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Regional screening of subsurface resource interactions in the northern Perth Basin, Western Australia

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Abstract

Sedimentary basins can host multiple subsurface resources, creating potential for direct competition where activities target the same pore space and for pressure or fluid interaction where they occupy separate but connected intervals. In the onshore northern Perth Basin, Western Australia, these relationships may involve petroleum production, carbon geological storage (CGS), underground gas storage (UGS), geothermal development and groundwater abstraction. Regional spatial overlap can identify where potential resources interactions warrant closer assessment, but these resources may still be vertically and hydraulically separated.

This study provides a data-driven framework for evaluating potential subsurface resource interactions and identifying potential risks and opportunities for regulators, industries and communities. The project uses a Geographic Information System (GIS)-based multi-criteria and hierarchy evaluation process to assess the suitability of different resources and quantify their spatial interactions with focus on petroleum and CGS operations and potential conflicts with groundwater usage.

The overlap of suitable petroleum and CGS resources is most pronounced in the Permian succession, particularly on the Dongara, Beharra Springs and Donkey Creek terraces and in the northwestern Dandaragan Trough. Candidate areas where CGS could follow petroleum production and reservoir depletion extend south along the Cadda Terrace and Coomallo Trough. CO_2 source–sink proximity screening identifies a western basin corridor, particularly between Dongara and Leeman, where prospective CGS areas lie relatively close to potential future gas-related CO_2 sources.

The potential for vertical interaction between resources was also examined by considering faults and petroleum wells as possible vertical pathways between deep formation and to shallow groundwater aquifers. Water bore density was used as a proxy for evaluating the competition for groundwater.

While groundwater resources are typically hydraulically isolated from deeper resources development activities by thick intervening shale aquitards, potential impacts of petroleum and CGS operations on groundwater resources are possible in heavily faulted areas in a central-western corridor inland of Dongara and extending south along the Cadda Terrace and Coomallo Trough.

The presented framework provides a regional basis for more targeted, field-scale assessments and identification of resource development synergies, options for sequential development, and cumulative groundwater management.

1. Introduction

Sedimentary basins are increasingly used for several forms of resource development. Petroleum extraction, carbon geological storage (CGS), underground gas storage (UGS), geothermal development and groundwater abstraction may target the same formations or different levels of a vertically connected succession, creating potential interactions among these resource uses. Here, resource interaction is used neutrally for beneficial or adverse relationships between resource developments, including:

1. Synergies in resource development
2. Competition for pore space within the same interval
3. Detrimental impacts on resources development (change in pressure or temperature) or resource quality (contamination) within the same interval or in adjacent intervals

Uses that share a reservoir–seal system can compete for pore space, creating a reason to examine whether sequential use is feasible. Uses in separate intervals can still interact through pressure propagation or fluid migration where faults or wells provide transmissive pathways. Basin-scale assessment therefore needs to distinguish direct overlap from possible indirect connection and to identify where resource opportunities and constraints are concentrated (Rawling and Sandiford 2013; Michael et al. 2016; Field et al. 2018).

The onshore northern Perth Basin in Western Australia (Fig. 1) presents this problem within a faulted succession that contains established and prospective resources. Petroleum exploration and production are established activities (Fig. 2), and renewed exploration has extended interest in deep Permian gas reservoirs (Fig. 3), including the discoveries at Waitsia, West Erregulla and Beharra Springs Deep (Cortis et al. 2021). UGS operates at Mondarra (APA Group 2026) and depleted fields have been screened for their suitability to store hydrogen (RISC Advisory 2022). Depleted fields like Dongara and Beharra Springs (Fig. 1) are also considered for CGS (Trupp 2024) and CGS in saline formations and petroleum fields has been assessed, in the Permian reservoirs and the Lesueur–Cattamarra succession, on a basin-scale (3D-GEO 2013; Varma et al. 2013; Ellis et al. 2024; WA Carbon Dioxide Geological Storage Atlas 2025). CGS development has progressed to pilot testing with ~ 45 t of CO_2 injected into the depleted Dongara gas field (Fig. 1; Kato and Akai 2024). The northern Perth Basin has also been explored for geothermal resources in deep saline aquifers (e.g., Kingia Sandstones, Fig. 2 and Fig. 3); while elevated temperatures are documented, sustained fluid deliverability remains uncertain and there is no geothermal energy project for electricity generation currently in operation (Ballesteros et al. 2020).

In addition to groundwater-dependent ecosystems, groundwater sources provide approximately 90% of the regions water supply for domestic, agricultural and industrial usage (Department of Water 2017).

These uses overlap in plan view but differ in depth, geological setting and development maturity (Fig. 2).

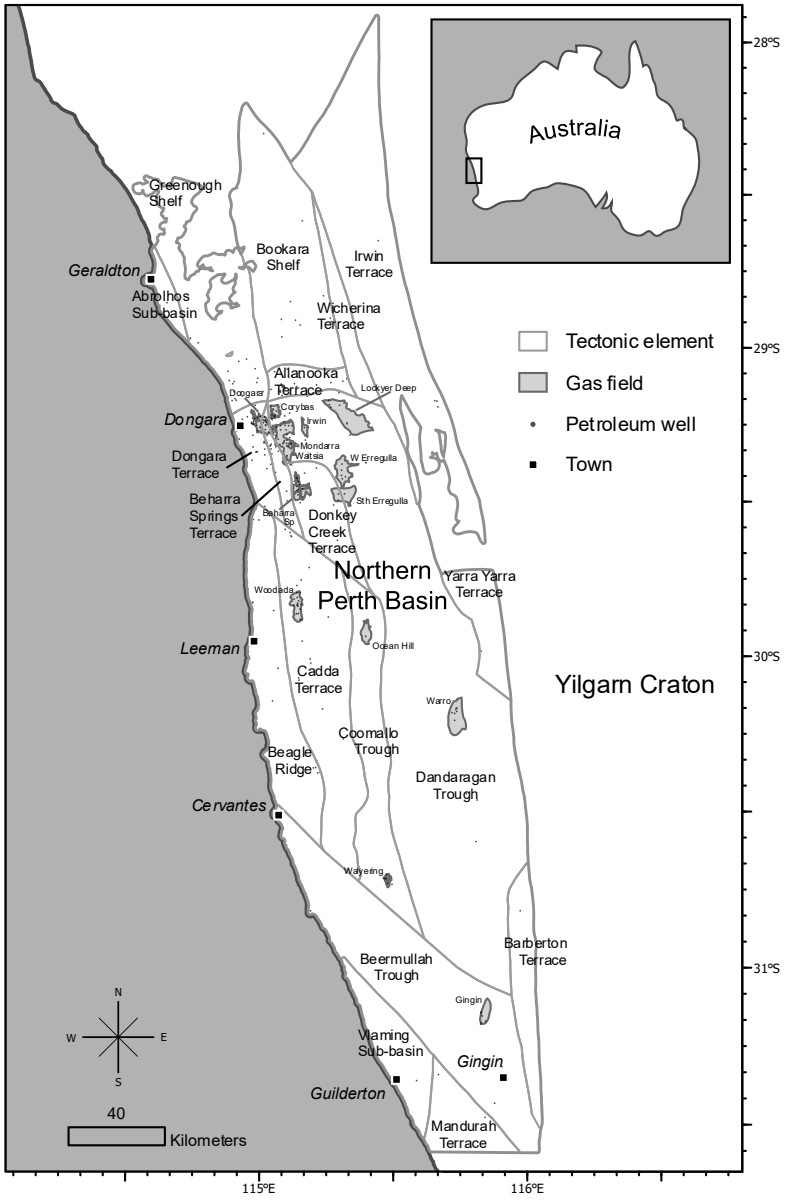


Fig. 1 Onshore northern Perth Basin setting and tectonic elements

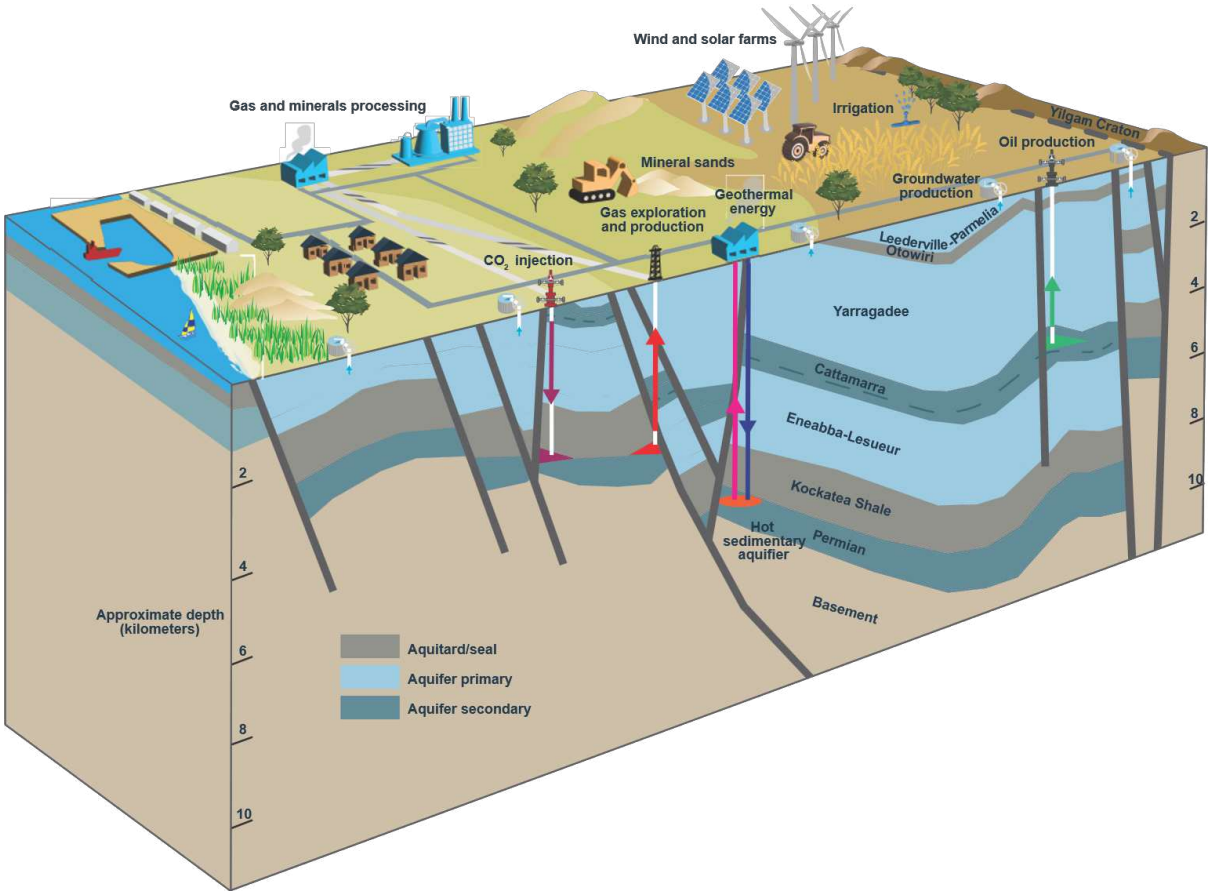


Fig. 2 Regional block diagram across the central northern Perth Basin, from the coastline (west) to the Yilgarn Craton (east). The distribution of resources is illustrative only

Available studies provide resource-specific information on petroleum, CGS and groundwater, but they do not place all of these resources in a common regional framework. The unresolved issue is how to compare suitability across the basin without treating every map overlap as a demonstrated conflict or connection. In this study, suitability denotes the relative favourability of an area for a specified resource use, based on the adopted screening criteria and weights (Appendix). Same-interval overlap between petroleum and CGS may indicate competition for a reservoir compartment, whereas overlap in adjacent intervals may represent separate targets with possible pressure or containment interactions (Fig. 2). Likewise, an aquifer above a deep resource is not necessarily hydraulically connected to it. Its relevance to screening depends on stratigraphic separation, mapped faults and wells, and the intensity of groundwater use. Multi-criteria mapping can combine heterogeneous geological evidence and identify areas for closer assessment, provided that ranked suitability is not interpreted as storage capacity, project feasibility or risk probability (Wei et al. 2013; Bump et al. 2021).

This study uses regional geological and spatial data to map the first-order suitability and interaction potential for petroleum, CGS, UGS, geothermal and groundwater resources across the onshore northern Perth Basin. The analysis concentrates on petroleum–CGS relationships and on the potential impacts of resources development on groundwater. Petroleum–CGS

overlays are used to examine mutual suitability within and between deep intervals. A cumulative deep-resource index sums petroleum, CGS, UGS and geothermal suitability values across the assessed intervals and is evaluated together with aquifer suitability, mapped fault and well pathways, and water-bore density.

The study addresses two questions. First, where does petroleum and CGS suitability coincide in the same or adjacent intervals, and which areas represent opportunities for coexistence, sequencing or source–sink investigation? Second, where do groundwater aquifers coincide with greater cumulative deep-resource suitability, concentrations of mapped potential pathways and likely greater water use? The outputs are regional screening maps intended to direct more detailed geological, engineering and hydrogeological assessment. They do not estimate recoverable petroleum, storage capacity, injectivity, hydraulic connectivity, leakage probability, groundwater stress or development priority.

2. Basin Setting

2.1 Hydrogeological framework

The onshore northern Perth Basin is a sedimentary rift basin along the western margin of the Yilgarn Craton (Fig. 1). Its architecture records successive phases of extension, subsidence and sedimentation from the late Carboniferous to the Early Cretaceous, culminating in continental separation between Australia and Greater India (Mory and Iasky 1996; Norvick 2004). Fault-bounded troughs, terraces and basement highs control the thickness, burial depth and lateral continuity of the sedimentary succession (Fig. 1 and Fig. 2).

The Dandaragan Trough forms the principal deep onshore depocentre. To its west, the Dongara, Beharra Springs and Donkey Creek terraces, together with the Cadda Terrace, Coomallo Trough and Beagle Ridge, define a series of fault-bounded structural domains. The Greenough and Bookara shelves and Allanooka and Wicherina terraces characterise the northern part of the study area, whereas the Beermullah Trough occupies its southern part (Thomas 2014). The block diagram in Fig. 2 illustrates the conceptual distribution of geological formations and resources on a schematic section from the coastline to the Yilgarn Craton.

Late Carboniferous–Early Permian extension was accompanied by deposition of glaciogenic, fluvial and deltaic sediments. The Lower Permian succession includes the High Cliff and Kingia sandstones, Irwin River Coal Measures and Carynginia Formation. Subsequent uplift and subsidence were followed by deposition of Upper Permian strata, including the Wagina and Dongara sandstones and Beekeeper Formation. The Lower Triassic Kockatea Shale overlies the Permian succession and forms a regionally important shale interval (Mory and Iasky 1996; Fig. 3).

The overlying Triassic–Jurassic succession includes the Lesueur Sandstone, Eneabba Formation, Cattamarra Coal Measures and Cadda Formation. Late Jurassic–Early Cretaceous extension further developed the basin's fault architecture before continental breakup, with

deposition of the Yarragadee Formation during this later phase of basin development (Norvick 2004). Younger strata include the Parmelia and Leederville units and Cenozoic superficial deposits. The succession therefore contains multiple sandstone-rich intervals separated by shale-rich formations and other aquitards (Fig. 2 and Fig. 3), although their thickness and continuity vary spatially (Mory and Iasky 1996; Department of Water 2017).

For this assessment, the sedimentary succession is grouped into three regional hydro-stratigraphic intervals (Fig. 3):

1. Permian aquifer system below the Kockatea Shale aquitard, which includes the gas-prone Lower Permian (High Cliff and Kingia) and Upper Permian (Dongara and Wagina) reservoirs,
2. Triassic–Lower Jurassic Eneabba-Lesueur aquifer system below the Cattamarra Coal Measures aquitard,
3. Yarragadee aquifer system and shallow Parmelia-Leederville and Superficial aquifer systems (Upper Jurassic-Cenozoic).

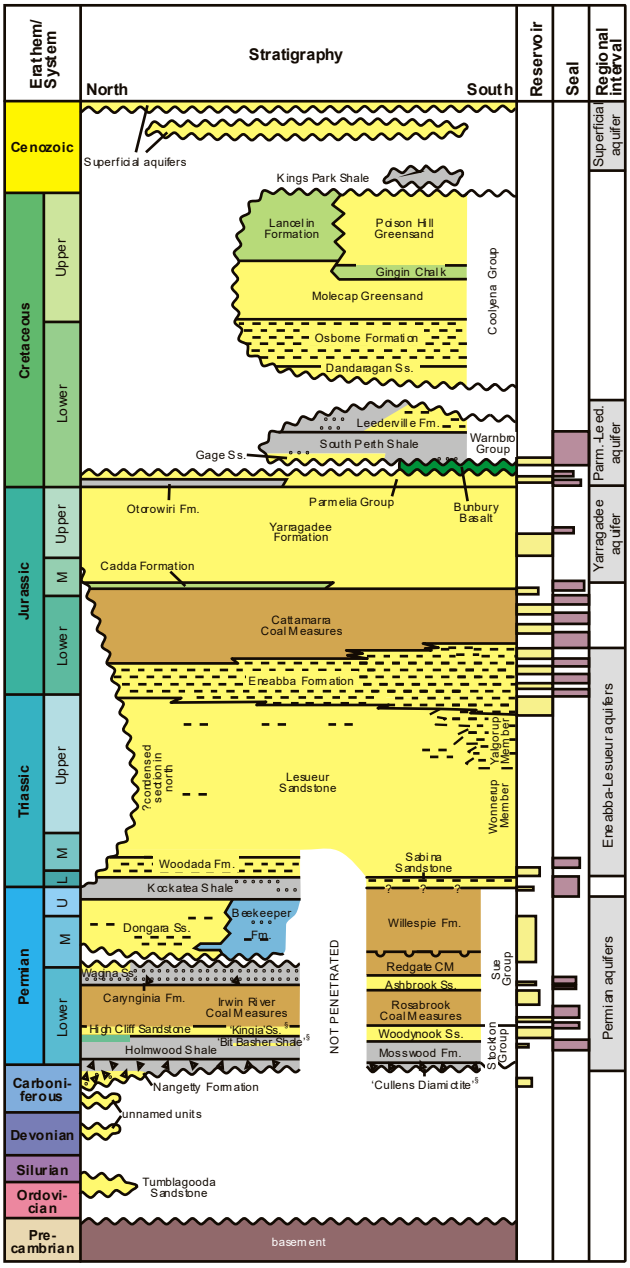


Fig. 3 Stratigraphy of the northern Perth Basin (modified from A. Mory, personal communication, 2025)

Three groundwater-flow systems are recognised. Shallow local flow systems are driven by meteoric recharge over local topographic highs and discharge to rivers and lakes. They are generally active at depths of less than 200 m and contain fresh groundwater in the subcrop and outcrop areas of the Parmelia–Leederville, Yarragadee and Eneabba–Lesueur aquifers (Fig. 4 and Fig. 5). An intermediate flow system extends to approximately 2,000 m, with meteoric recharge in the east and regional westward flow of relatively fresh formation water towards the coast. Below approximately 2,000 m, a deep, stagnant-to-sluggish system contains brackish to saline formation water that flows slowly westward (Fig. 4 and Fig. 5).

In the northern part of the study area, fresh, usable groundwater with salinity below 1,000 mg/L is restricted to approximately the upper 200 m of the Dandaragan Trough, and the intermediate flow system occurs largely above the Cattamarra Coal Measures (Fig. 5A). Near the Dongara Terrace, salinities above 7,000 mg/L occur at shallow depths along the coast, probably because of seawater incursion and mixing (Fig. 5A).

The highest salinities, exceeding 30,000 mg/L, occur offshore, in coastal areas affected by seawater of approximately 35,000 mg/L, and in the deeper parts of the basin, particularly in Permian aquifers below the Kockatea Shale (Department of Water 2017; Fig. 5). In these deeper parts of the basin, connate water trapped during sedimentation has undergone little mixing with fresh meteoric water. Maximum salinities measured in petroleum wells deeper than 2,000 m are approximately 40,000 mg/L.

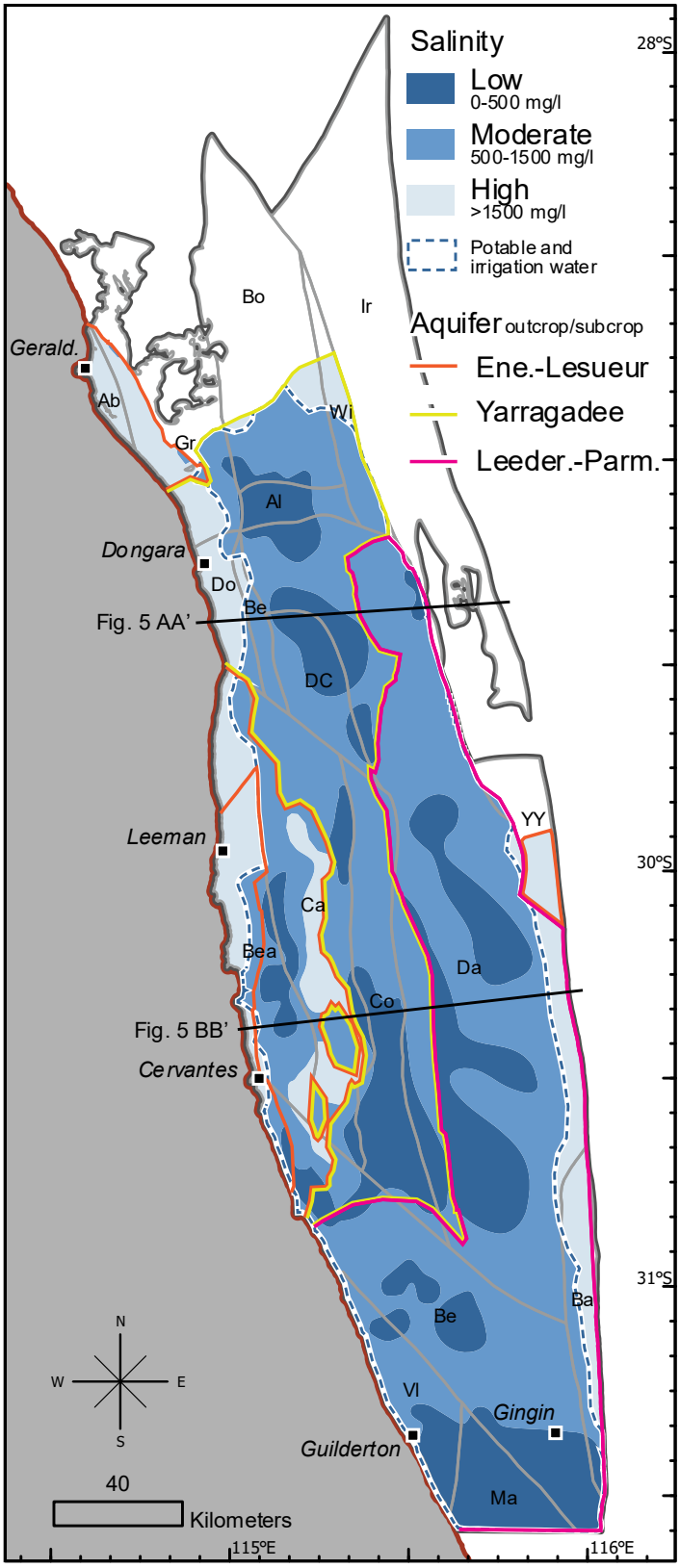


Fig. 4 Near-surface groundwater salinity in the northern Perth Basin, reclassified from Department of Water (2017) into low (0–500 mg/L), moderate (500–1,500 mg/L) and high (>1,500 mg/L) salinity classes. The blue dotted line represent salinity lower than 1,500 mg/L for potable and irrigation water. Orange, yellow and magenta lines show the mapped outcrop

or subcrop boundaries of the Eneabba–Lesueur, Yarragadee and Parmelia–Leederville aquifers, respectively (modified from Department of Water 2017). Black lines show the locations of cross-sections A–A′ and B–B′ in Fig. 5

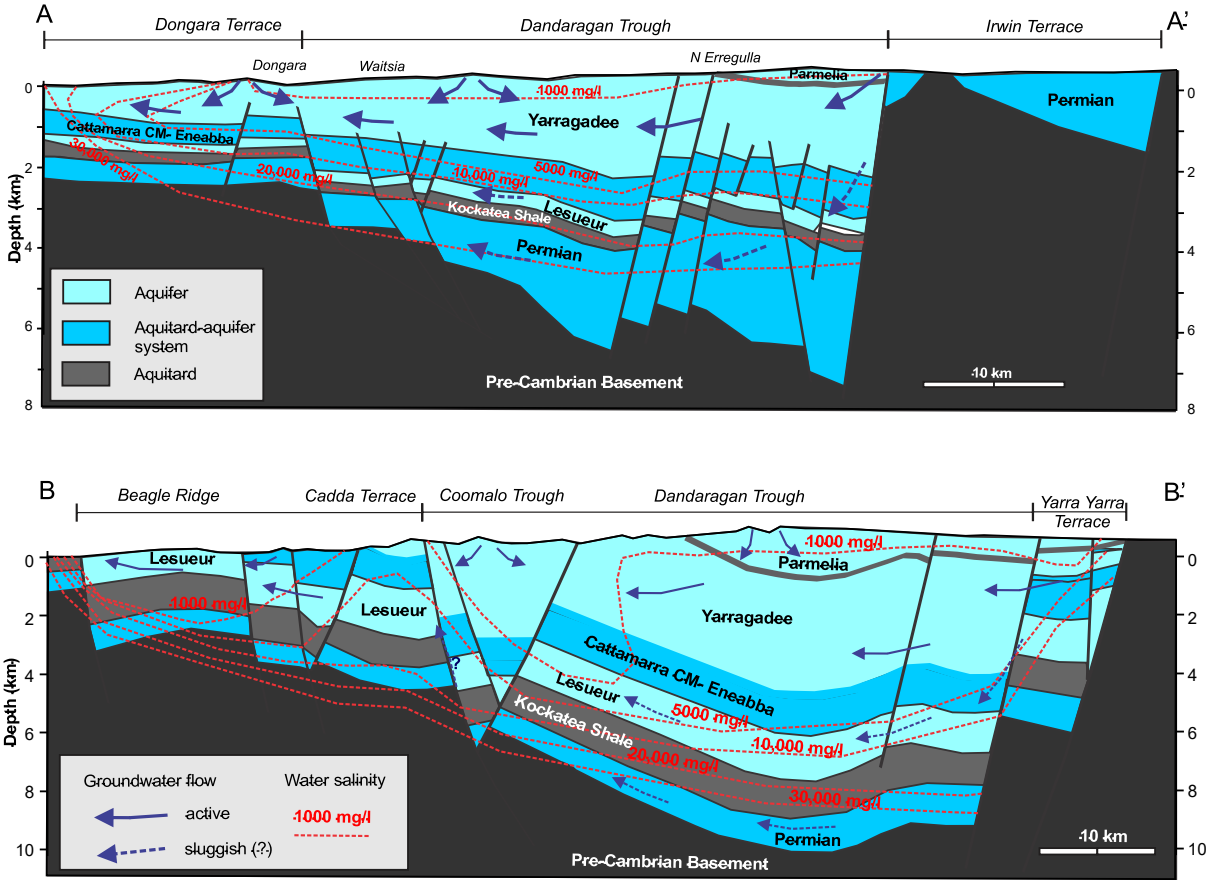


Fig. 5 Conceptual west–east hydrogeological cross-sections showing aquifers, aquitards, groundwater-flow directions and salinity contours across the (A) northern and (B) central parts of the northern Perth Basin. Section locations are shown in Fig. 4. Salinity and flow in approximately the upper 1,000 m are based on Department of Water (2017). Deeper interpretations are more uncertain because they rely on less abundant pressure and salinity observations from petroleum wells

3. Methodology

3.1 Data and suitability mapping

Geospatial data, representing suitability factors (Fig. 6A), were compiled for petroleum, carbon geological storage, underground gas storage, geothermal resources and groundwater within a common northern Perth Basin assessment extent (Langhi and Michael 2025; CSIRO-GISERA 2025). Inputs included mapped stratigraphy, reservoir and seal distribution, faults, wells and bores, petroleum fields and prospects, permits, pipelines, formation depths and

temperatures, and groundwater salinity. Data were obtained from the Data and Software Centre (Department of Energy, Mines, Industry Regulation and Safety 2025), the Western Australian Petroleum and Geothermal Information Management System (WAPIMS 2025), GeoVIEW.WA (Geological Survey of Western Australia 2025), the Department of Water and Environmental Regulation (2025), the Bureau of Meteorology (2025), S&P Global (2024) and Geoscience Australia (2025), together with published geological and storage studies (Mory and Iasky 1996; 3D-GEO 2013; RISC Advisory 2022; Ellis et al. 2024) (Appendix). Existing geological and geophysical interpretations were used; no new geological model or geophysical interpretation was produced. All suitability outputs were resampled to a 500 × 500 m grid.

Suitability was evaluated by resource and stratigraphic interval using multi-criteria evaluation and the Analytic Hierarchy Process (AHP) (Saaty 1980; Belton and Stewart 2002). Each suitability factor was normalised using binary classes, regular intervals, natural breaks or expert-defined classes as appropriate (Fig. 6A; Carr and Zwick 2007). AHP pairwise comparisons assigned relative weights to each factor. For each resource–interval pair, the weighted factor maps were combined on the common grid and classified as low, moderate or high suitability (Fig. 6A).

Petroleum inputs comprised petroleum-field and prospect densities, mapped reservoir and seal extents and thicknesses, fault density, permit coverage and distance to pipelines. CGS inputs comprised reservoir and seal extents and thicknesses, fault density and distance to faults at the regional-seal level, with the adopted 800–3200 m depth window applied to storage reservoirs. Factors, their roles in the assessment, data sources and AHP weights are documented in the Appendix.

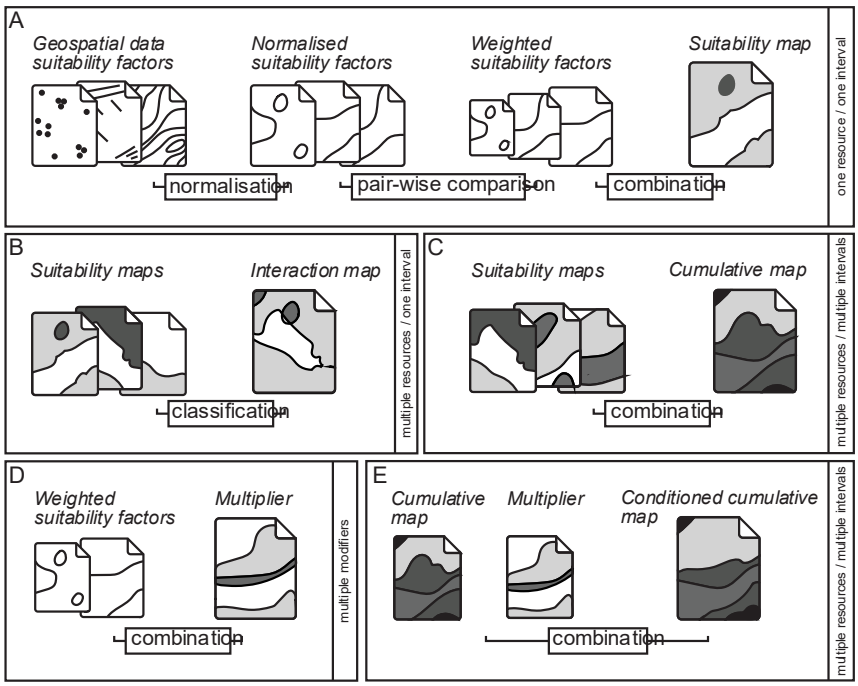


Fig. 6 Schematic methodology workflow. A) Construction of suitability map, for one resource in one interval, from normalisation and weighting of suitability factors. B) Construction of interaction potential map from combination of multiple resource suitability maps in one interval. C) Construction of cumulative map from combination of multiple resource maps in multiple intervals. D) Construction of multiplier player from the combination of normalised and weighted factors. E) Construction of conditioned cumulative map from the cumulative map combined with the multiplier layer

3.2 Resource interaction potential and cumulative map

Within each interval, co-located suitability classes, for coexisting resources, were assigned to low, moderate, high or resource-dominant interaction categories using an empirical permutation and combination scheme (Fig. 6B; Jing et al. 2021; Langhi and Michael 2025). Pair-specific petroleum–CGS interaction potential maps presented later retained six classes: low, dominant CGS, dominant petroleum, moderate, moderate with high CGS, and high (Table 1).

Table 1: Petroleum–CGS interaction potential classification.

		Petroleum suitability		
		Low	**Moderate**	**High**
CGS suitability	**Low**	Low	Low	Dominant petroleum
	Moderate	Low	Moderate	Moderate (Petroleum high)
	High	Dominant CGS	Moderate (CGS high)	High

A cumulative deep-resource map was then calculated by adding the petroleum, CGS, UGS and geothermal suitability values at each grid cell across the intervals in which each resource was assessed (Fig. 6C). The resulting relative ranked screening index represents the spatial concentration of potentially interacting deep resources across the assessed Permian to Lower Jurassic intervals. Groundwater was excluded from this cumulative map.

3.3 Multipliers and conditioned cumulative maps

Multiplier layers (Fig. 6D) were used to condition the cumulative deep-resource index for factors relevant to a particular interaction. Input factors were normalised and, where more than one factor contributed, weighted and combined before being rescaled to a multiplier. The multiplier was applied cell by cell to the cumulative index (Fig. 6E): a value of 1 left the index unchanged, values below 1 reduced it, and values above 1 increased it.

Potential vertical pathways between deep-resource intervals and overlying aquifers were represented by mapped faults and petroleum wells. Kernel density estimation produced three surfaces: critical faults interpreted to fully displace the Cadda Formation or Kockatea Shale, regional faults intersecting these seals, and petroleum wells penetrating reservoirs below the seals. The normalised surfaces were combined with weights of 0.45, 0.10 and 0.45 (critical faults, regional faults, wells, respectively) then rescaled to the 0–2 pathway multiplier. Multiplication with the cumulative deep-resource map produced a pathway-conditioned index. This adjustment represents the concentration of potential pathways; it does not establish fault transmissivity, well integrity or hydraulic connection.

Water-bore density was used as a proxy for relative groundwater use. Bore density was divided into ten quantile classes and reclassified as a multiplier ranging from 0.8 to 1.7 under the proposed scheme. Lower bore-density classes reduced the pathway-conditioned score, a multiplier of 1 left it unchanged, and higher classes increased it. The bore-density multiplier was applied to the pathway-conditioned cumulative index within the suitable aquifer areas to identify where greater deep-resource suitability and mapped pathway concentrations coincide with relatively greater inferred groundwater use. Bore density does not measure abstraction volume, identify the type of water use or demonstrate groundwater stress.

3.5 Appropriate use of the regional screening outputs

The assessment integrates heterogeneous regional datasets on a 500 × 500 m grid using ranked factors and expert-derived weights. Its value lies in comparison across the basin, showing where combinations of mapped conditions are concentrated under a common method. The outputs are not calibrated probabilities and have not been validated as forecasts of resource volume, project feasibility or groundwater impact. The petroleum–CGS overlays can guide formation- and field-scale investigation of coexistence or sequencing, while the groundwater maps can guide examination of potential pathways and receptors. Decisions on development timing, storage feasibility or monitoring design require site-specific geological, engineering and hydrogeological evidence.

4. Results

4.1 Petroleum and CGS suitability

Permian petroleum suitability is highest in the northern Dandaragan Trough and on the Dongara, Beharra Springs and Donkey Creek terraces, where mapped suitability forms clusters around known accumulations (Fig. 7A). Moderate suitability extends more widely through the basin, from the Bookara Shelf and Irwin Terrace southwards towards the Beermullah Trough. High CGS suitability has a broader north–south distribution, including the Wicherina and Allanooka terraces, the Dandaragan Trough, the Dongara, Beharra Springs, Donkey Creek and Cadda terraces, Beagle Ridge and the Beermullah Trough (Fig. 7B). The mapped CGS pattern follows the occurrence of Permian reservoir units (Fig. 3) within the adopted depth window (800–3200 m; Langhi and Michael 2025) and the regional distribution of the Kockatea Shale and the Carynginia Formation.

In the Triassic–Lower Jurassic interval, high petroleum suitability is restricted to clusters in the Coomallo and Beermullah troughs (Fig. 8A), mostly defined by known accumulations in Ocean Hill, Walyering and Gingin fields (Fig. 1). High CGS suitability extends more broadly through the Dandaragan Trough and across the Beharra Springs, Donkey Creek and Cadda terraces, Coomallo Trough and Beermullah Trough (Fig. 8B). Moderate CGS suitability occurs in smaller areas between the Bookara Shelf and Beagle Ridge. The storage pattern follows mapped Lesueur and Cattamarra reservoir units within the depth window and the regional thickness of the Cadda Formation (Fig. 3).

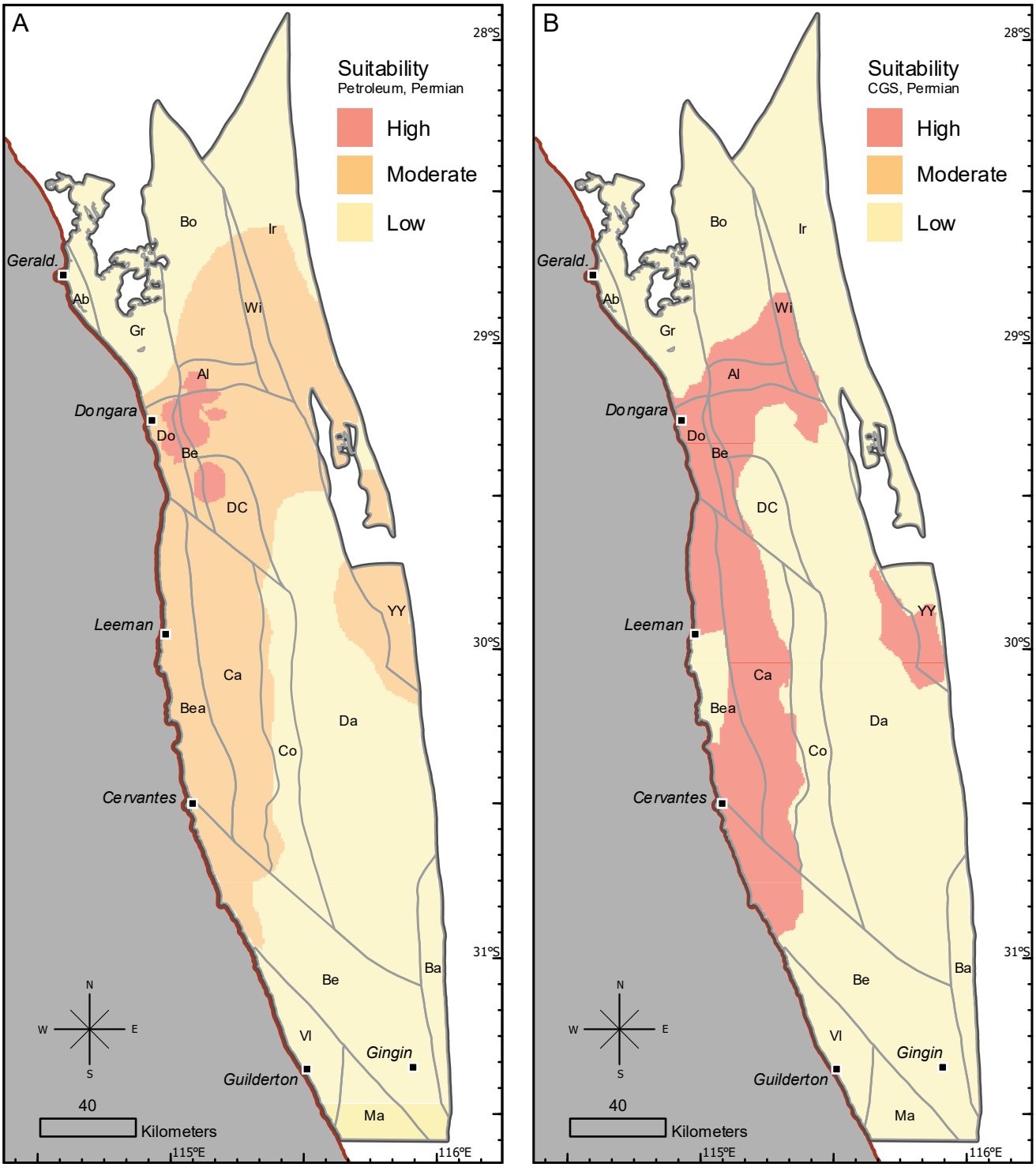


Fig. 7 Resource suitability for the Permian interval. A) Suitability of petroleum resources. B) Suitability of CGS resources

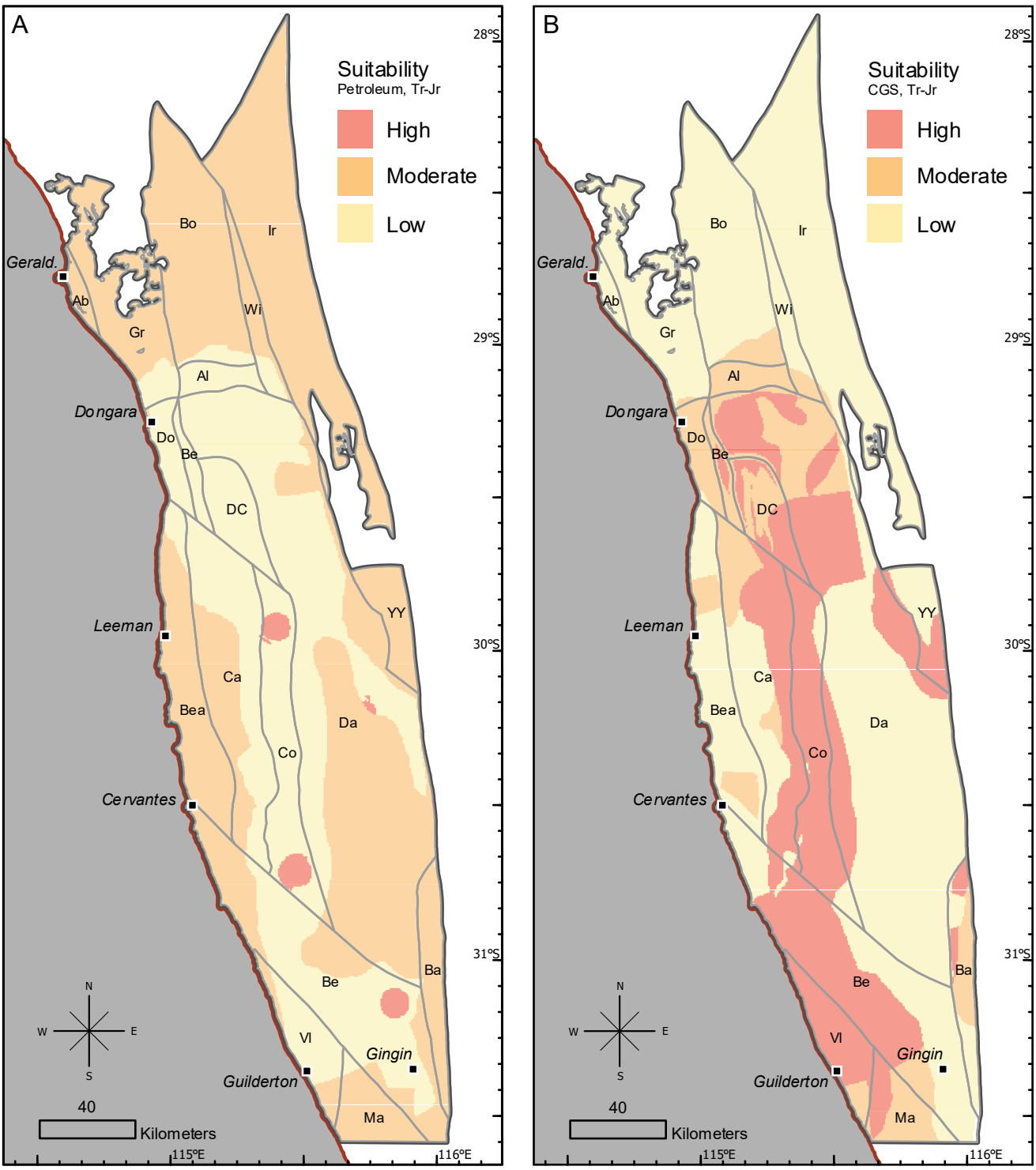


Fig. 8 Resource suitability for the Triassic - Lower Jurassic interval. A) Suitability of petroleum resources. B) Suitability of CGS resources

4.2 Groundwater distribution

Near-surface groundwater with salinity below 1,500 mg/L forms a broad footprint of water of potential potable or irrigation value for the Lesueur–Eneabba, Yarragadee, Leederville–

Parmelia and Superficial aquifer systems (Fig. 4). The footprint extends from the Bookara and Greenough shelves, and Wicherina, Allanooka and Dongara terraces south through the Beharra Springs, Donkey Creek and Cadda terraces and Beagle ridge and across much of the Dandaragan, Coomallo and Beermullah troughs. Areas below 500 mg/L occur within this footprint, while local areas above 1,500 mg/L occur along parts of its western margin, including around the Cadda Terrace and Beagle Ridge (Fig. 4).

The aquifers underlying this footprint vary across the basin. Regional aquifer mapping places Superficial groundwater mainly along the western flank and coast and in the south around the Beermullah Trough; the Leederville–Parmelia aquifers contribute more strongly along the eastern flank; and the Yarragadee aquifer underlies much of the central basin, including parts of the Dandaragan and Coomallo troughs and northern terraces. The Eneabba–Lesueur aquifer has a more restricted distribution along the western flank, particularly around the Cadda Terrace and Beagle Ridge (Fig. 4; Department of Water 2017; Langhi and Michael 2025).

4.3 Vertical resource distribution

The vertical resource schematic places the main petroleum, CGS, UGS and geothermal targets in the Permian succession beneath the Kockatea Shale (Fig. 9). The Triassic–Lower Jurassic succession contains petroleum, CGS and UGS targets as well as shallower groundwater occurrences in the Lesueur–Eneabba–Cattamarra aquifer group. Groundwater dominates the younger Yarragadee, Leederville–Parmelia and superficial aquifers.

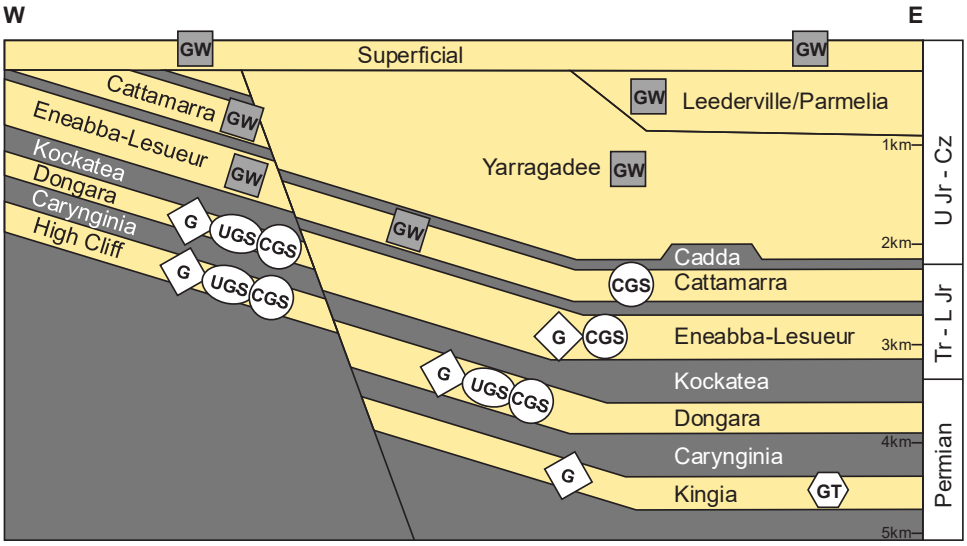


Fig. 9 Resource schematic for the onshore northern Perth Basin. G: gas (petroleum); UGS: underground gas storage; CGS: carbon geological storage; GT: geothermal; GW: groundwater

4.4 Potential pathways and groundwater usage

The pathway inventory comprises regional faults, a subset of critical faults interpreted to displace the Kockatea Shale or Cadda Formation fully, and petroleum wells penetrating Permian reservoirs (Fig. 10A). Critical faults and petroleum wells are most concentrated inland of Dongara across the Dongara, Beharra Springs and Donkey Creek terraces. A second concentration of large faults that displace the regional seals occurs along the Cadda Terrace. Elsewhere, faults and wells are more dispersed. These mapped features indicate where potential vertical pathways are present; the regional dataset does not establish fault transmissivity, individual well integrity or active fluid migration.

Water bores are shown in Fig. 10B but were excluded from the pathway inventory because most do not penetrate the deeper assessed intervals. The few bores extending below the Cadda Formation occur mainly where Triassic–Lower Jurassic petroleum and CGS suitability is moderate to low (Fig. 8). Water bore density was used as proxy for groundwater use.

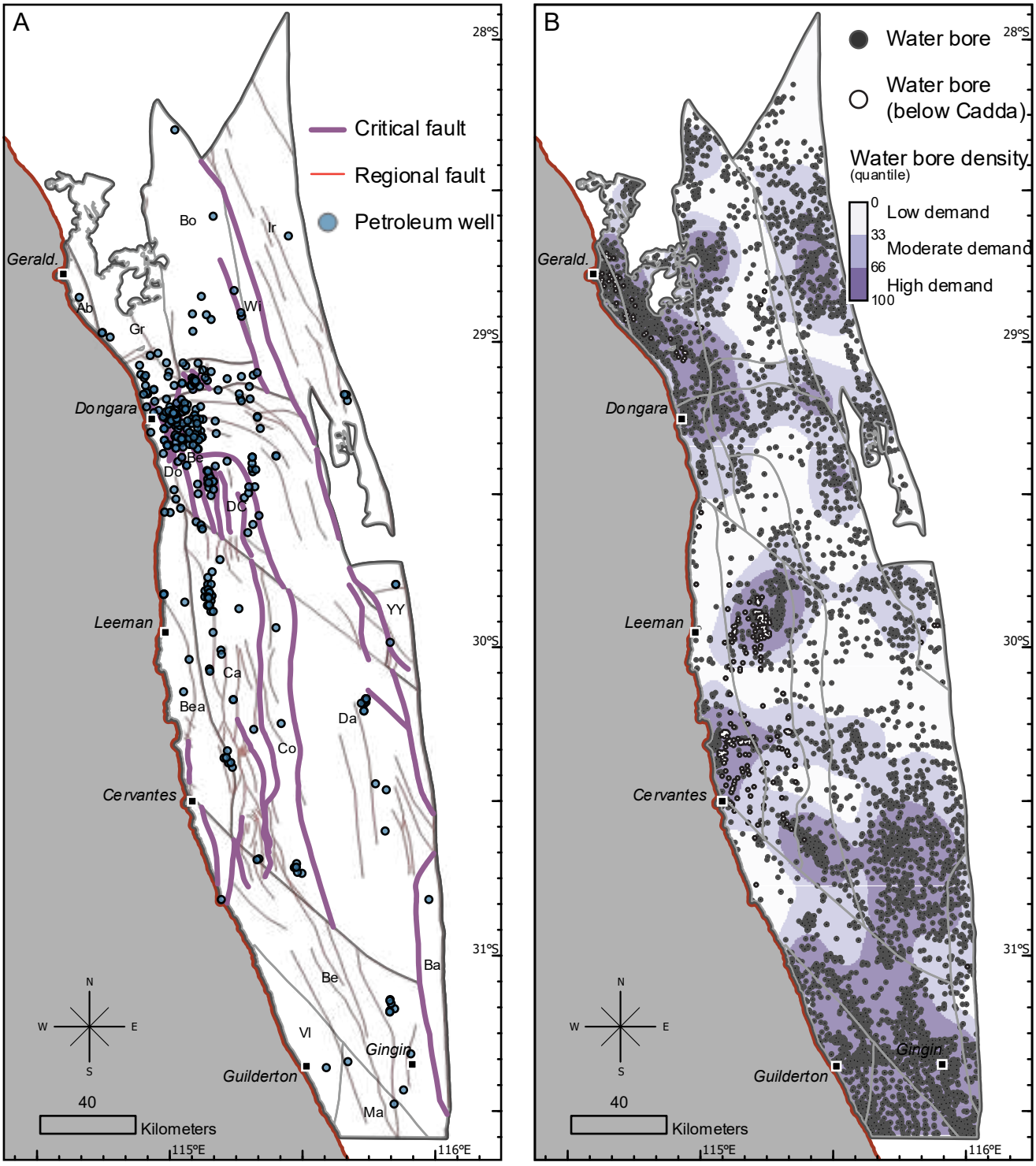


Fig. 10 Faults, petroleum wells and water bores. A) Regional faults (red), critical faults interpreted to fully displace the Kockatea Shale or Cadda Formation (purple), and petroleum wells penetrating Permian reservoirs. These features constitute the potential vertical-pathway inventory. B) Water bores (black), highlighting those that extend below the Cadda Formation (white). Water bore density is used as proxy for groundwater use

5. Discussion

In Western Australia, different resources can be explored for and developed in the same geographic area, each requiring a separate license under the Petroleum and Geothermal Energy Resources Act 1967 (PGER Act 1967). For example, an exploration license for oil or gas issued to one operator can overlap geographically with a geothermal exploration license of another operator as long as there are no detrimental impacts on the other resource. Guidelines for the regulation of overlapping titles (Department of Mines, Petroleum and Exploration 2025) try to ensure that new applicants are aware of any existing subsurface exploration or development activities in the area and that proposed activities do not interfere with those of subsisting titles or rights. Moreover, existing recovery operations and discovered resources have priority over exploration activities and prospective resources. If potential adverse impacts have been identified, the Minister reserves the right to restrict work programs or outright reject an application.

Groundwater resources are managed by the Department of Water and Environmental Regulation (DWER) under the *Rights in Water and Irrigation Act 1914* (RIWI Act 1914).

While the current study does not assess individual locations nor does it propose management solutions, it provides a framework for identifying areas where subsurface resources management may be required.

5.1 Petroleum–CGS interaction potential

Petroleum and carbon geological storage (CGS) suitability overlap because both uses depend on porous reservoir units beneath effective seals. The strongest coincidence occurs in the Permian succession, where petroleum evidence and prospective storage conditions are concentrated in the same reservoir–seal systems (Fig. 11).

However, these mapped relationships occur between resources at different stages of development. Petroleum, principally natural gas, is currently produced and undergoing further development in the basin, whereas CGS remains at the assessment and project-development stages, with no commercial CO_2 storage operation in the study area. Therefore, the interaction potential classes describe potential co-suitability within the regional screening criteria; they do not assign the resources equal development maturity or establish recoverable petroleum, storage capacity, commercial viability or that CGS development will proceed.

In the Permian interval, high interaction potential is concentrated on the Allanooka, Dongara, Beharra Springs and Donkey Creek terraces and in the northwestern Dandaragan Trough (Fig. 11A). These areas combine high petroleum and CGS suitability in the High Cliff, Kingia, Wagina, Dongara and Beekeeper reservoir units beneath the Carynginia Formation and Kockatea Shale. A broader zone of high CGS and moderate petroleum suitability form a moderate potential interaction corridor which extends south from the Wicherina and Allanooka terraces through the western and central basin (Fig. 11A). Local petroleum-dominant and CGS-dominant areas show that favourable conditions for one use do not invariably imply equivalent suitability for the other.

High interaction potential in the Triassic–Lower Jurassic interval is more restricted, with small areas in the Coomallo Trough (Fig. 12B). High CGS and moderate petroleum suitability form a broader north–south belt through parts of the Dandaragan, Coomallo and Beermullah troughs, while moderate suitability for both resources occurs farther north between the Cadda Terrace and Bookara Shelf (Fig. 12B). This distribution reflects the wider mapped occurrence of storage-suitable Lesueur and Cattamarra reservoir units compared with the more localised petroleum-suitability pattern. The Cadda Formation provides the regional sealing context (Fig. 3), although its role and continuity require local assessment.

Same-interval overlap has the clearest potential for direct competition because petroleum production and CO_2 storage may seek access to the same reservoir compartment (Fig. 9). Overlap between adjacent intervals can instead represent separate targets within a stacked succession (Fig. 9). Even where pore space is separate, extraction and injection may interact through pressure propagation or through transmissive faults and wells (Rawling and Sandiford 2013; Field et al. 2018). Distinguishing these cases requires formation-scale reservoir correlation, pressure data, seal and fault analysis, and an understanding of structural compartmentalisation.

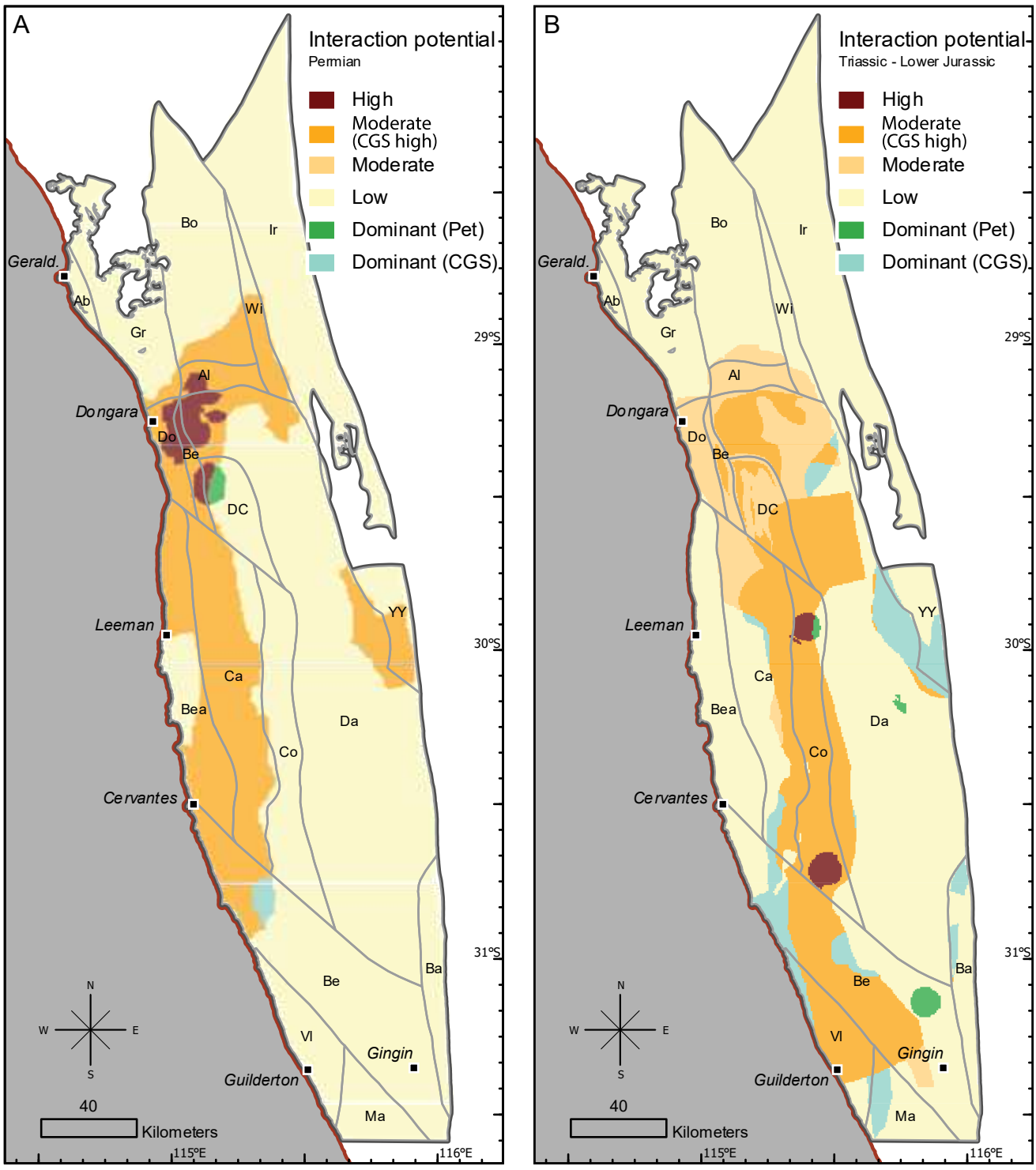


Fig. 11 Petroleum–carbon geological storage (CGS) interaction potential across the northern Perth Basin for the (A) Permian and (B) Triassic–Lower Jurassic intervals. Interaction classes combine the regional suitability rankings for the two resources: High denotes high suitability for both; Moderate (CGS high) denotes moderate petroleum and high CGS suitability; Moderate and Low denote matching suitability levels; and Dominant (Pet) or Dominant (CGS) indicates higher suitability for the named resource

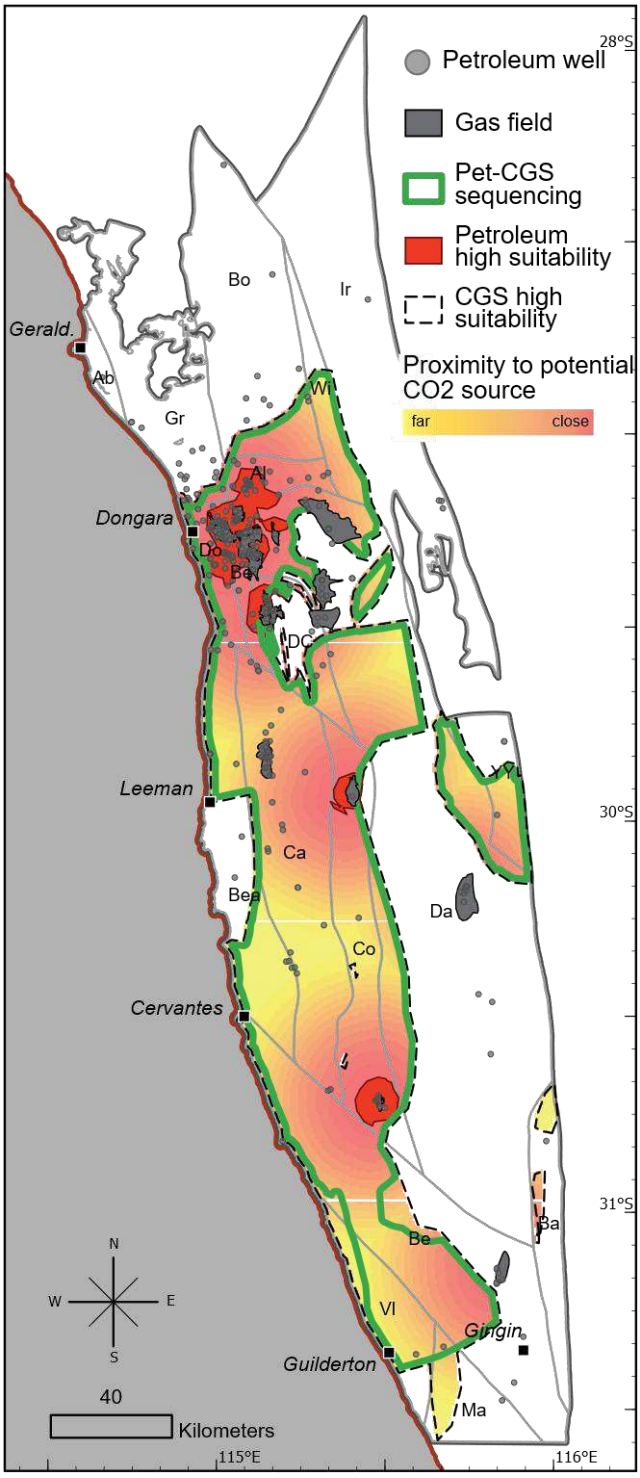


Fig. 12 Regional screening of potential petroleum–CGS sequencing and source–storage proximity in the northern Perth Basin. Green outlines identify areas where high CGS suitability intersects high or moderate petroleum suitability. Red polygons show high-petroleum-suitability areas. Black dashed outlines show merged high-CGS-suitability areas and yellow-to-red shading represents relative distance to the centres of high-petroleum-suitability illustrating where CO_2 sources are more likely to occur.

5.2 Sequencing or co-development opportunities

The combined overlap map, in Fig. 12, identifies zones where high CGS suitability intersects high or moderate petroleum suitability in the same or adjacent intervals (Fig. 12, *green outline*). The most prominent overlap occurs around the established petroleum province inland of Dongara, including the Dongara, Beharra Springs and Donkey Creek terraces and the northern Dandaragan Trough. Additional zones extend south through the Cadda Terrace and Coomallo Trough. These locations warrant investigation of whether gas extraction and CO_2 storage could co-exist or should be developed sequentially.

Sequential production of petroleum and CGS is most plausible where both suitability classes refer to the same reservoir, and petroleum development would otherwise constrain storage access. Prior petroleum production results in pressure depletion which may increase CO_2 storage capacity and provides subsurface data for storage characterisation. However, it can also leave wells and altered pressure conditions with detrimental effects on containment and injection performance. The regional map in Fig. 12 does not resolve field status, remaining reserves, connected pore volume, pressure limits, injectivity or well condition. It therefore identifies sequencing opportunities rather than demonstrates that gas extraction must precede storage. Where overlap is confined to separate stratigraphic intervals or compartments, concurrent development may remain possible if pressure effects and pathway risks can be managed.

The source-proximity heatmap in Fig. 12 provides a second screening perspective by locating merged high-CGS-suitability areas relative to the centres of merged high-petroleum-suitability polygons, using Euclidean distance (Fig. 12, yellow-to-red areas within dashed outlines). It highlights a western basin corridor, particularly the Dongara–Leeman region, where prospective storage areas lie comparatively close to inferred future gas-related activity. Source proximity can help narrow a large geological search area, as demonstrated by screening frameworks that combine storage suitability with mapped emission sources (e.g., Wei et al. 2013). In this assessment, however, petroleum suitability is an indirect source proxy. The map contains neither an inventory of operating facilities nor estimates of capturable CO_2, source continuity, transport cost or storage capacity. Its red–yellow pattern identifies possible source–storage relationships for further testing, not development priority or an optimum pipeline route.

5.3 Groundwater and deeper resource development

The principal groundwater resources generally occur above the assessed petroleum, CGS, UGS and geothermal targets (Fig. 4 and Fig. 9). The Yarragadee, Leederville–Parmelia and Superficial aquifers overlie the main Permian resource intervals, with the Kockatea Shale, Cadda Formation and other aquitards contributing to their stratigraphic separation (Fig. 2, Fig. 3, Fig. 4 and Fig. 9). The Lesueur–Eneabba–Cattamarra aquifer group requires a depth-dependent interpretation because these formations contain groundwater where they are

shallow or subcropping but form petroleum or storage targets where they are more deeply buried (Fig. 9).

Fig. 13A shows the cumulative deep-resource map, calculated by summing petroleum, CGS, UGS and geothermal suitability values across the intervals in which each resource was assessed (Fig. 6C). It identifies where suitable deep-resource targets are concentrated in plan view, even when they occur in different stratigraphic intervals. Higher values are concentrated inland of Dongara, on the Allanooka, Dongara, Beharra Springs and Donkey Creek terraces and in the northwestern Dandaragan Trough. They also extend south along the western basin, particularly across the Cadda Terrace towards Cervantes; lower values continue into the Beermullah Trough.

Fig. 13B shows the cumulative deep-resource index after application of the potential-pathway multiplier derived from mapped faults and petroleum wells, followed by the water-bore-density multiplier used as a proxy for relative groundwater use (Fig. 6E and Fig. 10). The resulting map shows how these factors modify the regional pattern of deep-resource suitability and highlight areas where low to moderate salinity groundwater systems could potentially be under higher pressure due to resource development and or due to water use. Elevated scores become more focused around Dongara, Beharra Springs Donkey Creek terraces and along parts of the Cadda Terrace. Where those scores overlap suitable groundwater, they identify areas for closer assessment of potential vertical connectivity and groundwater demand.

The first area extends across the Dongara, Beharra Springs and Donkey Creek terraces and the northern Dandaragan Trough. High petroleum and CGS suitability in the Permian succession, CGS suitability in the Triassic–Lower Jurassic interval, and smaller contributions from geothermal and UGS suitability produce a high cumulative deep-resource index (Fig. 7, Fig. 8; Langhi and Michael 2025). This area also contains dense concentrations of petroleum wells and regional faults, including critical faults interpreted to displace the regional seals fully (Fig. 10A).

The second area follows the eastern Cadda Terrace. Here, high CGS and moderate petroleum suitability, together with local geothermal suitability, coincide with regional and critical faults and elevated water-bore density (Fig. 7, Fig. 8 and Fig. 10; Langhi and Michael 2025). In both areas, the Yarragadee aquifer is identified as the principal mapped groundwater resource (Fig. 4; Department of Water 2017).

These areas bring together two concerns for groundwater assessment. Faults and petroleum wells may provide pathways through which pressure changes or fluids associated with deeper resource development could reach overlying aquifers. Existing groundwater use could also be compounded by operational water demand from petroleum or future CGS development. The mapped coincidences do not demonstrate hydraulic connection or contamination. Water-bore density indicates current relative groundwater use but does not distinguish agricultural, domestic or resource-industry abstraction, quantify cumulative withdrawal, or represent the future water demand of proposed developments.

Local assessment of the mapped groundwater–deep-resource overlaps would require depth-specific aquifer and reservoir geometry, pressure and water-quality baselines, measured groundwater-abstraction data, fault-seal and transmissivity analysis, and construction and integrity records for individual petroleum wells. These data would test whether the regional pathway indicators correspond to connected systems and whether a pressure or fluid response could reach a groundwater receptor.

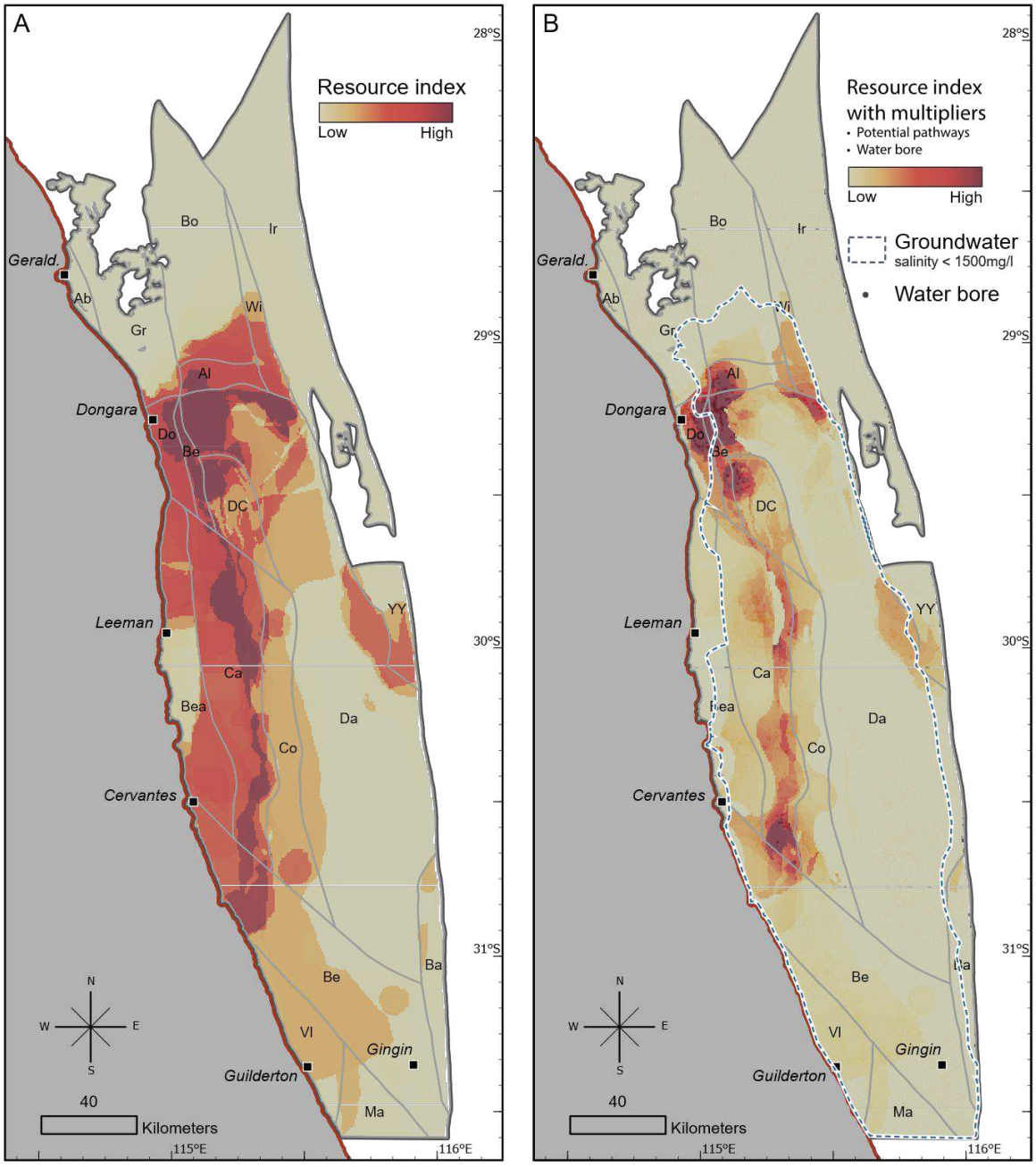


Fig. 13 Resource cumulative and conditioned cumulative maps in the northern Perth Basin. A) Cumulative deep-resource map with index showing the relative distribution of Permian-Jurassic resources. B) Cumulative deep-resource map conditioned by potential-pathway multiplier and water-bore multiplier used as a proxy for relative groundwater use. Hotspots of resource index highlight where shallow groundwater resource is more likely to be under

higher pressure due to resource development and or due to water use. The outline of low to moderate salinity groundwater is shown as the blue dashed line

6. Conclusions

Regional suitability mapping shows that petroleum–CGS co-suitability is strongest in the Permian succession. High interaction potential is concentrated on the Dongara, Beharra Springs and Donkey Creek terraces and in the northwestern Dandaragan Trough. Candidate sequencing areas extend south through the Cadda Terrace and Coomallo Trough, whereas high interaction potential in the Triassic–Lower Jurassic interval is more restricted. CGS suitability is generally more extensive than petroleum suitability, because, while both resources require similar reservoir and seal properties, a petroleum prospect also needs a hydrocarbon source and migration mechanism. The mapped overlaps identify areas where coexistence, sequential use or source–storage relationships warrant formation- and field-scale testing; they do not establish that gas extraction must precede storage. The source-proximity screen identifies a western corridor, particularly between Dongara and Leeman, but petroleum suitability remains an indirect proxy for possible future gas-related CO_2 sources.

Groundwater resources generally occur above the deeper resource intervals, with the Kockatea Shale, Cadda Formation and other aquitards contributing to hydraulic separation. Potential competition for groundwater use and potential interaction with deeper resources development is highest along a central-western corridor inland of Dongara, extending through the Beharra Springs and Donkey Creek terraces and south along the Cadda Terrace and Coomallo Trough. Here, low or moderate salinity aquifers coincide with greater deep-resource potential, denser mapped pathway indicators and greater water-bore density, used as a proxy for groundwater use. Areas outside this corridor have a lower density of potential pathways, but they are not necessarily hydraulically isolated; isolated petroleum wells can occur outside the corridor.

This study provides foundations for future resource management decisions at the basin scale, offering a spatial framework for assessing subsurface resource interactions in the northern Perth Basin. The maps provide a first-order regional comparison, not estimates of resource volume, storage capacity, hydraulic connectivity, leakage probability or groundwater impact. Detailed assessment of the identified areas requires formation-specific reservoir and aquifer geometry, pressure and water-quality baselines, storage capacity and injectivity, fault transmissivity, measured groundwater abstraction, and petroleum-well construction and integrity data.

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Appendix

Suitability factors, roles, data sources and Analytic Hierarchy Process (AHP) weights used to generate the petroleum and CGS suitability maps.

Resource	Assessment interval or aquifer group	Factor	Role in suitability assessment	Source	AHP weight
Petroleum	Lower Permian	Petroleum-field density	Proxy for exploration success	EDIN (S&P Global)	0.21
Petroleum	Lower Permian	Reservoir: Irwin River Coal Measures and Kingia Sandstone (presence)	Presence of reservoir and pore space	WAPIMS (DEMIRS); 3D-GEO (2013)	0.21
Petroleum	Lower Permian	Seal: Carynginia Formation (presence)	Presence of containment	3D-GEO (2013)	0.21
Petroleum	Lower Permian	Fault density	Proxy for structures and closures	WAPIMS (DEMIRS)	0.21
Petroleum	Lower Permian	Petroleum-prospect density	Proxy for prospectivity	EDIN (S&P Global)	0.09
Petroleum	Lower Permian	Petroleum-permit presence	Presence of exploration or production rights	WAPIMS (DEMIRS)	0.05
Petroleum	Lower Permian	Distance to pipeline	Proxy for commercial viability	WAPIMS (DEMIRS)	0.02
Petroleum	Upper Permian	Petroleum-field density	Proxy for prospectivity	EDIN (S&P Global)	0.21
Petroleum	Upper Permian	Reservoir: Wagina Sandstone, Beekeeper Formation and Dongara Sandstone (presence)	Presence of reservoir and pore space	Mory and Iasky (1996)	0.21
Petroleum	Upper Permian	Seal: Kockatea Shale (thickness)	Presence of containment	WAPIMS (DEMIRS)	0.21
Petroleum	Upper Permian	Fault density	Proxy for structures and closures	WAPIMS (DEMIRS)	0.21
Petroleum	Upper Permian	Petroleum-prospect density	Proxy for prospectivity	EDIN (S&P Global)	0.09
Petroleum	Upper Permian	Petroleum-permit presence	Presence of exploration or production rights	WAPIMS (DEMIRS)	0.05
Petroleum	Upper Permian	Distance to pipeline	Proxy for commercial viability	WAPIMS (DEMIRS)	0.02
Petroleum	Triassic–Lower Jurassic	Petroleum-field density	Proxy for exploration success	EDIN (S&P Global)	0.21
Petroleum	Triassic–Lower Jurassic	Reservoir: Cattamarra Coal Measures (presence)	Presence of reservoir and pore space	WAPIMS (DEMIRS); 3D-GEO (2013)	0.21

Resource	Assessment interval or aquifer group	Factor	Role in suitability assessment	Source	AHP weight
Petroleum	Triassic–Lower Jurassic	Seal: Cadda Formation (thickness)	Presence of containment	Mory and Iasky (1996)	0.21
Petroleum	Triassic–Lower Jurassic	Fault density	Proxy for structures and closures	WAPIMS (DEMIRS)	0.21
Petroleum	Triassic–Lower Jurassic	Petroleum-prospect density	Proxy for prospectivity	EDIN (S&P Global)	0.09
Petroleum	Triassic–Lower Jurassic	Petroleum-permit presence	Presence of exploration or production rights	WAPIMS (DEMIRS)	0.05
Petroleum	Triassic–Lower Jurassic	Distance to pipeline	Proxy for commercial viability	WAPIMS (DEMIRS)	0.02
CGS	Lower Permian	Seal: Carynginia Formation (presence)	Presence of containment	3D-GEO (2013)	0.43
CGS	Lower Permian	Reservoir: Irwin River Coal Measures (presence in the screening window 800–3200m)	Presence of reservoir and pore space	WAPIMS (DEMIRS); 3D-GEO (2013)	0.43
CGS	Lower Permian	Fault density	Proxy for compartmentalisation and flow baffling	WAPIMS (DEMIRS)	0.09
CGS	Lower Permian	Distance to fault at Kockatea Shale level	Proxy for potential permeability increase near major regional-seal faults	WAPIMS (DEMIRS)	0.04
CGS	Upper Permian	Seal: Kockatea Shale (thickness)	Effectiveness of containment	WAPIMS (DEMIRS)	0.43
CGS	Upper Permian	Reservoir: Wagina Sandstone, Beekeeper Formation and Dongara Sandstone (presence in the screening window 800–3200m)	Presence of reservoir and pore space	WAPIMS (DEMIRS); 3D-GEO (2013)	0.43
CGS	Upper Permian	Fault density	Proxy for compartmentalisation and flow baffling	WAPIMS (DEMIRS)	0.09
CGS	Upper Permian	Distance to fault at Kockatea Shale level	Proxy for potential permeability increase near major regional-seal faults	WAPIMS (DEMIRS)	0.04
CGS	Triassic–Lower Jurassic	Seal: Cadda Formation (thickness)	Effectiveness of containment	Mory and Iasky (1996)	0.43
CGS	Triassic–Lower Jurassic	Reservoir: Lesueur Sandstone and Cattamarra Coal Measures (presence in the screening window 800–3200m)	Presence of reservoir and pore space	WAPIMS (DEMIRS); 3D-GEO (2013)	0.43
CGS	Triassic–Lower Jurassic	Fault density	Proxy for compartmentalisation and flow baffling	WAPIMS (DEMIRS)	0.09
CGS	Triassic–Lower Jurassic	Distance to fault at Cadda Formation level	Proxy for potential permeability increase near major regional-seal faults	WAPIMS (DEMIRS)	0.04