major roads, national recreation and conservation parks, groundwater wells, farm dams, airports and airstrips, fire regime, and railway infrastructure.<br><br>The White Dam gold mine is the prominent mining operation in the northern part of the study area. It is anticipated to yield a total output of 120,000 oz of gold, with an annual production of 50,000 oz (SARIG, 2023). 11,101 km$^2$ (~54% of the study area) of the Braemar iron region is located in the study area, mainly from the northeast to the southwest. Magnetite resources in the Braemar iron region are primarily comprised of magnetite Braemar ironstone facies (BIF), situated within the Nackara Arc, a tectonic subdivision of the Adelaide Geosyncline. These resources are predominantly located within 2 distinct formations: the Pualco Tillite and Benda siltstone. These formations consist of narrow folded Neoproterozoic rocks within the Adelaide Geosyncline (Currie and Richardson, 2023). Defined mineral resources of magnetite BIF total 6.9 billion tonnes, excluding the Hawsons deposit (2.5 billion tonnes located south of Broken Hill in NSW). This represents the eastern extremity of known BIF. The geological form of these defined resources is characterised by gently dipping slabs, with some deposits displaying open folding. While total iron percentages are typically 15–20 per cent iron, there are favourable factors for mining which include very large resource inventories, relatively simple geology, and lower values for hardness and grind indices. This should enable economic recovery of high-grade magnetite concentrate with low levels of impurities. There are 4 population centres within the region and they are all situated along the Barrier Highway (ABS 2024):<br>- Yunta (population of 60 according to the 2021 census)<br>- Manna Hill (population of 4 according to 2021 census)<br>- Olary (population of 4 according to the 2021 census)<br>- Mingary (population of 75 according to 2016 census).<br><br>The sealed Barrier Highway is the major road through the Braemar region (for approximately 147 km ), and it extends toward Broken Hill and connects SA to NSW (SARIG, 2023). The remaining network of roads consists of unsealed tracks. There is one open railway track, the Crystal Brook–Broken Hill line, spanning approximately 147 km within the study area. This route is used by both passenger and freight trains (SARIG, 2023). Air transport infrastructure within the region includes 7 landing areas and the remainder are categorised as unknown/minor airstrips (SARIG, 2023).<br><br>There are 31 pastoral stations primarily used for cattle or sheep production, which require extensive grazing land. These cover an area of 14,705 km$^2$ (~72% of the study area). The extents of the properties are often defined by fence lines rather than legal lease boundaries (SARIG, 2023).<br><br>Within the study area, there are 3 conservation reserve areas (SARIG, 2023):<br>- Pualco Range (79 km$^2$ or ~0.4% of the study area)<br>- Bimbowrie (86 km$^2$ or ~0.4% of the study area)<br>- Danggali (511 km$^2$ or ~2.5% of the study area).<br><br>These areas protect both the fauna and flora species and are major 'biological reservoirs' to maintain species diversity. Fire scar mapping of the region indicates that no major bushfires have occurred since the 1984 bushfire which affected approximately 451.8 km$^2$ (~2% of the study area). However, recent fires include the 2017 Oulnina bushfire and the 2023 Oakvale |

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| | Station bushfire (SARIG, 2023). Bushfires in the Danggali Conservation Park were recorded in the summers of 1979 and 1984, and spring 1990 and there was a prescribed burn in 2009. These incidents covered 29 $km^2$ (~0.1% of the study area), 144 $km^2$ (~0.7% of the study area), 14 $km^2$ (~0.07% of the study area), and 106 $km^2$ (~0.5% of the study area), respectively. Additionally, there was a bushfire in Pualco Range Conservation Park in spring 2013 that covered approximately 6 $km^2$ (~0.03% of the study area).<br><br>There are 753 wells, of which only 212 are active, including 21 domestic wells and 176 stock wells.[2] Farm dams are also prevalent in the study area. 961 dams have been identified and their surface areas range from 187 $m^2$ to 18,889 $m^2$ with a median of 3,011 $m^2$ (Shanafield 2024). |
| **Hydrology and topography** | The hydrology and topography of the study area includes watercourses, waterbodies, evaporation, springs, potential groundwater dependent ecosystems (GDEs), and precipitation.<br><br>Most of the watercourses drain into the River Murray, while the northern section is part of the Cooper Creek catchment. The drainage density is higher in the Olary Ranges than in the Murray Basin. The creeks are ephemeral, flowing only after significant rainfall events.<br><br>The major creeks, like Olary Creek and Manunda Creek in the south and Mingary Creek in the northeast, flow for 20 km to 30 km after significant rainfall events before the water seeps into the sediments (Barnett, 2015). But there are no permanent gauging stations that record flow. The local alluvial sediments along creeks and drainage lines host limited, local groundwater systems (Barnett, 2015). These likely allow for waterholes to persist along drainage lines for extended periods.<br><br>River red gums are the dominant species within the riparian zones of major watercourses, while minor waterways are dominated by elegant wattle (DEH and SAALNRM, 2009). There are 47 lakes in the study area, 11 areas which are subject to inundation, and 3 swamps, all of which are highly ephemeral. Notable examples include Olary Creek, Manunda Creek, and Wiawera Creek, which are listed as GDEs in the Groundwater Dependent Ecosystems Atlas (SARIG, 2023). The potential coverage of terrestrial GDEs in the region is 39% (Guan and Peeters, 2024). In the northwest of the region, 7 springs or spring groups have been identified (Guan, 2024).<br><br>Rainfall is irregular and sporadic and tends to be localised when heavy rainfall occurs. The Yunta Airstrip (BOM site 020062) experiences a mean annual rainfall of 197 mm. Topographic features have a strong orographic effect on rainfall distribution and create a gradient of decreasing rainfall from west to east and from south to north within the study area (Currie and Richardson 2023). The mean annual potential evaporation of the study area is ~2,000 mm (Currie and Richardson 2023). |
| **Geology (Currie and Richardson, 2023)** | Three primary geological zones within the study area include the Willyama Inliers, the Olary Ranges/Adelaide Geosyncline, and the Murray Basin. These zones correspond to distinct structural and metamorphic events:<br><br>1. The Olarian Orogeny, which took place during the Early to Middle Proterozoic era, primarily impacted the rocks of the Willyama Supergroup. This event induced deformation and metamorphism of basal sediments and volcaniclastic rocks to amphibolite grade. It was accompanied by localised melting and the intrusion of felsic granitoid.<br><br>2. The Delamarian Orogeny spanned from the late Cambrian to the Ordovician period, affecting both the Willyama Supergroup and the Adelaidean rocks. During this period, rocks underwent folding, metamorphism, and intrusion by Anabama granite and associated dykes. Deformation led to the formation of north–south-oriented folds initially, followed by major northeast–southwest-oriented folds. The Adelaidean |

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| | rocks experienced the effects of broad, steeply dipping folds with an east–northeast orientation, along with faults directed northwest.<br>3. In the Tertiary period, downwarping and downfaulting occurred within the Murray Basin. This facilitated deposition of continental sand and shallow marine to estuarine clay and limestone. Evidence of this process is observable along the Anabama fault, a northeast to southwest-striking fault along the edge of the Murray Basin, with an offset of up to 70 meters that is deeper on the basin side.<br>4. During the early to middle Cenozoic era, a network of extensive rivers drained the continent during a notably wetter period. These rivers carved out large paleovalleys and deposited fluviatile sediment in the process (Currie and Richardson 2023). While such paleovalleys are present in the study area and have been recently identified through geophysical techniques (Mule et al, 2022), their occurrence is restricted due to the study area's position atop a drainage divide. Consequently, the presence of deep, highly-incised, and extensively-filled paleovalley systems is limited. Deeper paleovalleys are more prevalent further north in the Curnamona Province, where they are associated with uranium deposits, and further south within the Murray Basin, where they comprise ancestral tributaries and channels of the Murray–Darling catchment (Currie and Richardson 2023). The paleovalleys cover a total area of 534 $km^2$ (~3%) within the study area (Mule et al, 2022). |
| **Hydrogeology** | The study area contains several aquifer systems that are divided into 2 main physiographic regions:<br>1. In the Olary Ranges, groundwater occurs mainly within the fracture networks of pre-Cenozoic rocks, such as the Adelaide Geosyncline or Willyama Inliers. These aquifer systems are spatially confined with interconnected fractured networks extending only over short distances, typically several kilometres at most (Currie and Richardson 2023). Consequently, the available groundwater storage is limited and only allows for low-flow or short-term pumping rates. Water table depths are significantly influenced by topography and generally remain within 10 m of the land surface in valleys. Distributed, regional groundwater recharge is expected to be minimal (< 1 mm/year) due to low rainfall and high potential evapotranspiration. This creates generally high groundwater salinities. However, localised recharge occurs along drainage lines and is linked to infrequent heavy rainfall and periods of surface runoff. These groundwater resources generally have a lower salinity that allows for stock and domestic use (Currie and Richardson 2023).<br>2. The Murray Basin comprises a vast Cenozoic sedimentary basin that stretches from the riverine plains of NSW and Victoria to the mouth of the River Murray. Within this basin, 3 principal aquifer systems are noteworthy: the Pliocene sands/Loxton-Parilla sands aquifer, the Murray group limestone aquifer, and the Renmark group (or Onley formation) aquifer. These aquifers form part of a regional groundwater flow system that generally moves from east to west. Modern-day recharge primarily occurs in the higher rainfall areas to the east. The Pliocene sandsare largely unsaturated or possess minimal saturated thickness across much of the study area. In lower elevations to the southeast, the water table intersects with this sands unit, but the aquifer system is characterised as having low yields (<5 L/s). Consequently, it is not considered highly prospective as a groundwater resource. The Murray group limestone is not present within study area but occurs at a considerable distance to the south. Conversely, the lower Renmark group aquifer is mapped across the southern portion of the study area. It shows reasonably high yields (>5 L/s) in SA and even higher yields (>50 L/s) within NSW which are associated with the Menindee and Tarrara troughs. The lower Renmark group aquifer has emerged as a promising |

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| | groundwater resource in the Murray Basin, close to the Braemare region. This extensive aquifer boasts considerable thickness, with its depth reaching up to 140 m in the Menindee–Tarrara trough area of NSW. However, the aquifer may thin out towards its outer extent (towards the Olary Ranges) due to constraints imposed by basement highs. The lower Renmark aquifer is characterised as a confined aquifer. This means that any pumping from the aquifer is unlikely to impact the water table or affect surface ecosystems, including GDEs. While it does support stock and domestic groundwater supplies, it is a minimally-developed groundwater resource (Currie and Richardson 2023).<br><br>In the study area, 494 wells have associated water level data (DEW, 2024a). The recorded groundwater levels range from a minimum of ~16.5 m Australian Height Datum (AHD)to a maximum of ~565 m AHD. The median groundwater level in the study area is reported to be ~265 m AHD.[2] |
| **Biodiversity (DEW, 2024b)** | The biodiversity within the study area incorporates flora and fauna and represents an overview of the data fields outlined in DEW (2024c). The dominant land cover for this region is non-woody native vegetation, where native flora includes black bluebush, oblique-spined bindyi, and bladder saltbush, and non-native species such as Ward's weed and onion weed are prevalent. Needle wattle and slender bell-fruit are nationally-vulnerable species that grow within this region, with the latter considered endangered at a state level. Red kangaroos, western grey kangaroos, emus, and common wallaroos are all native fauna that commonly reside in this region. The endangered striated grasswren and the vulnerable red-lored whistler, malleefowl, and yellow-footed rock-wallaby, have all been identified within this area. These protected species are threatened by various factors. These include feral goats, feral sheep, and rabbits who cause soil damage and contribute to overgrazing, which limits food supply for native fauna. Feral predators that inhabit this region, such as cats and foxes, also pose a threat to the native fauna. |

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Fact Sheet

# Resource development in the Braemar region

## HIGHLIGHTS

- The Braemar region is highly prospective for iron ore and particularly magnetite resources within the Nackara Arc of the Adelaide Geosyncline. Six state-significant iron deposits have been identified in the region. Other resources that are economically-significant include copper, cobalt, gold and uranium.
- Mining is currently not a land use in the Braemar region. Land in this region is predominantly used for native vegetation grazing and some conservation, but the region is almost entirely covered by exploration leases and there are 7 major projects under development (feasibility and mining lease proposal stages).

## INTRODUCTION

The Braemar region is under-developed in a mining context when the high concentrations of mineral resources are considered. These are dominated by magnetite as well as cobalt, copper and gold. The South Australian government is seeking to facilitate mining development and economic growth in the region.

This fact sheet provides an overview of current and potential resource development in the Braemar region, including mining (e.g. open pit, underground and in situ recovery) and large infrastructure (e.g. road, railway, transmission and water). Other types of resource development currently or potentially occurring in the region, such as renewable energy, are summarised but were not assessed as a part of this project. Current development activity in the Braemar region is focused on ore and uranium and there are 6 magnetite projects at advanced stages of planning.

## PROJECT TEAM


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# LAND USE

Land within the Braemar region is predominantly used for grazing (native vegetation) and there are some conservation areas (nature conservation and managed resource protection) (Figure 1). The Pualco Range Conservation Park and Bimbowrie Conservation Park (IUCN Category VI protected areas) and Danggali Conservation Park and Wilderness Protection Area (IUCN Category IA and IB) are located along the southwest, north and southeast edges of the study area, respectively.

Mineral exploration and mining activities are permitted within the Bimbowrie Conservation Park (DEWNR, 2012). Currently, mining is not a land use in the region, but this is expected to change as mineral exploration activities are being undertaken (discussed in further sections). Land use in the region is described in more detail in the regional ecohydrological conceptual model (Jazayeri and Werner, 2024).

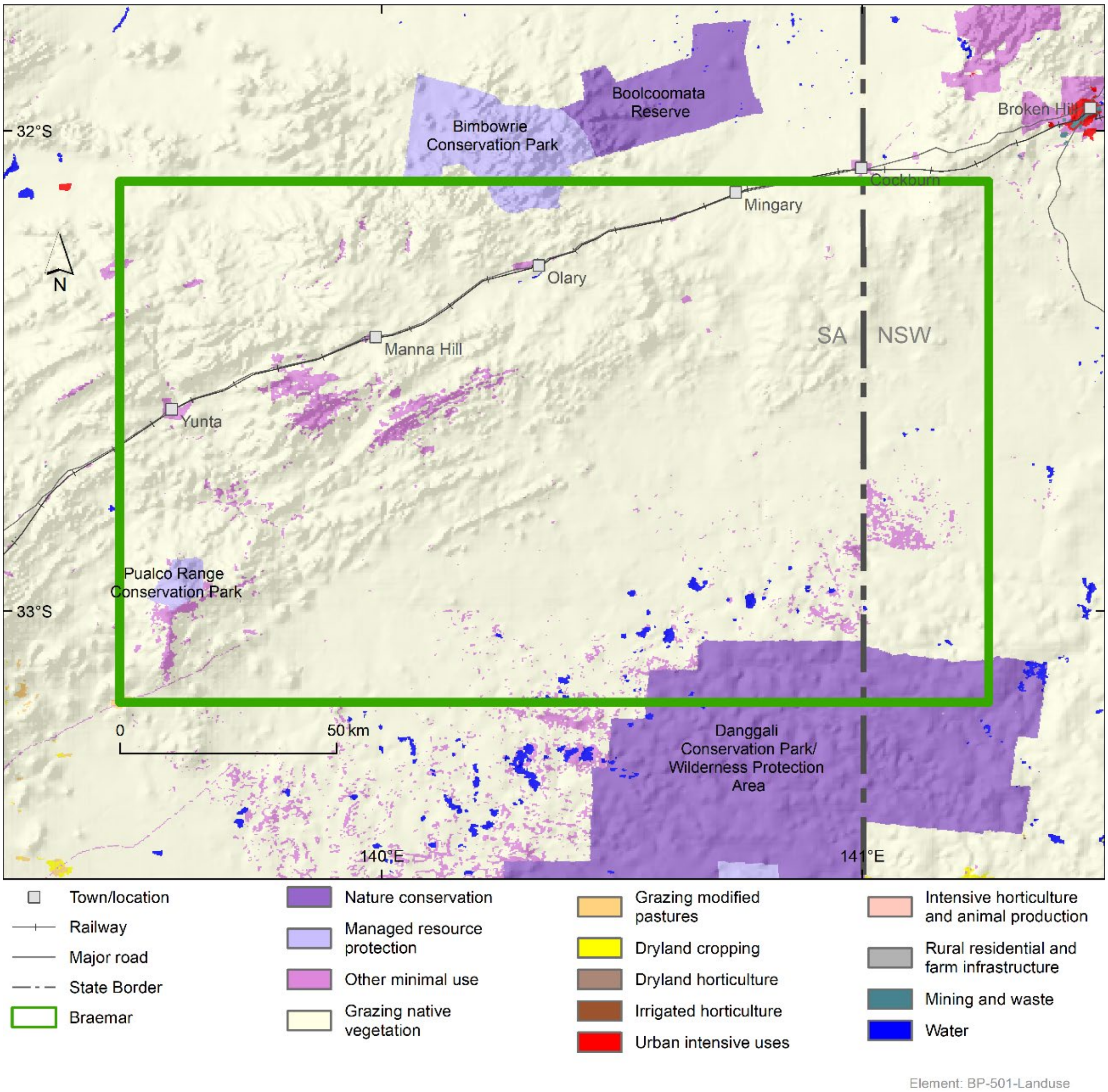



***Figure 1. Land use within and surrounding the Braemar region 2015-16 based on the Australian Land Use and Management Classification Version 8 (ABARES, 2022)***

## NATIVE TITLE AND LAND USE AGREEMENTS

Native Title Determinations (NTD) in the region include the Ngadjuri Nation #2; Adnyamathanha, Ngadjuri and Wilyakali Overlap Claim; and Wilyakali determinations (Figure 2). The rights conferred in the Ngadjuri Nation #2 Native Title determination include the right to camp on the land, hunt and take resources from the land and waters, perform ceremonies, teach law and engage in cultural activities and protect cultural sites (Divakaran, 2023).

One Indigenous land use agreement (ILUA) in the region is the Ngadjuri Faraway Hill Pastoral ILUA (Figure 2). This ILUA represents agreement between the Ngadjuri people and the McBride Pastoral Company for the land to continue to be used for traditional activities including hunting, camping and performing ceremonies by the Ngadjuri people as well as continued grazing by the pastoral company (ATNS, 2006).

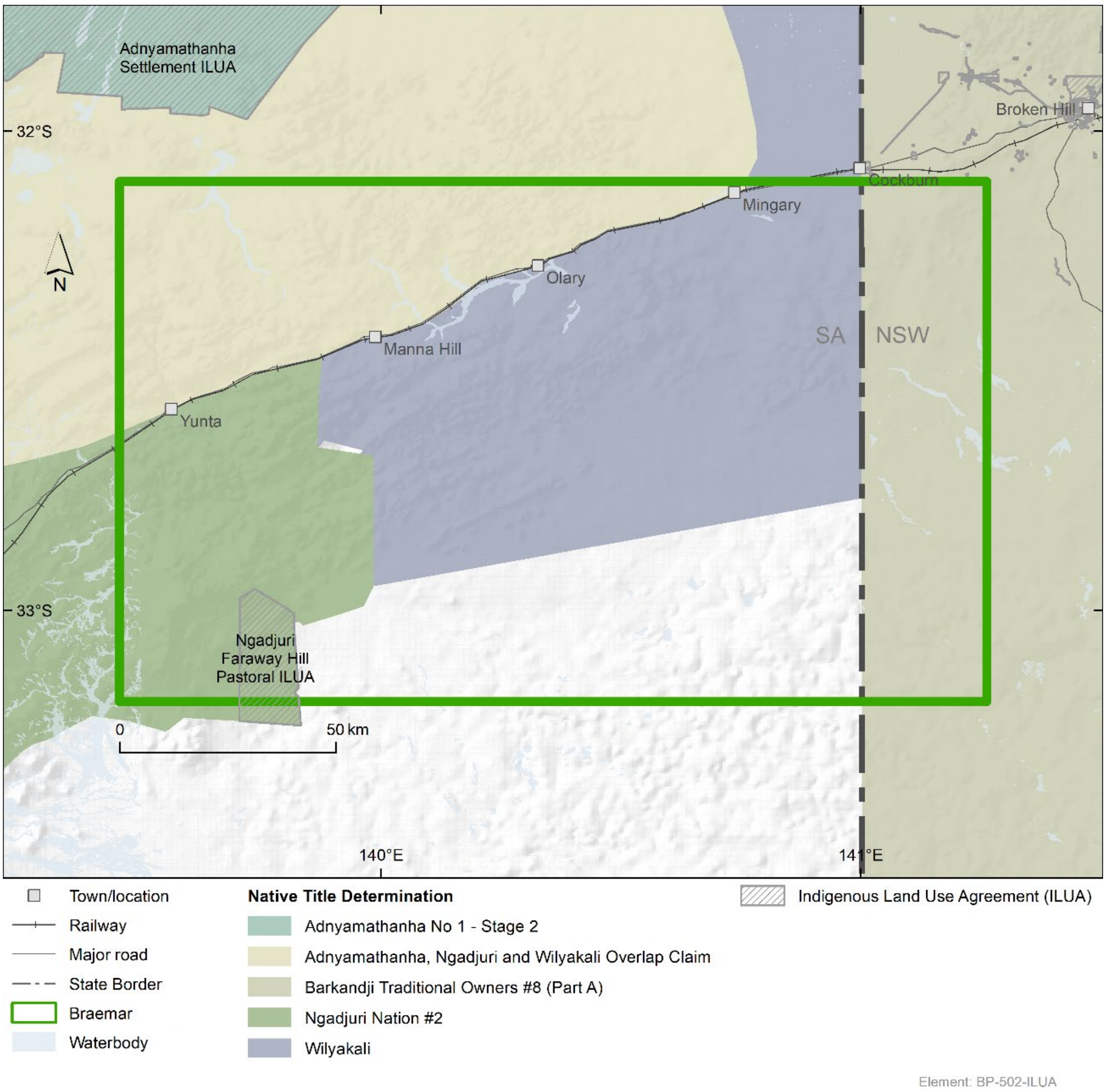



***Figure 2. Native Title Determination and Indigenous Land Use Agreements in the region. Sourced from NNTT (2024a and 2024b)***

# MINERAL RESOURCES

The Braemar region has a high concentration of known mineral resources, including iron, cobalt, copper and gold (Figure 3). Iron ore containing magnetite dominates the mineral deposits (Figure 5). Magnetite is a highly prospective and valuable source of iron, particularly for steel-making. The South Australian Resource Information Gateway (SARIG) provides information relating to mines and mineral deposits, occurrences and prospects, including the major commodities known to occur in the deposits and their significance in terms of economic worth (DEM, 2022). While the majority (427) are of low economic significance, there are 38 locally-significant deposits and 6 that are significant to South Australia.

## IRON

Mineral resources in the region are dominated by iron in the form of magnetite (Figure 5) and are part of the Braemar Iron Formation in the eastern Adelaide Geosyncline. The iron-rich rocks were formed in the Neoproterozoic, between 720 and 660 million years ago, when the region was covered in ice sheets. The ironstone is well exposed and forms prominent ridges (England and Thomas, 2017).

The Joint Ore Reserves Committee (JORC[1]) estimates that iron-containing ore resources (iron ore) in the Braemar region exceed 13 billion tonnes, which represents 40.8% of South Australia's total iron ore resource estimates. The total iron contained in the iron ore estimates exceeds 2.3 billion tonnes, which is 13.9% of Australia's estimated iron ore (Geoscience Australia, 2022). In 2022, the South Australian government published a Magnetite Strategy (DEM, 2022) to guide the development of the state's iron ore resources for economic growth. The government is seeking to increase the production of magnetite to 50 million tonnes (Mt) per year by 2030.

The region contains 14 deposits of local economic significance where the major commodity is iron or iron ore. There are also 6 deposits considered to be significant to the South Australian resource economy. These include Razorback Ridge (Razorback Ridge, Iron Peak and Ironback Hill), Grants, Grants Basin and Hawsons.

From a mining perspective, the magnetite deposits in the Braemar region have low to negligible cover and overburden thickness, which means that open pit mining will typically be the most suitable mining method (Davies and Twining, 2018).

## COPPER–COBALT–GOLD

Copper–cobalt resources are hosted predominantly in the sulfide ore bodies of the Willyama Supergroup in the Curnamona Province, situated in the northeast of the region. The rocks in the Curnamona Province were formed in the Paleoproterozoic, over 1.7 billion years ago. These rocks were deformed in multiple mountain-forming periods, which led to several deposits of copper, gold, silver, cobalt and uranium. The Broken Hill deposits, to the northeast of the region, are also part of the Curnamona Province.

The Mutooroo deposit contains 195 Kt of copper, 20.2 Kt of cobalt and 82.1 Koz of gold (Figure 5**Error! Reference source not found.**). The mining operation is proposed to have an shallow open pit initially, followed by underground mining (Havilah Resources, n.d.).

There are 15 deposits of local economic significance, where copper or gold is the major commodity. However, the copper–cobalt–gold resources are small when compared to the total inventory of magnetite resources.

## URANIUM AND OTHER COMMODITIES

In addition to the above minerals, the region also has uranium, rare earth elements, silver, lead, molybdenum and zinc deposits. There are 3 deposits of local economic significance where uranium is the major commodity. There are large kaolin deposits in the south of the region, but there are no plans to exploit these at the moment.

[1] The Australasian code for reporting of exploration results, mineral resources and ore reserves (the JORC Code) is a professional code of practice that sets minimum standards for public reporting of minerals exploration results, mineral resources and ore reserves.

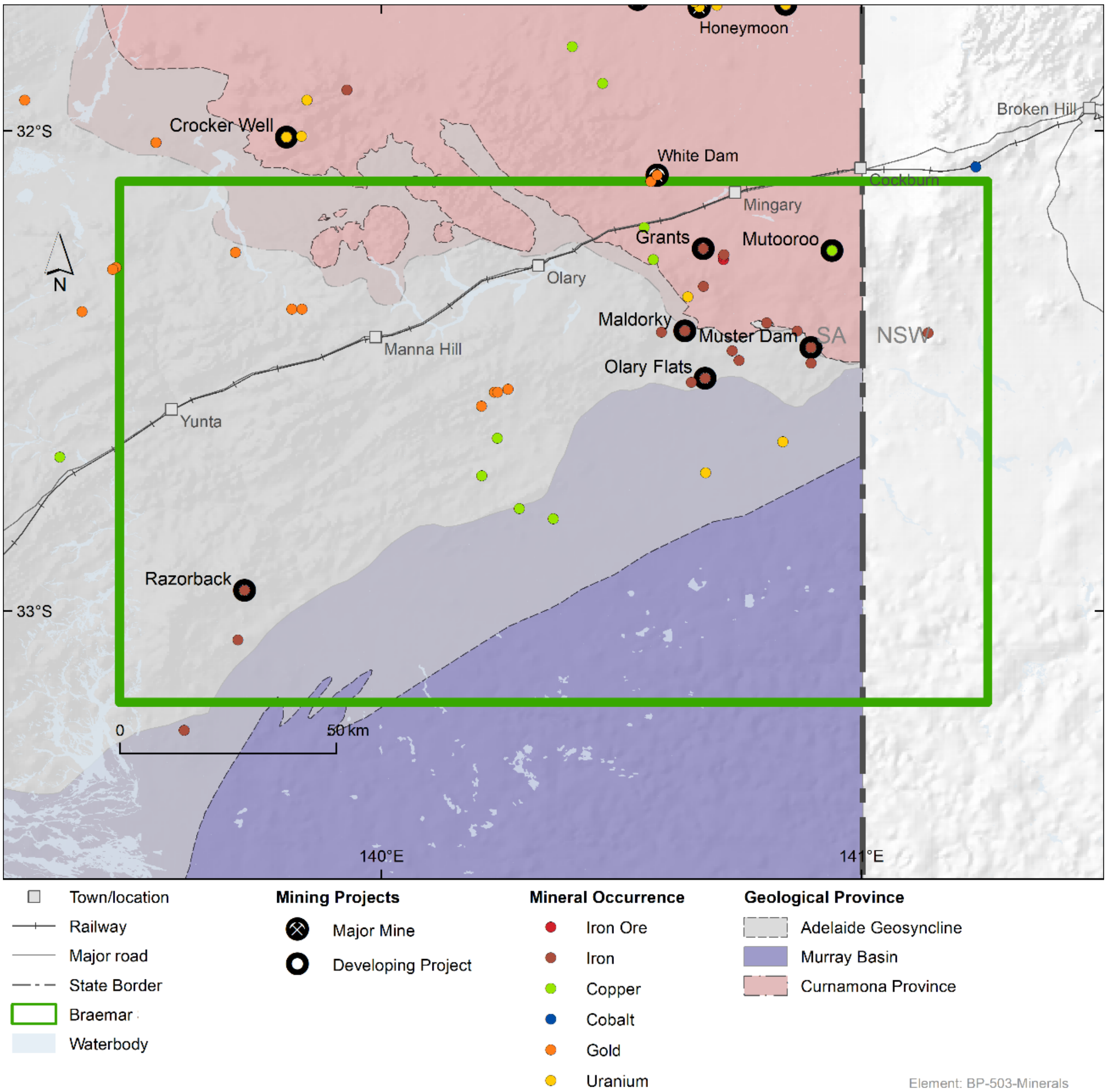



*Figure 3. Mines and mineral deposits, occurrences, and prospects sourced from SARIG (DEM 2024)*

## MINERAL EXPLORATION

Exploration since the mid-2000s has identified many magnetite prospects, with several deposits defined as JORC-compliant. Exploration leases, predominantly for copper, cobalt, gold, uranium and iron, among other minerals, currently cover almost the entire Braemar region (Figure 4).

## MINING OPERATION AND DEVELOPMENT

While there are no active mining operations in the region at the moment, there are 6 major magnetite projects (Maldorky, Grants, Razorback Ridge, Muster Dam, Olary Flats, and Hawsons) and one major copper–cobalt–gold project (Mutooroo) undergoing feasibility assessment (Figure 5). The White Dam mine located just north of the region has been producing gold from heap-leaching ~7.5 Mt of ore mined from 2 open pits since 2010 (GBM Resources, n.d.).

The Razorback Iron Ore project, consisting of the Razorback Ridge, Iron Peak and Ironback Hill deposits, is planning to use traditional open pit mining methods as the deposits have negligible overburden (part of the resource outcrops) (Magnetite Mines 2022). The Maldorky project has also proposed open pit mining methods.

A mining lease application has been accepted by the Department for Energy and Mining for the Maldorky project but it is not publicly-available.

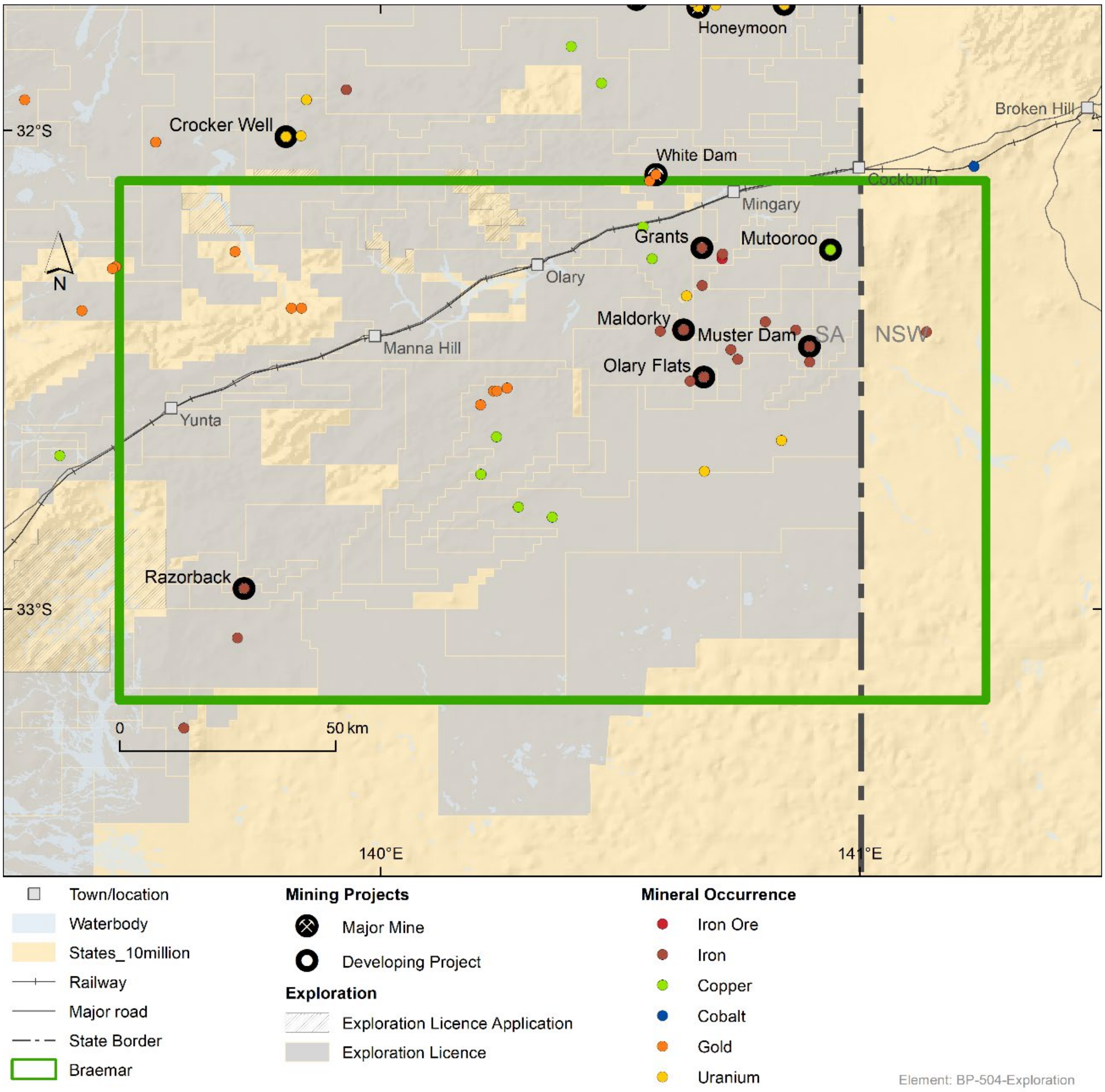



***Figure 4. Exploration licences, licence applications and deposits of local and state economic significance (SARIG 2023b and 2023c)***

## Braemar Province - major mineral projects and mining activities

| Region | Total major mines | Total major quarries | Total developing projects |
|---|---|---|---|
| State (SA) | 30 | 44 | 38 |
| Braemar | - | - | 7 |

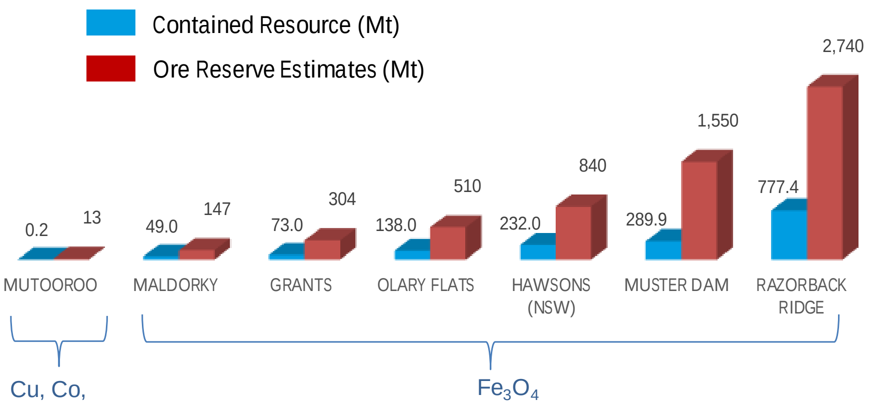
### Major projects

| Name | Development status | Owner | Commodity |
|---|---|---|---|
| White Dam[1] | Operating | Exco Operations (SA) Pty Ltd | Gold (Au), Copper (Cu) |

1. ~ 1.4km N of Study Area

### Developing projects

| Project | Commodities | Owner | Development status |
|---|---|---|---|
| Maldorky | Magnetite ($Fe_3O_4$) | Havilah Resources Ltd | Mining Lease Proposal |
| Grants | Magnetite ($Fe_3O_4$) | Havilah Resources Ltd | Feasibility studies |
| Razorback | Magnetite ($Fe_3O_4$) | Magnetite Mines Ltd | Advanced feasibility studies |
| Muster Dam | Magnetite ($Fe_3O_4$) | Magnetite Mines Ltd | Scoping |
| Olary Flats | Magnetite ($Fe_3O_4$) | Lodgeston Mines Ltd | Advanced feasibility studies |
| Hawsons (NSW) | Magnetite ($Fe_3O_4$) | Hawsons Iron | Advanced feasibility studies |
| Mutooroo | Copper (Cu), Cobalt (Co), Gold (Au) | Havilah Resources Ltd | Feasibility studies |




### Commodity: % of State's Ore Reserve


*Figure 5. Resource estimates for the Braemar region (SARIG 2023a)*

# INFRASTRUCTURE CORRIDORS

The Braemar region has limited infrastructure due to a lack of intensive industrial activity, such as mining (Figure 6). An assessment of the existing infrastructure in the region and its capacity to support future needs was undertaken in 2013 (Deloitte, 2013). An expansion of the region's power, water and transport infrastructure is necessary to support the expansion of mineral production.

There is an interstate rail network which runs through the north of the region. The rail network has some spare capacity, but it is unlikely to be sufficient to meet the forecasted demand. The Barrier Highway is the only major sealed road in the region, but there are a large number of unsealed roads. The bulk freight of product from mining is estimated to be between 11 Mt p.a. and 65.18 Mt p.a., assuming an annual mineral/concentrate production of 10–59.25 Mt p.a. Therefore, there is a lack of suitable bulk transport links between mines in the Braemar region and the nearest port for export.

Water for human consumption and stock is supplied by groundwater. Future mining would require water for a range of activities such as dust suppression, processing, slurry operation and potable supply. However, there is insufficient groundwater supply to meet the mining demands, which are estimated to be between 10 GL p.a. and 60 GL p.a. depending on the level of mining activity (Currie and Richardson, 2022).

Magnetite mining, which is expected to be the predominant type of mining in the region, is electricity-intensive, but there is no transmission network in the region that can support mining. The peak power demand is estimated to be between 74.8 MW and 492.2 MW and energy consumption is estimated to be between 734 GWh p.a. and 3,835 GWh p.a.. The existing sub-stations in the region are small-scale and powered by on-site diesel generation.

Potential future infrastructure projects to support an emerging mining industry in the region:

- A new underground slurry pipeline, including a water supply and return water line, that would service multiple mines using a common corridor.
- A new transmission link from Port Augusta to the Braemar region.
- A new gas line connection to the existing pipeline in the region and establishment of a local gas power generation plant.
- A new desalination plant located along the coast with a transmission line to the Braemar region.
- A new pipeline for the transmission of raw seawater for desalination in the Braemar region.
- A new water main to pump mains water to the Braemar region.

In 2013, the South Australian government announced the Braemar Bulk Export Project which proposed a 385 km infrastructure corridor to link the Upper Spencer Gulf to the iron ore mines in the Braemar region (ABC News, 2013). The corridor would comprise up to 4 underground iron slurry pipelines and roads, electricity transmission and fibre optic communications as well as 4 underground process water pipelines to support and facilitate mining in the region.

In 2023, the Australian Energy Market Operator (AEMO) released details of a proposed high-voltage transmission link from Bundey to Yunta as part of the Mid North Expansion (Northern) Project. This was intended to accommodate new renewable energy projects and it has been indicatively designed to pass within 20 km of the Razorback iron ore project (ABC News, 2013).

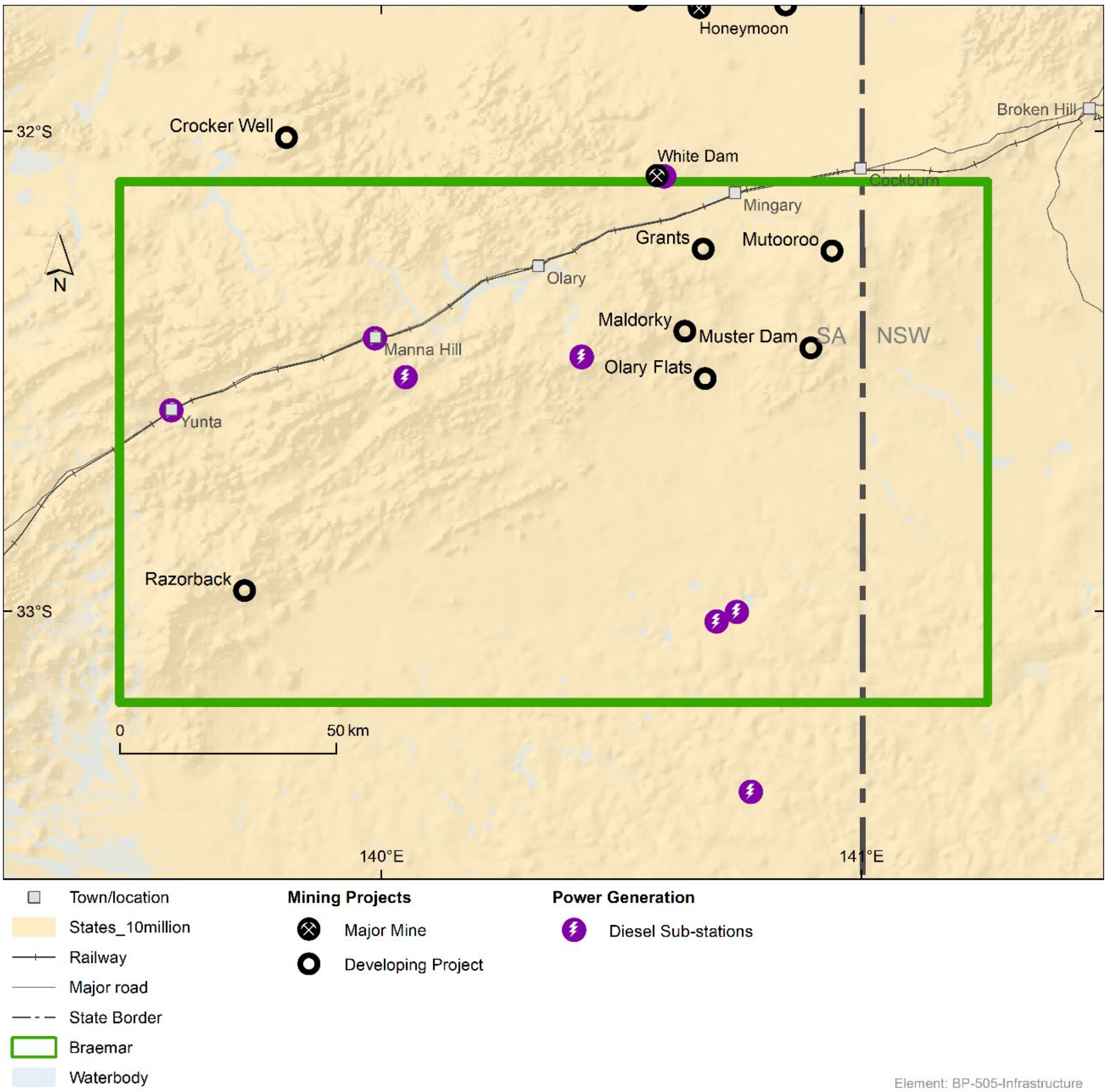



*Figure 6. Existing infrastructure in the Braemar region (SARIG, 2023d)*

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Fact Sheet

# Regional ecohydrological conceptual model – Northern Eyre

## HIGHLIGHTS

- The regional ecohydrological conceptual model (ECM) of the Northern Eyre region shows key components of groundwater, surface water and hydro-ecological systems.
- Despite the arid climate, the Northern Eyre region has significant infrastructure for accessing groundwater and large areas of protected ecosystems.

## BACKGROUND

This fact sheet presents a conceptual pictorial block diagram depicting an ECM of the Northern Eyre region. The ECM shows the key features of the landscape and subsurface that are important to assess the impacts of development. ECMs are commonly adopted in the initial stages of visualising and understanding how a system interacts and lead to more detailed analysis of individual components, including climate drivers, catchment runoff, groundwater flow and contaminant movements as well as ecological responses to these driving forces. ECMs establish a shared understanding among government entities, prospective companies, and landscape boards regarding the potential environmental impacts of resource development activities. They outline the necessary information and data required to evaluate the likelihood, consequences, and mitigation strategies associated with these impacts. The conceptual models that are used to develop numerical models need more detailed investigations that quantify the system parameters and the natural and human-induced stresses on the landscape (Commonwealth of Australia, 2024).

## PROJECT TEAM

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## REFERENCE

Jazayeri A and Werner A (2024) *Regional ecohydrological conceptual model – Northern Eyre fact sheet*, Goyder Institute ecohydrological conceptual model and impact pathway diagram project, Goyder Institute for Water Research.

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The Goyder Institute for Water Research is a collaborative partnership of the South Australian government through the Department for Environment and Water, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.

The project was conducted with support from the South Australian government through the Department for Environment and Water and Department for Energy and Mining, South Australian Arid Lands Landscape Board and Eyre Peninsula Landscape Board.

## STUDY AREA

The Northern Eyre region was chosen as an area of interest due to its dense concentration of known mineral resources that are situated in a region with limited water availability. The study area encompasses a diverse range of commodity types, including iron ore (magnetite and hematite), gold, silver, base metals, graphite, kaolin-halloysite, and uranium (Currie, 2023). Alongside these mineral resources, the region hosts various existing land uses (primarily agriculture) and features several significant energy and resource development prospects that are currently undergoing feasibility studies. These prospects include renewable energy production (wind, solar and green hydrogen), storage, transmission, and export as well as green steel production that incorporates magnetite and green hydrogen resources. Other developments involve seawater desalination, exemplified by the Northern Water Supply initiative (Currie, 2023). Given the scarcity of surface water resources, there is already substantial demand for groundwater resources in the region and these are managed through diverse regulatory mechanisms. These include a water allocation plan for the Musgrave Prescribed Wells Area.

## CONCEPTUAL PICTORIAL BLOCK DIAGRAM

Figure 1 illustrates the conceptual pictorial block diagram of the landscape and subsurface processes that are relevant to Northern Eyre. Table 1 outlines detailed descriptions of each component featured in the conceptual pictorial block diagram for the Northern Eyre region, along with the corresponding sources of information.

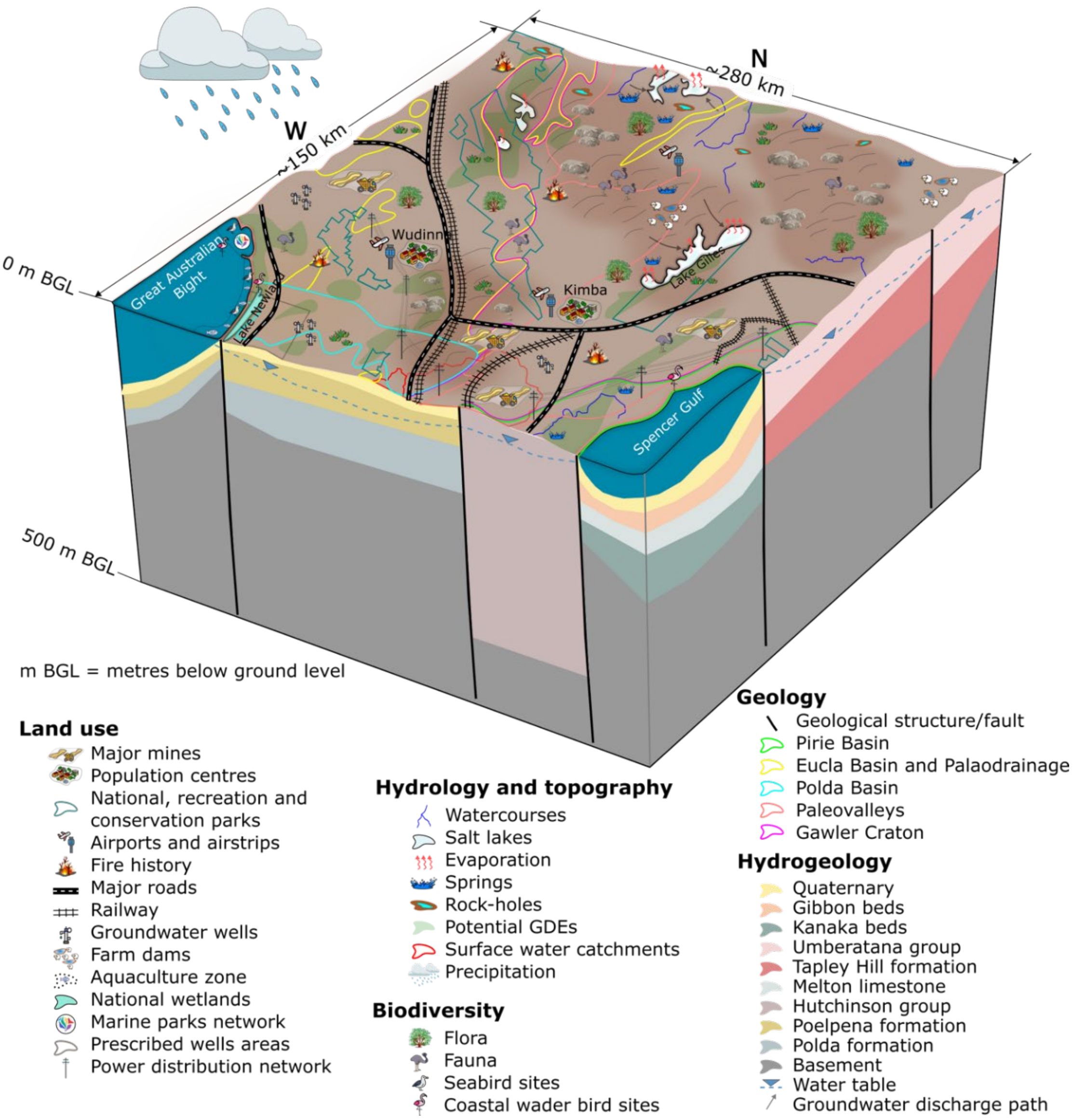


*Figure 1. Conceptual pictorial block diagram for Northern Eyre region*

*Table 1. Components, descriptions, and information sources of the conceptual pictorial block diagram for the Northern Eyre region*

| ITEM | DESCRIPTION |
|---|---|
| **Land use** | The land use for this region incorporates various subcategories: major mines, population centres, national recreation and conservation parks, airports and airstrips, fire history, major roads, railway, groundwater wells, farm dams, aquaculture zones, national wetlands, marine park network, prescribed well areas, power distribution networks and petroleum wells.<br><br>There are 4 major mines in the study area:<br>- Great White (kaolin–halloysite)<br>- Middleback Range (hematite and magnetite),<br>- Campoona (graphite)<br>- Central Eyre Iron Project (magnetite) (DEM, 2024).<br><br>In the study area, there are 2 population centres: Kimba and Wudinna (DEM, 2024). According to the 2021 census, Kimba has a population of 1,037, while Wudinna has a population of 659, according to the 2016 census. Population data are sourced from the Australian Bureau of Statistics (Australian Bureau of Statistics, 2024).<br><br>The major roads extending through the region are the sealed segments of the:<br>- Flinders Highway (74 km)<br>- Birdseye Highway (54 km)<br>- Lincoln Highway (84 km)<br>- Tod Highway (54 km)<br>- Eyre Highway (348 km)<br><br>The remaining network of roads consists of unsealed tracks (DEM, 2024).<br><br>In the study area, there are 21 open railway tracks spanning approximately 273 km in length (DEM, 2024). The primary railway track network is a part of the Eyre Peninsula line which forks out in 2 directions at Cummins (a township south of the study area). One segment of this line travels through Wudinna, connecting the seaports of Port Lincoln and Thevenard, while the other branches out from Cummins to Kimba. Historically, these lines have transported grain. The other railway tracks within the region connect and transport iron ore between the Iron Duke, Iron Baron, and Iron Knob mines (part of the Middleback Range mine).<br><br>Air transport infrastructure within the region includes 11 airplane landing areas, one certified, 2 registered, and 5 unknown airstrips (DEM, 2024).<br><br>There are 6 overhead distribution networks managed by ElectraNet, operating at 132 kV. These networks transfer electricity from wind farms at Mount Miller to Yadnarie, Wudinna and Middleback (DEM, 2024).<br><br>There are 9 national wetlands, including Lake Newland, and 31 conservation reserve areas spanning a total area of 4959 km$^2$ (~12% of the study area). These include sites such as Pureba, Gawler Ranges, Pinkawillinie, Lake Gilles, Kulliparu, and Hambidge among others (DEM, 2024). These areas protect fauna and flora species and are a major biological reservoir for the maintenance of species diversity (DEM, 2024).<br><br>Over 188 fire incidents, including both bushfires and prescribed burns, have been reported in the study area. The largest fire within the region in the last 5 years was the 2019 Milatlie |

| | |
|---|---|
| | bushfire which affected approximately 102 $km^2$. The most recent fire, the Mount Wedge bushfire in the summer of 2022, affected 22 $km^2$ of the study area.<br><br>There are 3 marine parks including: Upper Spencer Gulf, West Coast Bays, and Franklin Harbor. The South Australian marine parks aim to protect the biological diversity of coastal waters along South Australian coasts and facilitate the ecologically-sustainable use of the state's natural resources (DEW, 2024a). The study area includes the Anxious Bay aquaculture exclusion zone. This zone is guided by policies designed to facilitate the systematic advancement of aquaculture by ensuring access, and specifying the locations, nature, and extent of permissible aquaculture development within state waters (DEW, 2024a).<br><br>There are 286 monitoring wells, 75 domestic wells and 319 stock wells in the study regions. In total, there are 1781 groundwater wells, out of which only 673 are currently operational. Approximately 1,558 $km^2$ (~4% of the study area) of the Musgrave Prescribed Wells Area falls within the study area.<br><br>There are 2 dry-type petroleum wells (exploration wells) with total depths ranging from approximately 122 m to 124 m. The current status of all rigs in the study area is 'abandoned'.<br><br>A total of 3,312 farm dams have been identified, with areas ranging from 25 $m^2$ to 197,479 $m^2$, and a median area of 990 $m^2$ (Shanafield, 2024a). |
| **Hydrology and topography** | The hydrology and topography of the study area includes watercourses, salt lakes, evaporation, springs, rock-holes, potential GDEs, surface water catchments and precipitation.<br><br>There are a total of 719 lakes, 9 mangroves, 6 reservoirs, 30 areas subject to inundation and 3 watercourses (DEM, 2024).<br><br>The study area includes a portion of the Salt Creek–Franklin Harbor catchment and the Driver River catchment, which cover an area of approximately 1,593 $km^2$ (~4% of the study area) and 118 $km^2$ (~0.3% of the study area), respectively (DEW, 2024b).<br><br>Surface water resources are limited in the study area due to various factors, including low rainfall, high evaporation rates, flat terrain, and permeable soils. Streams, where they exist, are intermittent and often saline. Some ephemeral streams drain the Cleve Hills in the southeast but most do not reach the coast.<br><br>There are 28 known springs and spring groups in the region, with the majority situated in the northern area (Guan, 2024).<br><br>The potential terrestrial GDEs coverage in the region is 24% (Guan and Peeters, 2024).<br><br>Rock-holes are found within granite outcrops characterised by gentle slopes (less than 20 degrees) and these are primarily located in the northern part of the region (Shanafield, 2024b).<br><br>The study area has ephemeral salt lakes, notably Lake Gilles, which is a terminal salt lake. While permanent waterbodies are rare, seasonal flooding and waterlogging can occur particularly in low-lying areas during wet years.<br><br>Dryland salinity issues are a concern and are attributed to shallow water tables and high evaporation rates in low-lying regions across the study area (Currie, 2023).<br><br>The climate in the study area is described as cool, with wet winters and dry, hot summers. The average annual rainfall is 327 mm (BOM, 2024). Notably, there is a noticeable rainfall gradient from the southwest to the northeast. Elliston receives an average rainfall of approximately 425 mm per year, Kimba experiences around 345 mm per year and Iron |

| | |
|---|---|
| | Knob receives an average rainfall of approximately 220 mm per year (Currie, 2023). A prolonged downward trend in rainfall has been observed at Elliston since the mid-1980s, yet this trend is not mirrored at Kimba or Iron Knob. These disparities are likely attributable to varying weather patterns across the study area that are connected to distinct rainfall events (Currie, 2023). The pan evaporation in the study area ranges from 1,600 mm per year to 2,400 mm per year (BOM, 2024). |
| **Geology (Currie, 2023)** | The Northern Eyre region is geologically complex. It is predominantly composed of the Gawler Craton, which underlies the entirety of the study area. It is prominently exposed in the Gawler Ranges and in the eastern half of the region.<br><br>Other notable geological features include the:<br>- Polda Basin situated in the southwest<br>- Eucla Basin in the west<br>- Pirie Basin along the eastern coastal margin.<br><br>The Gawler Craton, a significant cratonic element of South Australia, encapsulates a rich geological history dating back to the Mesoarchean to Mesoproterozoic era. This history is characterised by multiple phases of crustal growth and tectonic activity that resulted in a diverse assemblage of metamorphosed sedimentary units and extensive magmatic suites. Key geological formations within the Gawler Craton include the:<br>- Sleaford complex<br>- Hutchinson group<br>- Lincoln complex<br>- Ifould complex<br>- Gawler Range volcanics<br>- Hiltaba suite.<br><br>These basement units are commonly covered by a substantial clay-rich weathered profile of mixed regolith and saprolite. Overlaying the Gawler Craton is a prominent east–west trending graben, where sediments were deposited during the Meso- and Neoproterozoic to the Permian, Jurassic, and Tertiary periods. This graben extends across the Eyre Peninsula and continues offshore approximately 200 km west of Elliston.<br><br>The Polda Basin within this graben hosts Permian (Coolardie formation) and Jurassic (Polda formation) sediments that are characterised by mudstone, sandstone, siltstone, and lignite that reach thicknesses of approximately 180 m. These sediments are subsequently overlain by Tertiary formations (predominantly the Poelpena formation) and consist of sand, silt, clay, and lignite interbeds with thicknesses exceeding 100 m.<br><br>The southeastern margins of the Eucla Basin cover the western half of the study area. They feature paleovalleys such as the Narlaby Paleochannel, which contains Paleogene Pidinga formation and Neogene Garford formation deposits of fluviatile sand, silt, and clay.<br><br>Much of the Eucla Basin province within the study area is blanketed by the Quaternary Bridgewater formation. This is characterised by a thin layer of calcareous aeolianite overlaying both Archaean-Mesoproterozoic crystalline basement and Tertiary sediments.<br><br>Lastly, the Pirie Basin, which forms the narrow coastal plain in the east of the study area, is a Tertiary sedimentary basin centered on the Spencer Gulf. Its sedimentary sequence includes Eocene–Oligocene Kanaka beds, Oligocene–Miocene Melton limestone, Pliocene Gibbon beds and Quaternary marine and aeolian deposits. |

| | |
|---|---|
| **Hydrogeology** | The aquifers within the Northern Eyre region consist of Quaternary and Tertiary sedimentary units underlain by weathered and fractured basement rocks. In many places, Quaternary units directly overlay the basement rock of the Gawler Craton. In the study area, the Gibbon Beds are observed to conformably overlie the Melton limestone and represent a fluvial deposit from the late Tertiary period (Pliocene–Pleistocene). These non-fossiliferous and non-marine Gibbon beds exhibit a thickness of approximately 16–18 m and are made of: mottled grey, red, and yellow clayey sand; gravel; and silt (Currie, 2023).<br><br>In coastal settings with minimal relief to the west, the Gibbon beds and Melton limestone converge make contact with the sloping Gawler Craton basement. Conversely, in areas where the Gibbon beds terminate towards the west, Quaternary sediments persist. The mid to upper Tertiary Melton limestone sporadically intersects with the Kanaka beds, which are marked by polymictic sand sheets within the study area. This bio-clastic limestone is characterised by fossils and features a component of quartzite sand alongside occurrences of calcareous clay and glauconite. Its thickness ranges from 16 m to 20 m (Currie, 2023).<br><br>The Kanaka Beds represent the oldest Tertiary (Eocene) unit and overlay the Gawler Craton basement through an unconformity. They are composed of calcareous sand and shale without matrix and exhibit traces of white clay and grey to black lignite interspersed within the calcareous sands. With a thickness of up to 40 m, the Kanaka Beds are sporadically overlain by fluvial-derived polymictic sands from the mid-Tertiary period. These sands, fossiliferous and unconsolidated, also contain gravel and quartzite with a variable sheet thickness from 1 m to 6 m (Currie, 2023).<br><br>In the study area, 1270 wells have associated water level data. The recorded groundwater levels range from a minimum of ~-7.6 m Australian Height Datum (m AHD) to a maximum of ~324 m AHD. The median groundwater level in the study area is reported to be ~35.4 m AHD (DEW, 2024b). |
| **Biodiversity** | Datasets that characterise the biodiversity of the region are provided by DEW (2024c). Prevalent non-native flora, including wards weed, onion weed, and bearded oats, are found intermixed with native vegetation such as spear grass, yorrell, gilja, dryland tea-tree and native apricots.<br><br>The nationally-endangered chalky wattle, desert greenhood and the jumping-jack wattle have all been identified within this region, along with the vulnerable yellow Swanson-pea and West Coast mint bush. Additionally, the state-recognised vulnerable species sandalwood is found to grow here.<br><br>Native fauna prevalent in the area include malleefowl, yellow-tailed black cockatoos, emus and a variety of kangaroo species (e.g. western grey kangaroo and red kangaroo). Non-native fauna include feral sheep, house mice and feral goats. Sandhill dunnarts, common greenshanks, Gawler Ranges short-tailed grasswren, and Australian sea lions are all nationally-endangered species that have been recorded in this area, along with the yellow-footed rock-wallaby and Western grasswren. The state-classified vulnerable fairy tern and white-bellied sea eagle have also been identified within this region. The only recorded seabird site in the region is located in Venus Bay Islands, which is home to the fairy tern (population of 51–100) and the Caspian tern, silver gull and pacific gull (all with a population of 1–10) (DEW, 2024a). There are 4 recorded significant wader bird sites, 3 in the West Eyre region (Port Kenny, Venus Bay and Lake Newland) and one in the Spencer Gulf (Whyalla to Shoalwater Point) (DEW, 2024a). |

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Fact Sheet

GOYDER INSTITUTE FOR WATER RESEARCH

# Resource development in the Northern Eyre region

## HIGHLIGHTS

- There are currently 4 operating mines in the region that are extracting iron ore (magnetite and hematite) (Middleback Range and Central Eyre Iron Project), kaolin-halloysite (Great White) and graphite (Campoona).
- Six major projects are under development that target gold, rare earth elements, magnetite, uranium, silver, lead, zinc and kaolin-halloysite.

## INTRODUCTION

The Northern Eyre region has a high concentration of minerals, particularly iron ore (magnetite and hematite), gold, silver, base metals, graphite, kaolin-halloysite and uranium (Currie, 2023). There are 4 operating mines in the region and 6 under development. Other developments occurring in the region include: renewable energy (wind, solar and green hydrogen) production, storage, transmission and export; green steel production; and seawater desalination.

This fact sheet provides an overview of current and potential resource development in the Northern Eyre region, including mining (e.g. open pit, underground and in situ recovery) and large infrastructure (e.g. road, railways, transmission and water). Other types of resource development currently or potentially occurring in the region, such as renewable energy, are summarised in this fact sheet but were not assessed as part of this project.


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The project was conducted with support from the South Australian government through the Department for Environment and Water and Department for Energy and Mining, South Australian Arid Lands Landscape Board and Eyre Peninsula Landscape Board.

## LAND USE

Land is used for a variety of purposes within the Northern Eyre region, including grazing (native vegetation), dryland cropping, nature conservation and managed resource protection. Nature conservation areas include the Hambidge Wilderness Protection Area (IUCN Category IB), among others. Managed resource protection areas include the Gawler Ranges National Park and Conservation Park (IUCN Category VI), Pinkawillinie Conservation Park (IUCN Category VI), Hiltaba Nature Reserve (IUCN Category VI), Kulliparu Conservation Park (IUCN Category VI), Cocata Conservation Park (IUCN Category VI), Lake Gilles Conservation Park (IUCN Category IA) and Ironstone Hill Conservation Park (IUCN Category VI).

Land use in the region is described in more detail in the regional ecohydrological conceptual model (Jazayeri and Werner, 2024).

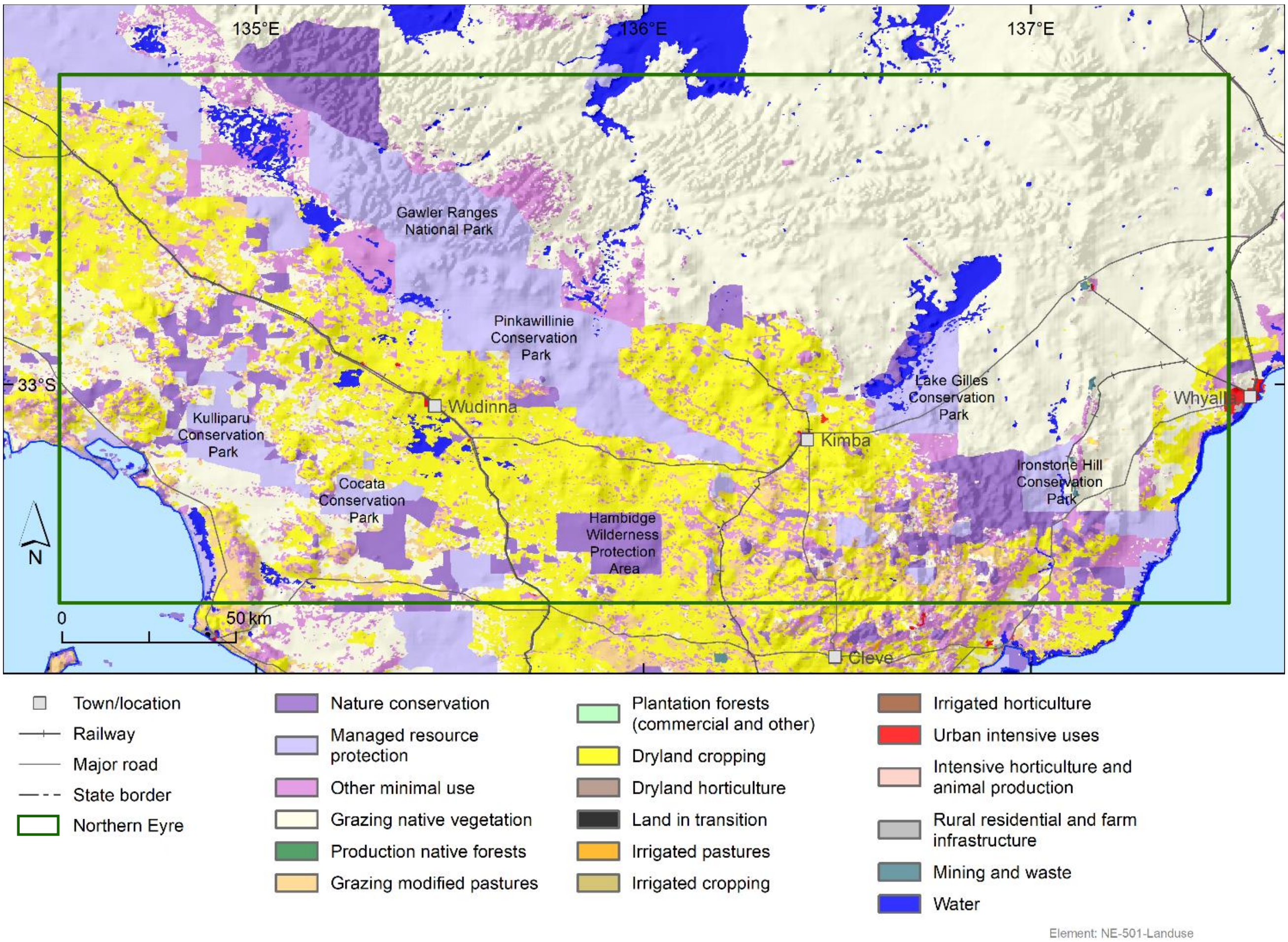


*Figure 1. Land use within and surrounding the Northern Eyre region 2015–16 based on the Australian Land Use and Management Classification Version 8 (ABARES, 2022)*

## NATIVE TITLE AND LAND USE AGREEMENTS

The Barngala, Nauo, Wirangu, Kokatha and Mirning people are the Traditional Custodians of Eyre Peninsula. Native Title determinations (NTD) and Indigenous land use agreements (ILUA) exist across the entire Northern Eyre region (Figure 2). Native Title determinations in the region include:

- Gawler Ranges People
- Far West Coast
- Barngarla Native Title Claim
- Wirangu People – Part A
- Wirangu No 2 (Part B), Wirangu No 3 (Part B), Wirangu Sea Claim #2 and Nauo #3

Indigenous land use agreements in the region include:

- Gawler Ranges Mineral Exploration
- Thurlga Pastoral
- Siam North Pastoral
- Part Hiltaba Pastoral
- Yeltana Pastoral
- Siam Pastoral
- Koweridda Pastoral
- Yardea Pastoral
- Lockes Claypan Pastoral
- Hiltaba Pastoral
- Gawler Ranges National Park
- Lake Gairdner National Park
- Lake Gilles Conservation Park
- Gawler Ranges Native Title Claim Settlement
- Cultana Expansion Area
- Middleback Ranges SA
- Far West Coast Native Title Settlement
- Far West Coast Parks
- Barngarla/Central Eyre Iron Project
- Barngala Determination
- Barngarla/Central Eyre Iron Project Amended
- Wirangu No 2 (Part B), Wirangu No 3 (Part B), Wirangu Sea Claim No 2 (Part B) and Nauo #3 Settlement
- Wirangu No 2 (Part A), Wirangu No 3 (Part A) and Wirangu Sea Claim No 2 (Part A) Settlement

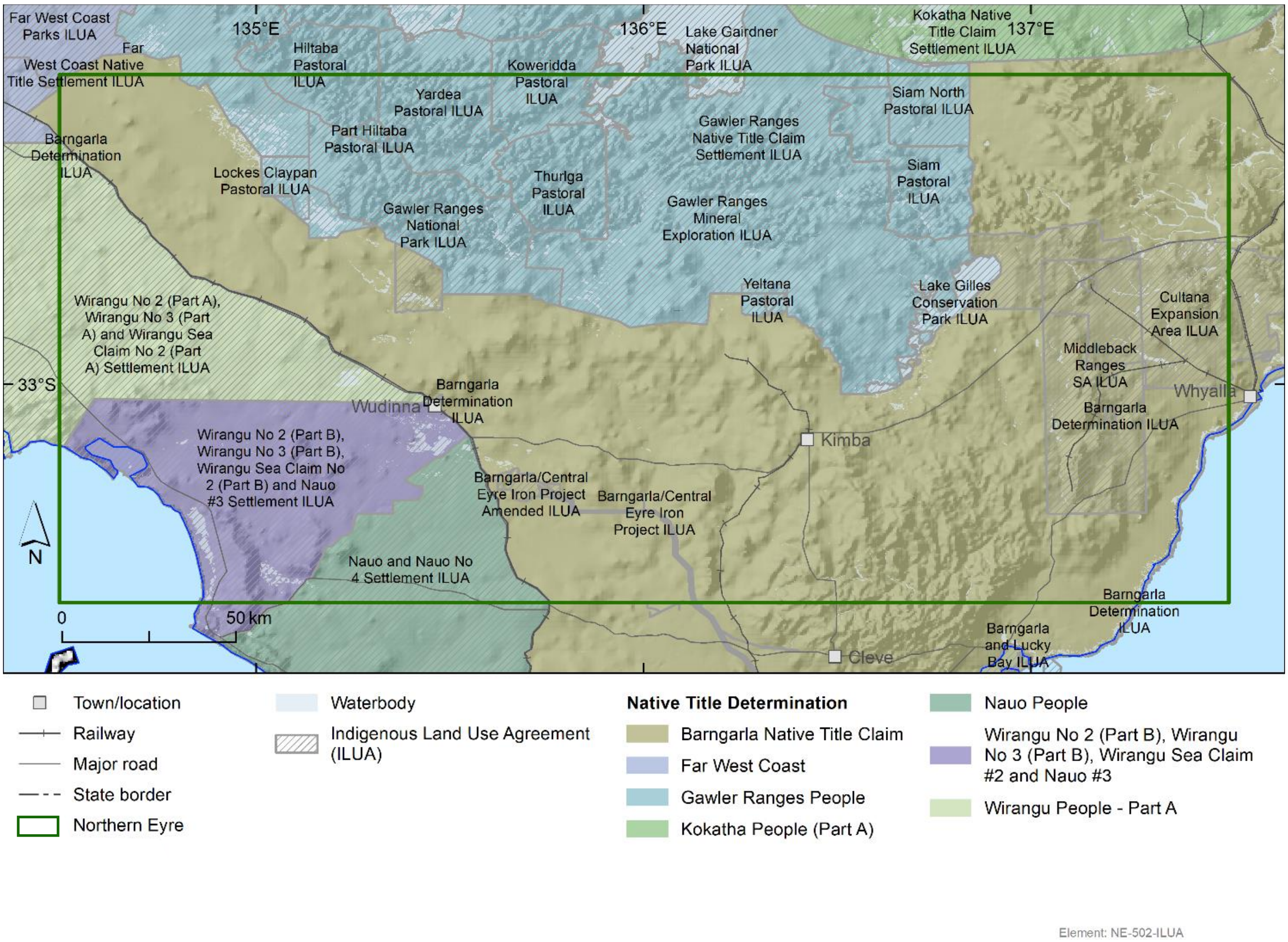


*Figure 2. Native Title Determinations and Indigenous Land Use Agreements in the region, sourced from NNTT (2024a and 2024b)*

# MINERAL RESOURCES

The South Australian Resource Information Gateway (SARIG) provides information on mine and mineral deposits and their economic significance. Within the Northern Eyre region there are 383 deposits with low economic significance, 109 of local significance and 9 with significance to South Australia (Figure 3). The region has a high concentration of mineral resources, including iron ore (magnetite and hematite) (east), gold, silver and base metals (central), kaolin-halloysite (west) and uranium (southeast) (Currie, 2023).

Iron ore mining in South Australia began in 1915 at the Iron Knob mine in the Middleback Range (Currie, 2023). Hematite has historically been the main form of iron ore production in South Australia but magnetite mining commenced in the mid-2000s at the Iron Magnet mine. This has been the principal source of iron ore for the Whyalla steelworks. The iron ore resources of the Northern Eyre region are estimated to contain 34.3% of South Australia's reserve (*Figure 5*).

Gold mineralisation is widespread in the mineral systems of the Gawler Craton. Mineral occurrences of economic significance are generally located towards the centre of the region. Silver mineralisation is hosted by the Paleoproterozoic Hutchison Supergroup metasediments (Currie, 2023).

Graphite occurrences have been recorded in Neoarchean and Paleoproterozoic high-grade metamorphic rocks of the southern Gawler Craton between Port Lincoln and Kimba (Currie, 2023). Kaolin is an important component of industrial clay. Kaolin occurrences in the region are generally located in the west near the Great White and Hammerhead deposits. The kaolin resources in the region are estimated to contain 18.7% of South Australia's reserves (*Figure 5*).

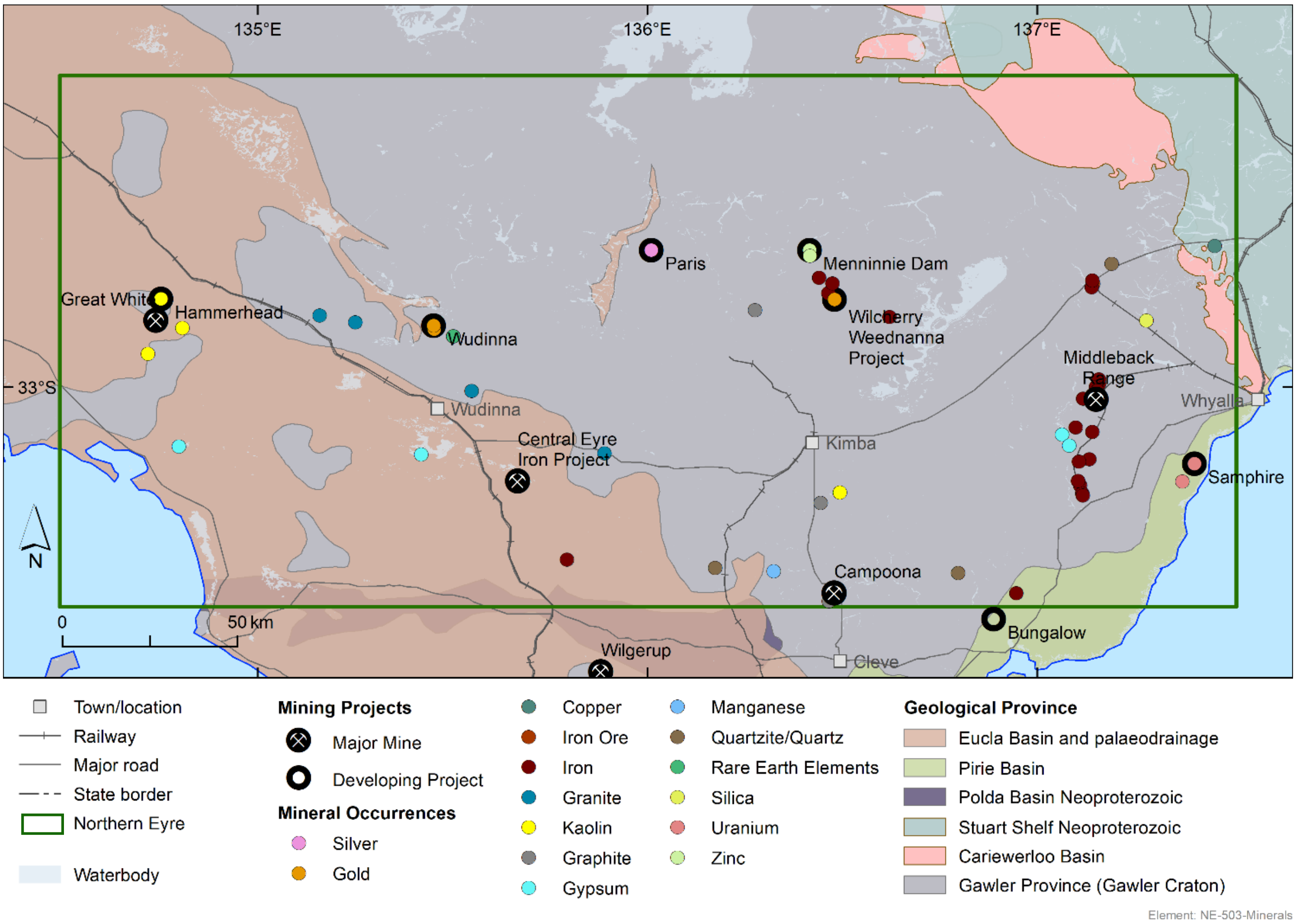


*Figure 3. Mines and mineral deposits, occurrences, and prospects of (at least) local economic significance, sourced from SARIG (2023a and 2023e)*

## MINERAL EXPLORATION

Exploration leases have been granted across most of the region, with the exception of some conservation and protection areas (*Figure 4*).

## MINING OPERATION AND DEVELOPMENT

There are 4 major projects in the region and 6 developing projects, targeting Proterozoic Gawler geological province deposits (Figure 5). The Middleback Range mine is an open pit mine near Whyalla that mines hematite and magnetite. The Central Eyre iron project aims to mine magnetite and has an approved mining lease, but its program for environmental protection and rehabilitation (PEPR) is pending. The Campoona mine in the region's south will develop a graphite deposit and it also has a mining lease granted and a pending PEPR. The Great White project in the west of the study area has been approved to develop kaolin and halloysite.

The developing projects are situated more in the region's north and they target gold, silver, lead, zinc, rare earth elements and uranium as well as magnetite, kaolin and halloysite. The region has more than 90% of the state's total reserve of halloysite and manganese, and close to 35% of the iron reserve. The Northern Eyre region also has a considerable part of South Australia's kaolin, graphite, rare earths, lead and zinc reserves (between 10% and 20%).

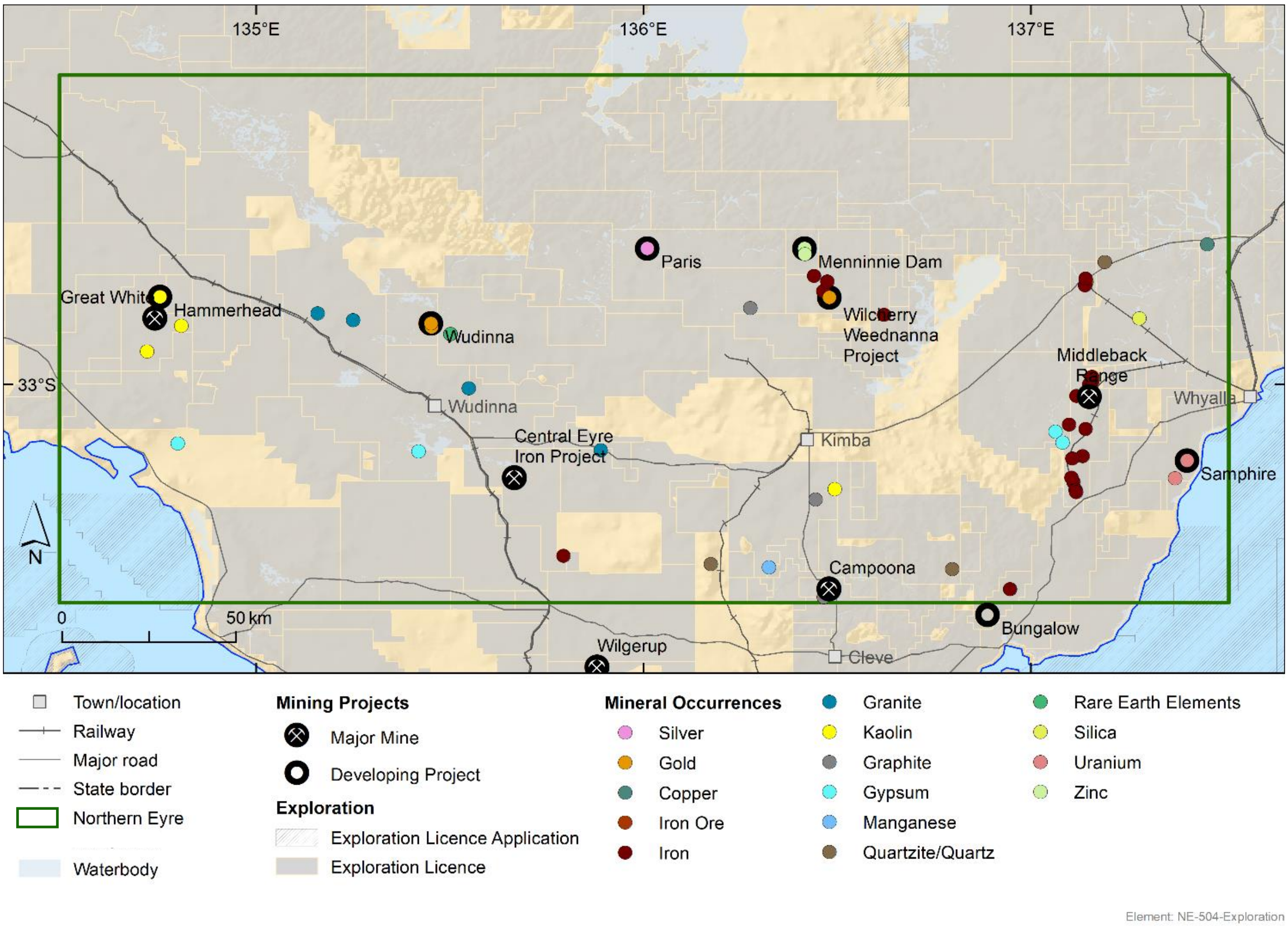


*Figure 4. Exploration licences, licence applications and deposits of local and state economic significance (SARIG, 2023b and 2023c)*

## Northern Eyre - major mineral projects and mining activities

| Region | Total major mines | Total major quarries | Total developing |
|---|---|---|---|
| State (SA) | 30 | 44 | 38 |
| Northern Eyre | 4 | 10 | 6 |

### Major projects

| Name | Commodity | Owner | Development status |
|---|---|---|---|
| Middleback Range | Hematite ($Fe_2O_3$), Magnetite ($Fe_3O_4$) | SIMEC Mining | Operating |
| Great White | Kaolin-Halloysite | Andromeda Metals Ltd | Approved |
| Campoona | Graphite | Archer Materials Ltd | ML granted (PEPR[1] pending) |
| Central Eyre Iron Project | Magnetite ($Fe_3O_4$) | Iron Road Ltd | ML granted (PEPR pending) |

1. Program for Environment Protection and Rehabilitation

### Developing projects

| Project | Commodities | Owner | Development status |
|---|---|---|---|
| Wudinna | Gold (Au), Rare Earth Elements (REE) | Andromeda Metals Ltd | JORC Resource |
| Wilcherry Weednanna Project | Gold (Au), Magnetite ($Fe_3O_4$) | Havilah Resources | Assessment |
| Samphire | Uranium Oxide (U308) | Alligator Energy Ltd | Assessment |
| Paris | Silver (Ag), Lead (Pb) | Investigator Resources Ltd | Feasibility studies |
| Menninnie Dam | Lead (Pb), Zinc (Zn), Silver (Ag) | Terramin Australia Ltd | JORC Resource |
| Hammerhead | Kaolin Halloysite | Andromeda Metals Ltd | JORC Resource |

### Commodity: % of State's Total Reserve

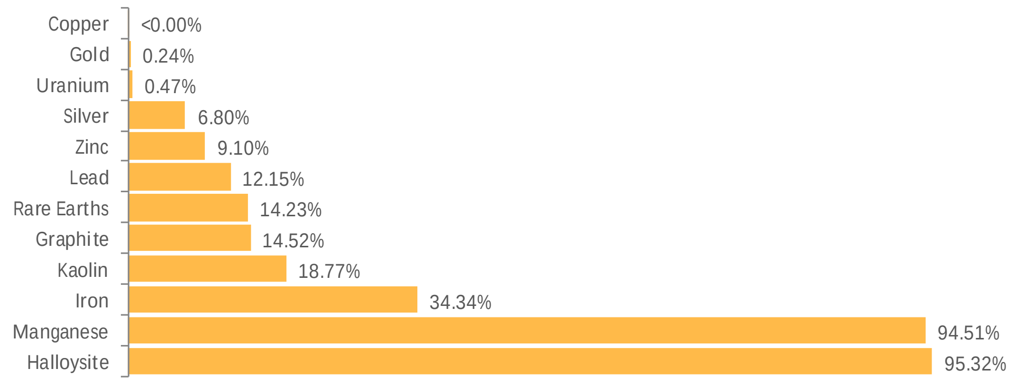


*Figure 5. Resource estimates for the Northern Eyre region (SARIG 2023a)*

## LARGE INFRASTRUCTURE

Figure 6 shows the current infrastructure in the Northern Eyre region. Most of the road and rail infrastructure is in the southern half of the region. The existing mining projects are linked by road and rail to the regional transport corridors.

The double-circuit 132 kV transmission line between Cultana and Port Lincoln is in the east of the region. The 66 kV transmission line from Cleve to Ceduna crosses the region from southeast to northwest. ElectraNet in its 2023 Transmission Annual Planning Report Update outlined plans to upgrade the 132 kV transmission line from Cultana to Yadnarie to 275 kV to increase the capacity to supply large new loads. This would support planned renewable energy zones on the east and west of the Eyre Peninsula. There are currently no planned renewable energy projects in the study region. However, the Yadnarie project (300 MW solar farm with 150 MW battery storage) and the Mt Millier project (70 MW windfarm) are situated close to Cleve, just south of the region. There are several hydrogen, wind and solar farm projects proposed near Whyalla, to the east of the study area. EntX holds the hydrogen gas exploration tenure over the onshore Polda Basin in the west of the study area, near Elliston. EntX is investigating the potential for underground hydrogen storage in salt caverns.

The Northern Water supply project is currently proposing a 260 ML/day desalination plant at Cape Hardy that would be linked via a pipeline to Whyalla, Port Augusta, Woomera, Carrapateena, Roxby Downs, Pimba and Olympic Dam. This pipeline will cross the south-eastern part of the study region.

In November 2021, the federal Minister for Resources and Water declared a property at Napandee, near the town of Kimba, a proposed site for a national radioactive waste management facility. After a federal court order on 10 August 2023, the Minister for Resources and Water stated that the government will no longer pursue the Napandee site for a radioactive waste management facility (DISR 2023).

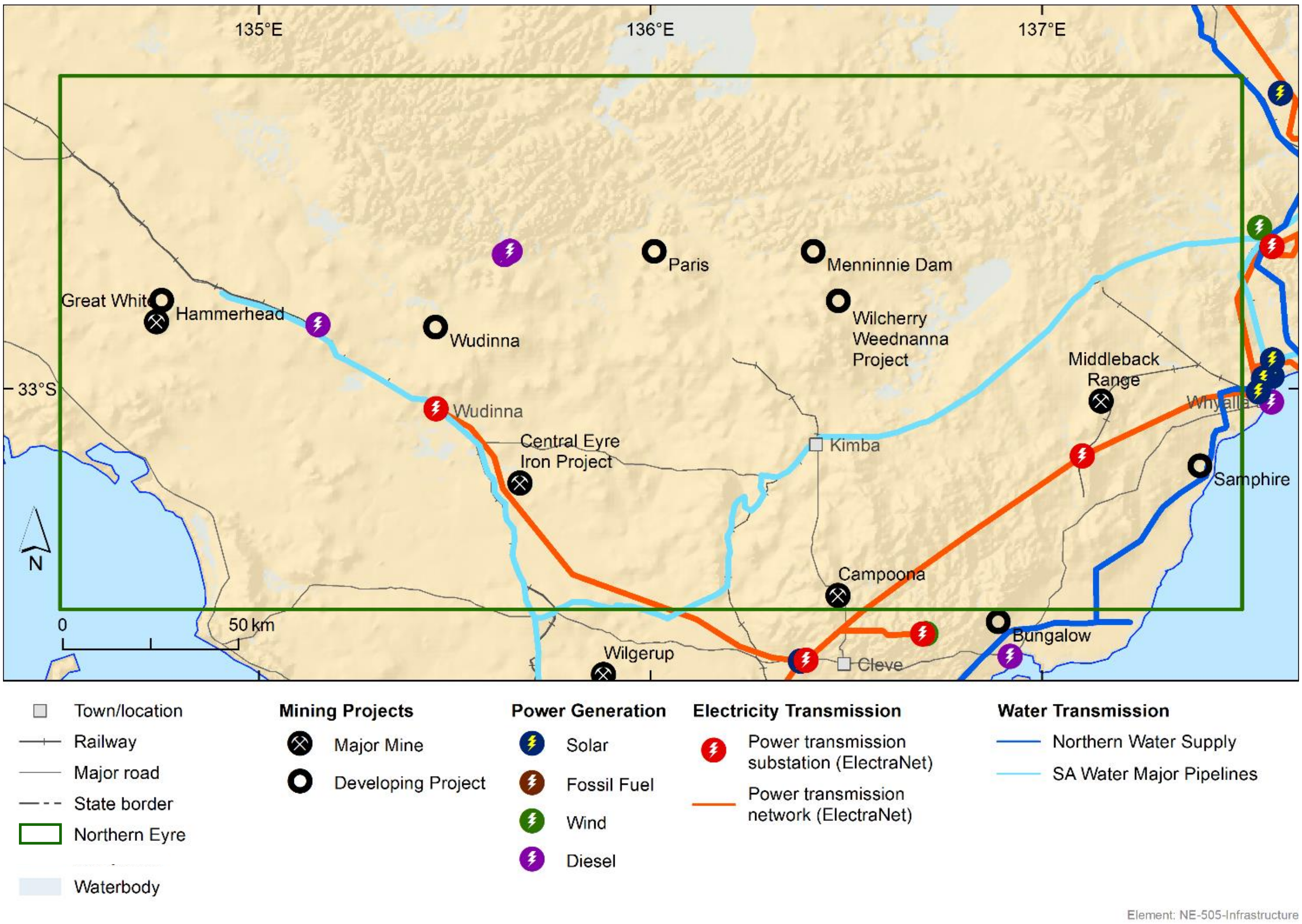


*Figure 6. Current and planned infrastructure in the Northern Eyre Region (SARIG, 2023d)*

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Fact Sheet

# Regional ecohydrological conceptual model – Stuart Shelf

## HIGHLIGHTS

- The regional ecohydrological conceptual model (ECM) of the Stuart Shelf region shows key hydrological aspects within both the subsurface and surface environments.
- Conceptual models illustrate the dominant effects of ephemeral lakes in the study area and other characteristics that reflect the rainfall-limited conditions.
- Despite the arid climate, the Stuart Shelf region has significant infrastructure for accessing groundwater and large areas of protected ecosystems.

## BACKGROUND

This fact sheet presents the ECM of the Stuart Shelf region. The Stuart Shelf ECM captures the key features of the landscape and subsurface that are important to assess the impacts of development. ECMs are commonly adopted in the initial stages of visualising and understanding how a system interacts and lead to more detailed analysis of individual components, including climate drivers, catchment runoff, groundwater flow and contaminant movements as well as ecological responses to these driving forces. In contrast, the conceptual models required to develop numerical models need more detailed investigations to quantify the system parameters and the natural and human-induced stresses on the landscape (Commonwealth of Australia, 2024).

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## REFERENCE


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The project was conducted with support from the South Australian government through the Department for Environment and Water and Department for Energy and Mining, South Australian Arid Lands Landscape Board and Eyre Peninsula Landscape Board.

## STUDY AREA

The selection of the Stuart Shelf as an area of interest is driven by a notable concentration of valuable mineral resources. These are predominantly iron oxide–copper–gold (IOCG) deposits. The ore processing requirements associated with mining require a substantial amount of water, which is a limited resource in this region. Therefore, governmental guidance and support are needed to support mining development activities while protecting sensitive ecosystems from human-induced stresses.

## CONCEPTUAL PICTORIAL BLOCK DIAGRAM

Figure 1 displays a conceptual block diagram of the relevant environmental factors and landscape and subsurface processes of the Stuart Shelf region. Table 1 outlines detailed descriptions of each component featured in the pictorial conceptual model of the Stuart Shelf region, along with the corresponding sources of information.

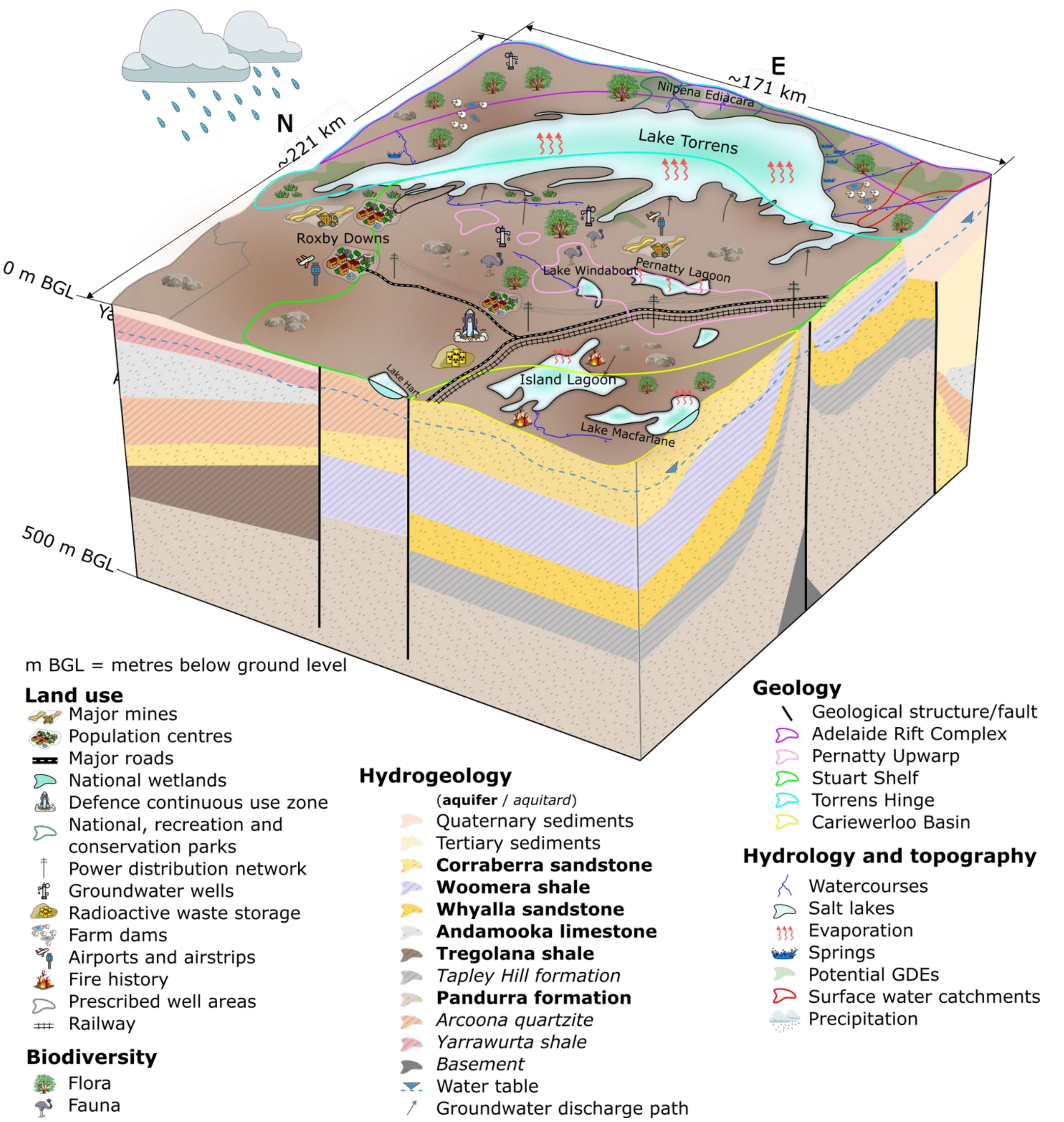


*Figure 1. Conceptual pictorial block diagram for the Stuart Shelf region, with hydro-stratigraphic cross sections based on Currie et al. (2023)*

*Table 1. Components, descriptions, and information sources of the conceptual pictorial block diagram for the Stuart Shelf region.*

| ITEM | DESCRIPTION |
|---|---|
| **Land use** | The land use in the study area encompasses several categories: major mines, population centres, major roads, national wetlands, Defence continuous use zones, national recreation and conservation parks, power distribution networks, petroleum and groundwater wells, radioactive waste storage, farm dams, airports and airstrips, fire history, prescribed well areas, and railway infrastructure.<br><br>Two active mines, Olympic Dam and Carrapateena (both operated by BHP), extract resources such as Copper (Cu), Uranium ($U_30_8$), Gold (Au), and Silver (Ag) (DEM, 2024a). The current mine water usage by Olympic Dam and Carrapateena mines totals 18 GL per year. Approximately 6 GL per year is supplied by local saline groundwater resources. The remainder water is sourced from the Great Artesian Basin which is outside of the study area and has lower-salinity groundwater. Projected estimates suggest that mine water demand is expected to increase to approximately 30–60 GL per year by 2050, based on anticipated production rates and typical mine water requirements (Currie et al., 2023; DEW, 2024a).<br><br>There are 3 population centres:<br>- Roxby Downs (3,976 residents according to the 2021 census)<br>- Andamooka (316 residents according to the 2016 census)<br>- Woomera (146 residents according to the 2016 census) (Australian Bureau of Statistics, 2024).<br><br>Road networks vary from sealed highways to unsealed tracks, with notable routes being the Stuart Highway (150 km) and Olympic Dam Highway (98 km) (DEM, 2024a). Railway infrastructure includes 5 tracks (43 currently open and 22 closed) and approximately 153 km of the Port Augusta–WA Border railway line (DEM, 2024a).<br><br>Air transport infrastructure includes 8 airplane landing areas, 2 certified airports, one military site and 4 unspecified structures (DEM, 2024a). Lake Torrens is a national wetland and one of Australia's largest saline playa lakes. It holds significant cultural importance as a sacred site for Traditional Owners (Currie et al., 2023; DEM, 2024a).<br><br>Additionally, the Woomera Prohibited Area (WPA) is delineated into 4 access zones (Red, Amber Zone 1, Amber Zone 2 and Green) and public entry is restricted during Defence testing. For example, the Red Zone is dedicated to continuous Defence use, thus barring public access, resource tenements or activities. The WPA Red Zone occupies approximately 3,055 km$^2$ (~8% of the study area) (DEM, 2024a).<br><br>The Woomera Test Range currently stores 10,000 drums of waste resulting from the cleanup of a former nuclear research site. It is predominantly made of soil and building material. Measurements conducted in May 2018 demonstrate that radiation levels adjacent to the storage align with typical natural background values for Australia. This indicates that there has been no release of radioactivity to the soil or water (CSIRO, 2024).<br><br>Conservation areas like Nilpena Ediacara National Park and Lake Torrens cover approximately 589 km$^2$ (~1.5% of the study area) and 5,688 km$^2$ (~15% of the study area), respectively (DEM, 2024a).<br><br>Fire scar mapping includes major bushfires that have occurred within South Australia. For example, the Wirramina bushfire, which occurred in the summer of 2023, affected approximately 312 km$^2$ (~0.8% of the study area). Fire scar mapping also includes prescribed |

| | |
|---|---|
| | burning activities conducted on land managed by state government agencies, including the Department of Environment and Water, Forestry SA and SA Water (DEM, 2024a).<br><br>The Far North Prescribed Wells Area falls within the study area and covers approximately 2,121 $km^2$ (~6% of the study area) (DEM, 2024a). ElectraNet manages the transmission networks that deliver electricity from wind and solar farms in Port Augusta to Mount Gunson, Pernatty, Pimba, Woomera and Olympic Dam at the respective voltages. Seven overhead distribution networks have been identified which operate at 2 different voltages (132 kV and 275 kV) (DEM, 2024a).<br><br>There are 8 abandoned petroleum wells (exploration wells) that were last operated between 1958 and 1997, with depths ranging from approximately 270 m to 1450 m. Five of these wells are located in the Arrowie Basin, while the remaining 3 are situated in the Adelaide Geosyncline Basin. The current status of all rigs in the study area is 'abandoned' (DEM, 2024a).<br><br>Groundwater resources in the region are significant. There are 331 active groundwater wells, including 22 domestic wells and 96 stock wells (DEW, 2024a). Additionally, there are 68 farm dams, with storage areas ranging from 270 $m^2$ to 35,280 $m^2$, and a median area of 3,741 m (Shanafield, 2024). |
| **Geology (Currie et al., 2023)** | Several significant structural features are present within the Stuart Shelf itself. These include the:<br><br>- Torrens Cratonic Uplift – a north-trending basement high running through the centre of the Stuart Shelf<br>- Andamooka Dome – a dome-shaped basement high in the northern part of the Stuart Shelf<br>- Pernatty Upwarp – a north-trending uplift of the Pandurra Formation, which lies adjacent to (west of) the Torrens Cratonic Uplift.<br><br>The Pernatty Upwarp leads to the pinching out and compartmentalisation of lower strata within the Neoproterozoic sequence, including the Whyalla sandstone, and appears to be responsible for faulting in the upper sequence of Neoproterozoic sediments (Currie et al., 2023). Additionally, it appears to be responsible for faulting in the upper sequence of Neoproterozoic sediments. The influence of the Pernatty Upwarp is evident as it creates a groundwater flow divide.<br><br>Other geological features include the:<br><br>- Torrens Hinge zone, which is a transitional area spanning up to 25 km in width, located between the Stuart Shelf and the Adelaide Geosyncline. It comprises a complex half-graben fault system that has acted as a depocenter for Cenozoic sedimentation<br>- Stuart Shelf platform which extends over the eastern Gawler Craton and is characterised by its flat-lying nature and relatively minor deformation (although faulting is present)<br>- Cariewerloo Basin which is unconformably overlying a portion of the northeastern Gawler Craton that developed due to subsidence in the early Mesoproterozoic. This intracratonic basin is currently characterised as an elongate, 120-km-wide, NW-trending basin bounded by major NW-trending faults bordering basement highs. Younger NE-trending faults disrupt the faulted eastern margin<br>- Adelaide Rift Complex which is a succession consisting of sandstone, siltstone, shale and limestone, deposited in a predominantly shallow marine setting (DEM, 2024b). |

| | |
|---|---|
| **Hydrogeology** | The hydrogeology of the study area is characterised by Quaternary sediments covering a significant portion of the low-lying land areas, along with Tertiary sediments deposited within both the Torrens Basin and the Billa Kalina Basin. The 2 primary aquifers in the region are the Whyalla sandstone and the Pandurra formation.<br><br>The Whyalla sandstone acts as both an aquifer and an aquitard. Its permeability is more pronounced towards the southwest, particularly near the Pernatty Upwarp, and it occurs at shallower depths in this area. The thickness of the Whyalla sandstone ranges from 50 m to 150 m.<br><br>The Pandurra formation is a substantial geological unit with a thickness exceeding 500 m. It is comprised of poorly sorted sands and conglomerates that function as a fractured rock aquifer. Despite containing saline to hypersaline groundwater, the Pandurra formation is one of the primary aquifers used for water supply at the Carrapateena mine.<br><br>Other aquifers present in the study area include the Corrabera sandstone, Woomera shale, Andamooka limestone and Tregolana shale aquifers. Additionally, various aquitards occur in the region, such as the Tapley Hill formation, Arcoona quartzite, Yarrawurta shale, and basement rocks (Currie et al., 2023).<br><br>Regarding the water table in the study area, 586 wells have associated water level data. The recorded groundwater levels range from a minimum of -274.5 m Australian Height Datum (m AHD) to a maximum of 195 m AHD. The median groundwater level in the study area is reported to be 60.64 m AHD (DEW, 2024a). The regional water table elevation indicates flow towards the center of Arrowie Basin and Lake Torrens.<br><br>Groundwater discharge occurs through 2 main mechanisms in the study region:<br>- evaporation from shallow water tables<br>- discharge either as diffuse or point sources (e.g. spring discharge) that contributes water to salt (playa) lakes. Groundwater flow into Lake Torrens stands out as the largest discharge pathway (Currie et al., 2023). |
| **Hydrology and topography** | The hydrology of the study area is characterised by defined surface water catchments, watercourses, salt lakes, potential GDEs and springs. Within the study area, a portion of the Willochra Creek catchment is identified and covers an area of approximately 452 $km^2$ (~1% of the study area). The Lake Torrens catchment, which encompasses a portion of the Stuart Shelf and extends larger to the east of the lake and expands into the Flinders Ranges, forms another significant feature (Currie et al., 2023; DEM, 2024a). Moreover, an extensive network of over 1,000 canals and watercourses are identified within its boundaries.<br><br>Surface water, though highly ephemeral, drains the Stuart Shelf plateau in a dendritic pattern and terminates within large salt lakes (playas) such as Lake Torrens, Pernatty Lagoon, and Lake Windabout (Currie et al., 2023; DEM, 2024a). Despite flowing only for a short period following significant rainfall, some permanent pools persist along a few creeks. This includes the persistence of shallow groundwater discharge. Although these resources are finite and not large enough to be developed into a reliable water resource, they likely have some ecological value. Additionally, 6 springs have been identified in the southeast of the region (Guan, 2024), along with 3 watercourse springs and 40 regional springs in the Lake Torrens area (Currie et al., 2023).<br><br>The potential terrestrial GDE coverage in the region is 15% (Guan and Peeters ,2024)<br><br>Rainfall patterns are identified through measurements at the Roxby Downs Olympic Dam Aerodrome (BOM station 16096) and Woomera Aerodrome (BOM station 16001). They reveal mean annual rainfall levels of 139 mm since 1998 and 181 mm since 1949, respectively. The |

| | |
|---|---|
| | approximate mean annual potential evaporation in the study area is estimated at 3,000 mm (Currie et al., 2023). |
| **Biodiversity (DEW, 2024b)** | The dominant land cover type for this region is non-woody native vegetation. Commonly occurring species include Buffel grass (non-native), bladder saltbush (native), *Tecticornia medullosa* (native) and Western Myall (native). Several species found within this region are of national significance (DEW, 2024c), including the endangered *Frankenia plicata* and the vulnerable granite mudwort. Additionally, there are several species of state significance, such as the vulnerable Koch's saltbush and sandalwood as well as the rare Australian broomrape and Western tar-vine.<br><br>In terms of fauna, red kangaroos are the dominant species for this region. Other common fauna includes burrowing bettongs, central sandplain geckos and eastern desert *Ctenotus*. The state conservation status of the burrowing bettongs is endangered and, as of November 2022, 2,750 burrowing bettongs were reported within this region. Other state endangered species include the Western barred bandicoot, Kowari, and the western quoll. The plains mouse and the greater bilby are vulnerable species that are also found in this area.<br><br>The region is home to feral goats and rabbits, which threaten the native fauna by reducing the available food sources. Other feral pests in the region include cats and foxes, which attack native species. |

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Fact Sheet

GOYDER INSTITUTE FOR WATER RESEARCH

# Resource development in the Stuart Shelf region

## HIGHLIGHTS

- The Stuart Shelf region has over 90% of South Australia's copper and uranium reserves.
- Current mining operations include Olympic Dam and Carrapateena, with 4 other mines under development.
- There is a renewable energy zone planned for Roxby Downs, but this is a low priority.

## INTRODUCTION

This fact sheet provides an overview of current and potential future resource development in the Stuart Shelf region, including mining (e.g. open pit, underground and in situ recovery) and large infrastructure (e.g. road, railways, transmission, and water). Other types of resource development currently or potentially occurring in the region, such as renewable energy, are summarised in this fact sheet but were not assessed as part of this project. Current development activity in the Stuart Shelf region is focused on the mining of copper–gold–silver resources.


## PROJECT TEAM

**CSIRO:** Marko Draganic, Kate Holland, Angela London, Luk Peeters (Lead), Carmel Pollino, Haylee Thomas

**Flinders University:** Huade Guan, Amir Jazayeri, Margaret Shanafield, Cristina Solórzano-Rivas, Adrian Werner

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## REFERENCE

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The Goyder Institute for Water Research is a collaborative partnership of the South Australian government through the Department for Environment and Water, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.

The project was conducted with support from the South Australian government through the Department for Environment and Water and Department for Energy and Mining, South Australian Arid Lands Landscape Board and Eyre Peninsula Landscape Board.

# LAND USE

Land within the Stuart Shelf region is predominantly used for grazing (native vegetation), with some land used for nature conservation (Witchelina Nature Reserve in the northeast) and intensive urban development (Roxby Downs and Woomera towns) (Figure 1). Lesser land uses include mining and waste (Olympic Dam). The surface waters of Lake Torrens, Island Lagoon, Lake Macfarlane, Lake Finiss, Lake Blyth, Lake Dutton, Lake Windabout and Pernatty Lagoon also take up a large area within the region.

Land use in the region is described in more detail in the regional ecohydrological conceptual model developed for the Stuart Shelf region (Jazayeri et al, 2024).

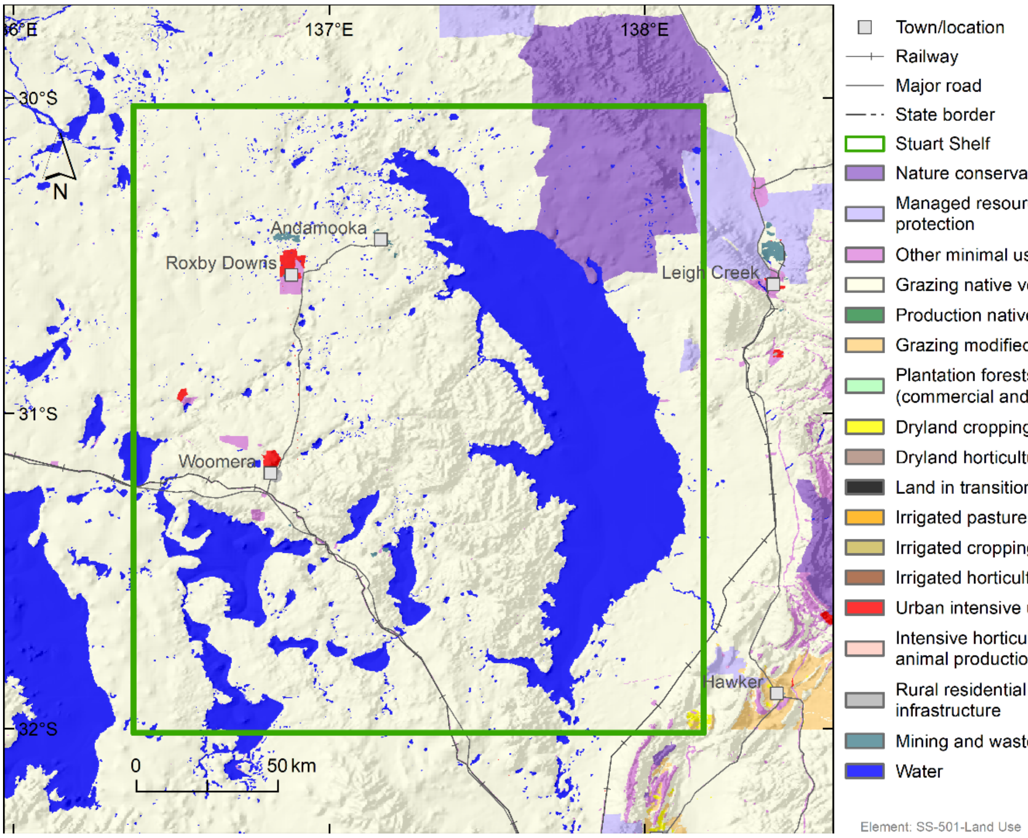


***Figure 1. Land use within and surrounding the Stuart Shelf region 2015–16 based on the Australian Land Use and Management Classification Version 8 (ABARES, 2022)***

## NATIVE TITLE AND LAND USE AGREEMENTS

Native Title determinations (NTD) in the region include Kokatha People (Part A), Arabana People, and Adnyamathanha People No. 1 (Stage 1) as well as 4 others in the southeast corner (Figure 2).

Indigenous land use agreements (ILUA) in the region include The Arabana Native Title Claim Settlement ILUA, Andamooka Precious Stones Field Agreement, Kokatha Native Title Claim Settlement ILUA, Adnyamathanha Settlement ILUA and Adnyamathanha Mineral Exploration ILUA (Figure 2).

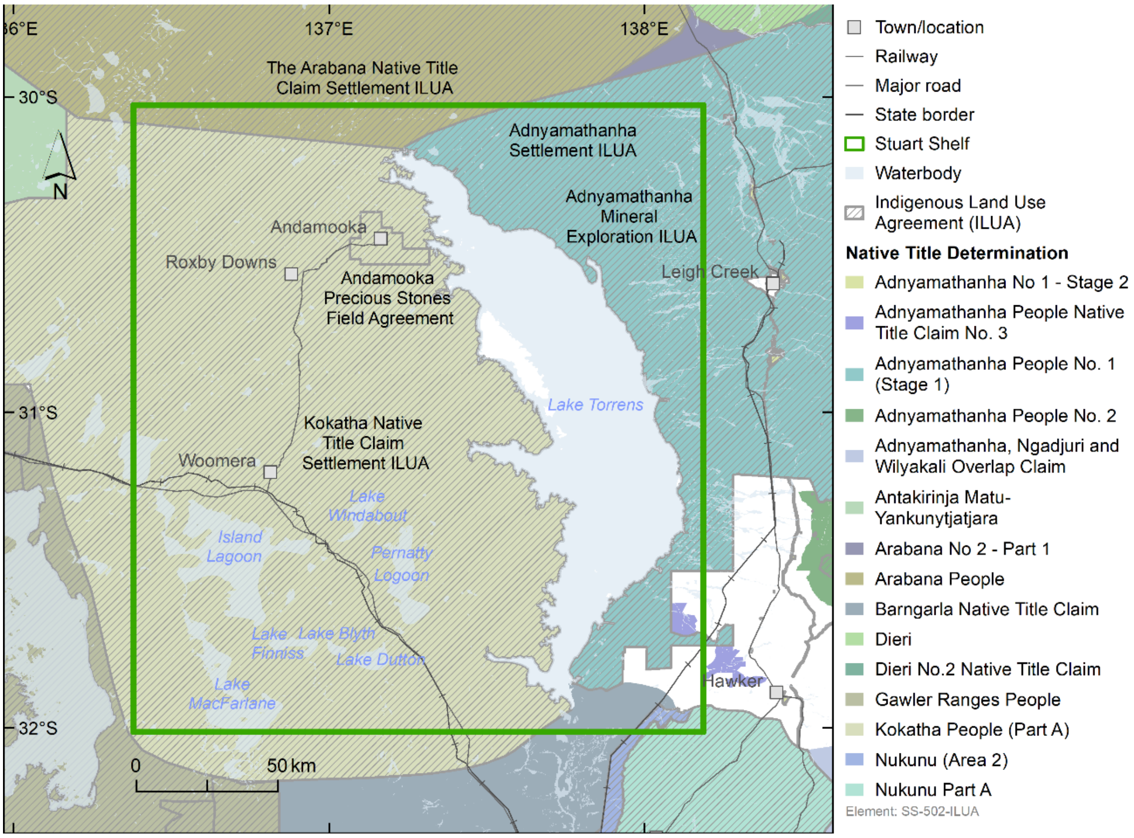


***Figure 2. Native Title determinations and Indigenous land use agreements in the region, Sourced from NNTT (2024a and 2024b)***

## MINERAL RESOURCES

The Stuart Shelf region has a high concentration of known mineral resources dominated by rich iron oxide–copper–gold (IOCG). The South Australian Resource Information Gateway (SARIG) provides information relating to mines and mineral deposits, occurrences and prospects including the major commodities known to occur in the deposits and their significance in terms of economic worth. In the Stuart Shelf region, there are 152 deposits of low economic significance, 28 of local significance and 6 that are significant to South Australia, including the Carrapateena mine and the Olympic Dam mine, which is of world-wide significance (Figure 3).

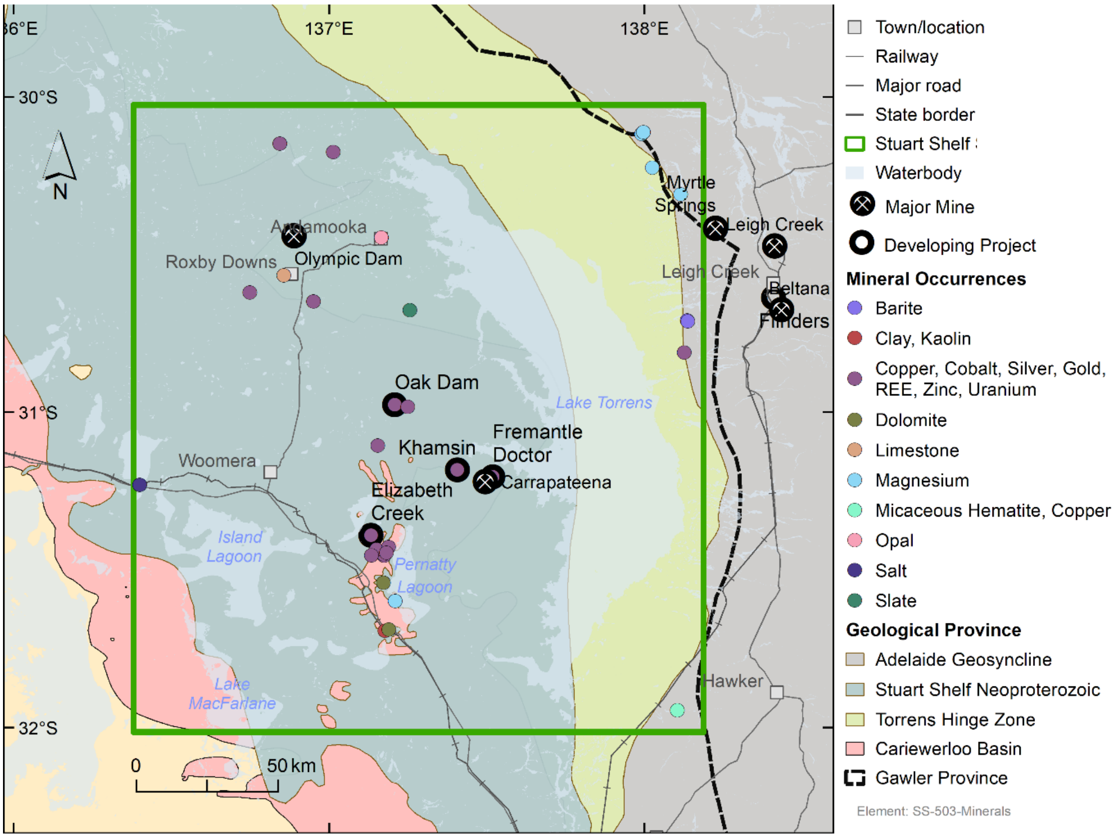


***Figure 3. Mines and mineral deposits of local, state and world significance sourced from SARIG (2023a and 2023e)***

The majority of deposits in the study region are west of Lake Torrens in the Stuart Shelf Neoproterozoic rocks that overlie the older Gawler Province. There are a small number of deposits east of Lake Torrens in the Adelaide Geosyncline. Just outside of the study region, to the east, are the Leigh Creek and Beltana coal mines and the Myrtle Springs magnesite mine.

## MINING OPERATION AND DEVELOPMENT

There are 2 active mines in the region (Olympic Dam and Carrapateena) and 4 developing projects (Oak Dam, Fremantle Doctor, Elizabeth Creek and Khamsin) (Figure 4 and Figure 5). Both Olympic Dam and Carrapateena are underground mines.

Copper is the main commodity mined in these projects. Copper deposits in the study region represent over 90% of the copper reserve in South Australia. Other commodities mined in the region are uranium, gold and silver. The region contains over 85% of the state’s total reserve for these commodities. The Elizabeth Creek project is also prospective for cobalt and zinc.

## Stuart Shelf - major mineral projects and mining activities

| Region | Total major mines | Total major quarries | Total developing projects |
|---|---|---|---|
| State (SA) | 30 | 44 | 38 |
| Stuart Shelf | 2 | 7 | 4 |

### Major projects

| Name | Commodity | Owner | Development status |
|---|---|---|---|
| Carrapateena | Copper (Cu), Gold (Au), Silver (Ag) | BHP | Operating |
| Olympic Dam | Copper (Cu), Uranium (U3O8), Gold (Au), Silver (Ag) | BHP | Operating |
| Myrtle Springs[1] | Magnesium (Mg) | MS Minerals | Operating |

[1]. ~ 3.6km W of Study Area

### Developing projects

| Project | Commodities | Owner | Development status |
|---|---|---|---|
| Oak Dam | Copper (Cu), Gold (Au), Uranium (U), Silver (Ag) | BHP | Advanced Exploration |
| Fremantle Doctor | Copper (Cu), Gold (Au), Silver (Ag) | BHP | JORC Resource |
| Elizabeth Creek | Copper (Cu), Cobalt (Co), Silver (Ag), Zinc (Zn) | Coda Minerals | Feasibility Studies |
| Khamsin[2] | Copper (Cu), Gold (Au), Silver (Ag) | BHP | JORC Resource |

2. "former Mineral Resource no longer stands 202 Mt at 0.6% Cu, 0.1 g/t Au, 1.7 g/t Ag and 86 ppm U"

### Commodity: % of State's Total Reserve

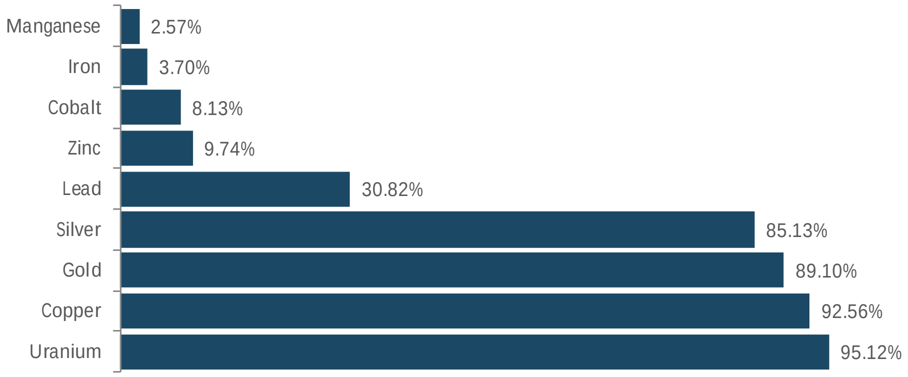


*Figure 4. Resource estimates for the Stuart Shelf region (SARIG 2023a)*

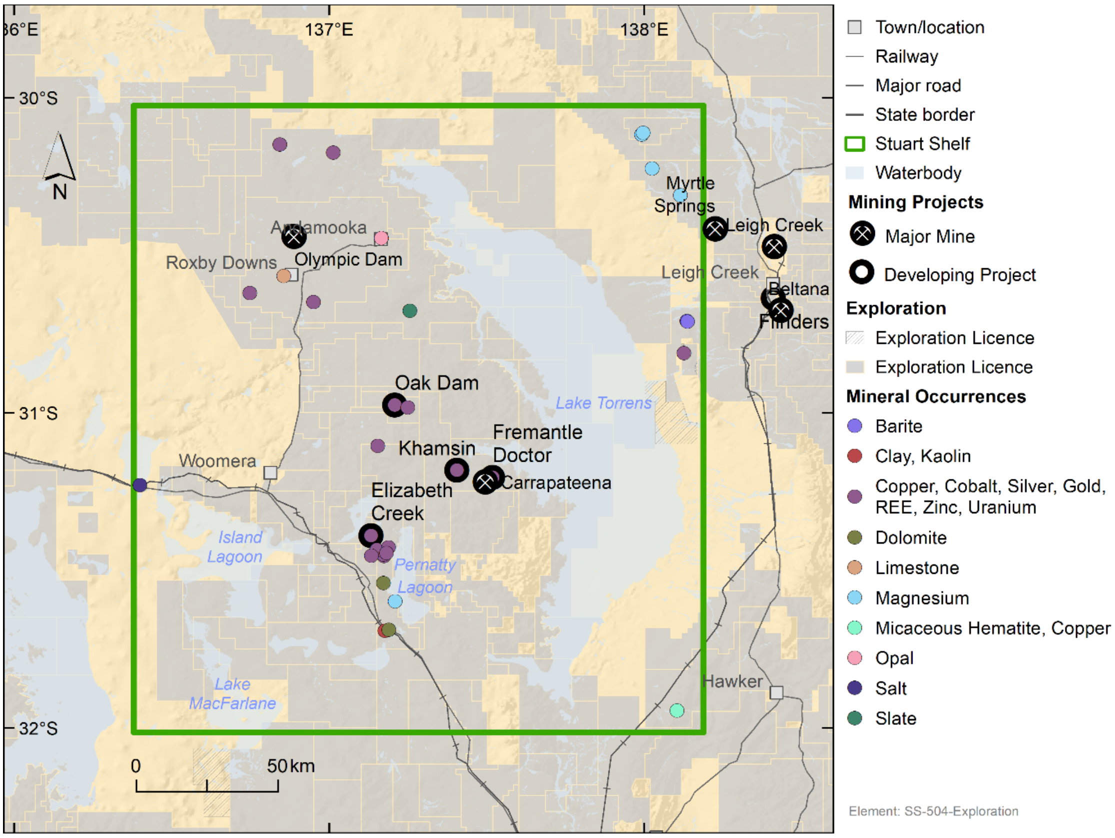


***Figure 5. Exploration licenses and license applications in the Stuart Shelf region (SARIG, 2023b and 2023c)***

## LARGE INFRASTRUCTURE

The main infrastructure in the region is the Stuart Highway and the Adelaide–Darwin rail line, as well as the roads and railway infrastructure that service Olympic Dam and Carrapateena. Power is provided in the region through the 275 kV Davenport–Olympic Dam transmission line and the 132 kV Mt Gunson South–Pernatty transmission line (to Carrapateena). In addition, there are diesel power generators in Andamooka and Roxby Downs. Yadlamaka Energy is developing a 6 MW solar farm with 2 MW battery storage capacity west of Hawker, in the south-eastern corner of the study region.

The Northern Water Supply project aims to develop a 600 km pipeline to provide desalinised water from the Spencer Gulf to the region. The proposed trajectory for the water pipeline largely coincides with the existing transmission lines.

In its 2023 Transmission Annual Planning Report Update, ElectraNet identified an area to the north-west of Woomera and Olympic Dam as the Roxby Downs onshore Renewable Energy Zone (REZ). Compared to other renewable zones in South Australia, the Roxby Downs zone is of low priority. ElectraNet is no longer considering a REZ development around Leigh Creek because of considerable environmental and cultural concerns.

The Woomera Test Range currently hosts low-level radioactive waste from the clean-up of a former research site in Melbourne in the early 1990s. Soil and building materials form the majority of this waste and testing in 2018 showed that the material in storage does not present risks to worker safety or the environment (CSIRO 2021).

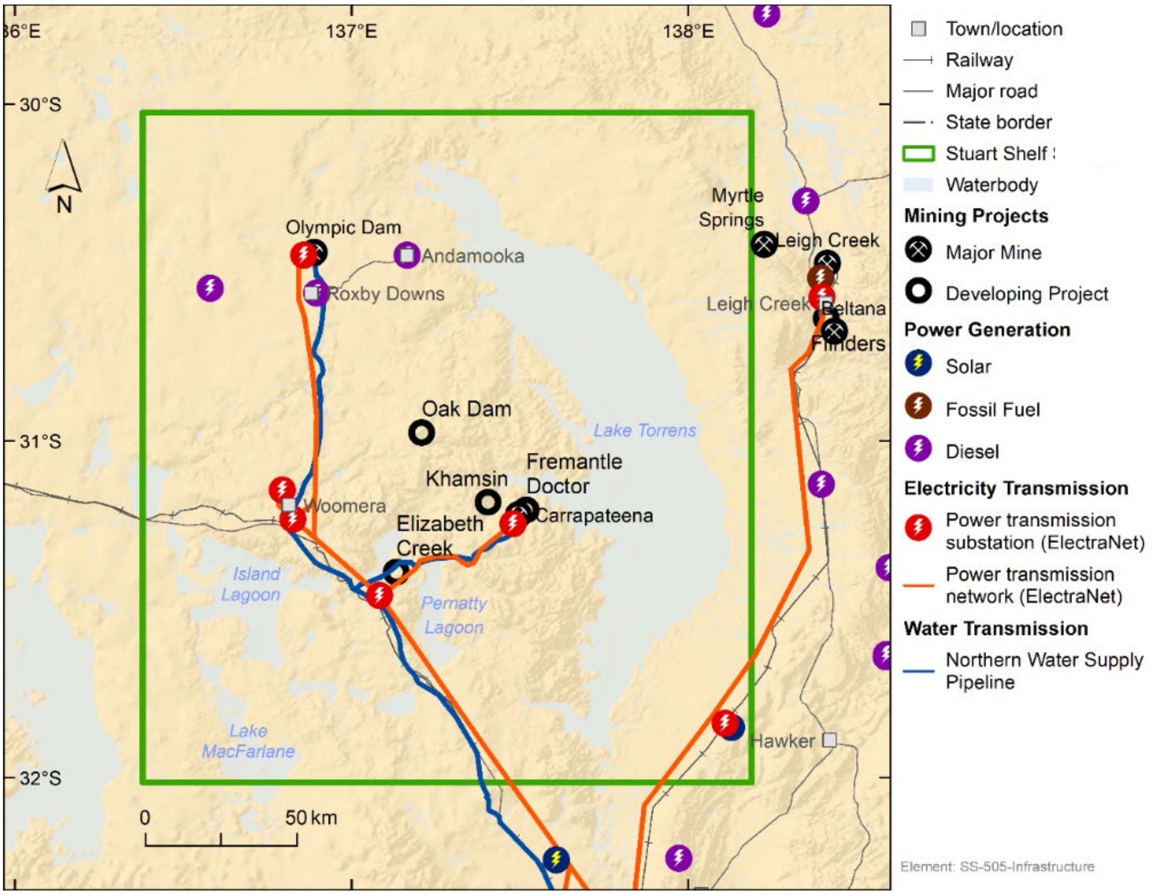


***Figure 6. Current and planned infrastructure in the Stuart Shelf region (SARIG, 2023d)***

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Fact Sheet

GOYDER INSTITUTE FOR WATER RESEARCH

# Annual precipitation patterns and projections

## HIGHLIGHTS

- Clear spatial precipitation gradients occur in the Northern Eyre region from southwest to northeast and in the Stuart Shelf region from south to north.
- Relative interannual variability is 30% in the Braemar and Stuart Shelf regions and 20% in the Northern Eyre region.
- Four selected CMIP6 models (after bias correction for the 3 regions) reproduce mean annual rainfall and interannual variability.
- No significant future annual precipitation change is predicted for any of the 3 regions.

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## NECESSITY OF MITIGATION AND ADAPTATION MEASURES TO CLIMATE CHANGE

Climate change is the shifts in temperature and weather patterns over a long-term period. It was comparatively modest in preceding centuries, but it has undergone significant changes in recent decades. This is primarily attributed to anthropogenic activities. Human-induced climate change in Australia is affecting the frequency and intensity of extreme events, including heatwaves, bushfires, droughts, and storms (Hanna and McIver, 2018; Lansbury Hall and Crosby, 2022).

The imperative of addressing and responding to climate change through both mitigation and adaptation measures is of paramount importance and necessitates concerted efforts. However, the precipitation dynamics in Australia exhibit a higher degree of variability than typically observed in analogous climatic regions across the globe, attributable in part to the influence of the El Niño-Southern Oscillation (ENSO) (Nicholls et al, 1997). This pronounced variability in Australian rainfall patterns further complicates the identification of enduring trends and presents additional obstacles to the projection of climatic trends within the Australian context (Nicholls et al, 1997).

Any measures to mitigate climate change should be based on the knowledge of current and future climates. Annual precipitation is one key climate variable. Here, historical and projected annual precipitation patterns are provided for the Braemar, Northern Eyre and Stuart Shelf regions.

## ANNUAL PRECIPITATION PATTERNS IN THE BRAEMAR, NORTHERN EYRE, AND STUART SHELF REGIONS

Historical precipitation data spanning from 1950 to 2019 from the Australian Gridded Climate Data (Evans et al, 2020) were analysed for temporal and spatial patterns of annual precipitation. Figures 1–3 present the historical mean annual precipitation in the Northern Eyre, Stuart Shelf and Braemar regions with 0.05 degree resolution. Spatial gradients of annual precipitation occur in the Northern Eyre (Figure 1) and Stuart Shelf (Figure 2) regions. For Northern Eyre, the mean annual precipitation decreases from >320 mm in the southwest to <200 mm in the north. For Stuart Shelf, it is wetter in the south and drier in the north, with mean annual precipitation varying between 150 mm and 225 mm. In Braemer, mean annual precipitation varies between 200 mm and 275 mm without a clear spatial pattern.

Figures 4–6 show the time series of spatially-averaged annual precipitation in the Northern Eyre, Stuart Shelf and Braemar regions in 1950–2019, with long-term averages of 250.7 mm, 178.4 mm and 234.5 mm for the 3 regions, respectively. Minor decreasing trends in annual precipitation are observed for all 3 regions, although they are not statistically significant. The decreasing rates are -4.9 mm/decade in Northern Eyre, -2.3 mm/decade in Stuart Shelf and -2.1 mm/decade in Braemar regions. The relative interannual variability of annual precipitation, defined as the average absolute deviation from the long-term mean (Nicholls et al, 1997), is about 30% in Braemar and Stuart Shelf, and about 20% in Northern Eyre.

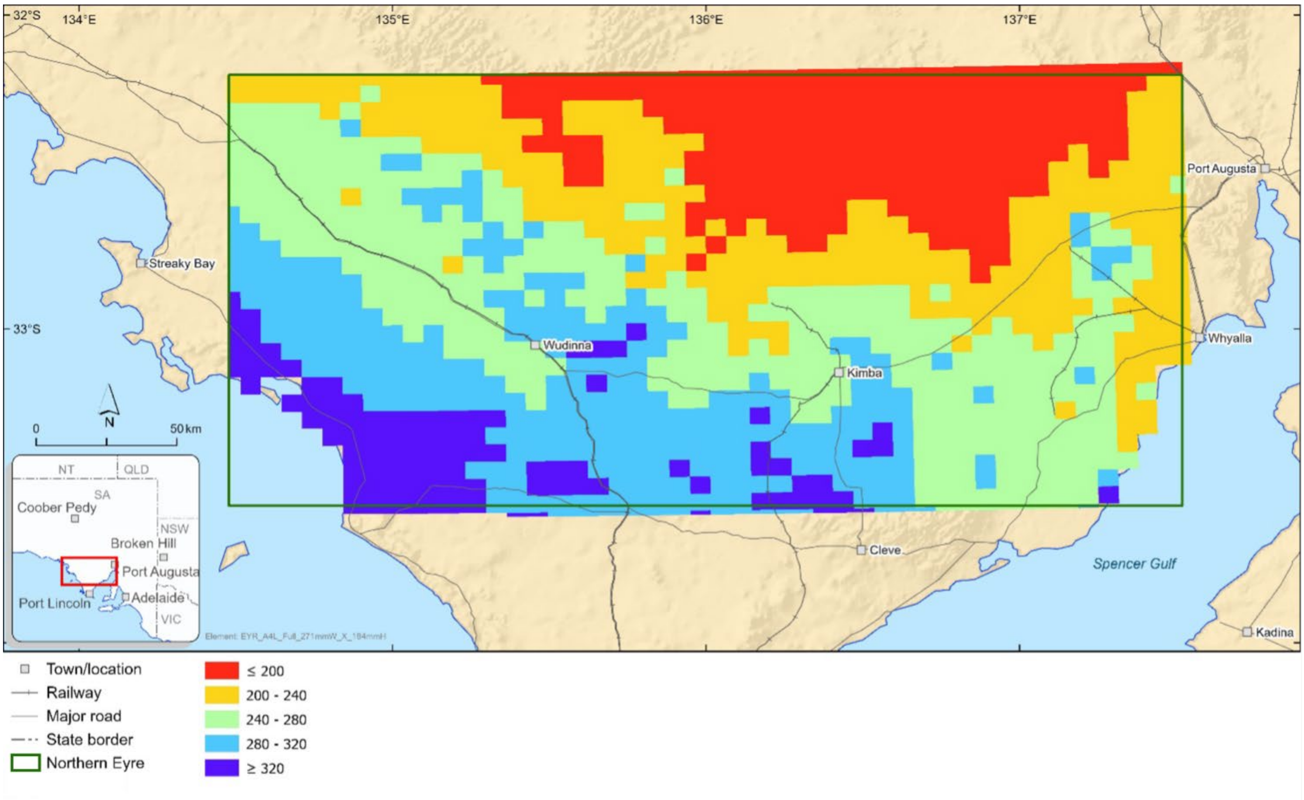


*Figure 1. Historical mean annual precipitation (1950–2019) in the Northern Eyre region*

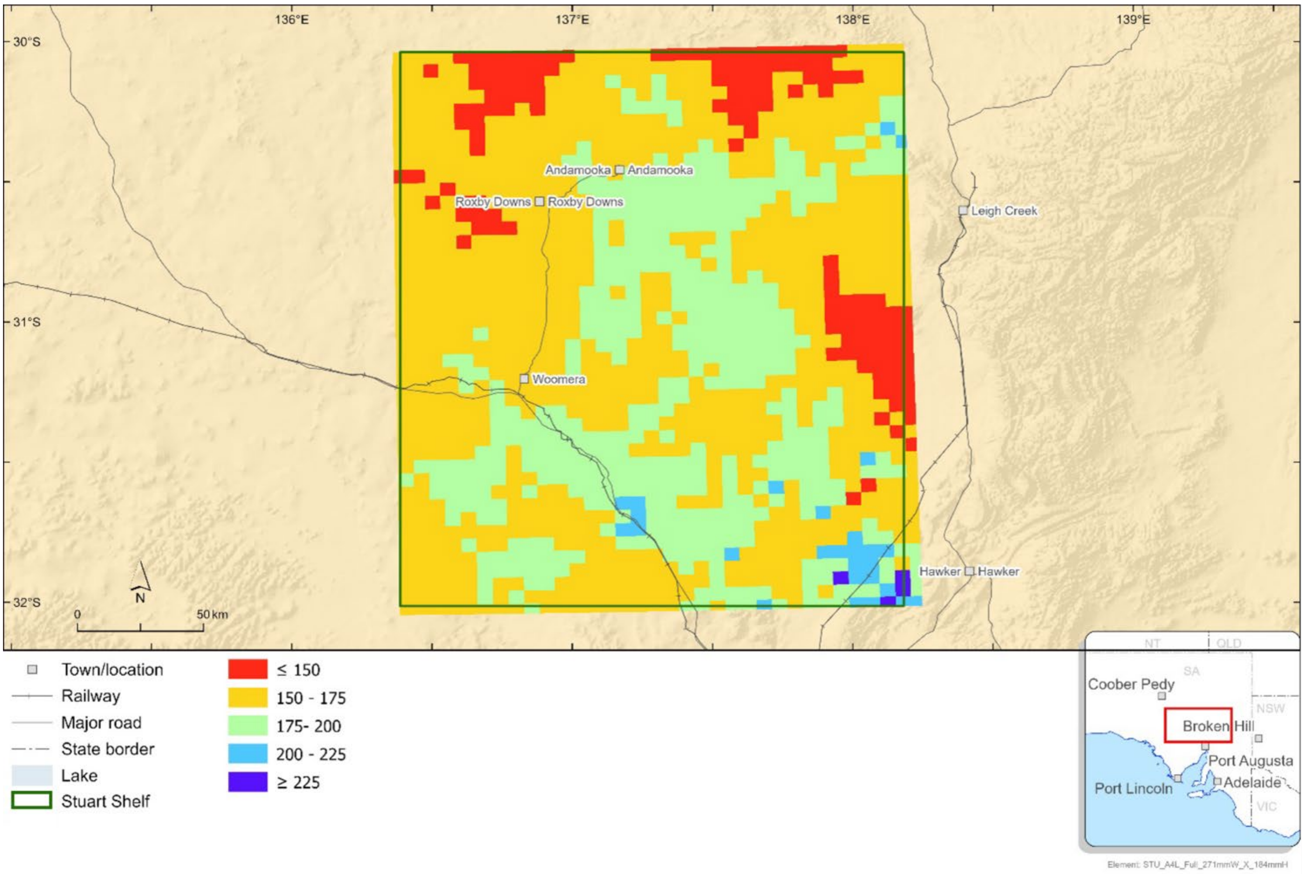


*Figure 2. Historical mean annual precipitation (1950–2019) in the Stuart Shelf region*

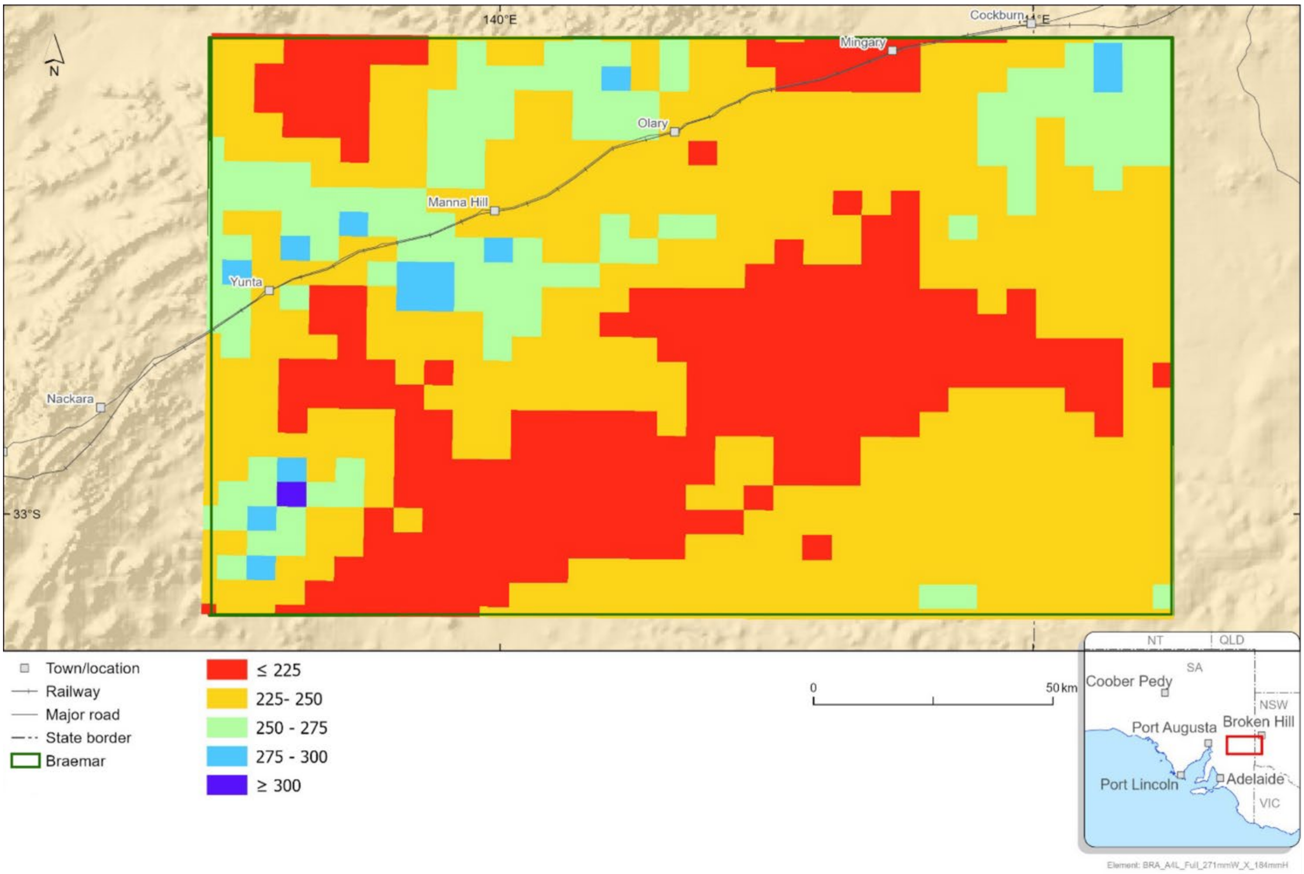


*Figure 3. Historical mean annual precipitation (1950–2019) in the Braemar region*

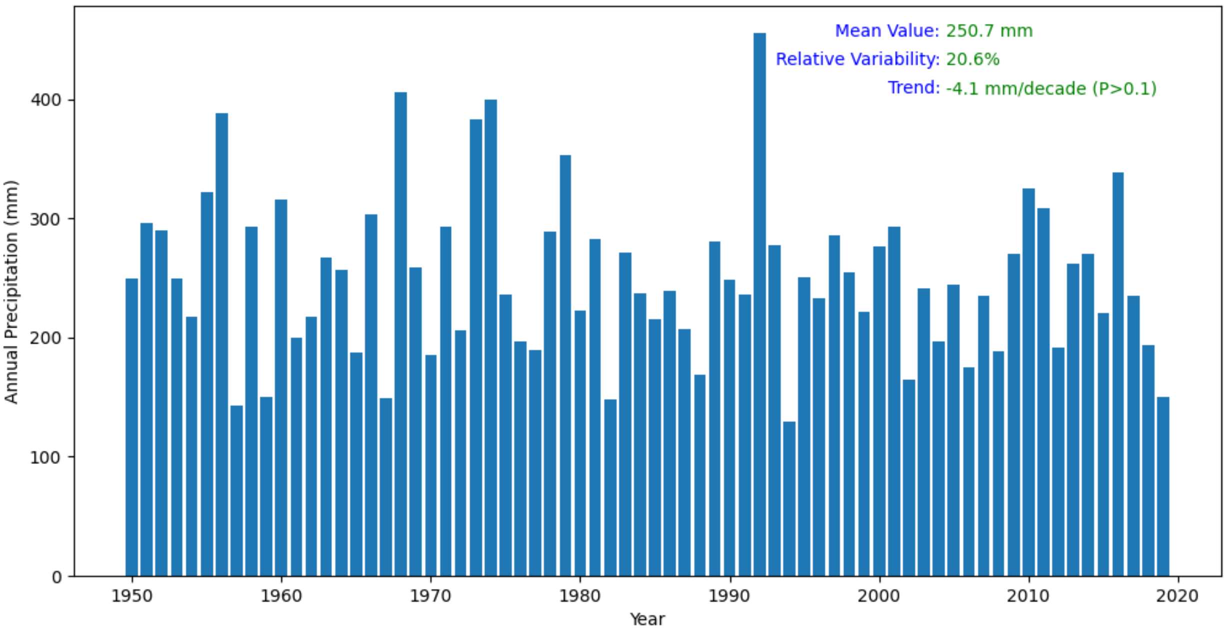


*Figure 4. Historical annual precipitation time series in the Northern Eyre region, where annual precipitation is calculated as the average of all grid cells in the region*

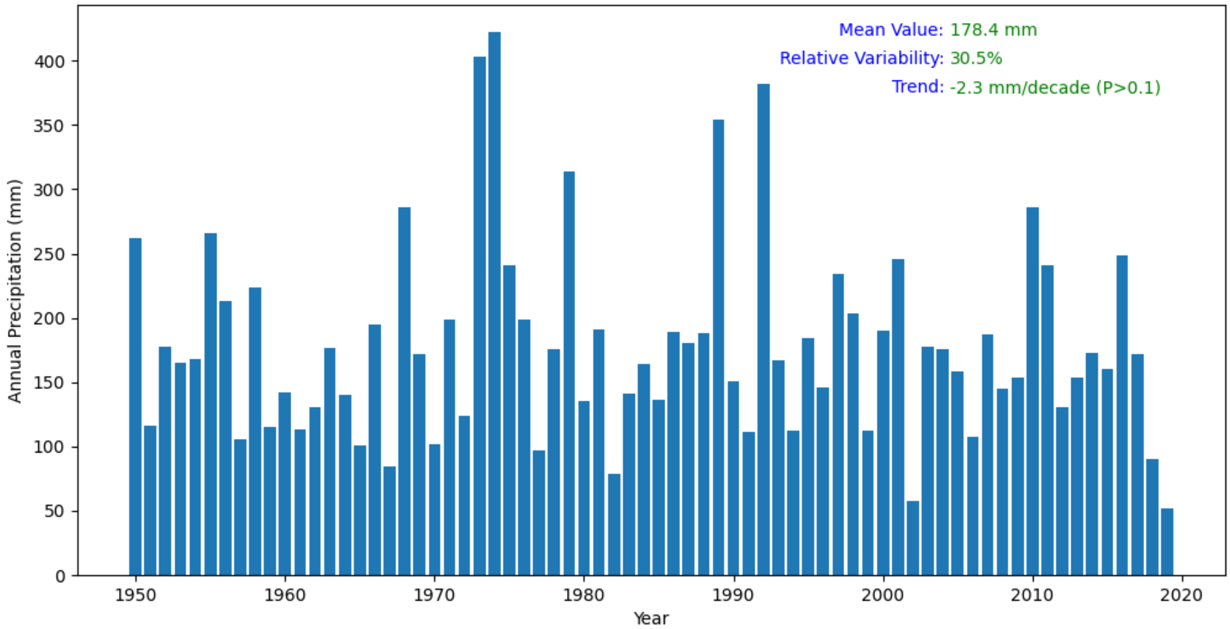


*Figure 5. Historical annual precipitation time series in the Stuart Shelf region, where annual precipitation is calculated as the average of all grid cells in the region*

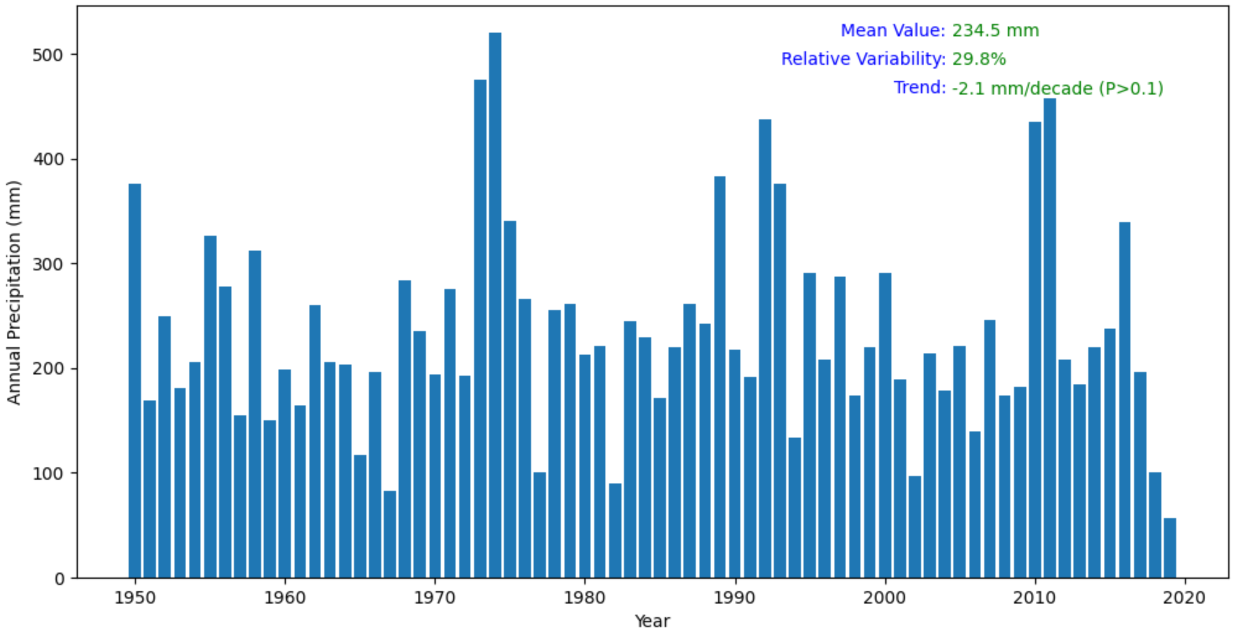


*Figure 6. Historical annual precipitation time series in the Braemar region, where annual precipitation is calculated as the average of all grid cells in the region*

## ANNUAL PRECIPITATION PROJECTIONS UNDER SSP1-2.6 AND SSP5-8.5 SCENARIOS

Analyses of climate projections are carried out using outputs derived from the new state-of-the-art climate models within the framework of the Coupled Model Inter-comparison Project (CMIP). The Scenario CMIP6 simulations are made under a combination of a Shared Socioeconomic Pathway (SSP) and a Representative Concentration Pathway (defined as radiation forcing 1.9, 2.6, 3.4, 4.5, 6.0, 7.0, and 8.5 $Wm^{-2}$ at 2100) (Grose et al, 2019). For example, SSP1-2.6 is the implementation of environmentally-friendly policies coupled with low greenhouse gas emissions. Conversely, SSP5-8.5 is designated as a worst-case scenario characterised with fossil-fuel development.

A set of 22 Scenario CMIP6 models are considered. These provide monthly projections of precipitation and temperature under the SSP1-2.6 and SSP5-8.5 scenarios available at the time of this analysis (15 Jan 2024). To select models which are more suitable for the Braemar, Northern Eyre, and Stuart Shelf regions, 2 screening steps were conducted. These involved examining the model performance against the historical data in terms of annual precipitation correlation coefficient, mean absolute error, root mean squared error, percent bias and standard deviation. First, the 22 sets of model outputs were evaluated for their historical simulation performance of monthly precipitation from 2000 to 2014. Thirteen of them exhibiting better performance were further assessed based on their historical simulation performance from 1950 to 2014. Finally, 4 models – CNRM-CM6-1, CNRM-ESM2-1, EC-Earth3 and NESM3 – were identified for the 3 regions and adopted for ensemble climate projection.

It is essential to recognize that the CMIP6 outputs are modelling results for coarse grids from Global Climate Models (GCMs), with cell sizes generally larger than 100 km (Iorio et al, 2004; Sachindra et al, 2018). They do not reproduce historical precipitation nor do they accurately predict future precipitation. Some methods have been developed to correct systematic bias in climate models and bridge the scale gap between GCM output and observed data. Here, quantile mapping, a bias-correction method, (Gudmundsson et al, 2012), is adopted. It transforms the cumulative distribution function (CDF) of the simulated variables into the observed variables to align the statistical properties of the bias-corrected data with those of the observational data. The quantile mapping method effectively adjusts the simulated data, ensuring that its distribution closely matches that of the observed data. This correction helps the CMIP6 models more accurately reproduce mean annual rainfall and interannual variability in the 3 regions and thereby enhance the simulations' reliability in representing historical climate conditions.

The mean annual precipitation, correlation coefficient and relative variability of CMIP6 outputs for the historical period (1950–2014) before and after bias correction are listed in Table 1. Figures 7–12 illustrate annual precipitation projections after bias-correction under SSP1-2.6 and SSP5-8.5 scenarios.

The corrected CMIP6 models reproduce mean annual precipitation and relative variability for the historical period (1950–2014). After the correction, the annual precipitation projections into the future under 2 scenarios are shown in Figures 7 and 8 for Braemar, Figures 9 and 10 for Northern Eyre, and Figures 11 and 12 for Stuart Shelf. Based on these results, the projected change of annual precipitation in the 3 regions is very small until 2100 under either scenario (within 2 mm per decade). Other aspects of climate variables, such as rainfall intensity and temperature patterns, should be focused on when developing mitigation and adaptation measures in these regions.

*Table 1. Selected statistics of 4 selected raw and corrected CMIP6 model ensemble for the 3 regions for the period of 1950–2014*

| REGION | MEAN | | | CORRELATION | | RELATIVE VARIABILITY | |
|---|---|---|---|---|---|---|---|
| | OBS | RAW | CORRECTED | RAW | CORRECTED | RAW | CORRECTED |
| **Northern Eyre** | 252.5 | 336.2 | 251.9 | 0.09 | 0.08 | 0.31 | 0.20 |
| **Stuart Shelf** | 181.0 | 259.9 | 181.0 | 0.07 | 0.06 | 0.57 | 0.30 |
| **Braemar** | 238.3 | 298.8 | 238.3 | 0.06 | 0.07 | 0.43 | 0.29 |

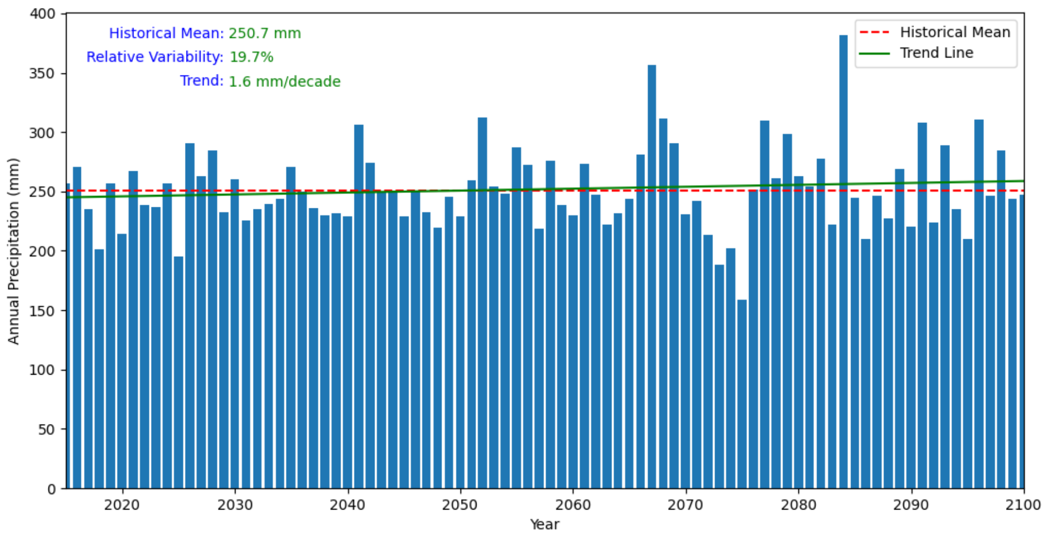

*Figure 7. Annual precipitation ensemble projection under SSP1-2.6 for the Northern Eyre region, in comparison to the historical mean (1950–2019). The relative variability is the average value of the 4 CMIP models.*

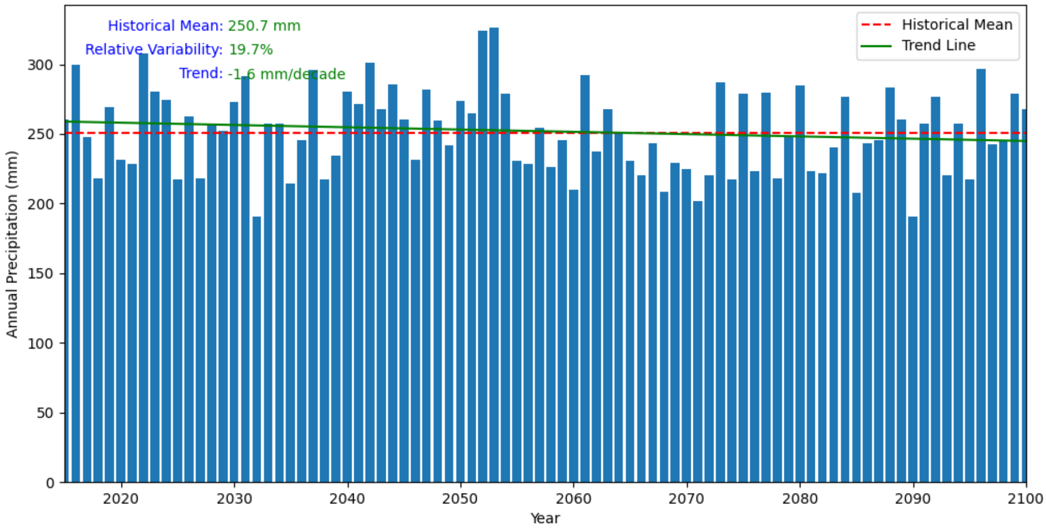


*Figure 8. Annual precipitation projections under SSP5-8.5 for the Northern Eyre region, in comparison to the historical mean (1950–2019). The relative variability is the average value of the 4 CMIP models.*

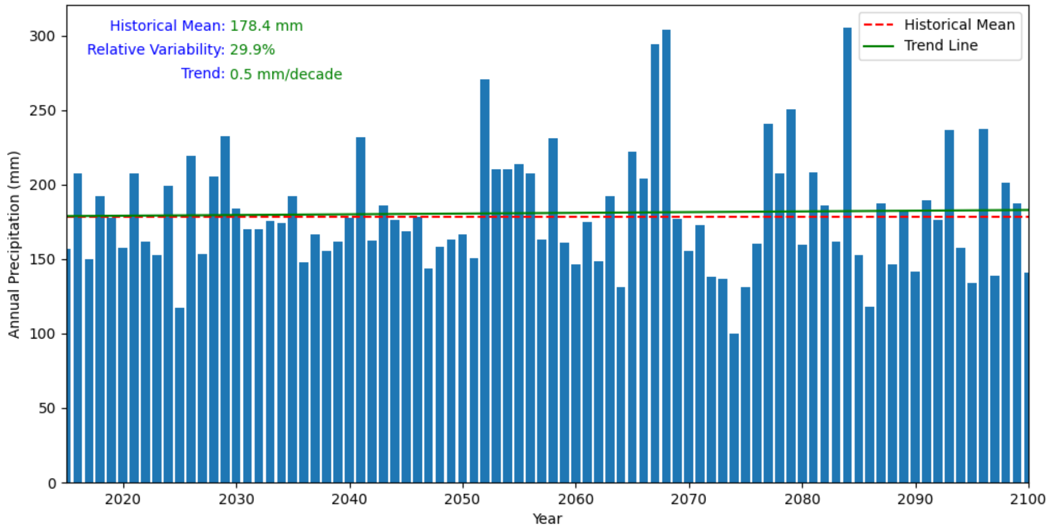


*Figure 9. Annual precipitation projections under SSP1-2.6 for the Stuart Shelf region, in comparison to the historical mean (1950–2019). The relative variability is the average value of the 4 CMIP models.*

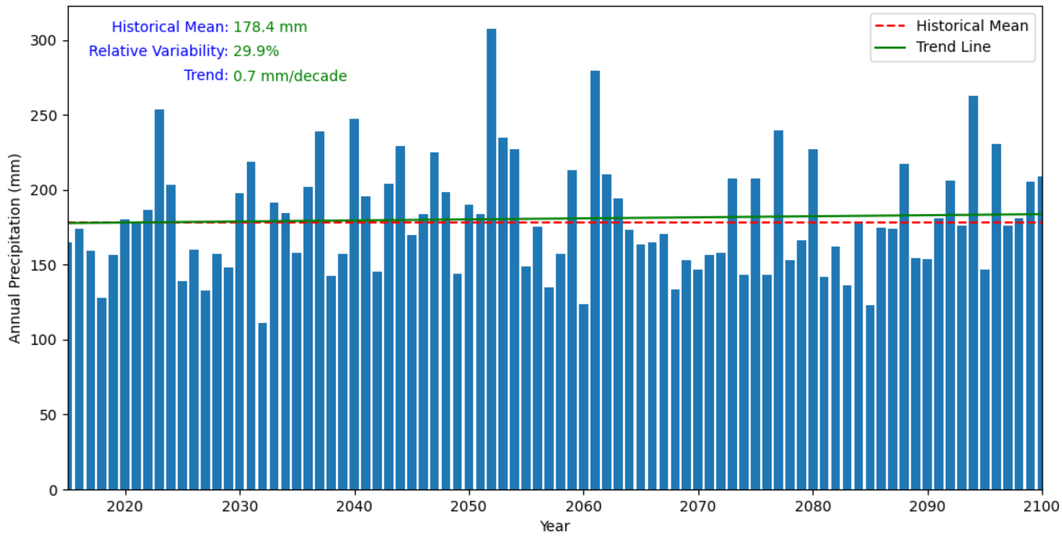


*Figure 10. Annual precipitation projections under SSP5-8.5 for the Stuart Shelf region, in comparison to the historical mean (1950–2019). The relative variability is the average value of the 4 CMIP models.*

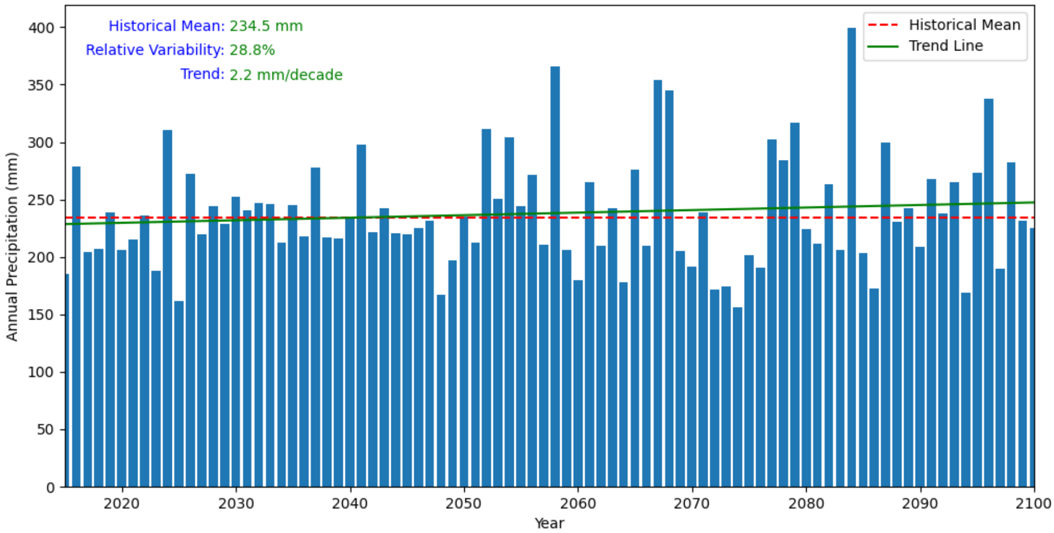


*Figure 11. Annual precipitation projections under SSP1-2.6 for the Braemar region, in comparison to the historical mean (1950–2019). The relative variability is the average value of the 4 CMIP models.*

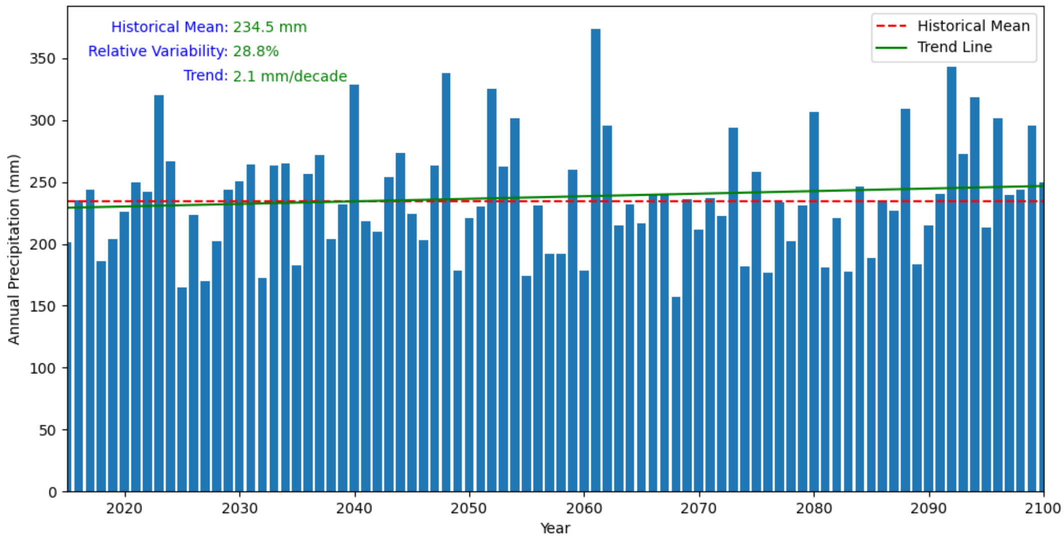


*Figure 12. Annual precipitation projections under SSP5-8.5 for the Braemar region, in comparison to the historical mean (1950–2019). The relative variability is the average value of the 4 CMIP models.*

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Fact Sheet

GOYDER INSTITUTE FOR WATER RESEARCH

# Maximum temperature patterns and projections

## KEY FINDINGS

- Summer daily maximum temperatures are commonly above 33°C in the Stuart Shelf region, 31°C in the Braemer region, and 28°C in the Northern Eyre region.
- Increasing rates of hot-day (>35°C) occurrences became more obvious after 2000 for all 3 regions. The number of hot days increased by 12–15 days (about 2 weeks) in 2000–19.
- Future daily maximum temperatures are highly dependent on the climate scenarios. Under moderate SSP2-4.5, daily maximum temperatures in summer can increase by 0.2–0.25°C per decade. The number of hot days per annum can reach 55 days in Northern Eyre, 85 days in Stuart Shelf, and 60 days in Braemer by 2100.

## HISTORICAL DAILY MAXIMUM TEMPERATURE IN NORTHERN EYRE, BRAEMAR PROVINCE, AND STUART SHELF

Historical maximum temperature data spanning from 1950 to 2019 from the Australian Gridded Climate Data (Evans et al, 2020) were analysed for the temporal and spatial patterns of maximum temperature. Figures 1–3 present the historical mean summer daily maximum temperature in Northern Eyre, Stuart Shelf, and Braemar regions. Spatial gradients of maximum temperature occur in Northern Eyre (Figure 1) and Stuart Shelf (Figure 2). For Northern Eyre, maximum temperatures increase from 26.2°C in the southwest to >33°C in the north. For Stuart Shelf, the maximum temperature varies between 32.7°C and 36.3°C. In Braemar, the spatial pattern of maximum temperature shows a smaller variation of between 30.7°C and 32.9°C.

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Guan H and Pan L (2024) *Maximum temperature patterns and projections fact sheet*, Goyder Institute ecohydrological conceptual model and impact pathway diagram project, Goyder Institute for Water Research.


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The Goyder Institute for Water Research is a collaborative partnership of the South Australian government through the Department for Environment and Water, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.

The project was conducted with support from the South Australian government through the Department for Environment and Water and Department for Energy and Mining, South Australian Arid Lands Landscape Board and Eyre Peninsula Landscape Board.

Figures 4–6 show the time series of spatially-average seasonal maximum temperature in the Northern Eyre, Stuart Shelf, and Braemar regions in 1950–2019 with 0.05degree resolution. Increasing trends in maximum temperature are observed for all seasons in all 3 regions. The trends are more obvious in summer and spring than in winter and autumn. Summer daily maximum temperature increased by over 2°C in 1950–2019 for all 3 regions.

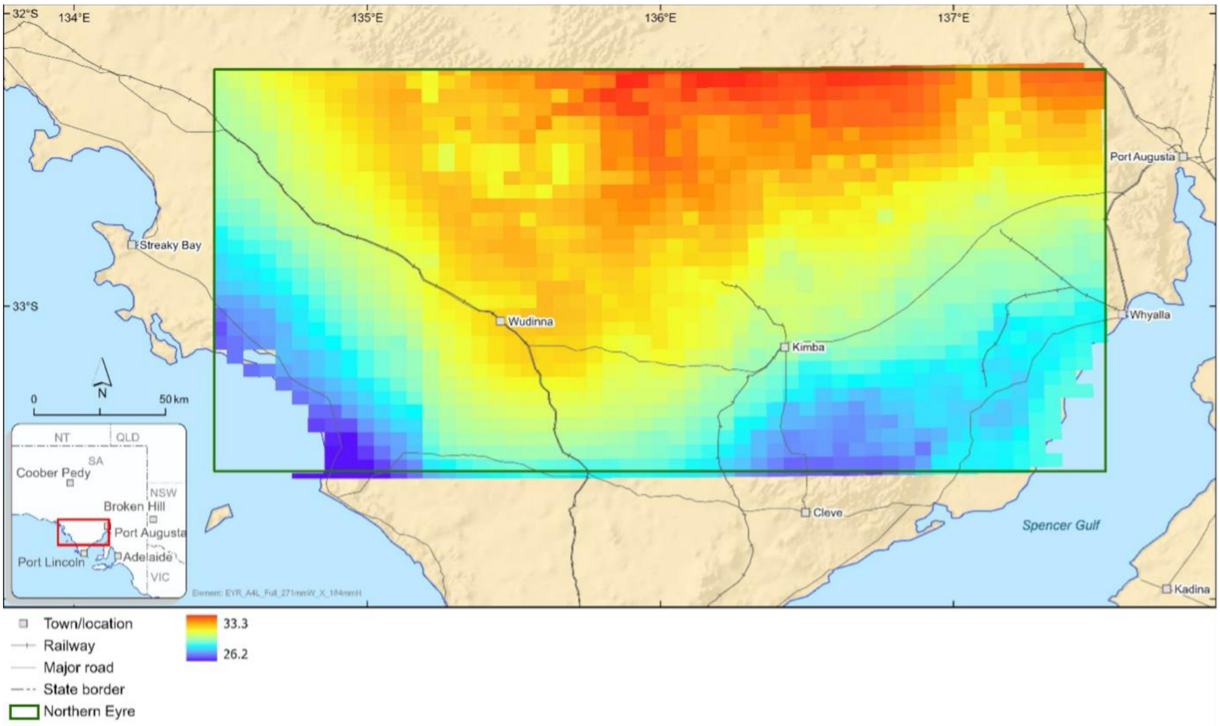


*Figure 1. Historical mean summer daily maximum temperature (°C, 1950–2019) in the Northern Eyre region*

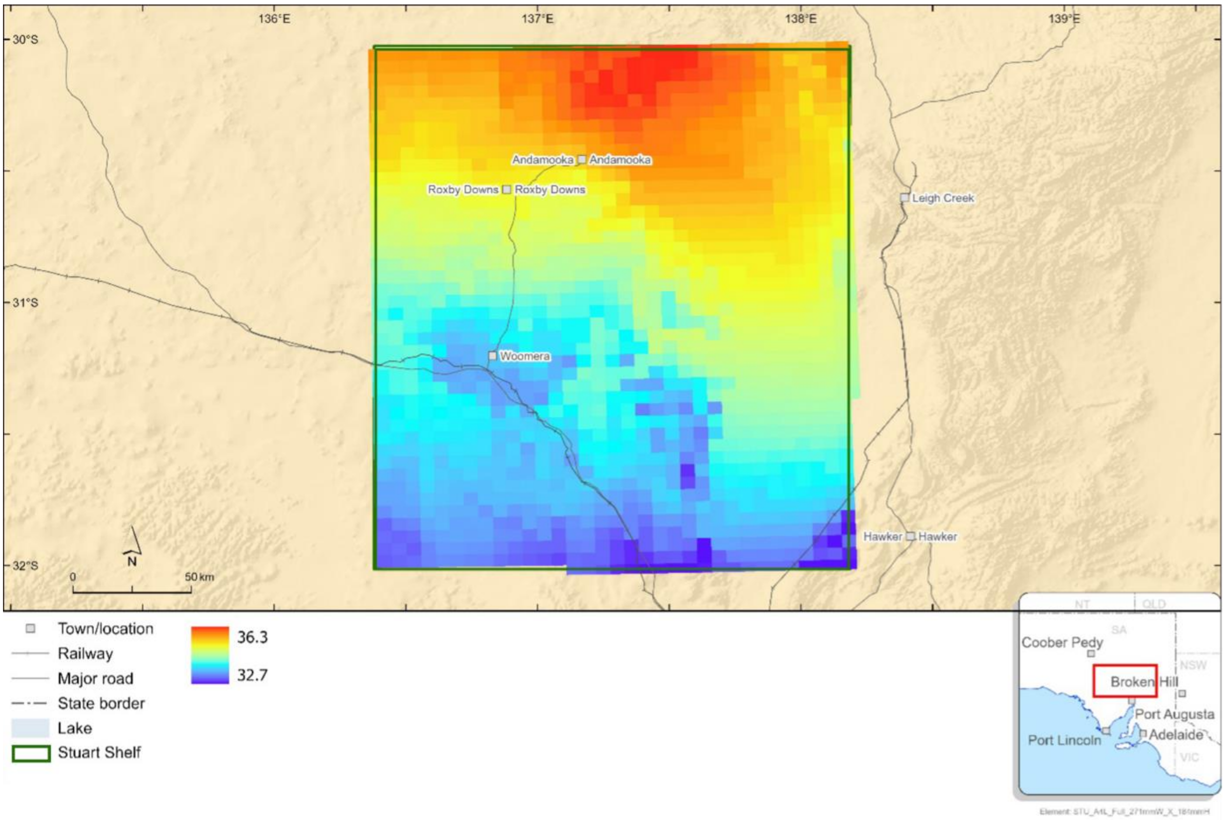


*Figure 2. Historical mean summer daily maximum temperature (°C, 1950–2019) in the Stuart Shelf region*

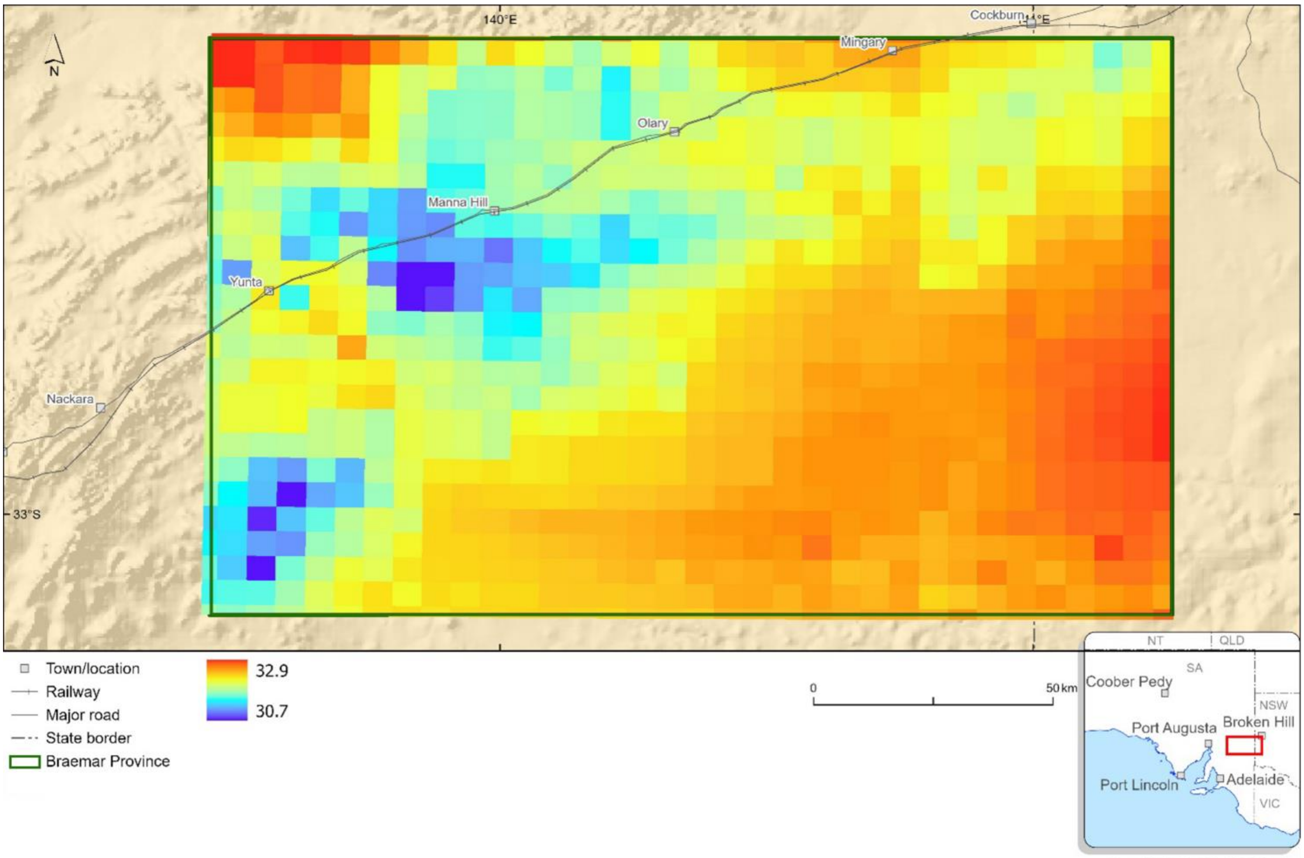


*Figure 3. Historical mean summer daily maximum temperature (°C, 1950–2019) in the Braemar region*

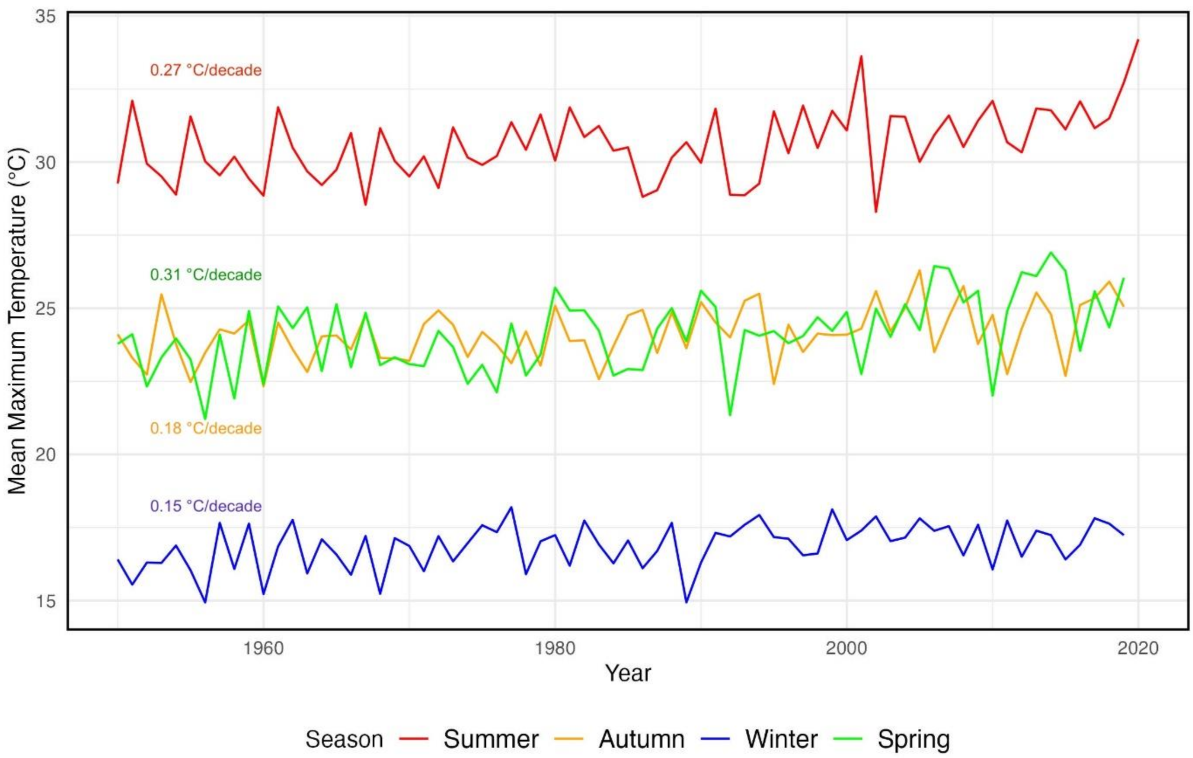


*Figure 4. Seasonal maximum temperature from 1950 to 2019 in the Northern Eyre region*

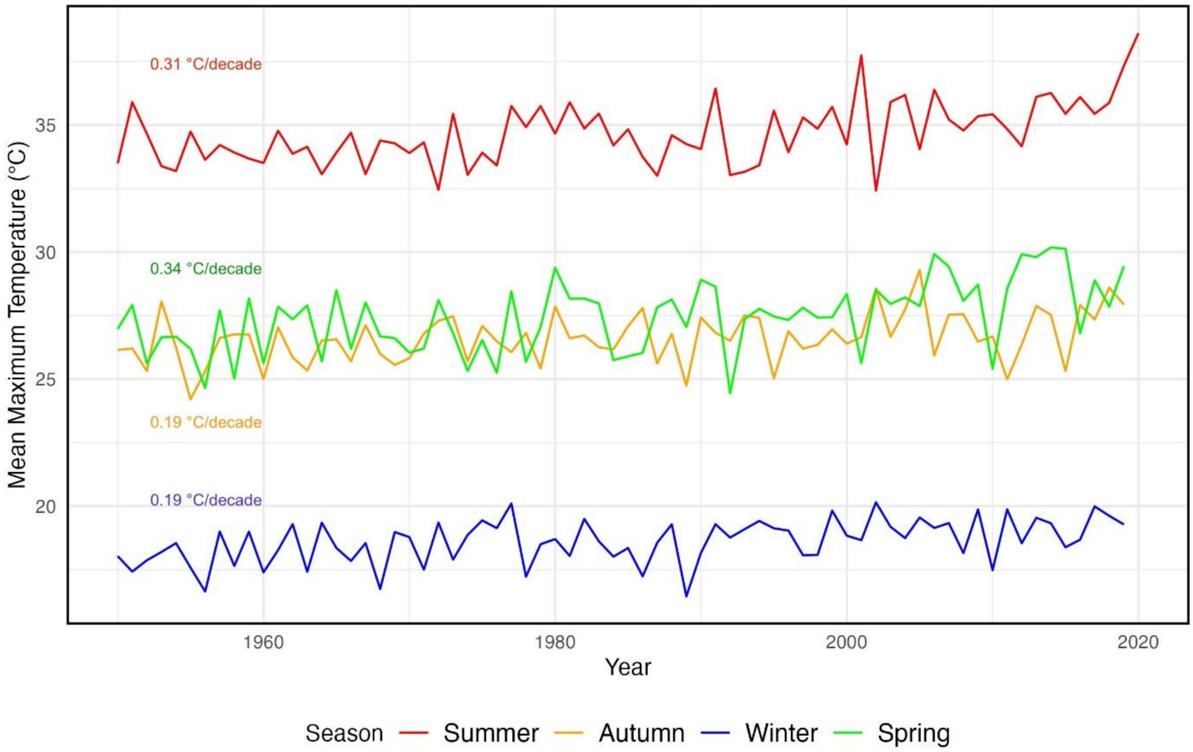


*Figure 5. Seasonal maximum temperature from 1950 to 2019 in the Stuart Shelf region*

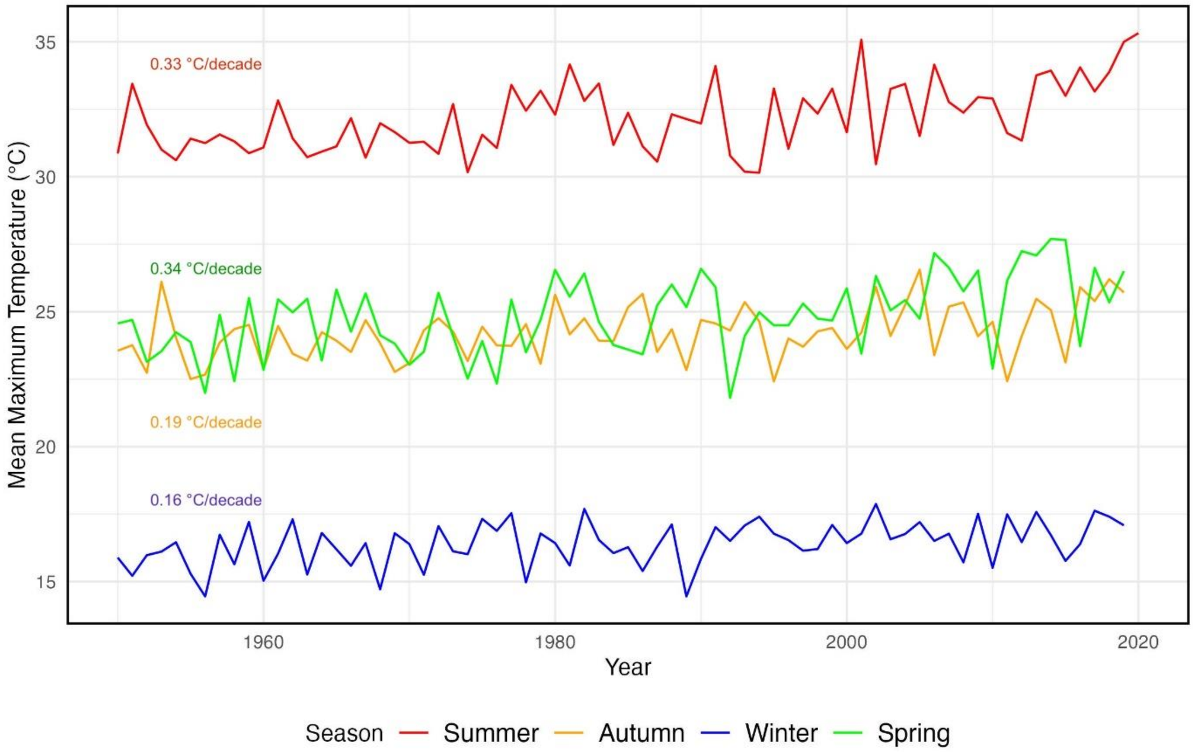


*Figure 6. Seasonal maximum temperature from 1950 to 2019 in the Braemar region*

## NUMBER OF HISTORICAL HOT DAYS IN NORTHERN EYRE, BRAEMAR, AND STUART SHELF

A threshold of 35°C is adopted for daily maximum temperature to define 'hot days.' At this threshold temperature and above, the human body's ability to sweat for cooling reduces (Ogge et al, 2019). Figures 7–9 show the numbers of hot days in the Northern Eyre, Stuart Shelf, and Braemar regions in 1950–2019, in which the daily maximum temperature was greater than 35°C.

The frequencies of hot days have increased in all 3 regions. The change seems to have mostly occurred after 2000. Around 2000, the annual number of hot days was about 28 days in the Northern Eyre region. It reached 40 days after 2015. In the Stuart Shelf region, the number of hot days was 65 days around 2000 and increased to 80 days after 2015. In the Braemer region, the number of hot days per annum was 40 days around 2000 and rose to 55 days in 2015–2019. In summary, the number of hot days has increased by 12–15 days in 2000–19 for the 3 regions.

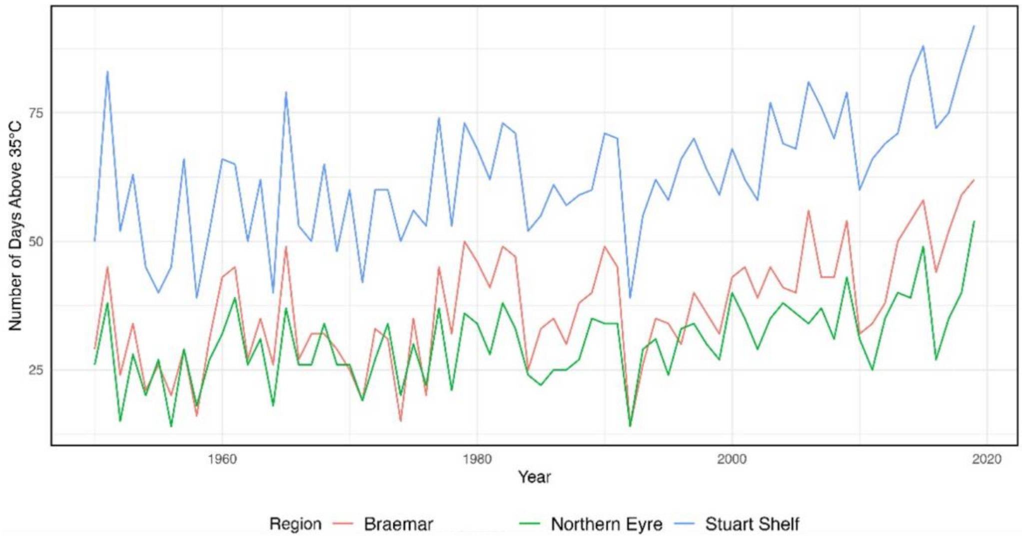


*Figure 7. Annual number of hot days (>35°C) during 1950–2019*

## MAXIMUM TEMPERATURE PROJECTIONS UNDER FUTURE SCENARIOS

Analyses of climate projections are carried out using outputs derived from the new state-of-the-art climate models within the framework of the Coupled Model Inter-comparison Project (CMIP). The Scenario CMIP6 simulations were conducted under a combination of a Shared Socioeconomic Pathway (SSP) and a Representative Concentration Pathway (defined as radiation forcing 1.9, 2.6, 3.4, 4.5, 6.0, 7.0, and 8.5 $Wm^{-2}$ at 2100) (Grose et al, 2019). For example, SSP1-2.6 is the implementation of environmentally-friendly policies coupled with low greenhouse gas emissions. Conversely, SSP5-8.5 is designated as a worst-case scenario characterised by fossil-fuelled development. And SSP2-4.5, which is an update to scenario RCP4.5, represents the medium pathway of future greenhouse gas emissions.

A set of 36 Scenario CMIP6 Global Climate Models (GCMs) were considered that provide monthly projections of maximum temperature under the SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios available at the time of this analysis (February 2024). To select models which are more suitable for the Braemar, Northern Eyre, and Stuart Shelf regions, the model performance was examined against the historical data in terms of correlation coefficient, statistics significance, and percentage bias. Four models – CanESM5, GISS-E2-1-H, INM-CM5-0 and MPI-ESM1-2-HR – were identified for the 3 regions and are adopted for ensemble temperature climate projection.

Quantile mapping (Gudmundsson et al, 2012) was adopted to correct the systematic bias in climate models and bridge the scale gap between GCM historical simulated output and historical observed data. Figures 8–10 illustrate the maximum temperature projections after bias correction under the scenarios of SSP1-2.6, SSP2-4.5 and SSP5-8.5. The trends of mean daily maximum temperature under different scenarios are shown in the figures and listed in Table 1.

Predicted future maximum temperatures in the regions are highly dependent on future climate scenarios. Under SSP1-2.6, the increasing rates of daily maximum temperature could be reduced to one third of those in the historical period (1950–2014), about 0.1°C per decade or less. However, under SSP5-8.5, the increasing rates of daily maximum temperature could be 2–3 times those for the historical period (1950–2014) for autumn and winter and about 1.5–2 times for spring and summer. Across all seasons, the increasing rates of daily maximum temperature are estimated to be around 0.5°C per decade under SSP5-8.5, which is 5 times those under SSP1-2.6. Under the moderate scenario, SSP2-4.5, the increasing rates keep almost stable in autumn and winter, when compared to the values in the historical period, and decrease in spring and summer.

*Table 1. The trends of the historical observation (1950–2014) and bias-corrected CMIP6 projection*

*(2015–2100) of seasonal mean daily maximum temperature (°C per decade) in the Northern Eyre, Stuart Shelf, and Braemar regions.*

| | Scenarios | Autumn | Winter | Spring | Summer |
|---|---|---|---|---|---|
| | Historical | 0.18 | 0.15 | 0.31 | 0.27 |
| Northern Eyre | SSP1-2.6 | 0.08 | 0.07 | 0.10 | 0.11 |
| | SSP2-4.5 | 0.19 | 0.22 | 0.24 | 0.20 |
| | SSP5-8.5 | 0.52 | 0.51 | 0.52 | 0.50 |
| | Historical | 0.19 | 0.19 | 0.34 | 0.31 |
| Stuart Shelf | SSP1-2.6 | 0.06 | 0.06 | 0.11 | 0.10 |
| | SSP2-4.5 | 0.18 | 0.20 | 0.25 | 0.25 |
| | SSP5-8.5 | 0.54 | 0.47 | 0.56 | 0.55 |
| | Historical | 0.19 | 0.16 | 0.34 | 0.33 |
| Braemar | SSP1-2.6 | 0.07 | 0.06 | 0.10 | 0.09 |
| | SSP2-4.5 | 0.20 | 0.19 | 0.24 | 0.21 |
| | SSP5-8.5 | 0.53 | 0.46 | 0.53 | 0.55 |

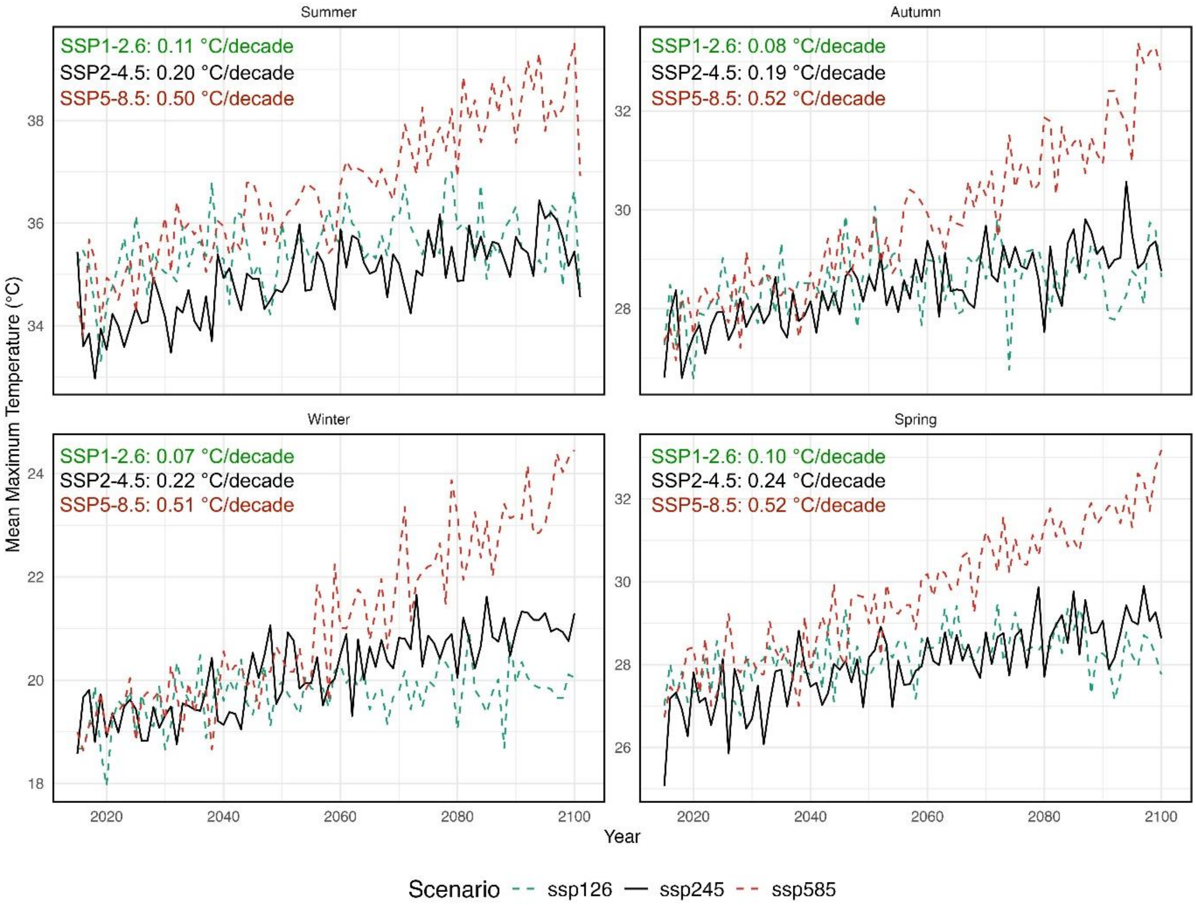


*Figure 8. Ensemble projections of seasonal average daily maximum temperature for the Northern Eyre region*

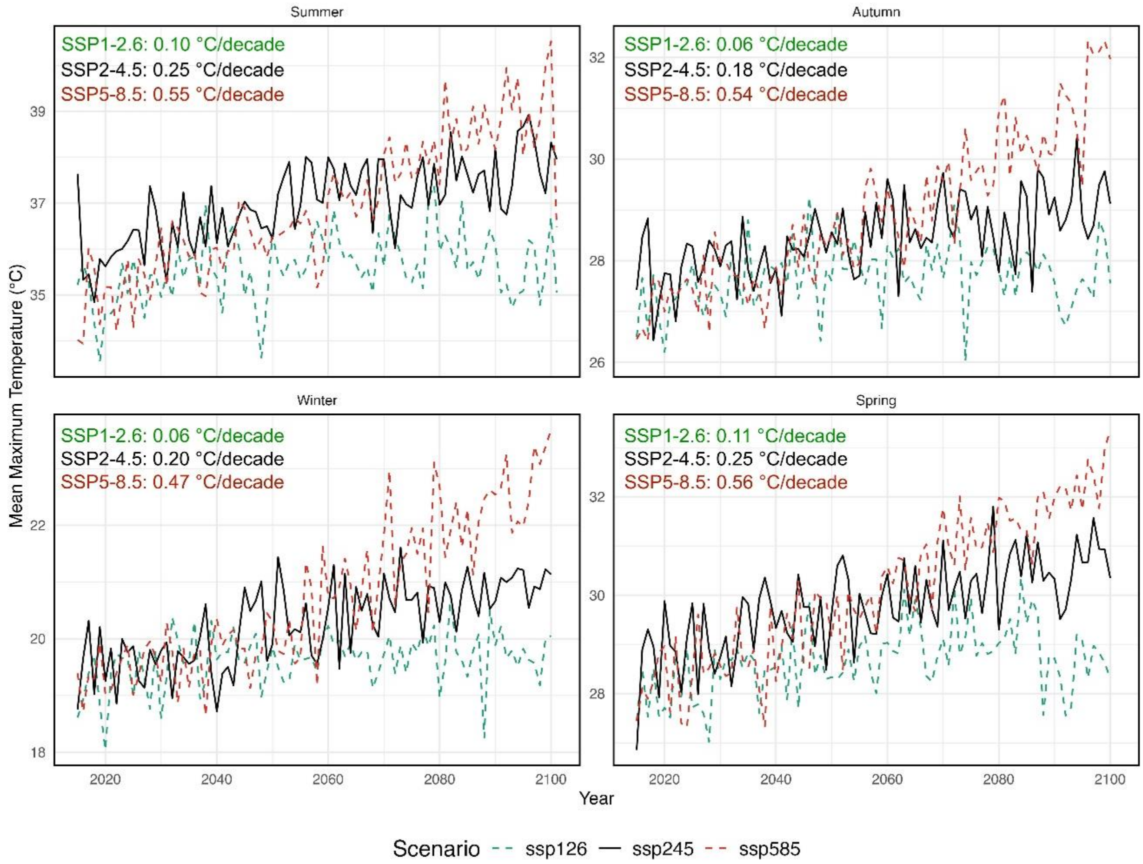


*Figure 9. Ensemble projections of seasonal average daily maximum temperature for the Stuart Shelf region*

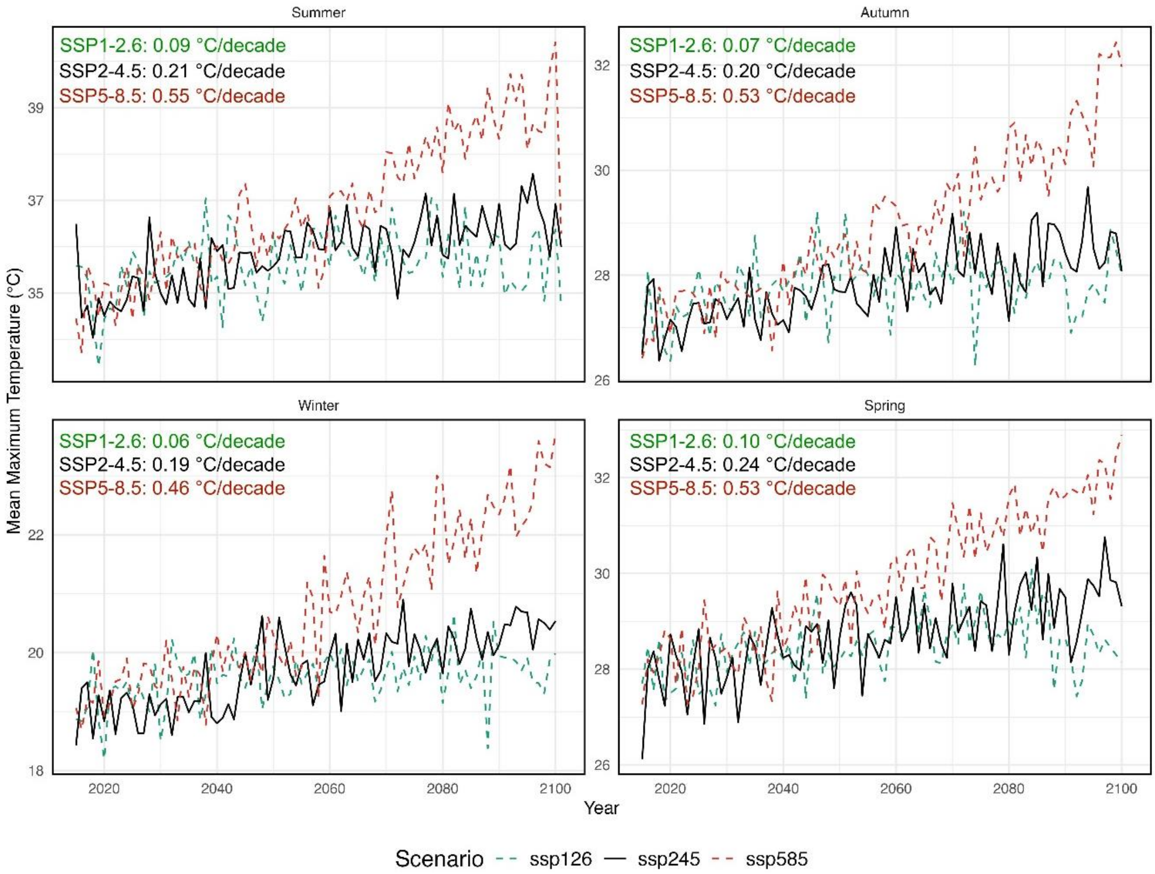


*Figure 10. Ensemble projections of seasonal average daily maximum temperature for the Braemar region*

## PROJECTIONS OF NUMBER OF HOT DAYS UNDER FUTURE SCENARIOS

Similarly, the projected number of hot days differs among the 3 scenarios, based on bias-corrected MPI-ESM1-2-HR which has the best performance of the 4 CMIP6 models (Figures 11–13). Under SSP1-2.6, the number of hot days would be around 45 days for Northern Eyre, and 80 days for Stuart Shelf and Braemer regions by 2100. This is similar to what they are now. Under SSP5-8.5, the number of hot days by 2100 can be 2 months long in Northern Eyre, 4 months long in Stuart Shelf and 3 months long in Braemer. Under moderate SSP2-4.5, the number of hot days per annum will be around 55 days in the Northern Eyre region, 85 days in the Stuart Shelf region and 60 days in the Braemer region by 2100.

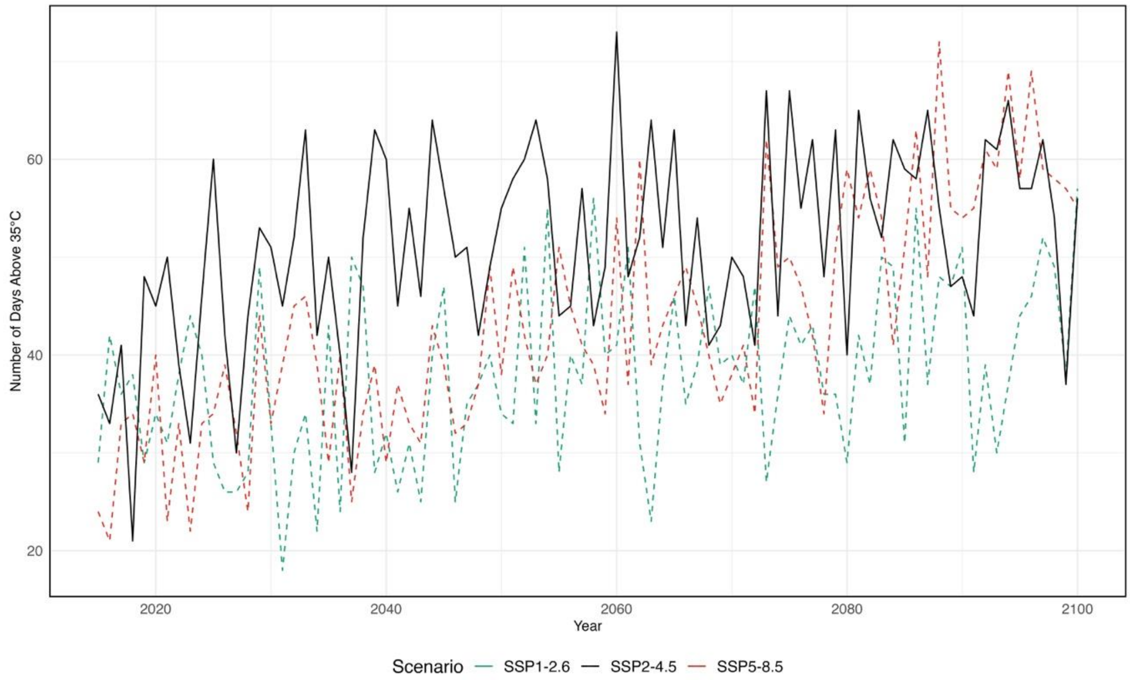


*Figure 11. Projected number of hot days (>35°C) for the Northern Eyre region*

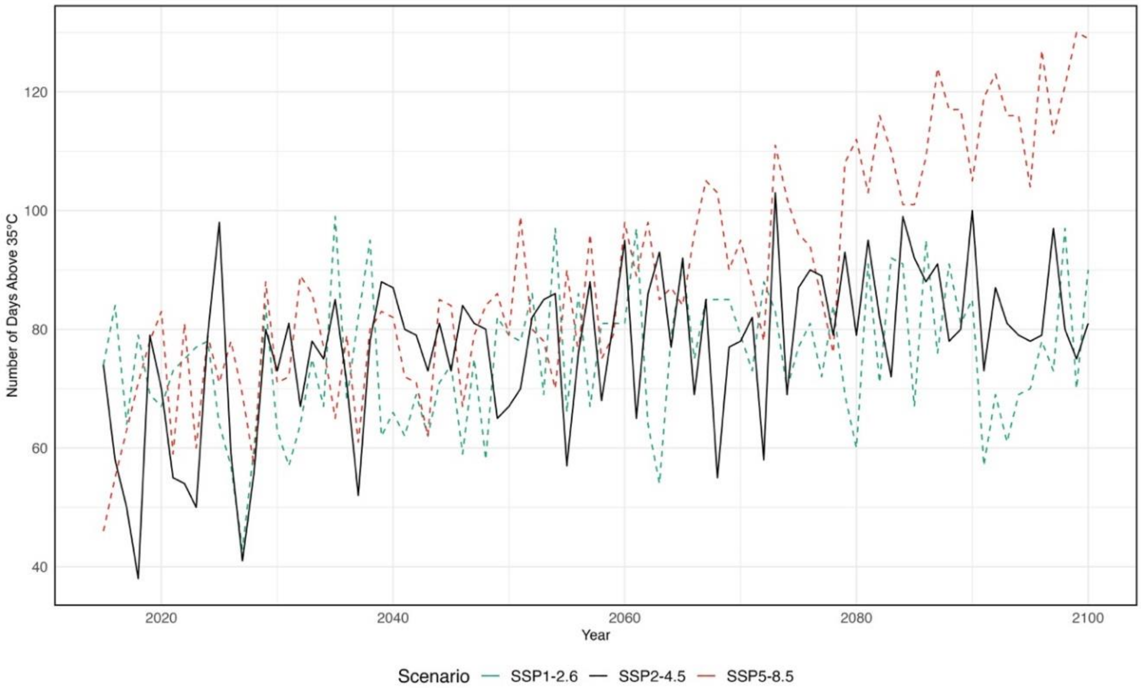


*Figure 12. Projected number of hot days (>35°C) for the Stuart Shelf region*

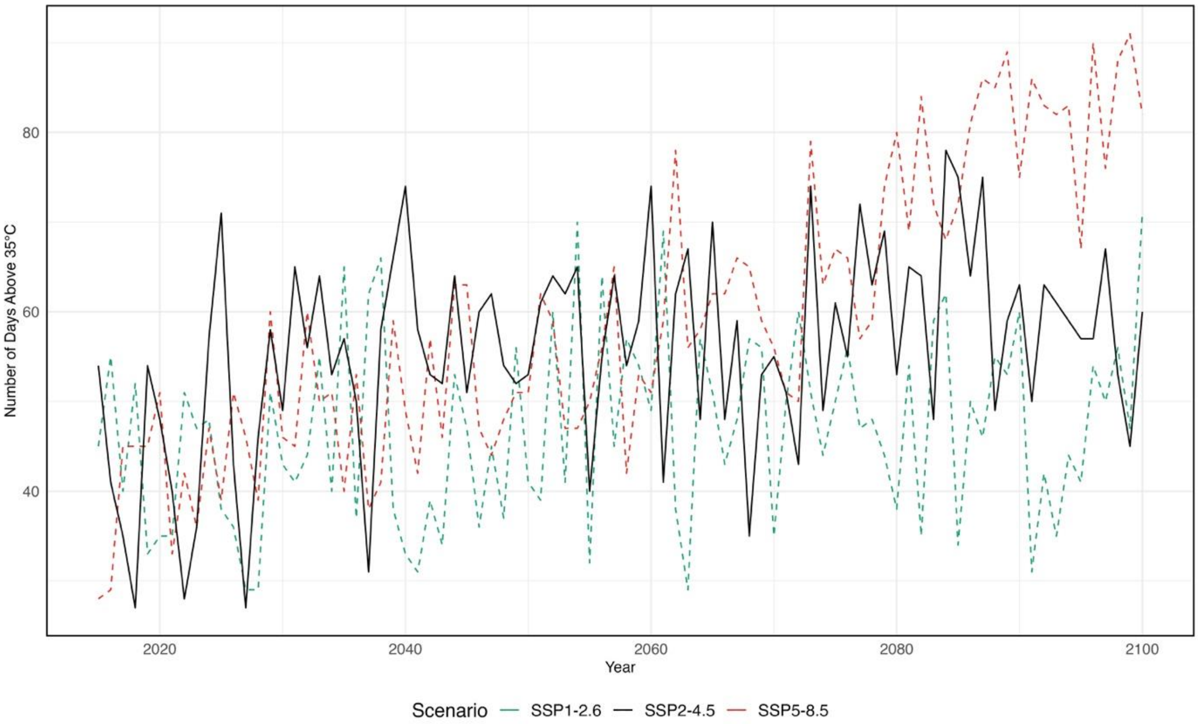


*Figure 13. Projected number of hot days (> 35 °C) for the Braemar region*

## ENVIRONMENTAL AND SOCIOECONOMICAL IMPLICATIONS OF CLIMATE WARMING

The projected warming trends in the 3 regions have profound hydrological, ecological and socio-economical implications. Hydrologically, increasing temperatures will certainly elevate potential evapotranspiration and lead to quicker landscape desiccation following episodic rainfall events. Ecologically, a warming climate will stress fauna and flora, impact native vegetation distribution, and threaten biodiversity in the regions. Socio-economically, an increasing number of hot days will have negative impacts on pastoral productivity and the health of residents.

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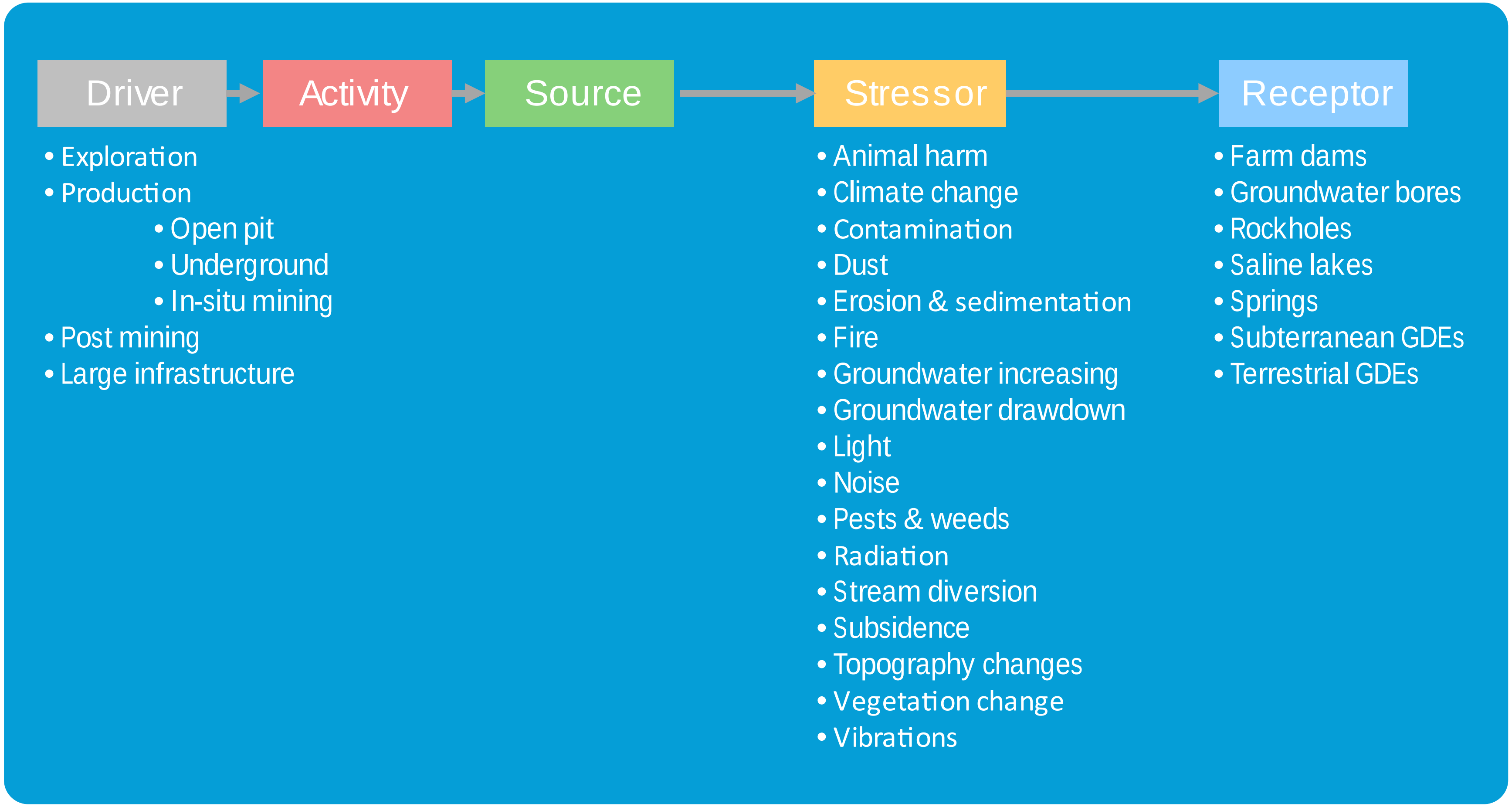
# Impact pathway diagrams



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Fact Sheet

# Impact pathway diagrams

## HIGHLIGHTS

- Impact pathway diagrams for the exploration, production and post-mining phase of open pit, underground and in situ recovery mining
- Overview per stressor of the impact pathways that pass through the stressor, with the sources that lead to the stressor and how the receptors can be affected by the stressor

## INTRODUCTION

The impact pathway diagram for the production phase of mining shows the cause-and-effect relationships that connect activities associated with open-pit, underground and in-situ recovery mining (the drivers) to receptors (Figure 1).


*Figure 1 Impact pathway diagram structure*

The next pages show the impact pathway diagrams for open pit, underground and in-situ mining for the production, exploration and post-mining stage as box-and-arrow diagrams (Figure 2, Figure 4 and Figure 6) and as matrix diagrams (Figure 3, Figure 5, Figure 7). We chose to make different impact pathway diagrams as the activities and their intensity are different between the different stages of mining. The post-mining phase describes the situation after mining has ceased and the mine site is decommissioned and rehabilitated. That diagram therefore has no activities and only describes the sources that remain in the landscape.

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## REFERENCE

Peeters L, London A, Thomas H, Holland K (2024) *Impact pathway diagrams,* Goyder Institute ecohydrological conceptual model and impact pathway diagram project, Goyder Institute for Water Research.

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## IMPACT PATHWAY DIAGRAM EXPLORATION PHASE

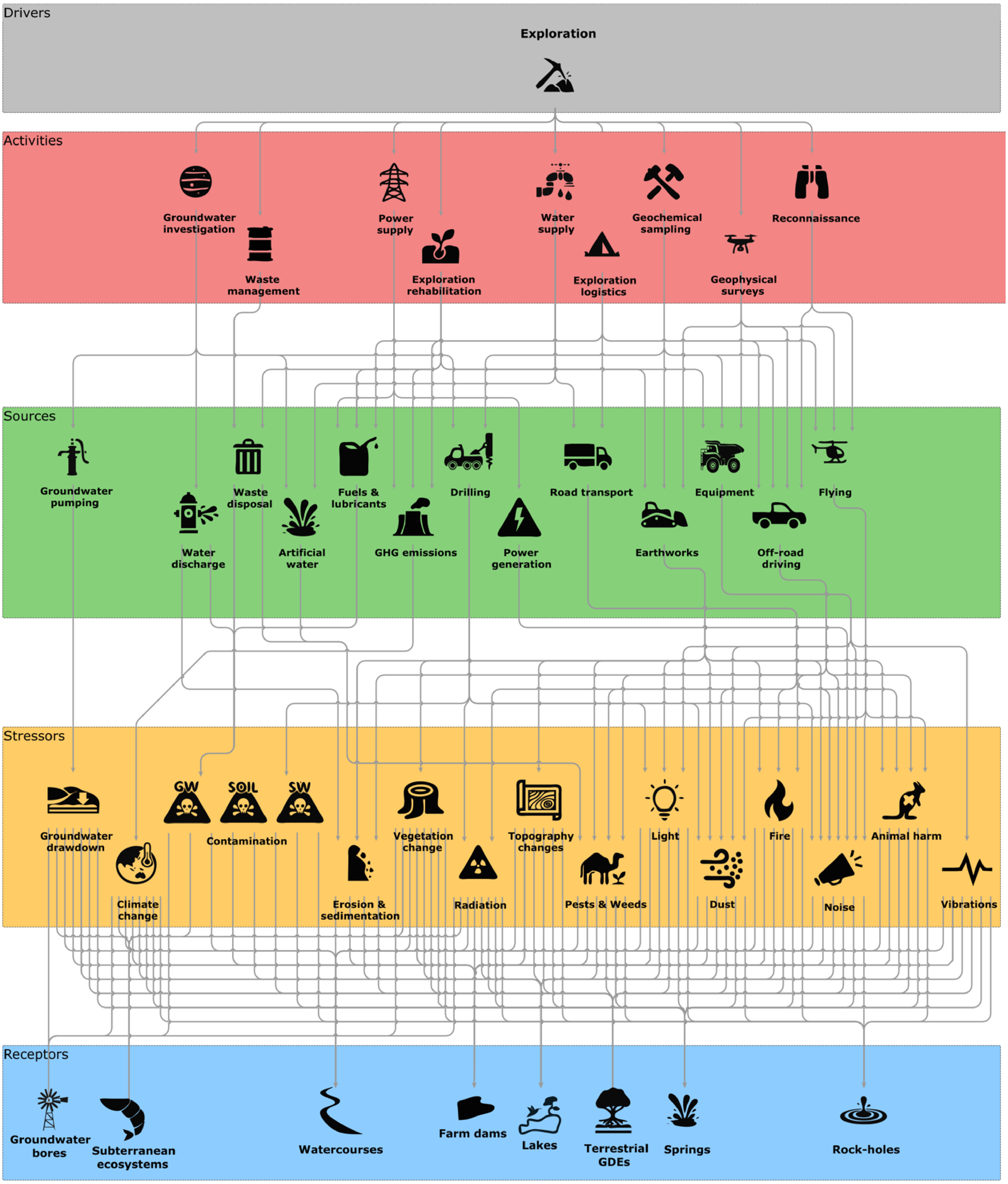
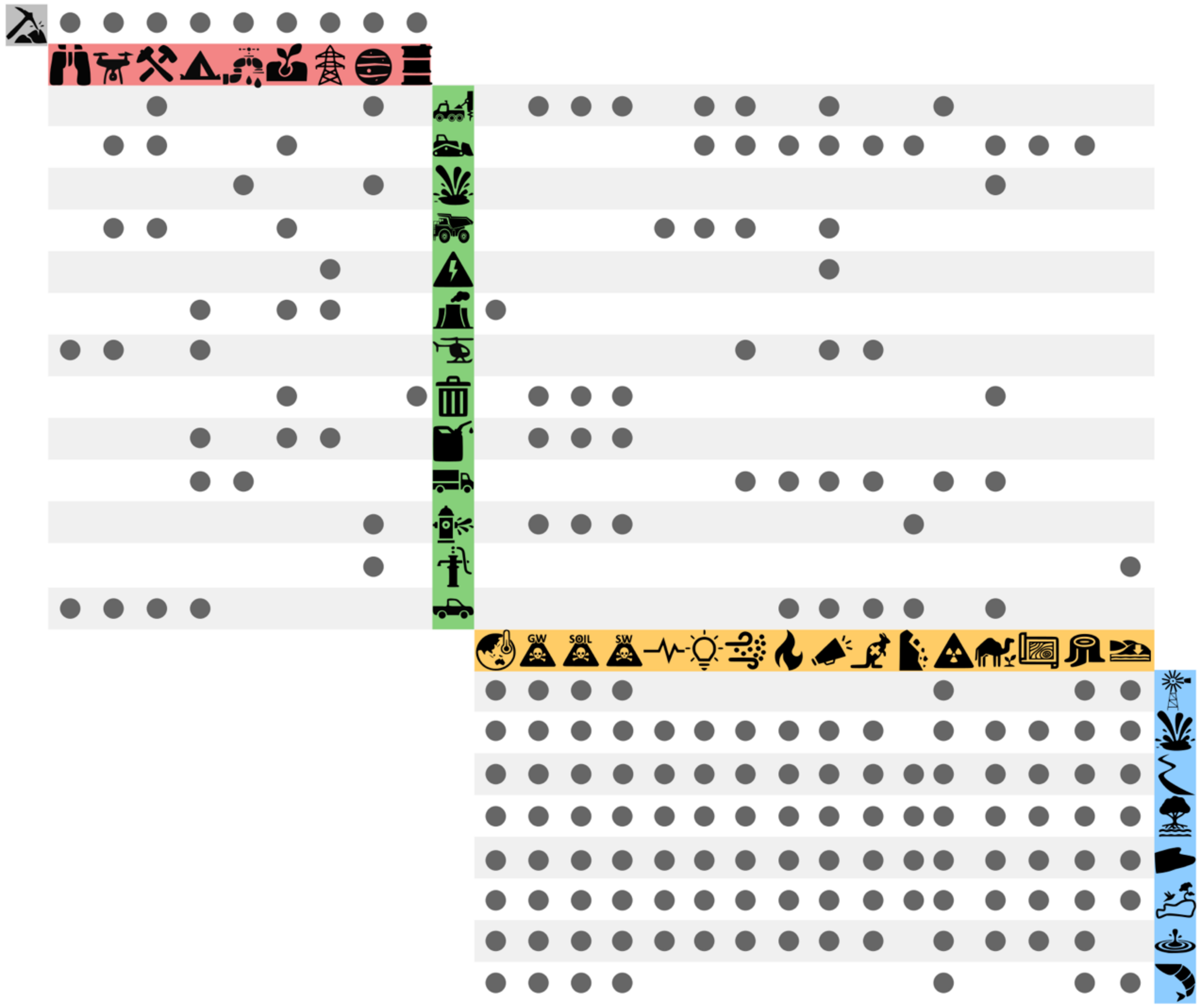



*Figure 2. Impact pathway diagram for the exploration phase of open-pit, underground and in situ recovery mining (figure designed to be printed on A3).*

# Impact pathway diagram exploration phase mining



## Drivers

- Exploration

## Activities

- Reconnaissance
- Geophysical surveys
- Geochemical sampling
- Exploration logistics
- Water supply
- Exploration rehabilitation
- Water supply
- Groundwater investigation
- Waste management

## Sources

- Drilling
- Earthworks
- Artificial water
- Equipment
- Power supply
- GHG emissions
- Flying
- Waste disposal
- Fuel and lubricants
- Road transport
- Water discharge
- Groundwater pumping
- Off-road driving

## Stressors

- Climate change
- Soil contamination
- Groundwater contamination
- Surface water contamination
- Vibration
- Light
- Dust
- Fire
- Sound
- Animal harm
- Erosion & sedimentation
- Radiation
- Pests & weeds
- Topography changes
- Vegetation change
- Groundwater drawdown

## Receptors

- Groundwater bores
- Springs
- Watercourse
- Groundwater dependent ecosystems
- Farm dams
- Lakes
- Rock-holes
- Subterranean ecosystems

*Figure 3 Impact pathway diagram in matrix form for the exploration phase of open-pit, underground and in situ recovery mining (figure designed to be printed on A3).*

## IMPACT PATHWAY DIAGRAM PRODUCTION PHASE

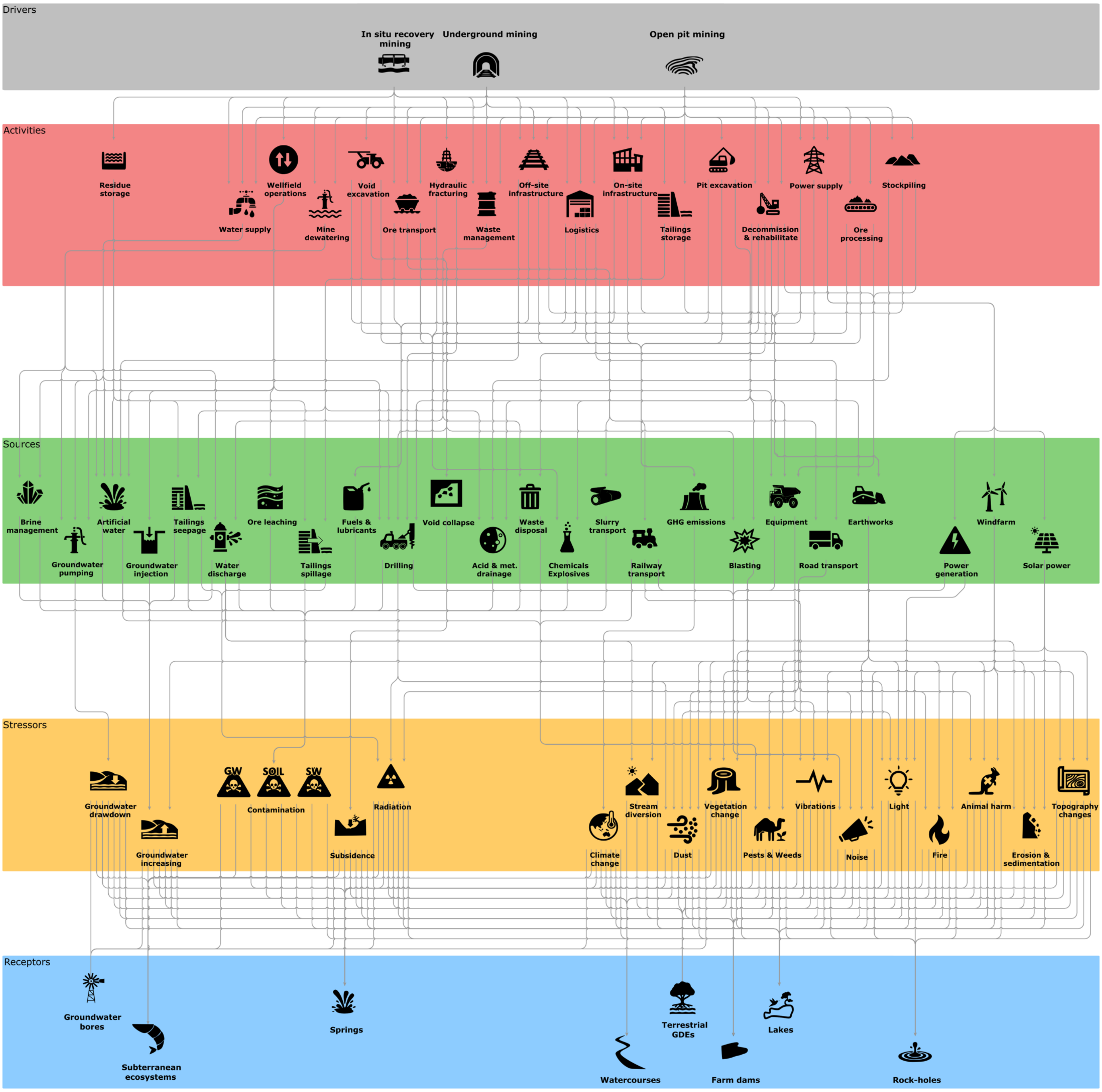



*Figure 4. Impact pathway diagram for the production phase of open-pit, underground and in situ recovery mining (figure designed to be printed on A3).*

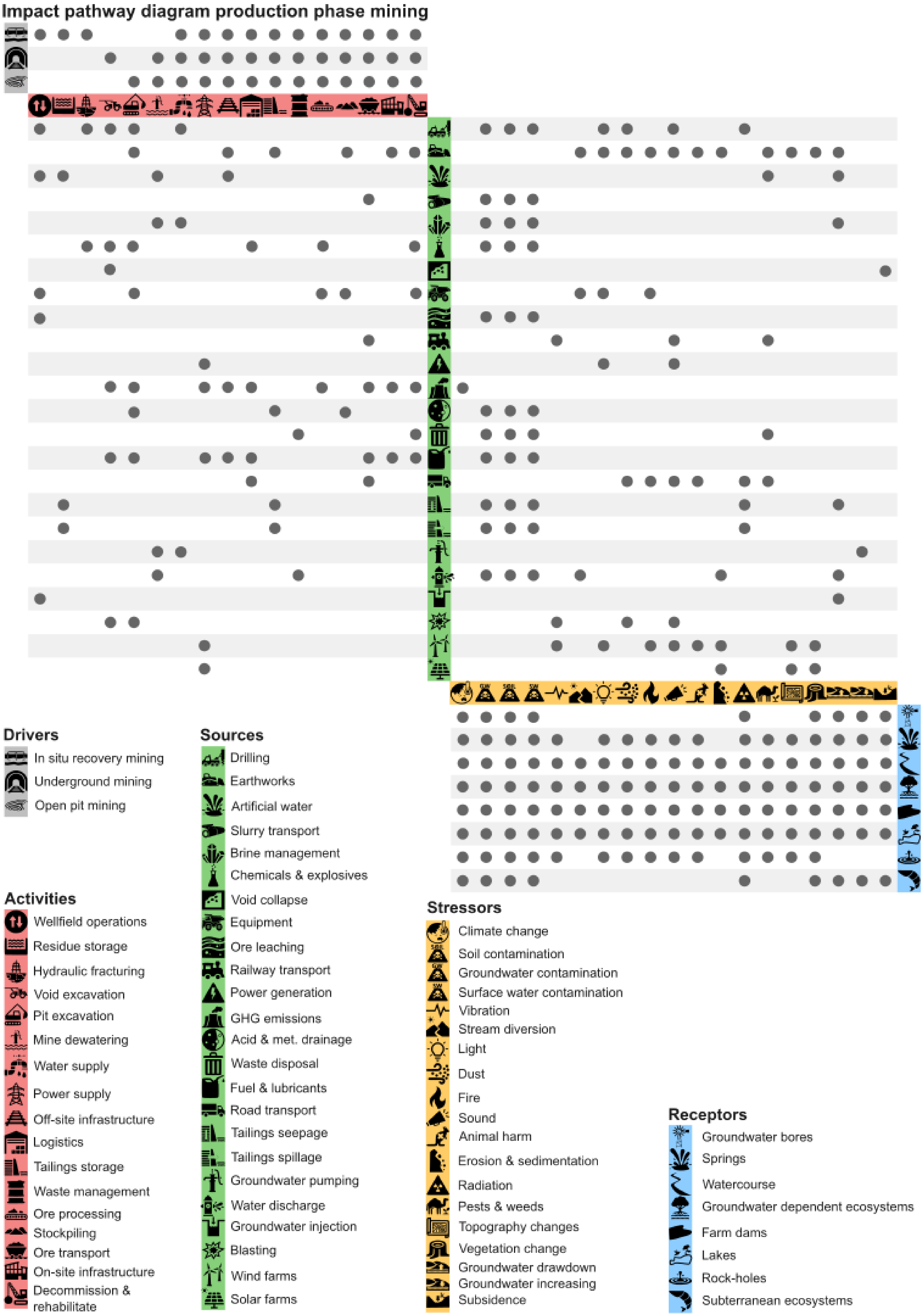



*Figure 5 Impact pathway diagram in matrix form for the production phase of open-pit, underground and in situ recovery mining (figure designed to be printed on A3).*

## IMPACT PATHWAY DIAGRAM POST-MINING PHASE

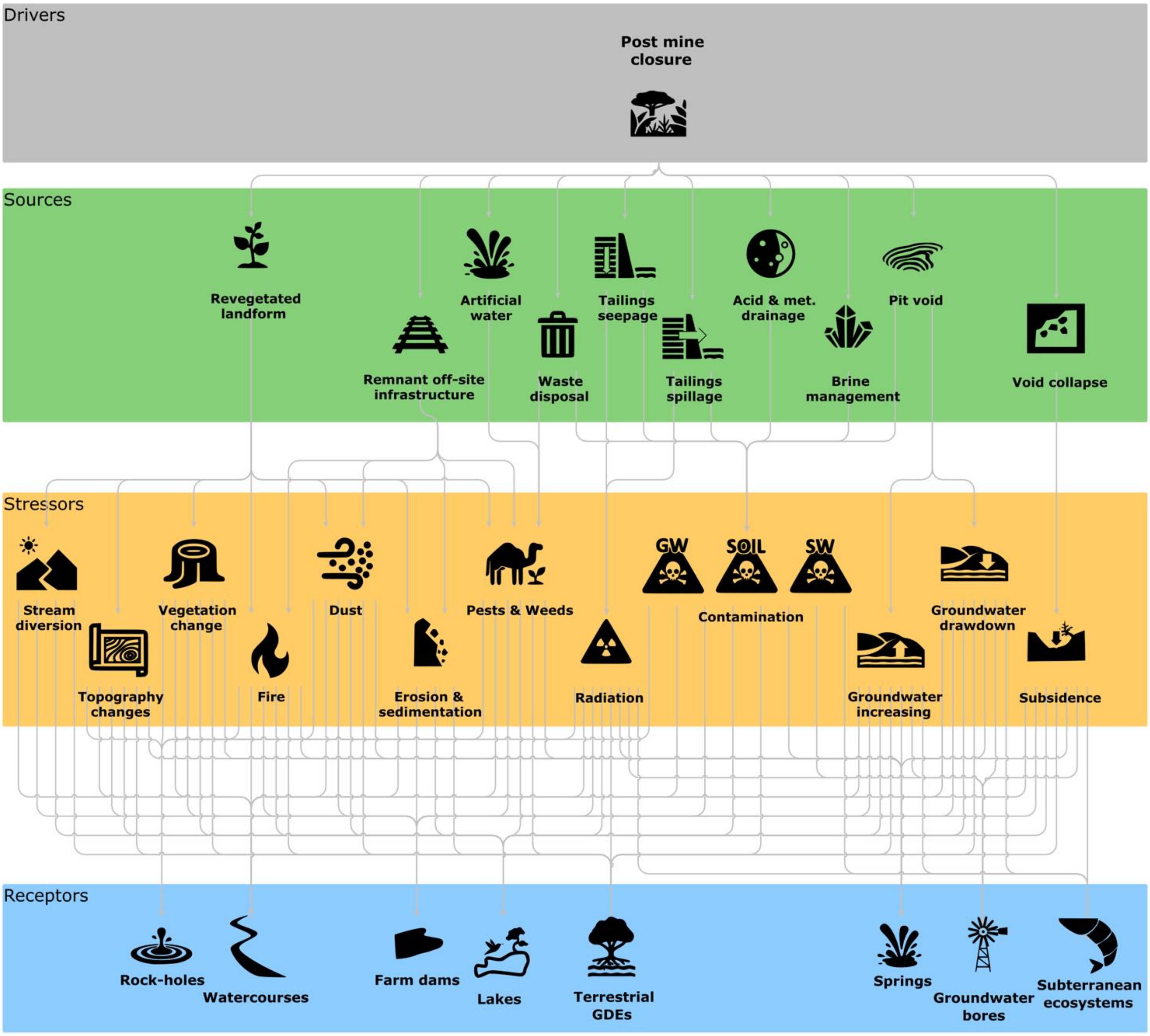
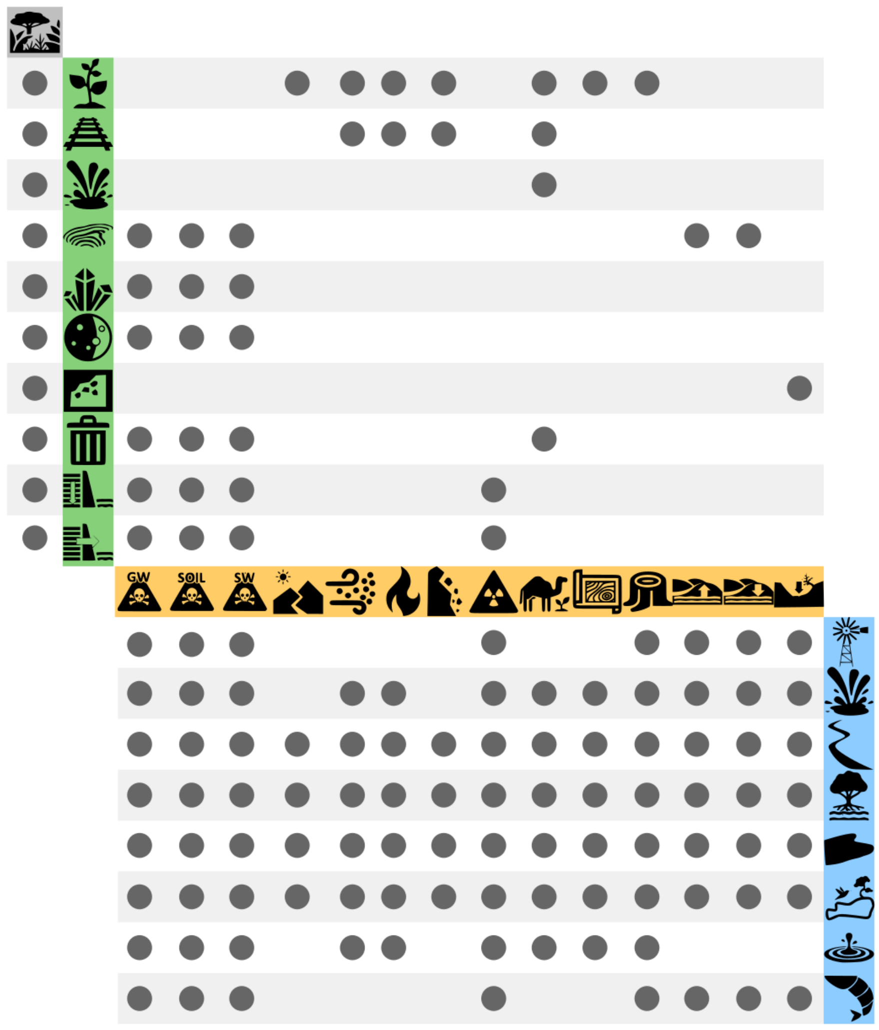



*Figure 6 Impact pathway diagram for the post-mining phase for open-pit, underground and in situ recovery mining (figure designed to be printed on A3)*

## Impact pathway diagram production phase mining



**Driver**

Post mine closure

**Sources**

- Revegetated landform
- Remnant off-site infrastructure
- Artificial water
- Pit void
- Brine management
- Acid & met. drainage
- Void collapse
- Waste disposal
- Tailings seepage
- Tailings spillage

**Stressors**

- Soil contamination
- Groundwater contamination
- Surface water contamination
- Stream diversion
- Dust
- Fire
- Erosion & sedimentation
- Radiation
- Pests & weeds
- Topography changes
- Vegetation change
- Groundwater drawdown
- Groundwater increasing
- Subsidence

**Receptors**

- Groundwater bores
- Springs
- Watercourse
- Groundwater dependent ecosystems
- Farm dams
- Lakes
- Rock-holes
- Subterranean ecosystems

*Figure 7 Impact pathway diagram in matrix format for the post-mining phase for open-pit, underground and in situ recovery mining (figure designed to be printed on A3)*

Fact Sheet

GOYDER INSTITUTE FOR WATER RESEARCH

# Open-pit mining activities and sources

## HIGHLIGHTS

- Open pit mining operations generally include activities associated with power and water supply, mine dewatering, pit excavation, ore processing and transport, stockpiling, tailings storage, waste management, infrastructure (on-site and off-site), logistics, decommissioning, and rehabilitation.
- The aspects of these activities (sources) which can cause changes in the environment include acid and metalliferous drainage, artificial water, blasting, brine management, chemicals and explosives, drilling, earthworks, equipment, fuel and lubricants, greenhouse gas emissions, groundwater pumping, hydraulic loading, power generation, railway transport, road transport, slurry transport, solar power, tailings seepage and spillage, waste disposal, water discharge and wind power.

## INTRODUCTION

Open pit mining (also known as open-cut or open-cast mining) is a surface mining technique where rock is removed in a series of levels or benches (Darling 2023). It is used when the ore is near the surface and the overburden (overlying rock) is thin. The technique is used to mine different commodities, including gold and copper, but it is especially suited for the extraction of larger lower-grade ore deposits, such as deposits of the iron-bearing minerals magnetite and hematite. Some mines start out as open pit mines and change to underground mining when the pit becomes too deep to operate safely and economically.

This fact sheet provides an overview of the activity and source components within the impact pathway diagram (IPD) for open pit mining operations (Figure 1). Complete IPDs for open pit mining operations are covered in more detail in Peeters (2024) and Peeters et al (2024).

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The Project was conducted with support from the South Australian government through the Department for Environment and Water and Department for Energy and Mining, South Australian Arid Lands Landscape Board and Eyre Peninsula Landscape Board.

The life cycle of an open pit mining development includes exploration, operation (production), decommissioning and rehabilitation (closure) and post-closure as well as care and maintenance if the mine pauses production (GSSB 2023; DEM 2021). Across each of these phases, mining activities affect water-dependent ecosystems via a complex network of interconnected ecohydrological pathways. These pathways include a driver, activities, sources, stressors and receptors and can be represented in an IPD.

**Activities** (Figure 2) are the high-level actions that are typically needed to develop a resource. **Sources** (**Error! Reference source not found.**) are the aspects of activities that may cause changes in the environment. The following sections discuss the activities and sources during operation (and care and maintenance) in more detail. They are grouped in topics such as excavation and ore processing, tailings and waste management, infrastructure development, water supply and management, power supply, ore transport, and closure (decommissioning and rehabilitation).

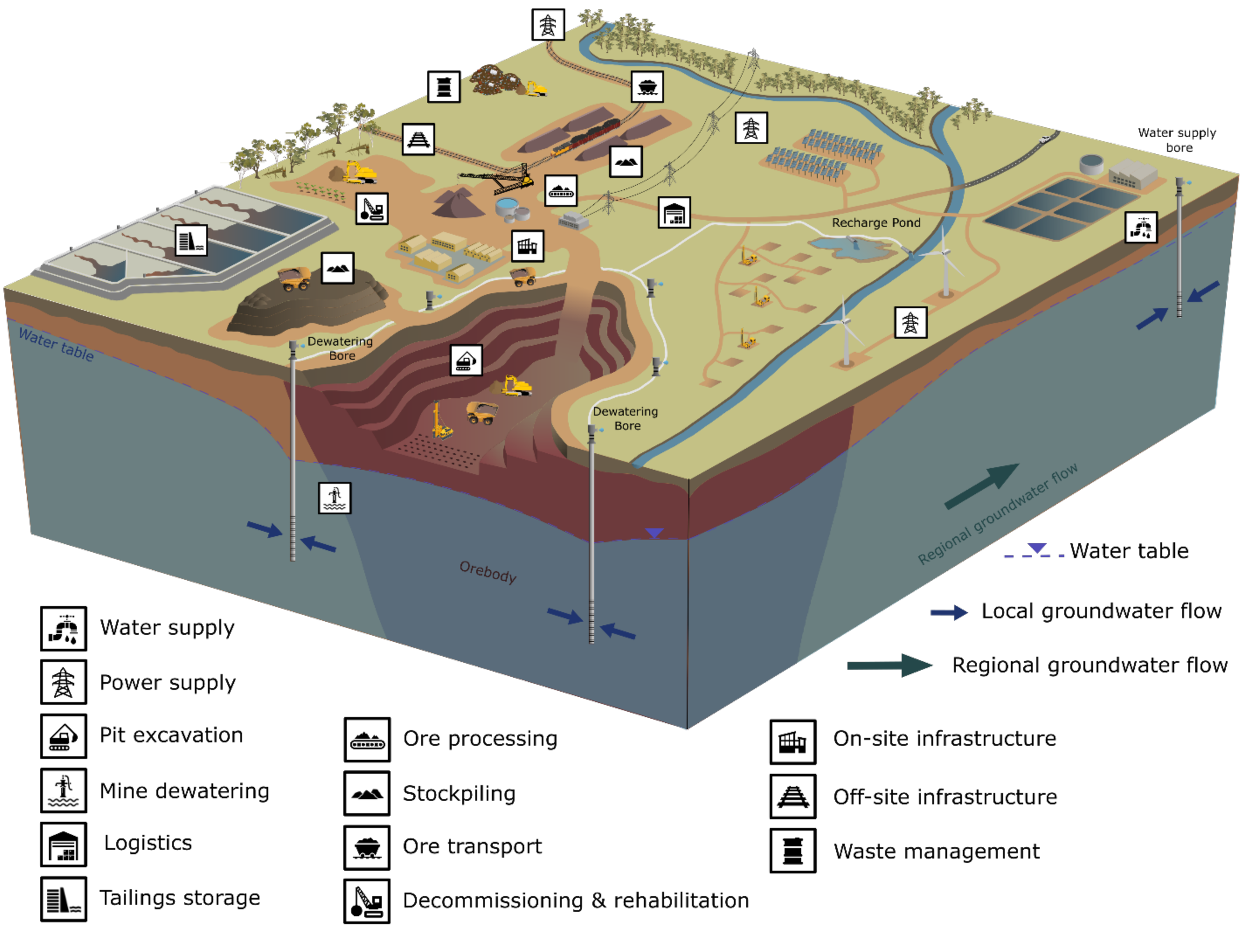


*Figure 1. Pictorial conceptual diagram of activities and sources of open pit mining (not to scale)*

## INFRASTRUCTURE DEVELOPMENT

On-site infrastructure, such as workshops, warehouses, offices and accommodation, is needed for operational support. This infrastructure expands the spatial footprint of the mine and requires additional earthworks and land clearance. It also includes facilities to store chemicals, explosives, fuel and lubricants, which are designed to minimise the risk of soil, air or water contamination during substance handling and storage. Mine operations also include light vehicle movements on the site to transport material, chemicals and personnel. Off-site infrastructure, such as roads, railways, transmission lines and pipelines, extends the spatial footprint beyond the mine site. Transport of material and personnel on sealed and unsealed roads can increase traffic locally.

## POWERING THE MINE

Power supply options include connection to the state-owned electricity distribution network, renewable energy generation (e.g. solar or wind), gas or use of on-site diesel-fuelled generators. Fuel is also required to power mobile vehicles and machinery, but the mining industry is increasingly adopting low-emission options, such as electric battery-powered vehicles, to offset or reduce their greenhouse gas emissions.

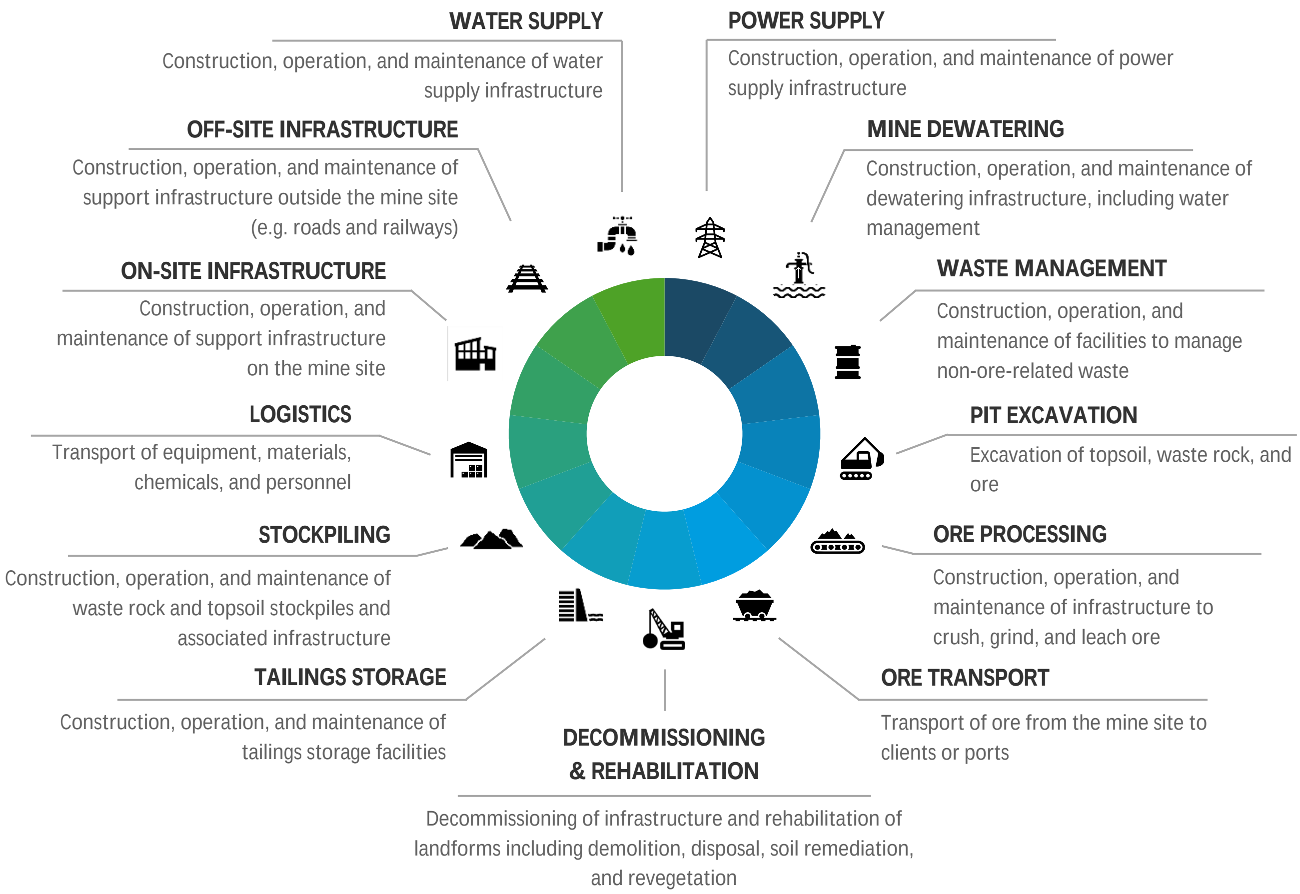


*Figure 1. Open pit mining activities undertaken during the operational period*

## WATER SUPPLY AND MANAGEMENT

Mine dewatering is a process where production wells are drilled close to the pit and groundwater is abstracted at a rate high enough to lower the water table. This is required where open pits extend below the water table to allow the extraction of the mineral resources. Dewatering can also occur directly within the pit if sumps are installed to intercept water and pump it out of the pit. The dewatering requirements depend on the excavation depth of the pit and the local hydraulic properties of the aquifer. For example, the proposed Maldorky iron ore project in the Braemar region estimates it will require mine dewatering rates of up to 4,061 kL/day (Currie et al, 2023).

Water supplied by mine dewatering can be used for dust suppression and on-site processing. Water supplied by mine dewatering may not be of sufficient quantity or quality to meet the needs of drilling, construction, dust suppression, potable use and processing. If this is the case, the mine will need to source additional water via groundwater extracted from a distant bore field or elsewhere (e.g. mains water or desalination).

The water supply for the Maldorky iron ore project includes an estimated 2,113 kL/day of groundwater from additional bores as well as the supply from dewatering. An estimated 691 kL/day is required for mine and construction use, 1,790 kL/day is needed for treatment (reverse osmosis) to produce 4 kL/day of potable water, 538 kL/day of rinse water is needed for plant operations and 1,248 kL/day for high salinity brine, among other requirements (Currie et al, 2023). It is not possible to obtain surface water as there is little to no available surface water in the Braemar, Stuart Shelf and

Northern Eyre regions (Currie and Richardson 2022; Currie 2023). Some projects may pipe in surface water from outside the region.

Additional water supply from outside the region will introduce more water where previously no water was present (artificial water), such as in turkey's nests (dams), ponds, from leaky taps and pipelines and in puddles, making more surface water available for both native and invasive plants and animals. Despite the limited water availability, some mining sites may produce more water from dewatering than can be used at the mine site at that time. Such excess water can be recharged (via a pond), reinjected into underlying aquifers (known as managed aquifer recharge or MAR), or discharged to nearby creeks. Water quality is a major concern when releasing mine dewatering water back into the environment. It is important to make sure that its quality is similar to that of the receiving water.

## MATERIAL EXCAVATION AND PROCESSING

An open pit mine requires land clearing and earthworks to access the underlying soil and rock to excavate the pit, grade the surface, lay the foundations for associated infrastructure, and stockpile removed soil and vegetation. The process of mining the ore is commonly referred to as drill, blast, load and haul. First, a series of holes are drilled in close proximity and filled with explosives, such as ammonium nitrate fuel oil (ANFO) or bulk emulsion explosives (EE), to loosen the ore and overburden. The material is excavated and loaded out of the pit using mobile equipment, such as excavators and haul trucks. Excavation and explosion activities alternate progressively and deepen the pit over time. Some deposits, like kaolin, are sufficiently soft that they can be excavated without using explosives.

The ore is processed mechanically and chemically to extract the commercially-valuable minerals. Processing facilities contain stationary equipment and conveyor belts. The type of processing depends on the commodity. For example, magnetite processing generally includes crushing, grinding, concentrating (using dry magnetic separation), and flotation to remove the sulfur-bearing material. Gold can be extracted by crushing and blending the ore with lime, treating the ore (e.g. heap-leaching with cyanide) and adsorption onto activated carbon.

## MANAGING TAILINGS AND WASTE

Soil and rock are stored in stockpiles around the mine. Tailings, often in the form of a slurry) are the left-over materials (by-products) from ore processing. They are stored in a tailings storage facility (TSF) and dried out. A TSF, much like a pond or dam, is designed, engineered, and constructed to permanently store tailings during mine operation and also long after the mine has closed (see also Thomas and Peeters, 2024). Stockpiles of waste rock, ore, tailings and the open pits themselves can be sources of acid and metalliferous drainage (AMD) (DISR 2016c). AMD has a pH $< 6$ and high concentration of dissolved metals. It occurs when sulfidic materials (such as pyrite) are disturbed and oxidised from exposure to the atmosphere.

Wastes such as brine, wastewater and solid waste also require management and disposal. Brine is highly saline water produced by water treatment and processing or from mine dewatering and it is often managed with wastewater in evaporation ponds. Solid waste that can't be recycled is commonly disposed of to landfill.

## TRANSPORTING THE PRODUCT TO THE END USER

The processed ore is transported by road, rail or pipeline (as slurry) to domestic customers or to a port for international export. For example, the Middleback Range Iron Duke mine on the Eyre Peninsula delivers magnetite along a 62 kilometre underground slurry pipeline to Whyalla.

## MINE CLOSURE

The whole-of-life mine process aims to culminate in tenement relinquishment and the minimisation or avoidance of further environmental impacts (DISR 2016b). Activities undertaken to advance a mining operation toward closure include:

- site decommission and rehabilitation, where equipment, infrastructure, chemical and explosives storage facilities (e.g. underground fuel storage tanks and ANFO facilities) are demolished, decontaminated, decommissioned and removed

- waste removal and disposal
- environmental emission (e.g. GHG) monitoring (EPA, 2016).

Rehabilitation includes earthworks to reshape and remediate mining landforms, re-establish surface hydrology and drainage systems, and revegetate the landscape to establish sustainable ecosystems or alternative land uses (DISR, 2016a and 2016b).

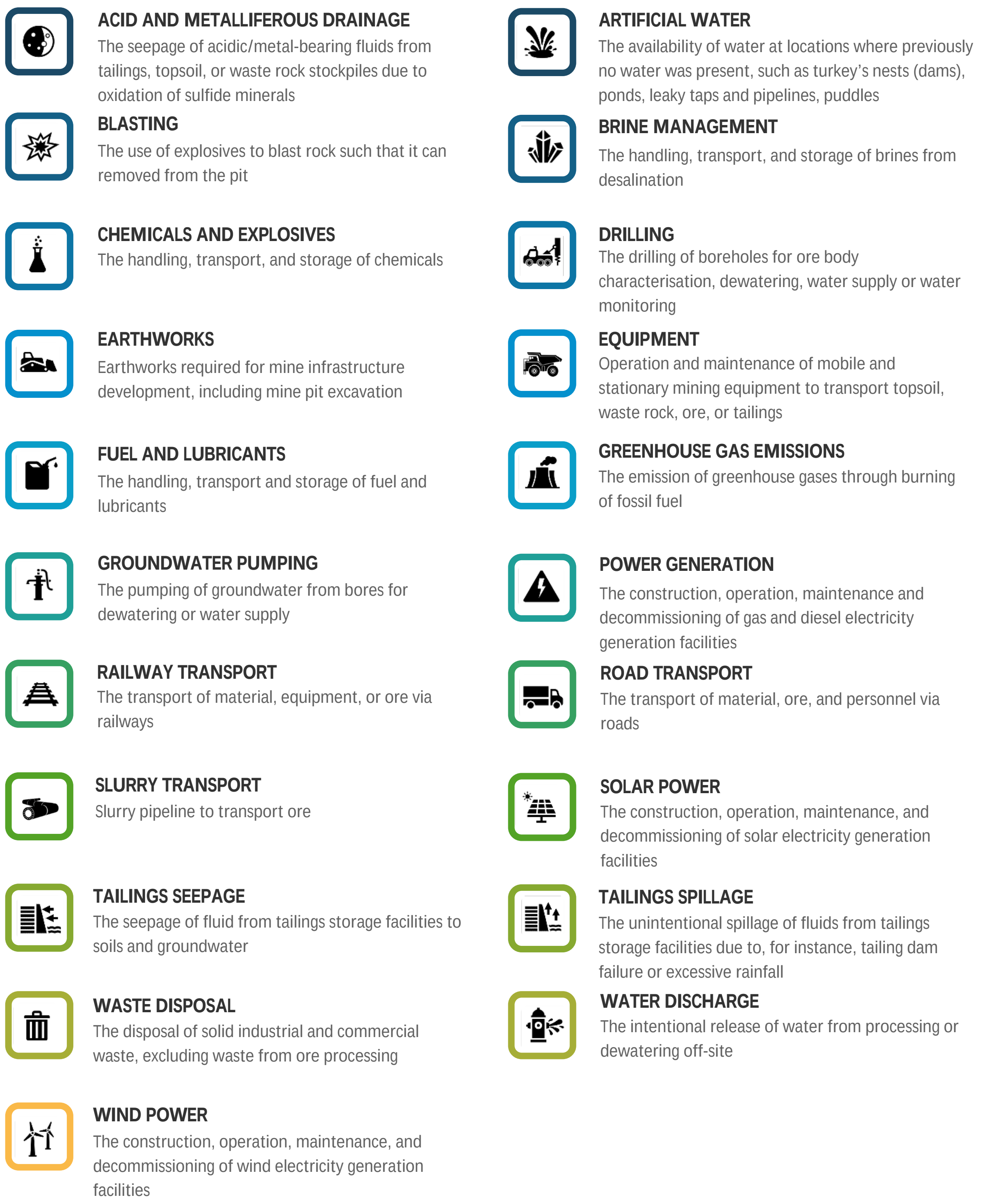


*Figure 3. Sources that can cause changes in the environment from activities related to open pit mining*

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Government of South Australia Department for Environment and Water | CSIRO | Flinders University | THE UNIVERSITY of ADELAIDE | University of South Australia

Fact Sheet

GOYDER INSTITUTE FOR WATER RESEARCH

# Underground mining activities and sources

## HIGHLIGHTS

- Underground mining operations generally include activities associated with power and water supply, mine dewatering, waste management, void excavation, ore processing and transport, stockpiling, tailings storage, logistics, on-site and off-site infrastructure, decommissioning and rehabilitation.
- The aspects of these activities (sources) which can cause changes in the environment include acid and metalliferous drainage, artificial water, blasting, brine management, chemicals and explosives, drilling, earthworks, equipment, fuel and lubricants, greenhouse gas emissions, groundwater pumping, hydraulic loading, power generation, railway transport, road transport, slurry transport, solar power, tailings seepage and spillage, void collapse, waste disposal, water discharge and wind power.

## INTRODUCTION

Underground mining is a mining technique considered when an ore body lies beneath a thick overburden (which can be as thick as several hundred metres). Surface mining becomes economically-prohibitive when a large amount of overlying waste rock must be removed to access an ore body.

This fact sheet provides an overview of the activity and source components within the impact pathway diagram (IPD) for underground mining operations (Figure 1). Complete IPDs for underground mining operations are covered in more detail in Peeters (2024) and Peeters et al (2024).

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The life cycle of an underground mine includes exploration, operation (production), decommissioning and rehabilitation (closure) and post-closure as well as care and maintenance if the mine pauses production. Across each of these phases, mining activities affect water-dependent ecosystems via a complex network of interconnected ecohydrological pathways. These pathways include a driver, activities, sources, stressors and receptors and can be represented in an IPD.

**Activities** (Figure 2) are the high-level actions that are typically needed to develop a resource. **Sources** (Figure 1) are the aspects of activities that may cause changes in the environment. The following sections discuss the activities and sources in more detail and are grouped into topics such as excavation and ore processing, tailings and waste management, infrastructure development, water supply and management, power supply and ore transport.

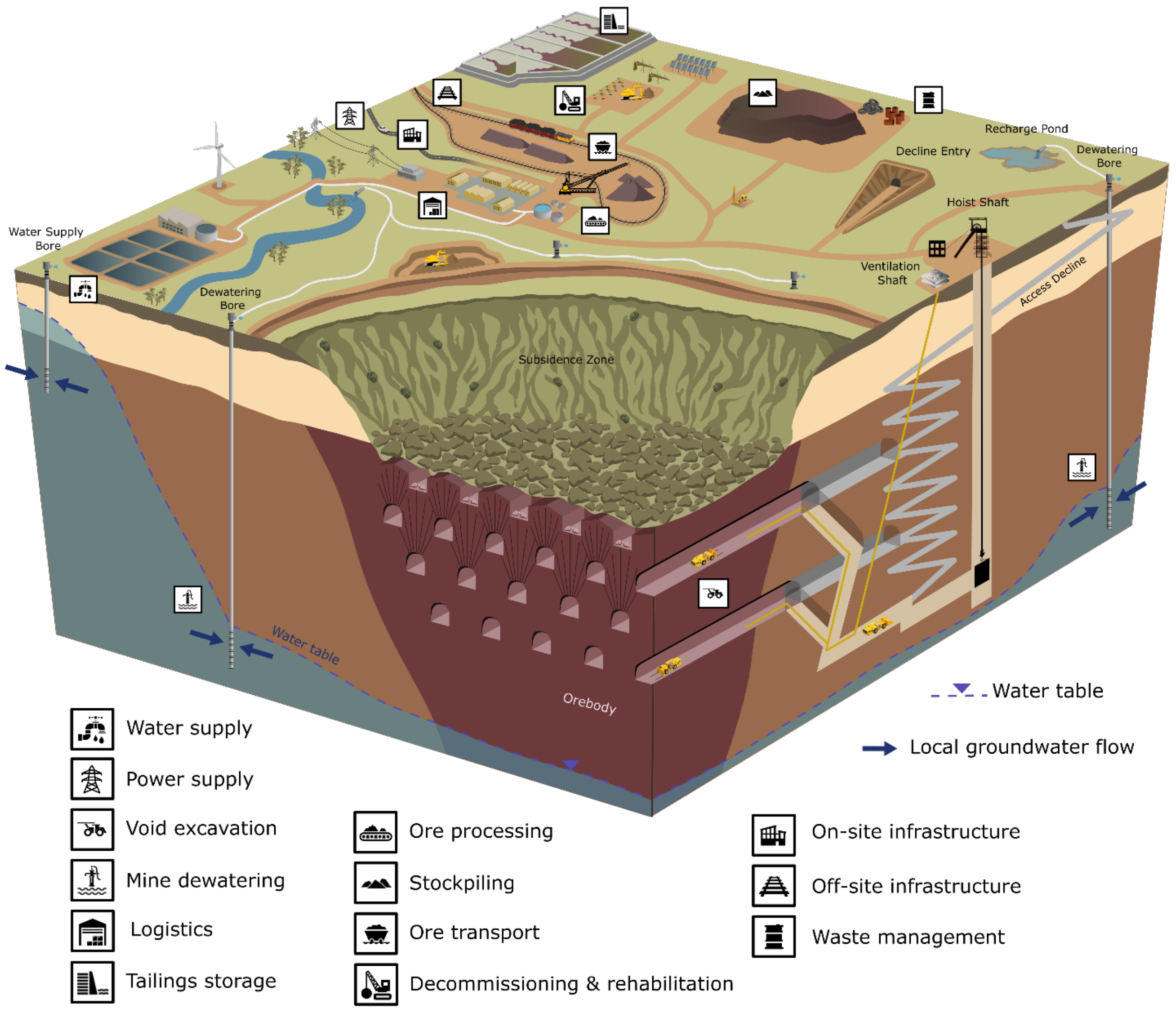


*Figure 1. Pictorial conceptual diagram of activities and sources of underground mining (not to scale)*

## INFRASTRUCTURE DEVELOPMENT

Extracting ore under deep cover requires extensive underground infrastructure. This comprises a network of interconnected declines, shafts and adits excavated to hoist ore to the surface, provide ventilation or transport workers and supplies (Cline et al, 2023). Declines are ramps which begin at a surface portal (box cut) and spiral downward, either around or alongside the orebody. Shafts are vertical (or near-vertical) openings from the surface to the deposit. Adits are horizontal openings. Tunnels (drifts) are excavated horizontally from the shafts or declines to the orebody. The Olympic Dam Mine has almost 700 km of underground roads and tunnels (BHP, 2023).

On-site surface supporting infrastructure like workshops, warehouses, offices and accommodation is needed to support mine operation. It also includes facilities for the storage of chemicals, explosives, fuel and lubricants, which are designed to minimise the risk of soil, air or water contamination during substance handling and storage. The mine operation also includes logistical activities such as transporting material, chemicals and personnel with light vehicles. Off-site infrastructure, such as roads, railways, transmission lines and pipelines, extend the spatial footprint beyond the mine site.

## POWERING THE MINE

Electricity for construction activities is commonly supplied via on-site (diesel) generation. Operational electricity demands can be met through connection to the South Australian electricity network, where overhead transmission lines connect substations within the mine to the network. The electricity is distributed throughout the mine using electrical infrastructure. During operation, mines often supplement network connections with on-site diesel generation, but the burning of diesel fuel emits a considerable amount of greenhouse gas (GHG).

The transition to net-zero GHG emissions and the current environment, social and governance (ESG) standards are driving an increase in the use of renewable energy, such as solar and wind, to power mining operations (Nadig, 2024). For example, the Olympic Dam Mine aims to source 70 MW of electricity by mid-2025 from wind power generated as part of the Goyder Renewables Zone project (BHP, 2022).

## WATER SUPPLY AND MANAGEMENT

Mine water management is a significant challenge for underground mining operations. The inflow of water (mostly groundwater but also surface water) into an underground mine presents a flooding and stability risk. The methods used to control groundwater inflows into an underground mine depend on the hydrogeological conditions, but can include dewatering wells, drains (boreholes in which water is gravity-fed into sumps and then pumped from the mine) (Cline et al, 2023) and borehole grouting (pumping grout/cement into boreholes to seal fractures) (St. Louis et al, 2023).

Water is also needed for road, hardstand, building and stockpile foundation construction works as well as concrete manufacture, drilling, dust suppression, mineral processing, potable purposes and, in some cases, the preparation of material for backfilling (OZ Minerals, 2017; St. Louis et al. 2023). Where water demands cannot be entirely met from mine dewatering, due to limited volumes or unsuitable quality, water can be sourced from nearby groundwater resources, mains supply or desalination. For example, the Carrapateena Mine sources water from local groundwater resources within 50 km of the mine. The Olympic Dam Mine sourced an average of 26 ML/day during 2021-22 from the groundwater resources of the Great Artesian Basin (GAB) (BHP, 2022). The ongoing demand for groundwater sourced from GAB well fields is projected to be around 351 ML/day to 2031 (Currie et al, 2023).

Water distribution around a mine site occurs via pipelines and transfer stations. These have the potential to leak and create artificial sources of water. During construction, groundwater is pumped to a tank or a lined turkey's nest (dam) and this also creates an artificial source of water before the water is transferred to water-carting trucks or pumped to processing facilities. Other sources of artificial water include open-water storage infrastructure such as ponds.

Despite limited water availability, some mines may produce more water from dewatering than can be used at the mine site at that time. Excess water can be recharged (via a pond), reinjected into underlying aquifers (a process known as managed aquifer recharge or MAR) or discharged to nearby creeks. Water quality is a major concern when releasing mine dewatering water back into the environment. It's important to make sure that its quality is similar to that of the receiving water.

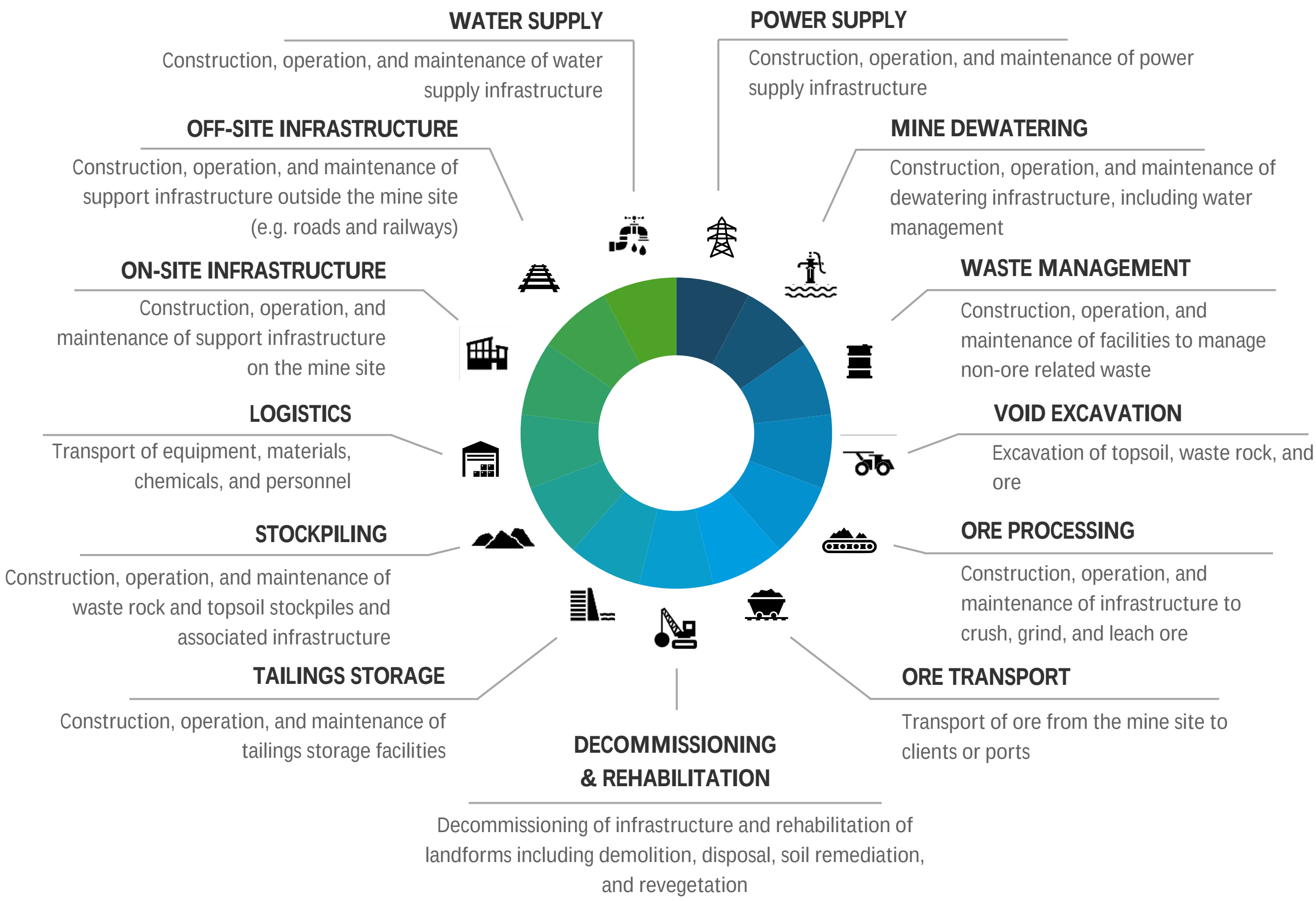


***Figure 2. Underground mining activities undertaken during the operational life cycle phase and their component boundaries***

## MATERIAL EXCAVATION AND PROCESSING

The most common excavation method in underground mining is a repetitive cycle of drilling and blasting. Blastholes are drilled into the orebody, flushed, loaded with explosives (such as ammonium nitrate fuel oil (ANFO) or bulk emulsion explosives (EE)), charged and prepared for blast initiation. The blasting loosens the ore (or ‘muck’) for removal by load-haul-dump (LHD) loaders. Diesel-engine LHD loaders and equipment make up a significant portion of a mine site’s mobile equipment fleet and consume large amounts of diesel fuel (Humphrey et al, 2023). Given the focus on reducing GHG emissions, companies are looking to alternative technologies, such as batteries and hydrogen fuel cells, to replace or at least supplement the use of diesel engines in mobile equipment over the coming decade.

Dust and fumes are removed via ventilation shafts which move air into and out of the underground mine. The ore is transferred by LHD loaders and equipment to an ore pass (a (sub)vertical raise) to gravity-feed ore from upper levels to lower levels. This ore excavation process creates openings or voids.

There are a number of different excavation configurations used to mine an orebody underground. These are determined by the geometry, dip (angle), and other physical and chemical properties of the orebody (Hambley, 2023). The room-and-pillar method is common for flat-lying deposits. Stoping, cut-and-fill and sublevel caving methods are common for steeply dipping deposits. Block caving is a method developed for massive deposits (Clark et al, 2024). For example, the Carrapateena Mine in the Stuart Shelf uses sub-level caving and sub-level open stoping (OZ Minerals, 2017).

Depending on the excavation configuration employed, voids may be backfilled using: a paste or other type of cemented fill; uncemented waste rock from the mine; or left open, which is common with caving operations. In caving operations, the mine voids are filled via the collapse of the overlying rock material. This causes the ground surface to subside (Figure 1).

Ore is processed mechanically and chemically using processing facilities to extract the commercially-valuable minerals. The type of ore processing depends on the commodity. For example, copper concentrate is produced via conventional crushing, grinding, flotation, and concentrate treatment processes such as thickening and filtering. Depending on the mine layout, crushing can be completed underground in a crushing chamber before material is hoisted by a shaft or conveyed along a decline system to the surface. Underground crusher chambers can be the largest excavation and infrastructure development in an underground mine (Cline et al, 2023). Following crushing, the ore is ground into smaller particle sizes using a mill and transferred into flotation tanks, where the ore slurry is separated into a copper-rich concentrate and a uranium-rich tailings stream. The copper concentrate is further processed by thickening, filtering, smelting and refining using sulphuric acid and copper sulphate.

## MANAGING TAILINGS AND WASTE

Mining and processing operations generate mineral and non-mineral wastes which can be classified as hazardous or non-hazardous. Mineral waste from underground mining typically includes overburden, waste rock, low-grade mineralised material and tailings from ore processing (Snow and Morrison, 2023). Waste rock and overburden would preferentially be used in backfilling underground voids or otherwise stockpiled in a waste rock dump (WRD). Low-grade mineralised material is also stockpiled. Tailings are the left-over materials (by-products) from the processing of ore, often in the form of a slurry, and include fine-grained mineral waste, process water and chemical reagents. Tailings storage facilities (TSF) are constructed for the disposal or indefinite storage of tailings and they are designed to minimise seepage and prevent spillage from embankment failure. Mineral wastes have the potential to be a source of acid and metalliferous drainage (AMD) depending on their geochemical properties (e.g. the presence of oxidised pyrite). AMD is typically characterised by concentrated dissolved metals and a pH <6.

Non-mineral industrial and hazardous waste include used oils and debris, spent reagents, solvents, greases, coolants, batteries and used paints (Snow and Morrison, 2023). These wastes are generally transferred off-site by contractors for disposal or recycling. Non-mineral, non-hazardous waste includes construction debris, packaging materials, used tyres and general office waste which may be recycled, sent to an off-site solid waste landfill or disposed of in a permitted on-site landfill.

Wastewater such as: high-salinity reject water (brine) from reverse osmosis; low-quality impacted water with elevated levels of suspended solids, hydrocarbons and nitrogen species (nitrate and ammonia) resulting from blast residue (St. Louis et al 2023); and sewage also require management and disposal. Options for brine management include treatment and re-use in the processing plant, transfer into a TSF. or disposal via aquifer injection using permitted groundwater injection wells (OZ Minerals, 2017). Surplus tailings water decanted (drained) from the TSF is managed using evaporation ponds.

## TRANSPORTING THE PRODUCT TO THE END USER

There are several methods for transporting the final product from the site over long distances to the distribution point (e.g. port or end user) which include trucks via roads, trains via railways or slurry pipelines. Long-distance slurry pipelines transport products including ore, concentrate, and/or tailings mixed with water (Ihle and Valencia, 2023). Pipelines do not produce a noise or dust problem, as is common with trucking or railway transport, but a significant amount of water is required for slurry preparation.

## MINE CLOSURE

The whole-of-life mine process aims to culminate in tenement relinquishment and the minimisation or avoidance of further environmental impacts. Activities undertaken to advance a mining operation to closure include:

- site decommission and rehabilitation, where equipment, infrastructure, chemical and explosives storage facilities (e.g. underground fuel storage tanks and ANFO facilities) are demolished, decontaminated, decommissioned and removed
- waste removal and disposal
- environmental emission (e.g. GHG) monitoring (EPA, 2016).

Rehabilitation includes earthworks to reshape and remediate mining landforms, re-establish surface hydrology and drainage systems, and revegetate the landscape to establish sustainable ecosystems or alternative land uses (DFAT, 2016a and 2016b).

**ACID AND METALLIFEROUS DRAINAGE**
The seepage of acidic/metal-bearing fluids from tailings, topsoil, or waste rock stockpiles due to oxidation of sulfide minerals

**ARTIFICIAL WATER**
The availability of water at locations where previously no water was present, such as turkey's nests (dams), ponds, leaky taps and pipelines, puddles

**BLASTING**
The use of explosives to blast rock such that it can removed from the pit

**BRINE MANAGEMENT**
The handling, transport, and storage of brines from desalination

**CHEMICALS AND EXPLOSIVES**
The handling, transport, and storage of chemicals

**DRILLING**
The drilling of boreholes for ore body characterisation, dewatering, water supply or water monitoring

**EARTHWORKS**
Earthworks required for mine infrastructure development, including mine pit excavation

**EQUIPMENT**
Operation and maintenance of mobile and stationary mining equipment to transport topsoil, waste rock, ore, or tailings

**FUEL AND LUBRICANTS**
The handling, transport and storage of fuel and lubricants

**GREENHOUSE GAS EMISSIONS**
The emission of greenhouse gases through burning of fossil fuel

**GROUNDWATER PUMPING**
The pumping of groundwater from bores for dewatering or water supply

**POWER GENERATION**
The construction, operation, maintenance and decommissioning of gas and diesel electricity generation facilities

**RAILWAY TRANSPORT**
The transport of material, equipment, or ore via railways

**ROAD TRANSPORT**
The transport of material, ore, and personnel via roads

**SLURRY TRANSPORT**
Slurry pipeline to transport ore

**SOLAR POWER**
The construction, operation, maintenance, and decommissioning of solar electricity generation facilities

**TAILINGS SEEPAGE**
The seepage of fluid from tailings storage facilities to soils and groundwater

**TAILINGS SPILLAGE**
The unintentional spillage of fluids from tailings storage facilities due to, for instance, tailing dam failure or excessive rainfall

**VOID COLLAPSE**
Collapse of rock beneath the surface due to excavation

**WASTE DISPOSAL**
The disposal of solid industrial and commercial waste, excluding waste from ore processing

**WATER DISCHARGE**
The intentional release of water from processing or dewatering off-site

**WIND POWER**
The construction, operation, maintenance, and decommissioning of wind electricity generation facilities

*Figure 1. Sources that can cause changes in the environment from activities related to underground mining*

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Fact Sheet

# In situ recovery mining activities and sources

## HIGHLIGHTS

- In situ recovery mining operations generally include activities associated with power and water supply, wellfield operation, ore leaching, waste management, ore transport, residue storage, stockpiling, logistics, on-site and off-site infrastructure, decommissioning and rehabilitation.
- The aspects of these activities (sources) which can cause changes in the environment include acid and metalliferous drainage, artificial water, brine management, chemicals and explosives, drilling, earthworks, equipment, fuel and lubricants, greenhouse gas emissions, groundwater pumping, groundwater injection, hydraulic loading, power generation, railway transport, road transport, slurry transport, solar power, tailings seepage and spillage, waste disposal, water discharge and wind power.

## INTRODUCTION

In situ recovery (ISR) mining, also known as in situ leaching or solution mining, is an approach to mineral extraction where the ore remains in place in the ground – there is no need to move large volumes of rock as is typical for open pit or underground mining (DEM n.d.). Minerals within the ore are chemically dissolved with a leaching solution and pumped to the surface. ISR has been applied widely in uranium mining and, to a lesser extent, copper and gold mining. For example, solution mining of copper has been trialled at the Mutooroo deposit (Haque and Norgate, 2014).

This fact sheet provides an overview of the activity and source components within the impact pathway diagram (IPD) for ISR mining operations (Figure 1). Complete IPDs for ISR mining operations are covered in more detail in Peeters (2024) and Peeters et al (2024).


## PROJECT TEAM

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The life cycle of an ISR mine includes exploration, operation (production), decommissioning and rehabilitation (closure), and post-closure as well as care and maintenance if the mine pauses production (GSSB 2023; DEM 2020; DEM 2021a; DEM 2021b). Across each of these phases, mining activities affect water-dependent ecosystems via a complex network of interconnected ecohydrological pathways. These pathways include a driver, activities, sources, stressors and receptors and can be represented in an IPD.

**Activities** (Figure 2) are high-level actions that are needed to develop a resource. **Sources** (Figure 3) are aspects of activities that may cause changes in the environment. The following sections discuss the activities and sources during operation (and care and maintenance) in more detail and they are grouped into topics such as infrastructure development, power supply, ore leaching and solution processing, water supply and management, residue and waste management, transport and mine closure.

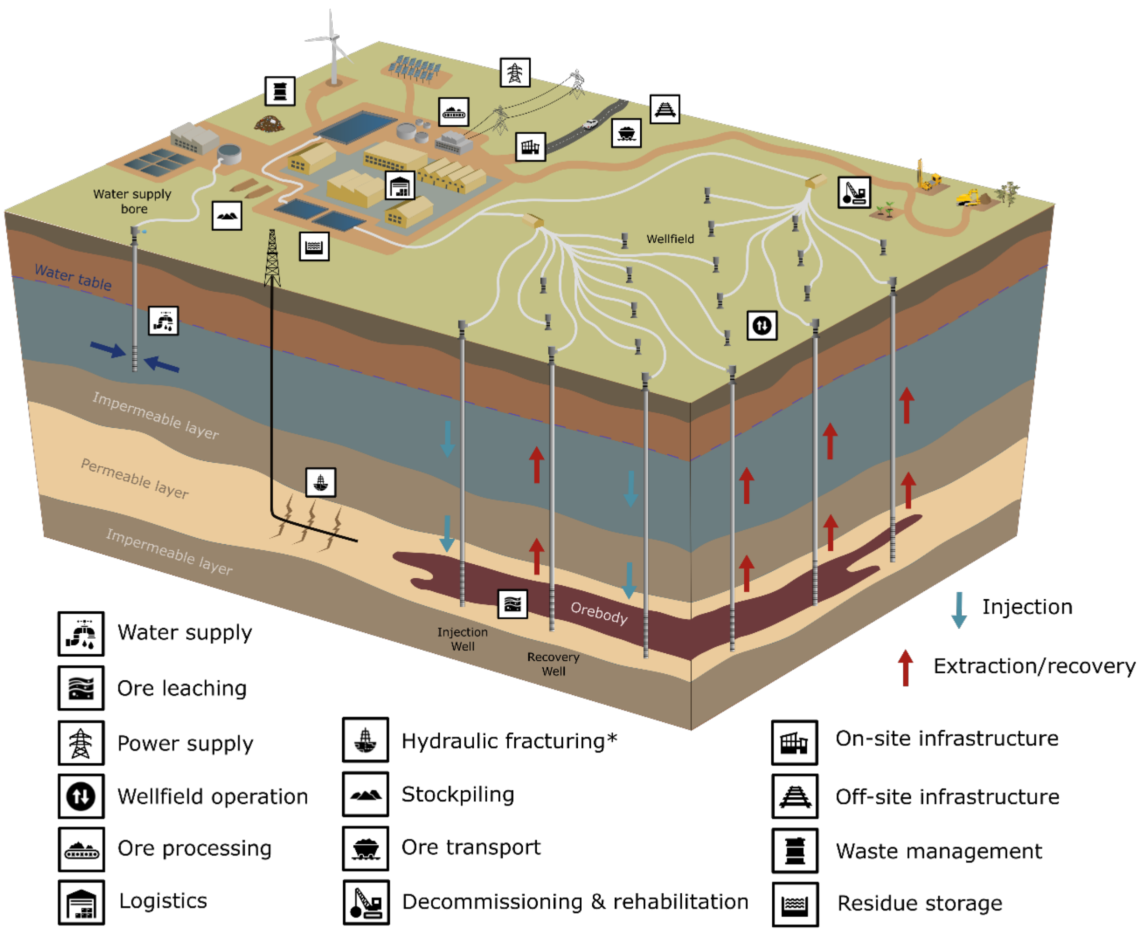


*Figure 1. Pictorial conceptual diagram of activities and sources of in situ recovery mining (not to scale)*
**Hydraulic fracturing is currently not undertaken in South Australia for ISR mining*

## INFRASTRUCTURE DEVELOPMENT

The infrastructure that supports ISR mining operations includes access roads, accommodation, offices and crib rooms, small laboratory facilities, communal mud-pits, laydown areas and fuel and chemical storage. The mine operation also includes logistical activities such as transporting material, chemicals and personnel with light vehicles.

## POWERING THE MINE

A power supply is needed to operate the mine facilities, which include a processing plant, wellfield, associated infrastructure and accommodation camp. Power can be supplied from various sources like fossil fuels (e.g. natural gas and diesel fuel) and renewable energy (e.g. solar and wind power). The Honeymoon Uranium Mine, to the north of the Braemar region, has a transmission line that connects the mine to the electricity grid network (Boss Energy, 2023). Diesel generators supply additional electricity where required. The Beverley Uranium Mine, near Lake Frome to the east of the Stuart Shelf region, uses natural gas from the Epic Moomba–Adelaide gas pipeline to drive gas engine-driven generators (Heathgate Resources, 2018). The burning of fossil fuels emits greenhouse gases (GHG) to the atmosphere. As a result, and in line with current environment, social and governance (ESG) standards, mining companies are increasingly investigating renewable energy options so they can transition to net-zero emissions (Nadig, 2024).

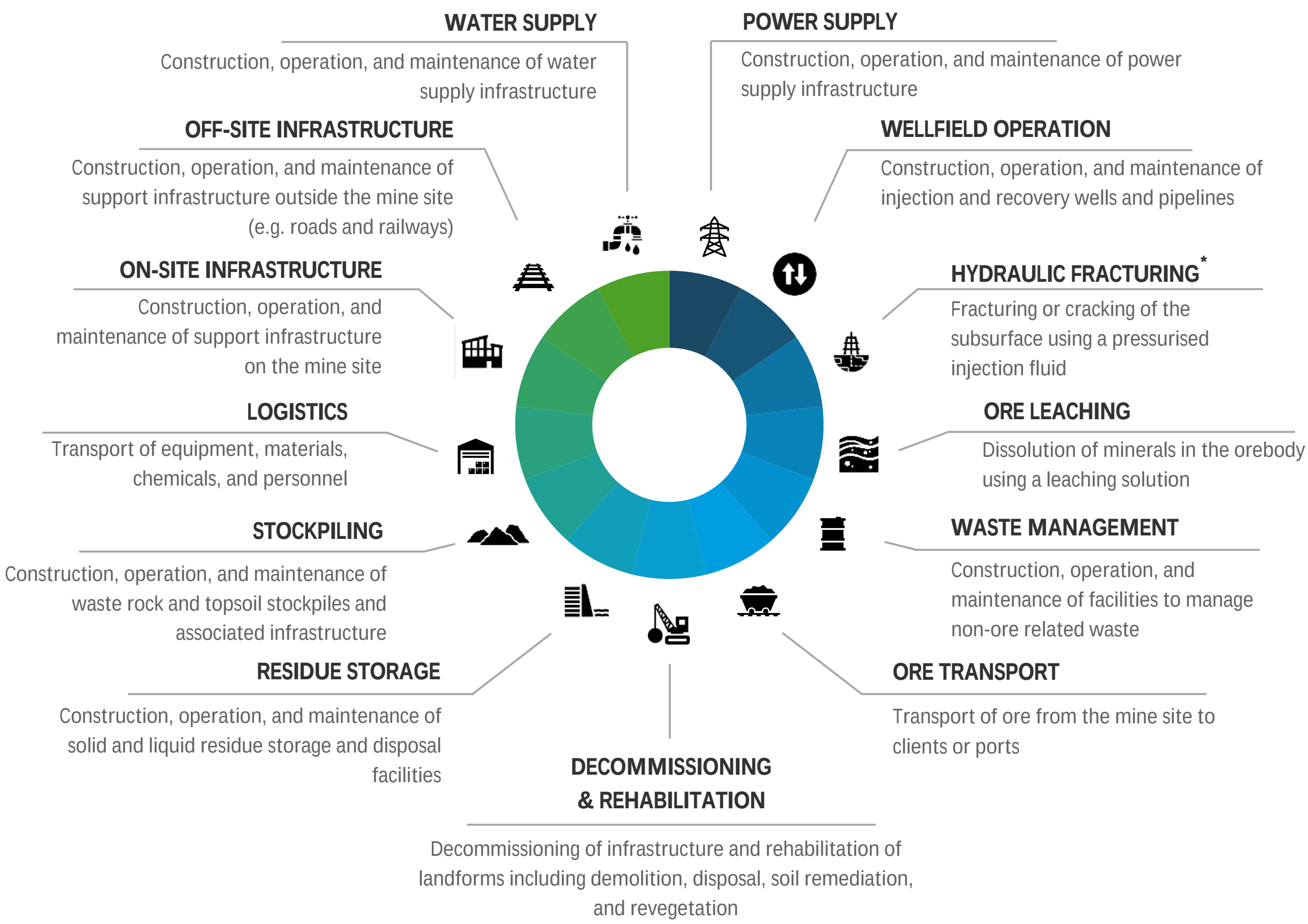


***Figure 2. In situ recovery mining activities undertaken during the operational life cycle and their component boundaries***

## ORE LEACHING AND SOLUTION PROCESSING

The ISR mining process utilises a closed-circuit wellfield to mine minerals of interest from an orebody. The basic requirement for ISR mining is that the mineralised ore be located within permeable formations of a saturated aquifer and confined by impermeable strata (e.g. clay-rich layers) (Commonwealth of Australia, 2010). A wellfield is a pattern of introduction (injection) and extraction (recovery) wells. Monitoring and compliance wells are also drilled and installed around the system to detect any movement of mining fluids outside of the permitted mining area. Additional wellfield infrastructure includes wellhouses (control rooms) and pipelines (trunklines, gathering lines and waste disposal lines).

There are two types of in situ (ore) leaching and these are determined by hydrogeology. Alkaline (carbonate) leaching is used where there is significant calcium present in the orebody aquifer (as limestone or gypsum). Otherwise, acid (sulphuric acid) leaching is generally more suitable (World Nuclear Association, 2020). Using extraction wells, groundwater is pumped from the host aquifer prior to the addition of a solvent that includes complexing reagents (acid or alkaline) and oxidising reagents (hydrogen peroxide or oxygen). The leaching agent, or lixiviant (solvent mixed with groundwater), is then injected into the aquifer via multiple injection wells where it is allowed to slowly migrate towards the extraction wells. During this migration, the injected leaching agent oxidises and dissolves the mineral from the ore which results in a solution enriched with the mineral of interest (e.g. uranium). The enriched solution (groundwater) is pumped to the surface via multiple extraction wells for processing.

The type of processing depends on the mineral to be recovered. Uranium is recovered using a resin/polymer ion exchange (IX) or solvent extraction (SX) process (World Nuclear Association, 2020) followed by precipitation, thickening and drying. The process results in a uranium-ore-concentrate product and a barren (mineral-free) solution, which is re-dosed with the complexing and oxidising reagents and cycled through the wellfield again via injection and extraction wells. The mining solution can be circulated 50–100 times through a given section of the wellfield. This continues until the ore is depleted to uneconomic levels.

The leaching operations are generally limited to specific wellfield areas at any one time, but the whole wellfield will eventually be mined-out. A single wellfield can have a production lifetime of between 12 and 36 months (Restrepo-Baena et al, 2023). Due to solution recycling, the ISR wellfield operation is carried out at a near-neutral water balance (Boss Energy, 2023). But it is necessary to extract slightly more groundwater than injected to keep the leaching solution in the vicinity of the orebody (Taylor et al, 2004). The excess (barren) solution is stored in a tank for later use.

## WATER SUPPLY AND MANAGEMENT

ISR mining requires water for processing, office and camp facilities, plant and machinery wash-down, road works, dust suppression and drilling. Potable water is typically sourced from an aquifer of suitable quality and transported via pipelines to the mine. For example, groundwater is pumped from the Great Artesian Basin to supply the Beverley and Honeymoon Uranium mines (Heathgate Resources, 2018; Boss Energy, 2023). The facilities associated with water supply and management include potable water tanks, water supply wells, water storage tanks and turkey's nests (dams). These facilities can provide artificial sources of water where water was not previously available or accessible.

## MANAGING RESIDUE AND WASTE

The waste generated from ISR mining includes liquid and solid waste. Solid wastes include drill cuttings, process wastes (residue and precipitates), industrial waste (workshop waste, tyres, drums, oil filters and chemicals), domestic wastes, putrescible wastes (food scraps and plastic wrapping), packaging and containers, commercial wastes (papers and documents) and radioactive wastes (pipes, valves and filters). Waste unable to be recycled is disposed of in an approved on-site or off-site landfill facility. Low-level radioactive waste (LLRW) is disposed of in on-site purpose-built facilities that are filled, closed and capped. Drill cuttings are disposed of in mud-pits (sumps) that are then filled-in and compacted.

Soil waste can also be generated during earthworks associated with processing plant, camp and wellfield construction. Soil waste is typically stored in stockpiles. Depending on the geochemical properties of the exposed soil (e.g. the presence of pyrite), mineral wastes have the potential to be a source of acid and metalliferous drainage (AMD). AMD is typically characterised by concentrated dissolved metals and a pH <6.

Liquid wastes include high-salinity brine from groundwater treatment (reverse osmosis) and process liquids (bleed solutions, wash-down waters and gypsum slurry). Liquid waste management and disposal can include: the recycling of water for re-use in the processing plant; injection of waste into deep aquifers that contain poor quality groundwater with 'no foreseeable use'; injection of waste into mined-out areas for dispersion, attenuation and/or containment; and surface evaporation using open (residue) ponds, although this can result in associated radiological handling issues (Commonwealth of Australia, 2010). Storage ponds have the potential for seepage and spillage as a result of excessive rainfall or pond lining failure.

## TRANSPORTING THE PRODUCT TO THE END USER

Road transport (via road freight or trucking) is the most common method of transporting the final product (e.g. uranium ore concentrate) to the distribution point (e.g. port or end user) following ISR mining in South Australia. The use of diesel-fuelled trucks for transport produces GHG emissions, particularly carbon dioxide.

**ACID AND METALLIFEROUS DRAINAGE**
The seepage of acidic/metal-bearing fluids from tailings, topsoil, or waste rock stockpiles due to oxidation of sulfide minerals

**ARTIFICIAL WATER**
The availability of water at locations where previously no water was present, such as turkey's nests (dams), ponds, leaky taps and pipelines, puddles

**BRINE MANAGEMENT**
The handling, transport, and storage of brines from desalination

**CHEMICALS AND EXPLOSIVES**
The handling, transport, and storage of chemicals

**DRILLING**
The drilling of boreholes for ore body characterisation, dewatering, water supply or water monitoring

**EARTHWORKS**
Earthworks required for mine infrastructure development, including mine pit excavation

**EQUIPMENT**
Operation and maintenance of mobile and stationary mining equipment to transport topsoil, waste rock, ore, or tailings

**FUEL AND LUBRICANTS**
The handling, transport and storage of fuel and lubricants

**GREENHOUSE GAS EMISSIONS**
The emission of greenhouse gases through burning of fossil fuel

**GROUNDWATER PUMPING**
The pumping of groundwater from bores for dewatering or water supply

**GROUNDWATER INJECTION**
The injection of solution via bores for in situ leaching

**POWER GENERATION**
The construction, operation, maintenance and decommissioning of gas and diesel electricity generation facilities

**RAILWAY TRANSPORT**
The transport of material, equipment, or ore via railways

**ROAD TRANSPORT**
The transport of material, ore, and personnel via roads

**SLURRY TRANSPORT**
Slurry pipeline to transport ore

**SOLAR POWER**
The construction, operation, maintenance, and decommissioning of solar electricity generation facilities

**TAILINGS SEEPAGE**
The seepage of fluid from tailings storage facilities to soils and groundwater

**TAILINGS SPILLAGE**
The unintentional spillage of fluids from tailings storage facilities due to, for instance, tailing dam failure or excessive rainfall

**WASTE DISPOSAL**
The disposal of solid industrial and commercial waste, excluding waste from ore processing

**WATER DISCHARGE**
The intentional release of water from processing or dewatering off-site

**WIND POWER**
The construction, operation, maintenance, and decommissioning of wind electricity generation facilities

***Figure 3. Sources that can cause changes in the environment from activities related to in situ recovery mining***

## MINE CLOSURE

The whole-of-life mine process aims to culminate in tenement relinquishment and the minimisation or avoidance of further environmental impacts. Activities undertaken to advance a mining operation to closure include:

- site decommission and rehabilitation, where equipment, infrastructure, chemical and explosives storage facilities (e.g. underground fuel storage tanks) are demolished, decontaminated, decommissioned and removed
- waste removal and disposal
- environmental emission (e.g. GHG) monitoring (EPA, 2016).

Rehabilitation includes earthworks to remediate the surface and revegetate the landscape to establish sustainable ecosystems or alternative land uses (DISR, 2016a and 2016b).

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Fact Sheet

GOYDER INSTITUTE FOR WATER RESEARCH

# Infrastructure corridor activities and sources

## HIGHLIGHTS

- An infrastructure corridor is land that is used for linear infrastructure such as roads, railways, pipelines (water supply and slurry), renewable energy infrastructure (solar and wind) and electrical transmission lines that support development.
- Off-site infrastructure is included as an activity of mining. The aspects of off-site infrastructure activities (sources) which can cause changes in the environment include: land clearing and compacting earthworks; artificial water from leaky pipelines; fuel and lubricants for use in vehicles, equipment and machinery; and greenhouse gas emissions from the burning of fuel for power.

## INTRODUCTION

Infrastructure corridors are used for linear infrastructure such as roads, railways, pipelines (water supply and slurry) and electrical transmission lines that support developments like mines (Infrastructure Australia, 2017). They have a relatively narrow footprint and extend over long distances. This results in a large edge, which leads to large edge-effects and disrupted habitat continuity.

This fact sheet provides an overview of the off-site infrastructure activity and associated sources (earthworks, greenhouse gas (GHG) emissions, artificial water, and fuel and lubricants) within the impact pathways developed for infrastructure corridor construction, use and rehabilitation.


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Infrastructure-related activities affect water-dependent ecosystems via a complex network of interconnected ecohydrological pathways. These pathways include a driver, activities, sources, stressors and receptors and can be represented in an impact pathway diagram (IPD).

**Activities** are high-level actions that are typically needed to develop a resource. Off-site infrastructure activity is defined as the construction, operation, maintenance, decommissioning, and rehabilitation of infrastructure outside of a mine site and includes roads, railways, water and slurry pipelines, solar and wind farms and transmission lines (Figure 1). More detail is provided in the Open Pit Mining, Underground Mining and In Situ Recovery Mining fact sheets. **Sources** (Figure 2) are the aspects of activities that can cause changes in the environment. Sources of off-site infrastructure include earthworks, artificial water, GHG emissions and fuel and lubricants.

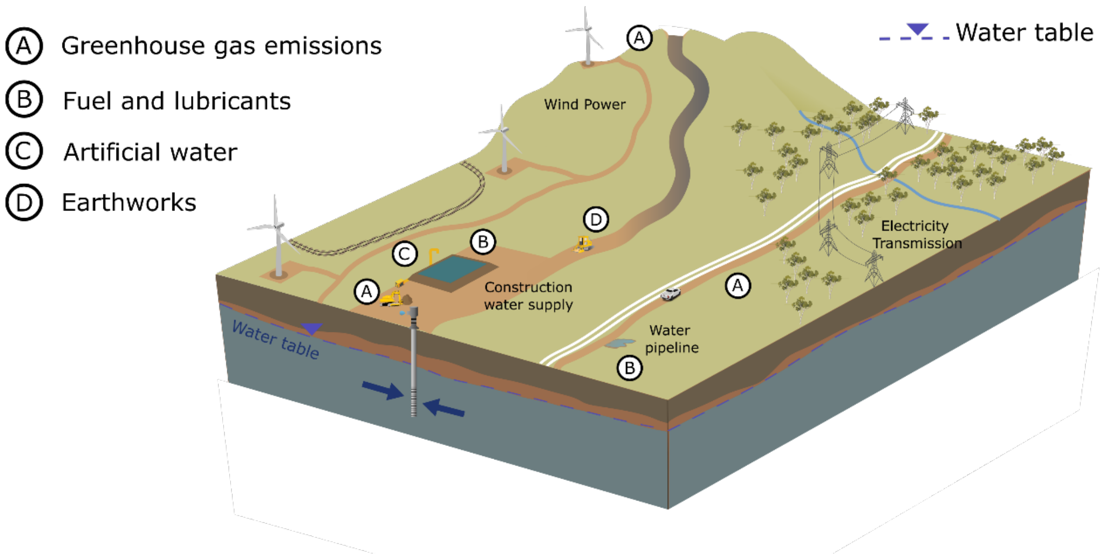


*Figure 1. Off-site infrastructure activity includes roads, railways, water and slurry pipelines, solar and wind farms and transmission lines (not drawn to scale)*

## CONSTRUCTION AND MAINTENANCE

Off-site infrastructure construction impacts the environment through earthworks, fuel and lubricant use, artificial water production and GHG emissions.

Earthworks are required to remove vegetation and topsoil as well as level and compact the ground for infrastructure directly (roads, rail lines, solar panels, wind turbines, transmission tower footings, substations, pipelines, temporary accommodation, laydown, storage and access tracks). The use of vehicles and equipment requires the handling, transport and storage of fuels and lubricants. Fuel combustion (by vehicles, plant and equipment) and land clearing give rise to GHG emissions (JBS&G 2021).

## ROAD AND RAIL TRANSPORT

Roads are constructed to transport chemicals, materials, equipment and personnel to and from mining operations. They can also be constructed to service other forms of infrastructure like railways, pipelines, and wind turbines. Roads can be sealed or unsealed. Railways are used to transport product (e.g. ore) between the mine and a port, or other domestic location, for the end user. Access tracks are typically constructed along some parts of a rail line for maintenance. Roads and railways are predominantly used by vehicles with diesel or petrol combustion engines that require fuel and lubricants to run and produce GHG emissions.

## WATER AND SLURRY TRANSMISSION

Pipelines are constructed to supply or distribute potable water, non-potable water, wastewater or slurry (mixture of water, ore and chemical reagent). Pipelines can be installed below ground or above ground for easy maintenance. For example, the Middleback Range Iron Duke Mine in the Northern Eyre Peninsula region delivers magnetite along a 62 kilometre underground slurry pipeline to Whyalla. Leaks in above-ground pipelines can pool on the surface and soil characteristics, such as clay content, can slow water infiltration. This creates an artificial source of water. Underground leaks can also rise to the surface and create artificial puddles of water that surface biota and their ecosystems can use.

## RENEWABLE ENERGY GENERATION

Sources associated with renewable energy infrastructure occur mainly during construction, where earthworks are required to create access tracks, turbine hard stand areas and panel array areas, as well as electrical and ancillary infrastructure. Wind turbines also require lubricants to ensure they operate effectively.

## ELECTRICITY TRANSMISSION

Electricity transmission infrastructure that supports mining includes transmission lines, support towers and substations. Lubricant handling, storage and use may be required when substations are included in an infrastructure corridor.

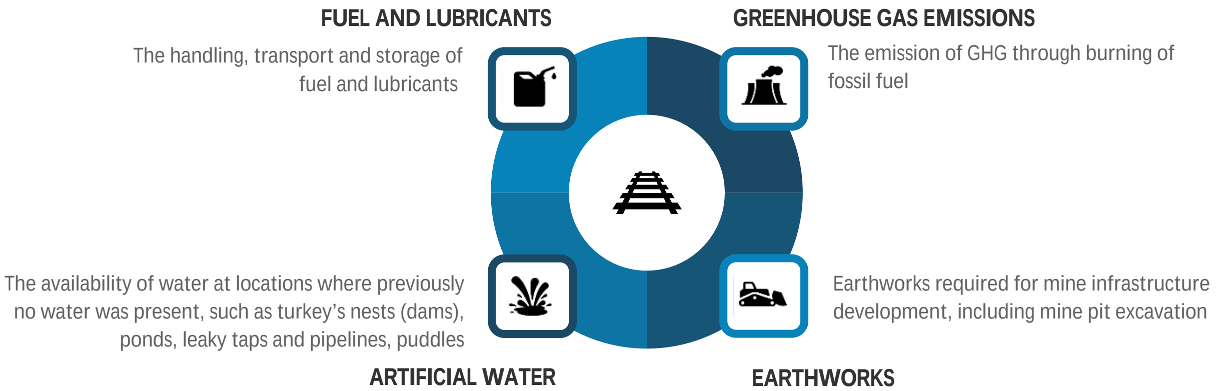


*Figure 2. Sources from the off-site infrastructure activity*

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Fact Sheet

# Mineral exploration activities and sources

## HIGHLIGHTS

- Mineral exploration generally includes activities associated with reconnaissance visits, water and power supply, geochemical surveys, geophysical surveys, groundwater investigations, logistics (campsites, laydown, etc.), waste management and post-exploration rehabilitation.
- The aspects of these activities (sources) which can cause changes in the environment include acid and metalliferous drainage, artificial water, chemicals, drilling, earthworks, equipment, flying, fuel and lubricants, greenhouse gas (GHG) emissions, groundwater pumping, off-road driving, power generation, road transport, waste disposal and water discharge.

## INTRODUCTION

Resource development starts with exploration and drilling to find and characterise mineral deposits. The *Mining Act 1971* defines exploration as any kind of operation carried out while prospecting, exploring for minerals and establishing the extent of a mineral deposit as well as the rehabilitation of environmental impacts associated with those operations. Mineral exploration programs typically commence with an initial 'low impact' exploration phase in which vast areas are explored to identify target areas that may contain indications of mineralisation (DEM n.d.). Once defined, a more detailed and advanced exploration phase (e.g. drilling) will generally focus on these target areas.

This fact sheet provides an overview of the activity and source components within the impact pathway diagram (IPD) for mineral exploration operations (Figure 1). Complete IPDs for mineral exploration are covered in more detail in Peeters (2024) and Peeters et al (2024).


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The mine development life cycle includes exploration, operation (production), decommissioning, rehabilitation, closure and post-closure as well as care and maintenance if the mine pauses production (GSSB 2023; DEM 2020). Across each of these phases, mining-related activities affect water-dependent ecosystems via a complex network of interconnected ecohydrological pathways. These pathways include a driver, activities, sources, stressors, and receptors and can be represented in an IPD.

**Activities** (Figure 2) are the high-level actions that are typically needed to develop a resource. **Sources** (**Error! Reference source not found.**) are the aspects of activities that can cause changes in the environment. The following sections discuss the activities and sources associated with mineral exploration in more detail for low-impact and advanced exploration.

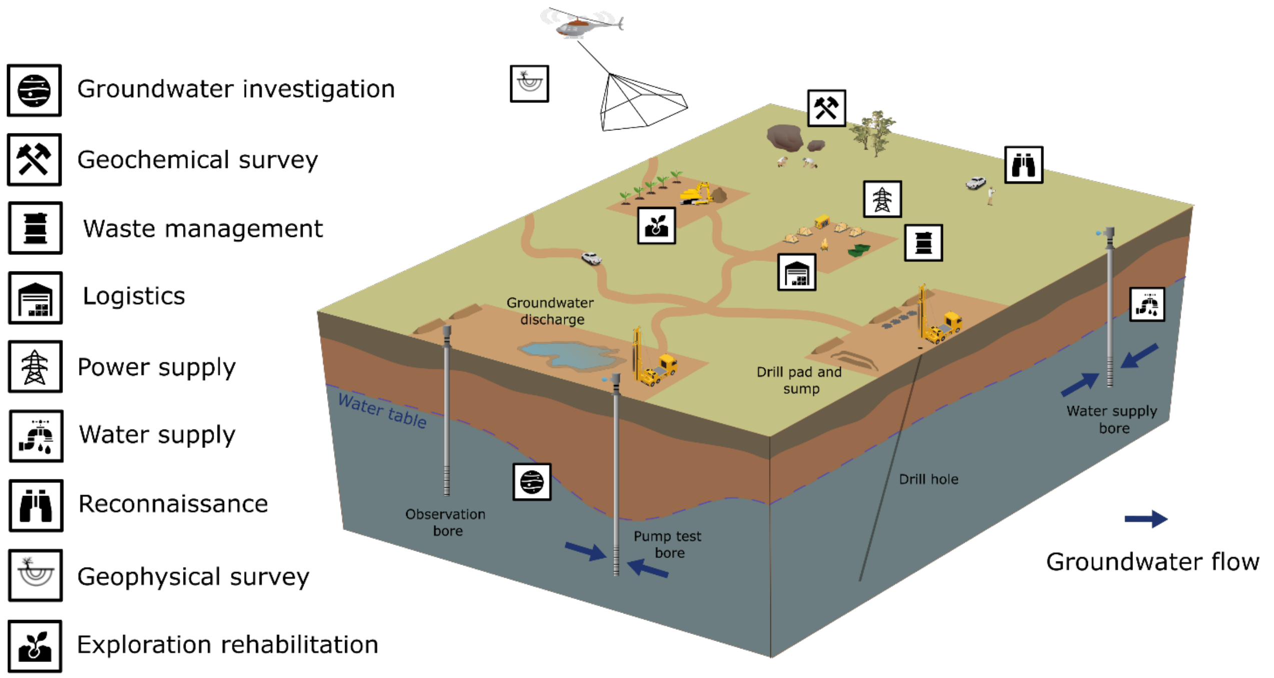


*Figure 1. Pictorial conceptual diagram of activities and sources of mineral exploration*

## LOW-IMPACT EXPLORATION

Low-impact exploration operations are defined under the *Mining Act 1971* as operations that:

(i) are not reasonably expected to have any significant adverse impact on the environment
(ii) will reduce the impact of such operations on the environment, being the rehabilitation activities performed to reduce or mitigate any impact caused by low-impact operations (DEM, 2022).

Low-impact exploration generally results in minimal ground disturbance and limited rehabilitation requirements, as the exploration activities usually involve walking, driving (via existing tracks or off-road over low vegetation) and sometimes flying through the landscape (DSD, 2014).

Mineral exploration typically starts with a reconnaissance (field) visit to a proposed exploration area to meet with landholders and obtain a better understanding of the landscape and the geological and environmental conditions. Geological, landform and environment mapping is also undertaken early on in the exploration process as are cultural clearance surveys which identify any items and sites of cultural significance.

Geochemical surveys are conducted to identify any abnormal chemical patterns over the landscape that may reveal near-surface or deep-seated hidden mineral deposits (Haldar, 2018a). Rock chip, soil and stream sediment samples can be collected using hand-held tools (DSD, 2014 and AMEC, 2021).

Geophysical surveys are undertaken to locate hidden subsurface mineral deposits by using measurements of gravity and magnetic, electrical, electromagnetic and radiometric properties (Haldar, 2018b). Geophysical surveys can be conducted from the air, at surface and down drillholes. Airborne surveys use aircraft (planes), helicopters or unmanned aerial vehicles (drones) equipped with multiple sensors and are generally considered to be low-impact. Instruments for on-ground surveys can be carried by hand or vehicle. These techniques are generally considered to be low-impact. Seismic surveys and downhole (borehole) geophysical surveys are considered to be advanced exploration activities (see Advanced exploration fact sheet).

Short-term exploration camps provide accommodation for workers and can include tents, caravans or transportable units with portable diesel-fuelled generators to supply power. Other logistical activities include temporary storage and laydown areas.

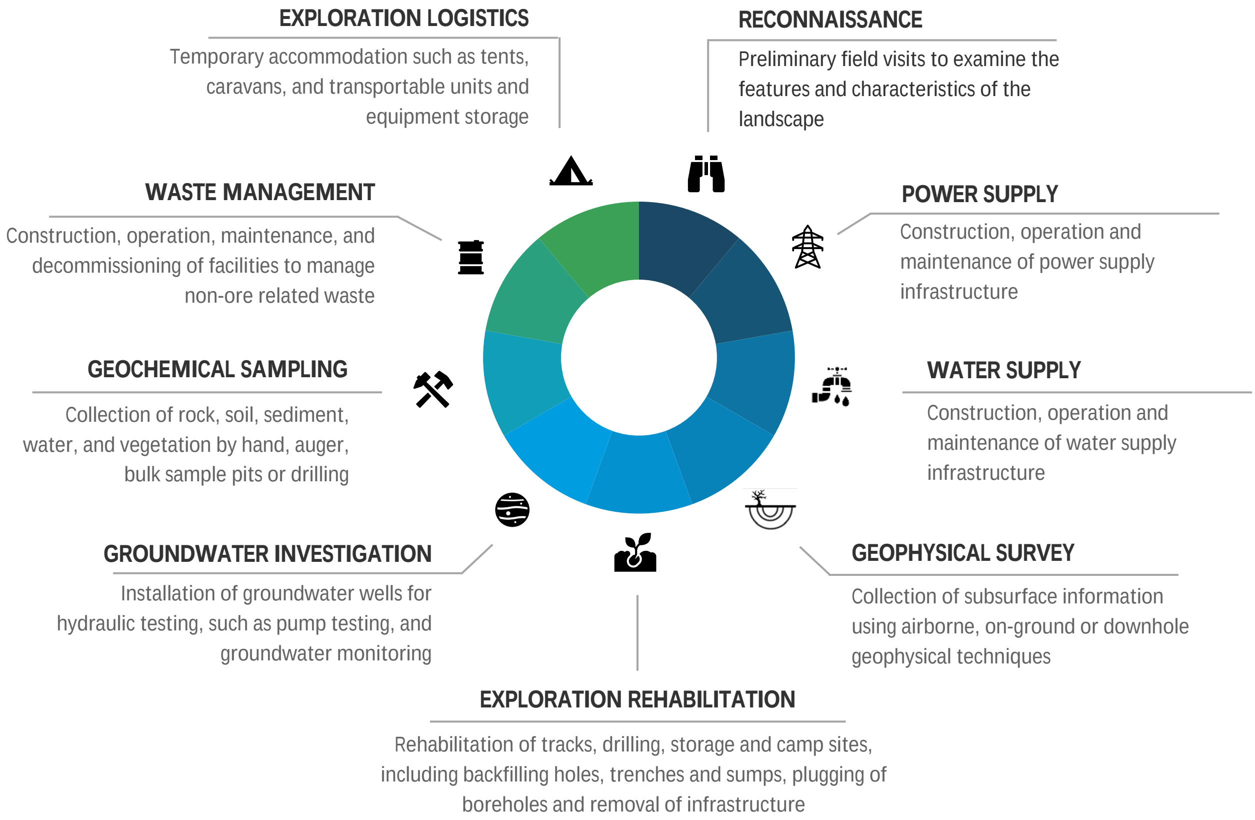


*Figure 2. Mineral exploration activities undertaken prior to the operational phase of mining*

## ADVANCED EXPLORATION

Advanced exploration, which is more intense and costly, follows low-impact exploration in areas with promising results. Advanced exploration operations are those that:

- do not fall within the scope of low-impact exploration operations
- involve the use of declared equipment
- involve collecting a bulk sample for evaluating the metallurgical and physical properties of a mineral deposit or the economic potential
- involve geotechnical testing (DEM, 2022).

Advanced exploration includes drilling to establish the extent of a mineral deposit and to estimate how much ore is present. Common drilling methods include rotary air blast, rotary mud, reverse circulation and diamond core drilling. Drilling may require earthworks to establish access tracks and drill pads for the transport of equipment such as drill rigs, water tankers, support vehicles (rod carriers etc.) and light 4WD vehicles. Further investigation of geological features can also include costeaning (excavating trenches 20 cm to 1 m wide) and preparing bulk sample pits for geochemical sampling. Exposure of sulfide-bearing minerals during excavation can lead to acid and metalliferous drainage (AMD).

While most of the activity is focused on estimating how much ore is available, there will also be geotechnical and groundwater investigations that complement geophysical surveys and drilling. Downhole geophysical logging (placing a probe down a drill hole) can establish orebody continuity (Haldar, 2018a; DSD, 2014). Some downhole geophysical logging techniques use a radioactive source. Seismic surveys can also be part of advanced exploration activities.

Groundwater investigations are undertaken in converted existing drill holes or newly-drilled and constructed wells to:

- investigate the suitability of local groundwater resources for water supply (drilling, track maintenance, camping and mine operations)
- estimate dewatering requirements
- identify monitoring requirements
- understand in situ leaching requirements.

Hydrogeological (pump) testing is often carried out to determine water availability and aquifer flow rates and properties. It involves the pumping and discharge of groundwater into a storage pond (like a turkey's nest dam).

**ACID AND METALLIFEROUS DRAINAGE**
The seepage of acidic/metal-bearing fluids from tailings, topsoil, or waste rock stockpiles due to oxidation of sulfide minerals

**ARTIFICIAL WATER**
The availability of water at locations where previously no water was present, such as turkey's nests (dams), ponds, leaky taps and pipelines and puddles

**CHEMICALS**
The handling, transport, and storage of chemicals

**DRILLING**
The drilling of boreholes for ore body characterisation, dewatering, water supply or water monitoring

**EARTHWORKS**
Earthworks required for mine infrastructure development, including mine pit excavation

**EQUIPMENT**
Operation and maintenance of mobile and stationary mining equipment to transport topsoil, waste rock, ore or tailings

**FLYING**
Flying aircraft at low altitude

**FUEL AND LUBRICANTS**
The handling, transport and storage of fuel and lubricants

**GREENHOUSE GAS EMISSIONS**
The emission of GHG through burning of fossil fuel

**GROUNDWATER PUMPING**
The pumping of groundwater from bores for dewatering or water supply

**OFF-ROAD DRIVING**
Driving vehicles on natural terrain and through watercourses where there are no established roads or tracks

**POWER GENERATION**
The construction, operation, maintenance and decommissioning of gas and diesel electricity generation facilities

**ROAD TRANSPORT**
The transport of material, ore and personnel via roads

**WASTE DISPOSAL**
The disposal of solid industrial and commercial waste, excluding waste from ore processing

**WATER DISCHARGE**
The intentional release of water from processing or dewatering off-site

*Figure 3. Sources that can cause changes in the environment from activities related to mineral exploration*

## WASTE MANAGEMENT AND REHABILITATION

Management of wastes and hazardous chemicals, such as domestic waste, wastewater and hydrocarbons, is required throughout exploration. The exploration area must be rehabilitated to make sure that impacted areas are restored to their pre-exploration condition and that no environmental hazards are still present in the landscape.

Drill holes are plugged below ground and at the surface to manage the risk posed to fauna and prevent aquifer contamination. Sumps are backfilled and drill pads are resurfaced (using earthworks) and revegetated. The incorrect disposal of drill cuttings containing radioactive minerals can result in contamination. Bulk sample pits and borrow pits may not be able to be backfilled to the surface and may therefore be battered down. Previously cleared topsoil and vegetation are typically used to revegetate disturbed areas.

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Fact Sheet

GOYDER INSTITUTE FOR WATER RESEARCH

# Post-mining sources

## HIGHLIGHTS

- Mining activities conducted during the construction and production phase can continue to interact with the environment even after the mine has ceased production and been decommissioned and rehabilitated.
- Aspects of previous mining activities (sources) in the post-mining landscape that cause changes in the environment include acid and metalliferous drainage, artificial water, brine management, pit voids, remnant on-site and off-site infrastructure, tailings seepage and spillage, void collapse, waste disposal and water discharge.

## INTRODUCTION

The modern mining industry considers mining to be a temporary land use (DISR, 2016a). Post-mining, or post-closure, is the period following closure activities when mining operations have ceased and the mine has been decommissioned and rehabilitated (mine closure). Some monitoring and maintenance may continue to observe the effectiveness of the closure and prevent potential further harm (EPA, 2016). The outcomes of mine closure ultimately determine the nature of post-closure land use for future generations and the options for post-mining land use are many and varied. If closure activities are not done in a planned and effective manner throughout the life of the mine (LOM), the mine site may continue to be hazardous and a source of pollution for many years to come. Legacy infrastructure from mining activities can include tailings storage facilities (TSF), waste-rock landforms, open voids, pit lakes and other sources of potential pollution (DISR, 2016a).

This fact sheet provides an overview of the source components within the impact pathway diagram (IPD) for a post-mining landscape (Figure 1). Sources (Figure 2) are aspects of the activities that can cause changes in the environment. Complete IPDs for post-mining are covered in more detail in Peeters (2024) and Peeters et al (2024).


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The life cycle of a mining development includes exploration, operation (production), decommissioning and rehabilitation (closure) and post-closure as well as care and maintenance if the mine pauses production. Across each of these phases, mining activities affect water-dependent ecosystems via a complex network of interconnected ecohydrological pathways. These pathways include a driver, activities, sources, stressors and receptors, and can be represented in an IPD.

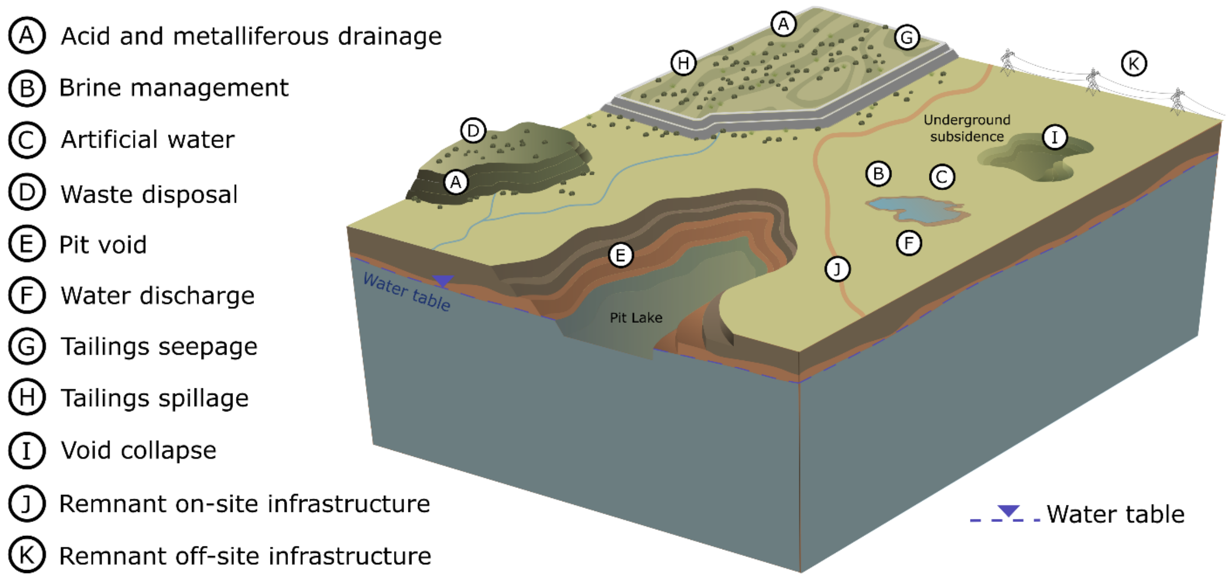


*Figure 1. Pictorial conceptual diagram of activities and sources of open pit mining (not to scale)*

Landforms such as pit voids, subsidence zones from underground void collapse, waste-rock dumps, and tailings storage facilities (TSFs) are significant elements in a post-mining landscape. They should be constructed so that they are physically and chemically stable and appropriately vegetated to pose minimal ongoing environmental risk (DISR, 2016a).

Outcomes of poor landform construction include excessive erosion (DMIRS, 2021). This can compromise the integrity of cover layers and result in:

- the movement of potentially contaminated sediment into the surrounding environment
- poor establishment of vegetation due to unfavourable material properties
- poor vegetation development due to inadequate water-holding capacity
- nutrient deficiency or chemical toxicity
- longer-term issues such as deep drainage through hostile stored material (DISR, 2016a).

Mine workings, such as open pits and underground voids, can often remain in the landscape following mine closure if backfilling is not included in rehabilitation. Open pits are voids extending from the surface. They may pose environmental problems such as: acid and metalliferous drainage (AMD) produced from exposed sulfide-bearing pit walls; pit-void instability from the slumping or failure of pit walls; and fauna and (unlawful) human ingress and potential mortality (DISR, 2016a).

Pit lakes can form in pit voids when water is added via groundwater sources and rainfall (McJannet et al, 2017; Liu et al, 2021). Pit lakes can impact the environment through interference with regional water balances (e.g. evaporation) and water quality. Subsidence and land fracturing from the collapse of underground voids can extend for kilometres beyond the surface footprint of a mine site as underground structures slowly deteriorate and collapse (Cole et al, 2024).

Remnant on-site and off-site infrastructure remaining in the landscape can include power lines, roads and railways. The environmental impacts of such infrastructure can include vegetation loss and drainage obstruction, where the natural topography of the landscape is altered and barriers to runoff and surface water flow occur. Infrastructure can also disrupt ecological and genetic connectivity when it interferes with fauna movement or isolates areas of habitat into smaller fragments.

Waste rock from mining operations can be managed and disposed of using waste rock dumps (significantly large stockpiles above the surface) or by backfilling into mined-out pits and underground voids. Waste rock dumps (WRDs) are usually the most visually obvious landforms left after mining. They can interact with surface water through active discharge, seepage, run-off, sediment loading, contamination, and the interruption of watercourses. They can interact with groundwater through contamination, impacts to recharge and localised mounding (DISR, 2016a; Cole et al, 2024). Acid and metalliferous drainage (AMD) is the most ubiquitous problem associated with WRDs, which can be a continuing source of contamination. When not effectively revegetated, WRDs can also cause dust pollution.

Tailings storage facilities (TSFs), or tailings dams, are often the main source of post-mining risk and become negative legacies in the landscape (DISR, 2016b). Seepage and spillage (such as ADM) are significant environmental risks of TSFs and these can take time to develop. Tailings seepage occurs when fluids in the tailings impoundment migrate through the foundation or through the embankment (Fortuna et al, 2021). Tailings spillage occurs when excess water inflows (e.g. from high rainfall) raise the phreatic surface in the TSF or the TSF fails.

Water management, including brine management, artificial water and water discharge, are also important considerations post-mining. Brine produced from water treatment includes a high concentration of salts and metals which can contaminate soil, surface water and groundwater if not managed effectively. Artificial water sources, such as water storage dams, can alter ecosystems by providing water sources where none were previously available. Water discharge, such as dewatering discharge, can contaminate soil, surface water or groundwater and change water quality (e.g. salinity, nutrients).

**ACID AND METALLIFEROUS DRAINAGE**
The seepage of acidic/metal-bearing fluids from tailings, topsoil or waste rock stockpiles due to oxidation of sulfide minerals

**ARTIFICIAL WATER**
The availability of water at locations where previously no water was present, such as turkey's nests (dams), ponds, leaky taps and pipelines, puddles

**BRINE MANAGEMENT**
The handling, transport and storage of brines from desalination

**PIT VOID**
Pit void remaining after rehabilitation of the mine site (dry or filled with groundwater)

**REMNANT OFF-SITE INFRASTRUCTURE**
The off-site infrastructure that remains after decommissioning (e.g. access roads and tracks, transmission lines and railways)

**REMNANT ON-SITE INFRASTRUCTURE**
The mining infrastructure that remains on the mine site after decommissioning (e.g., buildings, roads and railways)

**TAILINGS SEEPAGE**
The seepage of fluid from tailings storage facilities to soils and groundwater

**TAILINGS SPILLAGE**
The unintentional spillage of fluids from tailings storage facilities due to, for instance, tailing dam failure or excessive rainfall

**VOID COLLAPSE**
Collapse of rock beneath the surface due to excavation

**WASTE DISPOSAL**
The disposal of solid industrial and commercial waste, excluding waste from ore processing

**WATER DISCHARGE**
The intentional release of water from processing or dewatering off-site

*Figure 2. Sources that can cause changes in the post-mining environment from activities related to mining*

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Fact Sheet

# Stressors

## HIGHLIGHTS

- Stressors are changes in the environment, caused by development activities, that can affect receptors.
- An overview is presented of each stressor and its impact pathway from source to receptor, including potential materiality and mitigation options in the study regions.

## INTRODUCTION

The impact pathway diagram fact sheets (Peeters, 2024) show impact pathway diagrams for the exploration, production and post-mining phases of open pit, underground and in situ recovery mining. This fact sheet has a report card for each stressor that includes the following information:

- Name, icon and definition
- Impact pathway diagram section that show the sources leading into the stressor and the receptors linked to the stressor
- How sources can affect the stressor
- How the stressor can affect the receptors
- Why the stressor is material (see Peeters et al (2024) for a discussion on materiality assessment)
- How the stressor can be mitigated


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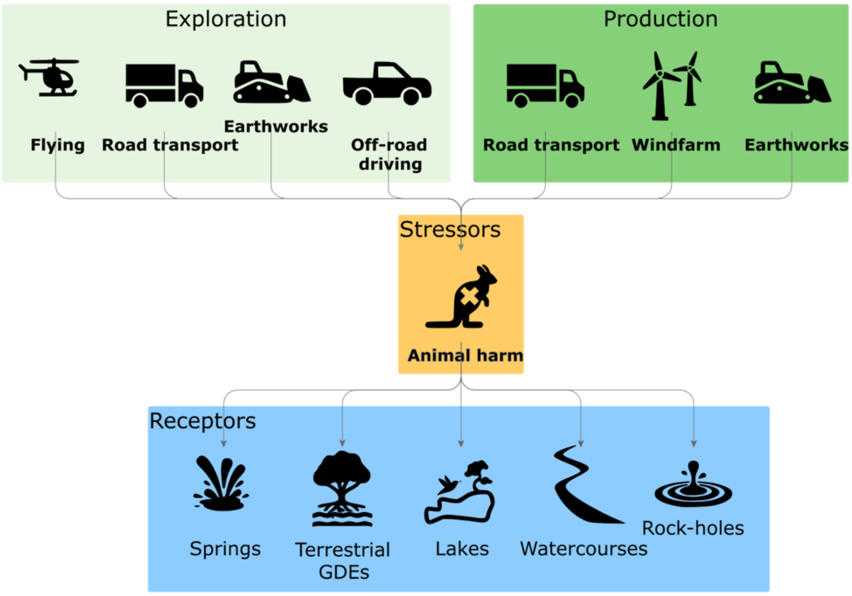
# Animal harm

The intentional or unintentional killing or harming of animals directly by stressors, such as vehicle strikes. Indirect effects, such as predation by invasive predators or animal harm due to bushfires, are considered in the fact sheets on other stressors.

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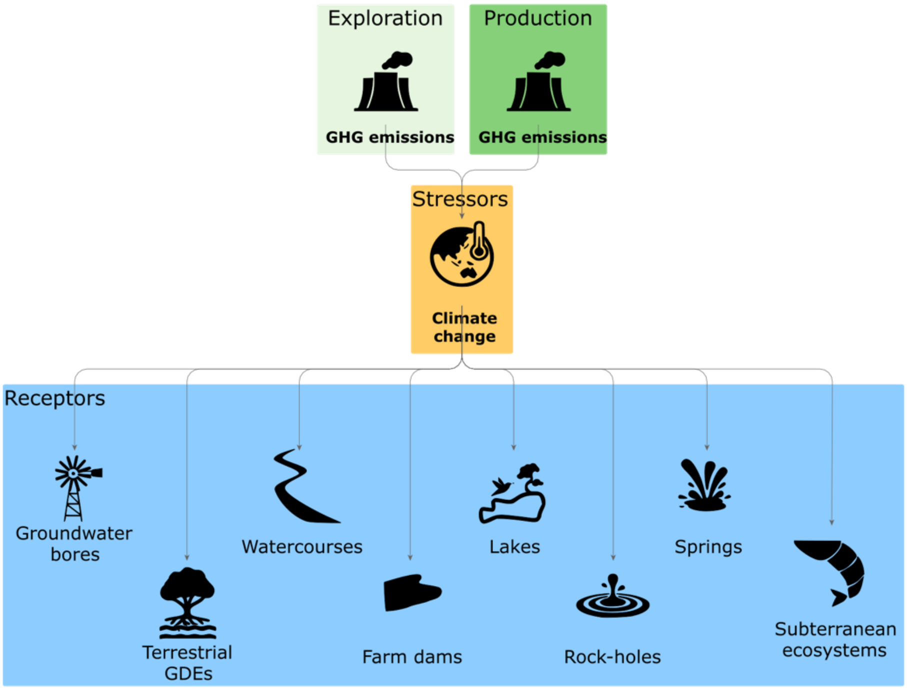
| Sources | Earthworks are a major disruption to habitat, and animals present at a construction site may not survive the disturbance (Neldner et al, 2017). Ditches and pits that can trap small animals and interfere with movement and migration are a particular issue with the construction of linear infrastructure, such as roads and pipelines (Swan et al, 2019). Vehicles for Road transport can strike and kill animals, especially when travelling around dusk and dawn. In Wind farms, blades of wind turbines can strike and kill birds (Scholl and Nopp-Mayr, 2021).<br><br>In exploration, in addition to Earthworks and Road transport, Off-road driving and Flying can cause harm to animals.<br><br>Indirect harm to animals is discussed in the Fire, Noise, Light, Pests and weeds, Contamination, Vibration and Radiation fact sheets. |
| Receptors | Animal harm affects any receptor that supports a surface ecosystem, including Springs, Terrestrial GDEs, Lakes, Watercourses, Farm dams and Rock-holes. |
| Materiality | Direct animal harm is not mentioned explicitly, but both the SAAL Regional Landscape Plan (SAAL, 2021) and the Eyre Peninsula Regional Landscape Plan (EPLB, 2021) list maintaining and enhancing biodiversity as a priority. |
| Mitigation | Remove animals from construction sites or sites where vegetation clearing is planned before construction commences.<br>Conduct frequent and regular inspections of open trenches.<br>Install fences to restrict animal access.<br>Train drivers, reduce driving speeds and minimise driving between dusk and dawn (Rytwinski et al, 2016).<br>Paint wind turbine blades to contrast (May et al. 2020). |

# Climate change

Climate change due to greenhouse gas (GHG) emissions

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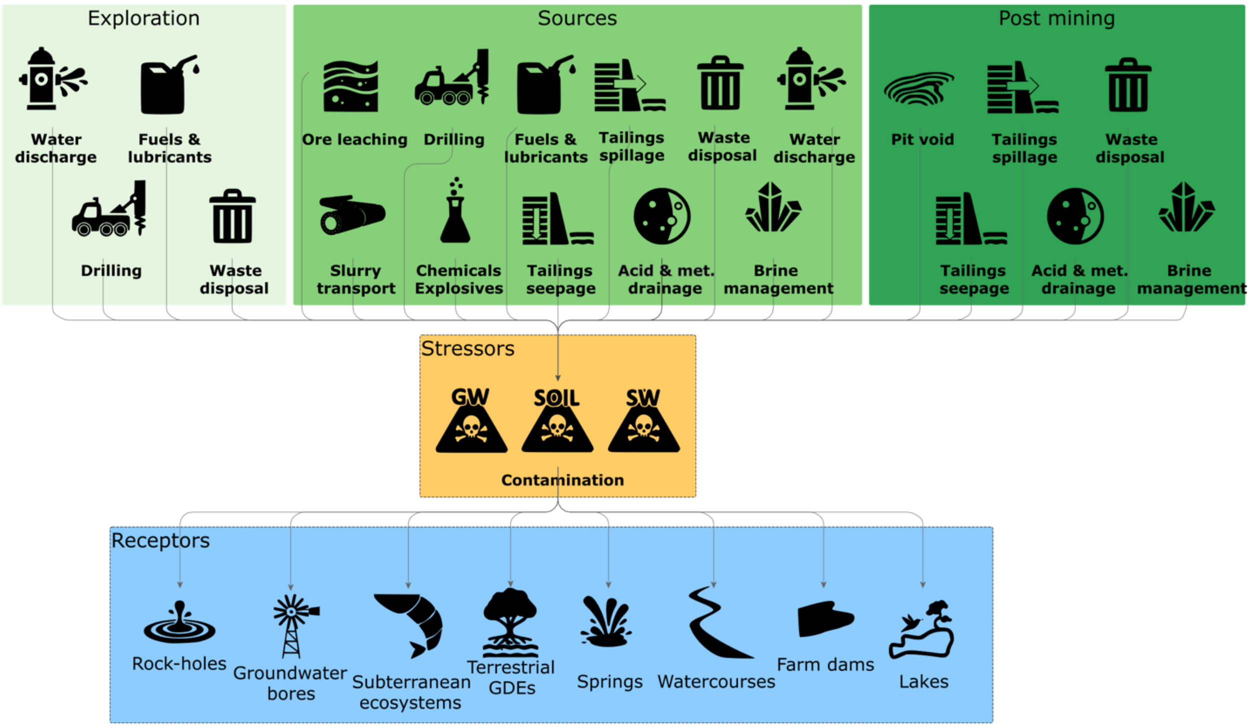
| Sources | Greenhouse gas emissions are one of the key causes of climate change. GHG emissions from mining are linked to any sources that use fossil fuels, like gas and diesel, to generate electricity or internal combustion engines to run earthworks machinery, on-site equipment and drilling rigs. The transport of material and personnel to and from the mine site via roads and railways will also create GHG emissions.<br><br>The main GHG of concern from these sources is $CO_2$. Other GHGs, such as methane, are an important concern in coal open pit mining, but methane accumulations are rare in mineral deposits within the study regions. However, methane can still escape from pipelines if natural gas is used to generate power. |
| Receptors | Climate change caused by GHG emissions will change rainfall, rainfall patterns and temperature (see Climate Change fact sheet for projected changes). The changes in rainfall pattern and evaporation will affect the hydrological regime of every endpoint. |
| Materiality | The reporting threshold for atmospheric emissions under the *National Greenhouse and Energy Reporting Act 2007* is 25,000 tonnes of $CO_2$ per year. Even if a company does not exceed the threshold, GHG emissions leading to climate change are material due to the cumulative effect of emissions. The mitigation of and adaption to climate change is a key priority in both the SAAL Regional Landscape Plan (SAAL, 2021) and the Eyre Peninsula Regional Landscape Plan (EPLB, 2021). |
| Mitigation | Decarbonise exploration and production operations by electrifying equipment or using hydrogen fuel cells and switch to renewable energy sources. |

# Contamination

The introduction to surface water, groundwater or soils of substances that are not naturally-occurring or are in concentrations that exceed local background levels and that do or may risk harming the environment.




**Sources**

Acid and metalliferous drainage occurs when sulphide minerals in the mine pit, tailings storage facilities or stockpiles of waste rock and topsoil are exposed to air and water (Tomiyama and Igarashi, 2022). The resulting chemical reaction produces sulphuric acid (with or without heavy metals). The sulphuric acid contaminated water can drain into and contaminate soil, surface water and groundwater. Once the process starts, it is very difficult to stop and it will continue until one of the components (sulphide minerals, oxygen or water) runs out or a reaction is prevented.

Tailings are the left-over materials (by-products) from ore processing and they are often in the form of slurry. They are stored in a tailings storage facility (TSF) and dried out. A TSF, much like a pond or dam, is designed, engineered, and constructed to prevent spillage and seepage and permanently store tailings long after the mine has closed. Extreme events, such as earthquakes or flooding, can lead to breaches of TSF barriers and Tailings spillage which will contaminate soil, surface water and/or groundwater. Tailings seepage occurs when, despite the engineering of the facility, water and solutes still infiltrate into the underlying soil and contaminate the soil and groundwater. Tailings seepage is gradual and harder to detect, unlike tailings spillage which can be an extreme event. Tailings seepage detection relies on the continuous monitoring of soil and groundwater in the vicinity of the TSF.

Fuel and lubricants are needed for most vehicles and machinery. Accidental spills can occur in vehicle accidents, during transport or when fuel and lubricants are not properly handled or stored. There are well-established guidelines and operating procedures to prevent spillages. When a spill does occur, an emergency response clean-up is crucial to prevent the spread of contaminants.

Drilling can lead to soil contamination if drill mud and drill chips are not correctly disposed of, or when drill mud enters an aquifer. The likelihood and magnitude of such contamination on a mine site is relatively small, but it is of greater concern in exploration drilling or when drilling water supply wells.

Chemicals and explosives are needed to process ore and blast rock. Accidental spillage during the transport, storage or handling of chemicals and explosives can lead to contamination.

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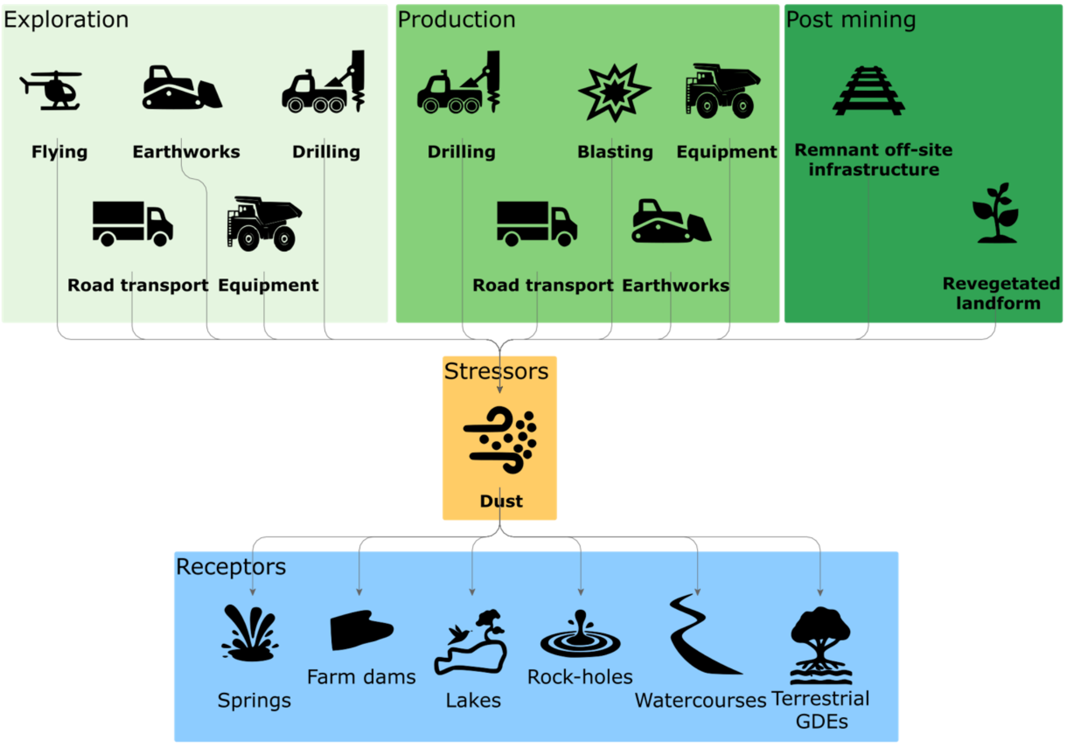
| | Waste streams other than tailings also have contamination potential. Drainage from Waste disposal landfills can lead to soil, groundwater and surface water contamination. Water discharge can cause contamination if the chemistry of the discharging water is not compatible with the chemistry in the receiving watercourse or waterbody.<br><br>Mine dewatering or processing and water desalination produce brines – water with a very high salt concentration. Brine management includes brine storage in evaporation ponds and unintentional brine release can lead to contamination.<br><br>Slurry is processed ore mixed with water that can be transported through a pipeline. Slurry transport can lead to contamination through leaks or other breaches of the pipeline, especially if they are not quickly discovered and remedied.<br><br>Sources of contamination in the exploration phase are Drilling, Fuels and lubricants, Waste disposal and Water discharge.<br><br>Post-mining sources of contamination include Tailings spillage, Tailings seepage, Waste disposal, Acid and metalliferous drainage, Brine management and the Pit void. The Pit void can be a continuing source of contaminants, either as a contaminated surface water feature in the landscape or through interaction with groundwater. |
| Receptors | Soil, surface water and groundwater contamination are intrinsically linked. Soil contamination can spread and cause groundwater contamination when it reaches the water table. Surface water contamination occurs when contaminated runoff reaches surface water, contaminants are spilled directly into surface water, or contaminated groundwater discharges into surface waters. Surface water contamination can in turn lead to soil contamination when contaminated flood waters spread or when contaminated surface water infiltrates groundwater. Contamination therefore affects all receptors. |
| Materiality | The *Environment Protection Act 1993* considers a site contaminated when:<br>• chemical substances are present on or below the surface of the site in concentrations above the background concentrations (if any)<br>• the chemical substances have, at least in part, come to be present there as a result of an activity at the site or elsewhere<br>• the presence of the chemical substances in those concentrations has resulted in:<br>    - actual or potential harm to the health or safety of human beings that is not trivial, taking into account current or proposed land uses, or<br>    - actual or potential harm to water that is not trivial, or<br>    - other actual or potential environmental harm that is not trivial, taking into account current or proposed land uses.<br>Environmental harm is caused by the presence of chemical substances:-<br>• whether the harm is a direct or indirect result of the presence of the chemical substances<br>• whether the harm results from the presence of the chemical substances alone or the combined effects of the presence of the chemical substances and other factors.<br>The Environmental Protection Authority provides site contamination assessment guidelines (EPA, 2019) with recognised criteria for human health and ecological receptors from the National Environment Protection (Assessment of Site Contamination) Measure (ASC NEPM) toolbox. |
| Mitigation | A program for environment protection and rehabilitation (PEPR; DEM, 2023) or mine operation plan (DEM, 2021) must identify contamination sources and emphasise plans to mitigate contamination.<br><br>Best practice guidance is available for many sources of contamination:<br>• Tailings dams (ANCOLD, 2012)<br>• Acid mine drainage (DISR, 2016b)<br>• Handling and storage of chemicals (Safe Work Australia, 2023)<br>• Transport of dangerous goods by road and rail (National Transport Commission, 2022)<br>• Construction of water bores (National Uniform Drillers Licensing Committee, 2020) |

# Dust

The creation, transport and deposition of fine airborne particles of solid matter by wind.

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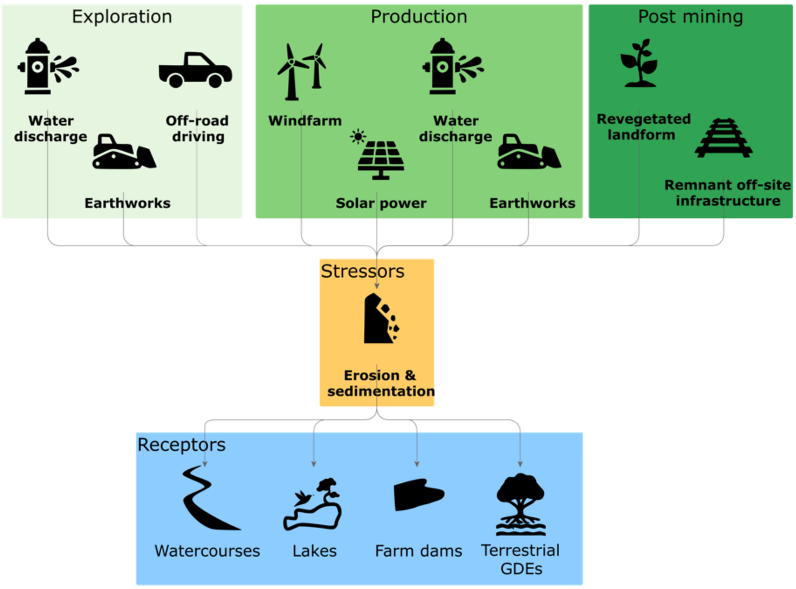
| Sources | Dust arises from several sources during mining, but mainly from Earthworks that use Equipment to move material and Blasting. These include dust generated by wind erosion of stockpiles and tailings. Dust from Blasting is predominantly an issue in open pit mining.<br><br>Outside of the mine site, Road transport is the main source of dust from travel on unsealed roads.<br><br>During exploration, dust can be generated during the landing and take-off of aircraft (Flying), Off-road driving, Road transport, Earthworks (well pad preparation) and Drilling (included in Equipment).<br><br>Post mining, Revegetated landforms and Remnant off-site infrastructure can continue to be a source of dust, especially if vegetation is not able to sufficiently stabilise the landform (e.g. early in revegetation or after severe fire). |
| Receptors | The fine airborne particles that make up dust can contain heavy metals and other pollutants. These can contaminate any open water (e.g. Wright et al, 2024), including Watercourses, Rock-holes, Saline lakes, Farm dams, Springs and Terrestrial GDEs that have exposed water. Dust deposition on vegetation is considered to reduce productivity (Field et al, 2010), but Matsuki et al (2016) found that dust deposition did not affect plant health. Animals, like humans, are susceptible to health impacts due to dust inhalation. |
| Materiality | The National Environment Protection maximum concentration standard for particles with a diameter of 10 µm ($PM_{10}$) is 50 µg/m$^3$ per day or 25 µg/m$^3$ per year and for particles with a diameter of 2.5 µm ($PM_{2.5}$) it is 25 µg/m$^3$ per day and 8 µg/m$^3$ per year. |
| Mitigation | Suppress dust on mine and construction sites by water carting.<br><br>Limit speed and drive to the conditions on unsealed roads. |

# Erosion and sedimentation

The geological process in which earth, soil and/or rock is worn away and transported by natural forces such as wind and water. The transported material is deposited downstream or downwind as sediment.

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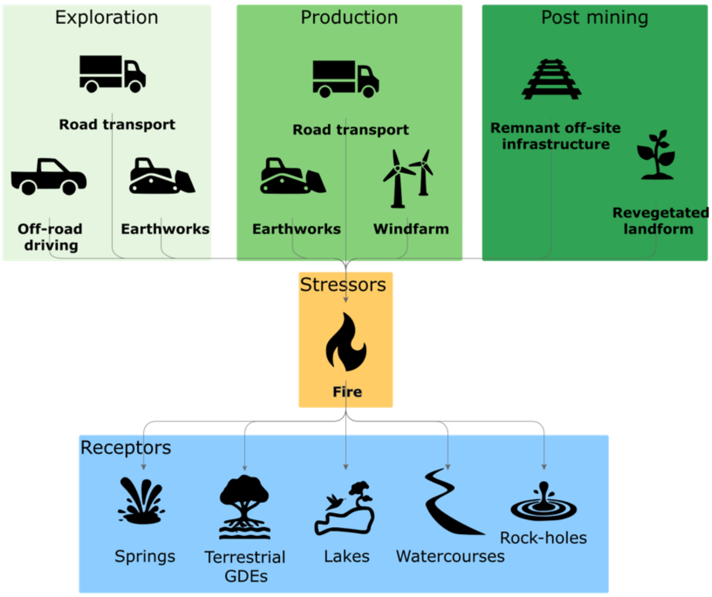
| Sources | The main cause of erosion is land clearance as part of Earthworks. Most land clearance is concentrated on the mine site, but land clearance is also needed for Off-site infrastructure, such as access roads, railways, pipelines and Windfarm or Solar power.<br><br>Water discharge can also contribute to erosion. This is less likely in the study regions as most mines are operating in a water-limited environment.<br><br>During exploration, Earthworks for drilling and Geochemical sampling or Water discharge during Drilling and Groundwater investigations can cause local erosion. Off-road driving during exploration in sensitive landscapes can cause or exacerbate erosion.<br><br>After mining and rehabilitation, Revegetated landforms can still erode and contribute sediments. Off-site infrastructure that is not removed or rehabilitated can continue to contribute to erosion and sedimentation.<br><br>Invasive, hard-hoofed animals can also contribute to erosion and this is covered in Pests and weeds. Contaminants from mining activities associated with sediment transported by water is discussed in Contamination. Contamination from wind erosion is discussed in Dust. |
| Receptors | Erosion removes soil and can create gullies. The removed soil can be rich in nutrients and microorganisms vital for plant growth. This removal results in decreased soil fertility and affects vegetation receptors, like Terrestrial GDEs, and the Watercourses profile as it changes the flow regime.<br>Increased sediment load and turbidity due to erosion decrease water quality and affects receptors with a catchment area like Watercourses, Saline lakes, Farm dams and Terrestrial GDEs. When sediments settle down and get deposited, they can change flood-out areas and change the flow regime. |
| Materiality | Erosion and sedimentation are recognised as threats to landscape condition in the SAAL Regional Landscape Plan (SAAL, 2021) and the Eyre Peninsula Regional Landscape Plan (EPLB, 2021). |
| Mitigation | Earthworks in or near watercourses or Water discharge into watercourses are considered water-affecting activities that require a permit under the *Landscape Act 2019.*<br><br>Adhere to best practice guidance on erosion and sediment control in the design and construction of infrastructure (e.g. IECA, 2008) and roads (e.g. Pringle et al, 2019). |

# Fire

The unintentional ignition of bushfires and/or changes to the natural bushfire regime.

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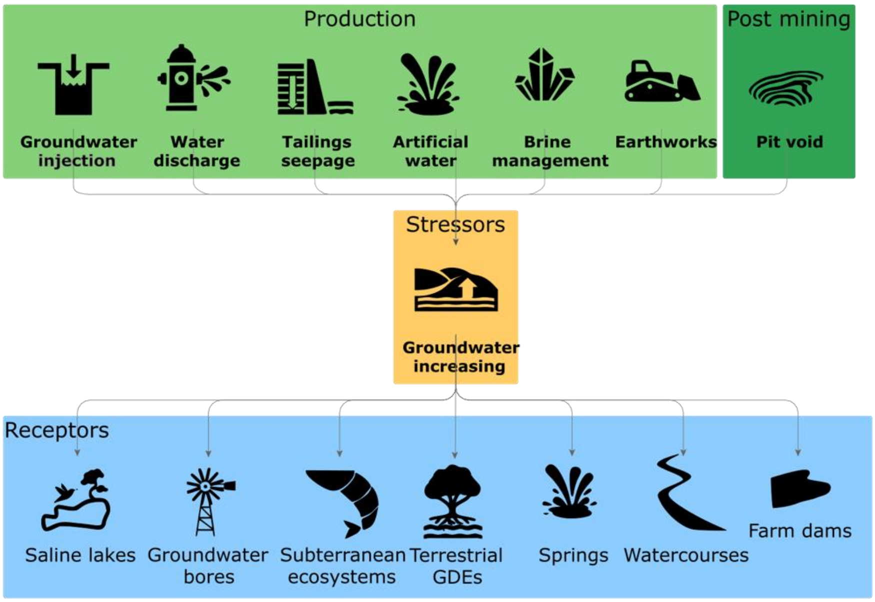
| Sources | There are many potential fire ignition sources on a mine site but fire prevention protocols make it unlikely that they will light a bushfire or change the bushfire regime. However, road Earthworks can create fire breaks in the landscape and change the fire regime. Road transport can be a source of accidental ignition, not only from traffic to and from the mine, but because the expanded road network allows access to areas that were previously inaccessible. Wind farms can be a source of ignition for bushfires if the turbine catches fire. In addition to Road transport and Earthworks, Off-road driving during exploration can accidentally ignite bushfires.<br><br>Post-mining, the Revegetated landform may be more or less prone to bushfires than the original vegetation and landform and so change the bushfire regime. Remnant off-site infrastructure, especially roads and tracks, allows continued access to the landscape and increases the risk of accidental ignition.<br><br>The effect of invasive plants on bushfire regime is discussed in Pests and weeds. |
| Receptors | Bushfires and changes to bushfire regimes affect both fauna and flora (DAWE, 2022). They affect receptors supporting surface ecosystems that can be prone to fire, including Terrestrial GDEs, Springs, Lakes, Watercourses, Farm dams and Rock-holes. |
| Materiality | Inappropriate fire is listed as low priority in the North East Pastoral District (Braemar region; SAAL, 2022). It is not listed as a priority in the Gawler Ranges District Plan (Stuart Shelf; SAAL, 2022a) or Kingoonya District Plan (Stuart Shelf; SAAL,2022b).<br><br>The Eyre Peninsula Regional Landscape Plan 2021-2026 (EP, 2021) lists bushfires as subregional and local drivers of change.<br><br>Fire regimes that cause declines in biodiversity are eligible for listing as a Key Threatening Process under the *Environment Protection and Biodiversity Conservation Act 1999* (DAWE, 2022). |
| Mitigation | Fit vehicles with fire extinguishers, impose smoking bans, restrict access by using signs or gates to deter unauthorised use of private roads, and regularly maintain vehicles to mitigate accidental ignition.<br><br>Design and construct mine rehabilitation (and rehabilitated vegetation) to make sure that fire regimes remain unaltered. |

# Groundwater drawdown

Lowering of groundwater levels due to pumping in a pumped or adjacent aquifer and/or evaporation from remnant voids.

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| Sources | Groundwater pumping for either mine dewatering or for water supply can lead to groundwater drawdown (lowering of groundwater levels). Mine dewatering is needed if the excavation level is below the water table. The water produced from mine dewatering is unlikely to be of sufficient quality and quantity to satisfy the mine's water demands. Therefore, some mines choose to pump groundwater elsewhere to satisfy their water demand and move the water via pipelines to the mine site. The hydrogeological framework reports (Currie and Richardson, 2022; Currie et al, 2023; Currie, 2023) discuss the availability of groundwater in each region and to what extent it can satisfy the expected demand.<br><br>While groundwater may be an option for individual mines, it is unlikely that the cumulative demand of water for the proposed projects in the Braemar and Northern Eyre regions can be satisfied solely by groundwater pumped within the region.<br><br>During exploration, Groundwater pumping can be part of groundwater investigations to characterise aquifers. This pumping usually occurs for a short amount of time and at low pumping rates.<br><br>The Pit void that remains after mining will fill with groundwater and groundwater levels will recover once active mine dewatering is stopped. The rate at which groundwater levels recover depends on the hydraulic properties of the mine site, whether or not the void is backfilled and evaporation rates (Bozan et al, 2022). In areas with high evaporation compared to groundwater inflows, the pit void can become a permanent groundwater discharge feature in the landscape and groundwater levels will not recover to pre-mining levels. |
| Receptors | Receptors that directly rely on groundwater can be affected by Groundwater drawdown. For Groundwater bores, drawdown means that there is less water available to pump, more energy is needed to pump the water to the surface and, in extreme cases, the bore falls dry.<br><br>For Subterranean ecosystems, Groundwater drawdown results in a reduction of their habitat. Stygofauna species often occupy a limited zone within an aquifer, depending on pore space and nutrient availability. In extreme cases, drawdown can cause stygofauna -suitable zones to be unsaturated which then causes the habitat to fragment or to disappear. This also leads to redox changes that affect groundwater quality when dewatered sediments are resaturated. |

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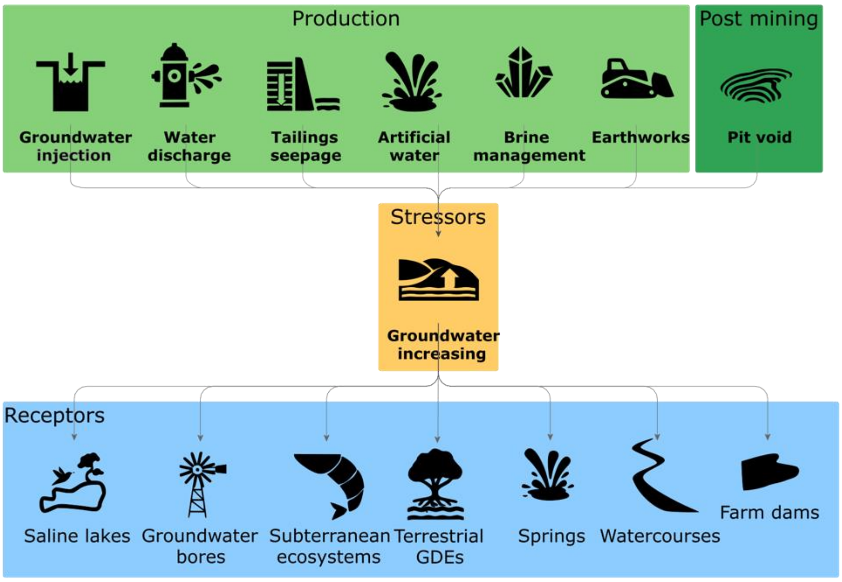
| | Groundwater drawdown, or the reduction of groundwater pressure, can affect Springs by decreasing spring flow. Terrestrial GDEs have roots that are deep enough to reach the water table. Sudden changes in water table depth means that this water source is no longer available for the plants (Glanville et al, 2023). Some species can be resilient to slow changes in water table elevation, provided that their roots grow fast enough to keep up with the drop in water table and they are able to pump the water up for transpiration to occur.<br><br>Groundwater drawdown can reduce groundwater inflow into Water courses, Saline lakes and Farm dams or increase infiltration from surface water into groundwater. |
| Materiality | The sustainable management of groundwater is a key priority of the SAAL Regional Landscape Plan (SAAL, 2021) and the Eyre Peninsula Regional Landscape Plan (EPLB, 2021). |
| Mitigation | Groundwater drawdown can only be mitigated by reducing pumping rates. Managed aquifer recharge can be used to mitigate drawdown from mine dewatering (Sloan et al, 2023). |

# Groundwater increasing

Increasing groundwater levels or pressures due to injection, infiltration and/or hydraulic loading at the surface.

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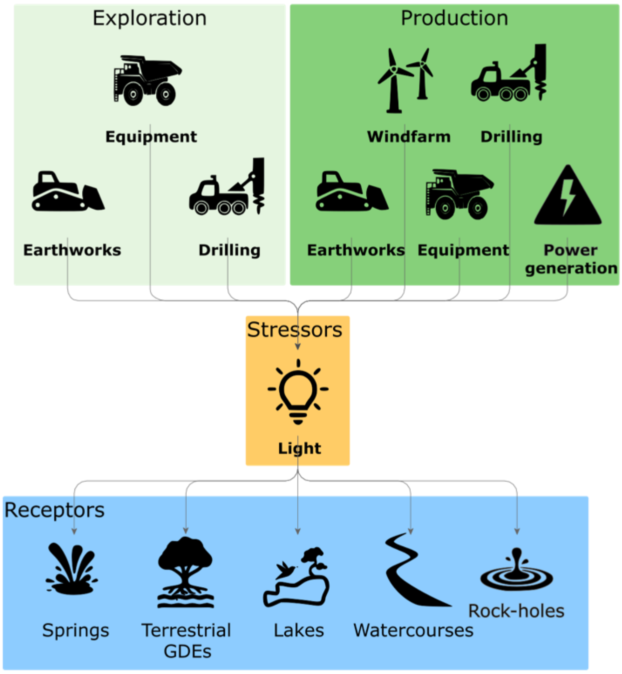
| Sources | Groundwater levels can locally rise where water infiltrates. This can be associated with Tailings seepage, Brine management, Water discharge and any other source of Artificial water in the landscape due to leaky pipelines or changes in microtopography that lead to ponding and infiltration.<br><br>Earthworks for the construction and operation of tailings storage facilities can create hydraulic loading. The placement of embankments and tailings increases the hydraulic pressure, increasing the pore pressure in the underlying aquifers (Fortuna et al, 2021).<br><br>Especially in the context of in situ recovery mining, well-field operation includes Groundwater injection, which can cause groundwater levels to rise. Groundwater injection can also be part of water management, such as aquifer injection of surplus or waste water.<br><br>Post-mining, recovery of groundwater levels in the Pit void, especially in urban areas, can cause contaminated groundwater to reach the surface (Peeters et al, 2004). This is currently an issue in Bendigo (https://www.water.vic.gov.au/water-sources/groundwater/managing-groundwater-from-bendigo-mines). |
| Receptors | Rising groundwater in urban environments can cause damage to infrastructure (Becker et al, 2022)<br><br>The spread of contaminated groundwater or the mobilisation of salt due to a rising groundwater table (Allison et al, 1990) can directly affect Groundwater bores, Subterranean ecosystems, Springs and Terrestrial GDEs. Rising groundwater can also affect Watercourses and Farm dams as the increased hydraulic gradient can lead to increased discharge of saline water.<br><br>Ecosystems in the study regions are adapted to a hydrological regime with limited groundwater availability. Increased groundwater availability due to rising water tables can waterlog plants and increase competition with species that are less drought tolerant (Glanville et al, 2023). |
| Materiality | While the sustainable management of groundwater is a key priority in the SAAL Regional Landscape Plan (SAAL, 2021) and the Eyre Peninsula Regional Landscape Plan (EPLB, 2021), groundwater drawdown is the main concern, rather than local increases in groundwater levels or pressures. |
| Mitigation | Consider hydrogeological conditions in the design and planning of tailing storage facilities (Fortuna et al, 2021).<br><br>Adhere to guidelines on aquifer injection (e.g. Dillon et al, 2020). |

# Light

Artificial lighting at night or interference with sunlight during the day

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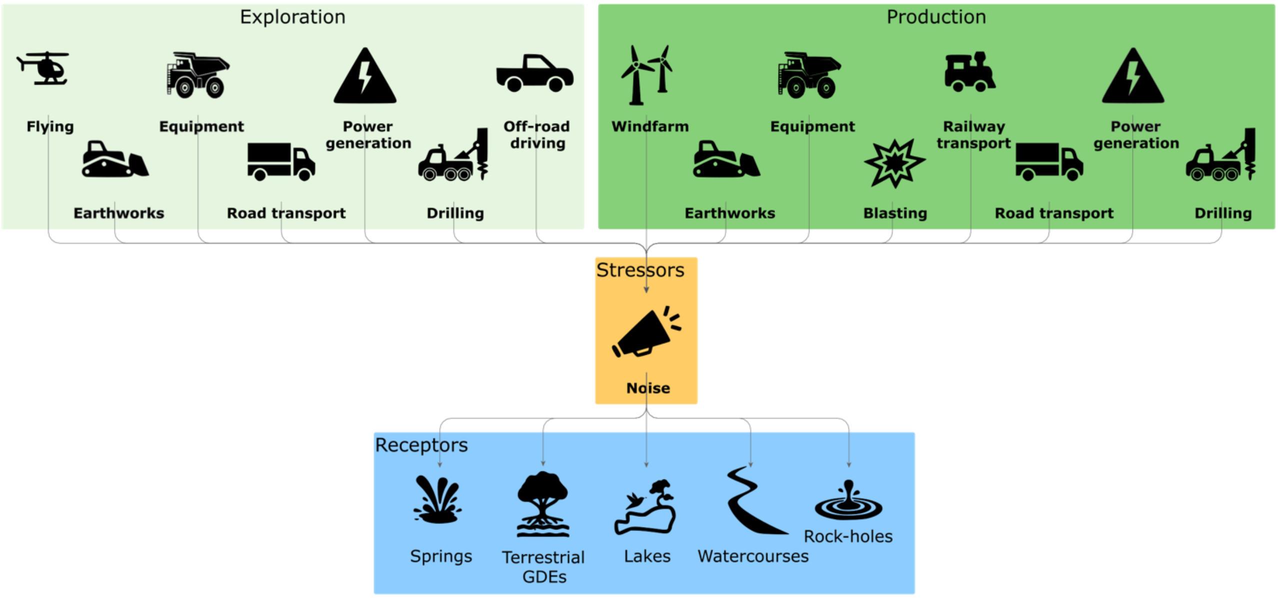
| Sources | Operations at a mine site after sunset will need artificial light. These operations include Drilling, Earthworks, Power generation and any Equipment needed for ore processing.<br>Wind farms do not require lighting at night but windfarms can create shadow flicker from the rotating blades and this can be a source of community annoyance (Haac et al, 2022).<br>During exploration, night activities like Earthworks, Drilling and Equipment operation can cause light pollution, albeit of shorter duration and extent than during mine operation.<br>The effects of artificial lighting from Road transport, Railway transport, Flying and Off-road driving are discussed in Animal harm. |
| Receptors | Artificial lighting has been shown to affect biodiversity (Newport et al, 2014), especially insects (Owens et al, 2020), and therefore has an impact on receptors that support the surface ecosystems associated with Terrestrial GDEs, Springs, Lakes, Watercourses, Farm dams and Rock-holes. |
| Materiality | The National Light Pollution Guidelines for Wildlife (DCCEEW, 2023) recommend undertaking an environmental impact assessment if there is an important habitat for listed species within 20 km of a development with outdoor lighting or indoor lighting that is visible outside. |
| Mitigation | Adhere to best practice lighting principles. |

# Noise

Excessive artificial sound, above background levels, from human activity, such as blasting and use of machinery.

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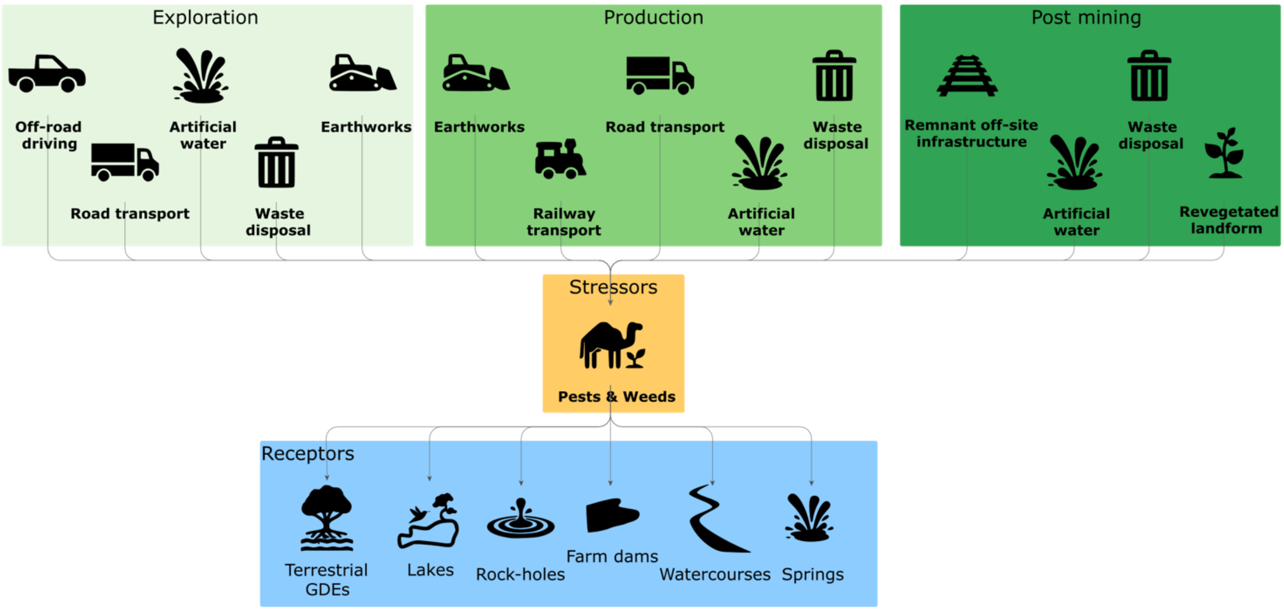
| Sources | There are many sources of Noise during mining. Earthworks and Drilling machinery, Equipment operation, and rock Blasting are common noise sources. The supply of power is another noise source. Noise comes from generators used for Power generation or from the rotating blades of wind turbines in Wind farms (low-frequency noise). Off-site, noise can come from Road or Railway transport.<br>During exploration, the main sources of noise are *Flying, Earthworks, Road transport, Power generation* and *Equipment* operation.<br>There are no sources of noise post-mining. |
| Receptors | Just as noise affects humans, there is evidence that it can disturb the behaviour of animals (Sordello et al, 2020) and therefore receptors that support ecosystems at the surface, such as Terrestrial GDEs, Lakes, Watercourses, Rock-holes, Springs and Farm dams. |
| Materiality | The *Environment Protection (Commercial and Industrial Noise) Policy 2023* sets indicative noise factors for different land-use categories. The lowest levels are for rural living, with an indicative noise factor of 47 dB(A) during the day and 40 dB(A) during the night. Noise from construction activities, railways, aircraft, vehicles and blasting is excluded from the policy.<br>The SA EPA wind farms environmental noise guidelines (Song and Yorke, 2021) sets noise criteria for new wind farm developments at 35 dB(A) in rural areas, 40 dB(A) elsewhere or at 5 dB(A) above background noise. |
| Mitigation | Use sound control on equipment.<br>Place sound barriers around mine sites<br>Minimise loud activities at night. |

# Pests and weeds

Introducing, maintaining and/or increasing populations of plants and/or animals that are not native to the region of the undesired overabundance of native animal and/or plant species. Pests and weeds typically increase predation and/or competition pressures on native species.

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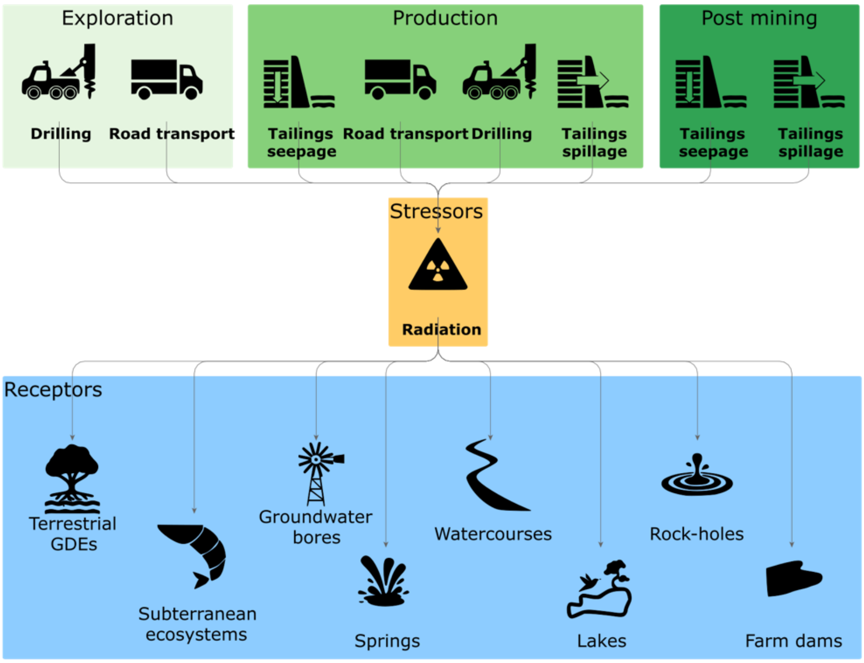
| Sources | Road transport and Railway transport can move weeds, insects and animals (e.g. toads, rodents) into the region. Similarly, earthmoving equipment for Earthworks can spread weeds and animals between sites if it is not cleaned properly. Artificial water sources such as ponds and borrow pits provide watering points for invasive animals to expand their territory or sustain their population. It also allows invasive plants to establish.<br><br>Waste disposal, especially domestic waste, can attract animals such as pigs, cats and foxes.<br>In the exploration phase, the threat of pests and weeds is mostly associated with Earthworks, Road transport, Artificial water and Waste disposal.<br><br>Post-mining, the Pit void and other sources of Artificial water, including Remnant off-site infrastructure can sustain Pests and weeds. The Revegetated landform can give invasive plants and animals opportunities to establish. |
| Receptors | Pests and weeds can facilitate pathogen transfer and outcompete native animals and plants for water and other resources. Invasive predators, such as cats and foxes, kill native animals, while invasive herbivores and overabundant native animals can overgraze native vegetation. This affects receptors that sustain ecosystems such as Terrestrial GDEs, Springs, Saline lakes, Rock-holes, Farm dams and Watercourses.<br><br>Invasive herbivores can exacerbate erosion by reducing vegetation cover and by trampling and damaging roots. This is particularly the case for hard-hoofed animals and especially around watering points like Watercourses, Rock-holes, Farm dams and Springs (Box et al, 2019).<br><br>Invasive plants can change the fuel load in the landscape and change the bushfire regime. |
| Materiality | The management of pests and weeds is a key priority in both the SAAL Regional Landscape Plan (SAAL, 2021) and the Eyre Peninsula Regional Landscape Plan (EPLB, 2021). |
| Mitigation | See the South Australian Arid Lands Landscape Board's information on identifying and managing pest plants and animals.<br><br>See the Eyre Peninsula Landscape Board's information on identifying and managing pest plants and animals. |

# Radiation

The emission of ionising radiation from radioactive sources above local, natural background levels.

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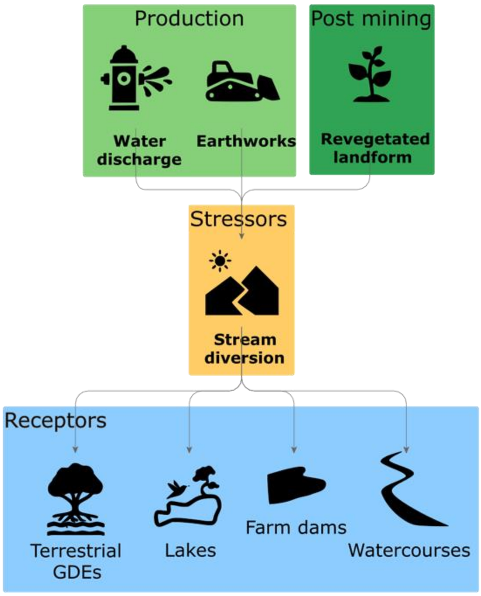
| Sources | Ionising radiation from radioactive sources arises from mining radioactive minerals, such as uranium. These radioactive minerals can be present in tailings and can be released into the environment through Tailings seepage or Tailings spillage. Radioactive minerals can also be exposed during Drilling, in drill chips or mud. Road transport of radioactive minerals in ore has the potential to cause radiation.<br><br>Some geophysical techniques, especially bore logging tools, use radiation. There is a radiation risk associated with the handling, storage and transport of this equipment. |
| Receptors | Radiation can affect animals and plants, as well as contaminate water sources. It can therefore affect all receptors. |
| Materiality | The *Radiation Protection and Control Act 2021* controls activities involving radiation sources, including mining and mineral processing. |
| Mitigation | Radiation protection guidelines on mining in South Australia: Mineral exploration (EPA, 2010).<br><br>Code for the safe transport of radioactive material (ARPANSA, 2019). |

# Stream diversion

Intentional, permanent or temporal changes to the course or channel of a watercourse. Modified watercourses often have different features, such as fewer meanders or less heterogeneity in channel topography.

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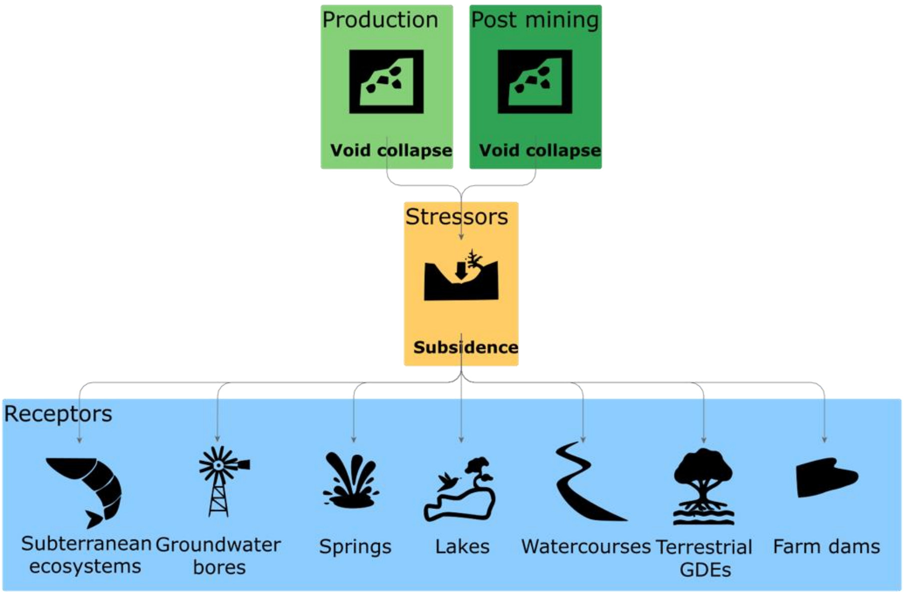
| Sources | The Earthworks associated with developing on-site mine infrastructure can involve diverting the channel of a stream or creek. In addition, mine operators need to ensure that all water that enters the mine site does not leave the site. Operators can therefore choose to divert a stream around a mine. Water discharge can also contribute to stream diversion as it changes the flow regime but it is less likely in the study regions as most mines are operating in a water-limited environment.<br><br>Post-mining, the Revegetated landform may permanently divert a creek or stream. |
| Receptors | Stream diversion will alter the flow volume and timing in the catchment areas of Water courses, Saline lakes, Farm dams and Terrestrial GDEs. Receptors with no or small catchment areas (Springs and Rock-holes) are not affected by stream diversion. |
| Materiality | Under the SA Arid Lands water-affecting activities control policy (SAAL, 2021a), a permit is required for an activity that diverts more than 10 ML of water from its natural watercourse in one flow event (except for the Murray-Darling Basin Management Zone where any activity diverting water from its natural watercourse requires a permit). On the Eyre Peninsula, any activity diverting a watercourse or discharging water into a watercourse requires a permit (EPLB, 2021a). |
| Mitigation | Stream diversion is challenging to mitigate during mining. Post-mining effects can be mitigated by adhering to effective mine closure criteria like those outlined in Flatley et al (2021). |

# Subsidence

Sinking of the ground due to underground material movement

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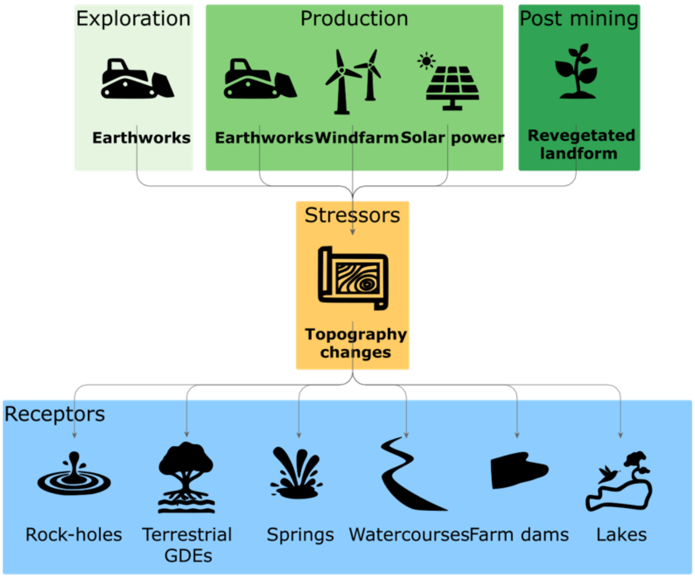
| Sources | Subsidence is only associated with underground mining. It occurs when the mine Void collapses and causes the surface above the void to sink. The void collapse can be intentional and controlled (e.g. the Carrapateena cave propagation to the surface on 29 December 2022).<br><br>Subsidence generally occurs during mining operations, but it can continue after this has ceased. The effects of subsidence remain in the landscape, even after mining. |
| Receptors | Subsidence is a local effect and occurs in the immediate vicinity above the mined area (Parker et al, 2021). As it changes the topography, it can affect local drainage patterns and thus locally change the flow regime of Watercourses, Saline lakes, Farm dams, Springs and Terrestrial GDEs.<br><br>In the context of coal mining, it is a concern that the fractured zone above the collapsed void increases aquifer permeability. This leads to decreased groundwater pressures that can affect groundwater-related receptors including Groundwater bores, Springs, Terrestrial GDEs and Subterranean ecosystems (Commonwealth of Australia, 2023). |
| Materiality | A program for environment protection and rehabilitation (PEPR; DEM 2023) requires an assessment of the expected extent of subsidence. |
| Mitigation | Backfill underground mine voids. |

# Topography changes

Changes in topography that change existing drainage patterns and/or alter the visual appearance of the landscape.

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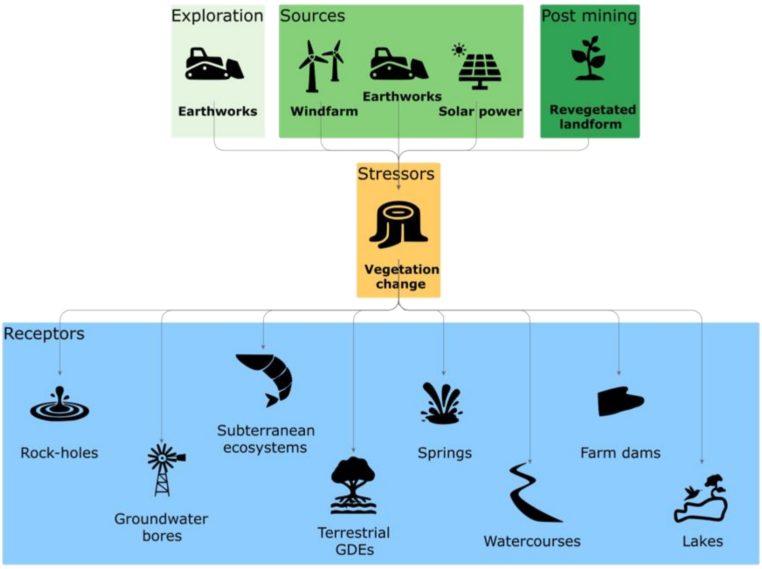
| Sources | Earthworks for mine development, especially open pit mines, can result in drastic changes to the topography. This is especially the case for large deposits like the iron mines in the Braemar and Northern Eyre regions. The development of off-site infrastructure also involves earthworks that change topography. These changes are much smaller, but they can be significant nevertheless. A road that is not constructed to a certain grade in areas with low-relief can drastically change the runoff patterns and cause topography changes particularly in flood-out areas commonly found in this region. This includes earthworks for Windfarms and Solar farms.<br><br>In the exploration phase, Earthworks to prepare drill sites or camp sites can locally change topography.<br>Post-mining, the Revegetated landform is a permanent change to the topography. |
| Receptors | Topography changes alter creek profiles, create gullies, and change flood-out areas. Large topography changes can alter the catchment area. This affects all receptors that have a catchment area, including Terrestrial GDEs, Watercourses, Farm dams and Lakes. Springs and Rock-holes can be affected if spring or rock-hole area is directly affected by the topography change. |
| Materiality | A program for environment protection and rehabilitation (PEPR; DEM, 2023) requires detailed descriptions of all earthworks associated with exploration, production and rehabilitation. |
| Mitigation | Topography changes are challenging to mitigate as part of a mining operation.<br><br>Minimise impact on natural drainage by adhering to best practice guidelines on erosion and sediment control in infrastructure design and construction (e.g. IECA, 2008) and roads (e.g. Pringle et al, 2019). |

# Vegetation change

Changes in native vegetation composition and condition, including physical removal, destruction and/or replacement of current vegetation with different native vegetation.

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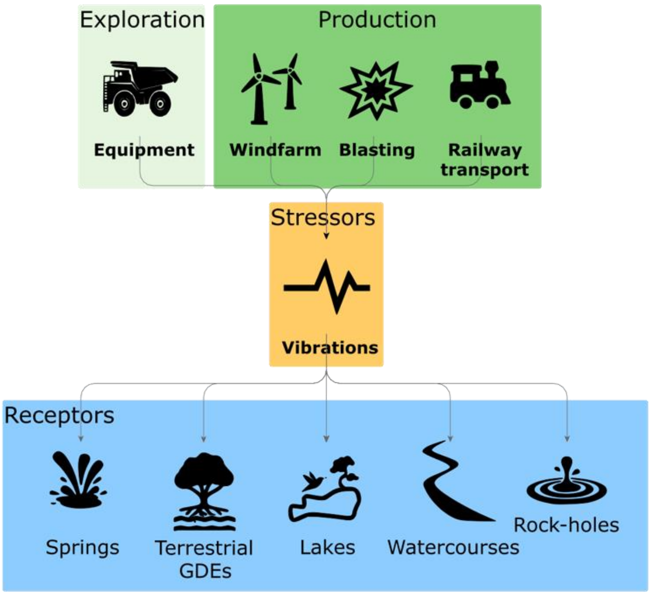
| Sources | Earthworks to develop mine infrastructure involves land clearance, both on the mine site as well as off-site, to construct new roads, pipelines, transmission lines and railways. Mine site rehabilitation after closure includes revegetation. During off-site infrastructure construction, the land clearance and disturbance is greater than that for lay-down areas. These sites can be revegetated after the construction phase. Areas adjacent to cleared areas are often also disturbed.<br><br>Solar power requires approximately 2 hectares of land per megawatt. While native vegetation may be cleared during construction, some solar farm designs allow for vegetation to be established under and next to the photo-voltaic panels, so that grazing is still possible at the solar farm.<br><br>Wind farms only clear land for wind turbines and access roads. The disturbed area on wind farms is less than for solar farms, but the total wind farm area can be large, depending on turbine spacing. Wind turbines are placed at locations with favourable wind conditions, such as ridges.<br><br>During the exploration phase, vegetation change is associated with Earthworks at drill sites and access tracks. Post-mining, the Revegetated landform can host different vegetation than it did before mining. |
| Receptors | Vegetation change and removal affects all receptors that support ecosystems (Neldner et al, 2017), including Watercourses, Farm dams, Saline lakes, Springs and Rock-holes. Vegetation changes can impact on the volume of recharge to unconfined aquifers (Allison et al, 1990) and affect groundwater-related receptors (Groundwater bores, Terrestrial GDEs, Springs, Subterranean ecosystems). |
| Materiality | The *Native Vegetation Act 1991* outlines the principles of native vegetation clearance and the conditions under which the Native Vegetation Council can decide not to allow clearance. |
| Mitigation | Vegetation can be cleared for operations authorised under a mining Act or for exploration under a mining Act, provided exploration activities are undertaken in accordance with Native Vegetation Council (NVC)-approved industry standards. The NVC needs to be provided with a management plan that incorporates details of the proposed clearance and a significant environmental benefit (SEB) management plan. The proposed clearance and SEB will be assessed in accordance with the mitigation hierarchy, which calls for proponents to plan their activity, in order of importance, to:<br><br>• avoid impacts on native vegetation, by planning infrastructure to avoid impacts on biodiversity<br>• minimise the duration, intensity and/or extent of impacts on native vegetation<br>• rehabilitate or restore ecosystems that have been degraded at the site<br>• offset to compensate for any significant residual adverse impacts that cannot be avoided or minimised. |

# Vibrations

Human-induced vibrations of the earth due to railway transport, seismic geophysical investigations, wind turbine operation or the use of explosives during mining.

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| Sources | Open pit and underground mining use explosives. The Blasting of rock causes vibrations that can be felt 10 km to 20 km away from the blast site. Railway transport generates ground vibrations as does the rotation of wind turbines in a Wind farm (Nagel et al, 2021).<br><br>Exploration can include seismic surveys. In seismic surveys, shockwaves are sent through the earth with a vibroseis truck (Equipment) and the wave travel recorded to image the subsurface. Seismic imaging is routinely used in oil and gas exploration but much less in mineral exploration.<br><br>There are no sources of Vibration post-mining. |
| Receptors | Vibrations, especially from explosives at mines, can be felt away from the mine site. Humans can perceive this as an annoyance. Animals can likewise be disturbed by ground vibrations: Caorsi et al (2019) documented the impact of ground vibrations from railways and wind turbines on toad communication. Vibration can therefore affect any receptor that supports an ecosystem at the surface, that is Springs, Terrestrial GDEs, Lakes, Farm dams, Watercourses and Rock-holes. |
| Materiality | A program for environment protection and rehabilitation (PEPR, DEM 2023) requires an outline of explosive use (TOR005 – 2.4.6). The ANZEC guidelines on minimising annoyance due to blasting overpressure and ground vibration recommend a maximum ground vibration level (peak particle velocity) of 5 mm per second (ANZEC, 1990). |
| Mitigation | Avoid blasting operations between dusk and dawn.<br><br>Target absorber use in wind turbine design (Nagel et al, 2021). |

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Fact Sheet

# Groundwater bores

## HIGHLIGHTS

- The Stuart Shelf region, the Braemar region, and the Northern Eyre region each have hundreds of stock and domestic bores.
- There are 3 town water supply bores in the Stuart Shelf region and one in the Northern Eyre region, but none in the Braemar region.
- Most of the groundwater in the 3 regions is highly saline (≥4,000 mg/L) with limited occurrence of fresh or brackish groundwater.

## INTRODUCTION

SA Health (2024) recommends that domestic bores be used primarily to extract groundwater for standard household purposes, such as laundry. For other uses, such as drinking, cooking, or watering a domestic garden, the water quality must comply with the Australian Drinking Water Guidelines (NHMRC, NRMMC, 2011). Stock bores are primarily used to access water for livestock. The quality requirements and contaminant tolerances for livestock are less stringent than those for domestic use and are outlined in the Livestock Drinking Water Guidelines (ANZG (2023). The 'stock' classification excludes irrigation rights, which are governed by the *Irrigation Act 2009*, as amended by the *Landscape South Australia Act 2019*.

In regional and remote areas, many communities are reliant on stock and domestic bores, especially when surface water is scarce. Reviews of regional and remote community access to reliable, safe water resources emphasised a need to improve potable water availability across Australia (Water Services Association of Australia, 2022).

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The project was conducted with support from the South Australian government through the Department for Environment and Water and Department for Energy and Mining, South Australian Arid Lands Landscape Board and Eyre Peninsula Landscape Board.

This fact sheet provides information on groundwater bores for stock, domestic purposes and town water supply in the Stuart Shelf, Braemar and Northern Eyre regions. Bores providing water for resource development are discussed in Thomas and Peeters (2024).

Ongoing government projects (e.g. Commonwealth Closing the Gap Implementation Plan 2023) incorporate initiatives (e.g. National Water Grid Fund) to address the lack of available water resources, improve water infrastructure, and increase safe access to water supplies for remote First Nations communities.

The management of water resources in South Australia is guided by the *Landscape South Australia Act 2019* (DEW, 2024a). Stock and domestic rights are outlined in Part 8 (Management and Protection of Water Resources), and Division 1 (General Rights in Relation to Water), within Section 100 of the Act. These permit individuals to extract water for stock and domestic purposes in South Australia, with certain conditions for 'prescribed' water resources (i.e. water resources that must be sustainably managed; DEW, 2024b). This applies to both surface water and groundwater. There is only one prescribed area across the 3 study regions – the Musgrave Prescribed Wells Area in the west of the Northern Eyre region around Elliston. The *Safe Drinking Water Act 2011* applies to bores that supply drinking water to the public (SA Health, 2024).

## GROUNDWATER USE FOR STOCK, DOMESTIC AND TOWN WATER SUPPLY IN THE STUDY AREA

The details presented in this factsheet have been primarily sourced from WaterConnect (https://www.waterconnect.sa.gov.au/Systems/GD/Pages/Default.aspx) and complemented with information from the Australian Groundwater Explorer of the Bureau of Meteorology (http://www.bom.gov.au/water/groundwater/explorer/map.shtml).

The number and distribution of stock, domestic and town water supply bores varies across the 3 study areas. Table 1 summarises the key characteristics of groundwater bores in each study area.

*Table 1 Summary of stock, domestic and drinking water bores in each study area*

| | | Stuart Shelf | Braemar | Northern Eyre |
|---|---|---|---|---|
| Surface area (km$^2$) | | 38,095 | 20,423 | 42,703 |
| Total groundwater bores | | 1,274 | 754 | 1,786 |
| Active bores$^{(*)}$ | | 272 | 199 | 544 |
| Bore purpose defined | | 224 | 199 | 498 |
| Total bores | Domestic | 22 | 21 | 75 |
| | Stock | 96 | 177 | 281 |
| | Town water supply | 3 | 0 | 1 |
| Proportion of bores$^{(**)}$ | Domestic | 9.8% | 10.6% | 15.1% |
| | Stock | 42.9% | 88.9% | 56.4% |
| | Town water supply | 1.3% | n/a | 0.2% |
| Average yield (L/s) | Domestic | 0.45 | 0.60 | 0.92 |
| | Stock | 0.59 | 1.1 | 0.58 |
| | Town water supply | Unknown | n/a | 2 |
| Average [range] bore depth (m) | Domestic | 16.2 [1.8-38.7] | 33.0 [7.3-139] | 22.0 [1.3-104] |
| | Stock | 34.1 [4.6-96.0] | 36.9[1.1-156] | 22.4[0.7-114] |
| | Town water supply | 14.9 [3.6-22.9] | n/a | 4.1 [4.1 – 4.1] |

$^{(*)}$ Bores with following status in WaterConnect: operational, operational as required, controlled flowing, equipped, flowing, uncontrolled flowing

$^{(**)}$ Number of bores (per purpose)/total active bores with a defined purpose

Table 1 highlights that the majority of bores in each study region are used for stock watering and that their yields are generally low. Only a small proportion of bores, between 10% and 15%, are used for domestic purposes. Additionally, only 4 active town water supply bores are identified across the 3 regions: 3 in Andamooka (Stuart Shelf) and one near Venus Bay (Northern Eyre). The 4 town water supply bores are relatively shallow, with an average depth ranging from 4 m to 15 m. In comparison, domestic and stock bores are deeper, with average depths varying between 16 m and 34 m across the three regions. Additionally, Table 1 shows that in the Stuart Shelf and Northern Eyre regions, a large proportion of the bores are not used for stock, domestic, or town water supply. These are mostly bores used for industrial and observation purposes.

The main aquifers supplying stock, domestic and town water supply bores across the 3 regions are presented in Table 2. This information is sourced from Currie et al (2023) and the Australian Groundwater Explorer of the Bureau of Meteorology (http://www.bom.gov.au/water/groundwater/explorer/map.shtml).

*Table 2. Hydro-stratigraphy and main aquifers identified across the 3 study regions*

| Region | Aquifer | Age |
|---|---|---|
| Stuart Shelf | Cotabena Formation | Eocene |
| | Andamooka Limestone | Cambrian |
| | Arcoona Quartzite | Neoproterozoic |
| | Corraberra Sanstone | Neoproterozoic |
| | Woomera/Tregolana Shale | Neoproterozoic |
| | Whyalla Sandstone | Neoproterozoic |
| | Pandurra Formation | Mesoproterozoic |
| Braemar | Renmark Group | Pleistocene-Holocene |
| | Loxton-Parrilla Sands | Pliocene |
| | Burra Group | Neoproterozoic |
| | Wilpena Group | Neoproterozoic |
| | Umberatana Group | Neoproterozoic |
| Northern Eyre | Saint Kilda Formation | Holocene |
| | Quaternary Rocks | Pleistocene-Holocene |
| | Bridgewater Formation | Pleistocene |
| | Garford Formation | Pleistocene |
| | Pidinga Formation | Eocene |
| | Gawler Range Volcanics | Mesoproterozoic |
| | Hiltaba Suite | Mesoproterozoic |
| | Hutchison Group | Palaeoproterozoic |

Table 2 summarises the main contributing aquifers identified in the 3 regions. However, the aquifers that contribute to the 3 water supply bores identified in the Stuart Shelf region and the one in the Northern Eyre region, as well as for a significant proportion of stock (73%) and domestic (67%) bores across all 3 areas, are not reported. This includes 74 stock and 11 domestic bores out of the 118 bores in the Stuart Shelf region, 118 stock and 15 domestic bores out of the 198 bores in the Braemar region, and 214 stock and 60 domestic bores out of the 356 bores in the Northern Eyre region.

Figures 1 to 3 illustrate salinity distribution across the 3 regions and its relationship with bore yield, for bores where this information is known. Following the EPA (2024) guidelines, 3 levels of salinities have been categorised in relation to the recommended salinity of drinking water for livestock (i.e. poultry, dairy cattle, beef cattle, sheep and horses). These are: low salinity with total dissolved solids (TDS) ≤2,000 mg/L; medium salinity, with TDS between 2,000 mg/L and 4,000 mg/L; and high salinity with TDS values >4,000 mg/L. Low-yield records are below 0.25 L/s, while medium-yield records are between 0.25 L/s and 5 L/s. Values higher than 5 L/s are categorised as high values.

Figures 1 to 3 show that, in general, bores with yields above 0.25 L/s extract high salinity groundwater (>4,000 mg/L), especially in the Stuart Shelf and Braemar regions. In contrast, a higher proportion of bores show high-salinity groundwater for yield values smaller than 0.25 L/s in the Northern Eyre region.

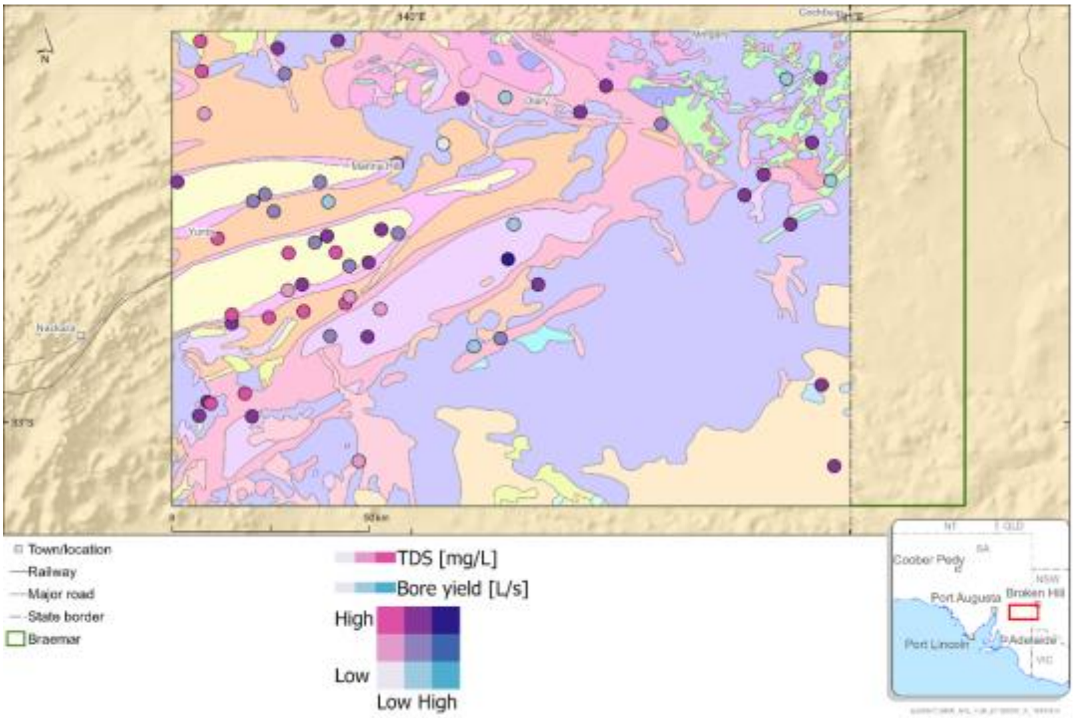


*Figure 1. Relationship between salinity and yield (based on the latest records for both measurements, 1891–2021) across stock, domestic, and town water supply bores in the Braemar region.*

Salinity ranges are: low: ≤2,000 mg/L, medium: 2,000 mg/L to 4,000 mg/L, high ≥4,000 mg/L. Yield ranges are: low: ≤0.25 L/s, medium: 0.25 L/s to 5 L/s, and high: ≥5 L/s. Background: 1:2,000,000 surface geology map (SARIG, [https://map.sarig.sa.gov.au/](https://map.sarig.sa.gov.au/)).

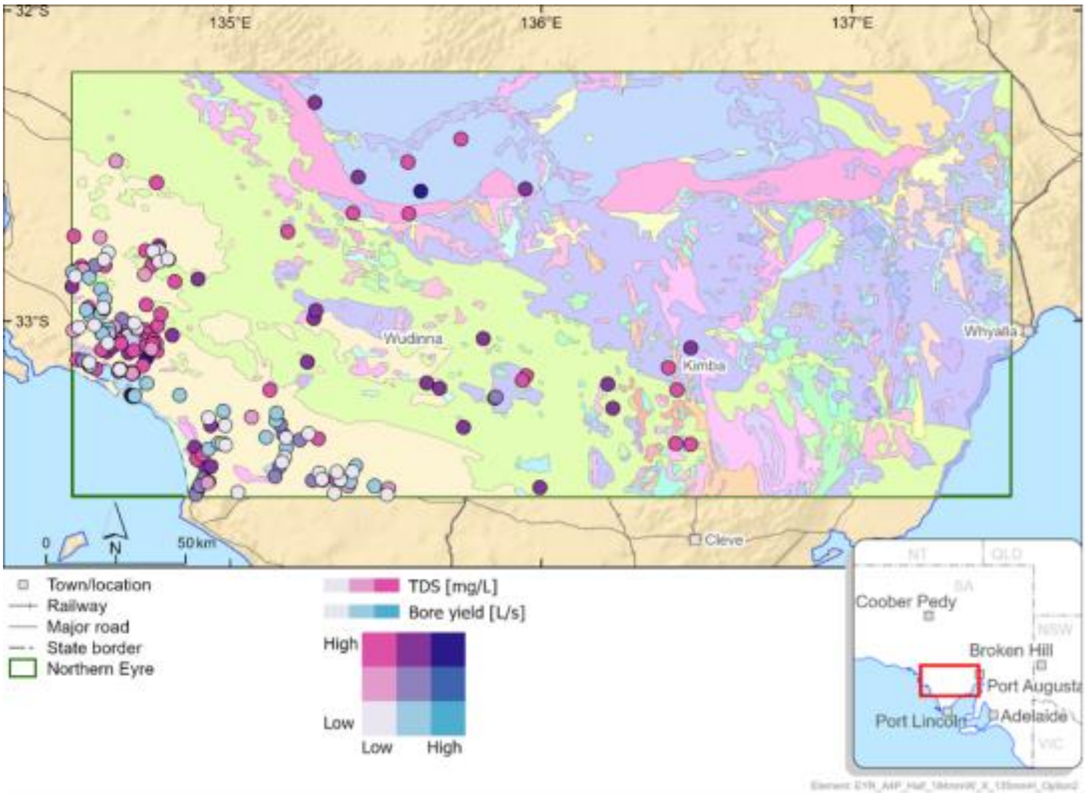


*Figure 2. Relationship between salinity and yield (based on the latest records for both measurements, 1891–2021) across stock, domestic, and town water supply bores in the Northern Eyre region.*

Salinity ranges are: low: ≤2,000 mg/L, medium: 2,000 mg/L to 4,000 mg/L, high ≥4,000 mg/L. Yield ranges are: low: ≤0.25 L/s, medium: 0.25 L/s to 5 L/s, and high: ≥5 L/s. Background: 1:2,000,000 surface geology map (SARIG, [https://map.sarig.sa.gov.au/](https://map.sarig.sa.gov.au/)).

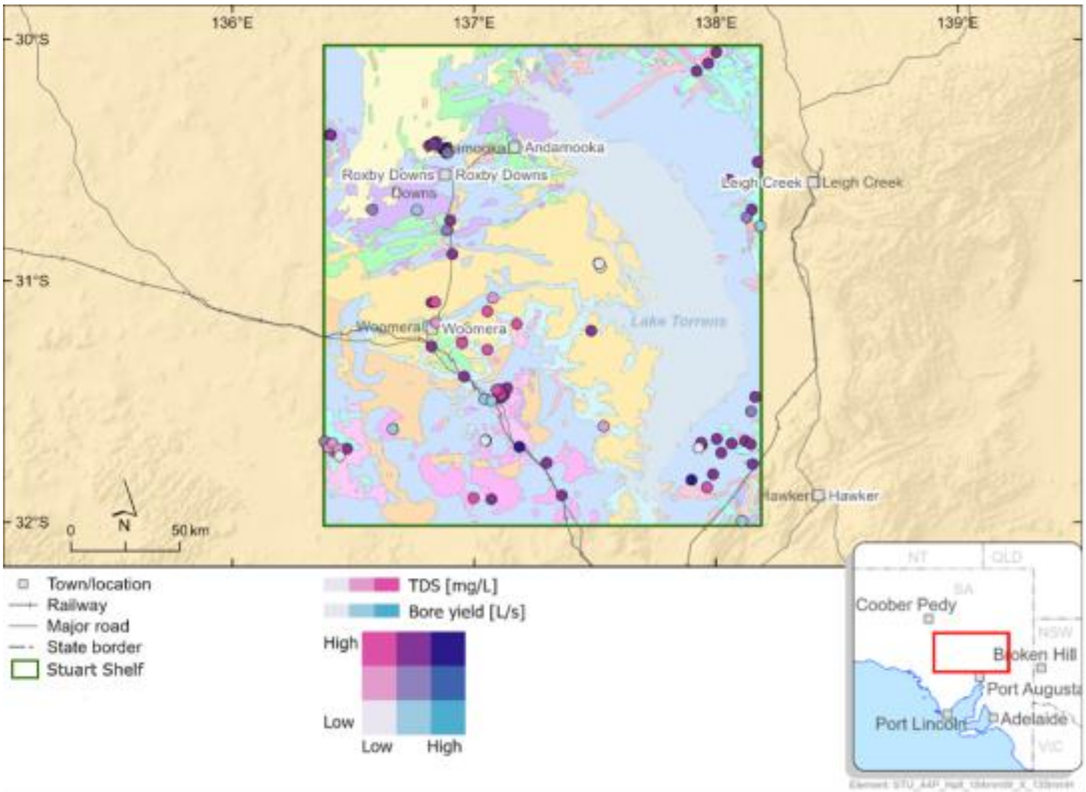


*Figure 3. Relationship between salinity and yield (based on the latest records for both measurements, 1891–2021) across stock, domestic, and town water supply bores in the Stuart Shelf region.*
Salinity ranges are: low: ≤2,000 mg/L, medium: 2,000 mg/L to 4,000 mg/L, high ≥4,000 mg/L. Yield ranges are: low: ≤0.25 L/s, medium: 0.25 L/s to 5 L/s, and high: ≥5 L/s. Background: 1:2,000,000 surface geology map (SARIG, https://map.sarig.sa.gov.au/).

## POTENTIAL IMPACTS FROM DEVELOPMENT

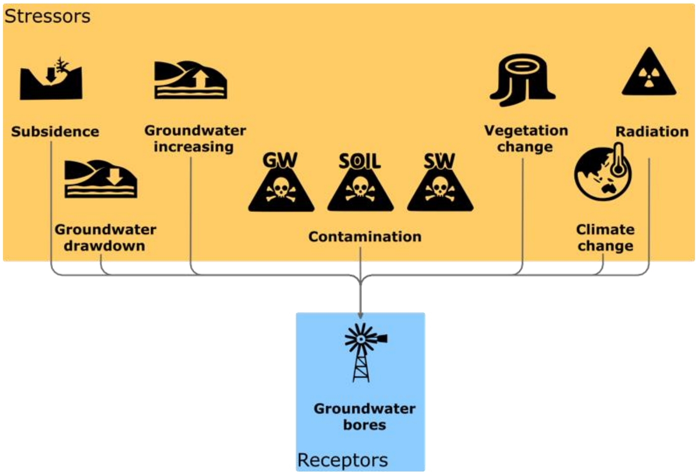


*Figure 4. Stressors that can lead to impact on stock, domestic and town water supply bores*

Resource development can affect stock, domestic and town water supply bores through stressors that change the quantity and/or quality of groundwater available (see also Subterranean ecosystems fact sheet) (Figure 4). Groundwater drawdown due to mining can reduce bore yield. Increases in groundwater levels, due to hydraulic loading for instance, can affect the headworks of a bore. Climate change and vegetation changes can lead to reductions in aquifer recharge and therefore reduce bore yield.

Groundwater contamination is the main stressor affecting bore groundwater quality. While contamination from resource development, such as tailing storage facility seepage, is a significant concern (see Impact pathway diagrams fact sheet), its effects are typically confined to areas near the source and not widespread areas. Groundwater bores can only be affected when contaminated groundwater flows towards the bore. Some groundwater contaminants attenuate naturally; the concentration of contaminants reduces through naturally-occurring processes in aquifers. Radiation is a special kind of contamination. Rising groundwater levels can mobilise salt and lead to contamination.

## DATA AND KNOWLEDGE GAPS

It is important to recognise significant data gaps that may impact the accuracy and relevance of the findings presented in this fact sheet. The following limitations are relevant to understanding the current groundwater condition and the impact of developments on groundwater supply:

- Purpose identification: Of the 272 suggested active bores in the Stuart Shelf region, 48 are not identified for their purpose. Similarly, 46 of the 544 bores in the Northern Eyre region lack purpose identification. It is recommended to conduct a thorough assessment to identify the purpose of the bores that are currently unidentified. Understanding the intended use of these bores is essential for accurate analysis and management of groundwater resources. Additionally, the information in WaterConnect, especially the older records, needs to be corroborated on-site, as there may be additional bores that are not included in the database.
- Aquifer information: In the Stuart Shelf region, 88 out of 212 active stock, domestic and town water supply bores lack information about the targeted aquifer for extraction. Similarly, 133 out of 199 bores in the Braemar region and 275 out of 357 bores in the Northern Eyre region do not have source aquifer information available. Efforts should be made to gather information about the targeted aquifers for extraction where such data are currently lacking. This information is critical to evaluate the sustainability of groundwater usage and to implement effective management strategies.
- Yield records: The latest yield measurements in the Stuart Shelf region span from 1891 to 2021, whereas in the Braemar and Northern Eyre regions, they occurred between 1929 and 2015, and between 1911 and 2020, respectively. Of the 121 stock, domestic and town water supply bores within the Stuart Shelf region, 42 do not have yield measurement records. One bore was surveyed in 2021, while the largest number of bores (22) were last surveyed in 1947. Therefore, current yield rates of stock, domestic and town water supply in the Stuart Shelf region are unknown. The same limitation occurs in the Braemar region, where only one bore (out of 199 bores) was last surveyed in 2015 and there are no records of yield measurements for 137 bores. In the Northern Eyre region, 201 out of 357 bores lack yield measurement data, with the last measurement occurring at one bore in 1995. Priority should be given to conducting comprehensive yield measurements and maintaining up-to-date records for all stock, domestic and town water supply bores. Regular monitoring and recording of yield data, with measurements taken at least annually, are essential to assess groundwater availability and plan future developments sustainably.
- Salinity measurements: The latest salinity measurements in the Stuart Shelf region, sourced from WaterConnect, span from 1925 to 2021. Of the 121 bores in this region, 29 have no salinity records and only 2 bores were surveyed in 2021. In the Braemar region, salinity measurements cover the period from 1959 to 1992. Of the 199 bores in this region, 8 lack salinity records, and only 2 bores were surveyed in 1992. In the Northern Eyre region, salinity measurements span from 1925 to 2023. Among the 357 bores in this region, 8 have not been surveyed for salinity, and only 5 bores were surveyed in 2023. To improve understanding of groundwater salinity levels and trends, comprehensive and regular monitoring of salinity measurements is recommended across all regions. Regular monitoring will enable early detection of salinity changes and facilitate proactive management (e.g. optimising water usage) to mitigate potential impacts on groundwater quality and availability.

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Fact Sheet

GOYDER INSTITUTE FOR WATER RESEARCH

# Farm dams

## HIGHLIGHTS

- Farm dams are common across the South Australian landscape. In the study regions, the number of mapped farm dams varies from more than 3000 in the Northern Eyre region to only 68 in the Stuart Shelf region. It is likely that this information is incomplete and additional dams exist.
- Farm dams impact the local hydrology and ecology by altering the natural flow of water across the landscape, but they may be ecologically-important water sources in dry landscapes.
- Farm dams can be impacted by activities within their catchment area or the addition of sediment through dust and erosion.

## INTRODUCTION

**Farm dams** include the hydrology, water chemistry, and ecosystems associated with artificial water storages created and managed by landowners. In-stream farm dams are created by constructing a barrier across a drainage line: off-stream dams are often created by modifying a natural depression (Figure 1).

Farm dams are a common feature of the Australian landscape. In South Australia, the seasonal climate requires storage of rainfall during the wet season for watering stock (or, less frequently, crops) during the dry season. There are over 30,000 private dams in South Australia according to the Waterbodies in South Australia dataset (DEW, 2020). There is no official record of the location or volume of many older dams. Thus, it is difficult to know the total extent of farm dams in each region.

## FARM DAMS IN THE STUDY REGIONS

In northern SA, on-stream dams are common. A barrier is constructed across a watercourse or natural (overland) drainage path to hold back surface water during periods of flow for storage during dry periods. There are fewer off-stream dams (Figure 1). Under the *Landscape SA Act 2019*, farm dams must be approved by the Eyre Peninsula Landscape Board or the South Australian Arid Lands Landscape Board through their Water Affecting Activity (WAA) Control policies.


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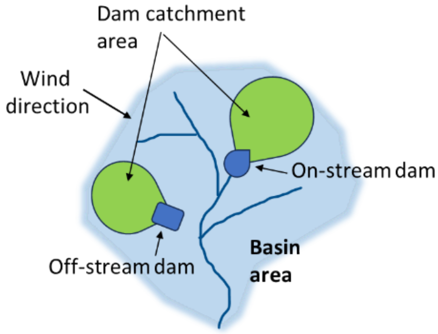


*Figure 1. Conceptual diagram of farm dams within the landscape, including the dam catchment for on-stream and off-stream dams, and the dominant wind direction (e.g. airborne impacts)*

Some regions, such as the Northern Eyre, have written guidance for the management of farm dams (EPLB, 2022). This guidance aims to control the potential water supply impacts that the dam will have on downstream users, sensitive ecosystems, runoff of agricultural pollutants and sediment and erosion management. The management of the numerous farm dams in northern Australia also sits within activities under the SA Arid Lands Regional Landscape Plan (SAAL, 2021) as farm dams can attract both native and feral flora and fauna and impact surface watercourses.

The number of mapped farm dams decreases from south to north across the 3 study areas, with over 3,000 in the Northern Eyre region, almost 400 in the Braemar region, and fewer than 70 in the Stuart Shelf region (Table 1, Figures 2–4). Few of these dams are named, according to the Department of Environment and Water database. It is likely that additional dams exist across the study regions. Farm dams are prevalent throughout the Northern Eyre (Figure 2), but especially in the central southeast portion of the study area. The named dams are predominantly along the creeks draining the southern flanks of the Gawler Ranges. The median size of dams in this region is smaller than in the other regions, at one-tenth of a hectare. There are also just a few large dams along creek lines south of the Gawler Ranges. Stuart Shelf has 35 named dams (Figure 3), which are predominantly along creek lines on the west and south sides of Lake Torrens. The median size of dams in this region is about one-third of a hectare, with just a few larger dams in the southeast corner of the region. There are over 900 dams spread throughout the Braemar region (Figure 4). The median size of the dams is approximately one-third of a hectare, with a small number of isolated, larger dams.

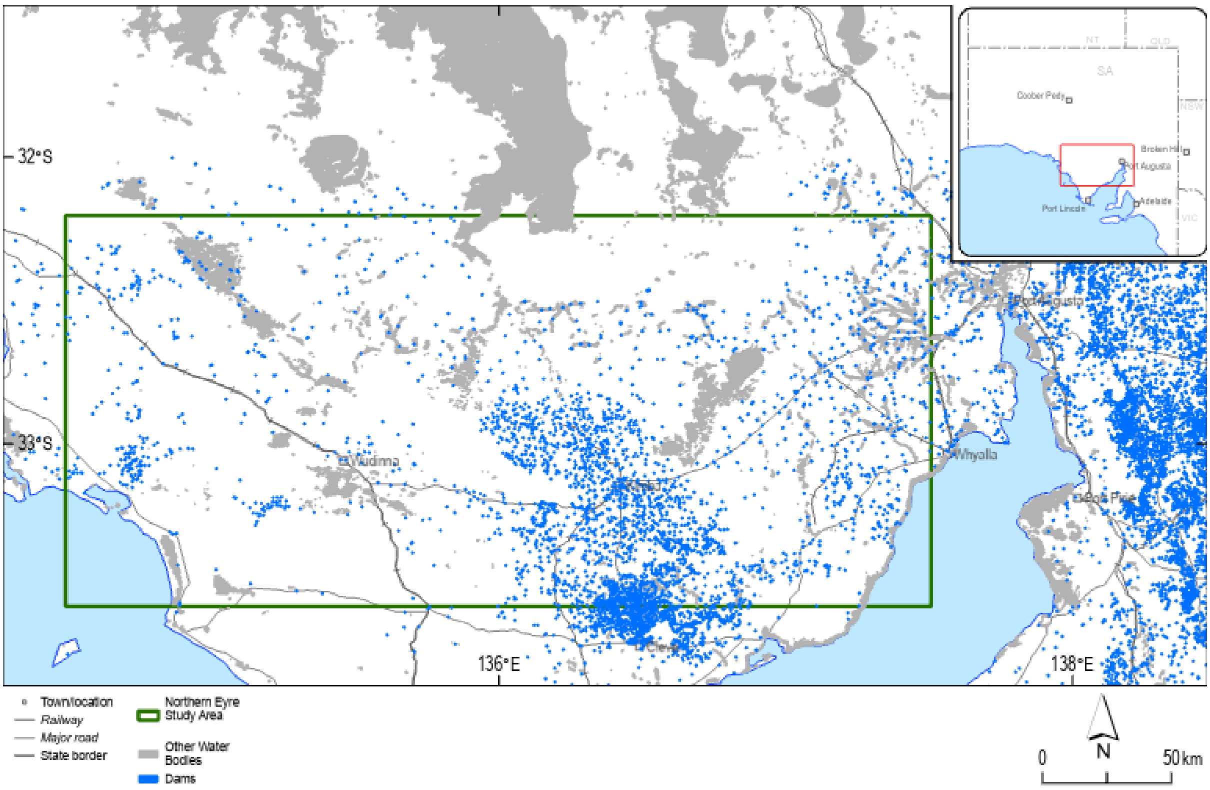


*Figure 2 Map of farm dams in the Northern Eyre region.*

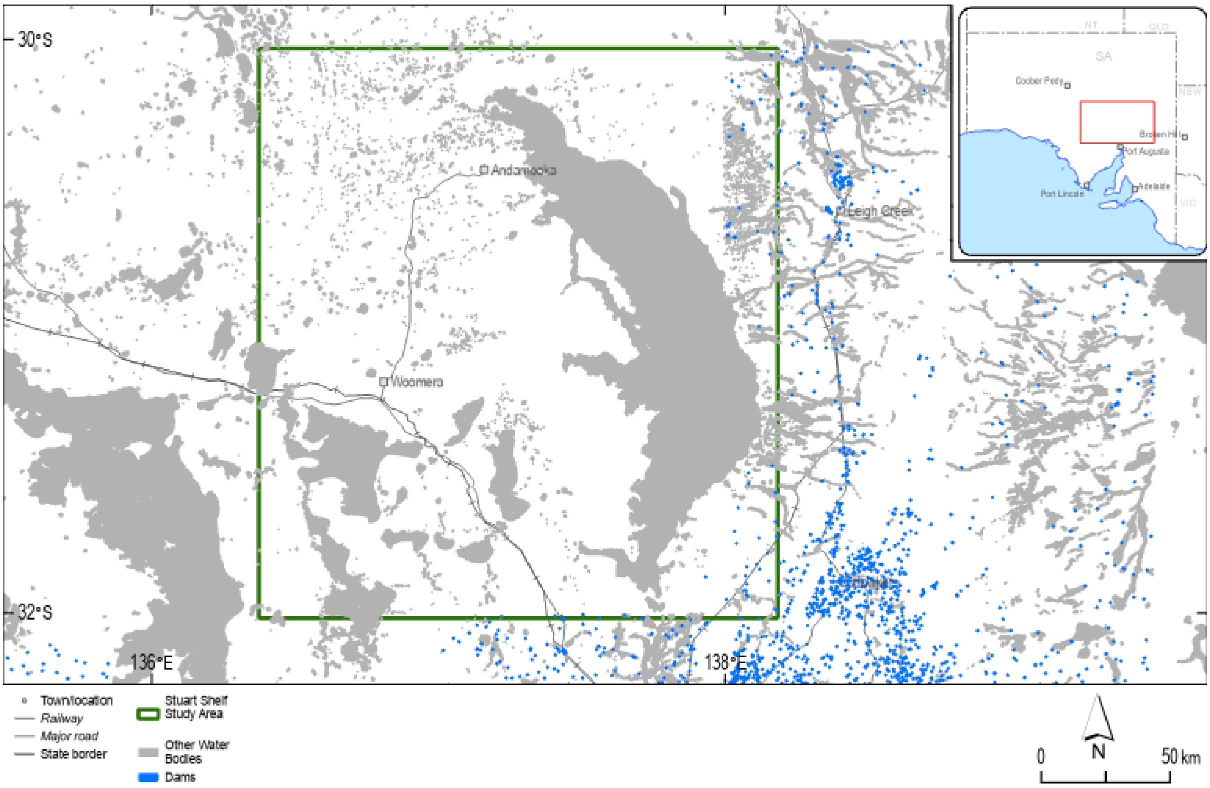


*Figure 3 Map of farm dams in the Stuart Shelf region.*

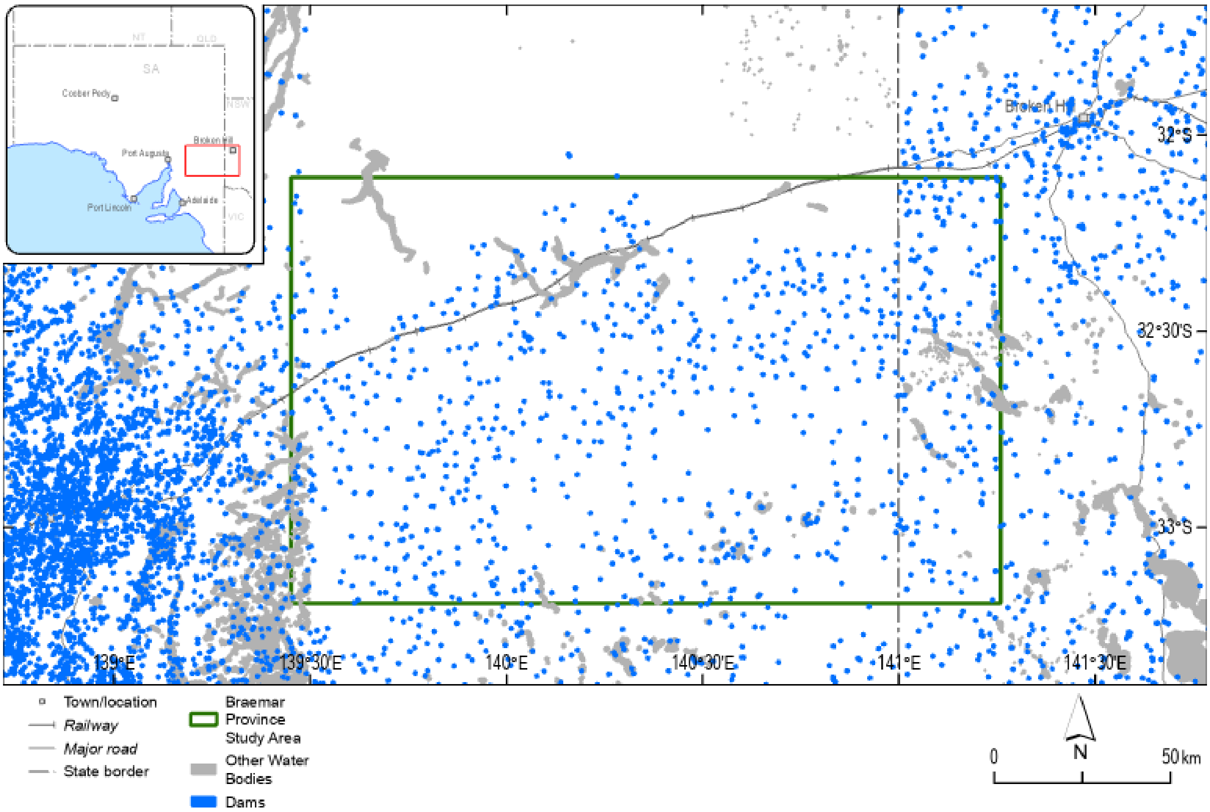


*Figure 4 Map of farm dams in the Braemar region.*

*Table 1. Summary of farm dam information for the 3 regions from the Waterbodies in South Australia dataset ([https://data.sa.gov.au/data/dataset/waterbodies-in-south-australia](https://data.sa.gov.au/data/dataset/waterbodies-in-south-australia), areas calculated in GCS_GDA_1994)*

| REGION | NAMED DAMS | TOTAL DAMS | MEDIAN AREA ($M^2$) | MIN AREA ($M^2$) | MAX AREA ($M^D$) |
|---|---|---|---|---|---|
| **Northern Eyre** | 388 | 3312 | 990 | 25 | 197,479 |
| **Stuart Shelf** | 35 | 68 | 3741 | 270 | 35,280 |
| **Braemar** | 374 | 961 | 3011 | 187 | 18,889 |

## POTENTIAL IMPACTS FROM DEVELOPMENT

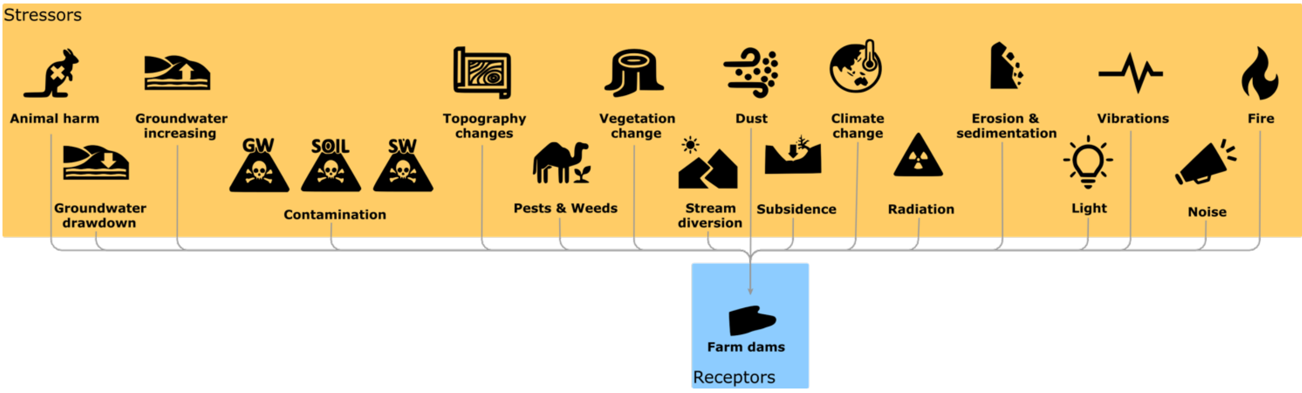


*Figure 5. Stressors associated with resource development that can potentially impact farm dams*

Farm dams are impacted by resource development in a similar way to natural lakes. Stressors are listed below and described more completely in the Stressor fact sheet (Peeters, 2024).

Stressors that impact water quantity in farm dams can include (Figure 5): increasing or decreasing groundwater levels; stream diversions or topography changes; direct contributions of wastewater or groundwater into the farm dam or tributary watercourse(s); and/or the introduction of pest species (feral, stock or excessive native animal populations or invasive or excessive native plants) that reduce water availability.

Farm dams themselves are acknowledged to impact stream flow within their catchment. The impact of this stream-flow interception is typically deemed to be low for an individual dam but the cumulative impact on catchment runoff may be much greater (Robertson et al, 2023). The magnitude of impact is influenced by the volume of the dams in a river catchment, the total portion of a catchment that is impacted, and how farmers extract the water for on-farm demand (Nathan and Lowe, 2012).

Stressors affecting water quality to farm dams can include direct pollution of the waterbody or pollution to tributary watercourse(s) and contributions of (contaminated or uncontaminated) soil via erosion or airborne dust. Increases in groundwater levels may cause a new connection to groundwater that alters the water quality (e.g. near the coast).

Physical changes to the waterbody can occur directly via direct alteration of the topography (e.g. through earthworks), erosion, and buildup of dust or sediment from erosion or indirectly through the physical alteration of the watercourses that supply the farm dams (e.g. increased sediment load in tributary watercourses). Pest species may also cause physical changes by trampling vegetation or soft sediment (especially at the margins, which can provide important habitat).

Biological modification of farm dams stems from the removal or addition of plants and animals. The ecohydrological functioning of the farm dam will be affected by native and invasive vegetation changes or the introduction or removal of stock, feral animals or native animals. Additional light, noise or vibrations from development can also stress the ecosystem and may change how native animals use farm dams.

There is growing recognition of the ecological value of farm dams in supporting native ecosystems in dry habitats. However, this requires enhancing the dam with native vegetation and excluding stock to improve water quality. For example, a study in Victoria showed that farm dams that are no longer in use, and have re-established vegetation, may serve as ecological refuges between undisturbed and modified habitats (Brainwood and Burgin, 2009).

Climate change impacts to farm dams are due to the release of greenhouse gas emissions. Climate change is likely to have a drastic impact on the availability of water, particularly in small farm dams, due to decreases in annual rainfall and increases in average annual temperatures (resulting in higher evaporation). Small dams across Australia are already significantly more likely to be empty now than in 1965 due to these factors (Malerba et al, 2022).

## DATA AND KNOWLEDGE GAPS

There is a lack of studies that document the impacts of developments on farm dams. Below is a non-exhaustive list of data needed to understand ecohydrological functioning and the impact of developments on farm dams.

- Datasets used in this fact sheet provide starting points for planning and development. However, they have major limitations. It is unknown whether all the farm dams in the study regions are included in the dataset or whether all documented farm dams are still in use. Moreover, there is extreme seasonal-to-decadal variation in the spatial extent of waterbodies in South Australia. Any development applications should include independent field studies to identify boundaries and potential downstream impacts.
- Field studies of farm dam water balance would be required to estimate connections between surface water and groundwater, evapotranspirative losses, dominant mechanisms controlling the persistence of water at the surface, and temporal water quality. These would be required to establish which ecohydrological pathways in farm dams may be at risk from the impacts of resource development.
- Farm dams exist in a landscape already altered by stock and agriculture. Cumulative impacts must be considered, and both current surveys and historical data should be used to identify sensitive ecological receptors that inhabit or visit farm dams.

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Fact Sheet

# Lakes

## HIGHLIGHTS

- Lakes are a common feature of the northern South Australian landscape.
- Some lakes have been the subject of research studies, but much remains to be learned about their physical hydrology and ecosystems.
- The pathways for this receptor should be used for all standing waters in the first instance. These include floodouts, inundated and flooded areas, claypans, swamps, salt marshes and coastal systems that are not expressly referred to as lakes, although ground-truthing of the hydrology is important.

## INTRODUCTION

Lakes refers to non-flowing perennial and ephemeral surface waters, including their hydrology, water chemistry and aquatic and fringing vegetation ecosystems. Examples include lakes (fresh and saline), claypans, swamps, salt marshes and coastal wetlands.

Lakes play important hydrological, geochemical and biological roles in arid and semi-arid regions globally but they are increasingly impacted by anthropogenic activities (Leblanc et al, 2012). Lakes are a common surface water feature in semi-arid to arid regions and make up about a quarter of the area of all lakes on Earth (Wurtsbaugh et al, 2017). Saline lakes often provide habitat for a unique and diverse aquatic community. Studies have found that large numbers of birds rely on saline lakes and that they have the potential to provide significantly better feeding grounds than adjacent freshwater lakes (Kingsford and Porter, 1994).

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# LAKES IN THE STUDY REGIONS

Under the *Landscape SA Act 2019*, the Eyre Peninsula and South Australian Arid Lands landscape boards review and approve any surface water affecting activities, including activities that impact lakes, through their Water Affecting Activity (WAA) Control policies. The Waterbodies in South Australia spatial dataset (DEW, 2023a) lists 2904, 163, and 1208 lakes for the Stuart Shelf, Braemar, and Northern Eyre regions, respectively (Figure 1). These lakes are classified as perennial, intermittent, or mostly dry although non-perennial lakes may be inundated for relatively long periods and then stay dry for years (Figure 2). Many of the lakes in the study regions are culturally-important waterholes to First Nations peoples.

Lakes in the spatial dataset range from 500 $m^2$ to over 5,000 $km^2$ in size, although smaller lakes are likely to exist. The wetted area of the lakebed varies considerably over time for most of these lakes and fluctuates naturally with variability in rainfall (Figure 2). The larger lakes are described as 'old' and of tectonic origin, while the smaller lakes have formed due to wind action (Williams et al, 1998). The shape and extent of larger lakes are also affected by wind action.

Although most of the inland lakes are likely to be saline, there are few data on the hydrology and water quality (salinity) of lakes in the study region. Lakes can be both recharge and discharge zones for groundwater. Due to the generally deep water tables, the primary recharge (inflow) are from surface water runoff, likely infiltrating to the underlying groundwater. However, groundwater discharge has been documented (e.g. groundwater flows westward off the Flinders Ranges to discharge in and around Lake Torrens (DEW, 2023)).

Lake Torrens is a prominent feature in the Stuart Shelf region. The first recorded filling of Lake Torrens since European settlement occurred in 1989 (the lake is approximately 6,000 $km^2$ in area when full), at which time 29 taxa of aquatic animals were recorded, including 3 previously unknown species (Williams et al, 1998). In addition, 64 bird species were observed, with many breeding. This included a species of stilt that had not been observed to breed in South Australia for 60 years. The dry lakebed also supports terrestrial fauna.

The water table is shallower on the Northern Eyre region and most coastal lakes receive (often saline) groundwater or marine groundwater input (Timms, 2009). This input alters both the salinity and the carbon and nutrient loads, in contrast to inland lakes. Several studies have noted that lakes are typically shallow (<50 cm deep), and although there are some fresh lakes, the majority are saline to hypersaline.

Ecological studies have been conducted on several of the saline lakes in the study areas, leading to relatively detailed lists of invertebrates and fish (Williams et al, 1998). However, the extremely episodic nature of some large lakes has meant that there have been few opportunities for sampling across the full range of environmental conditions. Conversely, many of the smaller inland lakes contain water in all but extreme El Nino weather years but little is known about their ecology. Moreover, little is known about how climate change is impacting the lakes' ecosystems.

Several wetland inventories have been conducted on the Eyre Peninsula. A 2002 inventory by Seaman (2002) found that: *"…the majority of [the wetlands] are saline lake systems with characteristic tea-trees forming circular bands around them. In spite of the high salinities, these lake systems contain excellent biodiversity values within the aquatic zone and adjacent terrestrial vegetation."* They span multiple key biodiversity areas and underlying geologies. Moreover, although simply labelled as 'swamps' in the Waterbodies dataset, it is apparent that coastal water features often include multiple types of sensitive systems.

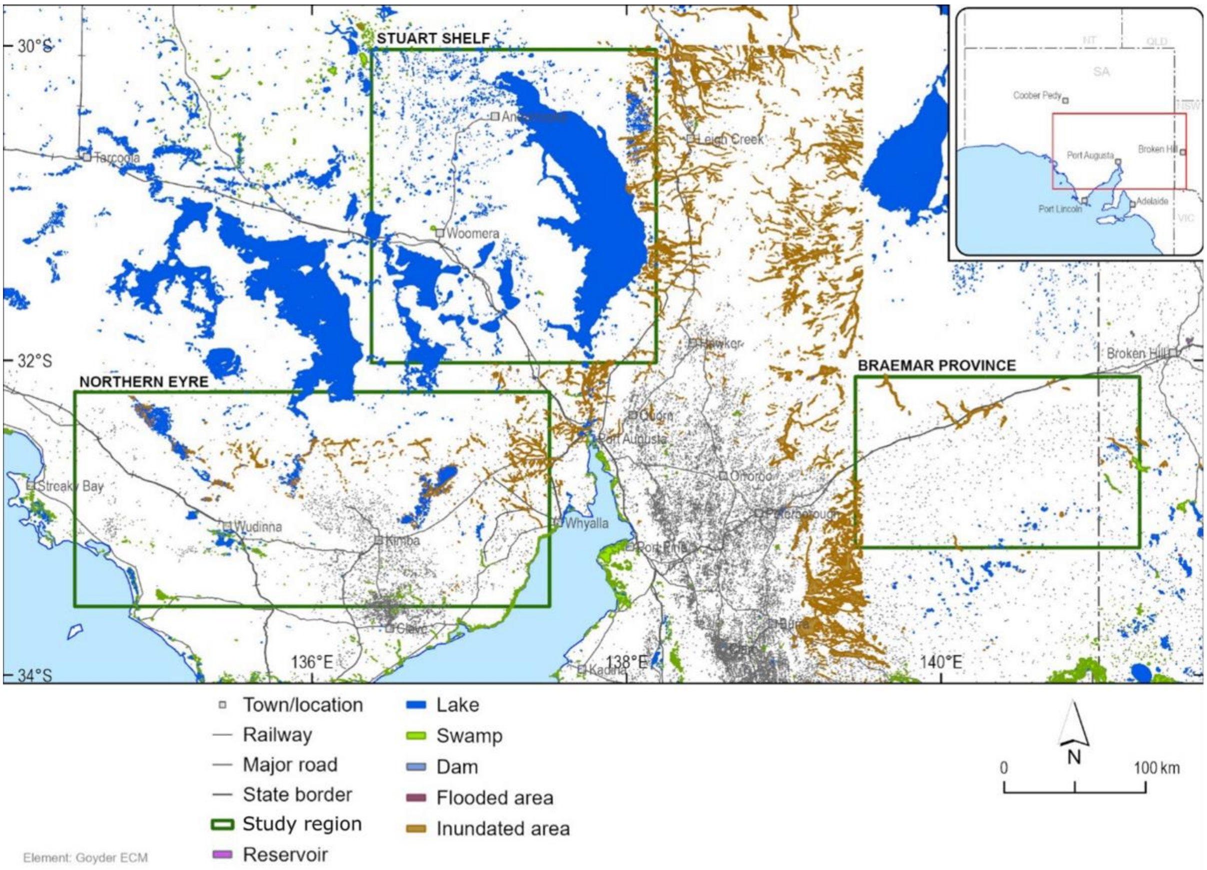


*Figure 1 Map of the lakes and other waterbodies across the 3 study regions using the Waterbodies of South Australia dataset (DEW, 2023a)*

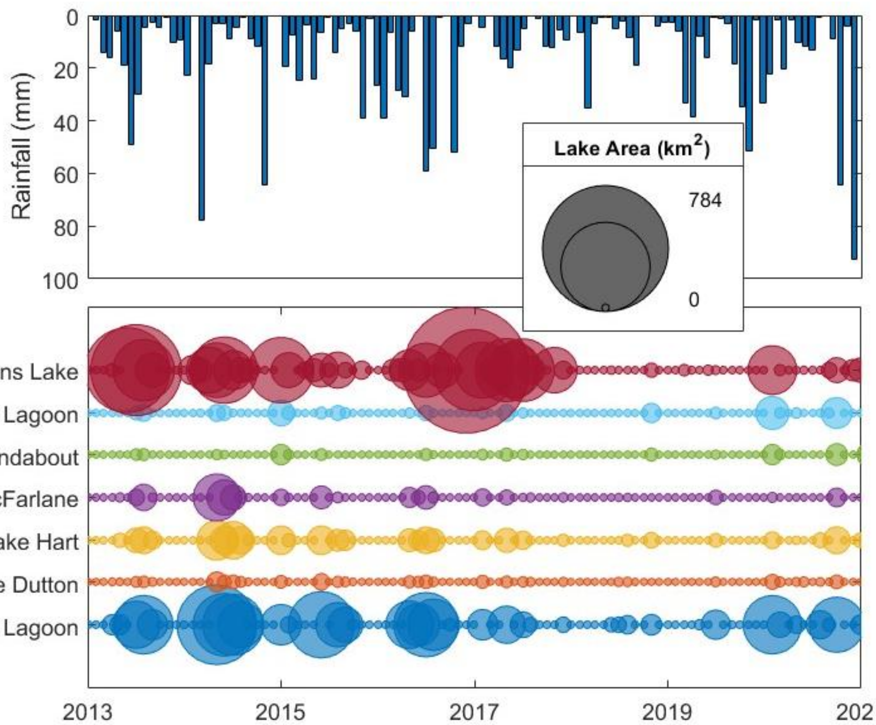


*Figure 2 Average monthly rainfall across the study areas (top) and corresponding inundated area of 7 saline lakes in the Stuart Shelf region. Note that Torrens Lake filled to an area of 784 km$^2$ on 31 December 2016, but the lake area is approximately 6000 km$^2$ when 'full'. Rainfall is often highly variable across the study region.*

## POTENTIAL IMPACTS FROM DEVELOPMENT

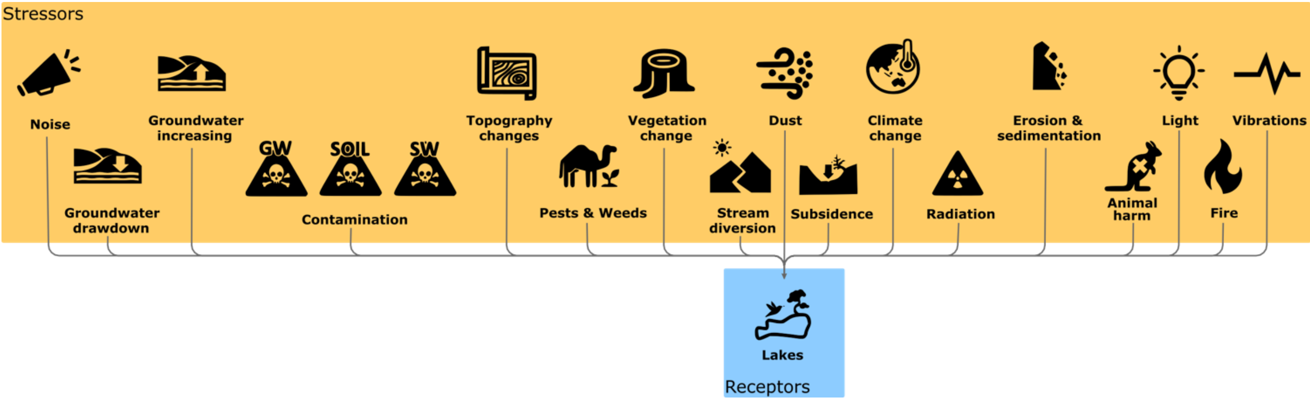


*Figure 3. Impact pathway diagram showing stressors that can affect saline lakes. Stressors are described further in Peeters (2024)*

The stressors (Figure 3) that can change the water regime include stream diversion, topography and vegetation changes as well as erosion and sedimentation in the catchment areas of waterbodies. These stressors alter the surface water runoff and therefore the timing and duration of waterbody inundation. Invasive weeds or overabundant native plant species in or near channels can also change runoff. The stream diversion stressor includes changes in flow due to water discharge from mine dewatering and waste management. Groundwater drawdown under or near a waterbody may increase the flow of water from the waterbody to groundwater if there is a connection between the waterbody and groundwater. Groundwater increasing under or near a waterbody can have the opposite effect, in that it would increase inundation or duration of inundation. Climate change due to greenhouse gas emissions will change the water regime as it changes precipitation and evaporation. Frequent and prolonged drought affects freshwater inflows to saline lakes and is linked to the drying of large saline lakes globally. Mobilisation of dust from dry lakebeds can have measurable health consequences for local and downwind populations (Feizizadeh et al, 2023).

The main stressors that would physically modify saline lakes are topography changes, vegetation changes, erosion and sedimentation and subsidence within waterbodies. This is especially the case for floodouts and floodplains, where even small changes in topography or sediment load (e.g. due to road construction) can drastically change the waterbody. The ecosystems supported by saline lakes can also be physically-affected by noise, light, vibrations and changes to the fire regime.

Contamination of waterbodies is possible if pollutants are discharged in the surface water or inflows of lakes directly, or if pollutants enter surface water via contaminated soil or groundwater. Increasing groundwater levels can create new surface water groundwater connections and therefore a pathway for contamination to enter lakes. Changes in erosion and sedimentation, dust pollution and radiation are also contamination pathways.

Saini and Pandey (2023) document examples of lakes from around the world that have been impacted by increased salinity due to water diversions, erosion, fertiliser pollution, pesticides, heavy metals and oil spills. Among the authors' literature review were studies documenting impacts to Lake Gairdner, Lake Torrens and Lake Eyre. Following contamination, lake water quality and sediment can be improved but not fully restored.

In general, the biodiversity of saline lakes decreases as salinity increases (Pinder et al, 2002). Salinity increases can be caused not only by diversion of fresh surface water inflows or decreases in groundwater input, but also through removal of natural vegetation (Saini and Pandey, 2023). Timms (2009) suggested that the salinity of many lakes in the Northern Eyre region has already increased over recent decades, leading to a corresponding decrease in the number of observed species. They concluded that this impact is likely due to changes in the groundwater level.

Resource developments in the study regions do not include exploitation of biological products associated with waterbodies, but vegetation change and animal harm can directly affect the health of ecosystems associated with waterbodies. Similarly, the introduction of exotic species, as well as an overabundance of native species, can change competition and predation within natural ecosystems and this could lead to local extinction of native species.

The potential for each of the above impact pathways to occur will depend on activity and location. Many of the inland saline lakes, such as Lake Torrens and smaller, nearby lakes, likely primarily rely on surface water. Any changes to the hydrology or water quality of the many small streams that feed these lakes will lead to hydrological – and thus ecological – impact. In contrast, groundwater plays a significant role in the coastal wetlands and lagoons. Changes to groundwater level and quality will impact these lakes.

## DATA AND KNOWLEDGE GAPS

There is a paucity of hydrological data for the majority of the waterbodies in the study regions. Below is a non-exhaustive list of data needed to understand ecohydrological functioning and the impact of developments on waterbodies.

- Datasets used in this fact sheet provide starting points for planning and development. However, they have major limitations. For example, inundated areas are incomplete for the Stuart Shelf and Braemar regions. There is extreme seasonal-to-decadal variation in the spatial extent of waterbodies in South Australia and any development applications should include independent field studies to identify their boundaries.
- Satellite data is useful to understand how often waterbodies fill (as in Figure 2) but it is not sufficient to determine the water balance. Establishing the hydrologic regime is an important step in determining potential impacts, especially for floodplains and floodouts, which are dynamic and must first be adequately delineated (Scamardo and Wohl, 2023). Extensive field studies are required to estimate connections between surface water and groundwater, evapotranspirative losses, the dominant mechanisms controlling water persistence at the surface and temporal water quality.
- Impacts to large lakes and inundated areas that only fill rarely after prolonged and heavy rainfall may not become apparent for years to decades. The collection of baseline data must consider this periodicity. Changes to the aquatic ecosystems of lakes and river floodplains may be difficult to link to development activities given the ephemeral natural of wetting.
- In addition to lakes and wetlands, the Waterbodies spatial dataset (DEW, 2023a) also includes features labelled as potentially-flooded or inundated areas. These waterbodies represent ephemeral river floodplains and floodouts (discontinuous portions of stream channels). Little is known about most of these waterbodies' hydrological dynamics or ecosystems. Although not classified as lakes, these waterbodies will also be ecologically-sensitive receptors and should be assessed for development impacts in a similar manner to lakes.
- These waterbodies exist in a landscape already altered by stock and agriculture. Cumulative impacts must be considered, and both current surveys and historical data should be used to identify sensitive receptors.

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Fact Sheet

GOYDER INSTITUTE FOR WATER RESEARCH

# Rock-holes

## HIGHLIGHTS

- Rock-holes, or gnammas, are waterholes in granite outcrops that receive local rainfall and can support a diverse variety of plants and animals.
- Rock-holes are highly important to First Nations peoples as they have historically provided a source of water when traveling through Country and, when large enough, a gathering place.
- The ecosystems of rock-holes can be affected by anthropogenic activities through: clearing of apron vegetation; alterations to the quantity or quality of water entering the rock-hole; dust and infill from windblown sands; the introduction of invasive species (both plants or animals); climate change; and increased pressure, as other nearby water sources are degraded or removed.
- Rock-hole complexes play an ecologically-significant role within the arid environment where the landscape does not support rivers and open waterbodies.

## INTRODUCTION

Rock-holes refers to the hydrology, water chemistry and ecosystems associated with natural water storages, often perched on low-permeability outcrops, such as granitoids, and filled by local rainfall. They are also referred to as gnammas. Over time, acids present in rain and soil water dissolve the rock to form a hole, which is periodically filled by local rainfall events. They can be categorised into pit or pan rock-holes (Bayly, 1999). Pit rock-holes are typically crescent-shaped at the surface and relatively deep (Figure 1) and pan rock-holes are irregularly shaped, with sloping sides, shallow depth, and a flat bottom. The size (typically ranging from 1m to 10 m in diameter) of the rock-hole, local rainfall frequency, evaporation rate, and animal and human use determine how long the rock-hole contains water (White, 2009).

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*Figure 1. Rock-hole in the Gawler Ranges on the Eyre Peninsula (Photo credit: G Scholz)*

Rock-holes provide important cultural sites for First Nations peoples, as they have long been a source of water, food, and medicinal resources. They provide a reliable source of water in regions where water is scarce, enabling First Nations communities to survive in arid environments. Rock-holes are often associated with stories, rituals and ceremonies, and have traditionally been gathering places for First Nations communities: people would come together to collect water, socialise, and engage in cultural activities. Additionally, water in rock-holes attracted wildlife and vegetation, making them important hunting and foraging locations for First Nations peoples. To maintain this function, First Nations peoples would sometimes construct traps near the rock-holes. They would maintain water quality by ensuring that animals did not fall in and die and use rocks to cover the rock-holes to prevent evaporation (Bindon, 1977). From the mid-1800s, European settlers also modified many rock-holes in the Gawler Ranges of the Eyre Peninsula. Cemented-stone walls were built to channel water into some rock-holes to increase water storage, while others were filled in with rubble and rocks to prevent stock using these sites instead of installed watering points (White et al, 2011).

A wide variety of endemic plants grow on the granite apron where rainfall collects and drains into the rock-hole. Thus, these aprons often serve as islands of biodiversity in arid landscapes. Well over a 1,000 plant species have been documented in Western Australia, with higher diversity in areas with higher rainfall (Hopper et al, 1997). A variety of flora also grow out of the soft sediment at the bottom of shallow pan rock-holes during periods when they are wet.
A variety of birds, reptiles, frogs, and mammals also rely on rock-holes. These animals use the rock-hole habitat and its surrounding variously for spawning, breeding, refuge, water and feeding. Some may live their entire lives in or at the edge of the rock-hole, while others visit opportunistically (White, 2009). Aquatic insects (macroinvertebrates) also occur in the rock-holes while they are wet (Timms, 2013) and help maintain the ecological balance of the aquatic ecosystem.

## ROCK-HOLES IN THE STUDY REGIONS

Granitoid outcrops are present across the Northern Eyre study regions, less frequent in the Braemar region and absent from the Stuart Shelf region (Figure 2). When the geological map and rockiness attribute of the soil map are combined, areas with potential for rock-holes are highlighted.

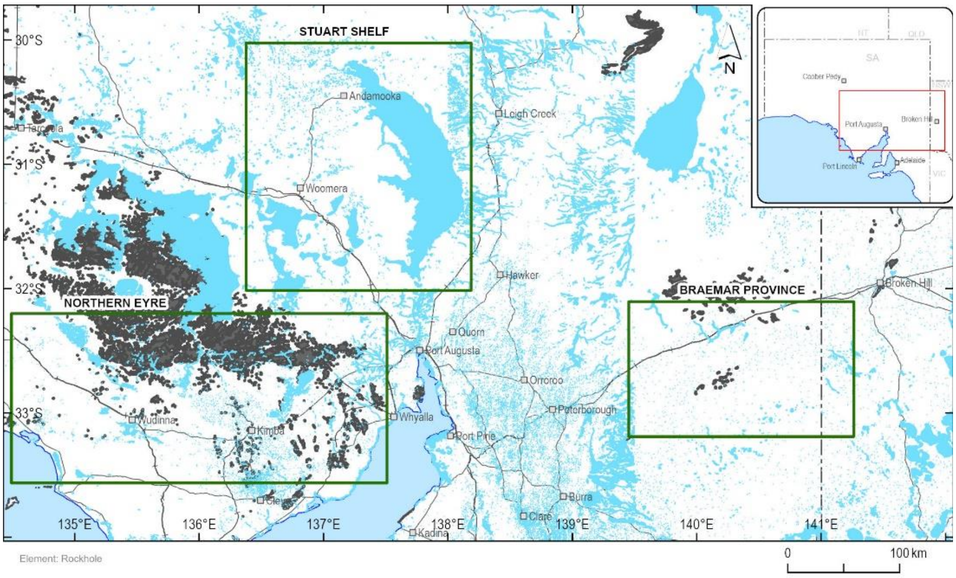


*Figure 2. Occurrence of granitoid rocks at the surface (dark grey areas) within the study areas. Rock-holes occur in granite outcrops with shallow slopes (less than 20 degrees). Data from Geoscience Australia (2012)*

## IMPACTS OF DEVELOPMENT ON ROCK-HOLES

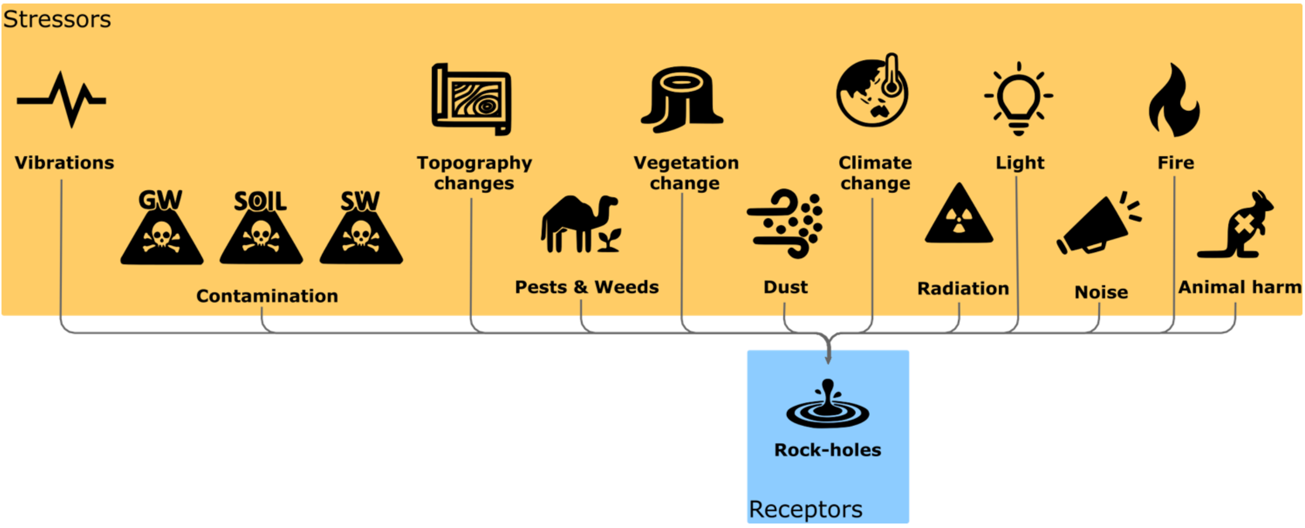


*Figure 3. Stressors associated with resource development that can potentially impact rock-holes*

Rock-holes may be impacted by development in similar ways to lakes, farm dams and other slow-moving bodies of water. Stressors are listed below and described more completely in the Stressors fact sheet (Peeters, 2024).

Stressors to rock-holes hydrology may occur through: altered flow of water on outcrops (e.g. through diverting rainfall on the outcrop or cracking the granite); direct contribution of wastewater or groundwater into the rock-hole; and/or the introduction of pest species (stock, invasive, or excessive native animal and/or plant populations) that reduce water availability (Figure 3). Additional light, noise, or vibration in the area surrounding the rock-hole can also impact the ecosystem.

Rock-holes can be polluted directly or indirectly by soil (contaminated or uncontaminated) via erosion or airborne dust. Changes in water quality and quantity will affect aquatic and terrestrial animals through habitat and water source degradation. There is also the potential for impact through clearing of vegetation or introduction of invasive species such as mice, rats, cats, or foxes that will compete with or prey on native animals.

Physical changes to rock-holes can occur directly via alteration of the topography (e.g. removal or cracking of the outcrop or damage to the rock-hole itself) or indirectly through the buildup of dust or sediment. Pest species may also cause physical changes (e.g. trampled vegetation). Camels, in particular, have a significant impact on waterholes as they consume a large amount of water in a short period of time and thus reduce the water available to native species (Figure

3). Physical disturbance may also occur through increased human visitation if developments bring a larger population to the area. Due to their cultural significance to First Nations peoples, many rock-holes have restricted access and any un-invited visitation could be considered an impact.

Biological modification of rock-holes stems either from the removal or addition of plants and animals. Changes in both native and invasive vegetation will impact the ecohydrological functioning of the rock-hole. Likewise, the introduction or removal of stock, feral or native animals will result in changes in the rock-hole ecosystem.

Climate change, and the release of greenhouse gas emissions, impacts rock-holes. Climate change is likely to have a drastic impact on the persistence of water in rock-holes due to decreases in annual rainfall and increases in average annual temperatures (resulting in higher evaporation). Many plants and aquatic animals are adapted to the arid conditions and can stay dormant for an extended period. However, there is a time limit to this period of dormancy beyond which they can no longer recover, and it is not known how climate change will impact them.

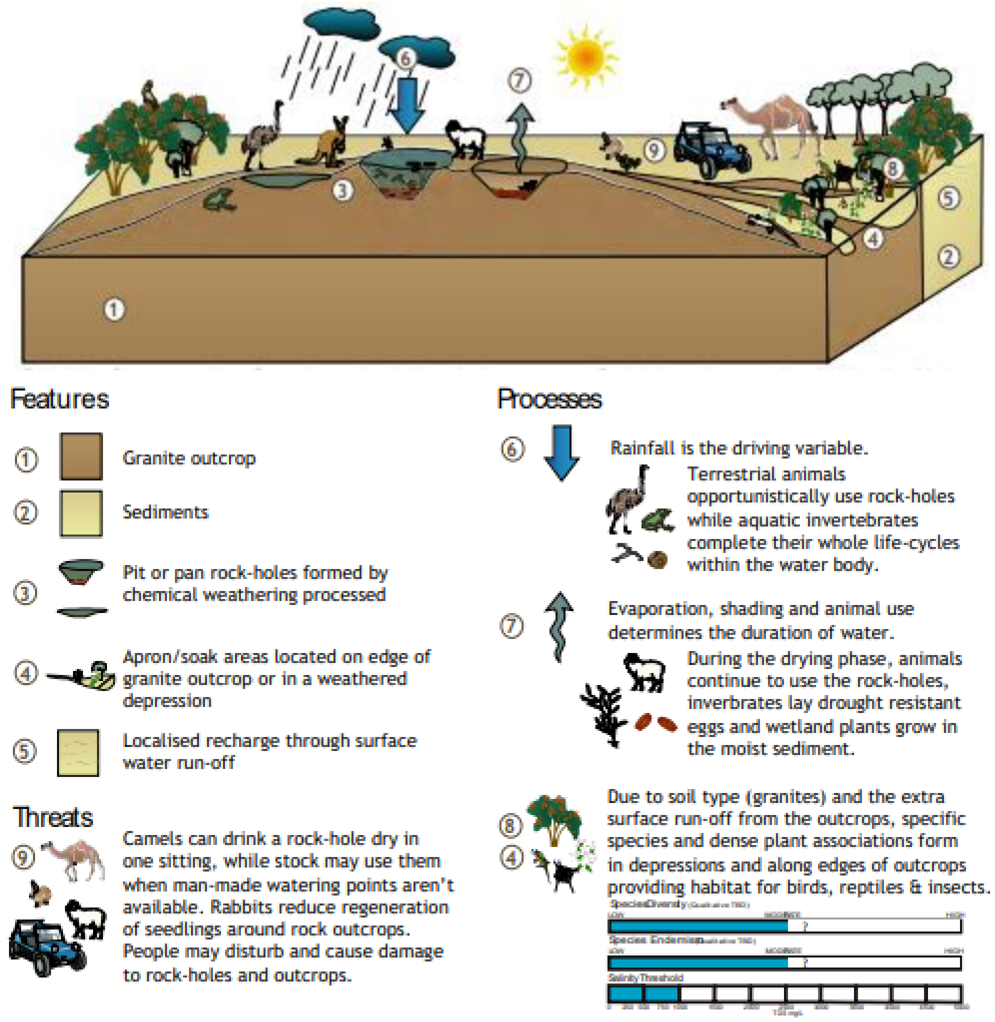


*Figure 4. Conceptual diagram of the functions and processes occurring in rock-holes in the study regions. Reproduced from Figure 2.7 in White (2009). Additional impacts that may occur due to development are discussed above.*

## DATA AND KNOWLEDGE GAPS

- Rock-holes are not explicitly presented in any publicly-available SA datasets as their locations are culturally-sensitive information. Therefore, it is necessary to work with First Nations groups to identify whether rock-holes may exist in any particular area where the conditions are favourable (e.g. Figure 2).
- There is little information on the hydrology of rock-holes in South Australia. Nikulinsky and Hopper (1999) reported that most rock-holes have nutrient-deficient freshwater as their catchments are typically small and entirely composed of granite outcrops. They are not connected to groundwater; their water balance is a

function of rainfall and evaporation. The water balance of rock-holes in any potential development area should be established before impact assessment. Further assessment of rock-holes in SA is needed.

- Many rock-hole complexes are intact and are thought to play an ecologically-significant role within the landscape, although the ecosystems of most rock-holes in SA are undocumented. Intact rock-hole complexes are likely to have a high level of biodiversity and endemism and support threatened species. Where rock-holes have been disturbed, the ecology of the rock-hole should be considered within a larger landscape context, for example by also surveying nearby rock-holes with similar habitat.
- Literature on rock-holes documents the occurrence of many of the potential impacts illustrated in Figure 3. These waterbodies exist in a landscape already altered by stock and agriculture. Cumulative impacts must be considered and both current surveys and historical data should be used to identify sensitive receptors.

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Fact Sheet

GOYDER INSTITUTE FOR WATER RESEARCH

# Spring groundwater-dependent ecosystems

## HIGHLIGHTS

- Spring groundwater-dependent ecosystems (GDEs) are biodiversity hotspots in water-limited landscapes.
- The springs identified in the 3 regions very likely carry cultural values.
- Springs are sensitive to regional development and climate change.

## SPRING GDES IN WATER-LIMITED LANDSCAPES

Springs are hydrological features where groundwater discharges at the Earth's surface. Based on the flow conditions, springs are often classified into limnocrene springs where groundwater discharges into and fills a depression, rheocrene springs where groundwater discharges into a defined channel, helocrene springs, which are associated with a diffuse discharge zone, and hillslope springs and hanging gardens, where groundwater emerges on steep slopes and cliffs (Bertran et al, 2011). This classification method is based on the surface appearance of springs. It does not tell the hydrogeological mechanisms. Figure 1 shows 2 springs that have different subsurface hydrogeology. Stevens et al (2021) shows springs that include the surface and subsurface characteristics. Springs can also be categorised based on their ecological characteristics (Cantonati et al, 2020).


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The project was conducted with support from the South Australian government through the Department for Environment and Water and Department for Energy and Mining, South Australian Arid Lands Landscape Board and Eyre Peninsula Landscape Board.

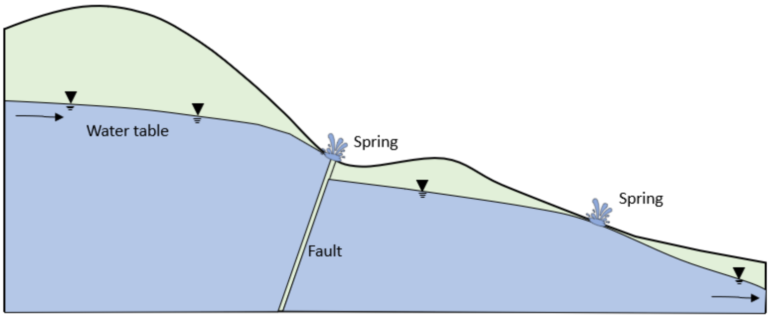


*Figure 1. A schematic diagram showing a fault-driven spring and a seep-type spring occurring where the water table intercepts the land surface (modified from Keegan-Treloar et al, 2022)*

Springs provide habitat for algae, vascular plants, invertebrates and vertebrates (Cantonati et al, 2020) and form spring GDEs. In water-limited landscapes, spring GDEs are biodiversity hotspots (Cartwright et al, 2020). Due to their small size and spatially-isolated nature, the biota in spring GDEs have adapted to these conditions (Davis et al, 2017). Given their connections to groundwater, springs serve as hydrological refugia for flora and fauna to grow in arid environments and survive through long droughts. In Australia, some endemic species may only occur in a few springs or a single spring complex (Murphy et al, 2010). They can be affected by grazing and development.

A spring is usually composed of 2 zones: the eucrenon (source area) and the hypocrenon (outflow stream) (Fernández-Martínez et al, 2023). Figure 2 shows the 2 zones of a mound spring in the Great Artesian Basin. Spring hypocrenon zones can vary greatly depending mainly on the spring discharge rate. Based on data from Nevada, USA, the outflow distance usually does not exceed 200 metres at springs with a flow rate smaller than 720 litres per hour (Patten et al, 2008). The hypocrenon should be considered as an integrated part of the spring habitat. In some cases, clusters of springs on the surface are directly connected to each other in subsurface. They are called a spring group (Murphy et al, 2012).

In addition to aquatic biota in the eucrenon and hypocrenon, springs in arid lands also provide drinking water for terrestrial vertebrates and birds, with their ecological influence extending far beyond their small size (Davis et al, 2017).

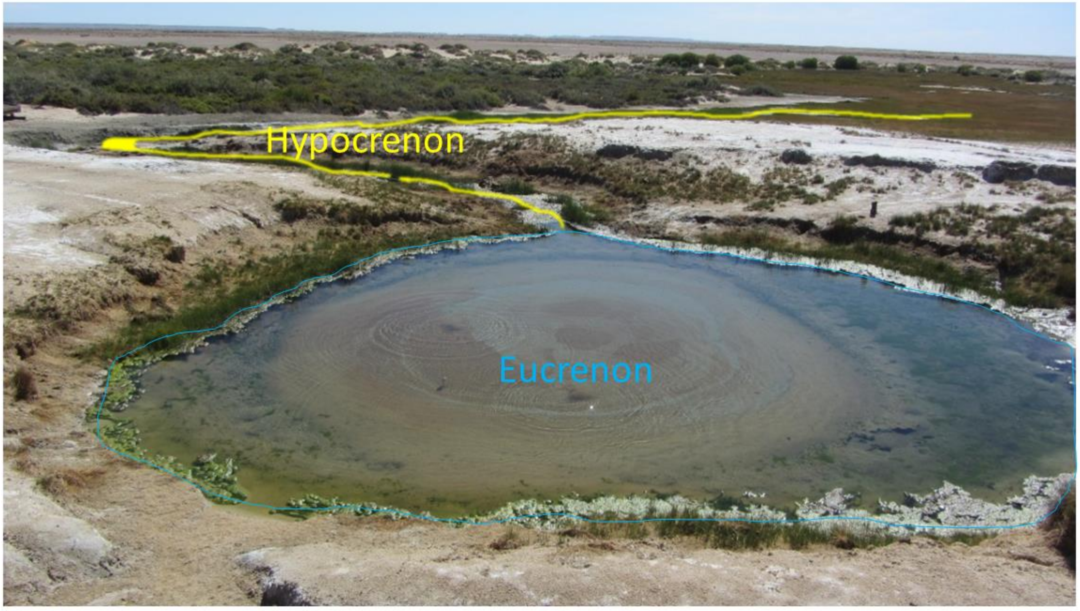


*Figure 2. The eucrenon and hypocrenon zones of Bubbler Spring of the Great Artesian Basin (photo courtesy of Huade Guan)*

## SPRING GDES IN NORTHERN EYRE, STUART SHELF AND BRAEMER REGION

As most springs have small surface areas, they are difficult to map using satellite-based remote sensing imagery. Springs are therefore mostly identified *in situ* and given specific names. The GDE Atlas (Data source: Bureau of Meteorology, retrieved October 2023) documents known springs in the Northern Eyre, Stuart Shelf and Braemar regions (Figures 3–5, respectively).

There are 28 known springs or spring groups in the Northern Eyre region, most of which are located in the north of the region (Figure 3). Only 6 springs are documented for the Stuart Shelf region, with 5 clustered in the southeast of the region (Figure 4). Seven springs or spring groups have been identified in the Braemer region, located in the northwest of the region (Figure 5).

Almost all of these springs can be located on Google Earth (as at March 2024). But only a few springs of large size are visible on the Google Earth image. Not all springs are shown in Figures 3-5, including the Yarra Werta springs that were recently investigated for the Olympic Dam mining expansion (Figure 6). The hydrogeological mechanisms for these springs are not known.

Nearly all of these springs have a name of First Nations' origin, suggesting that they have been known for a long time. In addition to their ecological significance, these springs are very likely to carry cultural values.

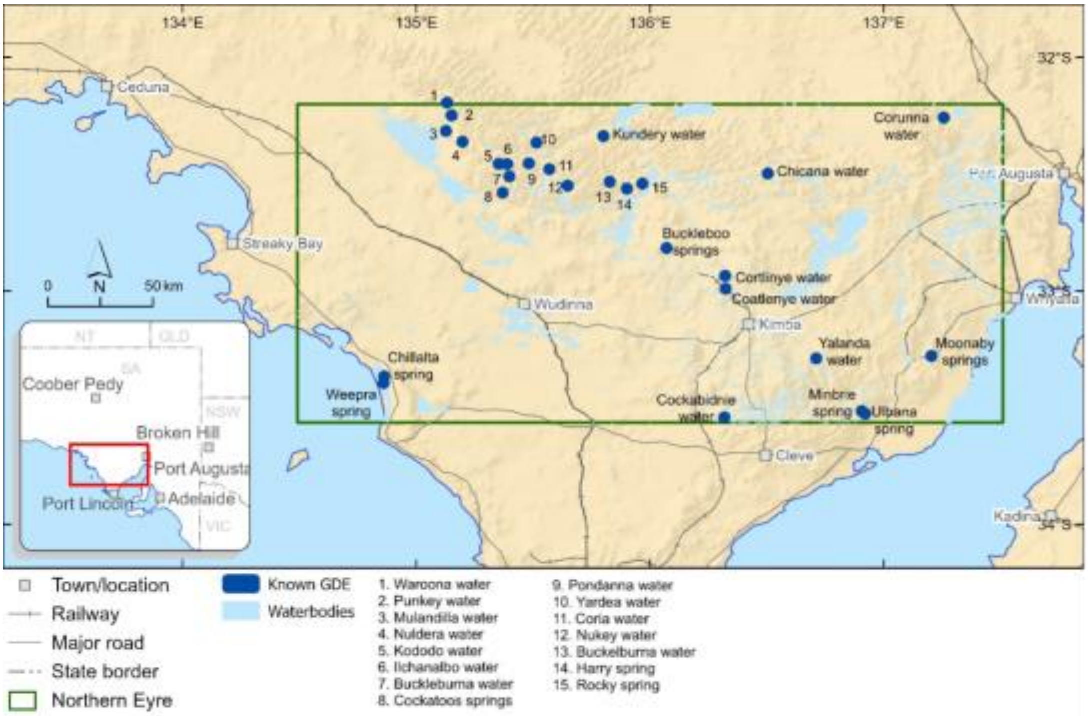


*Figure 3. Locations of known spring GDEs in the Northern Eyre region, sourced from Bureau of Meteorology (October 2023)*

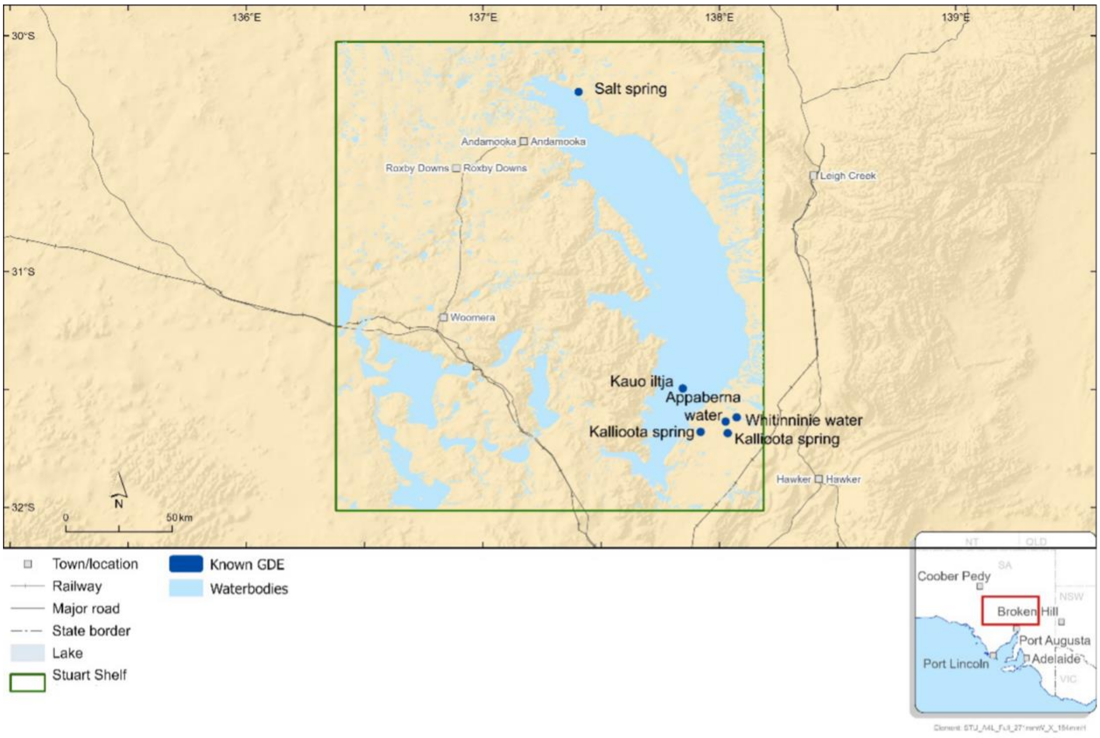


*Figure 4. Locations of known spring GDEs in the Stuart Shelf region, sourced from Bureau of Meteorology (October 2023)*

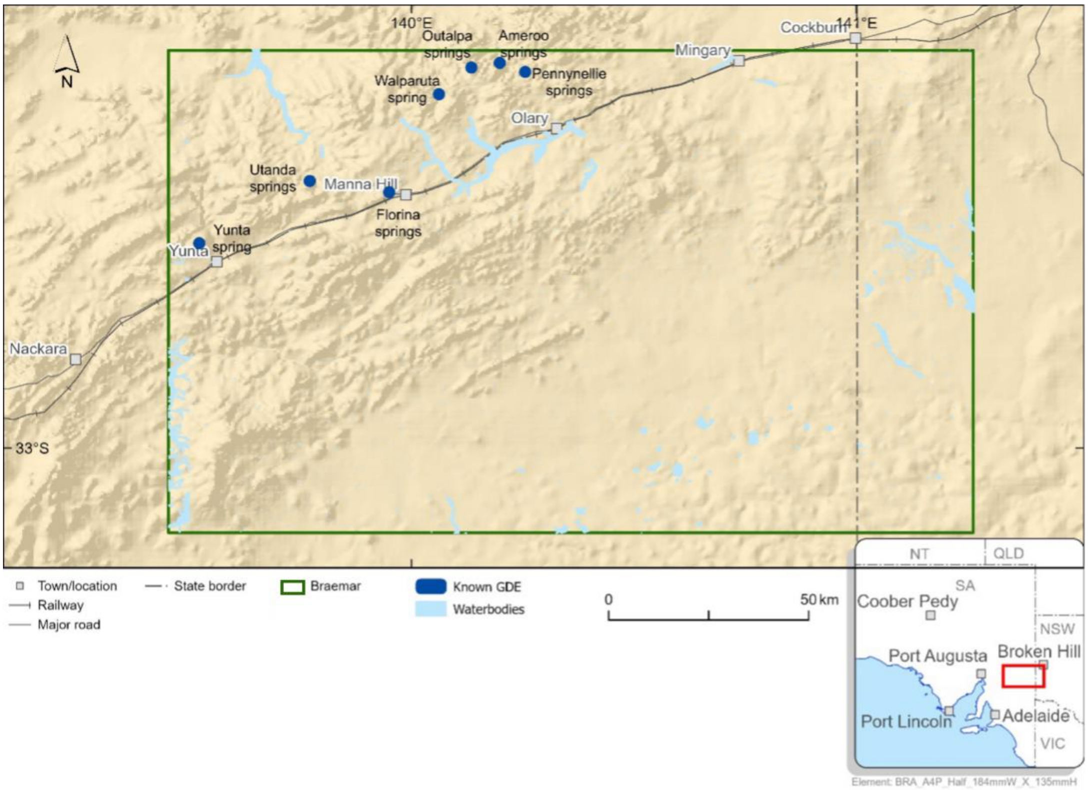


*Figure 5. Locations of known spring GDEs in the Braemer region, sourced from Bureau of Meteorology (October, 2023)*

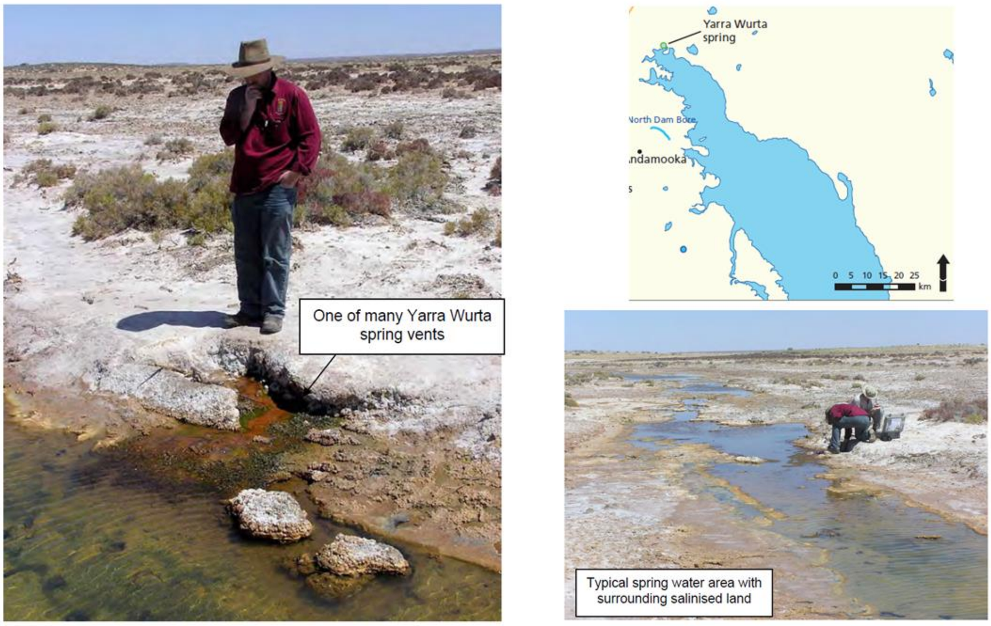


*Figure 6. The location and appearance of Yarra Wurta spring in the north of Lake Torrens of the Stuart Shelf Region (adopted from Waterhouse (2010) and Billiton et al, (2009); photos courtesy of John Waterhouse)*

## POTENTIAL IMPACTS FROM DEVELOPMENT

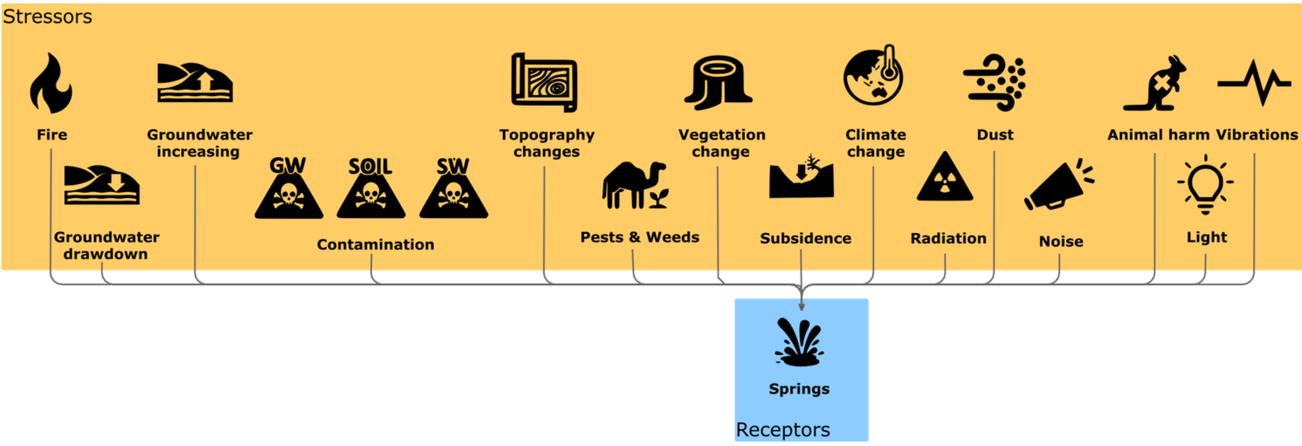


*Figure 7. Stressors associated with resource development that can potentially affect springs*

Springs can be affected by stressors that cause changes to spring flow volume, water quality and/or the ecosystems supported by the springs (Figure 7).

Groundwater drawdown can cause spring flow to reduce or, in extreme cases, can cause springs to dry up. Climate change can have a similar effect as it can reduce recharge to source aquifers and increase evaporation at the spring. These cumulative impacts must be carefully considered. Subsidence can alter flow paths in the subsurface and change spring flow rates. Changes in vegetation and topography can change recharge upstream of the spring and also reduce the flow rate of the springs fed by shallow aquifers. Increasing groundwater can increase spring flow or create new springs. Erosion and sedimentation can also affect springs.

Spring water quality can change if aquifers discharging into the spring are contaminated. Increased groundwater can mobilise salt and change spring water quality. Water quality in the spring can also be changed by livestock, pests, and contaminated dust or radiation deposition. Silt washed into the surface seep areas will smother submerged aquatic biota, potentially increase turbidity, and may carry contaminants adsorbed onto the sediment particles (Boulton et al, 2014).

The animals and plants supported by springs can be affected by increased competition and predation from pests and weeds (Davis et al, 2017; Box et al, 2019), vegetation change and direct animal harm. They can also be influenced by stressors that affect the habitat, including light, vibrations, noise and fire. Grazing pressure and trampling/pugging from sheep, feral goats and pigs are particularly problematic in many spring ecosystems, and their manure and carcasses can impact water quality (e.g. State of Queensland, 2016).

## DATA AND KNOWLEDGE GAPS

There are large data and knowledge gaps on the distribution and hydrogeological types of springs in the studied regions.

The lists of springs shown in this factsheet are adopted from the GDE Atlas. These lists do not include all springs in the studied regions. The real number of springs can be a lot larger (personal communication Mark Keppel, March 2024). Some springs are also documented in other reports (e.g. Billiton et al, 2009) but detailed coordinates were not available and so they are not included in this fact sheet. Information on documented springs is also incomplete. In most cases, the hydrogeological knowledge and ecological and cultural significance of the springs is missing. Currell et al (2017) emphasises the importance of adequate conceptualisation of springs for environmental impact assessment.

To protect spring GDEs, it is important to collect more data and information about them, including their names, coordinates, sizes, flow rates, seasonal variability, potential connected aquifers and cultural significance.

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Fact Sheet

# Subterranean ecosystems

## HIGHLIGHTS

- Subterranean ecosystems of living organisms beyond microbial communities occur in caves, voids, and spaces beneath the surface which contain stygofauna (aquatic animals living below the water table) and/or troglofauna (air-breathing animals living above the water table).
- Stygofauna, troglofauna and subterranean microbial communities play important roles in sustaining subsurface ecosystem services.
- While there are very few studies that describe their presence and distribution, stygofauna and troglofauna are very likely to be present in the aquifers and caves of the 3 regions.
- A change of groundwater level and/or quality is of concern for maintaining subterranean groundwater-depended ecosystems' ecosystem services.

## INTRODUCTION

Subterranean ecosystems are ecosystems that exist below the soil zone and especially ecosystems in the saturated zone. They include microbes and stygofauna (species that live in groundwater), and troglofauna (cave-dwelling species) in cave ecosystems. The subsurface aquatic systems include karstic aquifers, fractured rock aquifers, alluvial aquifers, hyporheic zones of rivers and caves (Eamus et al, 2006) that may support diverse microbial and invertebrate communities (Hancock and Boulton, 2008). Stygofauna are adapted to live in subterranean habitats and are characterised by their lack of eyes, whitish or translucent appearance, and elongate shape (Ingeme, 2009; Tomlinson and Boulton 2010; Goonan et al, 2015) (example in Figure 1).

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*Figure 1. Small blind crustacean (stygofauna) from the family Melitidae collected from a spring in the Flinders Ranges [adopted from Goonan et al, (2015)]*

Aquifers help to mitigate surface ecosystem flooding and erosion by absorbing and storing storm runoff. They can also provide wetted habitats for fauna and associated water-dependent vegetation (Goonan et al, 2015). Healthy subterranean groundwater-dependent ecosystems (SGDEs) contribute to maintaining these aquifer functions. Stygofauna play important roles in maintaining effective porosity of aquifer porous media by burrowing and grazing microbial biofilms (Griebler et al, 2019). Stygofauna can enhance prokaryotic transport in groundwater and underpin energy and matter turnover in aquifers to maintain groundwater purity (Smith et al, 2016). Together with bacteria and other organisms in aquifers, stygofauna sustain ecosystem services such as water purification and bioremediation in aquifers (Boulton et al, 2008).

Troglofauna are air-breathing species that live in underground caves or small voids (Ingeme, 2009). Troglofauna species can be characterised as organisms which live above the groundwater table within cave structures (Hamilton-Smith et al, 1998). They include a variety of beetles, spiders, cockroaches, slaters, crickets, scorpions and millipedes. Troglofauna, like stygofauna in subterranean inhabitants, have an important role in subsurface carbon and nutrient cycling (Tomlinson and Boulton, 2008).

## OCCURRENCE OF SGDES IN THE STUDY REGIONS

Very few field studies to determine stygofauna and troglofauna populations have been completed in the Braemar, Stuart Shelf, and Northern Eyre regions. The *Development and implementation of biodiversity information for sustainable management of South Australian groundwater* research project by the South Australian Environmental Protection Agency (EPA) sampled 547 sites in the selected areas of South Australia between 2007 and 2009. All sites contained micro-organisms and approximately 50% contained stygofauna (Goonan et al, 2015) (Figure 2). Many of these sites are not in the 3 regions. In another study, over 100 new species of stygofauna were identified in South Australia. They belong to Amphipoda, Isopoda, Syncarida, Gastropoda, Copepoda, Ostracoda, and Oliochaeta (Roudnew and Leijs, 2008). The western coastline of the Northern Eyre region was sampled as part of the study and several sites were found to contain stygofauna (Figure 3).

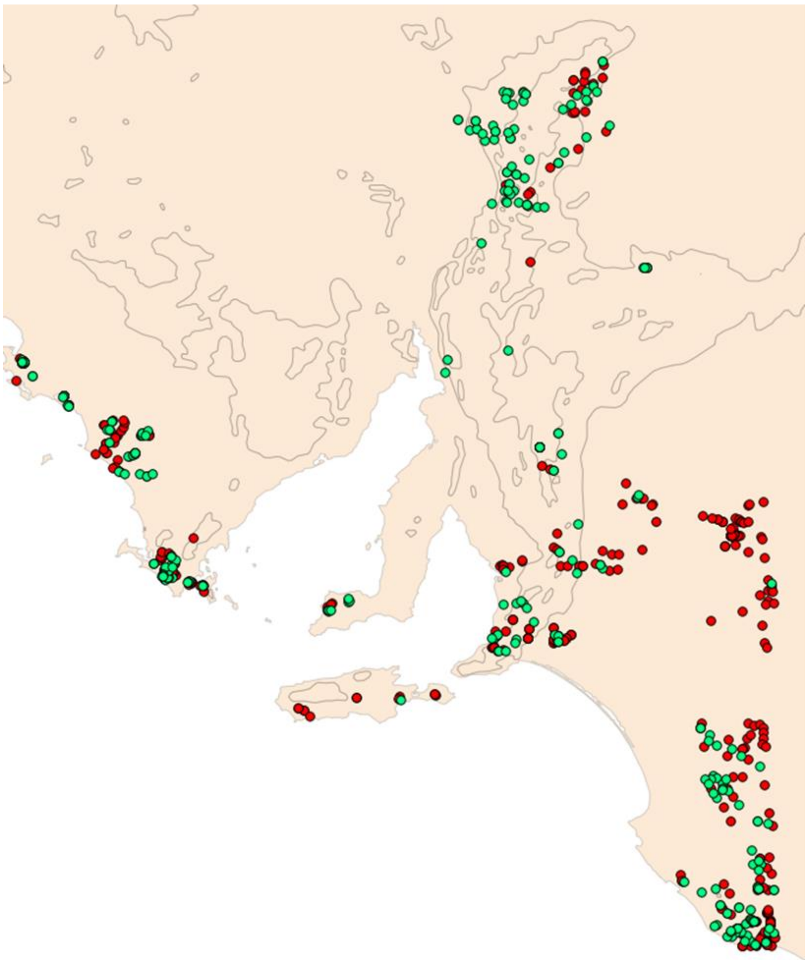

*Figure 2.* ***Localities sampled for groundwater fauna from 2007–09. Green markers show localities with stygofauna*** *and red markers show localities where fauna was absent. Stygofauna were present in approximately half of the 547 sites. (Source: Remko Leijs, South Australia Museum, 2024].*

In 2006, BHP undertook a survey of stygofauna communities within the Andamooka Limestone and Arcoona Quartzite aquifers in the vicinity of the Olympic Dam mine in the Stuart Shelf region. No stygofauna species were identified in the samples collected during the survey. The absence of stygofauna in the sampled groundwater bores is likely due to the aquifer's salinity and low-permeability, which may not provide a suitable habitat (BHP, 2009).

It is estimated that stygofauna and troglofauna very likely occur in some aquifers and caves of the 3 regions (Northern Eyre, Stuart Shelf and Braemer) based on the general understanding of conditions for subterranean fauna. Limestone or alluvial aquifers are more likely to have stygofauna (Glanville et al, 2016). Other potential habitats for stygofauna are the aquifers of a shallow water table (<20 m or <30 m) that have abundant organic matter for them to consume (Hancock and Boulton, 2008) and enough spaces and fractures to allow them to move and for water to deliver dissolved oxygen and nutrients (Hose et al, 2015). High aquifer salinity does not favour stygofauna and aquifer temperature is also a relevant factor.

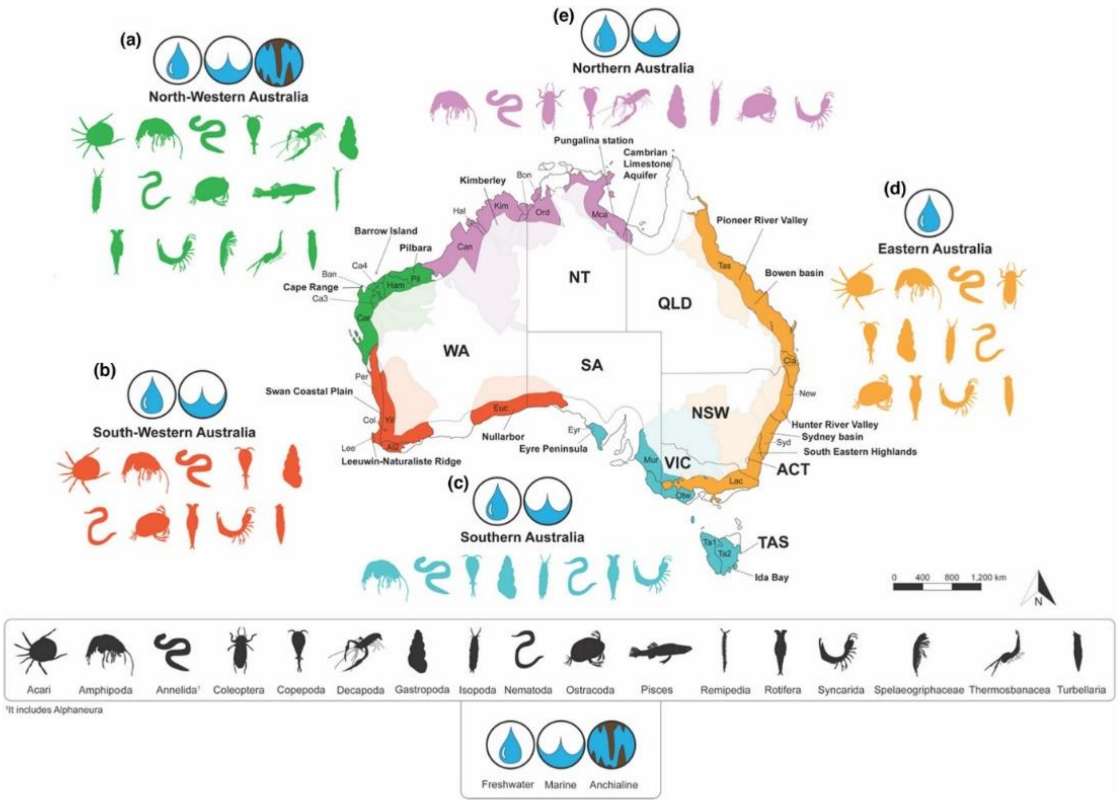


*Figure 3. Known biodiversity hotspots and distribution of stygofauna communities across the coastal groundwater regions, extracted from the National Groundwater Information System of the Australian Bureau of Meteorology, [adopted from Saccò et al, (2022)].*

## POTENTIAL IMPACTS FROM DEVELOPMENT

Stygofauna, troglofauna, and subterranean microbial communities are vulnerable to changes. They face various threats depending on the location of the aquifer (Figure 4) (Lewis, 2002).

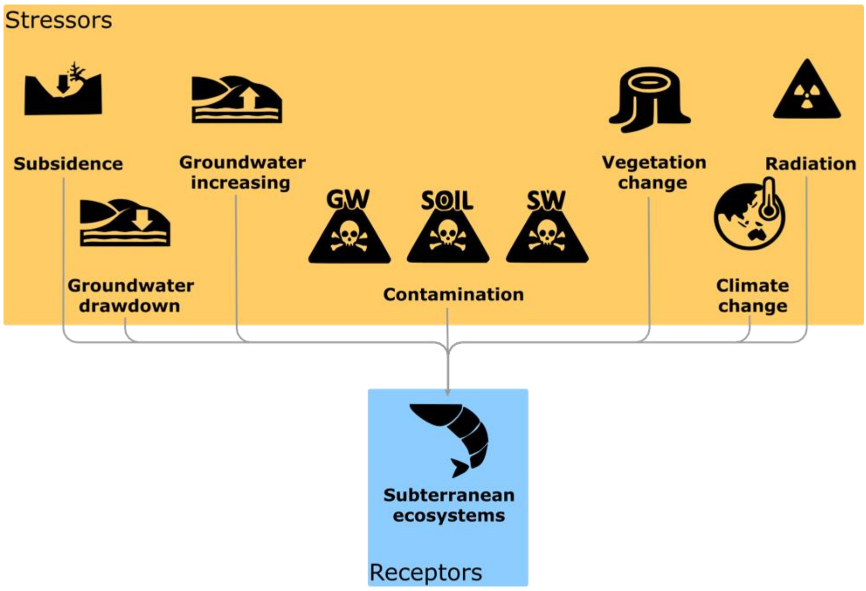


*Figure 4. Stressors associated with resource development that can impact on subterranean ecosystems*

Stygofauna diversity, abundance and community composition can be affected directly by altered water levels and groundwater quality (Hose et al, 2015). Potential impacts from resource development activities, such as land clearing, anthropogenic contamination, extractive industries and multifactorial impacts of mining, can significantly impact SGDEs and their inhabitants. Stygofauna communities can also be influenced by a change of aquifer porosity from siltation and by an altered nutrient balance (EPA, 2016b).

According to *Technical Guidance Subterranean Fauna Survey* by the Environmental Protection Authority (2016b, p10): "Excavation or mining of rock would impact permanently on troglofauna. Depending on the proportion of the geological feature containing the troglofauna habitat proposed to be excavated, the overall degree of impact would be moderate to high".

Of the list of stressors resulting from potential mining development, some of them can directly or indirectly impact SGDEs inhabitants (stygofauna and troglofauna) (Table 1).

*Table 1. Potential impacts to SGDE inhabitants from selected stressors*

| Stressors | Impacts |
|---|---|
| Radiation | Uranium in the subsurface can be considered a toxicity hazard for species. The introduction of radiation can impact subterranean fauna where there are exceedances of toxicity (EPA, 2016a). Radiation in groundwater may result in the impairment or mortality of subterranean species. |
| Groundwater increasing | Increased groundwater levels may reduce the lateral connectivity of habitats for troglofauna by flooding air-filled spaces above the water table. This may result in troglofauna becoming stranded and could lead to mortality and reduced biodiversity. |
| Groundwater drawdown | Lowering of groundwater levels via drawdown has the potential to limit vertical and lateral connectivity within aquifers. In highly complex and fragmented habitats, this may result in stygofauna becoming stranded and could lead to mortality and reduced biodiversity (Tomlinson and Boulton, 2010). Lowered water tables may impact troglofauna by altering humidity, but this has been poorly studied. |
| Contamination | Contaminants such as pesticides, fertilisers, metals, volatile organic compounds (VOC), and other emerging contaminants can act as stressors to stygofauna and troglofauna (Castaño-Sánchez et al, 2019). The effects of contaminants, such as species mortality, can vary depending on the duration and intensity of pollution events (Manenti et al, 2021) and the sensitivity of species to concentrations of toxicants. |
| Vegetation change | Vertical connectivity with the surface, such as plant roots, is important for supplying carbon and nutrients to subterranean ecosystems. Where populations are reliant on carbon infiltrating from the surface (in the absence of chemolithotrophic bacteria), changes to surface vegetation may result in a lower amount of carbon and other nutrients reaching the ecosystem. This could diminish the food and nutrient sources for subterranean fauna (Castaño-Sánchez et al, 2019). |
| Climate change | Changes in temperature and precipitation regimes induced by climate change are predicted to translate to decreased surface flows and aquifer recharge. This may change groundwater recharge patterns and alter the habitats for stygofauna and troglofauna (e.g. through changes in carbon and nutrient supply). |
| Subsidence | Subsidence (void collapse) may impact subterranean fauna (EPA, 2016a). The collapsing or sinking of substrate can reduce the lateral connectivity between air-filled spaces, as well as their size, and may lead to subterranean species mortality or reduced biodiversity. |
| Topography changes | Changes in topography, including the direct removal or compaction of the substrate, can alter subterranean ecosystems by removing or reducing habitats (EPA, 2016a). This may lead to mortality or reduced biodiversity of subterranean species. |
| Vibrations | Subterranean habitats may be altered by vibrations that collapse pores spaces or increase fractures. Habitat collapse may lead to the mortality or reduced biodiversity of species. However, increased fracturing may improve connectivity in the subsurface and improve biodiversity. |

## DATA AND KNOWLEDGE GAPS

Knowledge of SGDEs in South Australia is limited, with no specific information available for Northern Eyre, Stuart Shelf and Braemer regions. Thus, it is not known exactly where, and in which aquifers and caves, stygofauna and troglofauna are present. The knowledge of stygofauna and troglofauna responses to changes in groundwater level and quality is also limited (Hose et al, 2015). So is our understanding of microbial composition and how these assemblages may be affected by the stressors listed in Table 1 (personal communication Boulton, 2024).

These data and knowledge gaps are partly due to the difficulties of surveying rare fauna, particularly stygofauna and troglofauna in the SGDEs. In addition to groundwater sampling, the detection of target environmental DNA (eDNA) in the sediments and water can be an alternative method to screen and identify stygofauna species. This biotechnological approach does not need physical collection of stygofauna organisms (Sacco et al, 2022).

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CSIRO

Flinders University

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University of South Australia

Fact Sheet

# Terrestrial groundwater dependent ecosystems

## HIGHLIGHTS

- Terrestrial groundwater-dependent vegetation plays important ecological roles in semi-arid and arid areas.
- Moderate and high-potential groundwater-dependent vegetation covers 5–13% of the area in the regions according to the BOM GDE Atlas.
- Field investigation methods are available and should be applied to confirm groundwater dependence of relevant terrestrial vegetation.
- Terrestrial groundwater dependent ecosystems are sensitive to changes in groundwater regimes and surface conditions from developments and climate change.


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The project was conducted with support from the South Australian government through the Department for Environment and Water and Department for Energy and Mining, South Australian Arid Lands Landscape Board and Eyre Peninsula Landscape Board.

## INTRODUCTION

Terrestrial groundwater dependent ecosystems (GDEs) are terrestrial ecosystems in which one or more vegetation species requires continuous, seasonal or episodic groundwater access (Bertrand et al, 2011). They occur where groundwater of suitable quality is within the reach of GDE vegetation rooting depth (Figure 1). Terrestrial GDEs provide ecosystem services that are particularly important in arid and semiarid Australia. They conserve biodiversity by providing habitats for animals, regulating microclimates, providing scenery, and housing cultural and spiritual resources, particularly for the First Nations peoples (Murray et al, 2006). The larger storage volumes and temporal stability of groundwater relative to soil moisture in arid and semiarid areas provides GDEs with longer-term access to freshwater and greater resilience during drought periods than ecosystems that rely on more temporary water sources.

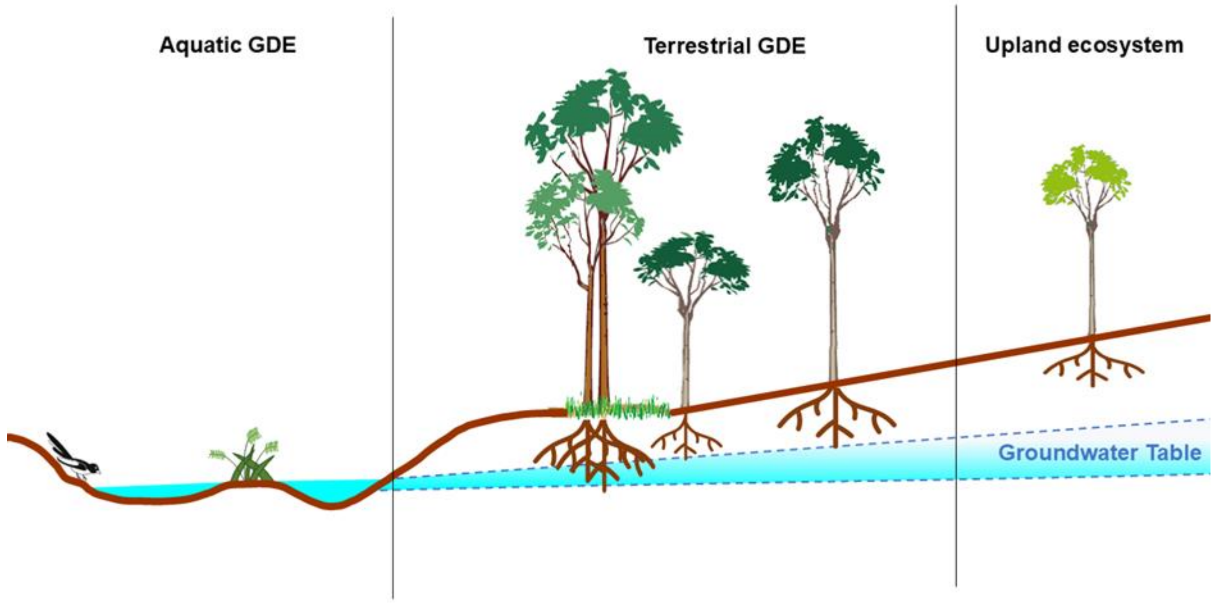


*Figure 1. A schematic diagram of a terrestrial groundwater-dependent ecosystem (GDE)*

## TERRESTRIAL GDES IN NORTHERN EYRE, STUART SHELF AND BRAEMER REGIONS

Terrestrial groundwater-dependent vegetation often has different seasonal patterns to other vegetation communities that are more dependent on rainfall. As a result, remote sensing imagery can be used to map terrestrial GDE extent by assessing the persistence of vegetation coverage (Brim Box et al, 2022; Fildes et al, 2023). Doody et al (2017) developed a methodological framework to integrate diverse data (including remote sensing imagery) and expert opinion for continental mapping of GDEs. In this framework, the groundwater-dependency likelihood of an ecosystem is estimated by the GDE potential, which is the sum of weighted normalised scores of 4 criteria:

1. Whether the ecosystem is inflow-dependent
2. Whether the groundwater table is shallow
3. Whether the soil water-holding capacity is low
4. Whether a typical GDE species is present.

A high GDE potential means that the ecosystem has a high probability of groundwater-dependence, while a low GDE potential indicates that the ecosystem is unlikely to be a GDE.

Based on this framework, terrestrial GDEs of high, moderate or low potential are shown in Figures 2, 3 and 4 for the Northern Eyre, Stuart Shelf, and Braemar regions, respectively (Data source: Bureau of Meteorology, retrieved October 2023). The potential terrestrial GDE coverage ranges from 15% in Stuart Shelf, to 24% in Northern Eyre and 39% in Braemar. Some of these potential GDEs have been confirmed by individual studies and then categorised as known terrestrial GDEs, such as those shown in the Braemar region (Figure 4). If the low potential GDE coverage is excluded, the mapped terrestrial GDEs cover 5.6% of Northern Eyre, 5.4% of Stuart Shelf and 13.1% of Braemar. The total area of terrestrial GDEs is small, but they provide significantly more ecosystem services in the regions than their size suggests.

While a recent study shows 12.5% potential terrestrial GDE coverage in Leigh Creek to the east of the Stuart Shelf region (Fildes et al, 2023), most of the terrestrial GDE coverage in Figures 2, 3 and 4 has not been locally examined. Therefore, the presented delineation of potential terrestrial GDEs contains significant uncertainty. This is particularly evident in the distribution patterns shown in Figures 3 and 4. The sharp boundaries of potential terrestrial GDEs in both maps are an obvious artefact of different levels of data availability and/or investigation.

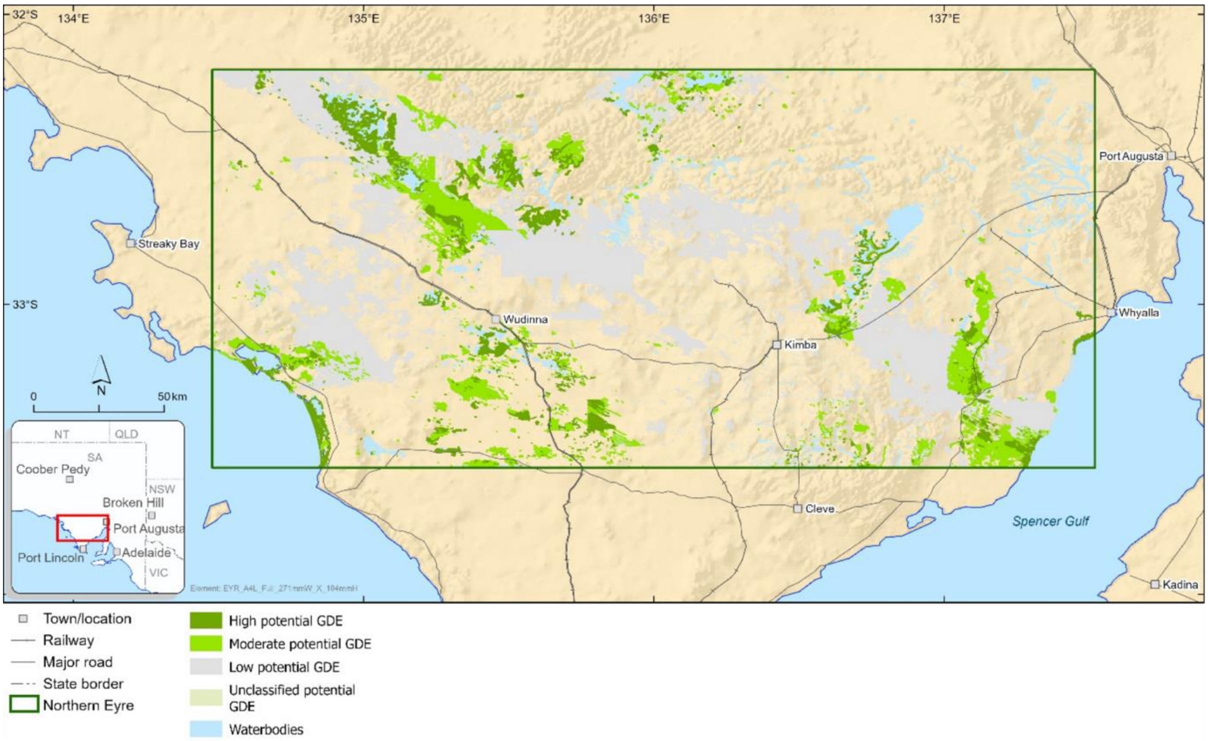


*Figure 2. Distribution of potential terrestrial groundwater dependent ecosystems in the Northern Eyre region (Bureau of Meteorology, 2023)*

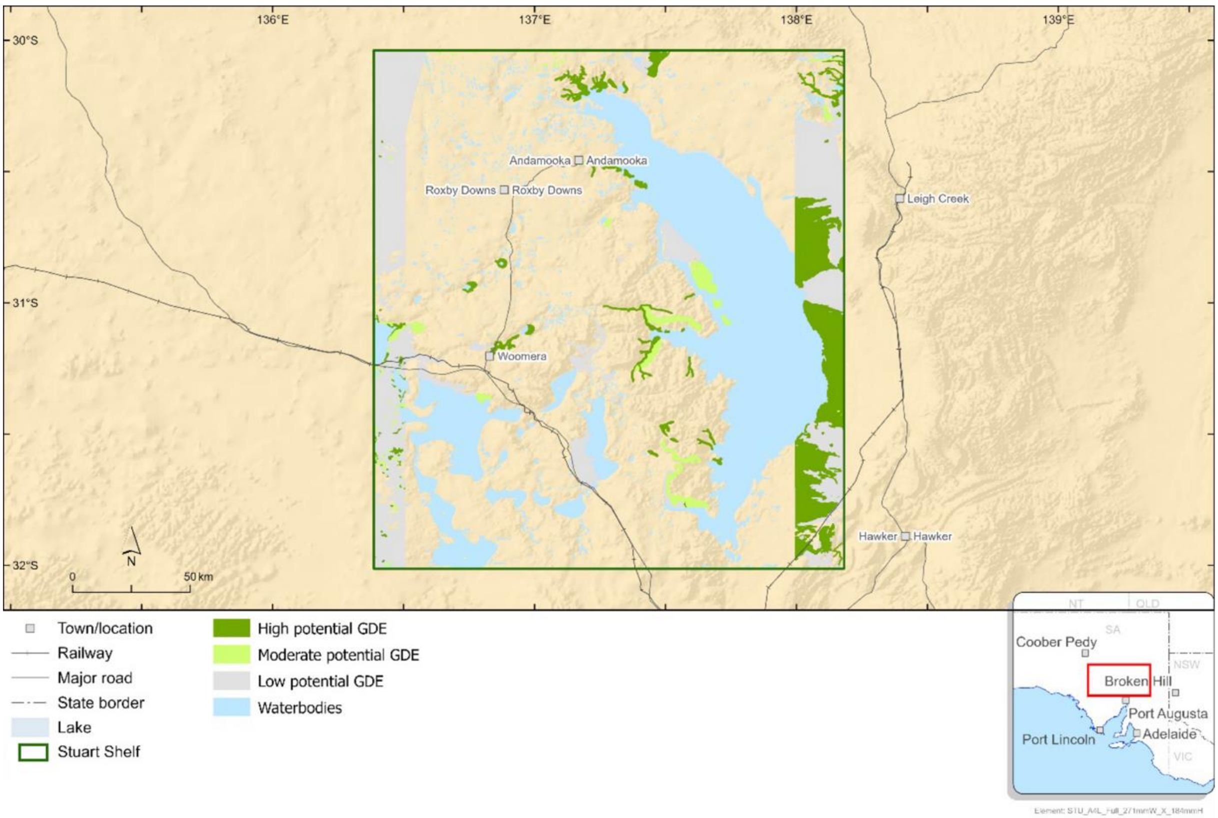


*Figure 3. Distribution of potential terrestrial groundwater dependent ecosystems in the Stuart Shelf region (Bureau of Meteorology, 2023)*

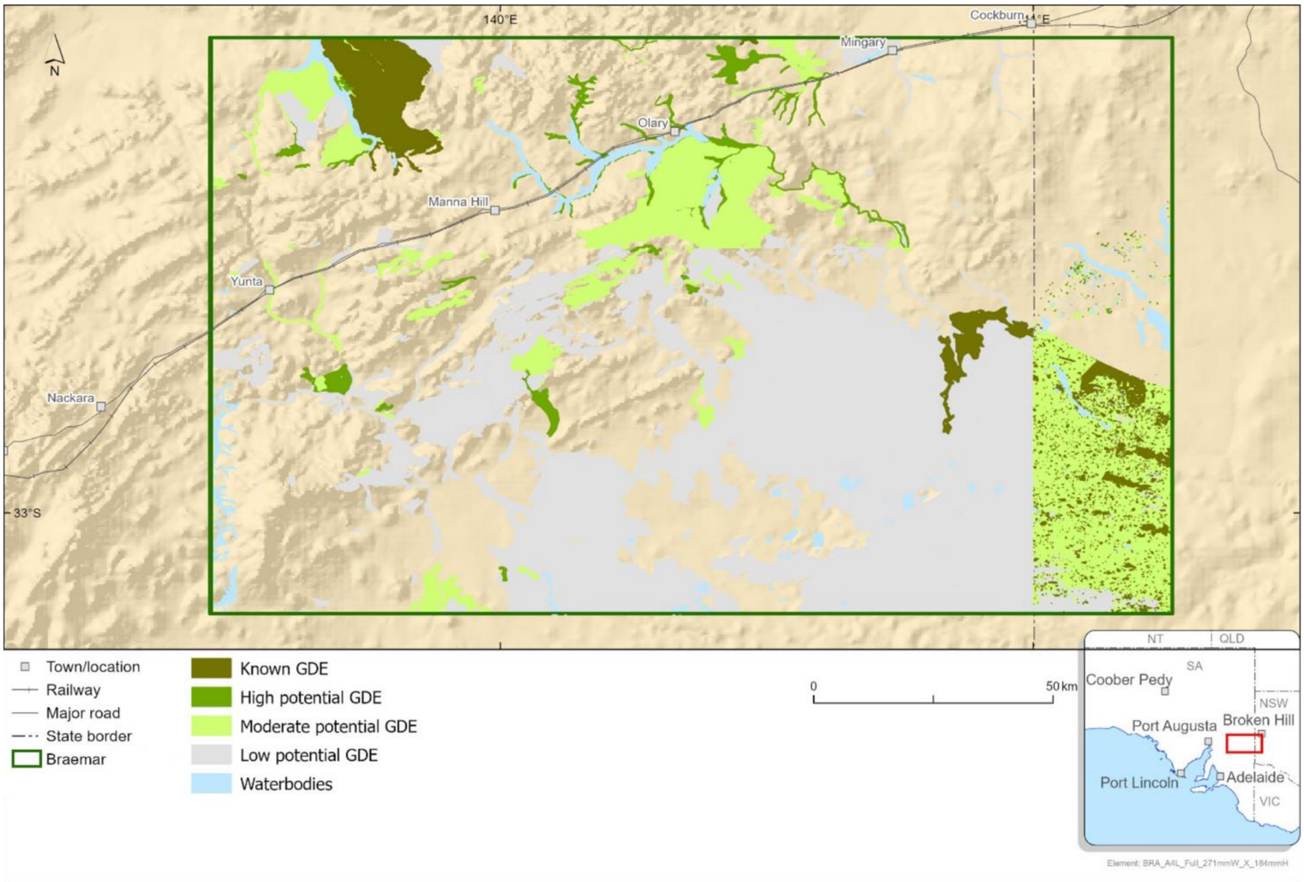


*Figure 4. Distribution of known and potential terrestrial groundwater dependent ecosystems in the Braemar region (Bureau of Meteorology, 2023)*

## POTENTIAL IMPACTS FROM DEVELOPMENT

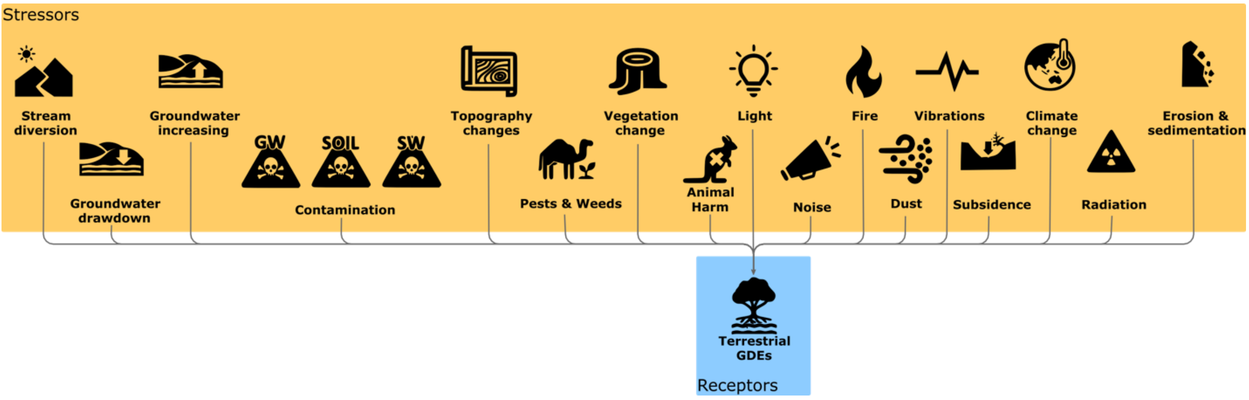


*Figure 5. Stressors that have the potential to impact terrestrial groundwater dependent ecosystems*

Stressors associated with resource development that can potentially lead to impacts on terrestrial GDEs are shown in Figure 5. These align with the potential impact causal pathways for GDEs identified by Doody et al (2019). The impact pathways can be grouped into: (1) altered connectivity to groundwater, (2) changed groundwater quality and (3) direct disturbance. Many of these pathways interact and affect each other.

Changes in groundwater connectivity that influence any of the stressors can alter the relationship between the GDE and the aquifer by affecting the water table. Groundwater drawdown from pumping or changes in recharge can reduce the frequency with which vegetation can access groundwater. Increases in groundwater levels can create greater access to groundwater. This can also affect the health of the vegetation if the soil is water-logged. Climate change will lead to reduced recharge to aquifers. Groundwater quality can change due to groundwater contamination. Rising groundwater can also lead to changes in salinity. Subsidence can alter the local groundwater flow patterns and therefore impact GDEs.

However, most of the stressors are in the direct disturbance group. The ecosystem can be affected by noise, light, dust, radiation, animal harm and vibrations. Vegetation removal directly affects the groundwater-dependent vegetation, while pests and weeds increase competition and predation. Many GDEs are close to surface water features. Changes in hydrology, including flooding frequency due to streamflow diversion, topography changes or erosion and sedimentation can therefore also affect GDEs.

## DATA AND KNOWLEDGE GAPS

More data are available on terrestrial GDEs than other GDEs, as groundwater-dependent vegetation is often large enough to be investigated using satellite remote sensing imagery. However, the remote sensing approach only gives the possibility of the occurrence of terrestrial GDEs; it does not confirm terrestrial GDEs. It is also difficult to tell the difference between obligate and facultative groundwater-dependent vegetation (GDV). The potential terrestrial GDE maps shown in Figures 2–4 for the study regions contain large uncertainty and additional field investigations are required to confirm GDE occurrences (Cook and Eamus, 2018).

The occurrence of typical terrestrial groundwater-dependent species increases the likelihood of groundwater dependence. Some species known in the literature to rely on groundwater, at least occasionally, including *Eucalyptus camaldulensis* (river red gum), *Corymbia aparrerinja* (ghost gum), *Corymbia opaca* (bloodwood), *Eucalyptus victrix* (smooth-barked coolabah), and *Melaleuca glomerata* (inland tea-tree) (Brim Box et al, 2022) as well as *Eucalyptus petiolaris* (Eyre Peninsula blue gum or water gum) (Doeg et al, 2012). These could be used as indicator species for terrestrial GDEs in the 3 studied regions. However, there might be other indicator species which are not yet documented in the literature.

Groundwater dependency could be evaluated using the knowledge of these typical species in combination with a knowledge of local groundwater depth. If groundwater of suitable quality occurs within the rooting depths of these species, groundwater dependency is generally assumed.

Further investigations could compare the isotopic signals of water in the vegetation with that of potential sources: groundwater and soil moisture. GDV should have isotopic compositions which cannot be solely explained by that of root zone soil moisture. Similarly, groundwater dependency can be examined by measuring plant and soil water potential (Nolan et al, 2018). In general, water potential (a term used for the unsaturated condition equivalent to water level in a river) in a plant should be lower (more negative) than that of its water sources. If plant water potential is higher than the unsaturated root zone, it must have a groundwater source.

GDV in semi-arid and arid environments is typically under less stress than other vegetation. This difference can result in its distinctive foliar $^{13}C$ composition that differs from other plant communities in the surroundings. Thus, foliar $^{13}C$ can be useful for identifying GDV (Cook and Eamus, 2018).

GDV generally transpires more water than other vegetation communities under the same climate. This difference is more obvious in dry seasons. When trees are under less stress and transpire more water, their canopies appear to be cooler (Liu et al, 2020). Thus, drone thermal imagery can be useful for locating terrestrial GDEs, particularly for the cases where GDV species knowledge is lacking.

When a terrestrial GDE is confirmed, information about relevant groundwater is needed to assess its responses to new developments in the area (Knight Merz, 2011). If a terrestrial GDE is dependent on a local perched aquifer, a change in regional groundwater may not be of a concern. Groundwater salinity and other quality aspects should be considered when the impacts on GDEs are assessed.

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Fact Sheet

GOYDER INSTITUTE FOR WATER RESEARCH

# Watercourses

## HIGHLIGHTS

- There are thousands of kilometers of streams and creeks in the study regions, most of which only flow for parts of the year.
- As water sources in a dry landscape, these watercourses support both aquatic and terrestrial biodiversity. Because waterholes retain water for weeks to months, they are ecologically and culturally-significant in the landscape.
- Mining and other developments can affect water quality and quantity in these watercourses by changing the flow regime, sedimentation and erosion rates, groundwater flow and ecosystems supported in-stream.

## INTRODUCTION

**Watercourses is a collective term for all flowing perennial and ephemeral surface waters, including their hydrology, water chemistry and aquatic and riparian ecosystems. Watercourses can include freshwater and saline creeks, streams and rivers (including their in-stream waterholes).**

Ephemeral watercourses only flow after significant rain events. Intermittent streams and rivers flow for a period of weeks to months, seasonally. Both watercourse types are common in semi-arid and arid regions, depending on the topography, size, and shape of the catchment. In Australia, a disproportionate percentage (70%) of the rivers are dry for part or most of the year due to our ancient landscape, dry climates, and highly-variable rainfall regimes (Sheldon, 2010). In South Australia, there are few perennial rivers (rivers that flow all year), although there are some perennial streams in the Northern Eyre and Braemar regions. Watercourses are nevertheless an important part of the landscape. They support native aquatic and terrestrial flora and fauna as well as stock and pasture-land, and they recharge aquifers and fill farm dams.

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Many Australian inland rivers have a characteristic boom–bust ecology. This is the ability of riverine species to lay dormant for a potentially long period until the river flows and then emerge (boom) during flows before disappearing again (bust) as the river goes dry (Puckridge and Drewien, 1988). However, there are still knowledge gaps around: flow; the contribution of groundwater to flow; the links between flow and geochemical processes; and the resulting controls on the ecosystem (Shanafield et al, 2024).

Instream waterholes, also known as pools, are sections of a creek that retain water for weeks to months after streamflow has ceased. They may exist due to a connection to shallow, perched alluvial aquifers that refill with infiltrated streamflow, a connection with a perched regional aquifer, or be completely disconnected from groundwater and retain water due to low-permeability sediments in the streambed (Bourke et al, 2023). It is crucial to understand the hydrological processes that control waterholes' persistence so that potential development impacts can be assessed. Waterholes are of special significance to plants and animals (including humans) as a water source in an otherwise dry landscape. This would particularly have been the case before the existence of farm dams and modern methods of accessing groundwater, but they remain important ecohydrologically and culturally (Silcock, 2010). They also provide important refuges for aquatic animals, whose lifecycles have evolved to match waterhole wetting and drying (Sheldon et al, 2010; Leigh et al, 2016).

## WATERCOURSES IN THE STUDY AREAS

Under the *Landscape SA Act 2019*, the Eyre Peninsula and South Australian Arid Lands landscape boards review and approve any surface water affecting activities, including those that affect lakes, through their Water Affecting Activity (WAA) Control policies. Few details of the watercourses in the regions are available**.** There are no official flow gauging stations in the Northern Eyre region, Stuart Shelf region, or Braemar region, and so the link between rainfall volume and streamflow has not been established. However, spatial datasets of watercourses in SA include over 47,000 km of streams and creeks, including 90 km of perennial rivers in the Braemar region that feed into the Murray River catchment (Figure 1 and Table 1).

Streams in the Northern Eyre region receive little runoff from the landscape due to the flat topography and are predominantly saline (due to clearing of native vegetation) (Wen, 2005). Many flow during winter for several months, and persistent pools may remain along the stream for several weeks after surface flows cease. Streams flowing off the northern side of the Gawler Ranges flow towards Lake Gairdner, while streams flowing south typically end in floodouts on the plains. Most flow only ephemerally, although there are also streams that flow all year (such as in the Cleve Hills, Northern Eyre).

In the Stuart Shelf region, streams flow off the Flinders Ranges to the east of Lake Torrens and typically discharge onto the permeable plain east of the lake. Much of this study area is of similarly low topography and there is a high density of small streams in the centre of the region that drain into salt lakes or floodouts. There are few studies of individual streams in the study regions. However, in the region in general, streams with high-quality habitat have the potential to contain rare and sensitive aquatic macroinvertebrate species (EPA, 2024).

The northwestern area of the Braemar region has undulating topography that creates a dense network of streams which empty into floodouts. Barnett et al (2015) noted that major creeks flow for 20 km to 30 km after heavy rain events in the Braemar region before infiltrating in the riverbed. The streams that flow out of the Olary Ranges, in particular, provide habitat and water for native flora and fauna of conservation significance (DEWNR, 2012). In contrast, the southeastern area of the region has few streams and contains the region's only perennial streams, which are tributaries to the River Murray system.

*Table 1. Summary of mapped watercourses in the study regions. Data sourced from the TOPO_Watercourses_GDA94 dataset. It is likely that the majority of undesignated watercourses are non-perennial.*

| STUDY REGION | KM OF WATERCOURSE MAPPED | KM DESIGNATED NON-PERENNIAL | KM DESIGNATED PERENNIAL |
|---|---|---|---|
| **Braemar** | 13,115 | 3661 | 90 |
| **Stuart Shelf** | 18,064 | 1679 | NA |
| **Northern Eyre** | 16,245 | 1680 | NA |

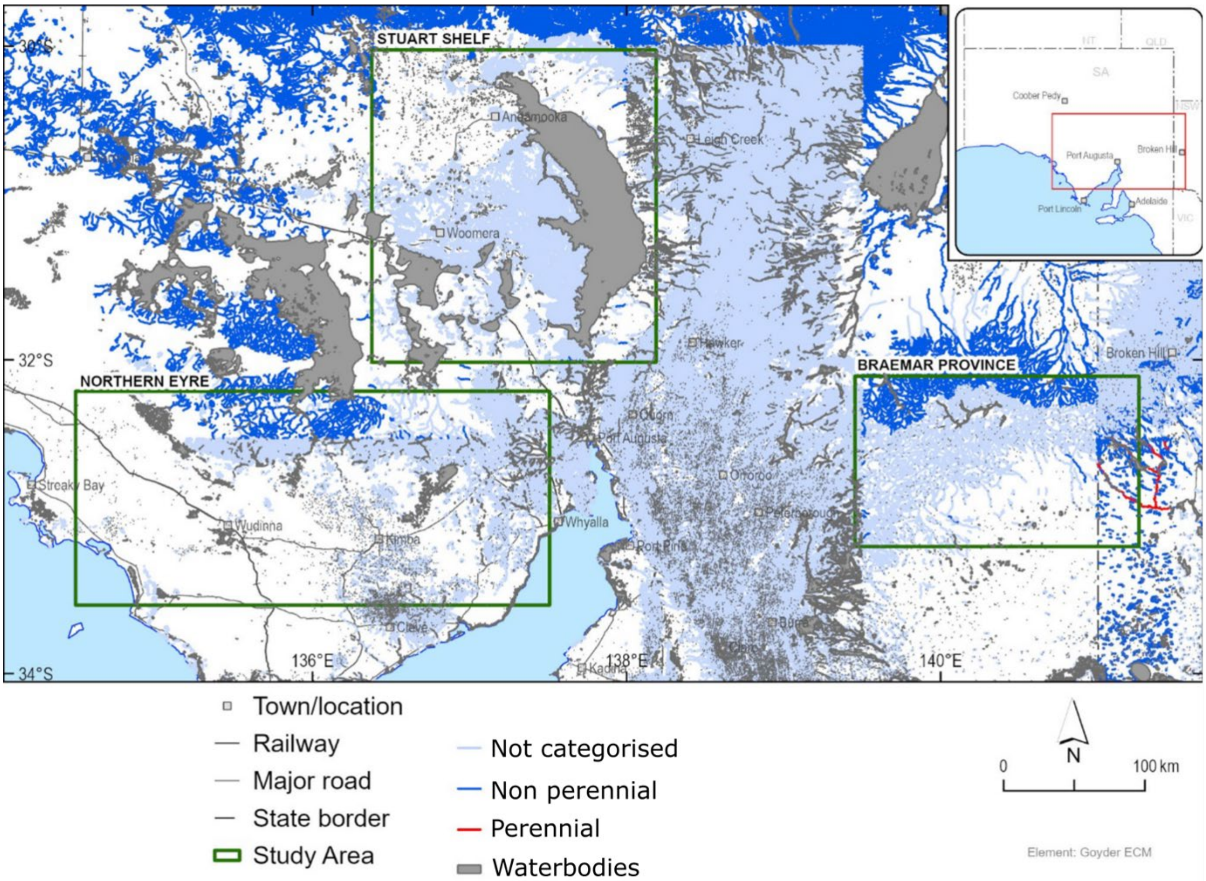


*Figure 1. Watercourses in the 3 study regions, classified by flow regime. Data sourced from the TOPO_Watercourses_GDA94 dataset using the AGFA classification. Note that additional entries have been added to the AGFA dataset by DEW; these provide the higher resolution but unclassified features in portions of each study area. Waterbodies from the TOPO_Waterbodies_GDA94 dataset are also shown for reference (data available at data.sa.gov.au).*

## POTENTIAL IMPACTS FROM DEVELOPMENT

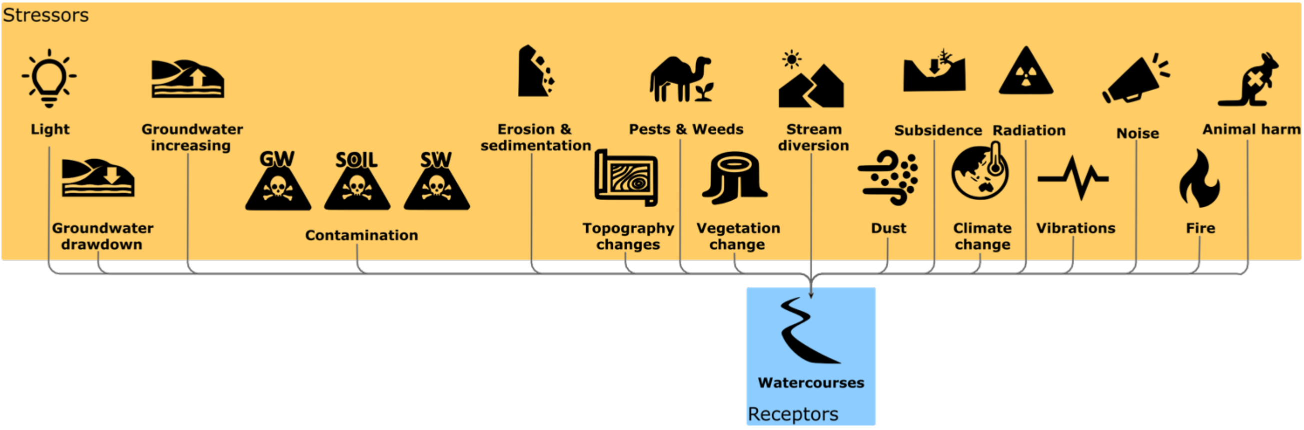


*Figure 2. Stressors associated with resource development that can potentially impact watercourses*

Streamflow diversion can directly affect watercourse hydrology (Figure 2) by changing watercourse flow volume and timing. Topography changes in the catchment, including subsidence, have a similar effect as they change the volume and timing of runoff that enters a watercourse. Changes in timing, duration and extent of wetted phases have profound effects on aquatic biodiversity.

Topography changes, together with infrastructure development across drainage lines, floodplains and floodouts, can change erosion and sedimentation patterns. This is particularly relevant where raised roads or railways run across low-relief catchments and often where there are ditches and culverts, changing floodplain and floodout drainage patterns. Changes in riparian catchment vegetation can affect runoff and lead to increased erosion and downstream sedimentation within watercourses. Invasive animals, especially hoofed animals like goats and camels, can contribute to bank instability and increased erosion. Over-abundant weeds in watercourses can obstruct streamflow. Climate change, which results in a combination of increased temperature and evaporation and changes in frequency and timing of rainfall, can also change streamflow dynamics. Groundwater drawdown can directly reduce streamflow in connected watercourses by reducing groundwater inflow. Even when groundwater levels are below the bed of the watercourse and there is no groundwater inflow to the watercourse, groundwater drawdown can still reduce streamflow. This is because lowered groundwater levels create more room in the unsaturated zone and therefore more infiltration from the surface to groundwater.

Streamflow chemistry can be changed through contamination, either by direct surface water contamination; erosion of contaminated soil into a watercourse; or direct deposition of contaminated dust particles. Indirect contamination may occur is soil or groundwater is contaminated within the watercourse catchment area. Rising groundwater levels can mobilise salt and increase groundwater inflow to streams.

The ecosystems supported by watercourses can be directly affected by vegetation change, increased competition and predation by pests and weeds, direct animal harm, noise, light, radiation, vibrations and fire.

## DATA AND KNOWLEDGE GAPS

The potential for each of the above impact pathways to occur will depend on activity and location. Little is known about the hydrology or ecology of most of the watercourses in northern South Australia. Below is a non-exhaustive list of data needed to understand ecohydrological functioning and the impact of developments on watercourses.

- Datasets used in this factsheet provide starting points for planning and development. However, they have major limitations. For example, stream network mapping is incomplete in some regions (e.g. Gawler Ranges). A small percentage of watercourses have been designated as non-perennial in the Australian Hydrological Geospatial Fabric dataset (Bureau of Meteorology, 2012). Many watercourses have no designation and field data will be needed to verify flow frequency.

- There is extreme seasonal-to-decadal variation in flow frequency and volume of most watercourses in the region. Field studies will be needed to estimate connections between surface water and groundwater, evapotranspirative losses, the dominant mechanisms controlling the persistence of water at the surface (e.g. in waterholes), and temporal water quality. Baseline studies of hydrology and ecology need to consider this temporal variability and will therefore need to be of sufficient duration to capture different flow conditions.
- These watercourses exist in a landscape already altered by stock and agriculture. Cumulative impacts must be considered, and current surveys and historical data should be used to identify sensitive receptors. For the Northern Eyre region, development and salinisation have been identified as the 2 main pressures on streams (Wen, 2005). Development has already altered groundwater flow and quality. Sampling near the Stuart Shelf region has identified stressors to streams that include nutrient enrichment, siltation, and damage to riparian habitat and stream banks by feral goats and stock (EPA, 2024). This is also likely to be true for the Braemar region. In the Braemar region, riparian vegetation in ecologically-important areas has been impacted by infestations of introduced weed species (DEWNR, 2012). This means that contemporary sampling events may not detect plants and animals that are relevant to development applications even though they are still potential receptors.
- Special attention must be devoted to understanding and protecting waterholes along watercourses. These features are of high cultural and ecological importance. Persistent waterholes along creeks provide water sources for a range of significant species in the Olary Ranges, on the saltbush plains, and in the open mulga woodlands.

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# Glossary

## DRIVERS

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| Exploration | All exploration activities required to find an ore body, estimate its mineral reserves and characterise it before mining can start. Includes reconnaissance field visits and mapping, airborne and on-ground geophysics and exploration drilling. |
| In situ recovery mining | Mining technique where the ore remains in place and minerals within the ore are recovered by injecting a leaching solution that dissolves the minerals. The solution is then pumped to the surface and the minerals are extracted. |
| Open pit mining | Surface mining technique where rock is removed in a series of levels or benches. Used when the ore is near the surface and the overburden (overlying rock) is relatively thin. Especially suited for larger, lower grade iron-ore deposits. |
| Post mine closure | The landforms and infrastructure that remain after the mine has closed and the site has been relinquished. Decommissioning and rehabilitation activities are part of the production phase. |
| Underground mining | Mining technique for ore bodies lying beneath a thick overburden (overlying rock) which requires development of an underground network of interconnected shafts and tunnels to excavate the ore and bring it to the surface. |

## ACTIVITIES

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| Decommissioning and rehabilitation | The decommissioning of infrastructure and rehabilitation of landforms after mining ceases. It includes demolition, disposal, soil remediation, earthworks and revegetation. Impacts after mine closure are in the post-mining impact pathway diagram. |
| Exploration logistics | Temporary accommodation such as tents, caravans and transportable units, and transport and storage of equipment. |
| Exploration rehabilitation | The rehabilitation of tracks, drilling, storage and camp sites after exploration, including backfilling holes, trenches and sumps, plugging of boreholes and removal of infrastructure. |
| Geochemical sampling | Collection of rock, soil, sediment, water and vegetation by hand, auger, bulk sample pits or trenches, or drilling. |
| Geophysical surveys | Collection of subsurface information using airborne, on-ground or downhole geophysical techniques. |
| Groundwater investigations | Installation of groundwater wells for hydraulic testing, such as pump testing, and groundwater monitoring. |
| Hydraulic fracturing | In situ recovery may require increasing the permeability of the ore body by injecting a pressurised fluid to fracture or crack the ore body and host rock. |
| Logistics | Transport of equipment, materials, chemicals and personnel to and from a mine site. Construction, operation and maintenance of transport infrastructure are in off-site infrastructure, while on-site infrastructure covers accommodation and storage. |

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| | Mine dewatering | The pumping of groundwater to lower the water table or groundwater pressure such that the mine pit or void is dry enough to allow extraction of ore. It includes drilling and operating pumping wells and the management of pumped water. |
| | Off-site infrastructure | The construction, operation and maintenance of infrastructure outside the mine site. This includes roads, railways, water and slurry pipelines, solar and wind farms and transmission lines. |
| | On-site infrastructure | The construction, operation and maintenance of operational support infrastructure such as workshops, accommodation, offices, warehouses, roads, airstrips and facilities for storage of chemicals, explosives, fuel and lubricants. |
| | Ore processing | The mechanical and/or chemical extraction of minerals from ore by crushing, grinding and leaching. It includes construction, operation and maintenance of infrastructure (e.g. conveyer belts) and handling and storage of chemicals. |
| | Ore transport | Transport of processed ore from the mine site via road, railway or slurry pipeline. Activities related to construction and maintenance of transport infrastructure are included in the off-site infrastructure node. |
| | Pit excavation | Excavation of topsoil, waste rock and ore as part of open pit mining. Holes are drilled and filled with explosives to blast the rock. Loosened ore and overburden are excavated and hauled out of the pit with excavators and haul trucks. |
| | Power supply | Mines are powered by connection to state-owned electricity grids, renewable energy (e.g. solar or wind) and/or on-site gas or diesel generators. This node includes construction, operation and maintenance of power supply infrastructure. |
| | Reconnaissance | Preliminary field visits to examine the general geological features and characteristics of the landscape. |
| | Residue storage | After extracting minerals from fluids that leached the ore body, solid and liquid residue remains. It includes construction, operation and maintenance of residue storage and disposal facilities, as well as spillage and seepage from them. |
| | Stockpiling | The temporary or permanent storage of waste rock and/or top soil in stockpiles on the mine site. It includes the construction, operation and maintenance of infrastructure associated with stockpiles. |
| | Tailings storage | Tailings are the slurry left over after ore processing, stored in a tailings storage facility (TSF), much like a pond or dam, to dry out. This node covers construction, operation, maintenance and any spillage or seepage from TSFs. |
| | Void excavation | Underground excavation of ore and waste rock. Holes are drilled and filled with explosives to blast the rock. The loosened ore and waste rock is transported to the surface with specialised hauling equipment. |
| | Waste management | Other than tailings and overburden, mines produce solid and liquid waste, such as tyres and domestic waste water. This node covers construction, operation and maintenance of facilities to manage non-ore related waste and treated waste water. |
| | Water supply | Water for mine operation and ore processing is sourced from mine dewatering, water distribution networks and/or bore fields. It includes construction, operation and maintenance of water supply infrastructure, and treatment and desalination. |
| | Wellfield operations | In situ recovery mining uses a closed-circuit wellfield to inject and recover leaching fluids from the ore body. It includes drilling, construction, operation and maintenance of wells, pipelines and associated infrastructure. |

## SOURCES

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| Acid and metalliferous drainage | The drainage to soils, groundwater and surface water of neutral to acidic, sulphate-bearing water, potentially containing heavy metals, formed by exposing sulphide minerals in the mine pit, tailings, waste rock or top soil to air and water. |
| Artificial water | The usage of water by fauna and flora at locations where previously no water was present, such as in turkey nest dams, ponds, borrow pits, puddles along road and rail networks, and leakage from taps or pipelines. |
| Blasting | The use of explosives to blast rock so that it can be more readily removed from the pit or void. |
| Brine management | Desalination and treatment of water from dewatering or for water supply results in a brine. It includes the handling, transport and storage of such brines. |
| Chemicals and explosives | The handling, transport and storage of chemicals and explosives used in the mining process. |
| Drilling | The drilling of boreholes for ore body characterisation, explosives, dewatering, water supply or environmental monitoring. |
| Earthworks | The excavation and changes to the landscape to develop mine infrastructure on-site (e.g. pit excavation, stockpiling) and off-site (e.g. road and railway construction). Earthworks for solar and wind farms are part of the solar and wind farm nodes. |
| Equipment | The operation and maintenance of mining equipment, that can be mobile (e.g. haulage trucks and excavators) or stationary (e.g. conveyor belts, crushers and grinders). |
| Flying | The flying at low altitudes and the landing and take-off of small aircraft, such as planes and helicopters, for reconnaissance, geophysical surveys or transport of personnel. |
| Fuel and lubricants | The handling, transport and storage of fuels and lubricants for mobile and stationary equipment used on and off the mine site. |
| Greenhouse gas emissions | The emission of greenhouse gases, such as carbon dioxide and methane, from burning fossil fuels such as diesel and natural gas. |
| Groundwater injection | The injection of groundwater with leaching fluid into an aquifer that hosts an orebody via bores for in situ leaching of minerals. It does not include groundwater injection for water storage, waste management or aquifer pressure rehabilitation. |
| Groundwater pumping | The extraction of groundwater for mine dewatering, water supply or extraction of leaching fluid through one or more bores. |
| Off-road driving | Driving vehicles on natural terrain and through watercourses where there are no established roads or tracks. |
| Ore leaching | The dissolution of minerals in the orebody by circulating a leaching solution from the injection wells to the extraction wells. |
| Pit void | The pit void that remains after rehabilitation of the mine site. The pit can be dry or filled with groundwater. |
| Power generation | The construction, operation and maintenance of gas- or diesel-driven electricity-generation facilities, including transmission lines. It excludes solar or wind electricity-generation facilities. |
| Railway transport | The transport of material, equipment, personal and/or ore via railways. |

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| Remnant off-site infrastructure | The mining infrastructure that remains on the mine site after decommissioning. This can include buildings, roads and railways. |
| Revegetated landform | The rehabilitated and revegetated mine site, including stockpiles and tailings storage facilities. |
| Road transport | The transport of material, equipment, personnel and/or ore via roads to and from the mine site. |
| Slurry transport | The transport of processed ore from the mine site as a slurry (i.e. a mixture of ore and water) through pipelines. |
| Solar power | The construction, operation and maintenance of solar electricity-generation facilities, including transmission lines. |
| Tailings seepage | The unintentional seepage of fluid from tailings storage facilities to soils and groundwater. The seepage of metal-bearing fluids is covered in the node on acid and metalliferous drainage. |
| Tailings spillage | The unintentional spillage of fluids from tailings storage facilities due to, for instance, tailings dam failure or excessive rainfall that causes overtopping of the dam wall. |
| Void collapse | The caving in of the subsurface due to the excavation of ore and waste rock. When this propagates through the subsurface it can cause subsidence. |
| Waste disposal | The on-site or off-site disposal of industrial, domestic and commercial waste from the mine site, excluding waste from ore processing, tailings or overburden. |
| Water discharge | The intentional and controlled release off-site of water from the mine site, including processing water, water from dewatering or treated waste water. |
| Wind farm | The construction, operation and maintenance of wind electricity-generation facilities, including transmission lines. |

## STRESSORS

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| Animal harm | The intentional or unintentional killing or harming of animals directly by stressors, such as vehicle strikes. Indirect effects, such as predation by invasive predators, or animal harm due to bushfires is considered in the other stressors. |
| Climate change | Climate change, primarily due to greenhouse gas emissions |
| Contamination | The introduction to surface water, groundwater or soils of substances that are not naturally occurring or are in concentrations that exceed local background levels and that do or may risk harming the environment. |
| Dust | The creation, transport and deposition of airborne particles of solid matter by wind. |
| Erosion and sedimentation | The geological process in which earth, soil or rock is worn away and transported by natural forces such as wind and water. The transported material is often deposited elsewhere as sediment. |
| Fire | The unintentional ignition of bushfires and/or changes to the natural bushfire regime. |
| Groundwater drawdown | Lowering of groundwater levels or pressures due to pumping in a pumped or adjacent aquifer. |

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| Groundwater increasing | Increasing of groundwater levels or pressures due to injection, infiltration and/or hydraulic loading at the surface. |
| Light | Artificial lighting at night and/or interference with sunlight during the day. |
| Noise | Excessive artificial sound, above background levels, from human activity, such as blasting and use of machinery. |
| Pest and weeds | Introduction, maintenance and/or increasing of populations of plants and/or animals that are not native to the region, or the overabundance of native animal and/or plant species. Pests and weeds increase predation and competition of native species. |
| Radiation | The emission of ionising radiation from radio-active sources, above local, natural background levels. |
| Stream diversion | Intentional, permanent or temporal changes to the course or channel of a watercourse. Modified watercourses often have different features, such as fewer meanders or less heterogeneity in channel topography. |
| Subsidence | Sinking of the ground due to underground material movement, for instance from void collapse during or after mining. |
| Topography changes | Changes in topography that change existing drainage patterns and/or alter the visual appearance of the landscape. |
| Vegetation change | Changes in native vegetation composition and structure, including physical removal, destruction and/or replacement of current vegetation with different native vegetation. Introduction of invasive plant species is included in the node pests and weeds. |
| Vibrations | Human-induced vibrations of the earth due to explosives during mining, railway transport, seismic geophysical investigations or operation of wind turbines. |

## RECEPTORS

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| **Farm dams** | Hydrology, water chemistry and ecosystems associated with artificial water storages created and managed by landowners. In-stream farm dams are created by constructing a barrier across drainage lines: off-stream dams by modifying a natural depression. |
| **Groundwater bores** | Groundwater bores that provide water for town water supply and stock and domestic use. Bores providing water for resource development are excluded. |
| **Rock-holes** | Hydrology, water chemistry and ecosystems associated with natural water storages, often perched on low-permeability outcrops, such as granitoids, and filled by local rainfall. Examples include rock-holes or gnammas. |
| **Lakes** | Non-flowing perennial and ephemeral surface waters, including their hydrology, water chemistry and aquatic and fringing vegetation ecosystems. It includes saline lakes, swamps, salt marshes and coastal wetlands. |
| **Springs** | Springs are hydrological features where groundwater discharges at the Earth's surface. This receptor includes ecosystems directly supported by the spring outflow stream or pond. |

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| | Subterranean ecosystems | Ecosystems that exist below the soil zone, especially ecosystems in the saturated zone, including microbes and stygofauna (species that live in groundwater), and in cave ecosystems, which include troglofauna (cave-dwelling species). |
| | **Terrestrial groundwater dependent ecosystems** | Terrestrial ecosystems in which one or more vegetation species requires continuous, seasonal or episodic groundwater access. |
| | **Watercourses** | Flowing perennial and ephemeral surface waters, including their hydrology, water chemistry and aquatic and riparian ecosystems. It includes freshwater and saline creeks, streams, and rivers (including their waterholes). |