FAR NORTH PWA

GROUNDWATER LEVEL AND SALINITY STATUS REPORT

2011

DEPARTMENT FOR WATER

Government of South Australia
Department for Water

Science, Monitoring and Information Division
Department for Water
25 Grenfell Street, Adelaide
GPO Box 2834, Adelaide SA 5001

Telephone	National	(08) 8463 6946
	International	+61 8 8463 6946
Fax	National	(08) 8463 6999
	International	+61 8 8463 6999
Website	www.waterforgood.sa.gov.au	

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SUMMARY 2011

The Far North Prescribed Wells Area (PWA) is located in the north-east of South Australia, approximately 400 km north-east of Adelaide and is bounded in the north and east by the State's shared borders with New South Wales, Queensland and the Northern Territory. The Far North PWA covers approximately 315 000 km^2 (~32% of the State) and was prescribed in 2003 under South Australia's *Water Resources Act 1997* that has since been superseded by the *Natural Resources Management Act 2004*. The Far North PWA Water Allocation Plan provides for the sustainable management of water resources in the region.

Groundwater in the Far North PWA is predominately sourced from the Great Artesian Basin aquifer, formed by the Cadna-owie Formation and Algebuckina Sandstone. The majority of wells completed in the GAB aquifer within the Far North PWA are flowing artesian wells.

Licensed allocations for 2011 in the Far North PWA totalled 46 776.65 ML. The SAAL Regional Natural Resources Management Plan[6] estimates stock and domestic groundwater use is in the order of 33 ML/d from the GAB aquifer. Extraction from the GAB aquifer for town water supply is estimated at around 3.3 ML/d in the Plan

Petroleum wells currently extract about 26 ML/d as co-produced water from the GAB aquifer and 1 ML/d from the Cooper Basin.

Current groundwater usage from the GAB aquifer for mining operations is 36.3 ML/d (Olympic Dam 36 ML/d; Beverley 0.3 ML/d). At Prominent Hill, 17 ML/d is extracted from the Arckaringa Basin.

Total groundwater discharge from the springs in the Far North PWA has been estimated at 66 ML/d. This is an order of magnitude estimate due to the inherent difficulties in measuring flows and the low number of spring flow measures.

Groundwater flow within the GAB aquifer is generally in a south-westerly direction from the eastern and northern boundaries of the Far North PWA and in a south-easterly direction from the western Far North PWA boundary.

Groundwater within the GAB aquifer is generally of good quality, with the majority of the basin's salinity less than 3000 mg/L.

Overall, the groundwater elevation and salinity of the GAB in the Far North PWA have remained relatively stable over a long period of time. While there have been small fluctuations over the years, the latest values are similar to historical measurements.

ASSESSMENT OF STATUS

Based on current trends, the Far North Prescribed Wells Area has been assigned a green status of "No adverse trends, indicating a stable or improving situation" for 2011. This status is supported by:

- relatively stable groundwater levels; while there have been small fluctuations in groundwater levels over the years, latest values are similar to historical measurements
- relatively stable groundwater salinity; while there have been small fluctuations in groundwater quality over the years, latest values are similar to historical measurements

STATUS (2011)

No adverse trends, indicating a stable or improving situation

Trends are either stable (no significant change) or improving (i.e. decreasing salinity or rising water levels).

Adverse trends indicating low risk to the resource in the medium term

Observed adverse trends are gradual and if continued, will not lead to a change in the current beneficial uses of the groundwater resource for at least 15 years. Beneficial uses may be drinking water, irrigation or stock watering.

Adverse trends indicating high risk to the resource eventuating in the short to medium term

Observed adverse trends are significant and if continued, will lead to a change in the current beneficial uses of the groundwater resource in about ten years.

Degradation of the resource compromising present use within the short term

Trends indicate degradation of the resource is occurring, or will occur, within five years. Degradation will result in a change in the beneficial use (i.e. no longer suitable for drinking or irrigation purposes) and may take the form of increasing groundwater salinities or a fall in the groundwater levels such that extractions from the aquifer may not be possible.

BACKGROUND

The southern boundary of the Far North Prescribed Wells Area (PWA) is located about 400 km north-east of Adelaide (Fig. 1). It is bounded in the north and east by South Australia's shared borders with New South Wales, Queensland and the Northern Territory.

The Far North PWA covers an area of approximately 315 000 km^2 (~32% of the State) and was prescribed in 2003 under South Australia's *Water Resources Act 1997,* which has since been superseded by the *Natural Resources Management Act 2004*. The Far North PWA Water Allocation Plan provides for the sustainable management of water resources in the region.

HYDROGEOLOGY

Geological information contained in this report is primarily sourced from Volume 2 of *The geology of South Australia*.[1] The Far North PWA overlies several sedimentary basins that can be grouped into four major depositional sequences (Table 1). The youngest sediments, of Quaternary and Tertiary age, form the Hamilton Basin, located in the far north-west, and the Lake Eyre Basin[*], which covers most of the eastern half of the Far North PWA. These basins overlie the Great Artesian Basin (GAB), which extends as an almost continuous blanket over the whole Far North PWA (Fig. 2). Underlying the GAB are the Arckaringa, Cooper, Warburton, Simpson and Pedirka Basins, which contain sediments deposited during the Palaeozoic era (Figs. 2 & 3). The oldest sediments in the Far North PWA were deposited during the Proterozoic eras. These sediments crop out in parts of the Far North PWA, such as the northern Flinders Ranges and the Peake and Denison Inliers (Fig. 2). Elsewhere, these sediments form the basement beneath the younger sediments.

The Hamilton Basin is a relatively small basin overlying the Eromanga Basin in the north-west of the Far North PWA (Fig. 2). The Tertiary sediments of quartz sandstone, sandy siltstone and claystone thicken gradually to 79 m at the western edge of the basin.

Like the underlying Great Artesian Basin, the Lake Eyre Basin consists of a thick sedimentary succession in a north-eastern depocentre and a south-western part where the sediments are significantly thinner and discontinuous. The basin is separated by the Birdsville Track Ridge into the Tirari Sub-basin in the west and Callabonna Sub-basin in the east (Fig. 2). Tertiary and Quaternary sediments of the Lake Eyre Basin can reach up to 410 m in the Cooper region. Quaternary sediments host unconfined aquifers, while the Tertiary Namba and Eyre Formations form the major aquifers of the basin. The aquifers vary between unconfined and confined with the Eyre Formation aquifer being artesian along the western margin of Lake Frome.

The Great Artesian Basin (GAB) is a Jurassic to Cretaceous-aged super-basin containing non-marine and marine sediments that covers approximately one-fifth of the Australian continent. The GAB is comprised of the Eromanga, Surat and Carpentaria Basins. In South Australia, the GAB is composed entirely of Eromanga Basin sediments that vary in thickness from less than 100 m on the margins of the basin to over 3000 m in the north-east of the State within the basin depocentres.

Within the GAB, the Cadna-owie Formation and equivalents and Algebuckina Sandstone form the major water-bearing aquifer system (hereafter referred to as the GAB aquifer). Depth to the GAB aquifer is as much as 2400 m in the State's north-east but rapidly decreases westwards with the aquifer cropping out along the western margin.

1 Drexel, JF and Preiss, WV 1995, *The geology of South Australia, Volume 2, The Phanerozoic*, Bulletin 54, Geological Survey, South Australia
* In this report, the Lake Eyre Basin refers to the geological province, which is distinct from the surface water catchment

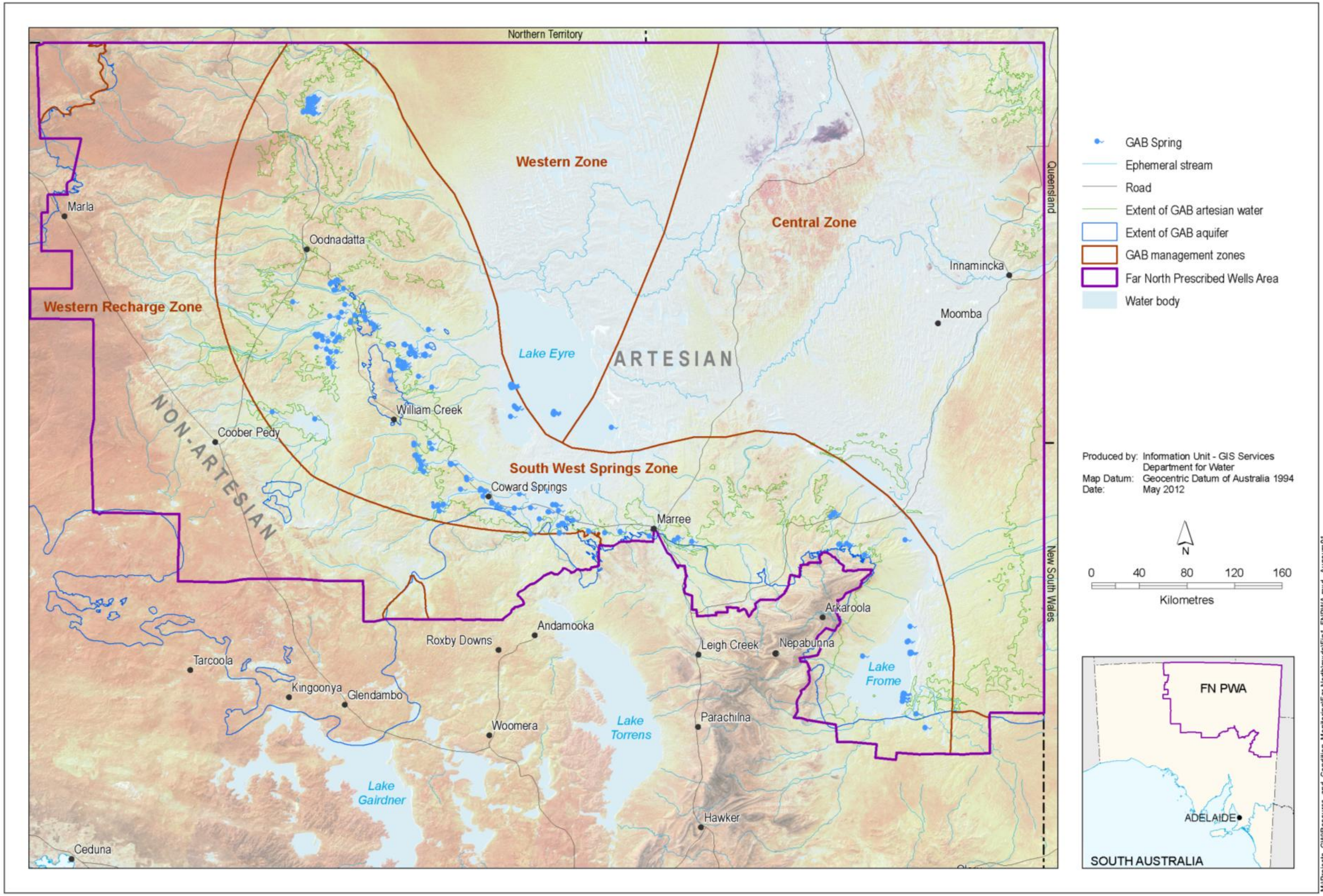


Figure 1. The Far North Prescribed Wells Area

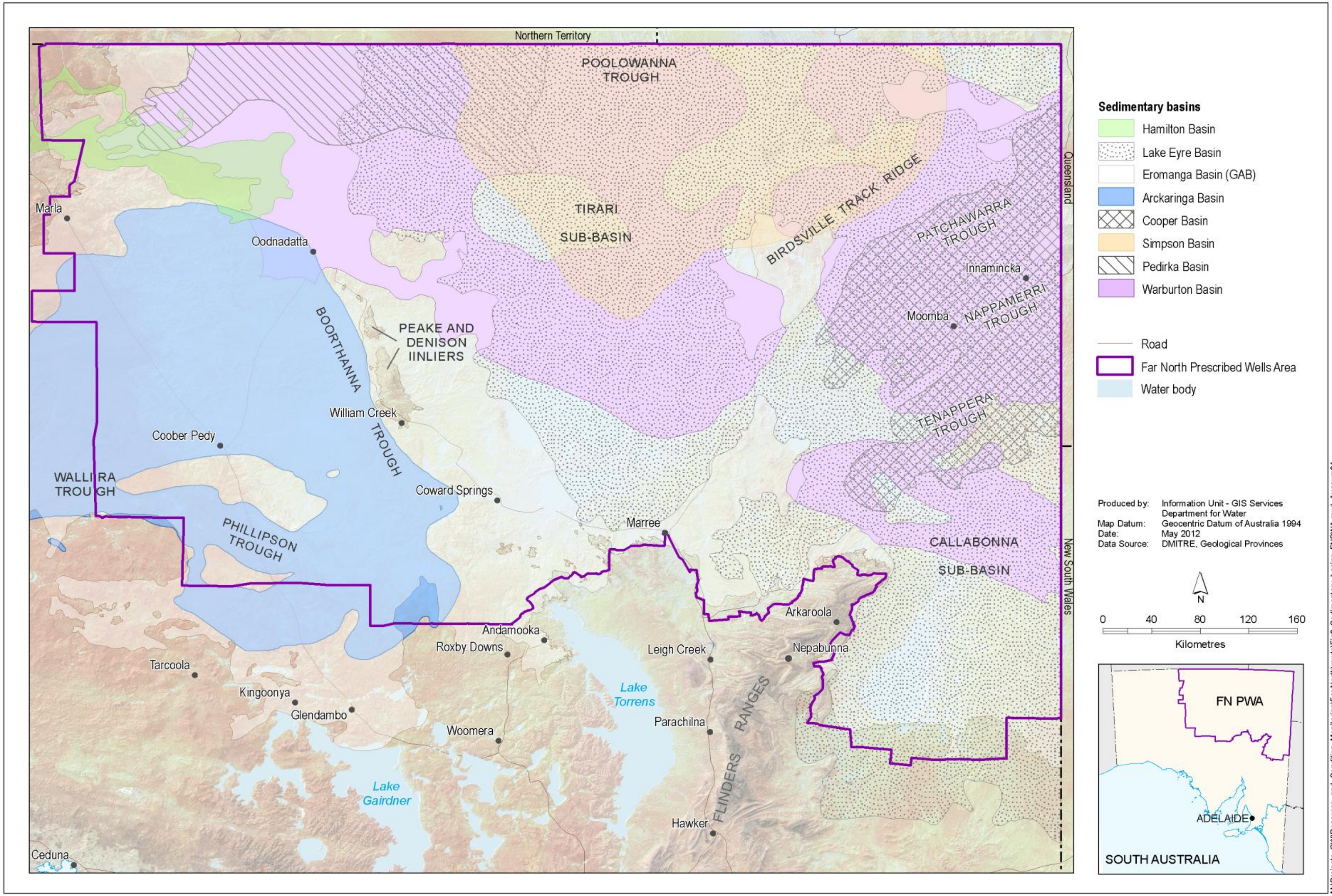


Figure 2. Sedimentary basins of the Far North Prescribed Wells Area

Groundwater in the Far North PWA is predominately sourced from the GAB aquifer, whose thickness ranges from less than 50 m around the basin's western margin to greater than 500 m near the Poolowanna Trough (Figs. 2 & 3). For this reason, all groundwater data presented in this report relates to the GAB aquifer unless otherwise stated. The majority of wells completed in the GAB aquifer within the Far North PWA are flowing artesian wells. In South Australia, the overlying aquifer formed by the Winton and Mackunda Formations is nominal as the units are predominantly shale and wells completed in this aquifer are typically non-artesian.

The dominant recharge mechanism of the GAB is the infiltration of rainfall along the western slopes of the Great Dividing Range in Queensland and New South Wales that provides lateral groundwater flow to the South Australian portion of the GAB. Recharge also occurs to a lesser extent where the aquifer crops out along the western margins of the basin in South Australia and Northern Territory, or where it is overlain by unconsolidated sediments and is unconfined. Upward leakage from the underlying Cooper Basin is also thought to contribute recharge to the GAB aquifer.

Approximately 17 ML/d of groundwater is extracted from the Arckaringa Basin at the Prominent Hill mine, the major user of groundwater from the basin. Localised recharge occurs at the edge of the Arckaringa Basin, which also provides stock water to smaller users. Groundwater is extracted from the Cooper Basin by the petroleum industry in conjunction with oil and gas production as co-produced water. Aquifers of the Warburton, Simpson and Pedirka Basins are generally considered too deep to develop at this time and because of the large supply of good quality groundwater available in the overlying GAB aquifer, they are not utilised. Limited information is available for the fractured rock aquifers within basement material.

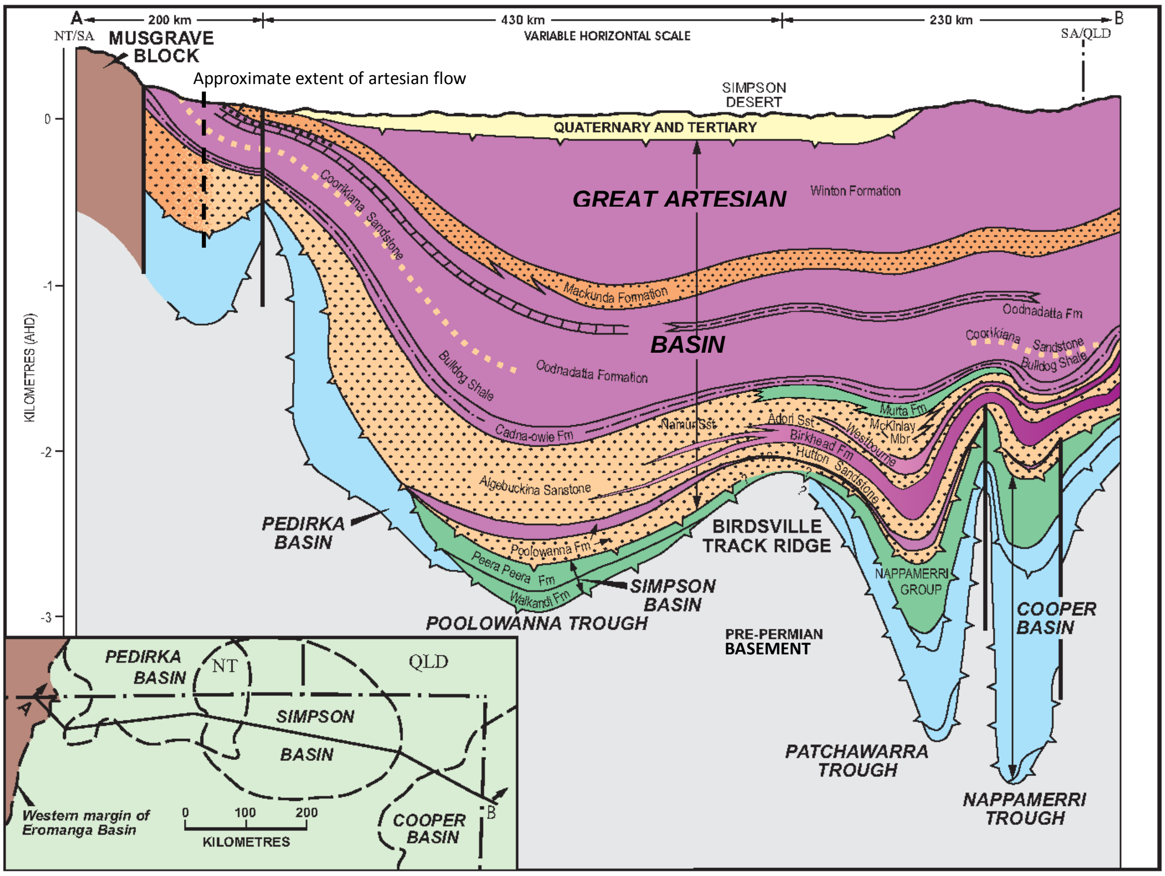


Figure 3. Geological cross section of the northern Far North PWA (after Cotton, Scardigno & Hibburt 2006[2])

2 Cotton, TB, Scardigno, MF and Hibburt, JE 2006, *The petroleum geology of South Australia, Volume two: Eromanga Basin,* 2nd edition, Draft, Department of Primary Industries and Resources South Australia, Adelaide

STRATIGRAPHIC UNITS

Information contained in this section is also sourced from volume 2 of *The geology of South Australia*.[3]

Lake Eyre Basin

Quaternary sediments – aeolian sands and alluvium, lacustrine and fluvial sands, silts and clays and occasional limestone beds. Reach a maximum thickness of 60 m in the Cooper region.

Namba Formation – alternating fine to medium-grained sand, silt and clay, with thin dolomite and limy, often oolitic, dolomite interbeds. The Namba Formation is restricted to the Callabonna Sub-basin and reaches a maximum thickness of 210 m in the Cooper region.

Etadunna Formation – white dolomite and limestone overlain by green and grey claystone and fine sand. The Etadunna Formation is restricted to the Tirari Sub-basin. Thickness varies from 25 m along the western side of Lake Palankarinna to 35 m beneath Lake Eyre and reaching 80 m to its north-east.

Eyre Formation – mature pyritic, carbonaceous sand. Grainsize varies from silt to gravel and beds of lignite and clay are common. The Eyre Formation is up to 140 m thick in the Cooper region and is widespread throughout the Lake Eyre Basin.

Eromanga Basin (GAB)

Winton Formation – interbedded fine to coarse-grained sandstone, carbonaceous and pyritic shale, siltstone and coal seams with conglomerates. The Winton Formation is widely distributed in South Australia and crops out along the south-western margin of the GAB. It is generally greater than 400 m in the Cooper region and reaches a maximum thickness of 1100 m in the northern Patchawarra Trough.

Mackunda Formation – regressive marine unit consisting of about 100 m of interbedded partly calcareous sandstone, siltstone and shale in the south-western Eromanga Basin. On the basin margin, the lower Mackunda Formation consists of irregularly layered very fine-grained sand and mud. A thin transgressive unit of fossiliferous marine mudstone and several thin limestone beds are also present. The Mackunda Formation is generally 60 to 120 m thick in the Cooper region.

Oodnadatta Formation – a fossiliferous, calcareous unit consisting of thin-bedded claystones and siltstones with interbeds of fine-grained sandstone, calcareous and ferruginous concretions and limestone. The formation was deposited in a low-energy, shallow marine environment and reaches a maximum thickness of around 300 m near Moomba.

Coorikiana Sandstone – fine-grained, silty, glauconitic, feldspathic and lithic sandstone with minor conglomerate with dark grey siltstone and mudstone interbeds at the base. It crops out extensively around the margins of the GAB in South Australia and is typically less than 20 m thick.

Bulldog Shale – dark grey bioturbated and fossiliferous mudstone with minor interbeds of micaceous siltstone and very fine-grained sandstone. The Bulldog Shale has a thickness of less than 200 m near Oodnadatta and Marree, increasing to more than 300 m in the north-east of the State and is the major confining bed for the GAB aquifer.

Cadna-owie Formation – pale grey siltstone with very fine to fine-grained sandstone interbeds and minor carbonaceous claystone. The Cadna-owie Formation varies in thickness from 10 to 20 m around the basin margin, increasing to 75 to 100 m in the deeper parts of the basin, reaching a maximum thickness of more than 115 m in the Nappamerri Trough. The formation records the transition from terrestrial freshwater to marine conditions.

3 Drexel and Preiss 1995

Algebuckina Sandstone – white, fine to coarse-grained quartzose sandstone with granule and pebble layers and shale intraclasts common in coarser beds. Minor lenses of siltstone and shale are locally developed. The Algebuckina Sandstone is thin in the south-west portion of the GAB and increases in thickness in a north-easterly direction with a maximum thickness of 800 m recorded in the Poolowanna Trough.

Murta Formation – shale, dark grey siltstone, pale grey very fine to fine-grained sandstone and minor medium and coarse-grained sandstone. The Murta Formation occurs throughout the Cooper region and as far west as the Birdsville Track Ridge. A basal siltstone is widespread in the Cooper region. Thickness varies from about 25 to 75 m across the basin with a maximum thickness of more than 90 m reached in the Nappamerri Trough.

Namur Sandstone – white to pale grey, fine to coarse-grained sandstone with minor interbedded siltstones and mudstones. The Namur Sandstone is generally 40 to 240 m thick, is the lateral equivalent of the Algebuckina Sandstone and is distributed throughout the Cooper region.

Westbourne Formation – interbedded, dark grey shale and siltstone with minor sandstone. The Westbourne Formation is restricted to the northern part of the Cooper region and the easternmost Pedirka region in South Australia. It is generally 30 to 140 m thick in the Cooper region.

Adori Sandstone – well-sorted, fine to coarse-grained sandstone that is the equivalent unit of the Namur and Algebuckina Sandstones. In South Australia, the Adori Sandstone is restricted to the northern Cooper Basin area and north-eastern Pedirka Basin area. It is generally 20 to 130 m thick in the Cooper region.

Birkhead Formation – interbedded dark grey and brown carbonaceous siltstones and mudstones and fine to medium-grained sandstones with thin coal seams, silcretes and calcretes. The Birkhead Formation is widespread in the sub-surface in South Australia and thickness varies from about 50 to 150 m with a maximum thickness of more than 150 m occurring in the Patchawarra and Nappamerri Troughs.

Hutton Sandstone – a fine to coarse-grained, white sandstone with dark grey carbonaceous siltstone and shale interbeds and pebble conglomerate layers. The estimated thickness of the Hutton Sandstone ranges from 40 m in the south of the Cooper region to more than 360 m in the north, with the major depocentre in the Patchawarra Trough.

Poolowanna Formation – interbedded grey to brown carbonaceous siltstone, pale grey to buff sandstone and rare coal seams. Sandstone beds range from very fine to medium-grained and contain minor pebbles and granules of quartzite and reworked basement. In the Poolowanna Trough, the Poolowanna Formation reaches a maximum known thickness of 205 m.

Arckaringa Basin

Mount Toondina Formation – siltstone and sandstone interbedded with coal, shale and rare carbonate; coal is generally restricted to the upper part of the formation. The Mount Toondina Formation reaches a maximum thickness of 598 m near William Creek.

Stuart Range Formation – marine shale with minor siltstone and sandstone and pale to dark greyish shaly, poorly-bedded mudstone. Directly overlying older rocks locally, the formation typically overlies the Boorthanna Formation with the two units intertonguing locally in the south-western Arckaringa Basin. A maximum thickness of 491 m is recorded about 60 km south-west of Coober Pedy.

Boorthanna Formation – comprises two units including a basal sandy to bouldery claystone, which is often calcareous and sometimes dolomitic, interbedded with shale and occasionally thin sandstone or carbonate. This unit appears to be restricted to the Wallira and Phillipson Troughs and the southern part of the Boorthanna Trough. The other unit is generally medium to coarse-grained sandstone but ranges from siltstone to boulder beds. A maximum thickness of 419 m is recorded near William Creek.

Cooper Basin

Cuddapan Formation – basal sandstone package with upwards increasing siltstone and coal interbeds. Sandstone beds range from fine-grained to granular and siltstone intraclasts are common. Carbonaceous and micaceous films cap sandstone layers. In South Australia, the Cuddapan Formation occurs as eroded remnants and reaches a thickness of 67 m north-west of Innaminka.

Tinchoo Formation – very fine to coarse, predominantly medium-grained, quartzose sandstone, brown and dark grey siltstone and mudstone clasts in a coarse-grained sandstone matrix. Siltstone interbeds are light olive-grey to brown and medium grey and contain layers of coarse sand grains. The Tinchoo Formation reaches a maximum thickness of about 109 m north-west of Innaminka.

Arrabury Formation – dark to pale grey mudstone and siltstone with pale grey, thin, fine to medium-grained quartzose sandstone interbeds overlain by sandstone with minor siltstone interbeds. The Arrabury Formation reaches a maximum thickness of 400 m in the Patchawarra Trough.

Toolachee Formation – interbedded buff to white, fine to coarse-grained sandstone, dark grey siltstone and dark grey to black carbonaceous shale, sometimes with thin coal seams (<3 m thick) and conglomerates. The Toolachee Formation is thickest in the Patchawarra and Nappamerri Troughs.

Daralingie Formation – dominated by light grey to black carbonaceous and micaceous siltstone and mudstone with interbedded light grey to brown fine to very fine-grained sandstone. Minor coal seams and carbonaceous partings and streaks occur. The Daralingie Formation reaches a maximum thickness of over 100 m in the Nappamerri Trough.

Roseneath Shale – light to dark brown-grey or olive-grey siltstone, mudstone and minor sandstone. Sandstone interbeds are pale brown and fine grained. The Roseneath Shale reaches a maximum thickness of 100 m at the border south-east of Innaminka and thickens into the Nappamerri and Tenappera Troughs.

Epsilon Formation – thinly-bedded, fine to medium-grained quartzose sandstone with dark grey-brown carbonaceous siltstone and shale and thin to occasionally thick (<2–20 m) coal seams. The Epsilon Formation reaches a maximum thickness of 156 m in the Nappamerri Trough.

Murteree Shale – black to dark grey-brown siltstone and fine-grained sandstone that becomes sandier in the southern Cooper Basin. Fine-grained pyrite and muscovite are characteristic and carbonaceous siltstone occurs. The Murteree Shale is widespread within the Cooper Basin and is relatively uniform in thickness, averaging about 50 m. It reaches a maximum thickness of 80 m in the Nappamerri Trough and forms a regional seal above the underlying Patchawarra Formation.

Patchawarra Formation – interbedded grey, buff or brown, fine to medium-grained, locally coarse-grained and pebbly sandstone, grey to black siltstone, shale and coal. It reaches a thickness of up to 680 m in the Nappamerri Trough.

Tirrawarra Sandstone – composed chiefly of brown and white, fine to coarse-grained, moderately well-sorted sandstone with minor shale interbeds and rare, thin coal seams. The Tirrawarra Sandstone is widespread but relatively thin, reaching 75 m in thickness.

Merrimelia Formation – complex unit of conglomerate, diamictite, sandstone, conglomeratic mudstone, siltstone and shale. The Merrimelia Formation attains a maximum thickness of greater than 290 m, but with irregular distribution.

Table 1. Stratigraphy and hydrostratigraphy of the units of the South Australian portion of the Lake Eyre, Great Artesian, Arckaringa and Cooper Basins

Age			Basin	Unit	Lithology	Hydrogeology	Comments
Cainozoic	Quaternary		Lake Eyre Basin	Undifferentiated	Aeolian sands and alluvium, lacustrine and fluvial sands, silts and clays, occasional limestone beds	Unconfined aquifer	Maximum thickness of 60 m in Cooper region. Fresh groundwater may be found at shallow depths adjacent major watercourses. Depth to watertable can be up to 90 m; salinity is highly variable (1000–100 000 mg/L).
	Tertiary	Oligocene		Namba Formation	Alternating fine to medium-grained sand, silt and clay, with thin dolomite and limy, often oolitic, dolomite interbeds	Unconfined and confined aquifer; aquitard in many places	Restricted to the Callabonna Sub-basin. Maximum thickness of 210 m in Cooper region. Lateral equivalent of the Etadunna Formation.
				Etadunna Formation	White dolomite and limestone overlain by green and grey magnesium-rich claystone and fine sand	Unconfined and confined aquifer; aquitard in places	Restricted to the Tirari Sub-basin. 25–80 m thick. Lateral equivalent of the Namba Formation.
		Eocene		Eyre Formation	Fluvial, fine to medium-grained, quartz sandstone with lignite interbeds and a basal conglomerate	Unconfined, confined and artesian aquifer	Up to 140 m thick in the Cooper region. Sand and sandstone beds can form useful aquifers particularly in the south eastern part of the FN PWA. Artesian along the western margin of Lake Frome. Salinity ranges from 3000–12 000 mg/L.
Mesozoic	Cretaceous	Late	Eromanga Basin (GAB)	Winton Formation	Interbedded fine to coarse-grained sandstone, carbonaceous and pyritic shale, siltstone and coal seams with conglomerates	Confined aquifer	Widely distributed in SA. >400 m in Cooper region. Maximum 1100 m in Patchawarra Trough. Predominantly shale in SA, therefore minimal aquifer.
		Early		Mackunda Formation	Interbedded, partly calcareous very fine-grained sandstone, siltstone and shale	Confined aquifer	Generally 60–120 m thick in the Cooper region. Predominantly shale in SA, therefore minimal aquifer.
				Oodnadatta Formation	Laminated and thin-bedded claystone and siltstone with interbeds of fine-grained sandstone	Aquitard	Mainly occurs over central portion of GAB. Maximum ~300 m in Moomba area.
				Coorikiana Sandstone	Fine-grained, silty, glauconitic, feldspathic and lithic sandstone, minor conglomerate with dark grey siltstone and mudstone interbeds at the base	Aquifer	Discrete saline, low-yielding aquifer of limited extent. Typically <20 m.
				Bulldog Shale	Dark grey, bioturbated and fossiliferous mudstone with minor interbeds of micaceous siltstone and very fine-grained sandstone	Aquitard	Occurs throughout GAB as the primary confining bed for the GAB aquifer. Maximum >340 m in Moomba area, thins to <200 m in outcrop.
				Cadna-owie Formation	Pale grey siltstone with very fine to fine-grained sandstone interbeds and minor carbonaceous claystone	Unconfined, confined and artesian aquifer	Unconfined along western margin, non-artesian and confined and artesian elsewhere. Salinities vary from 600–10 000 mg/L. Yields of up to 850 kL/d. Thickness of 10–20 m around basin margin, 75–100 m in deeper parts, maximum >115 m in the Nappamerri Trough.
				Murta Formation	Grey siltstone, shale, very fine to fine-grained sandstone, minor medium and coarse-grained sandstone. Basal siltstone in Cooper region	Aquifer	Found in the Cooper region. Intertongues the Algebuckina Sandstone west of the Birdsville Track Ridge. Maximum thickness of >90 m in the Nappamerri Trough.

Age			Basin	Unit	Lithology	Hydrogeology	Comments
Mesozoic	Jurassic	Late	Great Artesian Basin (Eromanga Basin)	Namur Sandstone	White to pale grey fine to coarse-grained sandstone with minor interbedded siltstone and mudstone	Confined aquifer	Found in the Cooper region. Thickness of 40–240 m. Lateral equivalent of Algebuckina Sandstone.
				Westbourne Formation	Interbedded dark grey shale and siltstone with minor sandstone interbeds	Aquitard	Aquitard of limited extent separating overlying Namur Sandstone and underlying Adori Sandstone between the Cooper and Simpson Basin regions. 30–140 m thick in Cooper region. Lateral equivalent of Algebuckina Sandstone.
				Adori Sandstone	Well-sorted, sub-rounded, cross-bedded, fine to coarse-grained sandstone	Confined aquifer	Found in northern Cooper Basin area and north-eastern Pedirka Basin area. 20–130 m in Cooper region. Lateral equivalent of Namur & Algebuckina Sandstones.
		Middle		Birkhead Formation	Interbedded dark grey and brown siltstone, mudstone and buff, fine to medium-grained sandstone with thin coal seams (<0.3 m)	Aquitard	Widespread. Maximum thickness of >150 m in Patchawarra and Nappamerri Troughs. Intertongues Algebuckina Sandstone west of the Birdsville Track Ridge.
				Hutton Sandstone	Fine to coarse-grained quartzose sandstone with minor siltstone interbeds	Confined aquifer	Good quality water with high yields. Typically not utilised in SA as depth exceeds 1500 m Thickness of 40 m in southern Cooper region to >360 m in the north. Passes laterally into Algebuckina Sandstone where Birkhead Formation is absent.
		Early		Algebuckina Sandstone	White, fine to coarse-grained quartzose sandstone with granule and pebble layers and shale intraclasts common in coarser beds	Confined aquifer	Maximum thickness of 800 m in Poolowanna Trough. Salinity varies from 600 to 4000 mg/L. Water discharge temperature is up to 99 °C. Lateral equivalents are Murta, Westbourne & Birkhead Formations, Namur, Adori & Hutton Sandstones.
				Poolowanna Formation	Interbedded grey to brown carbonaceous siltstone, pale grey to buff sandstone and rare coal seams	Untested	Maximum known thickness of 205 m in the Poolowanna Trough.
	Triassic	Late	Cooper Basin	Cuddapan Formation	Basal sandstone with upwards increasing siltstone and coal interbeds; interbedded grey siltstone and off-white sandstone with minor mudstone	Aquifer	Found in the Patchawarra Trough. Maximum thickness of 67 m about 50 km north of Innaminka.
		Middle		Tinchoo Formation	Medium-grained quartzose sandstone. Light olive grey to brown and medium grey siltstone interbeds contain layers of coarse sand grains	Aquifer	Found in north-eastern Patchawarra Trough and area north. Maximum thickness of ~109 m about 70 km north of Innaminka.
Palaeozoic	Permian	Late		Arrabury Formation	Mudstone and siltstone with thin fine to medium-grained quartzose sandstone interbeds overlain by sandstone with minor siltstone interbeds	Major aquitard between Cooper and Eromanga Basins	Widely distributed over the Cooper Basin but absent south of the Murteree Ridge. Maximum thickness of 400 m in Patchawarra Trough.
				Toolachee Formation	Interbedded buff to white, fine to coarse-grained sandstone, dark grey siltstone and dark grey to black carbonaceous shale, sometimes with thin coal seams (<3 m) and conglomerates	Aquifer	Widespread across the Cooper Basin. Up to 175 m thick in the Patchawarra and Nappamerri Troughs.

Age			Basin	Unit	Lithology	Hydrogeology	Comments
Palaeozoic	Permian	Early	Cooper Basin	Daralingie Formation	Carbonaceous and micaceous siltstone and mudstone, interbedded grey to brown sandstone	Both aquifer and aquitard	Found in Cooper Basin area west of Innaminka. Maximum thickness of >100 m in Nappamerri Trough.
				Roseneath Shale	Brown-grey or olive-grey siltstone, mudstone and minor sandstone. Siltstones are micaceous with minor fine-grained pyrite. Sandstone interbeds are pale brown and fine grained	Aquitard	Found in central Cooper region. Maximum thickness of 100 m. Where Daralingie Formation has been eroded, the Roseneath Shale is overlain by the Toolachee Formation.
				Epsilon Formation	Fine to medium-grained quartzose sandstone with dark grey-brown carbonaceous siltstone and shale, and thin to occasionally thick (<2.20 m) coal seams	Aquifer	Maximum thickness of 156 m in Nappamerri Trough. Where Roseneath Shale and Daralingie Formation have been eroded, Epsilon Formation is overlain by Toolachee Formation.
				Murteree Shale	Black to dark grey-brown siltstone and fine-grained sandstone. Sandier in the southern Cooper Basin. Fine-grained pyrite and muscovite are characteristic and carbonaceous siltstone occurs	Aquitard	Average thickness of ~50 m. Maximum thickness of 80 m in Nappamerri Trough. Where Epsilon Formation, Roseneath Shale and Daralingie Formation have been eroded, the Murteree Shale is overlain by Toolachee Formation.
				Patchawarra Formation	Interbedded grey, buff or brown, fine to medium-grained, locally coarse-grained and pebbly sandstone, grey to black siltstone, shale and coal	Aquifer	Up to 680 m thick in the Nappamerri Trough. Towards the edge of Cooper Basin, the Patchawarra Formation is overlain by Toolachee Formation or Poolowanna Formation and Hutton Sandstone.
			Arckaringa Basin	Mount Toondina Formation	Siltstone and sandstone interbedded with shale and coal. Coal generally restricted to upper part	Confined aquifer	Maximum thickness of 598 m west of Anna Creek. In some places it may overlie the Boorthanna Formation.
				Stuart Range Formation	Grey to dark grey, sometimes brown mudstone with minor white to grey, fine to medium-grained sandstone and mid to dark grey, carbonaceous siltstone	Aquitard	Maximum thickness of 491 m about 60 km south-west of Coober Pedy.
	Carboniferous	Late		Boorthanna Formation	Thick sandy to bouldery, pale grey or greenish grey, often calcareous claystone overlain by medium to coarse-grained sandstone grading into siltstone or silty shale	Basal unit is confined aquifer, otherwise aquitard	Maximum thickness of 419 m about 60 km south-west of Coober Pedy. Upper unit restricted to Wallira and Phillipson Troughs and southern part of Boorthanna Trough.
			Cooper Basin	Tirrawarra Sandstone	Composed chiefly of brown and white, fine to coarse-grained sandstone with minor shale interbeds and rare, thin coal seams	Aquifer	Principal Cooper Basin oil reservoir. Widespread and up to 75 m thick. The Tirrawarra Sandstone and Merrimelia Formation are difficult to separate.
				Merrimelia Formation	Conglomerate, diamictite, sandstone, conglomeratic mudstone, siltstone and shale	Aquifer	Thickness of 64 m in the north of the basin, up to 175 m in the south.

GROUNDWATER FLOW AND SALINITY

GAB Aquifer

Groundwater elevation contours indicate groundwater flow within the GAB aquifer is generally in a south-westerly direction from the eastern and northern Far North PWA boundaries and in a south-easterly direction from the western Far North PWA boundary (Fig. 4). The groundwater elevation contours were created using environmental head data from 2004 to 2011 to provide a better indication of recent conditions and have not been temperature corrected. Therefore, the groundwater contours are different to previous figures of the potentiometric surface of the GAB aquifer that have used data across a much longer historical period and have been corrected for temperature. The majority of groundwater extracted for mining is taken from Wellfields A and B on the boundary of the GAB aquifer for Olympic Dam and local cones of depression have developed in these areas.

Groundwater within the GAB aquifer is generally of good quality with the majority of the basin's salinity less than 3000 mg/L. Fresh groundwater is observed in the north-west and north–north-east, with highly saline groundwater in the south-west (Fig. 5).

GROUNDWATER DEPENDENT ECOSYSTEMS

Whilst groundwater-dependent ecosystems (GDEs) have not been used in the assessment of the status of the groundwater resources, it is important to note the presence and ecological characteristics of the GDEs in the Far North PWA. Groundwater-dependent ecosystems can be defined as ecosystems where groundwater provides all or part of the water quantity, chemistry or temperature requirements, either permanently, seasonally or intermittently. It is generally considered that shallow water tables, i.e. those less than ten metres below the surface, are more likely to support GDEs than deeper water tables. The exception to this is stygofauna (animals that inhabit water-filled spaces and pools below the ground), that can be found at greater depths.

Of most significance in the Far North PWA are the GAB springs and associated wetlands maintained by water pressure and flow from the GAB. There are three major supergroup complexes within this area: Dalhousie Springs in the north-west region, Lake Eyre in the central region and Frome in the south-eastern region. These permanent aquatic habitats are important refugia for endemic water-dependent species and are known to support diverse populations of aquatic plants, aquatic macroinvertebrates and fish. Dalhousie Springs is the most significant of these supergroups, supporting five fish species, three crustaceans and one invertebrate that are endemic to this supergroup.[4]

Within the Far North PWA there are a significant number of surface water and wetland ecosystems that have some dependency on groundwater. These include ephemeral lakes and semi-permanent pools in riverine systems that include potential habitats for stygofauna within the hyporheic zones of stream beds. Plants with a dependence on groundwater also exist along the watercourses and fringing zones of wetlands and largely consist of River Red Gum (*Eucalyptus camaldulensis*) and Coolabah (*Eucalyptus coolabah*) associations. Although these species are tolerant of hot, dry conditions and infrequent flooding, they are unlikely to persist without access to groundwater.[5]

4 Fencham, RJ, Ponder, WF and Fairfax, RJ (2010), *Recovery Plan for the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin,* Report to the Department of the Environment, Water, Heritage and the Arts, Canberra, Queensland Department of Environment and Resource Management, Brisbane

5 Roberts, J. and Marston, F (2011), *Water regime for wetland and floodplain plants: a source book for the Murray–Darling Basin*, National Water Commission, Canberra

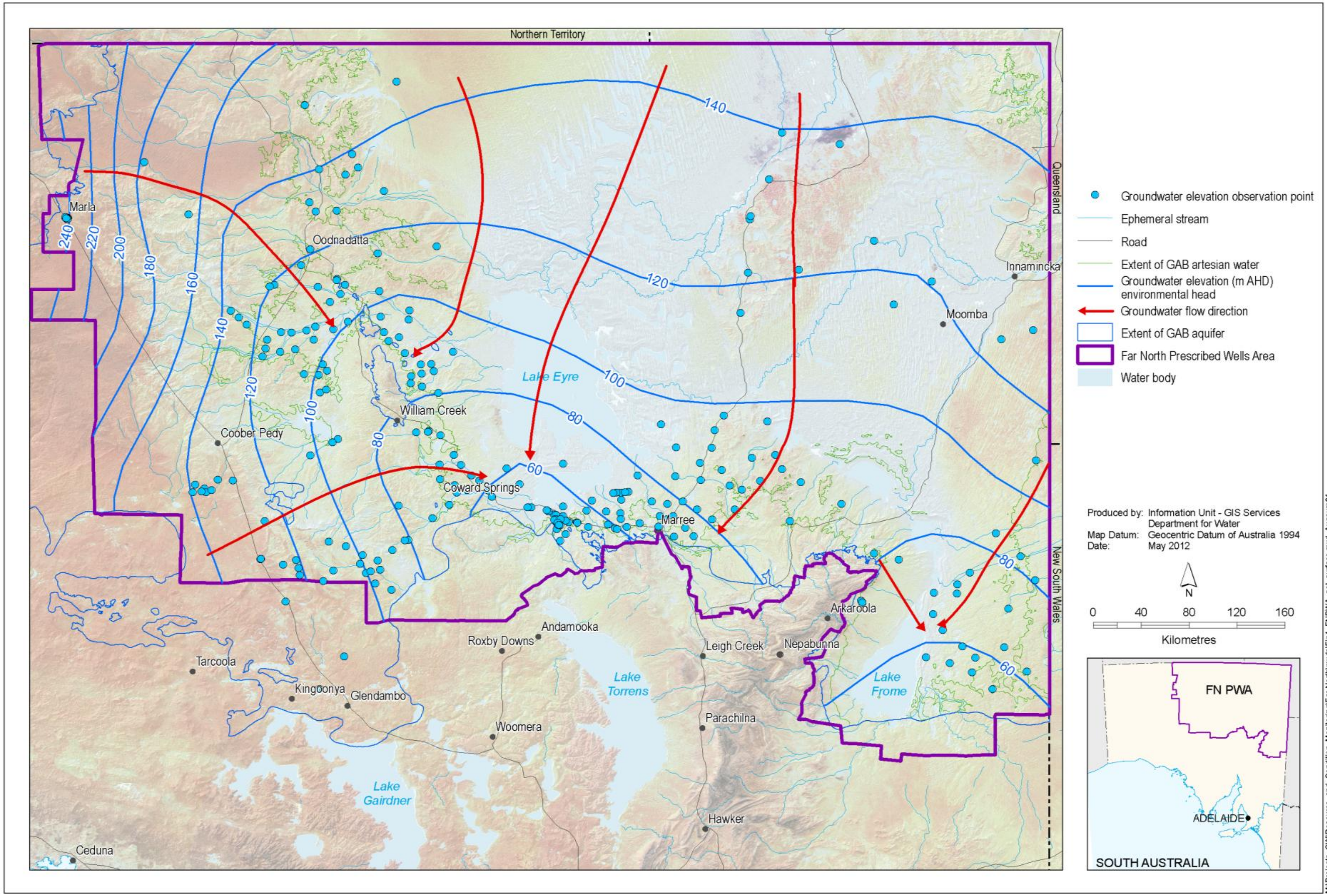


Figure 4. Groundwater flow (2004–2011) in the GAB aquifer in the Far North PWA

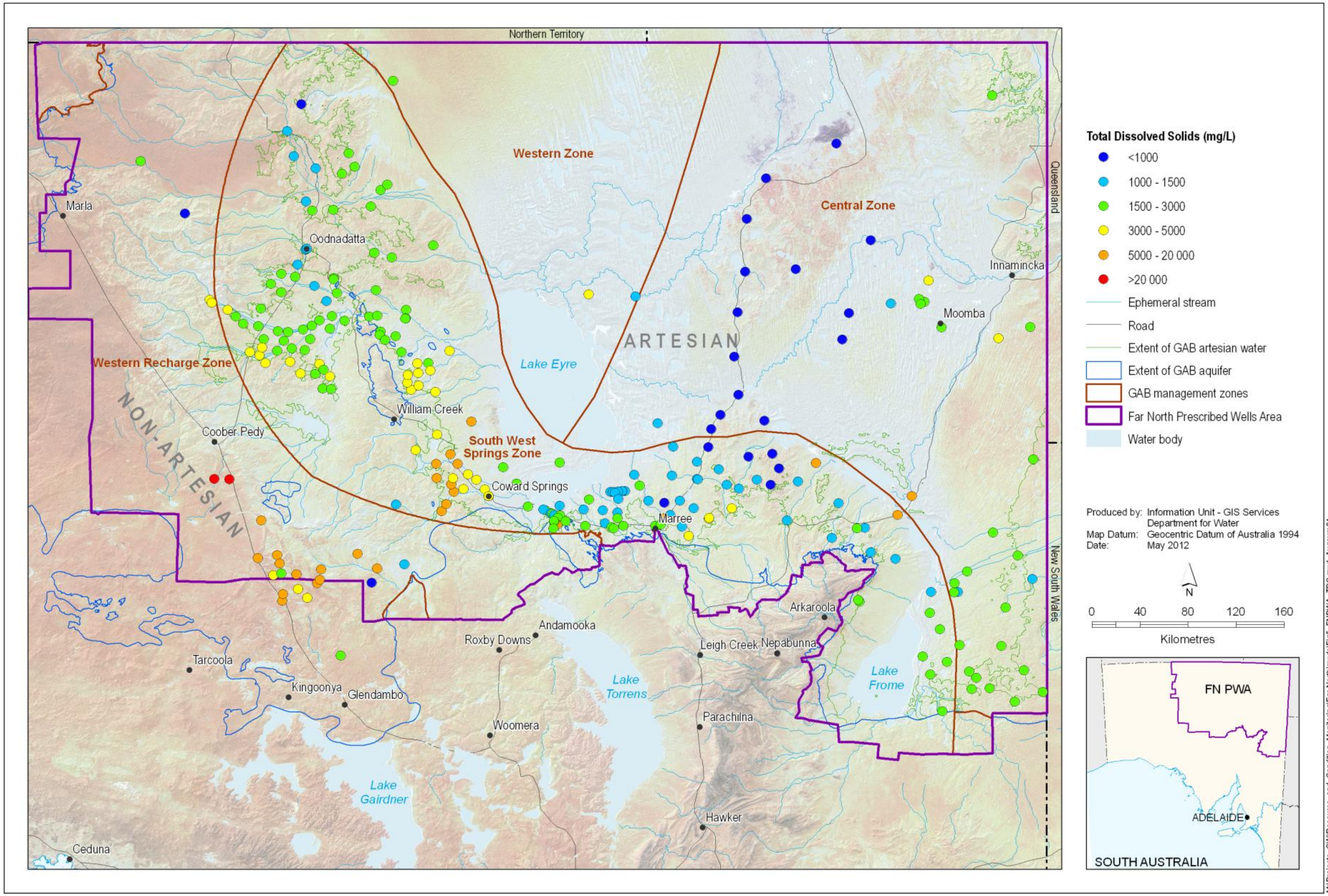


Figure 5. Groundwater salinity (2004–2011) in the GAB aquifer in the Far North PWA

RAINFALL

The Far North PWA is located in the South Australian Arid Lands Natural Resources Management Region. Rainfall occurrence and intensity is episodic, sometimes without significant rainfall for years, while intense rainfall can deliver annual amounts in a single event. Rainfall is generally less than 250 mm per year; however, as rainfall in the Arid Lands is unpredictable, averages can be misleading. Average annual evaporation is extremely high, ranging from 2400 to over 3700 mm, significantly exceeding rainfall and resulting in the rapid evaporation of surface water runoff.

The cumulative deviation measures the difference between the actual measured rainfall and the long-term average annual rainfall. An upward trend in the cumulative deviation indicates above-average rainfall and conversely, a downward trend indicates below-average rainfall.

The rainfall station at Hamilton Station is located in the north-west of the Far North PWA, about 100 km north–north-west of Oodnadatta (Fig. 6). The average annual rainfall for this station is 187 mm. For the decade beginning in 1956, rainfall alternated between above and below average (Fig. 7). From 1956 to 1972, rainfall was consistently low, with just one year (1968) above average. This low-rainfall period was followed by a period of well above-average rainfall that persisted until 1980. Since 1980, rainfall has again alternated between above and below average, with particularly wet years in 1989, 2000 and 2001. The year 1994 was a particularly dry year, as was 1990 and 2006. Since 2006, rainfall has steadily increased with just over 300 mm recorded in 2010.

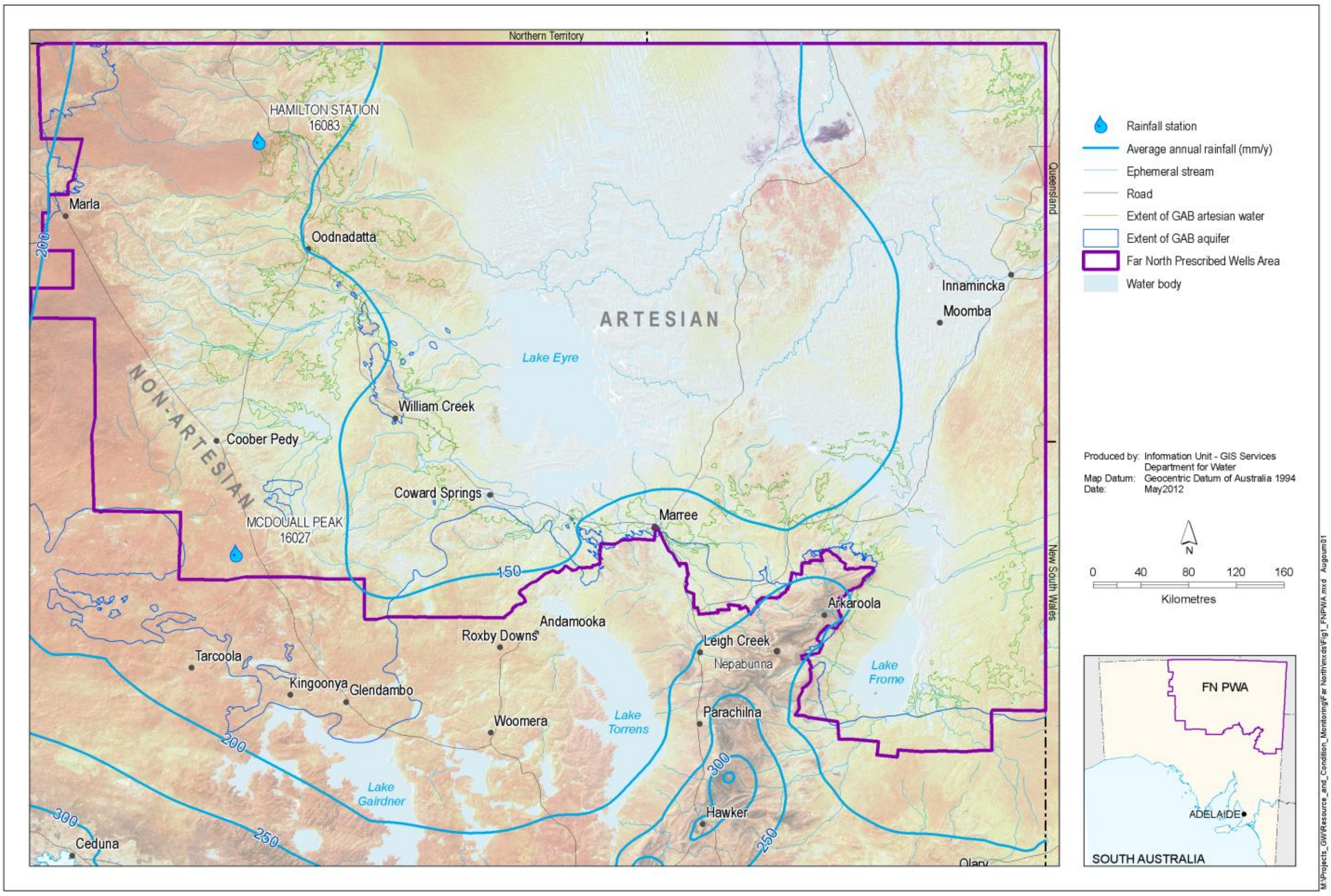


Figure 6. Average annual rainfall and location of rainfall stations in the Far North PWA

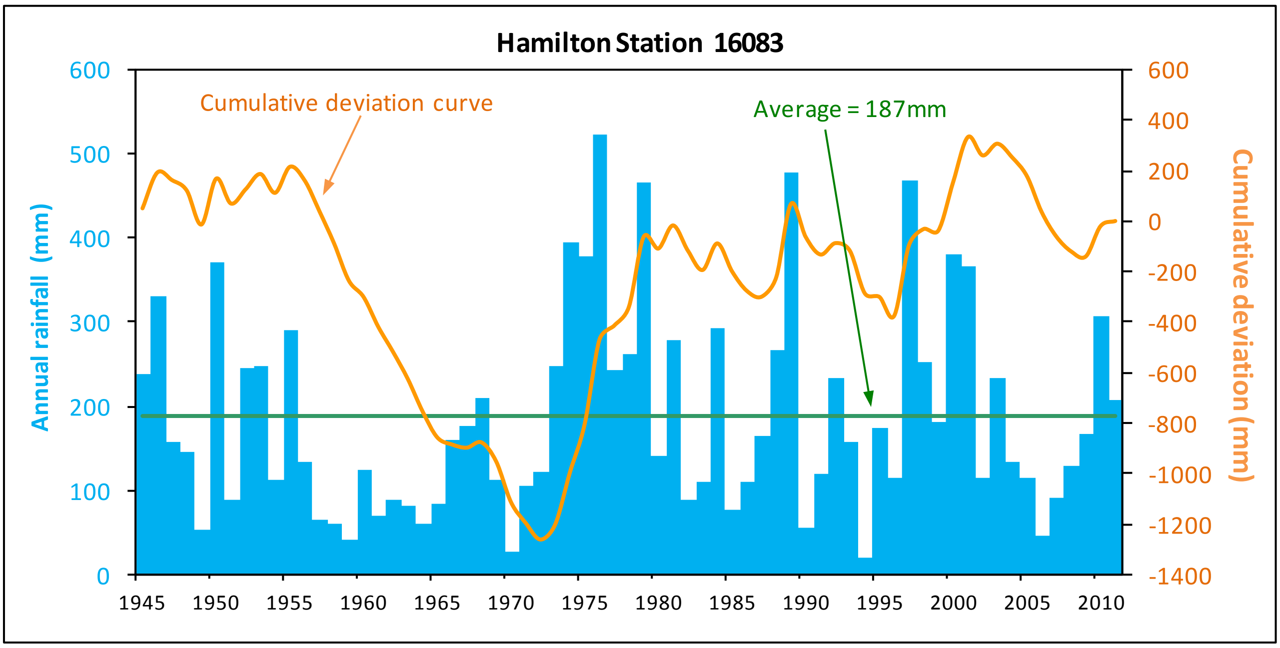


Figure 7. Annual rainfall and cumulative deviation from the average annual rainfall for the Hamilton Station rainfall station

The McDouall Peak rainfall station is located nearly 100 km south of Coober Pedy in the south-west of the Far North PWA (Fig. 6). The average annual rainfall is 157 mm and the overall long-term trend in rainfall follows the average closely (Fig. 8). Rainfall alternated between above and below average from 1946 to 1958 and was then consistently low until 1966. Rainfall then alternated between high and low again until the exceptionally wet year of 1973. Following 1973, rainfall was generally above average until another period of low rainfall from 1982 to 1986. Since then, rainfall has alternated between above and below-average periods with a particularly dry year in 2002. Both 2010 and 2011 have received above-average rainfall of over 200 mm.

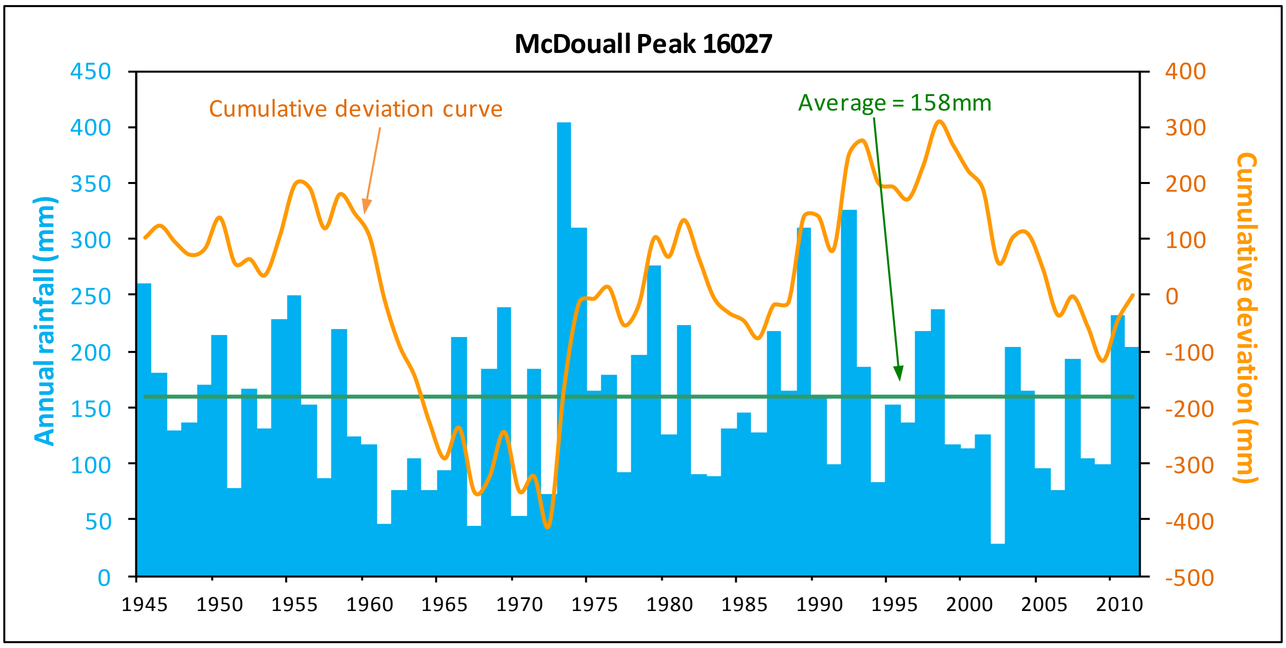
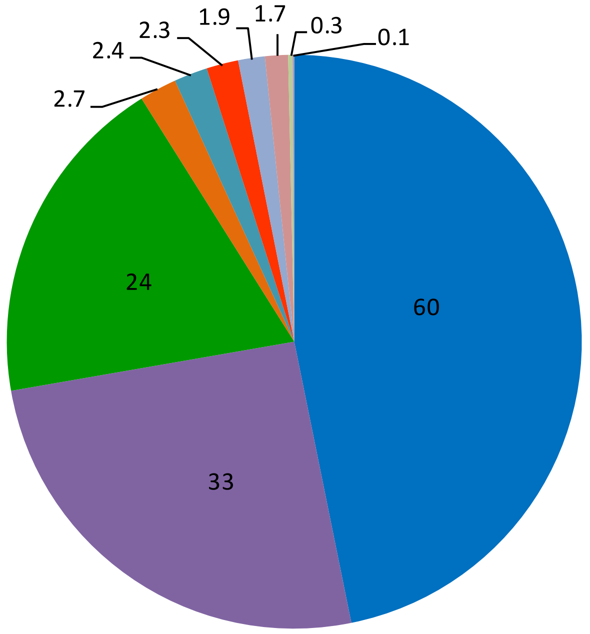


Figure 8. Annual rainfall and cumulative deviation from the average annual rainfall for the McDouall Peak rainfall station

GROUNDWATER USE

Licensed allocations for 2011 in the Far North PWA totalled 46 776.7 ML, or the equivalent of 128 ML/d (Fig. 9). Where information is available, groundwater usage is reported below.



Purpose	ML/d	ML/y
Petroleum co-produced water	60	21 900
Mining	33	11 903
Stock	24	8805
Industrial	2.7	981
Well-fed wetlands	2.4	883
Camp water	2.3	839
Domestic	1.9	701
Town water supply	1.7	605
Irrigation	0.3	115
Commercial	0.1	44

Figure 9. Licensed allocation volumes for groundwater extraction in the Far North PWA for 2011

The SAAL Regional Natural Resources Management Plan[6] estimates stock and domestic groundwater use is in the order of 33 ML/d from the GAB aquifer. Extraction from the GAB aquifer for town water supply is estimated at around 3.3 ML/d in the Plan.

Petroleum wells currently extract about 26 ML/d as co-produced water from the GAB aquifer and 1 ML/d from the Cooper Basin.

Current groundwater usage from the GAB aquifer for mining operations is 36.3 ML/d (Olympic Dam 36 ML/d; Beverley 0.3 ML/d). At Prominent Hill, 17 ML/d is extracted from the Arckaringa Basin.

Total groundwater discharge from the springs in the Far North PWA has been estimated at 66 ML/d. This is an order of magnitude estimate due to the inherent difficulties in measuring flows and the low number of spring flow measures.

It should be noted that the usage figures above are estimates only. A concise summary of GAB water usage is currently not available.

6 South Australian Arid Lands Natural Resources Management Board 2010, Regional Natural Resources Management Plan for the SA Arid Lands Natural Resources Management Region, Volume 1, Ten-year strategic plan

GROUNDWATER OBSERVATION NETWORKS

GAB NETWORK

Within the Far North PWA, six wells monitor groundwater at the township of Marla in the non-artesian part of the GAB (Fig. 10). Monitoring began with one well in 1980, with the other five wells commencing operation the following year. Yield, flow, accumulated flow and water level are monitored continuously with data loggers and the data are downloaded and the water levels measured manually every six months by the Department for Water (DFW). Information pertaining to this monitoring network is publically available through the WaterConnect website.

As part of their mining operations from the GAB, BHP Billiton is required to monitor the impact on groundwater resources in the vicinity of extraction wells in their Wellfield A and Wellfield B areas, north of Roxby Downs (Fig. 10). Details concerning the monitoring programs are reported annually to DMITRE. BHP Billiton also monitors a number of springs twice yearly.

Since the 1970s, wells within the artesian extent of the GAB have been monitored by DFW and its predecessors (Fig. 10). The artesian wells are monitored for shut-in pressure, water temperature and electrical conductivity. These wells are not dedicated observation wells, but consist primarily of existing pastoral wells. The high cost of drilling and monitoring wells in this remote area and the difficulties associated with access (e.g. floods, bushfires) means that wells have only been monitored when sufficient resources were available. However, a number of wells in the GAB aquifer have been identified to create an official monitoring network once all of the wells are equipped. Information for these wells will be publically available through the WaterConnect Website.

Although a number of wells throughout the Far North PWA were measured for groundwater levels in 2011, they do not have sufficient previous measurements to enable long-term trend analyses. Therefore wells that have a history of groundwater level measurements have been used for the long-term trend analysis despite the most recent measurements being taken in 2004, 2005 or 2009 (Fig. 11).

Similarly, although some wells were measured for salinity in 2011, many of them do not have sufficient previous measurements to enable long-term trend analyses. A number of wells in the north-west and west of the Far North PWA were measured for salinity in 2011 and have a number of historical measurements. In other areas of the Far North PWA, wells have not been measured for salinity since 2004, 2005 or 2009 but have numerous measurements recorded in previous years so are able to illustrate long-term trends in groundwater salinity (Fig. 12).

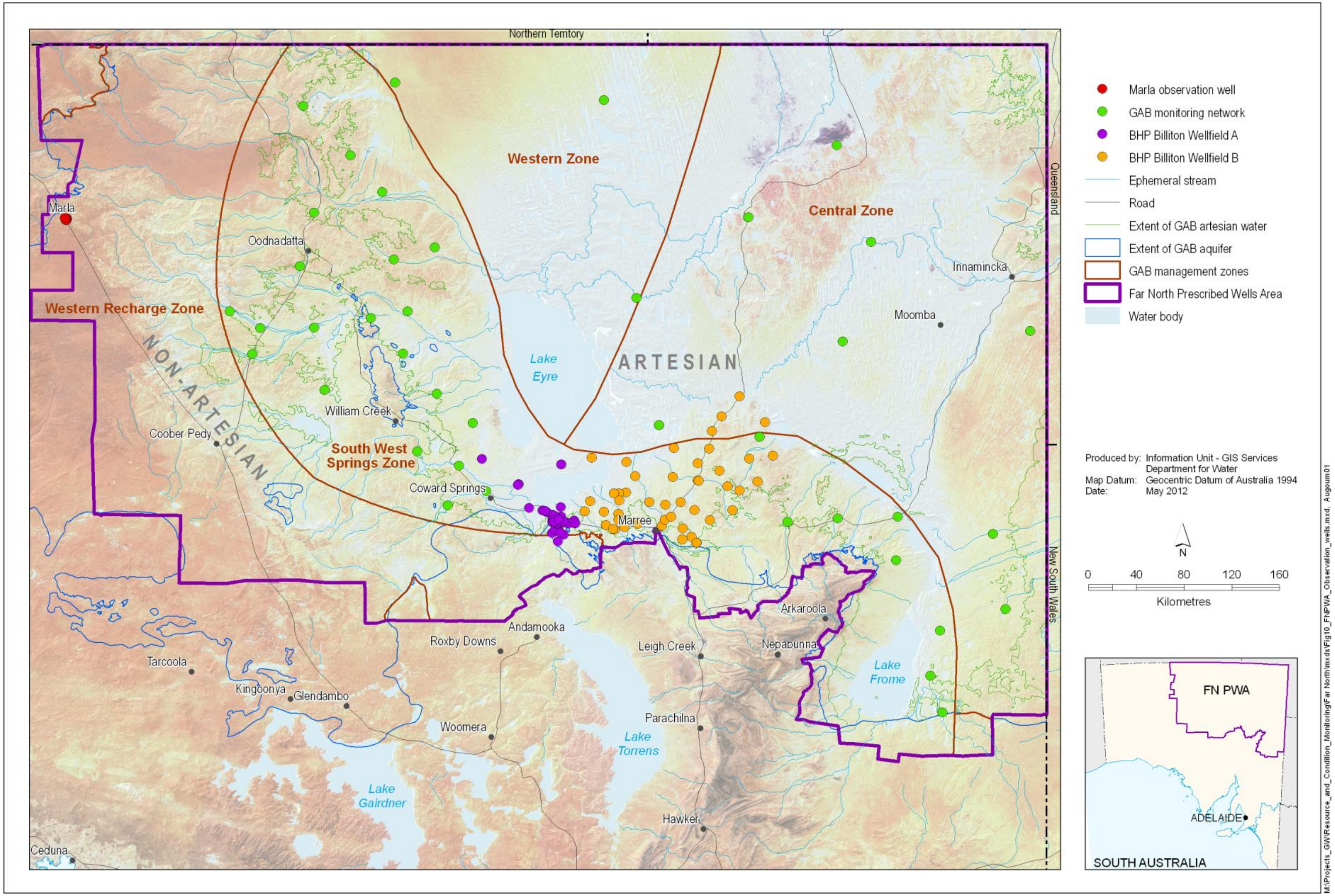


Figure 10. Location of groundwater level observation wells in the Far North PWA

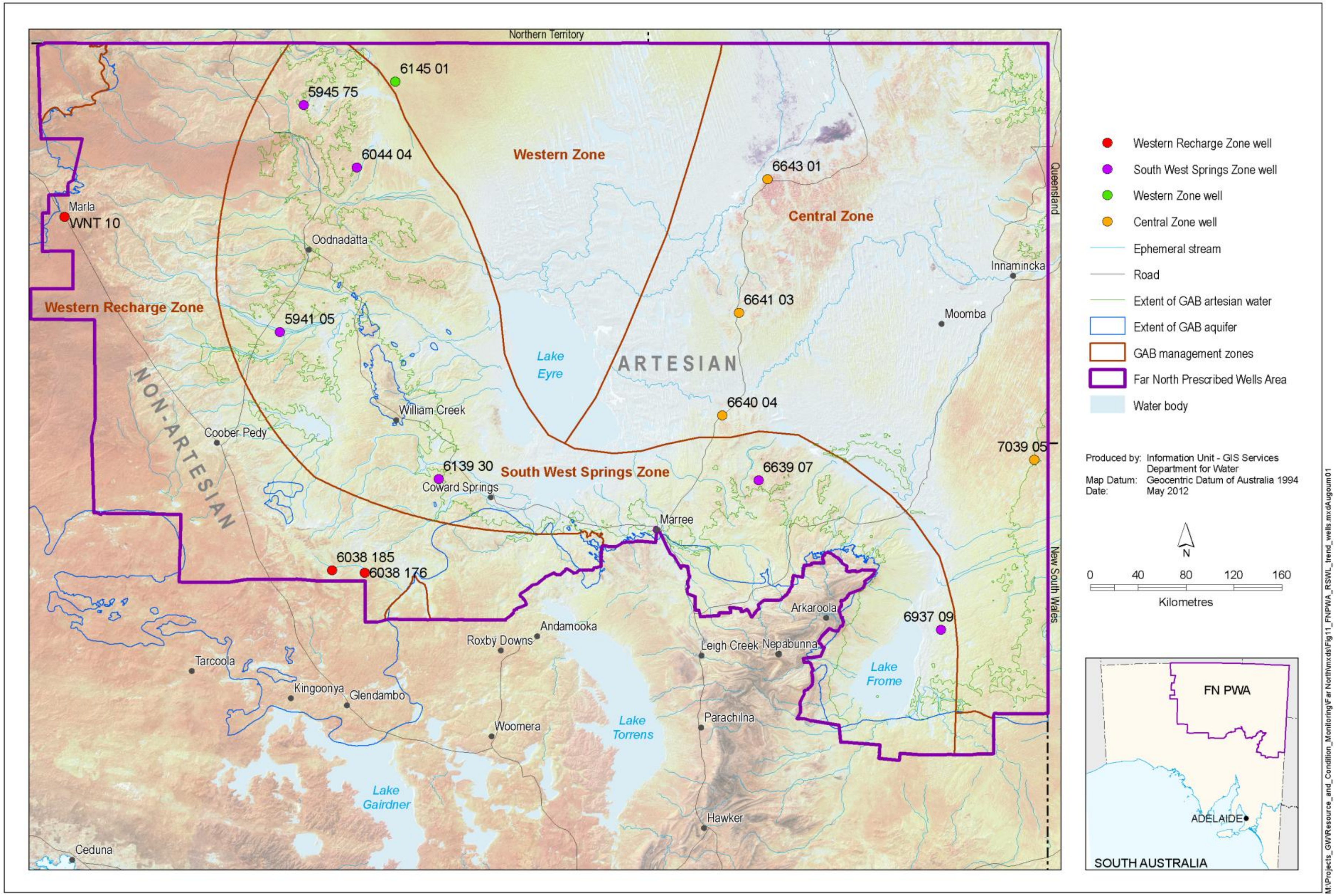


Figure 11. Location of groundwater wells in the Far North PWA used in the analysis of groundwater level trends

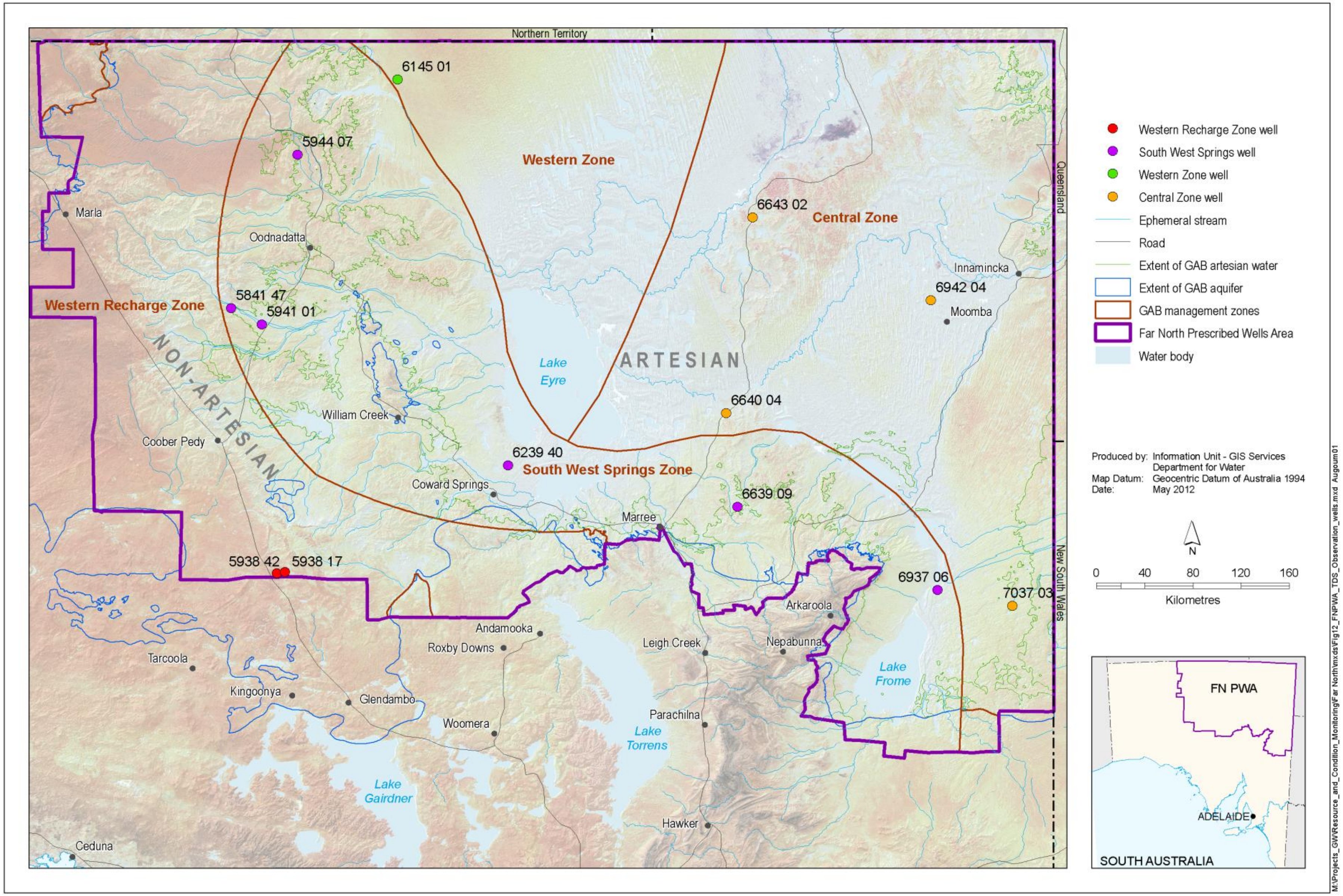


Figure 12. Location of groundwater wells in the Far North PWA used in the analysis of salinity trends

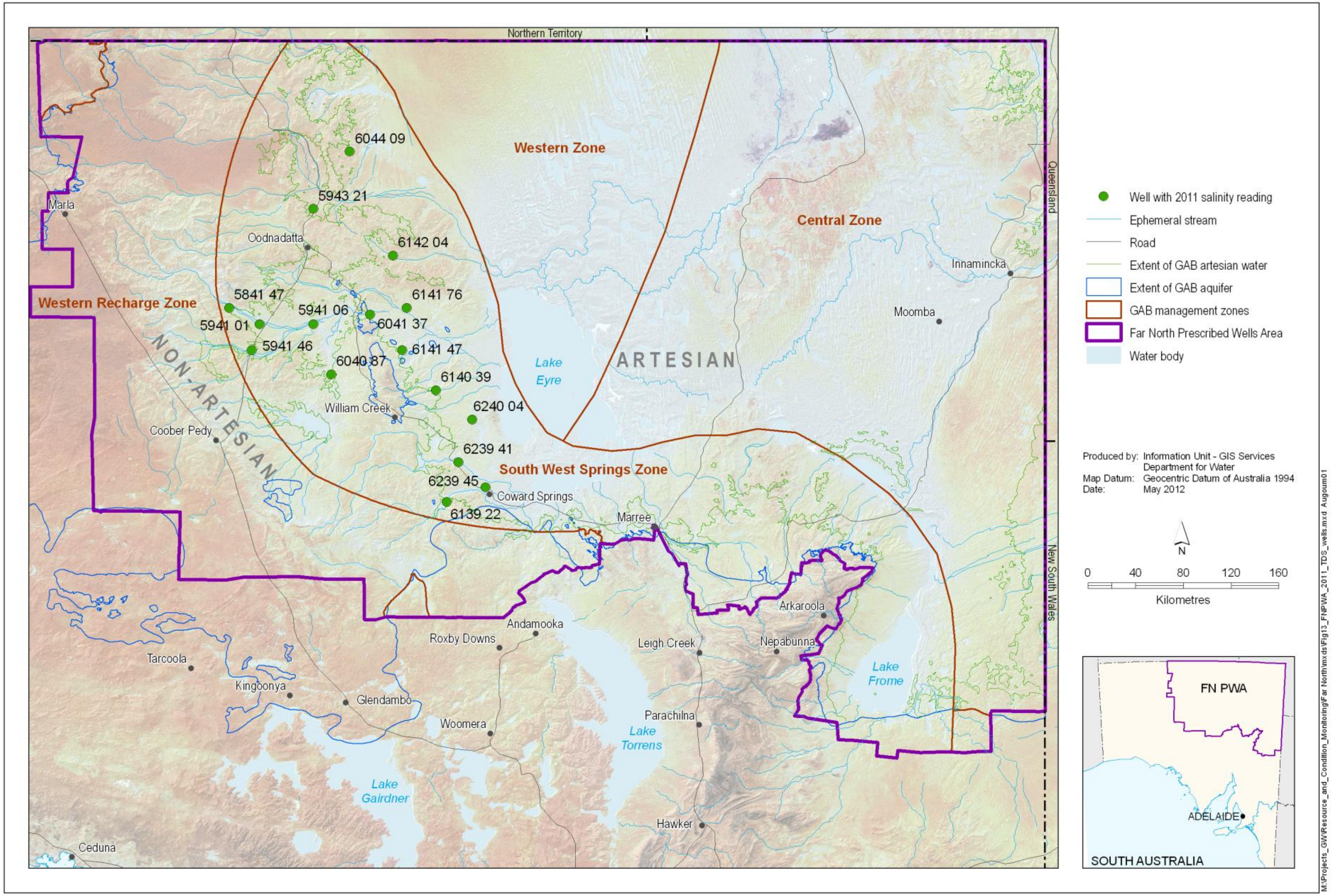


Figure 13. Location of groundwater wells in the Far North PWA with a salinity measurement recorded in 2011

GROUNDWATER LEVEL TRENDS

Groundwater level monitoring in the township of Marla began in 1980. As Marla is located in the non-artesian portion of the GAB aquifer, it is confined but non-artesian and therefore the groundwater levels are measured as depth to water. As it is also located within the Western Recharge Zone the groundwater level in one of the Marla observation wells has been plotted against the cumulative deviation from average annual rainfall from the nearby Hamilton Station rainfall station (Fig. 14). Between 1980 and 1990, the groundwater rose by a total of 3.5 m. This total has primarily occurred over short time periods on three occasions that coincide with periods of above-average rainfall. Since 1990, the groundwater level has been in a slow but steady decline. Between 1990 and 1997 and 2004 and 2009 this may be attributed to the below-average rainfall in the area. It is unknown if the above-average rainfall between 1997 and 2002 caused groundwater levels to rise as there is a lack of groundwater level data during this time. The recent above-average rainfall in 2010 and 2011 has resulted in only a minor rise in the water level.

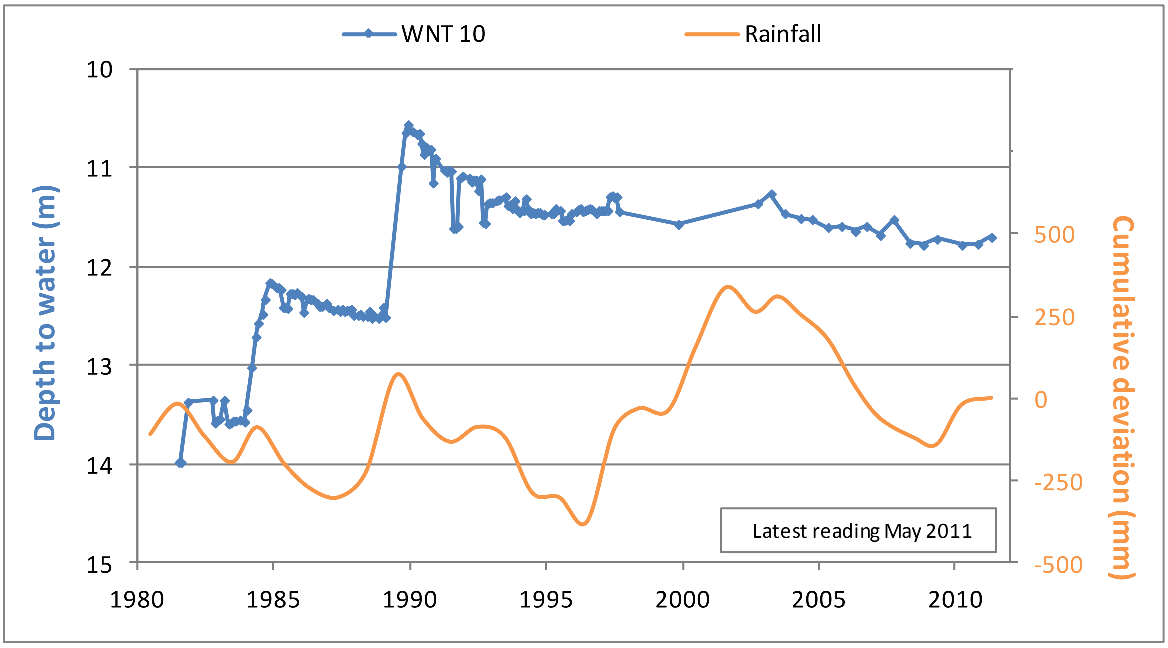


Figure 14. Groundwater level trends in the GAB aquifer (non-artesian) at the township of Marla and the cumulative deviation from mean monthly rainfall for the Hamilton Station rainfall station

Marla is the only location in the north-west of the Far North PWA where groundwater monitoring occurs on a regular basis. However, there a number of other wells in the area that have had groundwater pressure measured on a number of occasions and although they have not had a measurement taken in recent years, they can provide an indication of long-term trends in the groundwater elevation. When groundwater pressure measurements are entered into the State's hydrogeological database, SA Geodata, the pressure is converted into an elevation relative to the Australian Height Datum (AHD).

Overall, the groundwater elevation of the GAB aquifer in the Far North PWA has remained relatively stable over a long period of time. While there have been small fluctuations in groundwater elevation over the years, current values are similar to historical measurements.

In the Western Recharge Zone, two wells provide reasonable data for trend analysis (Fig. 11). The groundwater elevation in these wells has remained quite stable since records began in 2006 (Fig. 15). The groundwater elevation has fluctuated by a maximum of 1.5 m and the most recent data, measured in 2009, is on par with historical measurements.

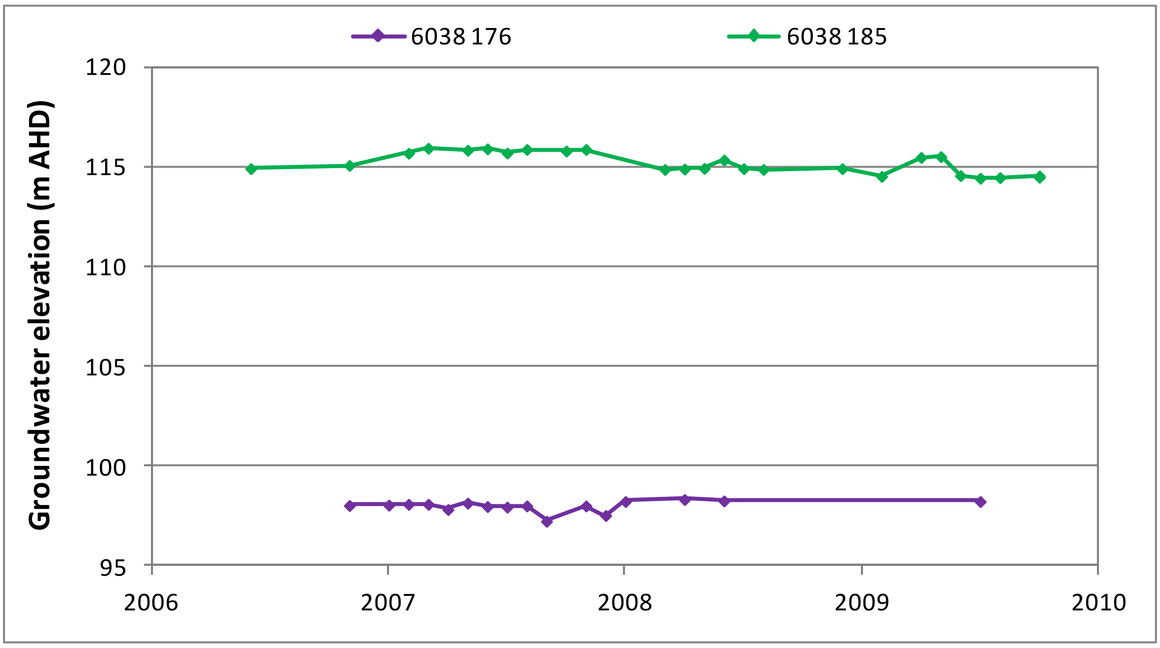


Figure 15. Groundwater level trends in the GAB aquifer in the Western Recharge Zone of the Far North PWA

Throughout the South West Springs Zone, long-term groundwater elevations are also quite stable (Fig. 16). In the north-west of the South West Springs Zone, long-term trends indicate both rise and falls in the groundwater elevation. The most recent data available, from 2006 and 2008 (6044 04 & 5945 75), indicate a fall in groundwater elevation (Fig. 16). In the west of the South West Springs Zone, some wells display groundwater elevations with fluctuations of up to 10 m, however, groundwater elevations in most wells, such as 5941 05, have changed little over the years.

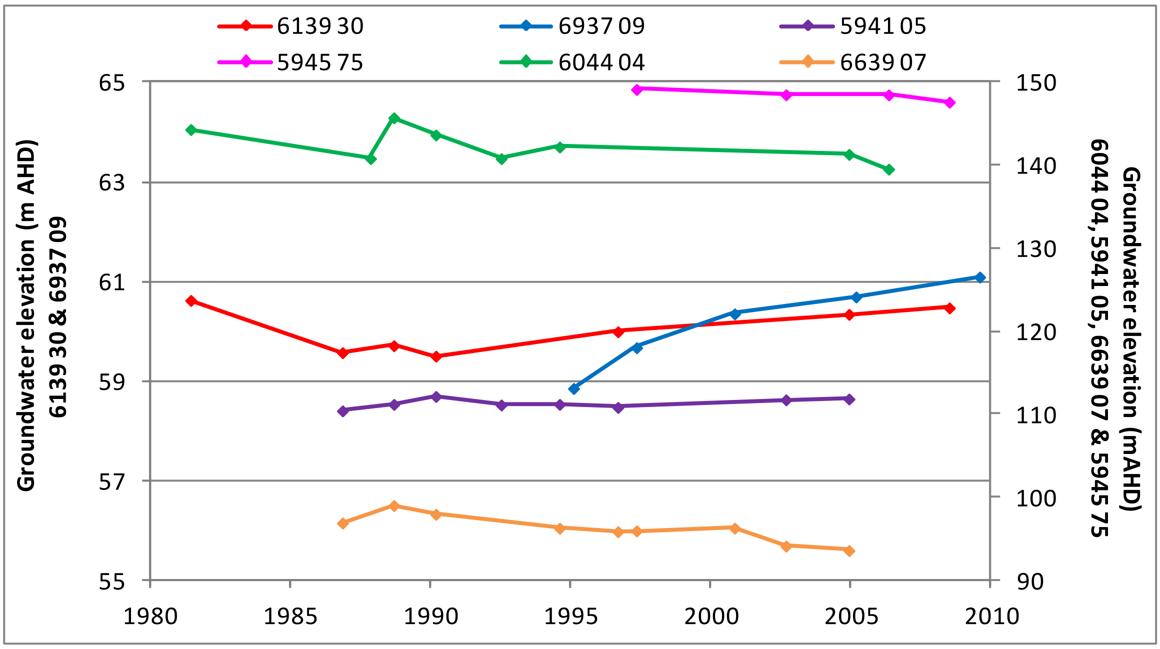


Figure 16. Groundwater level trends in the GAB aquifer in the South West Springs Zone of the Far North PWA

Well 6145 01 is the only well in the Western Zone with data suitable for analysis (Fig. 17). After an increase of 1.6 m between 1990 and 1997, the groundwater elevation has been very stable from 1997 to 2006 when the latest reading was taken.

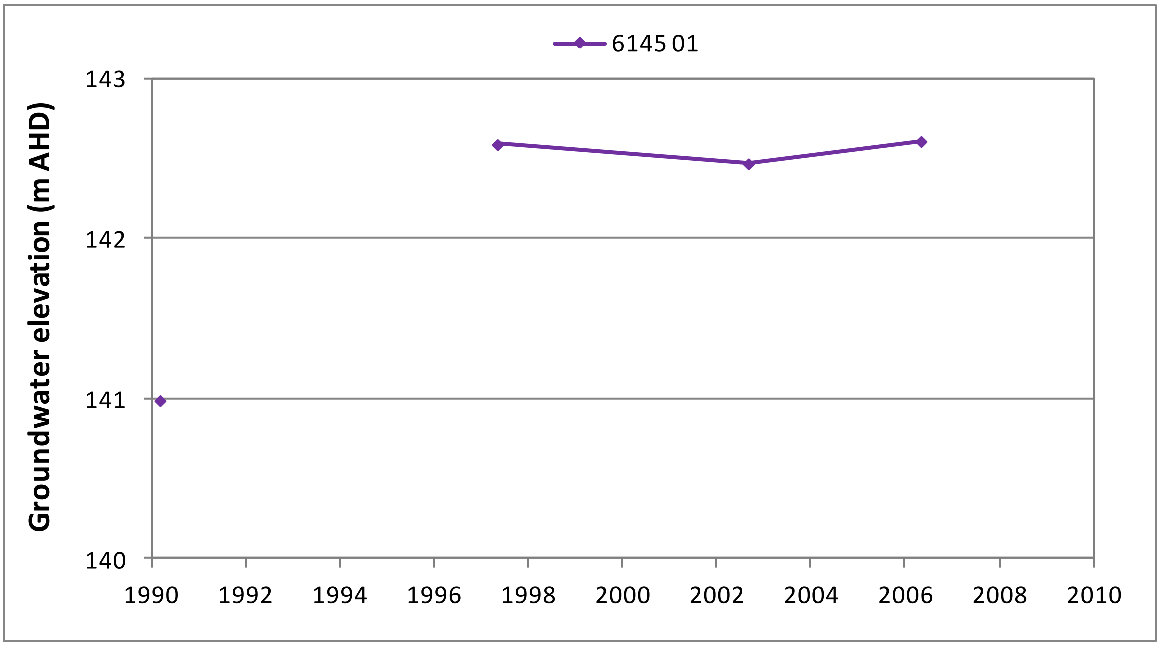


Figure 17. Groundwater level trends in the GAB aquifer in the Western Zone of the Far North PWA

The most recent groundwater elevation data available for the Central Zone was measured in 2005. For many wells the most recent measurement is the lowest recorded and the majority of wells in this management zone display an overall downward trend (Fig. 18).

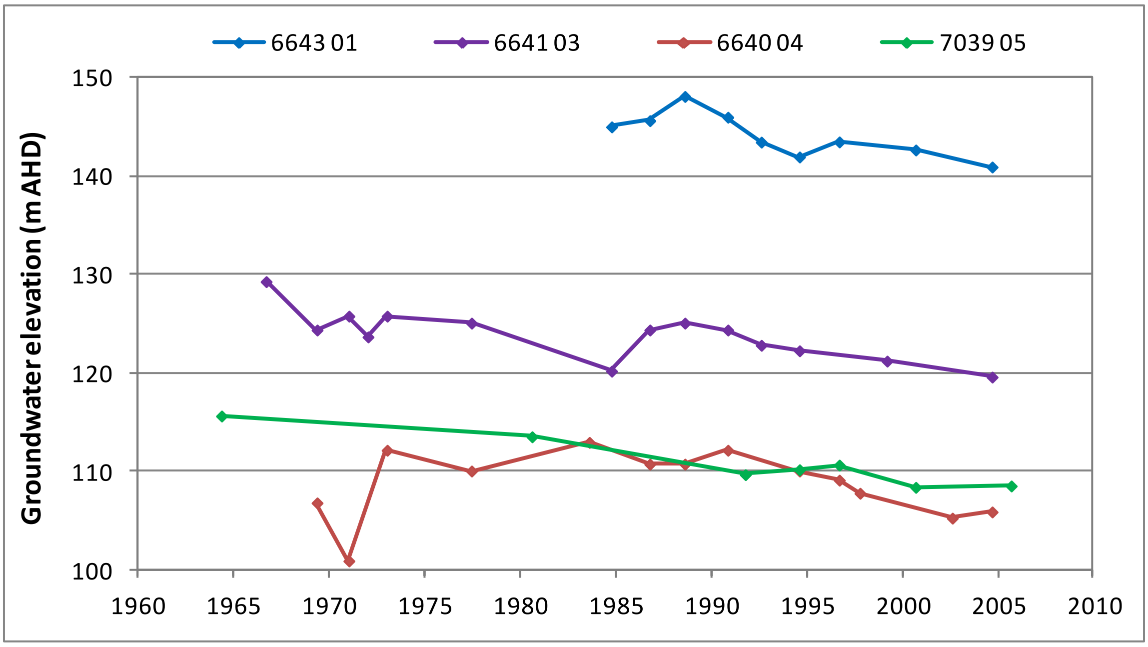


Figure 18. Groundwater level trends in the GAB aquifer in the Central Zone of the Far North PWA

GROUNDWATER SALINITY TRENDS

Overall, the salinity of the GAB aquifer has remained relatively stable since 1900 (Figs. 19, 20, 21 & 22). While there have been small fluctuations in groundwater quality over the years, current values are similar to historical measurements.

In the south of the Western Recharge Zone of the Far North PWA, salinity has changed little over the long-term with recorded fluctuations in individual wells of between 180 and 370 mg/L (Fig. 19). As salinity in this area is typically high (5000–20 000 mg/L, see Fig. 5), fluctuations of this magnitude are insignificant.

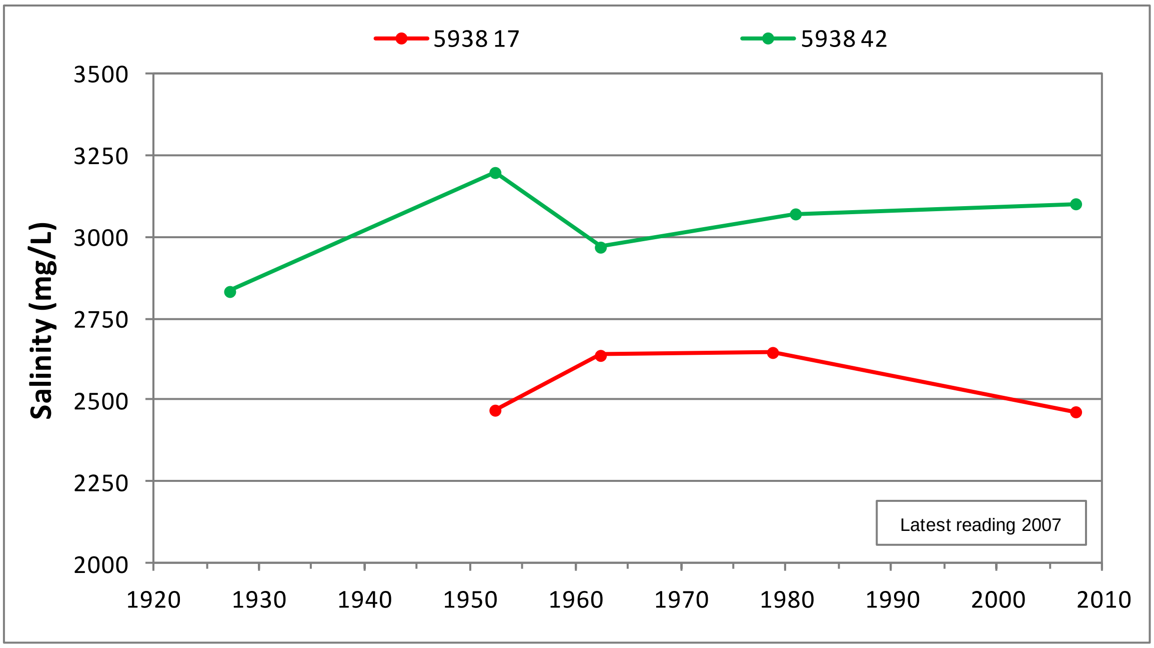


Figure 19. Groundwater salinity trends of the GAB aquifer in the Western Recharge Zone of the Far North PWA

Salinity in the South West Springs Zone of the Far North PWA is typically between 1000 and 5000 mg/L (Fig. 5). In many wells salinity is quite stable, changing little over the past 100 years and the majority of wells show an overall decrease in salinity. Fluctuations in salinity in individual wells range from 50 mg/L to nearly 2100 mg/L, with an average of around 270 mg/L. The pastoral well 6639 09, located north-east of Marree displays a significant increase in salinity from 2002 to 2004 (Fig. 20). The cause of this increase in unknown but the rapid change may indicate the integrity of the well has been compromised.

All 16 wells that recorded a salinity measurement in 2011 are located within the western arm of the South West Springs Zone (Fig. 13). All bar one well have a prior measurement taken in 2009. Fourteen of these 15 wells recorded an increase in salinity from 2009 to 2011 of between 11 and 311 mg/L, or 0.2 to 15%, with an average of 3%. Well 5841 47 recorded a decrease in salinity of just over 1000 mg/L from 2009 to 2011 (Fig. 20).

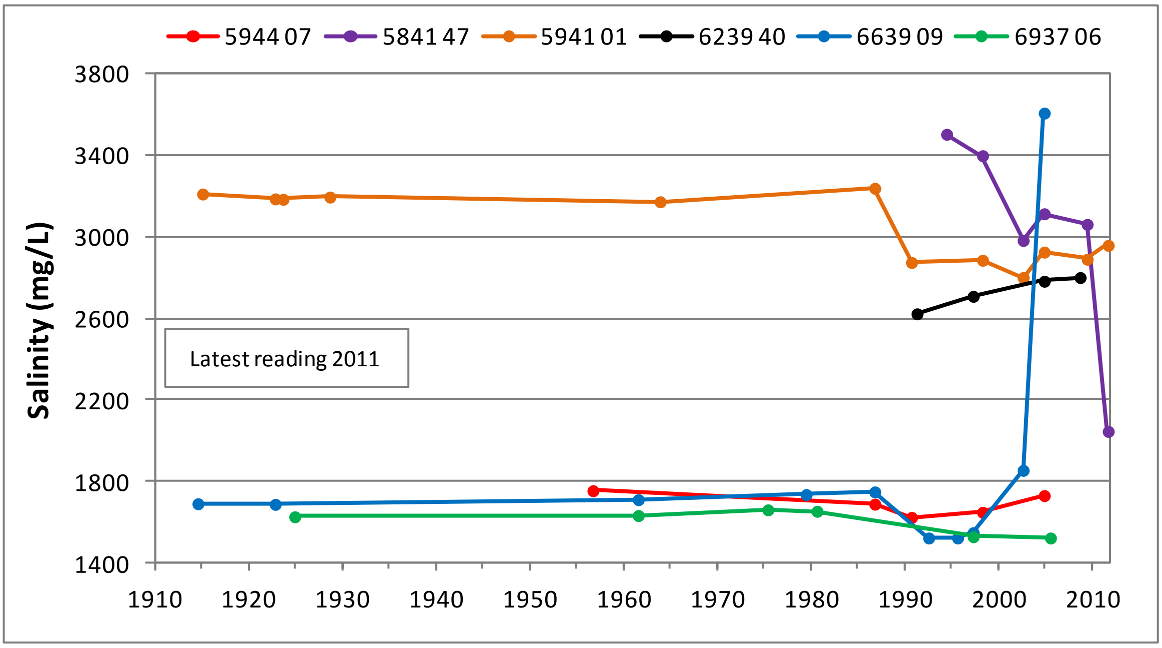


Figure 20. Groundwater salinity trends of the GAB aquifer in the South West Springs Zone of the Far North PWA

Salinity data is scarce for the Western Zone (Fig. 5). Between 2004 and 2011, three wells have recorded salinities of 1496, 2745 and 4863 mg/L. Well 6145 01 is the only well in the Western Zone with a salinity measurement taken since 2004 that has more than two salinity data records. The latest measurement, recorded in 2006, is similar to the older measurements (Fig. 21).

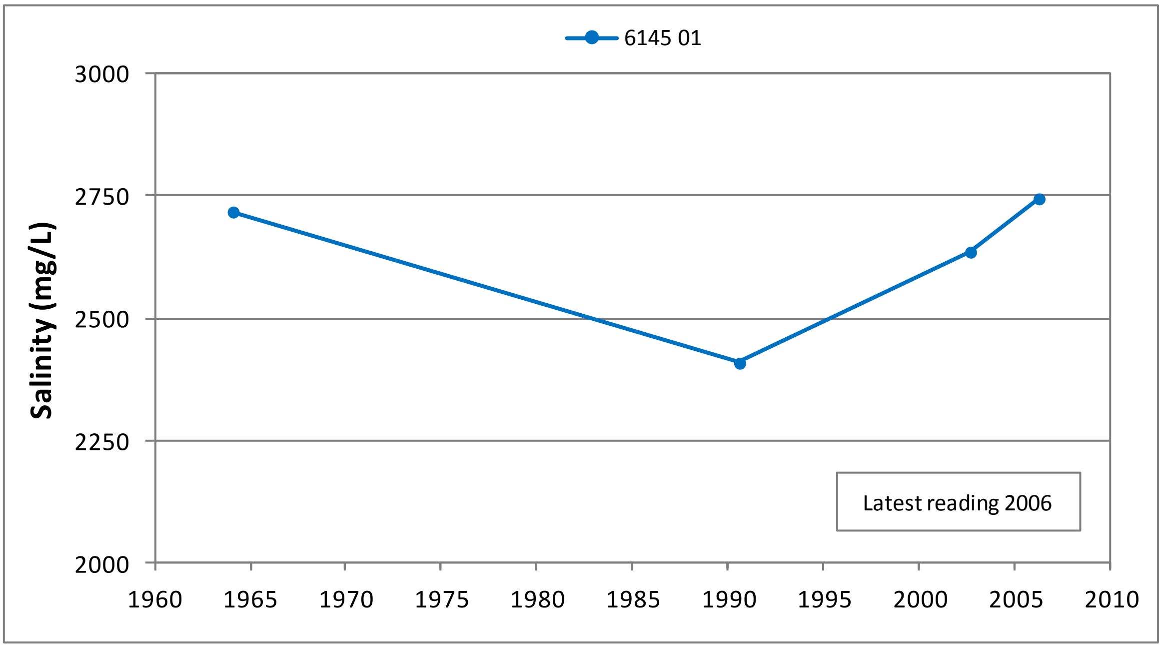


Figure 21. Groundwater salinity trends of the GAB aquifer in the Western Zone of the Far North PWA

In the Central Zone of the Far North PWA, many wells have salinities of less than 1000 mg/L, but the majority are between 1500 and 3000 mg/L (Fig. 5). Throughout the Central Zone, the majority of wells display an overall decline in groundwater salinity (Fig. 22). Fluctuations in salinity in individual wells are between 50 and 650 mg/L, with an average of just over 200 mg/L.

Analysis of the current salinity trends for this area is not possible as the most recent salinity measurements were recorded in 2009. However, due to the long-term stability of salinity in the area and overall decline in salinity, any increases in salinity in 2011 are expected to be minimal.

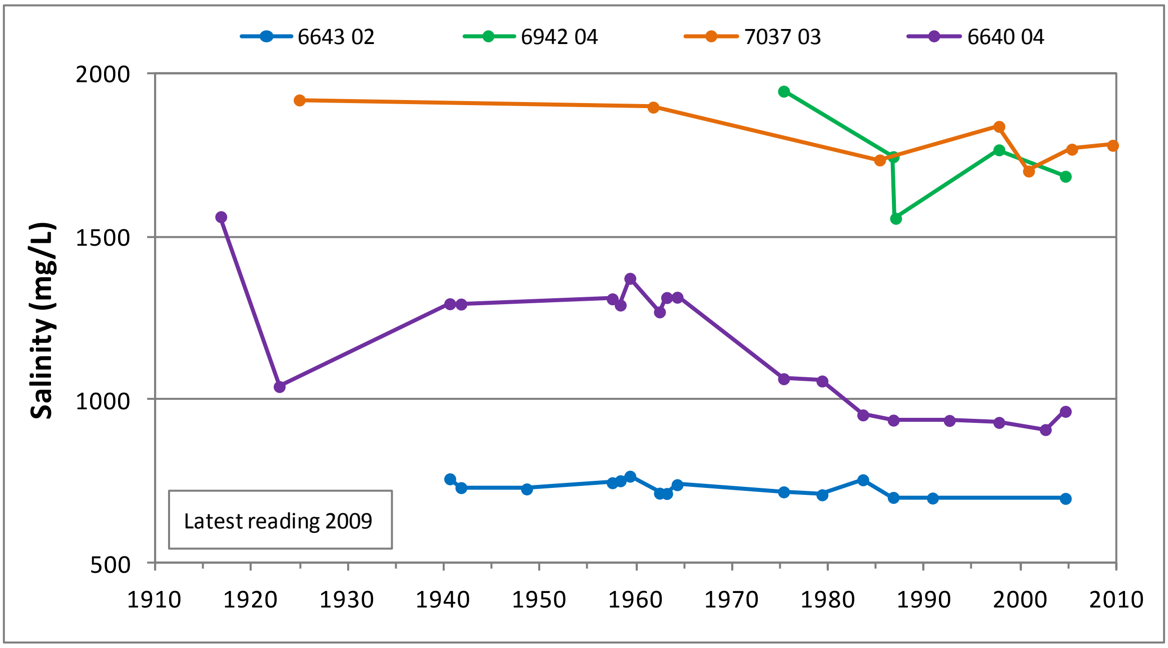


Figure 22. Groundwater salinity trends of the GAB aquifer in the Central Zone of the Far North PWA