2. Methodology

2.1. Overview

The methodology for identifying and delineating resources and potential interaction in the northern Perth Basin relies primarily on Geographic Information Systems (GIS). This approach leverages open-source and proprietary geospatial data related to subsurface and surface resources in the region. The scope of this work does not include further geological modelling or interpretation of geophysical data, as the existing data is deemed sufficient for a basin-scale resource interaction assessment.

The first phase of the project involves comprehensive data gathering, review, curation, and initial assessment. This phase sets the foundation for subsequent detailed analyses.

Geospatial datasets related to the overall geology of the northern Perth Basin, the petroleum resources, geothermal resources, carbon geological storage (CGS), underground gas storage (UGS) and groundwater resources are added to a GIS project that represents the foundation of the interaction assessment.

In general terms, the assessment follows a structured workflow designed to evaluate how multiple subsurface resources may coexist or compete across the northern Perth Basin (Figure 19). The process begins by identifying key *suitability factors* for each resource type: petroleum, CGS, UGS, geothermal, and groundwater. These suitability factors define the geological and spatial conditions under which a given resource is considered viable or developable.

Using these factors, *suitability maps* are created for each resource at key stratigraphic intervals. These suitability maps quantify and visualise where each resource is most likely to occur and be viable for development.

The next step involves combining the suitability maps of coexisting resources to generate *interaction maps*. These interaction maps highlight areas of potential overlap or competition between specific pairs or groups of resources. *Thematic interaction* maps are then derived to focus on specific interactions of interest, such as petroleum vs CGS, or groundwater vs other resources.

To provide a comprehensive view, a *cumulative interaction map* is constructed. The cumulative interaction map aggregates interaction signals across all major intervals to highlight broad spatial trends and areas where resource competition is most likely.

Finally, the cumulative interaction map is integrated with 2 additional factors:

- groundwater demand, using bore density as a proxy for usage pressure
- potential migration pathways, using fault and well density as indicators of vertical connectivity.

These *integrated cumulative maps* refine the assessment by identifying dual-stress zones where high-interaction potential coincides with high water demand or elevated risk of deep-shallow fluid movement.

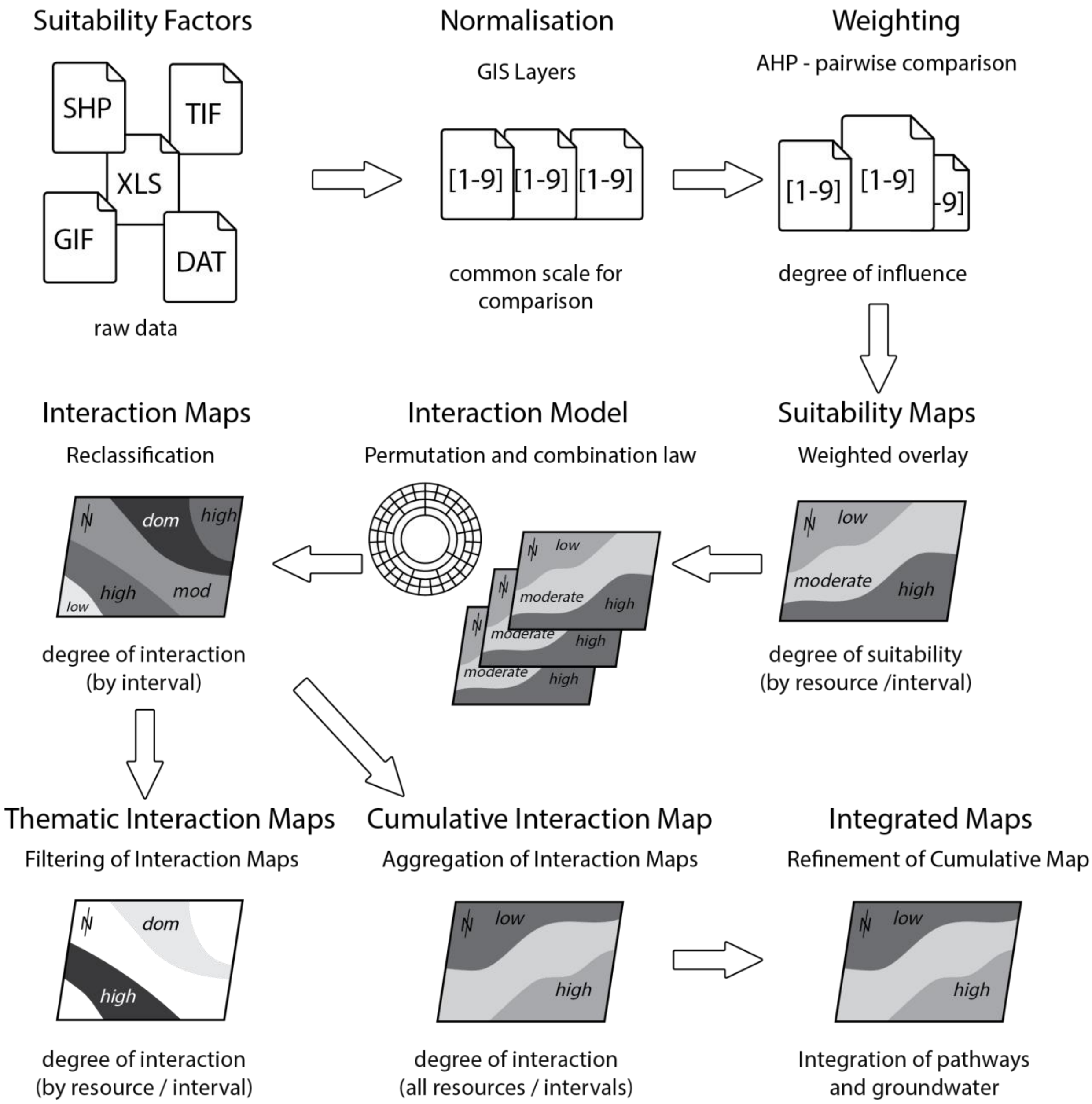

Figure 19. Schematic workflow for evaluation of resource interactions.

2.2. Identification and assessment of resources

The assessment of resource interactions in the northern Perth Basin applies a variant of the Multi-Criteria Evaluation (MCE) and Analytic Hierarchy Process (AHP) (Saaty, 1980; Belton and Stewart, 2002). These methodologies support 2 key objectives:

1. Evaluating the suitability of subsurface resources using a structured approach that integrates multiple factors influencing resource presence and viability.
2. Assessing potential resource interactions by quantifying spatial overlaps and competition for pore space, as well as ‘soft’ interactions resulting from indirect connectivity through geological pathways such as faults or wellbores.

The resulting suitability maps are combined into interaction maps that quantify resource overlap and competition. These maps facilitate decision-making for land and subsurface management by highlighting areas where multiple resources may coexist, compete, or require regulatory intervention.

The intervals considered in the assessment (Figure 5 and Figure **20**) include:

- G1low (Lower Permian, under the Carynginia Fm)
- G1up (Upper Permian, under the Kockatea Shale)
- G2A1 (Triassic-Lower Jurassic under the Cadda Fm)
- A1 (Lower Jurassic)
- A2 (Upper Jurassic)
- abA2 – Leeder, Parm (Cretaceous, including Leederville and Parmelia Fm)
- abA2 – Superficial (Cenozoic, including the Superficial formations).

<table>
<tr><th>Erathem</th><th>Stratigraphy</th><th>Petroleum System</th><th>Assessment Interval</th></tr>
<tr><td>Cenozoic</td><td>Superficial</td><td></td><td>abA2
Superficial</td></tr>
<tr><td rowspan="2">Createaceous</td><td colspan="3">Eroded</td></tr>
<tr><td>Leederville
Parmelia</td><td></td><td>abA2
Leeder, Parm</td></tr>
<tr><td rowspan="2">Jurassic</td><td>Yarragadee</td><td>Austral 2</td><td>A2</td></tr>
<tr><td>Cadda
Cattamarra</td><td>Austral 1</td><td>A1</td></tr>
<tr><td>Triassic</td><td>Eneabba
Lesueur</td><td>Gondwanan 2</td><td>G2A1</td></tr>
<tr><td rowspan="2">Permian</td><td>Kockatea
Dongara, Wagina</td><td rowspan="2">Gondwanan 1</td><td>G1up</td></tr>
<tr><td>Carynginia
High Cliff, Kingia</td><td>G1low</td></tr>
</table>

Figure 20. Key assessment intervals used in the assessment of resource interaction.

2.3. Suitability factors

Suitability factors are the geological and technical criteria used to assess the likelihood of a particular resource being present or developed in a specific location. These factors include the presence and effectiveness of reservoir and seal formations, and the depth, structure, temperature, and proximity to known resources. Georeferenced datasets (such as facies maps, borehole locations, and petroleum field outlines) are used to represent these factors spatially and are integrated into the suitability mapping process to visualise where conditions are most favourable for each resource. The complete set of evaluation factors for the resources is provided in Appendix 1: *Suitability* .

These factors are derived from proprietary and publicly available databases, as well as digitised records. They are classified within a GIS environment as either polygon layers with categorical value classes, point layers with categorical value classes, or raster grids with continuous pixel values.

The datasets supporting this work were accessed from multiple public agencies and proprietary sources, each contributing critical geological, hydrological and energy-related information relevant to the northern Perth Basin. Key data providers include DEMIRS Data Centre (2025), WAPIMS (2025), GeoView (2025), DWER (2025), the Bureau of Meteorology (2025), S&P Global (2024), Geoscience Australia (2025), and several peer-reviewed and industry reports, including 3D-GEO (2013), Craig *et al.* (2022), Ellis *et al.* (2024), and Mory and Iasky (1996).

To quantitatively assess these factors, original geospatial datasets must often be processed to a uniform resolution through resampling, ensuring comparability across layers. Many of these factors are then calculated or derived using spatial analysis techniques in GIS, including spatial interpolation (for example, inverse distance weighting), density estimation (for example, kernel density), distance and proximity analysis, hotspot detection, spatial clustering evaluation (for example, average nearest neighbour), and overlap analysis.

Normalisation of suitability factors

Since suitability factors are measured on different scales (nominal, ordinal, interval, and ratio), normalisation is required to convert them to a common scale for comparison (Figure 19).

Following the Land-Use Conflict Identification Strategy (LUCIS) (Carr and Zwick, 2007), all suitability factors are standardised using a 1–9 scale, where:

- 1 = lowest suitability
- 9 = highest suitability.

A 5-rank system (1, 3, 5, 7, 9) is applied to express how likely it is that resources are present for each factor. The choice of normalisation method is factor-dependent and can include regular intervals, natural breaks in data distribution or expert domain input.

Factors may be binary (for example, presence/absence) or exhibit gradual variations with up to 5 ranks.

Weighting of suitability factors

Because different factors influence resource suitability to varying degrees, they are weighted to reflect their relative importance (Figure 19). This weighting process is guided by the Analytic Hierarchy Process (AHP) (Saaty, 1980) and implemented using pairwise comparison matrices that compare each factor against another to establish relative importance. A consistency check is applied by computing the consistency index (CI) and consistency ratio (CR) to verify logical consistency. A CR < 0.10 is considered acceptable (Saaty, 1980).

2.4. Suitability maps

The suitability maps integrate normalised and weighted suitability factors into a single suitability representation for each resource (Figure 19). To ensure consistency, all suitability maps:

- are resampled to a 500 m x 500 m grid
- use a 1–9 scale, reclassified into 3 suitability categories:
    - low suitability (1–4)
    - moderate suitability (5–6)
    - high suitability (7–9).

This process results in 15 suitability maps, corresponding to different resources and stratigraphic intervals (Figure 21, Figure 42, A–D and Figure 45A–C).

<table>
<tr><th>Erathem</th><th>Stratigraphy</th><th>Assessment Interval</th><th>Suitability Map</th><th>Interaction Map</th><th>Thematic Interaction Map</th><th></th></tr>
<tr><td>Cenozoic</td><td>Superficial</td><td>abA2
Superficial</td><td>Suitability Groundwater (abA2 Superficial)</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Creataceous</td><td colspan="3">Eroded</td><td></td><td></td><td></td></tr>
<tr><td>Leederville
Parmelia</td><td>abA2
Leeder, Parm</td><td>Suitability Groundwater (abA2 Leederville Parmelia)</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Jurassic</td><td>Yarragadee</td><td>A2</td><td>Suitability Groundwater (A2)</td><td></td><td></td><td></td></tr>
<tr><td>Cadda
Cattamarra</td><td>A1</td><td rowspan="2">Suitability Groundwater (A1)

Suitability Petroleum (G2A1)
Suitability CGS (G2A1)
Suitability UGS (G2A1)</td><td rowspan="2">Interactions in Triassic Lower-Jurassic (G2A1)</td><td rowspan="2">Petroleum resource vs other (G2A1)
CGS resource vs other (G2A1)
Groundwater resources vs other (G2A1)</td><td rowspan="4">Cumulative Interaction</td></tr>
<tr><td>Triassic</td><td>Eneabba
Lesueur</td><td>G2A1</td></tr>
<tr><td rowspan="2">Permian</td><td>Kockatea
Dongara, Wagina</td><td>G1up</td><td>Suitability Petroleum (G1up)
Suitability CGS (G1up)
Suitability UGS (G1up)
Suitability Geothermal (G1up)</td><td>Interactions in Upper Permian (G1)</td><td>Petroleum resource vs other (G1up)
CGS resource vs other (G1up)</td></tr>
<tr><td>Caryngini a
High Cliff, Kingia</td><td>G1low</td><td>Suitability Petroleum (G1low)
Suitability CGS (G1low)
Suitability UGS (G1low)
Suitability Geothermal (G1low)</td><td>Interactions in Lower Permian (G1)</td><td>Petroleum resource vs other (G1low)
CGS resource vs other (G1low)</td></tr>
</table>

Figure 21. Outputs of resource assessment for the northern Perth Basin. Suitability maps, interaction maps, thematic interaction maps and the cumulative interaction map are shown with their respective assessment interval.

2.5. Interaction maps

An interaction map combines suitability maps for multiple resources within a specific assessment interval to highlight where those resources co-occur (Figure 19). It identifies areas of potential competition or overlap to support assessments of subsurface resource interactions.

Interactions can occur within the same stratigraphic interval, leading to direct competition for pore space (the natural empty space within underground rocks that can hold fluids like water, gas, or CO_2) when multiple resources coexist in the same subsurface unit. This is typically observed among petroleum, CGS, UGS, and geothermal resources in the Permian to Lower Jurassic intervals.

The development of interaction maps is based on permutation and combination laws (for example, Jing *et al.*, 2021). The suitability maps are combined for each assessment interval (Figure **20**), and interaction intensity is categorised as follows (Figure 22):

- **high interaction:** at least 2 resources exhibit high suitability
- **moderate interaction:** 2 or more resources show moderate suitability, or one resource has high suitability while others are moderate
- **low interaction:** at most one resource has moderate suitability, with no high-suitability resources
- **resource dominance:** one resource exhibits high suitability while all others remain low.

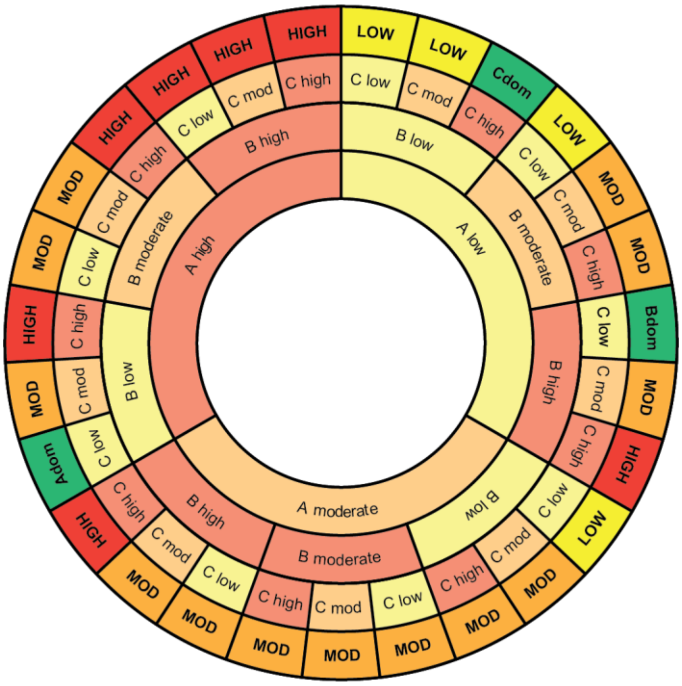

Figure 22. Schematic empirical permutation and combination laws for interaction maps of 3 resources. The first 3 rings from the centre represent resources A, B and C and their suitability (low, moderate, high). The outside ring represents the interaction intensity (low, moderate, high and dominant resource (#dom).

To improve granularity, interaction zones are further classified based on:

- the number of high-suitability resources
- the specific combinations of moderate and high-suitability resources
- the dominant resource, where applicable.

A detailed breakdown of resource-specific interactions is recorded, capturing the relationships between different resources and their suitability levels (for example, petroleum = high, geothermal = moderate, and CGS = low). This enables a more comprehensive understanding of how multiple resources interact within a given area.

This process produces:

- 3 general interaction maps for the Lower Permian, Upper Permian, and Triassic-Lower Jurassic intervals
- 7 thematic interaction maps (resource-specific maps showing the interaction of petroleum, CGS, and groundwater with all other resources).

2.6. Cumulative interaction map

A cumulative interaction map integrates all resource interactions across the Permian-Lower Jurassic intervals (Figure 48). The cumulative interaction map:

- Aggregates suitability values from suitability maps for petroleum, CGS, UGS, and geothermal resources.
- Computes a cumulative interaction value by adding the individual suitability values at each sample location to approximate the intensity of resource interaction across the Permian-Lower Jurassic intervals.

This cumulative interaction map offers a comprehensive view of overlapping resources. It provides a detailed representation of the resources that typically underlie groundwater aquifers.

2.7. Integrated cumulative interaction maps

Building on the cumulative interaction map, a series of integrated cumulative maps is developed to refine the assessment of resource interactions by incorporating additional information on groundwater demand and potential migration pathways (Figure 19). These integrated cumulative interaction maps enhance understanding of dual-resource stress zones and connectivity risks, supporting regional-scale risk assessment and resource management planning.

In addition to direct competition for the same pore space, interactions between resources can also be ‘soft,’ where they occupy different stratigraphic intervals but are still indirectly connected. This is particularly relevant for deeper resources (such as petroleum, CGS, UGS, and geothermal developments in the Permian to Lower Jurassic intervals) and shallower groundwater systems hosted in Jurassic to Cenozoic aquifers. Pathways, such as faults or deep boreholes, may allow vertical connectivity between these otherwise separated systems. The integrated cumulative interaction maps explicitly address this issue by incorporating proxies for both groundwater demand and the likelihood of vertical connectivity. As such, they provide a valuable tool for identifying areas where soft interactions may occur, supporting more informed decision-making regarding groundwater protection, resource coexistence and long-term development planning.

2.7.1. Integration of groundwater demand and resource interaction

A complementary integrated cumulative interaction map (Figure 49) is developed by combining the cumulative interaction map with water bore density data, which serves as a proxy for groundwater demand. This map illustrates how deep resource interactions (petroleum, CGS, UGS and geothermal) intersect spatially with areas of intensive groundwater use, highlighting zones where competing demands may arise.

This map contributes to a more comprehensive understanding of how groundwater and deep subsurface development intersect, supporting informed decision-making in the northern Perth Basin.

2.7.2. Integration of potential migration pathways

The integrated cumulative interaction map integrates faults and petroleum well infrastructure, which could act as vertical migration pathways between deep resource-bearing formations and overlying groundwater aquifers. The pathways are weighted based on their potential to enhance subsurface permeability and influence fluid movement across stratigraphic barriers. This process produces a pathway-integrated map (Figure 50), which adjusts cumulative interaction values based on the likelihood of vertical connectivity. This map helps to visualise regions with high fault displacement or well densities that experience elevated interaction values, emphasising areas where structural permeability could enhance vertical fluid movement and warrant further assessment. Regions with low fault or low well density see reduced interaction values, indicating a lower likelihood of migration pathways and a greater degree of separation between deep and shallow formations.

This integrated approach helps identify areas where resource interactions may extend beyond their primary depth intervals, informing risk assessments and management strategies for subsurface resource development in the Northern Perth Basin.