Hydrogeological Atlas of the Great Artesian Basin

Bibliographic reference


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Hydrogeological Atlas of the Great Artesian Basin
The Great Artesian Basin (GAB) is one of Australia’s most significant hydrogeological entities covering more than 1.7 million square kilometres, underlyng parts of Queensland, New South Wales, South Australia and the Northern Territory. The GAB contains a vast volume of underground water (estimated at 64,900 million megalitres\(^1\)) and is the largest groundwater basin in Australia. Groundwater resources in the GAB are used to support the pastoral, agricultural, and resource sectors as well as supplying water to inland communities. Properly managing these groundwater resources, often for competing interests, requires an understanding of how the groundwater system works at a regional scale.

This atlas presents a compilation of maps documenting some of the key regional geological, hydrogeological and hydrochemical aspects of the GAB. It provides insights into the current understanding of the regional geometry and physical characteristics of the rocks and water contained within this vast groundwater basin and baseline information against which future changes can be assessed.

The atlas draws upon recent work undertaken by Geoscience Australia (GA) that has contributed to a number of projects, such as the CSIRO-led Great Artesian Basin Water Resource Assessment (GABWRA) (http://www.ga.gov.au/scientific-topics/water/great-arteresian-basin) project and GA’s Carbon Capture and Storage project. Since these projects, new information has led to some of the concepts and interpretations being revised or refined for this atlas. Two key pieces of new work that are presented in this atlas are the up to date interpretations of the extent and thickness of the major aquifers and aquitards and the basin-wide perspective of the variation of water chemistry found within the major aquifers.

The atlas and associated datasets combine to form a valuable information resource base for water managers and communities to support informed water management decisions within the GAB. It will assist both water managers and communities to better understand the groundwater resources contained within the GAB and to evaluate the effectiveness of management activities.

The GAB extends across parts of outback Queensland, New South Wales, South Australia and the Northern Territory. Access to groundwater from the GAB has allowed a significant portion of arid Australia to be opened up to grazing. The groundwater resources contained within the GAB are, in many cases, the only reliable domestic and stock watering supply available to the many towns and properties, across the basin. Furthermore, groundwater from the GAB is a vital resource for mining operations, hydrocarbon exploration and is in some instances used for irrigation.

The atlas is structured into three sections. Section one (Maps 1–22) presents important hydrogeological and geological aspects of the GAB, including the regional hydrostratigraphy, the outcrop and subcrop extents of the major aquifers and aquitards, the position of major faults and structural features and groundwater pressure and flow directions in the main artesian aquifer. Section two (Maps 23–32) provides details on the extent and thickness of the major aquifers and aquitards that constitute the GAB. Section 3 (Maps 33–55) shows the spatial variation in groundwater chemistry found within the major aquifers of the GAB.

The datasets and interpretations produced for the atlas draw upon data that varies in scale and accuracy. The maps presented are intended to be used for a broad, regional understanding of the basin and are not designed to be used at a local scale. Where third party data has been used, the authors have attempted to verify its accuracy before incorporating it into the maps and datasets produced for this atlas.

The data for producing this atlas is available for download via the Geoscience Australia website at www.ga.gov.au (a table listing available digital data and download instructions is provided at the back of this document). Each dataset is accompanied by a metadata statement that details the source datasets and methods used to produce the data and interpretations presented in each map.
The Great Artesian Basin—what is it, and how interconnected is it?

Understanding large-scale groundwater systems requires a clear delineation of the system extent and its geological characteristics. Where we have an incomplete knowledge of such systems (as in many parts of Australia) we are forced to use a surrogate that can be readily mapped—one or several sedimentary basins.

Thanks largely to petroleum exploration in conjunction with continued groundwater extraction, we now understand that the GAB, as a hydrogeological entity, is contained predominantly within the Jurassic-Cretaceous Eromanga, Surat and Carpentaria geological basins. Artesian water is also exploited in limited parts of the Galilee and Bowen basins, where groundwater is sourced from Triassic aquifers, and from Cenozoic aquifers in the Karumba Basin of Cape York. Historically the GAB encompassed this diversity of host basins and this definition continues in Queensland for groundwater resource management purposes (with the addition of the Laura Basin, on the northeastern portion of Cape York, and part of the Clarence-Moreton Basin, east of Toowoomba).

Today the GAB is known not to be a discrete isolated system, but to be an entity with a variably-permeable boundary, interconnected with numerous underlying and adjoining sedimentary basins as well as fractured basement. In this current state of a conceptual, but unquantified, knowledge of such variable connectivity, the challenge has been to define mappable limits to the groundwater resource we know as the GAB. Given this complex character, it was proposed by the Great Artesian Basin Water Resource Assessment (GABWRA) that the GAB as a hydrogeological entity, be constrained to lie within the Surat, Eromanga, Carpentaria and Clarence-Moreton basins and their overlying Cenozoic basin cover.

This atlas continues with the GABWRA definition of the GAB but uses a modified hydrogeological boundary in Cape York. The revised boundary excludes the Laura Basin and is now defined by a groundwater divide at the northernmost tip of Cape York (northward of approx. 150 km northeast of Weipa). Elsewhere the hydrogeological boundary follows the geological margins of four component sub-basins—the Eromanga, Carpentaria, Surat and Clarence-Moreton sub-basins—except where the watertable delineates groundwater divides that indicate externally-draining regions. In specific areas, this drainage divide changes geographically upwards through the GAB sequence. One example is the GAB boundary within the Clarence-Moreton Basin where the broadest hydrogeological extent has been adopted as the GAB boundary.

For the purpose of this atlas, the portions of the Bowen and Galilee Basins that were historically included in the GAB, are excluded and instead are addressed through the concept of GAB basement hydroconnectivity (see Map 14). This concept qualitatively defines the hydraulic connectivity with the 27 known sedimentary basins that have contact with the base of the GAB (Figure 1).

The defined northern limit of the offshore Carpentaria Sub-basin corresponds to the international maritime boundary with Papua New Guinea. The GAB has apparent hydrogeological continuity into the southern offshore territory of Papua New Guinea in the Winton-Mackunda Aquifer and Equivalents.
Hydrostratigraphy*

The objective of hydrostratigraphic classification is to group contiguous layers of rocks with similar hydrogeological properties. Generally this classification allows rock layers to be categorised as either aquifers or aquitards (confining units) (see glossary).

The basin-wide categorisation of aquifers and aquitards is an oversimplification of the system. There is much more variability in the character of hydrostratigraphic units so a more illustrative classification differentiates aquifers, partial aquifers, leaky aquitards, tight aquitards and aquicludes. This qualitative categorisation has been adopted for the hydrostratigraphic chart of the GAB and shows that the hydrogeological properties of a unit may vary in different regions and between the geological sub-basins that make up the GAB. This variation in properties may be due to sediment source, accommodation rates during deposition, as well as diagenetic and structural overprints.

The hydrostratigraphic chart of the GAB correlates the numerous lithostratigraphic units applied across the constituent geological basins (see Maps 1 and 4), by grouping them into regional hydrostratigraphic units. Such a classification provides a basin-wide perspective of the hydrogeological architecture of the GAB.

*Modified from work undertaken for the Great Artesian Basin Water Resource Assessment (Ransley TR and Smerdon BD (2012)) using revised hydrostratigraphic classification for Hutton Sandstone and constituent sub-basins.
Some of the key hydrogeological aspects of the Great Artesian Basin
The Great Artesian Basin comprises the Surat, Eromanga, Carpentaria and part of the Clarence-Moreton geological basins and their overlying Cenozoic cover. Covering around 20% of the continent, the surface of the GAB is characterised by a variety of landforms, including low-lying interior plains, the tablelands and uplands of the Great Dividing Range and dune fields of the Simpson, Tirari and Strzelecki deserts. North of latitude 21°S, surface drainage is toward the coast across terrain that slopes gently toward the Gulf of Carpentaria. In contrast, south of latitude 21°S, ephemeral rivers draining the western slopes of the Great Dividing Range generally flow to the southwest as the ground surface slopes toward Lake Eyre. Ground elevations range from greater than 1500 m above sea level along the eastern boundary, to 15 m below sea level at Lake Eyre.
Map 2
Hydrogeology

The GAB hydrogeological boundary follows the geological margins of its four component sub-basins—the Eromanga, Carpentaria, Surat and Clarence-Moreton sub-basins—except where the watertable indicates groundwater divides within these regions that delineate externally-draining areas. In some regions, this drainage divide changes geographically through the GAB sequence. In such areas as the GAB boundary within the Clarence-Moreton Basin, the broadest hydrogeological extent has been adopted as the GAB boundary.

This map documents a basin-wide hydrostratigraphy of the GAB comprising five major aquifers, four intervening aquitards, and the cover of these units by Paleogene-Neogene rocks and sediments. The extensive Quaternary sediment cover has been removed to show the boundaries of the outcrop and near surface sub-crop extents of the hydrostratigraphic units of the GAB. Quaternary sediment cover is considered permeable and not an impediment to the recharge of underlying aquifers in most areas. However, the underlying Paleogene-Neogene rocks and sediments have highly variable hydrogeological character that can influence deeper connectivity. In this map individual aquifers and aquitards within the Paleogene-Neogene sequence have not been differentiated. Note that this map does not depict the full subsurface extent of these hydrostratigraphic units.

The major aquifers and aquitards of the GAB are mapped as continuous hydrostratigraphic units, which span across and between the sub-basins of the GAB. At a broad-scale it is possible to map the boundaries between the major aquifer and aquitard systems in most locations. This provides a basin-wide perspective of the regional architecture and character of this complex hydrogeological system. However, such generalisations are scale dependant and, at a local scale, the boundaries between the major aquifer and aquitards may be difficult to differentiate. Hence, this basin-wide hydrostratigraphic classification is a necessary simplification of the complex hydrogeology of the GAB.

Ten hydrogeological units are mapped within the Jurassic-Cretaceous sedimentary sub-basins and Cenozoic cover. These are an alternation of aquifers and aquitards, named after their predominant host stratigraphic units and listed in the order of their stacking, from the top down:

- Paleogene-Neogene Cover
- Winton-Mackunda Aquifer and Equivalents
- Rolling Downs Aquitard
- Cadna-owie – Hooray Aquifer and Equivalents
- Westbourne Aquitard
- Adori-Springbok Aquifer
- Birkhead-Walloon Aquitard
- Hutton Aquifer and Equivalents
- Evergreen-Poolowanna Aquitard and Equivalents
- Precipice Aquifer and Equivalents.

The outcrop, subsurface extent and thickness variations of each hydrostratigraphic unit are documented in Maps 23–32. Thickness is based solely on lithostratigraphic intercepts in drillhole data from petroleum exploration wells, water bores, and stratigraphic wells. These units are largely composites of contiguous lithostratigraphic units across the entire GAB as outlined in the hydrostratigraphic chart of the GAB (Figure 2).
Hydrostratigraphic units outcrop/subcrop extents

- Paleogene-Neogene volcanics
- Paleogene-Neogene outcrop
- Paleogene-Neogene subcrop
- Winton-Mackunda Aquifer and Equivalents
- Rolling Downs Aquitard
- Cadna-owie – Hooray Aquifer and Equivalents
- Westbourne Aquitard
- Adori-Springbok Aquifer
- Birkhead-Walloon Aquitard
- Hutton Aquifer and Equivalents
- Evergreen-Poolowanna Aquitard and Equivalents
- Precipice Aquifer and Equivalents

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Great Artesian Basin
Bathymetry contour (depth in metres)
Tropic of Capricorn
City/town
The most widely utilised artesian aquifer within the GAB is the Cadna-owie – Hooray Aquifer and Equivalents. Lying in the early Cretaceous–Late Jurassic sequence, the aquifer is exposed at ground surface along much of the eastern and western margins of the GAB. The aquifer dips toward the central deeper parts of the basin where it is covered by up to 1900 m of overburden.

Around 3100 flowing artesian bores intersect this aquifer with the majority of them situated in the shallower areas of the basin where the top of the aquifer is closer to the ground surface. Water bore depths (artesian and non-artesian) range from around 60 m in the areas where the aquifer is exposed to some cases >1000 m. The majority of bores have groundwater temperatures of between 40–60°C, a few approach 100°C in the deeper parts of the basin.

The map opposite shows the depth below ground level to the top of the Cadna-owie – Hooray Aquifer. This map was derived by subtracting a seismically mapped elevation surface of the base of the Wallumbilla Formation (equivalent to the top of the Cadna-owie – Hooray and Equivalents Aquifer) from a Digital Elevation Model representing ground surface elevation.
3

Depth to the top of the Cadna-owie – Hooray Aquifer and Equivalents

- Great Artesian Basin
- Aquifer extent
- Outcrop/subcrop
- Area of Great Artesian Basin where the hydrogeological unit does not exist

Depth to top of aquifer (metres)

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Aquifer extent

Isopach contour (metres)
Bathymetry contour (depth in metres)
Tropic of Capricorn

Data location
City/town

City/town

13-0001-4
Morphology of the base of the GAB and structural elements

There is a similar history of sediment accumulation within the component sub-basins of the GAB, closely linked to the tectonic evolution of the Eastern Plate boundary of Australia throughout the Mesozoic Era. However, each sub-basin differs slightly in timing of subsidence and deposition as a result of structural fabrics largely inherited from older underlying basins.

Eromanga Basin

The Eromanga Basin is a relatively thin (compared to underlying basins) but extensive intracratonic blanket of sediment of Jurassic to Late Cretaceous age. Its thickness and structure largely echo the structure and depocentres of underlying basins. It has a very thick sequence within a deep and heavily structured Central Eromanga Depocentre (see Maps 6 and 7). This is flanked to the northwest and southeast by a mosaic of shallower shelves of basement comprising crystalline, metamorphic or older Paleozoic rocks, which are covered by a much thinner sequence. The northeastern end of the depocentre shallows over the faulted Canaway Ridge (see Map 7).

The Central Eromanga Depocentre overlies the Cooper, Warrabin Trough and Adavale basins (Figure 1). This depocentre has the most extreme structuring within the Eromanga Basin, with a folding and superimposed faulting fabric aligned predominantly northwest to southeast. The southwestern limit of this feature is defined by the Birdsville Track Ridge.

The Birdsville Track Ridge is a broad saddle that extends in a northeast to south-southwest direction, separating the Central Eromanga Depocentre from the Poolowanna Trough to the west. The Birdsville Track Ridge, defined by surface exposures of the Winton Formation and older units, comprises a complex of related domes and ridges over Paleozoic and Proterozoic basement.

A broad complex high separates the Eromanga and Surat sub-basins (see Map 1). It comprises the antilinal Nebine Ridge that plunges southwestward from the groundwater recharge zone (see Map 9), with an en echelon juxtaposition of the Eulo Ridge to the west-southwest.

To the north and northwest of the Lovelle Depression (see Map 5), the sequence thins and shallows steadily onto the Euroka Arch and Diamantina Shelf where there is a pronounced north-northwest–south-southeast structural fabric imposed by underlying basement features of the Mount Isa Block. These basement trends extend eastward across the Euroka Arch–Canobie Depression over the Millungera Basin, the St Elmo Structural high, and the Millungra Depression further to the east. The Diamantina Shelf extends southwestward around the margin of the Mount Isa Block, is cross-cut by the Monedah Structure and Burke River Structural Belt, onto the broader Boulia Shelf.

Two very large circular explosion features were emplaced at about 125 Ma during deposition of the Cadna-owie Formation. These are the Toonoonooka (55-60 km diameter) and Talunidilly (84 km diameter) features (see Map 7). Cratering and canyon development from these events redistributed thickness of the Cadna-owie – Hooray Aquifer locally and the catastrophic event also fractured the underlying GAB sequence and basement. The current consensus is that these craters formed from bolide impacts. Previously, deep volcanic explosion events were also proposed as a possible cause.

Surat Basin

The dominant structural feature of the Surat Basin is the meridional Mimosa Syncline (Queensland)—Boomi Trough (New South Wales) that directly overlies the Taroom Trough of the Bowen Basin, and extends southwestward into the eastern Coonamble Embayment (see Map 7). West of this depocentre are the Roma Shelf, St George-Bollon Slope, and the Eulo and Nebine ridges that demarcate the separation with the Eromanga Basin.

The Surat Basin is bounded to the east by the Auburn Arch (to the northeast) and the New England Foldbelt (Texas High) to the southeast. Between these regions of basement, the Surat Basin is connected eastwards with the Clarence-Moreton Basin across the Kumbarilla Ridge. In the south, the Surat Basin is bounded by the Central Fold Belt, and in the north it has been eroded as a result of Cenozoic uplift.

Structure in the Surat Basin becomes more subdued upwards through the sequence than is evident in the central Eromanga Basin. At the top surface of the Evergreen Formation, the basement topography is still evident but is significantly subdued. The axis of the Mimosa Syncline follows that of the Taroom Trough but the syncline is much broader and shallower. Since the inception of subsidence of the Surat Basin, the depocentre of the Mimosa Syncline has migrated southward to near Meandarra and basement lies at about −1800 m AHD, with displacement on faults seldom exceeding 200 m. Higher in the sequence, at the base of Wallumbilla Formation, the structure is very subdued compared to the same horizon in the central Eromanga Basin.

The eastern flank of the Mimosa Syncline is disrupted by the meridional Burunga-Leichhardt Fault Zone and the Moonee–Goondiwindi Fault Zone. Both thrusts are probably continuous with the Hunter-Mooki Thrust system to the south and create the general appearance of a half-graben above the underlying Taroom Trough.

Two major fault systems delimit the Roma Shelf. The north-northwest trending Hutton-Wallumbilla Fault has a westerly downdrop of up to 800 m in the north. The Merivale Fault and Abroath Fault, which form the western limit of the shelf, may be separate structures but are on the same underlying structure. The maximum westerly downdrop exceeds 1000 m on the northerly-trending Merivale Fault which is a probable thrust. The Abroath Fault has a downdrop of about 1200 m.

Carpentaria Basin

The Jurassic-Cretaceous Carpentaria Basin is a broad shallow intracratonic sag basin that underlies most of the Gulf and extends onshore onto Cape York and southwards to the Euroka Arch to connect with the Eromanga Basin (see Map 5).

* Modified from work undertaken for the Great Artesian Basin Water Resource Assessment (Ransley TR and Smerdon BD (2012)) using revised GAB boundary.
Morphology of the base of the GAB and structural elements

Key:
- Great Artesian Basin
- Explosion structure - probable bolide impact crater
- Fault
- Bathymetry contour (depth in metres)
- Tropic of Capricorn
- City/town

Elevation of the base Jurassic–Cretaceous sequence (mAHD)

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Legend:
- 500
- 0
- -750
- -2000

0 250 500 km
0 100 200 300 km

Bathymetry contour (depth in metres)

10°S
20°S
30°S
25°S
30°S
40°S

- Lake Frome Embayment
- Toowoomba
- Brisbane
- Sydney
- Alice Springs
- Port Augusta
- Brisbane
- Sydney
- Alice Springs
- Port Augusta

150°E
145°E
140°E
135°E
130°E

10°S
20°S
30°S
25°S
30°S
40°S
Map 5
Detailed morphology of the base of the northern GAB and structural elements
Map 6
Detailed morphology of the base of the western GAB and structural elements
Detailed morphology of the base of the western GAB and structural elements

- Great Artesian Basin
- Explosion structure - probable bolide impact crater
- Fault
- Bathymetry contour (depth in metres)
- Tropic of Capricorn
- City/town

* Denotes underlying Cooper Basin feature active during deposition of the GAB sequence.

Elevation of the base Jurassic–Cretaceous sequence (mAHD)

Scale: 1:5 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Location Map
Map 7
Detailed morphology of the base of the eastern GAB and structural elements
Detailed morphology of the base of the eastern GAB and structural elements

Elevation of the base Jurassic–Cretaceous sequence (mAHHD)
Map 8
Depth to hydrogeological basement and sedimentary basins underlying the GAB*

The deepest regions of the GAB coincide with the depocentres of its three main constituent sub-basins, with maximum depths of approximately 1500 m, 2300 m and 1900 m in the Carpentaria, Eromanga and Surat basins respectively. The depth to hydrogeological basement diminishes approaching the margins of the GAB as well as across basement highs such as the Eulo-Nebine Ridge and Euroka Arch (see Map 4), where the Eromanga Sub-basin connects to the Surat and Carpentaria sub-basins.

A total of 27 sedimentary basins are known to directly underlie the GAB. The Jurassic-Cretaceous sequence in the central Eromanga, Surat and Clarence-Moreton basins thickens over underlying depocentres of several smaller, mainly nonmarine Permian-Triassic basins including the Bowen, Cooper, Galilee, Pedirka**, Simpson and Arckaringa** basins. Underlying crystalline basement provinces are extensive, and older sedimentary basins range in age from Precambrian to Carboniferous. These include the Drummond, Millungera, Arrowie, Barka, Warburton, Adavale, and Georgina basins.

Oil fields in the Cooper region of the central Eromanga sequence are largely the result of hydrocarbon migration up from the underlying Cooper Basin, although a smaller proportion of hydrocarbons were generated within the GAB. This upward hydrocarbon migration signals the possibility of migrating groundwater as well, but the hydrochemical evidence remains equivocal whether such migration continues today, at least at a detectable rate.

The Bowen and Gunnedah sedimentary basins directly underlie the Surat Basin. The Surat Basin has many structural features inherited from basement, including those that underlie the Bowen Basin. Below the Mimosa Syncline of the Surat Basin, the Bowen Basin sequence is contained predominantly within the meridional Taroom Trough and extends southward to the Gunnedah Basin. In the north of the Taroom Trough, the Bowen Basin sequence spreads northwestward over the Nebine Ridge to the Galilee Basin.

A series of stacked sedimentary basins overlie and underlie the Carpentaria Sub-basin. Underlying these Jurassic-Cenozoic basins are several relatively small pre-Jurassic basins, some are sag basins and others are fault-defined. These include the Olive River and Pascoe River Basins in the north, the offshore Bamaga Basin**, offshore Arafura Basin (north of the northwestern limit of the GAB), and the Gamboola Basin** at the southeastern end of the Staaten Sub-basin (see Map 5). All basins are separated by unconformities** and the stacked relationship of the Carpentaria Basin and its infrabasins is analogous to the Eromanga Basin and the basins that underlie it**.

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* Modified from work undertaken for the Great Artesian Basin Water Resource Assessment (Ransley TR and Smerdon BD (2012)) using updated GAB, Pedirka and Arckaringa basin boundaries.

** Updated Pedirka and Arckaringa basin boundaries supplied by D. Wohling (South Australian Department of Environment, Water and Natural Resources).
Sedimentary basins underlying Great Artesian Basin

- Basin boundary in contact with base of Great Artesian Basin
- Basin boundary not in contact with base of Great Artesian Basin

Elevation of the base Jurassic–Cretaceous sequence (mAHND)

- Great Artesian Basin
- Bathymetry contour (depth in metres)
- Tropic of Capricorn
- City/town

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Depth to hydrogeological basement and sedimentary basins underlying the GAB
Groundwater recharge zones are those areas where water can enter the various aquifers that make up the GAB. The spatial extents of the recharge zones shown are defined by a combination of the mapped outcrop extents of the various aquifer units, and interpolation between outcrops in cases where the units are covered by a thin veneer of Cenozoic deposits.

Recharge rates are a function of the aquifier capacity to store and transmit water, the amount of water available from rainfall and river leakage, and the nature of any overlying deposits. Estimation of the rates at which GAB aquifers are being recharged is essential for calculating the overall water budget for the Basin.

The mechanisms by which recharge occurs are diffuse percolation of rainfall and to a lesser extent, river bed leakage. The rates at which aquifer units are recharged has been estimated at close to zero in parts of the western recharge zones, to as much as 45 mm/year along parts of the northeastern recharge zones, south of Croydon.

In the northern GAB the volume of groundwater recharge to aquifers in the Carpentaria Sub-basin (area shown in green) has been estimated at 432 GL/year.

To the south, recharge to the Eromanga Basin aquifers has been estimated at 142 GL/year for the Jurassic–Cretaceous aquifers (shown in green) and 164 GL/year to the Winton and Mackunda formations (shown in blue).

Within the Surat Basin recharge to the Jurassic–Cretaceous aquifers (shown in green) has been estimated at 237 GL/year.
Groundwater recharge zones

- Great Artesian Basin
- Regionally variable local recharge with possible local upward leakage from Jurassic aquifers in some places
- Groundwater recharge area
- Area of negligible recharge to Great Artesian Basin aquifers

- Bathymetry contour (depth in metres)
- Tropic of Capricorn
- City/town

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Regionally variable local recharge with possible local upward leakage from Jurassic aquifers in some places

Groundwater recharge area

Area of negligible recharge to Great Artesian Basin aquifers
Regional groundwater flow directions within the Cadna-owie – Hooray Aquifer and Equivalents are inferred from a potentiometric surface estimated using measurements of groundwater head.

The potentiometric surface is inferred from waterbore head measurements obtained between 2000 and 2010 that were corrected for temperature and density. Regional flow is assumed to occur down hydraulic gradient. In general, groundwater flow is basinward away from recharge areas.

The map opposite shows a composite potentiometric surface derived from the South Australia and Northern Territory potentiometric surface—present day variable temperature assumption in Love et. al, (eds) 2013 and the New South Wales and Queensland portion of the GABWRA (2012) potentiometric surface.

On the basis of inferred regional groundwater flow, three major flow systems can be delineated—a northern, eastern and western flow system. The northern flow system (north of 20°S) is characterised by groundwater flow towards the offshore depocentre of the Carpentaria Sub-basin. To the south, the extensive eastern system is associated with recharge areas located along the eastern boundary of the aquifer in Queensland and New South Wales and is characterised by easterly-directed groundwater flow emanating from the recharge areas associated with the western boundary of the aquifer in South Australia and the Northern Territory. The Eastern and Western flow systems converge at approximately 140°E where the majority of groundwater flow is diverted to the south. The zone of groundwater flow convergence is coincident with a thinning of the aquifer that occurs along the Birdsville Track Ridge (see Maps 4 and 6).

The effects of groundwater extraction can produce reductions in artesian pressure and in some cases these reductions are manifested as isolated depressions in the potentiometric surface. In some cases these depressions can be attributed to extraction from densely-clustered water bores or oil fields.

In the Carpentaria Sub-basin, there is insufficient data to generate full coverage of this surface. Cenozoic aquifers are in direct contact with GAB aquifers in this region, may be artesian, and are generally utilised in preference to deeper aquifers.

Map 10

Potentiometric surface for the Cadna-owie – Hooray Aquifer and Equivalents, with inferred flow lines
Inferred groundwater flow
- High confidence
- Medium confidence
- Low confidence

Groundwater head (mAHD)
- Potentiometric surface contour (metres)
- Bathymetry contour (depth in metres)
- Tropic of Capricorn
- City/town

Great Artesian Basin
Aquifer extent
Outcrop/subcrop
No data
Area of Great Artesian Basin where the hydrogeological unit does not exist
Regional watertable

Watertable contours were constructed from shallow groundwater level data in the state databases of New South Wales and Queensland. South Australia and the Northern Territory data points were taken from a watertable surface developed at Flinders University. Water levels in South Australia were corrected for density effects due to salinity. Elsewhere, density corrections for the watertable aquifer were not deemed to be an issue.

Similar to the confined aquifers, regional groundwater flow in the watertable aquifer is from the highest potentials in the intake beds on the western slopes of the Great Dividing Range (GDR) in New South Wales and Queensland. This intake zone extends northward along the western slopes of the GDR to the tip of Cape York where the pressure levels are lower than those in the southern recharge area. The watertable lies within the Jurassic formations in the intake beds but basinward it passes into the Middle Cretaceous formations (Winton (Kw) and Mackunda (Klm) Formations in the Eromanga Sub-basin, Griman Creek Formation in the Surat Sub-basin). These aquifers comprise the most areally extensive host for the watertable in the GAB. In the Lake Eyre and Karumba Basins, the watertable passes into Cenozoic sediments.

Regional discharge zones for the watertable are Lake Eyre and an eastward arcuate band of salt lakes extending from Lake Frome to Lake Gregory. Both of these regional discharge zones lie in South Australia but there is another intra-basin discharge area at the Bulloo Overflow/Caryapundy Swamp on the NSW/Queensland border (see Map 13 h). Regional discharge from the shallow aquifer in the Carpentaria/Karumba Basins is into the Gulf of Carpentaria. In the southeast, regional discharge from the shallow aquifer in the Coonamble Embayment watertable is into the Darling River alluvium (see Map 7).

Although there is a major difference in resolution between the relatively high resolution watertable surface (Map 11) and the less well constrained surface of the Cadna-owie – Hooray Aquifer (Map 10), there are subtle but significant features evident in the watertable map which distinguish it from the potentiometric surface map of the Cadna-owie – Hooray (JKh) confined aquifer:

- The watertable contours are not smooth like the JKh contours, but form local recharge mounds extending far into the basin. Some of these recharge mounds are coincident with structures like the Innamincka Dome and all of them occur in areas mapped as Winton or Mackunda formation outcrop, or in areas where the Lower Cretaceous rocks are shallowly buried by Cenozoic sediments. (In the Eromanga Sub-basin, the total intra-basin recharge into the Winton-Mackunda Aquifer is estimated to be 164 GL/year which is 21 GL/year higher than recharge to the Hooray and Hutton Sandstones on the western slopes of the GDR. Intra-basin recharge has never before been included in GAB water budgets).
- The two largest rivers in the Eromanga Basin, the Diamantina River and the Cooper Creek are prominent watertable drains. By way of contrast, there is no apparent relationship between these major streams and the potentiometry of Cadna-owie – Hooray Aquifer; and
- The watertable mounds along the Eulo Ridge (see Map 13 i) and their extension southwestwards toward the boundary of the GAB in NSW come close to forming a groundwater divide between the Surat and Eromanga sub-basins, but the line of mounds is breached in some places permitting impeded lateral throughflow. For the watertable, the Eulo Ridge acts as an impermeable subsurface boundary but there is no apparent influence of this structure or its hydrogeological role on the potentiometry of the Cadna-owie – Hooray Aquifer.

Note. The facing map includes outlines of areas of interest shown on Maps 12 and 13.
a. Burketown: Relative to the coastline in the southern Gulf of Carpentaria, the zero watertable contour, lies up to 30 km inland from the coast, and is not coincident with the coast as might be expected. In fact the zero contour follows the landward boundary of a Quaternary unit designated ‘Qrp’ on the Burketown and Normanton 1:250 000 scale geology map sheets. Simpson describes ‘Qrp’ as a black organic saline clay which occupies tidal flats and is inundated during the wet season and partially dries to form a thin salt crust in the dry season. According to tide gauging by the National Tidal Centre, the range from highest to lowest astronomical tide at Mornington Island is 3.793 m and at Karumba it is 4.569 m. The large high tides explain the persistence of tidal mud flats for up to 30 km inland.

b. Georgina Basin: Along the northwestern margin of the GAB, the basin sequence comprises outcropping porous Longsight Sandstone overlain basinward by less permeable and less porous rocks of the Wilgunya Formation (equivalent to the Wallumbilla Formation further east). The GAB sequence wedges out against Cambro-Ordovician rocks, dominantly carbonate, of the Georgina Basin. Many basement inliers protrude through the GAB sequence. The watertable contours can be interpreted as a system which is locally recharged where the Longsight Sandstone outcrops and/or is shallowly covered by sandy Cenozoic alluvium, or a system where the Georgina Basin discharges into the GAB sequence, or a system exhibiting a combination of both of these processes.

c. Finke River: Four, possibly hydrogeologically linked features near the northwestern boundary of the western Eromanga Basin are the Finke River, the Dalhousie Anticline and an un-named fault parallel to the Anticline and Dalhousie Springs. These springs are the highest discharging spring complex in the GAB. A pronounced groundwater mound is developed in the Finke River alluvium and this mound persists all the way downstream to the fault. It appears that the bed underflow groundwater is then transmitted southward along this fault before being discharged at Dalhousie Springs. The Finke River leakage is a significant contributor to the groundwater discharging at Dalhousie Springs. In addition, an unknown proportion of deeper circulation groundwater contributes to this spring discharge.

d. Tallaringa Palaeovalley: Shown is the influence exerted on the watertable contours by the Tallaringa Palaeovalley, a prominent feature in the western Eromanga Sub-basin, filled with about 70 m of carbonaceous sand of the Pidinga Formation overlain by about 30 m of silt and sand of the Garford Formation. The Tallaringa Palaeovalley is incised into sediments of the Bulldog Shale and Cadna-owie Formation which are host to the regional watertable near the western GAB boundary. This is one of many palaeovalleys in the western Eromanga Sub-basin, and all of these palaeovalleys are prominent watertable drains. The majority of the palaeovalleys drain the watertable internally towards Lake Eyre but the Tallaringa Palaeovalley drains groundwater out of the GAB into the Officer Basin. The Kingoonya Palaeovalley to the south drains groundwater from the GAB watertable into the Eucla Basin.

e. Marla/Coober Pedy Watertable mound: A prominent watertable mound extends in a southeasterly direction from near Mintabie, through Coober Pedy and thence towards the south of Marree. The mound is very close to being a groundwater divide, isolating the far southwest of the GAB except at the southeastern extent of the mound. This watertable mound coincides with a topographic ridge.

f. Gason Dome: The Gason Dome is a major geological feature lying on the Birdsville Track Ridge, and coincides with a watertable mound. The dome is a broad structure formed in response to east-west compression and plunges to the northeast. Erosion has left a core of Winton Formation material exposed along the anticlinal axes of the dome. The watertable mound in the vicinity of the Gason Dome is unlikely to be a recharge mound, rather a groundwater discharge feature resulting from upward leakage, probably from the underlying Algebuckina/Hutton Sandstone
Regional watertable—areas of interest

- a. Burketown
- b. Georgina Basin
- c. Finke River
- d. Tallaringa Palaeovalley
- e. Marla-Coober Pedy Watertable Mound
- f. Gason Dome

- Great Artesian Basin
- Discharge area
- Approximate location of outcropping De Souza Sandstone
- Basement inlier

- Palaeovalley
- Lake
- Fault
- Anticline
- Anticline showing plunge

- Wateratable mound axis
- Inferred flow direction according to Love et al., (2013)
- Wateratable elevation contour (metres)
- Watercourse
- Tropic of Capricorn
- City/town

- Watertable elevation (mAHD)
- 850
- 0
g. Innamincka: A watertable mound overlies the Innamincka Dome. The Innamincka Dome is an elongate feature with closure (broad antiform) which formed in response to east-west compression and plunges to the northeast. This erosion has left a core of Winton Formation material exposed along the anticlinal axes of the dome. The favoured interpretation of this watertable mound is that it is in all probability a local recharge mound. Extension fractures formed from the folding would provide an enhanced infiltration capacity of the exposed Winton Formation if they have remained open.

h. Bulloo Overflow: The watertable contours are derived from pressures in the Winton Formation on the Milparinka 1:250,000 Sheet and from sub-artesian bores in undifferentiated Rolling Downs Group. The most prominent feature is a groundwater sink defined by the closures of the 60 m AHD and 80 m AHD watertable contours. The sink is defined by the 60 m closed contour overlies the terminus of the Bulloo River, the Bulloo River Overflow, and Caryapundy Swamp. The average elevation of these swampy areas is 78 m AHD.

The sink appears to have been created by an impedance to westward throughflow of groundwater afforded by Cenozoic (probably Pliocene) uplift along a pre-existing north-west trending fault, parallel and close to the Mt Poole, New Bendigo and Warratta Faults. The uplift was probably only of the order of about 20 m (there is a 20 m jump-up in the digital elevation model), but this appears to have been sufficient to defeat surface drainage in an almost flat landscape and to impede groundwater throughflow.

The sink constitutes a local groundwater discharge zone but the only surface expression of groundwater discharge is a salt lake of 45 km² surface area in the southern lobe of the 60 m closed contour. It would be expected that the sink would gradually fill over time and that discharge features such as salt lakes would become prevalent, but this has not eventuated. It could be that the excess groundwater is being transpired at the watertable by deep rooted vegetation, but this appears not to be the case since the dominant wetland vegetation is cane grass and lignum, not high transpiring species. Alternatively, the lack of a significant brine pool could indicate that the structural uplift and groundwater impedance occurred more recently than the Pliocene. Thus the sink appears to be something of a mystery that cannot be explained at this stage. It is not known whether the sink will gradually fill up and develop salinisation at ground surface.

Both local groundwater recharge and discharge features are expressed in the watertable aquifer. Although the watertable is considered to be regional in nature, on the Eulo Ridge it exhibits some characteristics of a local groundwater flow system. With this interpretation, there are local recharge mounds along the Eulo Ridge and there are two mounds straddling the Paroo River and a small granite intrusive (too small to see in the figure). Borers in these mounds intersect the Doncaster Member of the Wallumbilla Formation and are flowing artesian wells.

A local groundwater discharge zone is indicated by the closed 120 m watertable contour around Lake Wyara.

j. Dawson River Valley: The Dawson River joins the Fitzroy River west of Rockhampton and this drainage flows into the Pacific Ocean. Headward erosion of the Dawson River has produced a deeply dissected valley. The location of this dissection on the regional watertable is expressed as flow from the watertable aquifer towards the Dawson River and its tributaries, notably Hutton Creek—a line sink with many baseflow springs. The watertable converges to a choke in the Dawson River 45 km northeast of Taroom where it leaves the Great Divide. Thus the Dawson River valley is an area of flow loss from the GAB estimated to be in the order of 8500 ML/year.

k. Mulgildie Basin: The elongated lobe 10 km west of the town of Mundubbera is known informally as the Mulgildie Basin or outlier, and is underlain at its northernmost point by the Burnett River which flows eastward towards Bundaberg and the Pacific Ocean. The watertable map clearly shows the neck of the Mulgildie Basin drains groundwater from the north and from the south—from GAB aquifers, the Precipice and Hutton Sandstones. The groundwater leaves the system as baseflow into the Burnett River. Therefore, like the Dawson River valley, the Mulgildie Basin is an area of groundwater loss from the GAB.

Estimated groundwater flow loss northward from the GAB intake beds to the Mulgildie Basin and Burnett River is 3800 ML/year. Most of this flow loss is likely to be from the Precipice Sandstone and to a lesser extent from the Hutton Sandstone.

l. Macintyre River: The watertable is remarkable here because of the influence of the river on its configuration. East of Goondiwindi, the watertable aquifers are the Hutton Sandstone and sandstones of the Marburg Subgroup intake beds, which grade northward to the Kumbarra beds. On the New South Wales side the watertable aquifer is the Piliga Sandstone in the intake beds, grading westwards to undifferentiated Rolling Downs Group (probably Griman Creek Formation equivalent). The flow directions in the watertable are noteworthy. In Queensland, groundwater flow is towards the southwest and in New South Wales it is to the northwest. The flow lines converge around the Macintyre River. This is a rare example of a state boundary coinciding with a hydrogeological one. East of Goondiwindi, the watertable is depressed about the Macintyre Brook, Dumaesq River and Macintyre River indicating that these may be gaining streams. However, the watertable shows a groundwater mound 10 km west of Goondiwindi, possibly indicating the Macintyre River here is a losing stream recharging the Griman Creek Formation partial aquifer. The groundwater mound may in part be generated by hydraulic loading from the Goondiwindi Weir which lies 5 km downstream of the centre of the town.
Map 14
Hydraulic connectivity across the base of the Great Artesian Basin*

This map categorises the hydraulic nature of the basal surface of the GAB through the properties of rocks in direct contact below and above the base, on a regional scale. The map indicates areas of potential connectivity between aquifers in older basins and the basal aquifers in the GAB sequence.

Approximately twenty seven sedimentary basins are currently known to underlie and be in direct contact with the base of the GAB.

The basal hydroconnectivity is illustrated in the map by means of two superimposed coverages of hydraulic character, both with qualitative categories: from Aquiclude, through Tight Aquitard, Leaky Aquitard, to Partial Aquifer and Aquifer. The hydraulic character of underlying units in older sedimentary basins is classified by colour. The hydraulic character of GAB rock units sitting directly on the GAB basement is classified by monotone patterns.

The monotone scheme ranges from a dark cross hatch (aquiclude) diminishing through to a light stipple (aquifer) such that the more clearly the underlying colours can be discerned, the better the hydraulic connectivity across the base of the GAB.

* Modified from work undertaken for the Great Artesian Basin Water Resource Assessment (Ransley TR and Smerdon BD (2012)) using updated boundaries for GAB units directly overlying basement and revised Arckaringa and Pedirka basin mapping supplied by D. Wohling (South Australian Department of Environment, Water and Natural Resources).
Hydraulic connectivity across the base of the Great Artesian Basin

Basement units in contact with base of Great Artesian Basin
- Aquifer
- Partial aquifer
- Aquiclude
- Leaky aquitard

Great Artesian Basin units directly overlying basement
- Aquifer
- Partial aquifer
- Leaky aquitard
- Aquiclude

Legend:
- Great Artesian Basin
- Bathymetry contour (depth in metres)
- Tropic of Capricorn
- City/town

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S Central Meridian: 140°E
Datum: Geocentric Datum of Australia

0 250 500 km
0 100 200

Aquifer
Hydraulic connection between Quaternary alluvium and GAB aquifers in the Surat Sub-basin

Contours of recent water level measurements in the Quaternary alluvial aquifer in the Surat Sub-basin demarcate areas where water levels in the Quaternary alluvium are higher than the regional watertable in the uppermost GAB aquifer, and areas where the GAB regional watertable is equal to or higher than the water levels in the alluvium.

A higher water level in the alluvium than that in the GAB aquifer is a necessary but not sufficient condition for downward leakage and recharge from the alluvium to the GAB formations. A second condition which must be satisfied is that a pathway exists for inter-formational groundwater flow. During the Late Cretaceous to Early Paleogene, the exposed GAB rocks were subjected to prolonged and intense weathering which produced a basin-wide thick layer of saprolite. The lower part of the saprolite is clay rich and of very low permeability. It is this layer that generally prohibits vertical fluid flow.

Airborne electromagnetic surveys, calibrated by drilling programs, have been flown in the Lower Balonne and Lower Macquarie River valleys of the Surat Basin. These surveys have shown the lower impermeable saprolite forms a continuous blanket over the GAB rocks, and prevents hydraulic connection between the Quaternary alluvium and the GAB sequence. However, in places where the saprolite has been removed by erosion, hydraulic connection is possible and highly likely. Such areas occur beneath Neogene palaeochannels where erosion during their formation was sufficient to strip the saprolite to expose unaltered rock. There are many of these palaeochannels in the Surat Basin and they either underlie modern stream channels (eg. Warrego and Castlereagh Rivers) or are buried adjacent to them (eg. Namoi and Dirranbandi Palaeovalleys).

Thus the majority of the olive-coloured areas on the map of groundwater heads are those where the water levels in the Quaternary sediments are perched slightly above the regional GAB watertable as there is no hydraulic connection due to the saprolite seal. Some of these areas have been generated by irrigation loading in the alluvium, such as in the Lower Macquarie and St George irrigation areas. However, olive coloured areas on the map coincident with the modern rivers and their palaeochannels represent zones where it is highly likely that the GAB formations are recharged by downward leakage from the Quaternary alluvial aquifer which in many cases is fed by stream water (losing streams).

Areas where it is highly likely that leakage from the Quaternary aquifer recharges the GAB formations are:

- Warrego River—Augathella to Charleville and Dillalah to Quilberry.
- Castlereagh River—Mendooran to Curban.
- Macquarie River—Buddah kink (20 km north of Narromine).
- Condamine-Balonne River—Macalister to Beardmore Dam (including the northern third of the Dirrandandi Palaeovalley)
- Condamine River (South Branch)—Millmerran to Cecil Plains.
- Balonne River—Blue Lagoon to Whyenbah.

Conversely, areas where it is highly likely that there is vertical upward leakage from the GAB formations into the alluvium are:

- Border Rivers (Macintyre and Dumaresq Rivers and Macintyre Brook)—upstream of Goondiwindi.
- Gwydir River—upstream of Mehi River Anabranch.
- Namoi River, Plan Creek Anabranch and Namoi Palaeochannel—Narrabri to Burren Junction (leakage is into Neogene Gunnedah and Cubbaroo formations).
- Dirranbandi Palaeovalley—St George to Hebel.
- Condamine River (North Branch)/Oakey Creek—Brookstead to Macalister.

Map 15

Hydraulic connection between Quaternary alluvium and GAB aquifers in the Surat Sub-basin

Areas where it is highly likely that leakage from the Quaternary aquifer recharges the GAB formations are:

- Warrego River—Augathella to Charleville and Dillalah to Quilberry.
- Castlereagh River—Mendooran to Curban.
- Macquarie River—Buddah kink (20 km north of Narromine).
- Condamine-Balonne River—Macalister to Beardmore Dam (including the northern third of the Dirrandandi Palaeovalley)
- Condamine River (South Branch)—Millmerran to Cecil Plains.
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- Dirranbandi Palaeovalley—St George to Hebel.
- Condamine River (North Branch)/Oakey Creek—Brookstead to Macalister.
Hydraulic connection between Quaternary alluvium and GAB aquifers in the Surat Sub-basin

- Quaternary alluvial aquifer absent or unsaturated
- Head in Quaternary alluvial aquifer higher than Great Artesian Basin watertable
- Quaternary alluvial aquifer absent or unsaturated
- Head in Quaternary alluvial aquifer lower than Great Artesian Basin watertable
- Unknown
Groundwater loss from the GAB system through upward leakage in areas away from outcropping aquifers is indicated by several lines of indirect evidence.

Indirect evidence of groundwater loss includes:
- the anomalous imbalance in the groundwater budget for the GAB system;
- and
- anomalous evapotranspiration rates from riparian vegetation within these drainage systems (see Map 17).

The conceptual model below (Figure 3), illustrates the effect of fault displacement of aquifers, and possible conduits for upward leakage through a combination of faults and polygonal faulting into Cenozoic sediments and then to the ground surface. It should be noted that faults can act as impermeable barriers to groundwater flow as well as act as permeable conduits.

The regional understanding of fault displacements and fault-zone characteristics within the GAB sequence is basic, but major faults are known to have a range of vertical displacements from 200 m up to 780 m in the Jurassic-Cretaceous sequence, displacement which can completely disrupt aquifer continuity.

Additionally, the Rolling Downs Group has extensive to almost ubiquitous intraformational faulting—also known as polygonal faulting. Although little is known of the permeability of this faulting style in rocks of this age, the pervasive extent and multiple orientations of faulting, make a proportion of faults in each polygonal cell susceptible to dilation by any anisotropy in crustal stresses.

Polygonal overprints are generally manifested from the top of the Cadna-owie – Hooray Aquifer and Equivalents upwards, penetrating through both the Rolling Downs Aquitard and the Winton-Mackunda Aquifer and Equivalents.

Polygonal faulting is not known to generally penetrate Paleogene-Neogene cover but in some areas of Cenozoic duricrusted surfaces, circular to irregular patterns of comparable size to those of underlying polygonal cells appear to have been influenced during their formation by the underlying polygonal fault fabrics. Such features suggest upward groundwater leakage in such areas at the time of duricrust formation.

Map 16
Polygonal and normal faulting in the Great Artesian Basin

Figure 3  Vertical leakage of groundwater through a regional tectonic fault and polygonal faults
Polygonal and normal faulting in the Great Artesian Basin

Polygonal faulting
- Cenozoic duricrust with folding/doming
- Surface expression of polygonal faulting and/or related folding in Cretaceous Rolling Downs Group
- Area of Great Artesian Basin where the hydrogeological unit does not exist

Paleogene–Neogene Cover
Rolling Downs Aquitard

Great Artesian Basin
Seismic transects indicating polygonal faulting
Fault
Bathymetry contour (depth in metres)
Tropic of Capricorn
City/town
**Map 17**  
River tracts with inferred groundwater leakage from anomalous evapotranspiration

Water loss through evapotranspiration is an important factor for consideration in water-balance calculations in the GAB. To estimate water loss through evapotranspiration, the use of remote-sensing information allowed for the rapid, broad-scale identification of healthy, vigorous vegetation that was accessing shallow groundwater sources.

Changes in the health and vigour of vegetation are observable in satellite imagery through the application of vegetation index calculations such as the NDVI (Normalised Difference Vegetation Index). By comparing the spectral response and reflection from green plants in imagery acquired at separate dates, these calculations highlight changes in vegetation health and vigour over time.

Pre-existing time series imagery from the MODIS platform was assessed. The dataset covers the period from 2000 to 2008, consisting of 186 readings for each pixel of data. The Enhanced Vegetation Index (EVI) is applied to the MODIS data as the method is more responsive to canopy structural variations, including leaf area index (LAI), canopy type, plant physiognomy, and canopy architecture.

The assessment of the EVI data proved effective for detecting riparian vegetation that maintained health and vigour during the period 2000 to 2008 despite the severe drought across the GAB for this period. During drought conditions, vegetation with access to groundwater retains a higher EVI response relative to nearby vegetation with no access to groundwater.

The data used was The National Dynamic Land Cover Dataset. For each pixel, a set of 12 EVI coefficients have been calculated from the 186 time-series values at each pixel location. Coefficients included the mean, standard deviation, flatness, maximum, minimum, as well as a variety of rates-of-change coefficients.

Key coefficients to the outcomes of this approach are the mean, standard deviation, and flatness and were displayed as an RGB colour image for interpretation. The major rivers of the GAB were classified according to the adjacent riparian vegetation and corresponding consistency in high EVI values during 2000 to 2008, an extended drought.

This was extended to an evapotranspiration (ET) loss estimate by assessing tree density along the riparian zones of the major rivers. The National Dynamic Land Cover Dataset is a vegetation map for all Australia, with tree density broken into four classes (Closed, Open, Sparse, Scattered). Where riparian vegetation maintained a high EVI, the total numbers of trees were estimated from tree density. This allowed for the estimate of ET losses by applying typical transpiration values associated with major tree species as derived from previous studies. This approach allowed for the calculation of water-use along several major river systems in inland Queensland. These calculations were only undertaken on river systems that were unregulated and therefore not under the influence of irrigation or managed flow conditions.

The following list of potential ET losses from riparian vegetation from stream systems in the GAB in mega litres per year (ML/yr):

<table>
<thead>
<tr>
<th>Stream system</th>
<th>Mega Litres per year (ML/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flinders River</td>
<td>21 674</td>
</tr>
<tr>
<td>Warrego River</td>
<td>21 060</td>
</tr>
<tr>
<td>Barcoo River</td>
<td>15 275</td>
</tr>
<tr>
<td>Thomson River</td>
<td>6 446</td>
</tr>
<tr>
<td>Diamantina River</td>
<td>124</td>
</tr>
<tr>
<td>Bulloo River</td>
<td>123</td>
</tr>
<tr>
<td>Paroo River</td>
<td>110</td>
</tr>
<tr>
<td>Georgina River</td>
<td>84</td>
</tr>
<tr>
<td>Farrars Creek</td>
<td>3</td>
</tr>
<tr>
<td>Wilson River</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>64 882</strong></td>
</tr>
</tbody>
</table>
River tracts with inferred groundwater leakage from anomalous evapotranspiration
Although weathering of rocks is ongoing through time, several periods of extremely intense weathering resulted from high temperatures, precipitation and atmospheric CO$_2$ at the close of the Cretaceous and subsequently culminating in the Paleocene-Eocene Thermal Maximum event (PETM at 56 Ma). These and subsequent events have left distinct profiles and duricrusted surfaces on both exposed Mesozoic rocks and on older Paleogene-Neogene cover. The thickness of weathering is highly variable. Greatest weathering thickness is within and below the Cenozoic basin accumulations of Lake Eyre Basin and Karumba Basin. In contrast to these Cenozoic depocentres with thicker well-preserved weathering profiles, regional uplift along the Great Dividing Range and from the Flinders Ranges northward towards the Peake-Denison-Davenport Inliers (see Maps 4 and 7) has caused erosion, which significantly reduced the thickness of the saprolite. Uplift of the eastern ranges, in conjunction with subsidence in basin depocentres, has tilted the Surat and Eromanga sub-basins, steepening southwestward drainage to enable deep incision of channels that have commonly incised through the less-permeable saprolite. This has enhanced connectivity between GAB aquifers and the alluvial aquifers in many of the resultant deep leads.
MAP 18

Thicknes of Cenozoic weathering

- Great Artesian Basin
- Weathering thickness contour (metres)
- Bathymetry contour (depth in metres)
- Tropic of Capricorn
- City/town

Weathering thickness (metres):

- 0
- 10
- 20
- 30
- 40
- 50
- 100

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S
Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Bathymetry contour (depth in metres)
Weathering thickness contour (metres)
City/town
The geomorphology of the GAB, as with the thickness of weathering (see Map 18) and the Palaeogene-Negroe series (see Map 23), is the cumulative result of the distinctive climatic events and tectonism experienced throughout the Cenozoic. Intense climatic events created widespread thick weathering profiles topped by duricrusted surfaces around the Lake Eyre Basin.

The regional southwestward tilt controlled drainage from active denudation/erosional regions in the east (Rolling Downs) where the saprolite thickness was significantly thinned or entirely removed by erosion, and fluvial incision created deep leads at the headwaters of many (if not all) riverine plains that extended southwest, following parallel fracture systems that controlled fluvial and colluvial exhumation below the widespread duricrusted tablelands. These riverine systems have transported sediment from the Surat Sub-basin into the Darling River system of the Murray Basin, as well as from the eastern Eromanga Sub-basin into the Callabonna and Tirari depocentres of the Lake Eyre Basin. Today the southern margins of these depocentres continue to be the lowest areas in elevation within the basin, and are the groundwater sinks for the regional watertable (see Map 11), creating a belt of playa salt lakes along the southern margin of the GAB, that flanks the recently-uplifted Flinders-Willouran Ranges.

Fluvial sediments transported into these lake systems (Lakes Frome, Callabonna, Blanche, Gregory, Eyre South and Eyre North), have been partially redistributed by aeolian processes into the vast dune fields surrounding and downwind of these sinks and deflation areas. Pleistocene interglacial highstands of the Murray Basin, as well as from the eastern Eromanga Sub-basin into the Callabonna and Tirari depocentres of the Lake Eyre Basin, have created a belt of playa salt lakes along the southern margin of the GAB, that flanks the recently-uplifted Flinders-Willouran Ranges.

Southwest of these Cenozoic depocentres of the Lake Eyre Basin, the GAB sequence is thin, basement is shallow and relatively stable, and the terrain consists of predominantly dissected residual surfaces with scattered palaeolakes and palaeodrainage systems. Here the eastern extremities of the Great Victoria Desert offer only partial dune cover over a dissected and intensely weathered terrain.

Northwards across the Eureka Arch (see Maps 4 and 5) into the Karumba Basin (overlying the Carpentaria Sub-basin) fluvial landforms are predominant—as riverine plains northward-directed towards the Gulf, and as multi-phased fluvial fans off the eastern dividing range. Fan sediment was derived from mass wasting and erosion of duricrusted surfaces that developed during the three major depositional-weathering cycles of the Karumba Basin. During Pleistocene low stands of sea level, these fluvial features extended into the Carpentaria palaeolake. This became an isolated body of water when sea level dropped 53 m below current sea level and a sill to the northwest, outside of the GAB in Australian Territory, separated it from the Arunta Sea. Remnants of relic drainage valleys are evident in bathymetry surrounding the eastern margin of the palaeolake, but their connection with onshore drainage systems has been masked by the recent accumulation of a sediment wedge nearshore and on the coastal plain. A low stand event of this Carpentaria palaeolake is evident in bathymetry approaching 70 m below sea level (see Map 20). This low stand feature parallels the cape offshore from Cape Keeweer to the Torres Strait and lies on the eastern side of the palaeolake. It is rimmed on its eastern margin by apparent barrier/beach ridges.

Coral reefs, as plateaux and patches, developed prior to and during Pleistocene marine incursions in the southern tectonically uplifted region of the Gulf. These reefs and karstified plateaux are now sufficiently submerged to virtually suppress modern reef growth.

Cenozoic volcanic terrain exists as scattered foci along the eastern margin of the GAB—from the Coonamble Embayment in the south, northwards through the Darling Downs of the eastern Surat Sub-basin, to the Springsure and Hughenden basaltic flows of the eastern Eromanga Sub-basin. Basaltic flows have had variable influence on terrain in these regions.
Map 20
Geomorphology—northern GAB

**Fluvial**
- Alluvial plain
- Sandplain
- Coastal plain
- Palaeoriver valley
- Modern channel deposits

**Aeolian**
- Barrier ridge (coastal)
- Sandplain
- Submerged dune field flanking deepest basin
- Sand dune fields, undifferentiated (not seif dunes)
- Self dune field/longitudinal dune field

**Erosional terrain**
- Colluvial outwash slope
- Gibber Sand Plain, transitional
- Rolling Downs

**Playa-lacustrine**
- Lacustine terrace deposit
- Playas, claypans, salt lakes
- Eroded palaeolake terrain
- Submerged lake

**Overprints**
- Dominantly lava flows
- Eroded palaeolake terrain

**Relict surfaces**
- Erosional remnants of a dissected surface

**Geological units**
- Marine: Carbonate platform, Submerged canyon, deep holes, Submerged patch reefs, Marine shoals, banks, shallow nearshore terrace
- Aeolian: Barrier ridge (coastal), Sandplain, Submerged dune field flanking deepest basin, Sand dune fields, undifferentiated (not seif dunes), Self dune field/longitudinal dune field
- Erosional terrain: Colluvial outwash slope, Gibber Sand Plain, transitional, Rolling Downs
- Playa-lacustrine: Lacustine terrace deposit, Playas, claypans, salt lakes, Eroded palaeolake terrain, Submerged lake
- Overprints: Dominantly lava flows
- Relict surfaces: Erosional remnants of a dissected surface
Geomorphology—northern GAB

Great Artesian Basin

Bathymetry contour (depth in metres)

Tropic of Capricorn

City/town

Scale: 1:5,000,000

Projection: LAMBERT CONFORMAL CONIC

Parallels: 25°S, 35°S  Central Meridian: 140°E

Datum: Geocentric Datum of Australia

Location Map
Map 21
Geomorphology—western GAB

Geomorphology

Fluvial
- Fluvial delta and fan deposits
- Alluvial plain

Aeolian
- Sandplain
- Lunette
- Self dune fields modified by lunettes and interdunal playas
- Sand dune fields, undifferentiated (not seif dunes)
- Self dune field/longitudinal dune field

Lacustrine
- Lacustrine terrace deposit
- Playas, claypans, salt lakes
- Playa and lunette terrain with some seif dunes
- Erosional remnants of a dissected surface

Erosional terrain
- Colluvial outwash slope
- Gibber Sand Plain, transitional
- Rolling Downs

Overprints
- Mound Springs
- Dominantly lava flows
- Lacustrine
- Erosional
- Aeolian
- Relict surface
Map 22
Geomorphology—eastern GAB

- **Fluvial**
  - Fluvial delta and fan deposits
- **Alluvial plain**
- **Sandplain**
- **Modern channel deposits**

**Aeolian**
- Lunette
- Sand dune fields, undifferentiated (not seif dunes)
- Seif dune field/longitudinal dune field

**Erosional terrain**
- Colluvial outwash slope
- Gibber Sand Plain, transitional
- Rolling Downs

**Playa-lacustrine**
- Lacustine terrace deposit
- Playas, claypans, salt lakes

**Relict surfaces**
- Erosional remnants of a dissected surface

- Dominantly lava flows
- Lacustine
- Erosional
- Relict surface
Hydrostratigraphic units—outcrop, extent and thickness

The following maps have been derived from the lithostratigraphic intercepts in drillhole data from petroleum exploration wells, water bores, and stratigraphic wells. The maps presented are a regional interpretation produced at the scale of 1: 1 000 000. Outcrop extents were modified from Habermehl, M.A. & Lau, J.E. (1997) Hydrogeology of the Great Artesian Basin (Map at scale 1: 2 500 000), Canberra, Australian Geological Survey Organisation.
Map 23
Paleogene-Neogene cover

The Cenozoic cover over the GAB comprises surficial Quaternary sediment overlying Paleogene and Neogene sediments and rocks. The Quaternary cover consists predominantly of sands of alluvial, colluvial and aeolian origin, which are relatively permeable, and allow direct recharge to the underlying rocks. In contrast, the Paleogene and Neogene sequence has more variable hydrogeological properties.

Paleogene and Neogene accumulations over the GAB lie predominantly in two depocentres—the Karumba and Lake Eyre basins.

The Karumba Basin overlies but is more extensive than the Carpentaria Sub-basin except for the uplifted and eroded eastern margin. Within this basin, two depocentres are evident: offshore where the sequence reaches 450 m thickness, slightly offset to the northwest of the Cretaceous Carpentaria Depression (see Maps 4 and 5), and another within the Gilbert-Mitchell Trough (>200 m). These depocentres are separated by a northeast-southwest trending ridge, an extension of the Nicholson Ridge, which is foundation to a line of patch reefs.

Over the southwestern Eromanga Sub-basin, Paleogene-Neogene thickness is greatest in the Lake Eyre Basin which is partitioned by the Birdsville Track Ridge into the thicker Tinarra Sub-basin (up to 450 m) to the west over the Poolowanna Trough, and the Callabonna Sub-basin (up to 200 m thickness) over the Central Eromanga Depocentre and Lake Frome Embayment. Sediments in the Lake Eyre Basin are predominantly fluvial sands and are good aquifers. Northeastwards towards the eastern GAB margin, this cover becomes progressively eroded and more discontinuous in isolated basins or along palaeodrainage channels. Remnant pediments of duricrusted and indurated sheetwash deposits of the Glendower Formation are scattered along the eastern slopes of the Eromanga and Surul sub-basins. The southwestern side of the Lake Eyre Basin is influenced by basement inliers extending northwards from the Flinders Ranges, through the Davenport and Denison ranges. West of this basement high, the Talarranga and Kringoonya palaeovalleys, the Hamilton Basin and related remnants extend across the thin exposed GAB sequence which has a very thick well-developed weathering zone.

In the Surul Sub-basin, palaeovalleys and deep leads, incised up to 160 m depth, constitute localised cover over the GAB. Incision of the deep leads has generally cut through the thick saprolite developed on the GAB sequence and offers effective connectivity between Cenozoic and GAB aquifers.

Volcanic flows have created impermeable regions locally (see Map 22). These areas are located within the following 1:250 000 scale geology map sheet areas; close to the eastern basin margin of the GAB on the Hughenden and Richmond map sheets; in the northern Mimosa Syncline, on the Springsure map sheet; in the Darling Downs region on the Taroom map sheet and extending from the Chinchilla to Warwick map sheets; the Kaputar volcanics on the Inverell and Moree sheets; and the Warumbungles on the Gilgandra map sheet.
The Winton-Mackunda Partial Aquifer and equivalents has three distinct and separate extents, one in each of the main sub-basins. The broad subcrop/outcrop extent of this composite aquifer highlights the region potentially available for recharge from rainfall.

In the Eromanga Sub-basin, this composite aquifer comprises the lower marginal-marine Mackunda Formation and the overlying continental Winton Formation. Both the Mackunda Formation and the lower Winton Formation have relatively consistent and good aquifer characteristics but up sequence in the Winton Formation, aquifer sands become more sporadic as fluvial channel ribbons that lie within less permeable mudstones, siltstone and coal. The thickest region of this aquitard is within the Central Eromanga Depression (see Maps 4–7) with thickness exceeding 1000 m along its axis. The Poolowanna Trough, to the west, has in excess of 700 m thickness.

Northwards across the Euroka Arch into the Carpentaria Sub-basin, the equivalent of the Mackunda Formation is the marginal-marine Normanton Formation which has good aquifer characteristics onshore but transitions into a low permeability aquitard centrally offshore. Here the aquitard is predominantly <200 m thickness with a subtle offshore thickening toward the Carpentaria Depocentre, with an increased thickness to over 250 m in an east-northeastward orientation into the Weipa Depression (see Map 5). From Mornington Island to the southern Staaten and the Boomarra sub-basins there is localised thickening of the aquifer.

The Eulo-Nebine Ridge effectively separates the Eromanga and Surat sub-basins at this stratigraphic level. In the Surat Sub-basin, the Griman Creek Formation is the equivalent of the Winton-Mackunda Aquifer. The Griman Creek Formation has internal variability comparable to that in the Winton Formation, but overall it has poorer aquifer characteristics compared to the Winton and Mackunda Formations. The greatest thickness in this sub-basin exceeds 250 m, locally >300 m, from the central Mimosa Syncline and southwestwards along the Darranbandi Syncline.
The widespread Rolling Downs Aquitard comprises marine units of fine-grained siliciclastics, mudstone and limestone, and is considered the most effective aquitard in the GAB because of its extent, thickness and low permeability of mudstones and fine-grained sediments.

Within the eastern Eromanga Sub-basin, the aquitard comprises the combined sequence of the Wallumbilla Formation, Toolebuc Formation and Allaru Mudstone. Beyond the southwestern limit of the Toolebuc Formation, the Bulldog Shale and Oodnadatta Formation constitute the aquitard, even though they contain the intervening Coorikiana Sandstone, an aquifer which has comparability with the Coreena Sandstone stringers of the Wallumbilla Formation to the east.

The anomalous relief of crater rims of the Tookoonooka and Talundilly structures on the southern and eastern margins of the central Eromanga Depocentre was only completely buried well into deposition of the Wallumbilla Formation, so the cratering has locally affected the thickness of Rolling Downs Aquitard.

In the Surat Sub-basin, this aquitard comprises the Wallumbilla Formation and overlying Surat Siltstone. Southwards into the Coonamble Embayment, the aquitard comprises the Wallumbilla Formation and overlying Keelindi and Drildool beds to a southern limit at 31.5°S (see Maps 4 and 6). South of this latitude, the Keelindi and Drildool beds become sander with good aquifer characteristics, and are thus excluded from this aquitard and included in the Cadna-owie – Hooray Aquifer and Equivalents.

The Rolling Downs Aquitard is continuous northwards over the Euroka Arch into the Carpentaria Sub-basin. Offshore, differentiation between the Rolling Downs Aquitard and overlying Normanton Formation (Winton-Mackunda and Equivalents Aquifer) is equivocal in existing seismic coverage, so on the basis of proportional thickness of units in three control wells, the Rolling Downs Aquitard is assumed to comprise 75% of the seismic thickness of the Rolling Downs Group across the entire offshore region.

Greatest thickness of this aquitard is in the Carpentaria Depocentre (up to 800 m), the Poolowanna Trough (up to 750 m), along the Central Eromanga Depocentre and the Cork Fault (locally up to 650 m), and on the shore Staaten River Embayment (up to 650 m). In the Surat Sub-basin, the aquitard thickness is locally variable throughout, but largely between 150 m and 400 m thick.
Rolling Downs Aquitard

City/town

Area of Great Artesian Basin where the hydrogeological unit does not exist

Isopach contour (metres)
Bathymetry contour (depth in metres)
Tropic of Capricorn

Data location

Explosion structure - probable bolide impact crater

Great Artesian Basin

Outcrop/subcrop

0
20
40
60
80

975
515

100
200
300
400
500
600
700
800
900

0 100 200 400 500 700 900 1100 1300 1500 1700 1900 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 4000 4200 4400 4600 4800 5000
0 250 500 km

Thickness (metres)

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S - Central Meridian: 140°E
Datum: Geocentric Datum of Australia
The aquifer comprises the upper Cadna-owie Formation that includes the uppermost Wyandra Sandstone Member (Eromanga Sub-basin) and Bungil Formation (Surat Sub-basin), and the underlying Hooray Sandstone and its equivalents. These equivalents are the Longsight Sandstone, Ronlow beds, Namur Sandstone and Murta Formation, and Algebuckina Sandstone in the Eromanga Sub-basin; the Gubberamunda Sandstone, Orallo Formation and Mooga Sandstone in the Sular Sub-basin; Piliga Sandstone, including the Keelindii and Drildool beds south of 31.5° S in the Coonamble Embayment; and in the Carpentaria Sub-basin, the Gilbert River Embayment and underlying Eulo Queen Group equivalents—Garraway Sandstone, Helby beds, and Albany Pass beds. These Eulo Queen Group equivalent units are of comparable age to the Hooray Sandstone, but northwards across the Euroka Arch there is direct hydraulic connection between the overlying Gilbert River Formation and these units in the absence of intervening aquitards, so they are included in this aquifer grouping.

Although the Cadna-owie Formation is generally a poor aquifer, it commonly has a thin upper sandstone that is an excellent aquifer—the Wyandra Sandstone Member in the east, the Mount Anna Sandstone and Trinity Well Sandstone members in the southwest. Within the southwestern Central Eromanga Depocentre, beyond the limit of the Westbourne Aquitard, the Namur Sandstone with overlying Murta Formation form an equivalent to the Hooray Sandstone and these units extend southwards across into the Poolowanna Trough where the Algebuckina Sandstone is a lateral equivalent, as it is also with the Hutton Aquifer.

Two very large circular explosion features were emplaced at about 125 Ma during deposition of the Cadna-owie Formation. These are the Tookoonooka (55-60 km diameter) and Talundilly (84 km diameter) features. Cratering and canyon development from these events redistributed thickness of the Cadna-owie—Hooray Aquifer locally and the catastrophic event also fractured the underlying GAB sequence and basement.

Greatest thickness of the Cadna-owie—Hooray Aquifer is in the Poolowanna Trough (>700 m) and in the Surat Sub-basin, with up to 700 m in the southern Mimoso Anticline, and locally thick regions (up to 500 m) west of the Roma Shelf and to the south in the central Coonamble Embayment. The east and central Eromanga Sub-basin has >150 m thickness. Approaching the Ronlow beds in the northeast, as well as in the southwestern region, beyond the Peake-Denison-Davenport Inlier, aquifer thicknesses are predominantly underestimates as only partially penetrating waterbore are available in these regions. Water drilling rarely reaches the formation base, usually stopping once an adequate water yield is achieved.

In the Carpentaria Sub-basin, this aquifer is largely restricted to the Staaten and Weipa sub-basins (see Map 5). During deposition of these sandstones, rugged relief in basement terrain to the west in the Western Gulf Sub-basin precluded deposition of sands except within narrow deep gorges which are not readily delineated by the existing seismic imagery. The thickest region of this composite aquifer is an arc of ~200 m thickness along the southern side of the Weipa Sub-basin that thickens northeastward across the Bramwell Arch into the adjoining Papuan Basin. To the south, a thicker composite aquifer, intermittently >100 m, is apparent over the western edge of the Staaten Sub-basin, south into the Boonarra Sub-basin and southeastward onto the Euroka Arch. These thicker areas coincide with sandstones of the Eulo Queen Group present in the underlying Burketown, Canobie and Millinggura depressions.
The Westbourne Aquitard comprises the Westbourne Formation which is widespread along the eastern margins and central regions of both the Eromanga and Surat sub-basins.

The thicker part of the aquitard (>100 m) forms a discontinuous arc from the Surat Sub-basin towards the Canaway Fault and southwards along the Central Eromanga Depocentre onto the Birdsville Track Ridge (see Maps 4–7). A small isolated remnant of this aquitard at the western margin on Finke 1:250 000 scale map sheet suggests a former basin wide extent, as with the Birkhead-Walloon Aquitard, before subsequent erosion over the Poolowanna Trough region. In the northern Eromanga Sub-basin, the aquitard is generally <50 m thick.
Map 28
Adori-Springbok Aquifer

The Adori-Springbok Aquifer, comprising the Adori Sandstone in the Eromanga Sub-basin and the Springbok Sandstone in the Surat Sub-basin, has broad extent along the eastern margins of both sub-basins, comparable to the Birkhead–Walloon Aquitard and almost identical with the Westbourne Aquitard.

The aquifer is mostly uniformly thin, generally <50 m thick, but is thicker (50–100 m) over the southwestern Cooper Basin onto the Birdsville Track Ridge, as well as centrally in the Surat Sub-basin (see Maps 4–7). Present on the Nebine Ridge, it merges southwards with the Hutton and Cadna-owie – Hooray aquifers as the intervening Birkhead-Walloon and Westbourne aquitards wedge out along this ridge. The Adori-Springbok Aquifer has its identifiable western limit in the Eromanga Sub-basin defined by the extent of the overlying Westbourne Aquitard. In the absence of this aquitard, the underlying Adori Sandstone and overlying Hooray Sandstone merge into the Namur Sandstone, a component of the Cadna-owie – Hooray Aquifers.
Map 29
Birkhead-Walloon Aquitard

As evident by its name, the Birkhead-Walloon Aquitard comprises the Birkhead Formation in the Eromanga Sub-basin and the Walloon Coal Measures in the Surat and Clarence–Moreton sub-basins. In the Coonamble Embayment of the Surat Sub-basin, the Walloon Coal Measures transition southwards into the Purlawaugh Formation.

Between the Eromanga and Surat sub-basins, this aquitard thins away from the eastern margin and is absent southwestwards beyond the Nebine Ridge, as is the Westbourne Aquitard. Consequently there is direct connection between the Hutton Aquifer, Adori-Springbok and the Cadna-owie – Hooray Aquifers around the Eulo Ridge and the southwestern Surat Sub-basin.

In the Eromanga Sub-basin, the Birkhead Formation has broad extent along the entire northeastern margin and extends southwestwards within the Central Eromanga Depocentre, and over the Birdsville Track Ridge into the Poolowanna Trough (see Maps 4–7). Isolated remnants of the Birkhead Formation exist toward the western margin of the basin. Former continuity with the Poolowanna Trough appears to have been lost through erosion.

This aquitard is thickest in the Surat Sub-basin within the northern Mimosa Syncline (up to >500 m) and eastwards towards the Kumbarilla Ridge, and thins steadily southwestwards. In the Eromanga Sub-basin, the thicker regions of >100 m are continuous from the central Nebine Ridge northwestwards towards the Longreach Basement High, then southwards along the Central Eromanga Depocentre into the Poolowanna Trough with slightly diminished thickness, rarely over 100 m.

![Map 29: Birkhead-Walloon Aquitard](image-url)
Map 30
Hutton Aquifer and Equivalents

The Hutton Aquifer and Equivalents comprises predominantly the Hutton Sandstone which has broad extent in the Eromanga and Surat sub-basins (see Maps 4–7), and further extension to the southeast across the Kumbarilla Ridge into the Clarence-Moreton Basin where it is represented by the Heifer Creek Member of the Koukandowie Formation.

The axis of its greater thickness (>150 m) forms a slightly sinusoidal east-west tract across the GAB that closely follows the extent of the underlying Poolowanna-Evergreen Aquitard.

To the southwest in the Eromanga Sub-basin, the Hutton Sandstone, which is up to 600 m thick in the Poolowanna Trough, transitions laterally into the Algebuckina Sandstone. The Algebuckina Sandstone extends to the GAB margin in the west, and has common lateral connection with both the Hutton and Cadna-owie – Hooray aquifers. Accordingly, the Algebuckina Sandstone is included in both aquifer packages because of its lateral continuity, but here it is demarcated from the Hutton Sandstone to indicate their separate extents.

In the northern Eromanga Sub-basin, the Hutton Sandstone provides modest cover (>50 m and up to 100 m thickness) over the underlying Galilee Basin and thin cover over the Longreach Basement High.

This aquifer thins over the Nebine Ridge but again thickens (>200 m) across the northern Surat Sub-basin. It thins southward in the Mimosa Syncline, as well as southeastwards across the Kumbarilla Arch. Southwestwards from the Nebine Ridge and northern Surat Sub-basin, the aquifer thins and then merges with the Adoni-Springbok and Cadna-owie – Hooray aquifers beyond the extent of the intervening Westbourne and Birkhead-Walloon aquifers.

Northwards over the Eureka Arch into the Carpentaria Sub-basin, there is direct hydraulic connection between the Eulo Queen Group equivalents of the Hutton Sandstone and the overlying Cadna-owie – Hooray Aquifer as both Birkhead-Walloon and Westbourne aquitards wedge out and are absent over this basement high. Consequently in the Carpentaria Sub-basin, isolated remnants of the Eulo Queen Group in the southern Staaten Sub-basin and further north, although age equivalents of the Hutton Sandstone, are included in the Cadna-owie – Hooray Aquifer.
Map 31
Evergreen-Poolowanna Aquitard and Equivalents

The Evergreen-Poolowanna Aquitard and Equivalents has a slightly sinusoidal east-west linear extent across the GAB.

The Poolowanna Formation is the constituent rock unit in the west and extends eastward from the northern part of the Poolowanna Trough, across the deepest region of the Birdsville Track Ridge into the Central Eromanga Depocentre up to the Canaway Ridge (see Maps 4, 6 and 7).

The Evergreen Formation is contiguous across this structure into the eastern Eromanga Sub-basin and northern Surat Sub-basin, and then extends across the Kumbarilla Arch into the Clarence-Moreton Basin where the Gatton Sandstone and overlying Ma Ma Creek Member of the Koukandowie Formation are equivalents.

This aquitard is thickest along the axis of the Mimosa Syncline in the Surat Sub-basin, in the north-central Poolowanna Trough, and to a lesser extent along the northwestern side of the Central Eromanga Depocentre (>100 m). South of here, over the Gidgealpa-Merrimelia-Innamincka (GMI) Ridge and above the Wilson Depression, Nappamerri and Tenaperra troughs of the Cooper Basin, the aquitard is largely absent through erosion, so that the overlying Hutton Aquifer lies in direct contact with the Cooper Basin.
Evergreen-Poolowanna Aquitard and Equivalents

Great Artesian Basin

Evergreen-Poolowanna Aquitard and Equivalents

Outcrop/subcrop

Area of Great Artesian Basin where the hydrogeological unit does not exist

Isopach contour (metres)

Bathymetry contour (depth in metres)

Tropic of Capricorn

Data location

City/town

Thickness (metres)

0 155 305

Scale: 1:9 000 000

Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S
Central Meridian: 140°E
Datum: Geocentric Datum of Australia

10°S 15°S 20°S 25°S 30°S

135°E 140°E 145°E
The Precipice Sandstone is the basal aquifer and is present only in the eastern GAB where it parallels the northeastern side of the Surat Sub-basin, and extends over the Nebine Ridge into the northeastern side of the Eromanga Sub-basin up to the Longreach Basement High where its western limit is against the Canaway Ridge (see Maps 4–7).

From the Surat Sub-basin this aquifer also extends southwards around the Kumbarilla Arch into the northeastern side of the Clarence-Moreton Basin where the equivalent aquifer unit is the Ripley Road Sandstone.

A basal Lower Jurassic sandstone has been identified as an equivalent underlying the Hutton Sandstone around the Longreach Basement High into the Lovelle Depression where these thin outliers, possible erosional remnants, tend to adjoin major faults.

The Precipice Aquifer and Equivalents rarely exceeds 150 m thickness. It is thicker near outcrop in the northern Surat Sub-basin and within the Mimosa Syncline, as well as into the easternmost Eromanga Sub-basin. The aquifer thins and wedges out to the southwest of these regions.
Precipice Aquifer and Equivalents

Data location

City/town

Isopach contour (metres)
Bathymetry contour (depth in metres)
Tropic of Capricorn

Great Artesian Basin
Precipice Aquifer and Equivalents
Outcrop/subcrop
Area of Great Artesian Basin where the hydrogeological unit does not exist

Legend

Thickness (metres)

0
100
200
300
400

0
25
50
75
100

12-8/2011

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia
Hydrochemistry of the regional aquifers of the Great Artesian Basin
Introduction

Groundwater hydrochemical analysis can significantly improve understanding of processes controlling groundwater movement, recharge mechanisms, the age of groundwater, inter-aquifer connectivity and the likely chemical compositions of the aquifer material. A brief summary of some of the key hydrochemical parameters that are used to assist the understanding of groundwater systems are included below.

**Total dissolved solids (TDS)**

Total dissolved solids (TDS) is a measure of the total amount of salts dissolved in water and very fine particulate matter and is an indicator of salinity. As groundwater flows through an aquifer its chemistry evolves due to a combination of processes and interactions with the aquifer rocks, such as dissolution and precipitation of minerals. This generally results in a gradual increase in TDS down-flow, which can be used to approximate groundwater geochemical evolution paths and flow directions.

**pH**

pH is a fundamental property that describes groundwater acidity and is a measure of the activity of the hydrogen ion (H⁺). The pH largely controls the amount and chemical form of many organic and inorganic substances dissolved in groundwater. Many important properties of water are determined by pH; for example, both the suitability of groundwater for domestic and commercial uses and the occurrence and mobility of minor and trace elements.

**Alkalinity**

Alkalinity is a measure of the acid neutralizing capacity of water. Examples of alkaline ions include hydroxide, bicarbonate and carbonate ions. When an acid is added to water, these compounds combine with hydrogen ions (H⁺), to resist sudden changes in the pH of the water. This buffering action prevents waters from becoming acidic.

Alkalinity in groundwater is dependent on the following: recharge processes and rainfall composition; interactions with the aquifer material (dissolution/precipitation of minerals); and biological processes. As groundwater flows through an aquifer it may dissolve carbonates, giving rise to an increase in the alkalinity and the calcium concentration of the waters. Further reactions, namely exchange of calcium for sodium, potassium or hydrogen ions from clay minerals and biologically mediated generation of methane may drive sustained dissolution of carbonates and further rises in alkalinity.

**Calcium**

Calcium is useful for studying chemical weathering. Following the infiltration of rainfall, the evolutionary path of groundwater generally begins from low salinity, low alkalinity, slightly acidic groundwater, to Ca-Mg-HCO₃-CI type groundwater to Na-HCO₃-CI dominant groundwater and finally Na-CI and Na-CI-SO₄ type groundwater. The relatively faster weathering rate of carbonate rocks compared to silicate rocks exercises an important control on water chemistry. The Ca-Mg/HCO₃ ratio can be used to indicate a source of carbonate.

Dissolution of carbonate minerals lead to elevated alkalinity levels and Ca²⁺ and Mg²⁺ ion concentrations. As the groundwater progresses basinsward, ion exchange occurs and Na present in clays is exchanged for Ca and Mg.

**Sodium**

Sodium concentration is often used with reference to chloride in groundwater samples to differentiate sources of salinity. Seawater has a molar Na/Cl ratio of 0.65:1 and, if Na/Cl values lie above the seawater-dilution line, this indicates that sodium is derived from water-rock interaction such as silicate weathering or cation exchange. Values above the seawater-dilution line can often be found at lower sodium concentrations whereas high sodium concentrations are often strongly correlated with a marine signature.

**Chloride**

Chloride (Cl) is considered to be a conservative ion. Once it is introduced into the groundwater it remains dissolved because there are no water–rock interactions that can remove chloride from the groundwater, although halite dissolution may increase the concentration of Cl ions. In contrast, the other major ions can be adsorbed, desorbed, precipitated or dissolved in solution by various hydrochemical and/or biochemical processes. Decreases in chloride concentration in aquifers typically indicate mixing whereas increases in chloride concentration, in confined aquifers, typically results from diffusion of chloride ions from marine-derived mudstones or sediments or ingress of saline water.

**Magnesium**

Magnesium in solution originates from water-rock interactions with igneous or metamorphic minerals (amphiboles, pyroxenes, olivine and biotite) or from the dissolution of calcium-magnesium enriched calcite in sedimentary environments. Elevated levels of magnesium are found in volcanic-sourced sediments or waters with a marine origin.

The ratio Mg/Ca is a useful tracer of water origin as distinctly high values are found in seawater (Mg/Ca is 5.43:1) whereas a typical ratio in groundwater is 1:1 due to equilibrium with dolomite and calcite. Decreases in magnesium concentration are largely due to ion exchange in clays.

**Sulphate**

The concentration of sulphate and sulphide in groundwater or surface water is primarily controlled by mineral dissolution/precipitation and redox reactions between sulphate and sulphide minerals. In shallow groundwater, sulphur mainly occurs as sulphate (SO₄²⁻) but can be reduced to sulphide (HS⁻) under strongly reducing conditions. Due to the very low solubility of metal sulphides, these minerals precipitate out of solution and there is a net removal of sulphur from the groundwater. Highly reducing conditions typically occur at depth in the presence of organics such as coal or oil but can also occur in organic rich lake and river sediments.
Hydrostratigraphic units—

occurs at depth, in the absence of coal and other organics, a +20 ‰ can be found in coal seam gas fields. Where the process occurs in the absence of sulphate and preferentially uses reduction of carbonate to methane occurs. This process highly enriched with carbonate minerals down flowpaths it acquires a heavier typically close to 0 ‰, thus as groundwater increasingly reacts and soil. Alternatively, carbonate minerals typically have a although this is can vary depending on the nature of the plants in recharge zones will have a DIC of approximately –20 ‰, resulting in an enrichment in groundwater because of the large variations in carbon reservoirs. The following maps depict groundwater chemistry and thickness defined in the preceding section—outcrop, extent and thickness.

Carbon isotopes

Carbon-13 (13C) is an excellent tracer of carbonate evolution in groundwater because of the large variations in carbon reservoirs. The 13C values of dissolved inorganic carbon (DIC) in groundwater are generally in the range of -5 to -25 ‰. The dissolved inorganic carbon of groundwater in contact with soil in recharge zones will have a 13C of approximately -20 ‰, although this is can vary depending on the nature of the plants and soil. Alternatively, carbonate minerals typically have a 13C typically close to 0 ‰, thus as groundwater increasingly reacts with carbonate minerals down flowpaths it acquires a heavier 13C signature.

Highly enriched 13C can also be found where bacterial reduction of carbonate to methane occurs. This process preferentially uses 14CO2 over 13CO2, resulting in an enrichment of 13CO2, in the dissolved inorganic carbon. The process only occurs in the absence of sulphate and 13C values as high as +20 ‰ can be found in coal seam gas fields. Where the process occurs at depth, in the absence of coal and other organics, a 13C for the DIC of up to +2 ‰ typically results.

Potassium

The primary source of potassium in groundwater is from weathering of silicate minerals such as feldspars and micas. Initial concentration of potassium in the recharge zones closely reflect the mineralogy of the outcropping rock. As water moves down gradient, the original signature of the groundwater undergoes transformation due to secondary reactions (dissolution-precipitation or ion exchange) and mixing.

Oxygen and hydrogen isotopes

The stable isotopes of water (H2O) commonly used for groundwater studies are oxygen-18 (18O) and deuterium (1H). Using the isotopes of water itself allows the sources and processes of groundwater to be traced through isotopic fractionation. The oxygen-18 and deuterium composition of precipitation throughout the world is correlated and distributed along the global meteoric water line (GMWL). Due to the strong connection between oxygen and hydrogen, the GMWL is linearly related for precipitation that has not undergone evaporation. The GMWL provides a useful reference against which regional and/or local waters can be compared.

Several factors can cause water to plot above or below the GMWL including evaporation, water-rock interactions and geothermal mixing. Evaporation tends to produce 18O and 1H values below the GMWL, that sit along a line that intersects the GMWL at the location of the non-evaporated waters. This type of water is commonly found in the GAB and can be useful for understanding groundwater recharge processes. Groundwater with sufficient separation of 18O and 1H values can also be used to trace the water movement between aquifers.

Carbon isotopes

Carbon-13 (13C) is an excellent tracer of carbonate evolution in groundwater because of the large variations in carbon reservoirs. The 13C values of dissolved inorganic carbon (DIC) in groundwater are generally in the range of -5 to -25 ‰. The dissolved inorganic carbon of groundwater in contact with soil in recharge zones will have a 13C of approximately -20 ‰, although this is can vary depending on the nature of the plants and soil. Alternatively, carbonate minerals typically have a 13C typically close to 0 ‰, thus as groundwater increasingly reacts with carbonate minerals down flowpaths it acquires a heavier 13C signature.

Highly enriched 13C can also be found where bacterial reduction of carbonate to methane occurs. This process preferentially uses 14CO2 over 13CO2, resulting in an enrichment of 13CO2, in the dissolved inorganic carbon. The process only occurs in the absence of sulphate and 13C values as high as +20 ‰ can be found in coal seam gas fields. Where the process occurs at depth, in the absence of coal and other organics, a 13C for the DIC of up to +2 ‰ typically results.

Chlorine isotopes

The high solubility, conservative behaviour in groundwater and the natural occurrence of chlorine-36 (36Cl) in the environment, make this radiogenic isotope useful for studying salt and water transport within an aquifer system. Groundwater dating using 36Cl is based on (1) decay of cosmogenic 36Cl over long periods in the subsurface, or (2) 36Cl produced radioactively in the subsurface. Chlorine-36 has a half-life of 301 000 years.

Groundwater in recharge areas derives cosmogenic 36Cl from atmospheric production or surface production. Chlorine-36 isotope is produced naturally in the atmosphere by the bombardment of argon gas by cosmic radiation. Subsequently, 36Cl will enter the hydrological cycle through rainfall or as dry fallout. In the subsurface, the decay of (mainly) U, Th and K irradiates light elements and produces an in situ neutron flux, which acts upon 36Cl in the subsurface to produce a low background flux of 36Cl which will vary between aquifers and geological settings. A background 36Cl/35Cl value of approximately 10 x 1013 is the typical minimum value encountered in the GAB due to subsurface contributions.

There is a general trend of decreasing 36Cl/35Cl ratio in the GAB from recharge areas to discharge areas down regional flowpaths. In combination with chloride measurements and assumptions about mixing, flowrates can be determined using the half-life of chlorine-36.

Spatial mapping of groundwater chemistry

To allow interpretation and visualisation of the spatial distribution of various chemical and physical parameters of groundwater, spatial interpolation of point data representing concentration or magnitude is routinely used. The result is a continuous surface or grid with cells that represent a concentration or magnitude of the parameter. Recharge areas shown on the following maps correspond to the outcrop areas for the respective units, as defined in the preceding section—outcrop, extent and thickness.

The following maps depict groundwater chemistry concentration grids produced using a kriging surface interpolation method implemented via ArcGIS Geostatistical Analyst tool. Prediction standard error maps are included for each map to indicate prediction confidence levels. These maps illustrate the spatial standard error for a parameter and should be compared to the corresponding spatial maps. Where there is greater density of sample points, the prediction error is generally low. Interpolating over large distances, however, can lead to large prediction errors.
Low to moderate alkalinity values dominate the Wallumbilla-Rolling Downs Group Aquifers. Areas of low alkalinity (<300 mg/L) are found in the recharge zones in the northeast of the Eromanga Basin, across the Eureka Arch, the Eulo-Nebine Ridge area, northern Surat Subbasin, and the western margin of the Eromanga Sub-basin. Alkalinity values rarely exceed 500 mg/L across the basin.

Very low alkalinity values are observed west of the Eulo Ridge (see Map 4) and this corresponds with high calcium and sulphate concentrations and moderately high salinity. Sodium, calcium, sulphate and alkalinity plot above the seawater dilution line in this region, suggesting additional inputs from rock-water interactions. Parts of the groundwater in this region have Ca:Mg ratios greater than 40:1, suggesting that the Ca is not due to a marine signature or in equilibrium with calcite or dolomite. The Coreena and Doncaster members in this region contain minor components of muscovite, pyrite and calcite and the dissolution and oxidation of these minerals in low alkalinity environments could account for the elevated levels of Ca ions.

A striking feature of Wallumbilla-Rolling Downs Group alkalinity is the absence of high alkalinity, especially near the Central Eromanga Depocentre. While data coverage for this region is poor, the generally shallow and non-contiguous nature of the aquifers suggests that there is an absence of the large northeast-southwest flow paths found in the other GAB aquifers.
Wallumbilla-Rolling Downs Group Aquifers—Alkalinity

Alkalinity as CaCO₃ (mg/L)

- Great Artesian Basin
- Rolling Downs Aquitard
- Recharge zone
- No data

Area of Great Artesian Basin where the hydrogeological unit does not exist

Bathymetry contour (depth in metres)

Tropic of Capricorn

Groundwater sample location

City/town

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Predicted value error map
The Wallumbilla-Rolling Downs Group aquifers are shallow and generally brackish. It is an important sub-artesian stock water resource where access to underlying deep artesian aquifers is not economically viable.

High salinity is observed on the western GAB margin in the vicinity of the Finke River recharge zone, above the co-located low salinity feature in the deeper Cadna-owie – Hooray Aquifer (see Map 36). High levels of Na, Cl, SO₄, Ca and Mg occur in the region but only calcium, sulphate and alkalinity plot above the seawater dilution line, suggesting additional inputs from rock-water interactions. The Wallumbilla aquifer (Coorikiana Sandstone) contains minor components of gypsum, pyrite and calcite in this region and the dissolution and oxidation of these minerals in low alkalinity environments would contribute to elevated levels of these ions. A similar, but less pronounced, sulphate contribution to the salinity in the northern recharge zones of the Eulo-Nebine Ridge, is consistent with low rates of recharge and an evaporated signature.

Although one of the shallowest and more accessible aquifers in the GAB, there is little data on water quality, particularly in the southwestern Eromanga, along the southern margins and into the Carpentaria Sub-basin. Apart from along the Eulo-Nebine Ridge, the generally brackish nature of the aquifer and poor yields results in a relatively sparse distribution of groundwater bores.
Large regions of the Cadna-owie – Hooray Aquifer display low to moderate alkalinity.

Areas of low alkalinity (<300 mg/L) include recharge zones, much of the Eureka Arch and Carpentaria Sub-basin and the western Eromanga Sub-basin. Moderate values (<500 mg/L) are observed in northwestern Eromanga Sub-basin, the Eulo-Nebine Ridge area, and the Coonamble Embayment/southern Surat Basin.

Characteristic lower alkalinity values (<200 mg/L) are observed for recharge zones and younger waters, with values gradually increasing as they flow through the basins (i.e. down potentiometric gradient). This is clearly observed in the eastern Eromanga flow system, starting with low values in the recharge zone of the northeastern Eromanga Sub-basin, increasing to high values in the Central Eromanga Depocentre, which are then maintained through to discharge in the southern margin at the Lake Frome Embayment. An additional contribution to the high alkalinity accumulated in the central Eromanga Sub-basin is the decomposition of organic matter (oil and conventional gas accumulations are present within the Cadna-owie – Hooray aquifer in this area).

A region of low-value alkalinity is observed in the central region of the Eulo-Nebine Ridge, where the Westbourne and Birkhead aquifers thin or are absent. This is likely to be a result of mixing with lower alkalinity groundwater from deeper aquifers. Low alkalinity is observed in the Poolowanna Trough where sodium, chloride, potassium, magnesium, calcium and sulphate concentrations are all high. The aquifer in the western part of the basin is relatively shallow and predominantly quartzose sandstone compared to the quartz-lithic sandstone in the eastern Eromanga Sub-basin. The southwestern region of the basin is marked by low rainfall and high evaporation, but there is also a significant freshwater recharge component from the Finke River.

High alkalinity (>1000 mg/L) is observed in the deepest portion of the Surat Sub-basin in the vicinity of the Mimosa Syncline (see Map 4), and coincides with a strongly-depleted chloride isotope signature (Map 45), suggesting that this may be a region of low flow.
Figure 1: Predicted value error map of alkalinity as CaCO₃ (mg/L) in the Cadna-owie – Hooray Aquifer and Equivalents. The error map is predicted using the geostatistical indicator simulation technique (GIS). The map is produced using Surfer 14 software and projected on a Lambert Conformal Conic (LCC) projection with a datum of Geocentric Datum of Australia (GDA94). The spatial resolution is 1:9,000,000. The map shows the predicted value error for alkalinity as CaCO₃ (mg/L) with error ranges of low, medium, and high. The map also includes bathymetry contours (depth in metres) and groundwater sample locations.

Key to symbols:
- Great Artesian Basin
- Cadna-owie – Hooray Aquifer and Equivalents
- Recharge zone
- Area of Great Artesian Basin where the hydrogeological unit does not exist

Legend:
Alkalinity as CaCO₃ (mg/L)
- 1000
- 700
- 300
- 200

Groundwater sample location
City/town

Bathymetry contour (depth in metres)

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 35°S, 25°S - Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Error
Low
High
The Cadna-owie – Hooray Aquifer is one of the most widely utilised groundwater resources in the GAB. Large portions of the aquifer contain fresh groundwater that is suitable for human consumption.

The salinity as indicated by TDS, shows significant regional variability and recognizable trends. Measured TDS values range from less than 100 mg/L to more than 50 000 mg/L.

Generally low salinity is found along the eastern margins of the Eromanga, Carpentaria and Surat sub-basins, proximal to recharge zones. Cape York is dominated by low salinity due to the high annual rainfall and high rates of recharge to the groundwater.

High salinity values are observed in the southwestern Eromanga Sub-basin near the recharge zone, where recharge rates are extremely low and salt deposits are present at the surface.

In the Eromanga Basin, increasing salinity is observed down flowpaths. Regional maxima are observed within the deeper parts of the basin coincident with the Poolowanna Trough and Central Eromanga Depocentre.

The low-salinity anomaly centred on the Eulo-Nebine Ridge is likely due to enhanced recharge and mixing with other aquifers due to thinning or the absence of the Birkhead and Westbourne aquitards in this region. A small low-salinity plume on the western margin of the Eromanga Sub-basin (immediately north of the South Australia/Northern Territory border) is associated with fresh water recharge from the Finke River during flood events.

Brackish groundwater is present in the northeastern corner of the Surat Sub-basin as the Cadna-owie – Hooray Aquifer merges with outcropping Kumbarrilla Beds. Typically, salinity increases along flow lines from the recharge zones to the deeper parts of the basin. The presence of higher salinity groundwater coincides with low levels of permeability and low recharge rates in this region. Compared to other parts of the basin, the aquifer source materials include higher proportions of clay and interbedding of siltstones and mudstones, which tends to reduce permeability. A strongly depleted chlorine isotope signature (see Map 45) adjacent the recharge zone is coincident with the Mimosa Syncline and suggests that this may be a region of very low flow. Additionally, it is possible that increased salinity may be a result of vertical flow from underlying higher salinity aquifers along fractures or faults.
Chloride concentrations in the Cadna-owie – Hooray Aquifer show significant regional variability and largely mirror the distribution of total dissolved solids concentrations.

Regions of low chloride are found extending from the northeastern Eromanga recharge zone towards the central portion of the Eureka Arch; adjacent to the Eulo Ridge and its associated springs; and within the Pilgara region of the eastern Coonamble Embayment. The arc of low chloride concentration, extending from the northeastern Eromanga recharge zone (north of Longreach), southwest to Birdsville, then south along the Birdsville Track Ridge, coincides with a zone of higher groundwater flow. This zone of enhanced groundwater flow transports relatively young, low-chloride waters from the northeast recharge zone along groundwater flow paths to the central parts of the basin (see Map 10). Differing inferred groundwater flow rates, between the shallow and deep parts of the basin, are likely to be due to the increased effects of compaction and cementation on the aquifer, as depth increases (see Map 3). Regions of elevated chloride (>500 mg/L) occur within the western Eromanga Sub-basin; from the Central Eromanga Depocentre south to the southern margin; around the northeastern margin of the Surat Sub-basin; and localised regions on the Eulo-Nebine Ridge. Except for the central Eromanga Sub-basin, these regions of elevated chloride are characterised by Na-CI type chemistry or Na-CI-SO₄ for the western Eromanga Sub-basin. Much of the Na-CI dominated chemistry regions are likely to be influenced by the downward diffusion of ions from the marine mudstones of the Rolling Downs Aquitard due to greater concentrations in the Rolling Downs Aquitard relative to the underlying aquifers.

In the northeastern part of the Surat Sub-basin, low permeability and the presence of clays, siltstones and mudstones with marginal-marine depositional histories are likely to contribute to the elevated chloride concentration.
MAP 37

Cadna-owie – Hooray Aquifer—Chloride

Chloride (mg/L)

Great Artesian Basin
Cadna-owie – Hooray Aquifer and Equivalents
Recharge zone
Area of Great Artesian Basin where the hydrogeological unit does not exist
Sodium is the dominant cation in the Cadna-owie – Hooray Aquifer and its concentration is mirrored by the total dissolved salt concentration and, to a large extent, chloride concentration.

The dominance of sodium is likely related to the weathering of Na-bearing silicate minerals, cation exchange and conversion of Na-smectite to kaolinite with the release of Na to solution. The Na-dominant geochemical signature may, however, be influenced to some extent by the diffusion of salts from overlying or underlying aquitards with marginal-marine deposition.

Generally low sodium (<200 mg/L) is found in the Carpentaria Sub-basin, the eastern margins of the Eromanga Sub-basin, proximal to the recharge zone and in the centre of the Eulo-Nebine Ridge; and large parts of the Coonamble Embayment. The significant decrease in sodium in the centre of the Eulo-Nebine Ridge can be attributed to mixing with lower-salinity waters from the deeper Hutton Aquifer. The Birkhead-Walloon Aquitard that separates these two aquifers is absent in this part of the GAB.

High sodium values are observed in the south western Eromanga Sub-basin near the recharge zone, where recharge rates are extremely low and salt deposits are present at the surface. In the Eromanga Sub-basin, increasing salinity is observed down flow paths. Regional maxima are observed within the deeper parts of the basin coincident with the Poolowanna Trough and central Eromanga Depocentre.

Elevated sodium concentrations are present in the northeastern corner of the Surat Sub-basin, within and proximal to outcrop areas. Typically, salinity increases along flow lines from the recharge zones to the deeper parts of the basin. The presence of higher-sodium groundwater coincides with regions of low levels of permeability and low recharge rates. This is supported by an evaporated water isotope signature of the groundwater and the presence of clays and interbedding of siltstones and mudstones within the sandstone formation in these areas. These features will tend to reduce permeability and the clays will be a source of additional sodium ions.
Weakly acidic groundwater (pH=5.5–6) clearly delineates recharge zones within the Cadna-owie – Hooray Aquifer and generally reflects lower alkalinity values (see Map 35).

The pH values gradually increase with groundwater flow through the basin (i.e. down potentiometric gradient). This is clearly observed in the eastern Eromanga flow system, starting with pH ~ 5.5–6 in the recharge zone of the northeastern Eromanga Sub-basin, increasing to pH ~ 7.5–8.5 toward the central Eromanga Depocentre, which is then maintained through to discharge in the southern margin at the Lake Frome Embayment.

Similarly, weakly acidic groundwater is observed in the recharge zone along the northern portion of the Eulo-Nebine Ridge, a portion of the northern margin of the Surat recharge zone, eastern margin of the Surat Sub-basin, and eastern margin of the Coonamble Embayment. All flow within the Surat Sub-basin converges to the southern margin along the Eulo-Nebine Ridge. Cape York is dominated by weakly acidic groundwater due to the high annual rainfall and high rates of recharge to the groundwater.

Alkaline conditions (pH > 7.5) exist in the northeast corner of the Surat Basin within and proximal to the aquifer outcrop areas. This region is characterised by elevated salinity and low permeability and low recharge rates. The intake beds in this region are characterised by clayey sandstones with mudstone and siltstone interbedding and minor coal, which will tend to increase pH. High pH (> pH 8.5) groundwater and methane gas found adjacent to the Mimoso Syncline is likely to be due to the bacterial conversion of carbonate to methane and the corresponding consumption of acidity. This process is most likely responsible for most of the observed elevated pH across the deeper parts of the Surat Sub-basin.

Generally near neutral pH values are observed in the western and unconfined southwestern region of the Eromanga Sub-basin and these correspond with low alkalinity. Field pH measurements in this region are limited so predictions need to be considered with caution. The low alkalinity of the region makes the use of laboratory pH data particularly unsuitable, as it would tend to give higher readings than field measurements. The generally neutral pH values are consistent with the comparatively shallow nature of the aquifer and the paucity of evidence for methane gas or the presence of other organics. The region is also characterised by clean sandstones containing no volcanic and limited clay material, unlike the eastern region of the GAB. Given this, there is little opportunity for increased pH through dissolution of carbonate minerals or through bacterial conversion of carbonate to methane.
Cadna-owie – Hooray Aquifer—pH

Recharge zone
Area of Great Artesian Basin where the hydrogeological unit does not exist
Hooray Aquifer and Equivalents

Sulphate concentrations are generally low to moderate across the majority of the Cadna-owie – Hooray Aquifer

Elevated sulphate levels are observed along the north section of the Eulo-Nebine Ridge and in the northern margin of the Surat Sub-basin. The elevated sulphate concentrations correspond with elevated concentrations of magnesium (see Map 41), calcium (see Map 42) and weakly acidic groundwater (see Map 39). This is characteristic of recharge waters and suggests that this is a zone of high recharge flow. Similar groundwater chemistry with elevated sulphate is observed in the northern Eromanga Sub-basin in the recharge zones over the Euroka Arch.

Low sulphate is observed adjacent the recharge areas near the Longreach Basement High in the northeastern recharge zones in the Eromanga Sub-basin, directly below Lake Eyre on the southern margin of the basin and against the Mount Isa Block. This is potentially due to strongly reducing conditions and the conversion of sulphate to sulphide.

Moderate to low levels are observed for much of the Surat Basin and Coonamble Embayment. Very low levels are observed over the central and southern part of the Eulo Ridge, where Westbourne and Birkhead aquitards thin or are absent and there is likely mixing with groundwater from the deeper aquifers with low sulphate concentration.

High levels of sulphate are found in the western and southwestern recharge zones of the Eromanga Sub-basin. The very high values present basinward, away from the recharge zones where the aquifer is confined, may be due to sulphate leaching from the overlying Bulldog Shale. The deuterium and oxygen-18 ratios in this region also show a strongly evaporative signal, which is consistent with the accumulation of saline groundwater and the presence of surficial gypsum deposits.
Map 40
Cadna-owie – Hooray Aquifer—Sulphate

Predicted value error map

- Great Artesian Basin
- Cadna-owie – Hooray Aquifer and Equivalents
- Recharge zone
- Area of Great Artesian Basin where the hydrogeological unit does not exist

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Great Artesian Basin
Cadna-owie – Hooray Aquifer
and Equivalents
Recharge zone
Area of Great Artesian Basin where the hydrogeological unit does not exist

Sulphate contour (mg/L)
Bathymetry contour (depth in metres)
Tropic of Capricorn
Groundwater sample location
City/town

Sulphate (mg/L)

Error
Low
High

0
5000
70

0 250 500 km

0 100 200 300 400 500 km
Magnesium concentrations in the Cadna-owie – Hooray Aquifer show significant regional variability with spatial trends that are generally comparable to those of calcium (see Map 42).

Moderate magnesium concentrations (>10 mg/L) are observed in or near the recharge zones along the eastern margin of the GAB, with a gradual decrease along flow lines to the west and southwest, as a result of precipitation and ion exchange with clays. Low values are observed along the Birdsville Track Ridge flowpath through to the regional discharge zone at Lake Eyre South.

Elevated magnesium concentrations are found in the Central Eromanga Depression which decrease marginally then remain elevated towards the southern margin and Lake Frome Embayment. Sodium, calcium, sulphate and alkalinity plot above the seawater dilution line in this central region suggesting there is significant water-rock interaction. Variable Ca:Mg ratios exist in this central region, with generally low ratios (~1:4) where Mg and Ca concentrations are high, and high ratios eastwards of the depocentre where Mg and Ca concentrations are low. There is a mixed signal south of the Central Eromanga Depocentre and generally high ratios towards the southern discharge margin. This suggests that the area of the Central Eromanga Depocentre is likely to be a zone of mixing with groundwaters originating from the eastern margins.

High magnesium concentrations are found in the southwestern region of the Eromanga Sub-basin proximal to the recharge areas where the aquifer is unconfined. The very high concentrations in the southwestern region could be due to sulphate leaching from the overlying Bulldog Shale. The influence of the Finke River groundwater recharge plume in the western Eromanga Sub-basin (east of 135° longitude) is evident in this region and results in a significant reduction of the magnesium concentration.
Cadna-owie – Hooray Aquifer—Magnesium

Predicted value error map

- **Great Artesian Basin**
- **Cadna-owie – Hooray Aquifer and Equivalents**
- **Recharge zone**
- **Area of Great Artesian Basin where the hydrogeological unit does not exist**

**Magnesium (mg/L)**

- Low
- High

- 0
- 50
- 100
- 150
- 200

- **Depth in metres**
- **Groundwater sample location**
- **City/town**

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia

**Tropic of Capricorn**

**Groundwater sample location**

**City/town**

**Recharge zone**

**Area of Great Artesian Basin where the hydrogeological unit does not exist**
Calcium is the third most dominant cation in the Cadna-owie – Hooray Aquifer.

The calcium concentration is generally mirrored by the magnesium concentration (see Map 41) and, to a large extent, chloride concentration (see Map 37). Measured calcium concentrations range from less than 0.1 mg/L to 850 mg/L.

Similar to magnesium, moderate values (>10 mg/L) are observed for recharge zones and younger waters along the eastern margin of the GAB. This is clearly observed in the eastern Eromanga flow system, starting with higher values in the recharge zone of the northeastern Eromanga, decreasing to low values in the central Eromanga Sub-basin. Similarly, in the recharge zones along the northern portion of the Eulo-Nebine Ridge, northern margin of the Surat recharge zone, eastern margin of the Surat Sub-basin, and eastern margin of the Coonamble Embayment. All flow within the Surat Sub-basin converges to the southern margin along the Eulo-Nebine Ridge. Low values are observed along the Birdsville Track Ridge flowpath through to the regional discharge zone at Lake Eyre South.

Calcium levels decrease somewhat from the central depocentre towards the southern regional discharge zones but elevated levels are maintained towards the Lake Frome Embayment. These elevated calcium levels parallel elevated sodium and chloride concentrations in the region and are most likely due to downward diffusion of ions from the marine mudstones of the Rolling Downs Aquitard.

High calcium values are found in the southwestern unconfined region of the Eromanga Sub-basin due to a combination of weathering and evaporation. The Finke River groundwater recharge plume in the western Eromanga Sub-basin is overprinted in this region and results in a significant reduction of the calcium concentration.
**Cadna-owie – Hooray Aquifer – Calcium**

- **Map Legend**:
  - **Great Artesian Basin**
  - **Cadna-owie – Hooray Aquifer and Equivalents**
  - **Recharge zone**
  - **Area of Great Artesian Basin where the hydrogeological unit does not exist**

- **Map Features**:
  - **Calcium contour (mg/L)**
  - **Bathymetry contour (depth in metres)**
  - **Tropic of Capricorn**
  - **Groundwater sample location**
  - **City/town**

- **Other Notations**:
  - **Scale**: 1:9,000,000
  - **Projection**: LAMBERT CONFORMAL CONIC
  - **Parallels**: 25°S, 35°S
  - **Central Meridian**: 140°E
  - **Datum**: Geocentric Datum of Australia

- **Color Scale**:
  - Calcium (mg/L) values range from 0 to 850 mg/L.
  - Colors range from light blue (low calcium) to red (high calcium).

- **Predicted value error map**
  - High error
  - Low error

- **Textual Information**:
  - “Area of Great Artesian Basin where the hydrogeological unit does not exist”
  - “Calcium contour (mg/L)"
Potassium concentrations in the Cadna-owie – Hooray Aquifer show significant regional variability, with generally low levels in the Surat Sub-basin, high values in the central and western Eromanga Sub-basin and moderate values in the northern Eromanga and Carpentaria sub-basins. Toward the southwestern boundary of the Eromanga Sub-basin, potassium values generally exceed 20 mg/L, although the impact of the Finke River plume is clearly evident with a corresponding reduction in potassium concentration. The deuterium and oxygen-18 ratios in this region also show a strongly evaporative signal and potassium is strongly correlated with chloride and the seawater dilution line. Much of the potassium is probably sourced from brine advection from surface playas.

Similar to calcium and magnesium, elevated potassium concentrations (>5 mg/L) are observed for recharge zones and younger waters along the eastern margin of the GAB, particularly in the Surat Sub-basin. Higher values are observed in the recharge zones along the northern portion of the Eulo-Nebine Ridge, northern margin of the Surat recharge zone, eastern margin of the Surat Sub-basin, and eastern margin of the Coonamble Embayment. There is a strong correlation between elevated levels of potassium in the recharge zones and low alkalinity and low sodium concentrations in much of the Surat Sub-basin. This suggests there is significant ion exchange with clays along flowpaths as groundwater moves from the recharge zones into the deeper parts of the Surat Basin. Low levels are observed on the central part of the Eulo-Nebine Ridge, corresponding with the thinning or absence of the Westbourne and Birkhead-Walloon aquifers and mixing with deeper groundwater sources.

The pattern of potassium in the central Eromanga Sub-basin is quite different to that in the Surat Sub-basin and may be a consequence of differing aquifer source sediments, containing less volcanic and clay material. Potassium levels are maintained from the recharge zones along regional flowpaths toward the Central Eromanga Depocentre, where they increase and remain relatively high through to the southern regional discharge zones within the Lake Frome Embayment. This pattern is mirrored by sodium and chloride concentrations in the region and is inferred to be due to downward diffusion of ions from the marine mudstones of the Rolling Downs Aquitard.
Cadna-owie – Hooray Aquifer—Potassium

- Great Artesian Basin
- Cadna-owie – Hooray Aquifer and Equivalents
- Recharge zone
- Area of Great Artesian Basin where the hydrogeological unit does not exist

- Potassium contour (mg/L)
- Bathymetry contour (depth in metres)
- Tropic of Capricom
- Groundwater sample location
- City/town

Predicted value error map

Scale: 1:9,000,000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Potential error in potassium (mg/L) ranges from low to high.
Low fluoride concentrations are found in all the recharge zones: the northern Eromanga Sub-basin; the northern Eulo-Nebine Ridge region; eastern Surat Sub-basin/Coonamble Embayment; and the western Eromanga Sub-basin.

In the Eulo-Nebine Ridge area, fluoride concentrations are low where the Westbourne and Birkhead aquitards thin or are absent, and is likely to be the result of mixing with lower fluoride groundwater from deeper aquifers. Further west, high levels of fluoride are found around the granitic basement outliers near Eulo Springs and extend further south towards the Yancannia Range. Similarly, high levels of fluoride are found on the northwestern extent of the Eromanga Sub-basin and the western margin against the Mt Isa basement terrain. The interpolated high fluoride concentrations north of the Euroka Arch into the Carpentaria Basin are based on little or no data and high prediction errors are associated with fluoride concentration in this area.

Parts of the Cadna-owie – Hooray Aquifer have fluoride levels greater than the NHMRC recommended drinking water guideline of 1.5 mg/L.

High fluoride concentrations in the artesian groundwater have been attributed to groundwater being in contact with igneous (hydrogeological basement) rocks or with clay minerals and micas. The elevated fluoride concentrations in the eastern part of the Surat Sub-basin have been previously attributed to mixing with groundwater from deeper aquifers along the Leichhardt-Burunga and Goondwindi-Moonie Fault system. Recent mapping has found these faults do not extend to any significant degree into the Surat Sub-basin sequence but basin folding during the Late Cretaceous resulted in reactivation of earlier structures and potential small-scale fracturing in the upper sequences. While it is possible that there is connection between adjacent aquifers, an alternative explanation is that fluoride is released from the weathering of micas and clays within the source sediments. The northeastern boundary of the Surat Sub-basin is an area of low recharge and groundwater flow and the aquifer material has a volcanogenic sediment source. Weathering of the source material and conversion of kaolinite to illite would tend to release fluoride ions which could accumulate in the adjacent stagnant flow conditions of the Mimosa Syncline. A similarly high level of fluoride is observed down flowpaths from the northeastern recharge zones in the Eromanga Sub-basin in the Longreach Basement High and has been attributed to weathering of micas and facies control.
Predicted value error map

Error
- High
- Low

Fluoride contour (mg/L)
Bathymetry contour (depth in metres)
Tropic of Capricom
Groundwater sample location
City/town

Great Artesian Basin
Cadna-owie – Hooray Aquifer and Equivalents
Recharge zone
Area of Great Artesian Basin where the hydrogeological unit does not exist

Fluoride (mg/L)

0
2.5
11

Scale: 1:9,000,000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Great Barrier Reef
Gulf of Carpentaria
Tropic of Capricom
Tropic of Cancer
Broken Hill
Lyndhurst
Coober Pedy
Port Augusta
Adelaide
Brisbane
Gold Coast
Sydney
Melbourne
Perth
Canberra
Port Moresby
Darwin
Brisbane
Sydney
Melbourne
Perth
Canberra
Port Moresby
Darwin

Fluoride (mg/L)
2.5
11
0
Map 45
Cadna-owie – Hooray Aquifer

$^{36}$Cl/Cl Ratio

Chlorine-36 ($^{36}$Cl) is a naturally-occurring radiotracer useful for understanding regional flow paths and can be used to determine flow rate and the age of groundwater. With a half-life of 300,000 years, chlorine-36 is an ideal tool for extensive groundwater systems such as the GAB.

High chlorine-36 values are present in all the major recharge zones: the northern Eromanga Sub-basin; the northern Eulo-Nebine Ridge region; eastern Surat Sub-basin/Coonamble Embayment; and the western Eromanga Sub-basin. These recharge zones identified by a high chlorine-36 signature are mirrored by low alkalinity concentrations (see Map 35).

Low chlorine-36 values are found within the Mimosa Syncline of the Surat Sub-basin, the northern end of Cape York, and the central and southern parts of the Eromanga Sub-basin. The presence of highly-depleted chlorine-36 values adjacent to the recharge zone in the northeastern Surat Sub-basin suggest that groundwater flow rates in this region are very slow.

Data density for chlorine-36 analysis is much lower than all other chemistry parameters mapped in this Atlas and there are a number of significant data gaps. One critical data gap is in the northeastern recharge zone of the Surat Sub-basin across the Kumbarilla Ridge. There is considerable uncertainty around the groundwater flow paths for this part of the Basin and further chlorine-36 measurements would assist with determining recharge zones and the flow regime in this region.
Chlorine isotopes ($^{36}\text{Cl}/\text{Cl} \times 10^{-15}$)

- **Great Artesian Basin**
- **Cadna-owie – Hooray Aquifer and Equivalents**
- **Recharge zone**
- **Area of Great Artesian Basin where the hydrogeological unit does not exist**

**Chlorine isotope contour ($^{36}\text{Cl}/\text{Cl} \times 10^{-15}$)**

**Bathymetry contour (depth in metres)**

**Tropic of Capricorn**

**Groundwater sample location**

**City/town**

**Predicted value error map**

Scale: 1:9,000,000

Projection: LAMBERT CONFORMAL CONIC

Parallels: 25°S, 35°S  Central Meridian: 140°E

Datum: Geocentric Datum of Australia

Chlorine isotope contour ($^{36}\text{Cl}/\text{Cl} \times 10^{-15}$)
Hooray Aquifer and Equivalents

—Deuterium (²H Hydrogen)

Deuterium is the most conservative species in groundwater and indicates recharge phenomena and flow in the aquifer.

Recharge zones in the northeastern regions of the Eromanga Sub-basin have signatures typically less than -45 per mil (SMOW) and this is largely retained along basin-wide flowpaths through the Central Eromanga Depocentre or through the Poolowana Trough to discharge zones at the southern margins and western margins of the Eromanga Sub-basin. The Finke River groundwater recharge plume in the western Eromanga Sub-basin is an exception and has the lightest deuterium signature within the GAB. Recharge from the Finke River would only occur occasionally and the light signature suggests recharge primarily from monsoonal rainfall events and flooding with minimal evaporation ¹. Deuterium values in the Surat Sub-basin are enriched (> -45 per mil (SMOW)) in the eastern recharge zone of the Coonamble Embayment. In contrast, the northeastern part of the Surat Sub-basin there is a rapid transition from > 55 per mil (SMOW) in the outcrop areas to less the < -40 per mil (SMOW) in the deprecentre of the basin. In this part of the basin, there is a strong signature of methanogenesis found in the δ¹³C of the dissolved inorganic carbon and reflected in the isotopic carbon-13 signature of the methane gas ².

A region of higher deuterium values is located on the central part of the Eulo-Nebine Ridge, coinciding with lower salinity. The Westbourne and Birkhead-Walloon aquitards thin or are absent in this region and the variation in deuterium is a likely response from mixing with groundwater from the deeper aquifers.
Recharge zone

Area of Great Artesian Basin where the hydrogeological unit does not exist

Deuterium contour (δ²H ‰ SMOW)

Bathymetry contour (depth in metres)

Groundwater sample location

City/town

Great Artesian Basin

Cadna-owie – Hooray Aquifer and Equivalents

Tropic of Capricorn

Deuterium (δ²H ‰ SMOW)
The oxygen-18 values broadly mirror corresponding deuterium values and ratios between the two parameters generally indicate a groundwater signature consistent with a slightly-evaporated rainfall signal. Recharge zones in the northern and northeastern regions of the Eromanga Sub-basin have signatures typically less than -7 per mil (SMOW) and this is largely retained along basin-wide flow paths through to the Poolowana Trough to discharge zones at the southern margins. Unlike the pattern for deuterium, the consistency of the signature is not maintained from the eastern recharge zones, across the Eromanga Depocentre towards the southern margin. This could be potentially due to prolonged periods of water-rock interaction, due to very low groundwater flow rates in this deeper region.

In the low-alkalinity, high-salinity region of the southwestern Eromanga Basin, the oxygen-18 has a significantly less-depleted signature. The deuterium and oxygen-18 ratios in this region exhibit a strongly evaporative signal, which is consistent with the accumulation of saline groundwater. The Finke River groundwater recharge plume in the western Eromanga Sub-basin is overprinted in this region and has the effect of depleting the groundwater oxygen-18. Recharge from the Finke River would only occur occasionally and the depleted signature suggests recharge primarily from monsoonal rainfall events and flooding with minimal evaporation.

An inverse of the typical relationship is observed in the northeastern corner of the Surat Sub-basin. Here the groundwater has an isotopically depleted signature compared to the adjacent outcrop areas to the north and east. Water isotope ratios are unusual in this deeper, low-flow region and plot to the left of Local and Global Meteoric Water Lines. The isotopic signature is consistent with microbial CO₂ reduction to methane (methanogenesis), which is reflected by the presence of methane gas in the groundwater with a carbonate reduction isotopic signature. Methanogenesis preferentially uses hydrogen from water molecules and this enriches the residual water in deuterium. An additional contributor could be the formation of clays by hydrolysis of feldspars and lithic fragments in the host sandstone, which would leave the residual fluid depleted in oxygen-18 and enriched in deuterium.
Oxygen isotopes ($\delta^{18}$O ‰ SMOW)

- Great Artesian Basin
- Cadna-owie – Hooray Aquifer and Equivalents
- Recharge zone
- Area of Great Artesian Basin where the hydrogeological unit does not exist

Oxygen isotope contour ($\delta^{18}$O ‰ SMOW)

Bathymetry contour (depth in metres)

Tropic of Capricorn

Groundwater sample location

City/town

Predicted value error map

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Oxygen isotopes ($\delta^{18}$O ‰ SMOW)
More negative δ¹³C values are found in the recharge zones, increasing to less negative values along regional groundwater flow paths. Weakly negative to positive values are found in regions where biological reduction of carbonate to methane is prevalent.

There is considerable regional variation in δ¹³C values with depleted isotopic values in the recharge zones (< -15 ‰ PDB) of the eastern Eromanga Sub-basin progressing to more enriched values along groundwater flow paths. Isotopically very light values are found in the recharge beds around Tambo and Torrens Creek on the eastern margin and in Cape York in the northernmost extent of the GAB. The highly negative values suggest there is little dissolution of carbonate minerals in these regions and δ¹³C values are dominated by the influence of soil CO₂.

In the central and western margins of the Eromanga Sub-basin the δ¹³C values typically range from -5 to -10 ‰ PDB. Enriched values are observed adjacent to the northwestern recharge zones of the Eromanga Sub-basin where the Longsight Sandstone outcrops against Cambro-Ordovician rocks, dominantly carbonate, of the Georgina Basin. Enriched values are also found at the western margin against the Mt Isa basement terrain.

A large region of isotopically depleted δ¹³C is found on the southern margin of the aquifer from Lake Frome Embayment to Lake Eyre. This is unexpected given the regional flow patterns and the general enrichment of δ¹³C down groundwater flow paths. Typically, isotopically depleted δ¹³C is found in recharge zones. It suggests there is significant mixing in this region with very old groundwater (based on the chlorine-36) with a more depleted δ¹³C signature.

A region of highly enriched δ¹³C is found in the deeper, central part of the Surat Sub-basin. Values here range from -3 to +2 ‰ and are due to bacterial CO₂ reduction, where ¹²CO₂ is preferentially used over ¹³CO₂, resulting in an enrichment of ¹²CO₂ in the dissolved inorganic carbon. The higher δ¹³C signal in the groundwater is supported by the unusual shift in water isotope ratios (see Maps 46 and 47) and the presence of methane gas with a carbonate reduction signature.

Consistent with the low alkalinity measurements, the presence of groundwater with a δ¹³C signature typical of recharge, in the northeastern corner of the Surat Sub-basin, suggests that the elevated level of salinity in the region is due to low aquifer permeability and low recharge rates, rather than vertical leakage from deeper formations.

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**Map 48**

**Cadna-owie – Hooray Aquifer**

**Carbon-13 (¹³C)**

More negative δ¹³C values are found in the recharge zones, increasing to less negative values along regional groundwater flow paths. Weakly negative to positive values are found in regions where biological reduction of carbonate to methane is prevalent.

A large region of isotopically depleted δ¹³C is found on the southern margin of the aquifer from Lake Frome Embayment to Lake Eyre. This is unexpected given the regional flow patterns and the general enrichment of δ¹³C down groundwater flow paths. Typically, isotopically depleted δ¹³C is found in recharge zones. It suggests there is significant mixing in this region with very old groundwater (based on the chlorine-36) with a more depleted δ¹³C signature.

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Consistent with the low alkalinity measurements, the presence of groundwater with a δ¹³C signature typical of recharge, in the northeastern corner of the Surat Sub-basin, suggests that the elevated level of salinity in the region is due to low aquifer permeability and low recharge rates, rather than vertical leakage from deeper formations.
Carbon isotopes ($\delta^{13}C$ ‰ PDB)

Recharge zone

Area of Great Artesian Basin where the hydrogeological unit does not exist

Great Artesian Basin

Cadna-owie – Hooray Aquifer

and Equivalents

Bathymetry contour (depth in metres)

Groundwater sample location

City/town

Predicted value error map

Error

High

Low

Scale: 1:9 000 000

Projection: LAMBERT CONFORMAL CONIC

Parallels: 25°S, 35°S

Central Meridian: 140°E

Datum: Geocentric Datum of Australia

Predicted value error map

High

Low

Carbon isotopes ($\delta^{13}C$ ‰ PDB)

Recharge zone

Area of Great Artesian Basin where the hydrogeological unit does not exist

Great Artesian Basin

Cadna-owie – Hooray Aquifer

and Equivalents
Map 49
Adori-Springbok Aquifer—Alkalinity

The Adori-Springbok Aquifer generally shows low to moderate alkalinity levels except for the Central Eromanga Depocentre.

Areas of low alkalinity (<300 mg/L) are restricted to the recharge zones along the eastern margins of the Eromanga Sub-basin, the northeastern margin of the Surat Sub-basin, across the Eulo-Nebine Ridge area and the northern Eromanga Sub-basin.

Within the Eromanga Sub-basin, the groundwater is characterised by low alkalinity in the east, and increasing alkalinity down flow paths towards the Central Eromanga Depocentre. The low alkalinity centred on the Eulo-Nebine Ridge is likely due to enhanced recharge and greater throughflow of groundwater from the eastern margin of the basin.

Low alkalinity at the northern extent of the Adori-Springbok Aquifer may be explained by vertical flow from the underlying Hutton Aquifer along the Cork Fault or mixing with the overlying Cadna-owie – Hooray Aquifer. The Cadna-owie – Hooray and Adori aquifers merge northward of this region.

Elevated alkalinity values are observed proximal to a portion of the northern recharge zone in the Surat Sub-basin, which may be attributed to either low aquifer permeability and recharge rates, or potential mixing with the deeper higher-alkalinity groundwater from the underlying Walloon Coal Measures.

In contrast to the Hutton Aquifer, recharge to the Adori-Springbok Aquifer on the eastern margin of the Surat Sub-basin is significant, based on the low alkalinity values.
Adori-Springbok Aquifer—Alkalinity

- **Great Artesian Basin**
- **Adori-Springbok Aquifer**
- **Recharge zone**
- **Area of Great Artesian Basin where the hydrogeological unit does not exist**

- **Alkalinity as CaCO₃ contour (mg/L)**
- **Bathymetry contour (depth in metres)**
- **Tropic of Capricorn**
- **Groundwater sample location**
- **City/town**

**Predicted value error map**

- **Error**
  - **High**
  - **Low**

**Scale:** 1:9,000,000
**Projection:** LAMBERT CONFORMAL CONIC
**Parallels:** 25°S, 35°S
**Central Meridian:** 140°E
**Datum:** Geocentric Datum of Australia

**Alkalinity as CaCO₃ (mg/L)**

- 300
- 700
- 3000

**Recharge zone**

Area of Great Artesian Basin where the hydrogeological unit does not exist

**Groundwater sample location**

**City/town**
The salinity of the Adori-Springbok Aquifer shows significant regional variability. Measured values range from 150 mg/L to over 2500 mg/L. Within the Eromanga Basin, the groundwater is characterized by low salinity in the west and increasing salinity down along the eastern margin of the Surat Sub-basin. The Springbok Sandstone is absent from the Walloon Coal Measures for this part of the Surat Sub-basin, suggesting a strong influence from mixing or ion diffusion from the Westbourne Formation.

Higher salinity along the northeastern margin of the Surat Sub-basin is a consequence of mixing with more saline groundwater from the underlying Walloon Coal Measures. The Springbok Sandstone may be explained by vertical flow from the underlying Jundah Coal Measures contain some of the most saline groundwater within the Surat Sub-basin.

The Springbok Sandstone is the equivalent of the Adori Sandstone in the Surat Sub-basin. Similar to other aquifers in the Surat Sub-basin, groundwater from the Springbok Sandstone is often indistinguishable from the overlying Westbourne Formation.

The Hooray Sandstone is the equivalent of the Adori Sandstone in the Surat Sub-basin. The Cadna-owie Fm and the overlying Hooray Sandstone form the Cadna-owie – Hooray Aquifer. The Cadna-owie – Hooray Aquifer is underlain by the Hutton Sandstone along the Cork Fault or recharge from the eastern margin of the Eromanga Sub-basin. Brackish groundwater in the northeastern part of the Surat Sub-basin is likely due to enhanced recharge of recharge waters from the eastern margin of the Cadna-owie Fm.
Adori-Springbok Aquifer—Total Dissolved Solids

Total dissolved solids contour (mg/L)

Recharge zone
Area of Great Artesian Basin where the hydrogeological unit does not exist

Great Artesian Basin
Adori-Springbok Aquifer

Bathymetry contour (depth in metres)
Tropic of Capricorn
Groundwater sample location
City/town

113
Large regions of the Hutton Aquifer, away from the eastern recharge zone, show elevated alkalinity levels.

Areas of low alkalinity (<300 mg/L) are restricted to the recharge areas along the eastern margins of the Eromanga Sub-basin, the northern extent of the Surat Sub-basin, across the Eulo-Nebine Ridge area and the northern Eromanga Sub-basin. The low alkalinity centred on the Eulo-Nebine Ridge is likely due to enhanced through flow of recharge waters from the eastern margin of the basin. The Warrego River is thought to be a prominent source of localised recharge to the outcropping Hutton Aquifer in this region.

The majority of the Surat Sub-basin has alkalinity values greater than 500 mg/L with a large portion in the central part of the sub-basin greater than 1000 mg/L. The central and western parts of the Eromanga Sub-basin have alkalinity values greater than 500 mg/L. The progressive increase of alkalinity from the north to the south in the Surat Basin and from the eastern recharge zones to the southwest in the Eromanga Sub-basin suggests hydrochemical evolution along regional flow paths. An additional contribution to the high alkalinity accumulated in the Central Eromanga Depocentre is the decomposition of organic matter (oil and conventional gas accumulations are present within the Hutton Aquifer in this region). High alkalinity (>1000 mg/L) is observed in the vicinity of the Mimosa Syncline which coincides with a strongly depleted chloride-36 isotope signature (see Map 53), suggesting that this may be a region of low flow, verging on stagnation. High levels of biogenic methane are found in this part of the sub-basin due to the reduction of dissolved inorganic carbon [1].

Northwards toward the Eureka Arch (see Map 5), there is direct hydraulic connection between the Hutton Aquifer and the overlying Cadna-owie – Hooray Aquifers as both Birkhead-Walloon and Westbourne aquitards wedge out and are absent over this basement high. This is a region of relatively high rainfall and recharge resulting in low alkalinity.
Hutton Aquifer and Equivalents—Alkalinity

Predicted value error map

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Alkalinity as CaCO₃ (mg/L)

Recharge zone
Area of Great Artesian Basin where the hydrogeological unit does not exist

Great Artesian Basin
Hutton Aquifer and Equivalents

Gulf of Carpentaria
Queensland
New South Wales
South Australia
Northern Territory
Papua New Guinea
Australia

15°S 20°S 25°S 30°S 35°S 40°S 45°S
10°E 15°E 20°E 25°E 30°E 35°E 40°E 45°E

Tropic of Capricorn
Great Barrier Reef
Coral Sea
Gulf of Carpentaria
Arafura Sea

Sydney
Darwin
Brisbane
Cairns
Townsville
Coffs Harbour
Port Augusta
St George
Weipa
Port Hedland
Broken Hill
Leigh Creek
Coober Pedy
Birdsville
Coober Pedy

115
Dissolved Solids

Hutton Aquifer and Equivalents—Total

The Hutton Aquifer contains a large amount of fresh groundwater in the eastern Eromanga Sub-basin. Brackish groundwater regions dominate the Central Eromanga Depocentre and almost the entire Surat Sub-basin.

The salinity values show significant regional variability. Measured TDS values range from less than 100 mg/L to more than 2500 mg/L.

Within the Eromanga Sub-basin, groundwater is characterised by low salinity in the east, increasing in salinity downflowpaths towards the Central Eromanga Depocentre. The low salinity centred on the Eulo Nebine Ridge is likely due to enhanced throughflow of recharge waters from the eastern margin of the basin. The Warrego River is thought to be a prominent source of localised recharge to the outcropping Hutton Aquifer in this region.

In the Surat Sub-basin, brackish groundwater is observed in and proximal to the northern recharge zones, except for outcrop areas near Tara and further west of Injune. High recharge rates have been measured near Injune, but low rates of recharge extend further east towards the north of Dalby. Similar to the Cadna-owie – Hooray Aquifer, the Hutton Aquifer in this region has low permeability and contains clays and interbedding of siltstones and mudstones. Interestingly, a one metre thick band of halite has been recorded in the Hutton Sandstone in a cave near Jandowae in this near eastern corner. It is unknown how laterally extensive the halite is and whether it contributes significantly to the elevated NaCl signature in the region. Regional flow dynamics are not well understood within the Hutton Aquifer and this northern region may be subject to stagnant flow conditions.

Salinity is highest near the northeastern Surat Sub-basin recharge zone (~150 km east of Roma), possibly due to a combination of the low recharge rates, presence of halite, and infiltration of more saline groundwater from overlying units (e.g. Walloon Coal Measures) in areas where the overlying Eurombah Formation (aquitard) is thin or absent. Additionally, diffusion of chloride ions is possible from the underlying Evergreen Formation, which is characterised by a fluvial and marginal to shallow-marine depositional environment. Sodium and chloride against bromide ratios tend towards seawater ratios at greater salinity levels within the Hutton Sandstone. This potential Evergreen Formation overprint on the Hutton Aquifer recharge water chemistry (i.e. low alkalinity and presence of elevated calcium, magnesium and sulphate) occurs in the northeastern region of the Surat Basin.

![Map 52: Hutton Aquifer and Equivalents—Total Dissolved Solids](image_url)
There is limited chlorine-36 data for the Hutton Aquifer but it does provide insight into recharge mechanisms and possible flow paths.

High chlorine-36 values are restricted to the northern extent of the Mimosa Syncline—Roma Shelf and eastern margin of the Surat Sub-basin, across the Kumbarilla Ridge into the Clarence-Moreton Sub-basin. There are anomalously low chlorine-36 values in the northeastern corner of the Surat Sub-basin, suggesting this is a region of stagnant flow or that it is strongly influenced by the presence of very old salts.

Away from the margins of the aquifer, there are few measurements, and predicted values shown on the map are associated with considerable error. The predictions reflect the alkalinity map (see Map 51), with low values throughout most of the Surat Sub-basin, particularly in the Mimosa Syncline, and elevated levels across the Eulo–Nebine Ridge and in the eastern part of the Eromanga Basin. There are two low chlorine-36 values found on the Eulo–Nebine Ridge and their location is coincident with the so called TACEM anomalies in the shallower Cadna-owie—Hooray Aquifer, which are two unusual, discontinuous areas of high chloride that occur within a region of low chloride concentration, located approximately 75 km west and 200 km northwest of Roma (see Map 37). These have been attributed to recharge events immediately following sustained periods of aridity and the leaching of salts from overlying aquifers.
Hutton Aquifer and Equivalents—$^{36}\text{Cl}/\text{Cl}$ ratio

Chlorine isotopes ($^{36}\text{Cl}/\text{Cl} \times 10^{-15}$)

Predicted value error map

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Great Artesian Basin
Hutton Aquifer and Equivalents
Recharge zone
No data
Area of Great Artesian Basin where the hydrogeological unit does not exist

Groundwater sample location
City/town

Chlorine isotope contour ($^{36}\text{Cl}/\text{Cl} \times 10^{-15}$)
Bathymetry contour (depth in metres)
Tropic of Capricorn

Cl/Cl ratio

Area of Great Artesian Basin where the hydrogeological unit does not exist
Northern regions of the Precipice Aquifer display low alkalinity but alkalinity increases markedly southwards within the Mimosa Syncline and across the Roma Shelf.

The areas of low alkalinity (<300 mg/L) mirror the low salinity regions (see Map 55) and include recharge zones along the eastern margin of the Eromanga sub-basin and the northern margin the Surat Basin, the majority of the western region and a large section in the northern part of the Surat Sub-basin. Low alkalinity groundwater persists along the Nebine Ridge and is associated with anticipated higher flowrates due to the increased horizontal permeability in this region.

The large area of low alkalinity groundwater in the northern part of the Surat Sub-basin is coincident with increased thickness of the aquifer in the northern section (see Map 32) and that parts of the aquifer are in direct contact with the Clematis Aquifer from the underlying Bowen Basin (see Maps 8 and 14). Higher alkalinity values are observed with increasing depth within the Mimosa Syncline. Parts of the Precipice Aquifer within the Mimosa Syncline are in direct contact with the underlying high alkalinity waters of the Blackwater Group in the Bowen Basin. There is evidence that the Goondiwindi and Moonie faults in this region extend into the Precipice Sandstone, which could provide a conduit for vertical groundwater flow up from the Bowen Basin into the Surat Sub-basin. In addition, the very high alkalinity is co-located with production of oil and the presence of thermogenic gases in the region around Moonie. The decomposition of organic matter would provide an additional source of alkalinity.
Precipice Aquifer and Equivalents—Alkalinity

- **Precipice Aquifer and Equivalents**
- **Great Artesian Basin**
- **Recharge zone**
- **Area of Great Artesian Basin where the hydrogeological unit does not exist**

**Legend**

- Alkalinity as CaCO₃ contour (mg/L)
- Bathymetry contour (depth in metres)
- Tropic of Capricom
- Groundwater sample location
- City/town

**Scale:** 1:9,000,000

**Projection:** LAMBERT CONFORMAL CONIC

**Parallels:** 25°S, 35°S

**Central Meridian:** 140°E

**Datum:** Geocentric Datum of Australia

**Alkalinity as CaCO₃ (mg/L)**

- 0
- 100
- 300
- 700
- 1000
- 3000

**Predicted value error map**

- Low
- High

**Notes:**

- Map showing the distribution of Alkalinity as CaCO₃ in mg/L across various regions of Australia.
- The map includes contours for Alkalinity and Bathymetry, as well as markers for groundwater sample locations and city/town names.
Groundwater in the Precipice Aquifer is fresh to brackish and the salinity shows significant regional variability. Measured TDS values range from less than 100 mg/L to 6000 mg/L.

In this area, a portion of the Clematis Aquifer, of the underlying Bowen Basin, is in direct contact with the Precipice Aquifer (see Map 14). The Clematis Aquifer contains relatively fresh groundwater \(^\text{15}\) and any upward leakage may influence salinity concentrations in the Precipice Aquifer. Similarly, the rapid increase in salinity to the south coincides with an area of direct contact between the Precipice Aquifer and the Blackwater Group partial aquifers from the underlying Bowen Basin. In this case the Blackwater Group contains more saline groundwater and upward leakage into the Precipice Aquifer may explain the relatively rapid transition from low salinity to more saline conditions exhibited.

### Dissolved Solids

Fresh groundwater coincides with recharge along the eastern margin of the Eromanga Sub-basin and the northern margin of the Surat Sub-basin. Low salinity groundwater persists along the Seafront Ridge and is associated with anticipated higher flow rates due to the increased horizontal permeability in this region.

In contrast to the other aquifers in the Surat Sub-basin, a large portion of low salinity groundwater is found in the northern part of the Mimosa Syncline, which then transitions to brackish groundwater in the southern and eastern parts of the sub-basin. The northern low-salinity groundwater is coincident with a thicker portion of the Precipice Aquifer (see Map 30).

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**Map 55**

**Precipice Aquifer and Equivalents—Total Dissolved Solids**

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**Map 14**

**Precipice Aquifer and Equivalents**

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**Map 15**

**Clarence-Moreton Basin**

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**Map 16**

**Combabula Embayment (NMR)**
Precipice Aquifer and Equivalents—Total Dissolved Solids

- Great Artesian Basin
- Precipice Aquifer
- Recharge zone
- Area of Great Artesian Basin where the hydrogeological unit does not exist

Total dissolved solids (mg/L)

- Recharge zone
- Area of Great Artesian Basin where the hydrogeological unit does not exist

Total dissolved solids contour (mg/L)

Bathymetry contour (depth in metres)

Groundwater sample location

City/town

Error

Low

High

Scale: 1:9 000 000
Projection: LAMBERT CONFORMAL CONIC
Parallels: 25°S, 35°S  Central Meridian: 140°E
Datum: Geocentric Datum of Australia

Predicted value error map
References and Digital Datasets
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AEM. See Airborne electromagnetics

Aeolian. Term applied to landforms or sedimentary materials which are formed or transported by the action of wind, or to environments dominated by atmospheric geomorphic processes.

AHD. See Australian Height Datum

Airborne electromagnetics (AEM). A geophysical survey method that measures the electromagnetic properties of a geological profile using an airborne platform. Electrical conductivity and magnetic susceptibility are derived, and because these properties vary depending on the nature of the rock, water saturation, salinity and other parameters, the resultant maps are used for estimation of the nature of underground rock formations, groundwater, contamination and other geological and environmental changes.

Airborne radiometrics. See radiometrics

Alluvial. alluvium. Materials deposited from transport by flowing water confined to a channel or valley floor.

Anoxic. Conditions where oxygen is absent or present in very low concentrations.

Anticline. An arch-shaped fold of originally flat lying sedimentary layers.

Aquiclude. A geological unit with very low hydraulic conductivity that obstructs groundwater flow to or from an adjacent aquifer.

Aquifer. A geological unit, group of units or part of a unit which is saturated and sufficiently porous and permeable to store and allow the movement of groundwater. Aquifers may yield quantities of groundwater for consumptive use or discharge to springs.

Architecture. The relationship of different geological units to each other in space. For example, regolith architecture, sedimentary architecture etc.

Arkose. A sandstone containing abundant feldspar.

Artesian. Situation where the piezometric surface of a confined aquifer is above the land surface.

Artesian bore. A bore which intersects artesian conditions in an aquifer, so that the groundwater level in the bore rises above the natural ground level.

Australian Height Datum (AHD). The datum that sets mean sea level as zero elevation. Mean sea level was determined from observations recorded by 30 tide gauges around the coast of the Australian continent for the period 1966–1968.

Bank storage. The water in an alluvial system that was cemented from near-surface aquifers that are separated from each other by topographic divides.

Basement. Bedrock that underlies the geological materials of interest.

Basin. A large depression in the Earth's crust filled by sedimentary or volcanic rocks.

Basin inversion. The uplift of a sedimentary basin relative to surrounding low-lying areas due to a variety of tectonic processes.

Bed, bedding. Layers or layering of sediments or sedimentary rocks that reflect differences in size, composition or colour of constituent grains.

Bedrock. Loose term given to any geological material that underlies the stratum of interest. Bedrock is often composed of crystalline rocks such as granite or metasediments.

Berriasian. The oldest stage of the Lower Cretaceous. It occurred between 145.5 and 140.2 million years ago.

Biogenic carbonate. Calcium carbonate (CaCO₃) directly precipitated by biological processes, such as shells or corals.

Bioturbation. The displacement and mixing of sediment particles by plants and animals.

Bore. A narrow constructed hole used to intercept groundwater from an aquifer. Also known as a borehole, well or piezometer.

Bore yield. The volume of water that can be abstracted from a bore (either by pumping or natural artesian flow) over a specific time interval. Bore yields are typically reported in units like litres per second (L/s) or megalitres per year (ML/yr).

Bounding surface. A surface within a sedimentary succession that marks the upper or lower limits of a major mappable unit.

Calcrete. Calcium carbonate (CaCO₃) formed in soil or sediments in a semi-arid region under conditions of sparse rainfall and warm temperatures, normally by precipitation of calcium. Calcrete is common in low-lying areas in arid to semi-arid regions, particularly palaeovalleys ('valley calcrete'), and may form aureoles around salt lakes. It is commonly a significant near-surface aquifer in the arid zone.

Cambrian. A period of geological time, between 545 and 490 million years ago.

Carbonate. CO₂ ions that can be carried in solution in surface water or groundwater and precipitated with Ca, Mg, or Fe ions to form carbonate minerals and rocks.

Carboniferous. A period of geological time between 359 and 300 million years ago.

Catchment. The area of land from which rainwater drains into a river, stream or lake. Catchments are separated from each other by topographic divides.

Cemented. The cementation of sedimentary grains by later minerals precipitated from groundwater. Sometimes ‘consolidated’ is used as an approximate synonym.

Cenozoic. The geological era extending from 65.5 million years ago to the present.

Clay. A term that refers to either grain size or mineralogy; (a) an earthy sediment composed of rock or mineral fragments or detrital particles smaller than a very fine silt grain; (b) clay minerals that are hydrous aluminium silicates derived largely from feldspars, micas and carbonate by weathering.
Colluvial. Gravity depositional processes found in slope depositional environments forming colluvium.

Colluvium. The deposits associated with colluvial processes.

Cone of depression. The area around a well where the hydraulic head (or potentiometric surface) in the aquifer has been lowered by groundwater extraction.

Confined aquifer. An aquifer that is overlain and underlain by impervious layers (aquitards). The groundwater level in a borehole intercepting a confined aquifer will be above the top of the aquifer.

Consolidated. See cemented.

Core, coring. A drilling method that recovers intact samples of subsurface materials.

Cretaceous. The geologic period from 145 ± 4 to 66 million years ago. It follows the Jurassic and precedes the Cenozoic.

Deltaic. Pertaining to a delta, e.g. deltaic sediments.

DEM. See Digital Elevation Model.

Depocentre. The centre of deposition within a sedimentary basin. This is usually the deepest point within a sedimentary basin.

Devonian. The geological period extending from 416 to 359 million years.

Diagenesis. The changes that occur to sediments after they are deposited, including cementation and weathering.

Diffusivity. The ratio of conductivity to storage capacity (with units of L²/t). For example, hydraulic diffusivity is the ratio of hydraulic conductivity to specific storage.

Digital elevation model (DEM). Digital representation of the topography of the earth. DEMs are obtained by many systems, including ground surveying, airborne radar and laser surveys, or from satellite radar.

Discharge, groundwater. The volumetric flow rate of groundwater from the saturated zone to the earth surface.

Discharge, stream. The volumetric flow rate of water in the stream.

Discharge zone. An area in which subsurface water is discharged to the land surface. In the arid zone, evaporite minerals (salts) precipitate as the water evaporates to the atmosphere. See also spring.

Dissected. A term applied to landscapes which have been extensively eroded to form valleys and gullies.

Dolomite. Calcium-magnesium carbonate, CaMg(CO₃)₂.

Drawdown. Lowering of the groundwater level due to loss of groundwater from the aquifer.

Duricrust. A hardened layer formed in the regolith by cementation of soil or sediment, generally by minerals rich in iron, sulphate, silica, or carbonate.

EC. See Electrical conductivity

Electrical conductivity (EC). The ability of an electrical current to pass through a substance. EC is commonly used to estimate the amount of soluble salt in solution. EC measurements can be made with a range of devices on water, soils, and soil-paste extracts. Units of electrical conductivity are commonly given in mS/m, dS/m or μS/cm; 100 mS/m = 1 dS/m = 1000 μS/cm. Here, S is the symbol for siemens, and the prefixes d is deci (10⁻¹), c is centi (10⁻²), m is milli (10⁻³) and μ is micro (10⁻⁶).

Eocene. Geological epoch extending from 55.8 to 33.9 million years ago. Preceded by the Paleocene and followed by the Oligocene.

Ephemeral. A short-lived transitory event. Ephemeral wetlands are only inundated and ephemeral streams only flow for relatively short periods of time.

Evaporation. The process by which water changes its physical state from a liquid to a gas, so that vapour is lost from soil or water directly into the atmosphere, due to increased temperature.

Evaporative concentration. Concentration of solutes in groundwater due to evaporation. The chemical constituents may remain fairly constant although the volume of water in which they are dissolved decreases owing to evaporation.

Evapotranspiration. The total water loss from the land surface to the atmosphere, through the combined effects of evaporation and transpiration.

Fault. Fracture in a rock body along which displacement has occurred.

Floodplain. A low-lying area adjacent to a river or stream that is subject to inundation when the waterway floods. Floodplains are often sites of deposition of fine-grained sediments.

Fluvial. River depositional environment.

Fracture. Cracks in indurated rocks formed by stress and strain. Fractures along which significant movement has occurred are called faults.

Fractured rock aquifer. Aquifers which store and transmit groundwater in the fractures, joints, bedding planes and cavities of the rock mass.

Gaining stream. A stream or river-reach into which groundwater flows via the stream bed and/or banks.

GDE. See groundwater dependent ecosystem

Geomorphology. The study of landforms.

Gigalitre (GL). 1000 megalitres or 1 billion litres.

GL. See Gigalitre

Glacial-interglacial cycles. Earth ice-age climate cycles where ice-sheets advance (glacial) and contract (interglacial) on timescales of up to 100 thousand years, over the past 2.5 million years.

Global meteoric water line. The worldwide average relationship between hydrogen and oxygen isotope ratios in natural precipitation samples.

Graben. A depressed or down-thrown block bounded on at least two sides by faults. See also half graben

Groundwater. Water stored below ground in the saturated zone, within the pore spaces or fractures of a rock mass.
Groundwater dependent ecosystem (GDE). Ecosystems that rely on groundwater systems for their existence and health.

Groundwater divide. A divide that is defined by groundwater flow directions that flow in opposite directions perpendicular to the location of the divide.

Groundwater mounding. Outward and upward expansion of the watertable caused by enhanced recharge.

Head. A measurement of water pressure representing the total energy at the entrance of a piezometer. Usually measured as a water surface elevation. Differences in head between two or more points can be used to determine hydraulic gradient and direction of groundwater flow. synonymous with hydraulic head.

Holocene. The most recent geological epoch extending from 12,000 years ago to the present.

Hydraulic conductivity (K). The volume of water flowing through 1 m² cross-sectional area of an aquifer under a hydraulic gradient of 1 m/1 m (100%) in a given time (usually 1 day). The property of the geological material that describes the capacity for water to move through pore spaces or fractures.

Hydraulic gradient. With regard to an aquifier, the rate of change of hydraulic head per unit of distance of flow at a given point and in a given direction.

Hydraulic head. The height of the groundwater level above a given datum at a given point in an aquifer.

Hydrochemistry. Study of the chemical characteristics of water to interpret hydrological processes.

Hydrodynamics. Study of the motion of fluids.

Hydrogeology. The branch of geology concerned with the occurrence, distribution and effects of groundwater.

Hydrograph (Bore). The variation in time in the groundwater level within a bore.

Hydrograph (Stream). The variation in time of the water level and/or flow in a surface water body.

Hydrostratigraphy. The identification of mappable stratigraphic units on the basis of hydraulic properties (such as the distribution of aquifers and aquitards).

Infrabasins. Bedrock sedimentary basins underlying the geological sequence of interest.

Isotope. A variant of a chemical element with a different atomic mass. Used in hydrogeologic applications to date and understand the origin and evolution of groundwater.

Jurassic. The geologic period from 200 to 145 million years ago. It follows the Triassic and precedes the Cretaceous.

Kilolitre (kL). 1000 litres, equivalent to one cubic metre (1 m³).

Lacustrine. Depositional environments or sediments associated with lakes.

LANDSAT. A polar-orbit satellite launched by NASA to collect multispectral imagery of the Earth surface. Seven satellites have been launched in the series. Commonly written as Landsat.

Local meteoric water line. Average relationship between hydrogen and oxygen isotope ratios in natural precipitation at a given area.

Losing stream. A stream or river reach which leaks surface water to an underlying aquifer.

Lunette. Elongated, crescent-moon shaped dune built up by wind on the downwind margin of a lake.

Ma. Abbreviation for million ages ago. See My.

Megalitre (ML). 1 million litres.

Mesozoic. The geological era extending from 251 to 65.5 million years ago. It is followed by the Cenozoic.

Miocene. Geological epoch extending from 23 to 5.3 million years ago. Preceded by the Oligocene and followed by the Pliocene.

Mudstone. A fine-grained sedimentary rock composed of particles smaller than silt.

My. Abbreviation meaning a duration of one or more million years. See Ma.

National-scale. A synoptic view across the nation that crosses jurisdictional boundaries. For mapping in Australia, typically refers to scales of between 1:1 000 000 and 1:2 000 000.

Normal Fault. In normal faults the hanging wall (rock above the fault plane) has moved downward relative to the footwall (rock below the fault plane).

Oligocene. Geological epoch extending from 33.9 to 23 million years ago. It is part of the Cenozoic era, and is preceded by the Eocene and followed by the Pliocene.

Outcrop. An area over which a particular rock units occurs at the surface.

Palaeo-. Prefix meaning old or ancient.

Palaeochannels. Former river channels that are recognised in the surface (from aerial or satellite images) or subsurface (typically in AEM surveys or drilling).

Palaeosol. A buried soil profile representing a former land surface.

Palaeovalley. Ancient valley filling sediments including (but not restricted to) those of palaeochannels. Typically palaeovalley sediments are not associated with currently active river processes.

Paleocene. A geologic epoch from about 66 to 56 million years ago. It follows on from the Cretaceous and marks the start of the Cenozoic. The Paleocene is followed by the Eocene.

Pleistocene. Geological era extending from 542 to 251 million years ago. It is followed by the Mesozoic.

Permeability. The ability of a material, such as rock or sediment, to allow the passage of a liquid, such as water. Permeable gravel and sand, allow free movement, whereas impermeable clays are barriers.

Piezometer. A non-pumping bore, generally of small diameter, used specifically to monitor groundwater levels or hydraulic head within an aquifer.

Pleistocene. Geological epoch extending from 2.5 million to 12 thousand years ago.
Pliocene. Geological epoch extending from 5.3 to 2.5 million years ago. It is part of the Cenozoic era, and is preceded by the Miocene and followed by the Pleistocene.

Porosity. The proportion of the rock volume consisting of open spaces or pores that can hold water. Primary porosity formed when the sediments were laid down; these spaces may be variably infilled by cement, leaving remnant primary porosity. Secondary porosity forms through modification of rocks, such as by dissolution of soluble grains, formation of fractures, or solution-forming karst.

Potentiometric head. See hydraulic head

Potentiometric surface. A surface which represents the level that groundwater under pressure, within a confined aquifer, would rise to, if intercepted by a bore.

Proterozoic. The geological era between 2500 and 545 million years ago. The Proterozoic is formally divided into the Paleoproterozoic (2500 and 1600 million years), Mesoproterozoic (1600-1000 million years), and Neoproterozoic (1000-545 million years).

Quaternary. Geological period extending from 2.5 million years ago to the present.

Recharge. Replenishment of groundwater by natural infiltration of surface water (precipitation, runoff) or artificially via managed aquifer recharge operations.

Redox. Variations in chemical state between oxidation and reduction.

Riparian. Of, on, or relating to the banks of a natural stream.

Salinity. The measure of salt in water, geological material or the landscape.

Sandstone. A sedimentary rock composed of sand-sized particles.

Saprolite. Weathered rock in which more than 20% of the weatherable minerals in the original rock have been altered in situ, with interstitial grain relationships being undisturbed. Saprolite is altered from the original rock by mainly chemical alteration and loss without any change in volume. This is sometimes referred to as constant volume alteration. Saprolite can be highly porous and permeable and may be an important aquifer, or may be impermeable and act as an aquitard.

Saturated zone. Part of the geological profile where the voids are filled with water at a pressure greater than atmospheric. The watertable is the top of the saturated zone in an unconfined aquifer.

Sedimentary. Pertaining to sediments, the deposits formed by water, ice or wind.

Seismics, seismic survey. The study of vibrations of the earth and their propagation through the ground. A seismic survey is the acquisition of seismic data using artificial sources to induce vibrations in the earth. This provides information on the lateral extent and depth of geological layers.

Semi-confined aquifer. An aquifer which is partly confined by layers of lower-permeability material, through which water movement can still occur.

Shale. A sedimentary rock composed of clay particles.

Siltstone. A sedimentary rock composed of silt-sized particles (~65 microns but >3 microns).

Specific yield. Ratio of the volume of water obtained by draining a volume of saturated rock or soil, relative to the bulk volume of the rock or soil. Also known as the drainable porosity.

Spring. A naturally-occurring discharge of groundwater flowing out of the ground, often forming a small stream or pool.

Storativity. The study of how different layers of sediments can be related to each other.

Sub-artesian aquifer. An aquifer containing groundwater under pressure that rises to a level greater than that at which it is first encountered, when tapped by a bore, but does not reach the surface.

Subcrop. An area over which a geological unit is close to surface but not outcropping. Usually an area of subcrop is covered by a thin veneer of soil or alluvial sediments.

Transmissivity. A measure of the ability of groundwater to pass through soil, sediment or rock. The capacity of a rock to transmit water under pressure. Expressed as the volume of water flowing through a cross-sectional area of an aquifer that is 1m x the aquifer thickness under a hydraulic gradient of 100% in a given amount of time (usually 1 day). Transmissivity is equal to the hydraulic conductivity (K) times the aquifer thickness.

Transpiration. Water given off by plants via pores in the surface tissues. See also evapotranspiration

Trans-tensional region. An area that experiences both extensive and transtensive shear and is characterised by both extensional structures (normal faults, grabens) and strike-slip faults.

Triassic. The geologic period that extends from 251 to 201 million years ago. It is preceded by the Permian and followed by the Jurassic. It is oldest period in the Mesozoic era.

Unconfined aquifer. A type of aquifer in which the upper boundary is defined by the watertable. Unconfined aquifers can be recharged directly from the ground surface as there are no overlying confining beds.

Volcanic. Processes and materials (such as ash and lava) produced by volcanic activity.

Volcanogenic. Processes and products pertaining to volcanic activity.

Watertable. The surface below which an unconfined aquifer is saturated with water. At the watertable, pore water pressure equals atmospheric pressure. See also potentiometric surface.

Weathered, weathering. The physical and chemical changes that a rock undergoes when it is exposed to the atmosphere and shallow groundwater.

Well. A constructed hole in the ground to access groundwater. See also bore.