Far North Prescribed Wells Area Groundwater Model

Volume 5 – Well and spring time-series data

Department for Environment and Water
September, 2023

DEW Technical report 2023-73

Government of South Australia
Department for Environment and Water

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ISBN XXX-X-XXXXXX-XX-X

Preferred way to cite this publication

Department for Environment and Water (2023), *Far North Prescribed Wells Area Groundwater Model. Volume 5 – Well and spring time series data,* DEW-TR-2023-73, Government of South Australia, Department for Environment and Water, Adelaide.

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Foreword

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provide the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Landscape Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

John Schutz
CHIEF EXECUTIVE
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Acknowledgements

Internal review of the report was provided by:

- project technical lead Mark Keppel, Principal Hydrogeologist, Department for Environment and Water (DEW)
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- project groundwater modelling technical lead Juliette Woods, Principal Groundwater Modeller, DEW.
- project technical geology lead Tony Hill, Deputy Director, Geoscience and Exploration Branch and Principal Geologist, Department for Energy and Mining (DEM)
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External review of the report was provided by:

- Paul Howe Principal Hydrogeologist, CDM Smith Pty Ltd
- Keith Phillipson, Principal Modeller, Australasian Groundwater and Environmental Consultants Pty Ltd.

DEW would like to thank the following people and organisations for their assistance with this project:

- Andrew Stannard, Principal Environmental Advisor SANTOS, for the provision of water use data from south-west Queensland tenements of SANTOS
- Michael Mayrhofer Senior Specialist Environment – Water, Broken Hill Proprietary (BHP) Olympic Dam, for the provision of pressure, temperature and salinity data from BHPs Wellfield A and Wellfield B
- Scott Delaney, Manager Development Western Flank Oil of Beach Energy, for the provision of water use data from their Western Flank tenements
- Daniel Radulovic Team Leader Mining Compliance and Regulation, DEM: for coordinating a review of unreleased water-related drill-hole data from active and non-active tenements
- Dominic Pepicelli Principal Reservoir Engineer, DEM, for advice on petroleum well test data.

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Executive summary

The documentation for the Far North Prescribed Wells Area Groundwater Model is presented over several volumes. The purpose of these reports is to provide an overview of the study area, provide scientific evidence for the conceptual hydrogeological model (CHM) used as the basis for the decisions and assumptions used during model construction and history matching. This volume (Volume 5) presents time series data for wells and springs located within the study area, providing insight into the natural trends and development pressures of groundwater resources as well as stress responses by which model calibration can be targeted.

The Far North Prescribed Wells Area in South Australia (SA) extends across the Eromanga Basin in SA and the Northern Territory (NT), with a 'buffer zone' extension into south-western Queensland (Qld) and north-western New South Wales (NSW). This area also covers the Pedirka Basin in SA and the NT, the Arckaringa Basin in SA, and the Cooper Basin in SA, along with part of the Cooper Basin in south-western Qld, which all have potential hydraulic interactions with the Eromanga Basin.

The majority of groundwater pressure reduced standing water level (RSWL) and salinity data came from SA Government-maintained database SA Geodata. Of this a large portion of time series data is sourced from the SA Government monitored Far North Prescribed Wells Area (FNPWA) monitoring network (Figure 1). The FNPWA monitoring network is based upon the Great Artesian Basin (GAB) monitoring network established by the SA Government in the 1970s and is largely composed of pastoral bores. Prior to this there was no formal monitoring network for the Far North region and so any water level readings were either taken at the time of bore construction or were opportunistic in nature and irregularly spaced. Indeed, regular yearly or 6-monthly monitoring for the artesian portion of the Eromanga Basin did not become routine until the 2000s, while the non-artesian portion of the basin was not formally included into the network until the 2010s. Other time series data assessed came from a number of privately maintained networks, most notably the Olympic Dam Mine monitoring network located in the southern portion of the study area (Figure 1). Finally, selected data from the Prominent Hill mine monitoring network and the Cairn Hill mine and Peculiar Knob mine monitoring networks were also assessed (Figure 1).

Spring flow time series data (Figure 1) is largely sourced from the Olympic Dam mining operations annual Environmental Protection and Management Program. Springs covered by this monitoring program are located in the Kati Thanda-Lake Eyre south region. Additional historical data from four springs in the Dalhousie Springs group were also assessed.

Since more co-ordinated monitoring began in the 1970s groundwater pressures in the area between the Cooper Basin and Kati Thanda-Lake Eyre have seen declines in the tens of metres. These declines are likely to be due to extractions associated with pastoralism, oil and gas extraction in the Cooper Basin region, and the wellfield areas of the Olympic Dam mining operation. While there are few pressure readings recorded prior to the 1970s, those available indicate pressure declines had already begun in the pre-1970s period. Pressures and water levels in other areas generally appear stable, although some localised increases suggest that the impact of well-capping programs can be observed in monitoring data. Localised increases in pressure are particularly notable near the springs. The groundwater model is designed with capacity to 'unpack' these various water user effects.

Salinities for the most part have remained relatively steady, varying between <1000 mg/L Total Dissolved Solids (TDS) in eastern and central regions to >14,000 mg/L near the south-western margin.

In the southern springs region where Olympic Dam mining operations have been monitoring spring flow since the early 1980s, data reflects the impacts of extraction from their wellfields. Over the short period of monitoring record at Dalhousie Springs since the late 1990s, no notable trends were observed.

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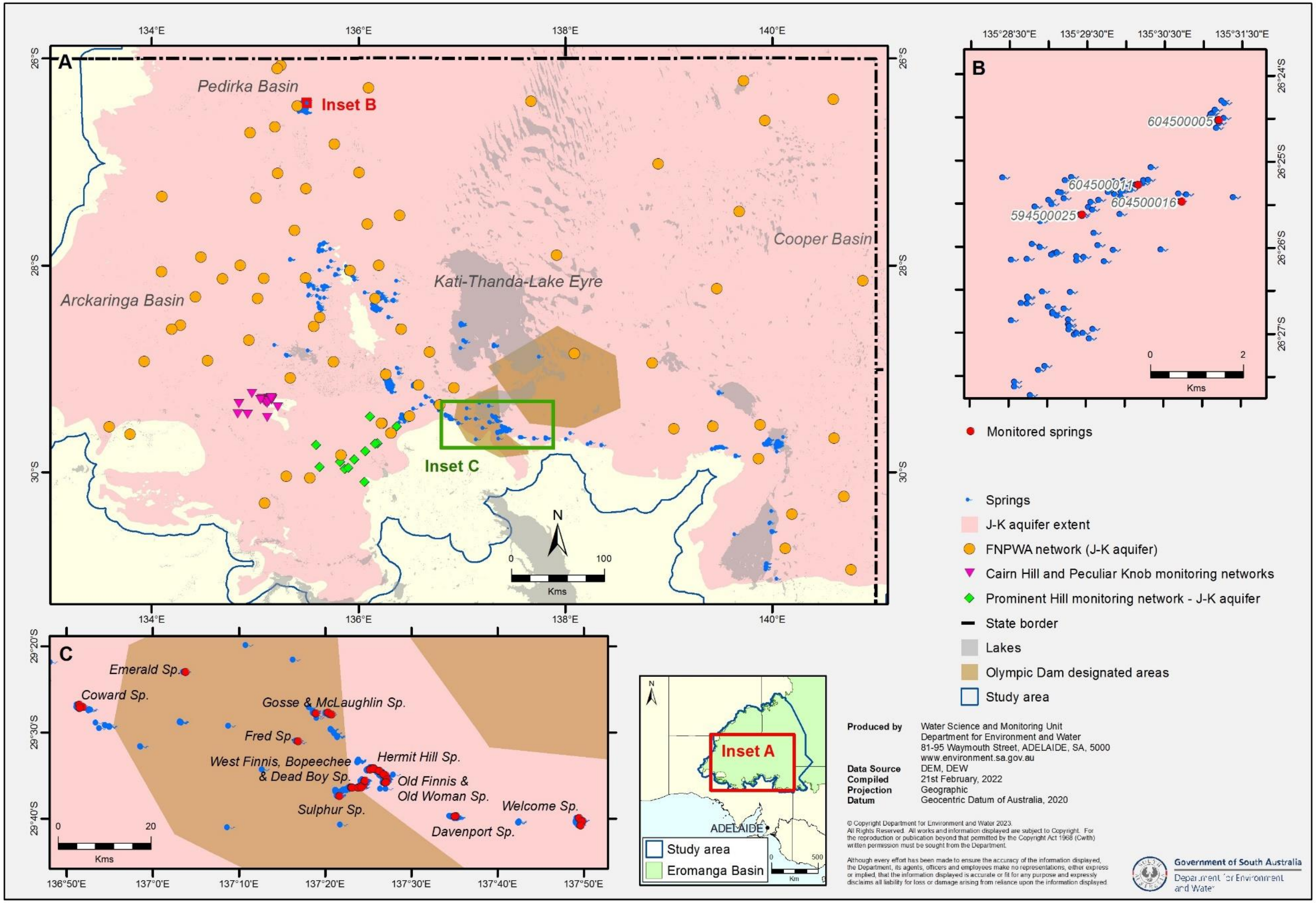

Figure 1: Location of well and spring monitoring networks assessed for this study

During the compilation and assessment of time series data, a few data gaps and uncertainties became apparent. In brief, these data gaps are generally associated with:

- The heterogeneous distribution of monitoring wells leaves some areas reliant on just a few points and other areas unmonitored.
- Monitoring errors may potentially impact accurate interpretation of water levels or may exacerbate time gaps between acceptable measurements if outliers are removed from the dataset.
- The maintenance of monitoring points is often left to third parties because the wells are commonly dual purpose. Further, the dual use may also impact the accuracy of measurement.
- The remoteness of monitoring points means that time gaps between measurements may be relatively long.
- Data from private monitoring networks may be inadequate for model conceptualisation and construction because such monitoring was never specifically undertaken for such a purpose. For example, spring flow monitoring is not designed to calculate discharge volumes, but rather to provide an indication of potential changes to flow as a consequence of groundwater pressure stresses associated with extraction. Consequently, only a very small proportion of spring vents found in the study area are routinely monitored, with current monitoring restricted to the southern springs area, although there are some flow monitoring records for Dalhousie Springs up until about 2010.

1 Introduction

Groundwater in the Far North Prescribed Wells Area (FNPWA) is vital for the success of the mining, petroleum, pastoral and tourism industries, and the provision of community water supplies in the Landscape SA South Australian Arid Lands (LSA SAAL) Management Region (Figure 1.1). The continued success and expansion of these industries is dependent on balancing the needs of existing users and the environment. Of particular environmental importance are the spring wetland communities in the discharge areas of the Great Artesian Basin (GAB) hydrogeological super-basin which are listed under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*. Protection of these environments is regulated and managed at a State level through the Far North Water Allocation Plan (FNWAP), through the description and implementation of spring buffer zones, water management zones and drawdown triggers at state borders. Further, the South Australian Government also has regulatory responsibilities over water management under the *Roxby Downs (Indenture Ratification) Act 1982*.

With demand for groundwater expected to grow in the mining and energy industries, a new numerical groundwater flow model is required to evaluate current knowledge and determine key knowledge gaps. This model will also be a tool to inform management of groundwater resources, both ongoing and for future major developments.

1.1 The Far North Prescribed Wells Area (FNPWA)

Groundwater in the FNPWA is managed under the FNWAP; a key principle being to manage groundwater resources by pressure (head) and to allocate by volume. The FNPWA was prescribed on 27 March 2003, and the first WAP was adopted on 16 February 2009. The 2021 FNWAP was adopted on the 27 February 2021.

Currently, the total groundwater allocation is 176 ML/d (2018–19 data) (Figure 1.2), with the majority (approximately 76% or 134 ML/d) sourced from the GAB hydrogeological super-basin aquifers (Figure 1.3). These allocations are made up of mining, industrial and human requirement supplies, co-produced water (water extracted with petroleum hydrocarbons), stock and domestic use, bore-fed wetlands and other amounts. Demand on the groundwater resources is expected to grow, particularly in response to growth in the mineral and petroleum industries.

1.2 Previous modelling

Although several groundwater models cover part of the western margin of the GAB hydrogeological super-basin, they are subject to one or more of the following limitations in terms of suitability for cumulative impact assessment to inform management of aquifers within South Australia (SA).

- a small or constrained geographical extent
- an over-simplified or limited aquifer system representation
- proprietary ownership by private companies that prohibits use for regulatory water resource assessments
- being based on outdated hydrogeological conceptualisations that do not reflect the current understanding of basin structure, and groundwater processes including recharge and discharge
- not taking into account other interconnected basins that form important water resources in the FNPWA
- not being designed to consider the cumulative impacts of multiple groundwater users.

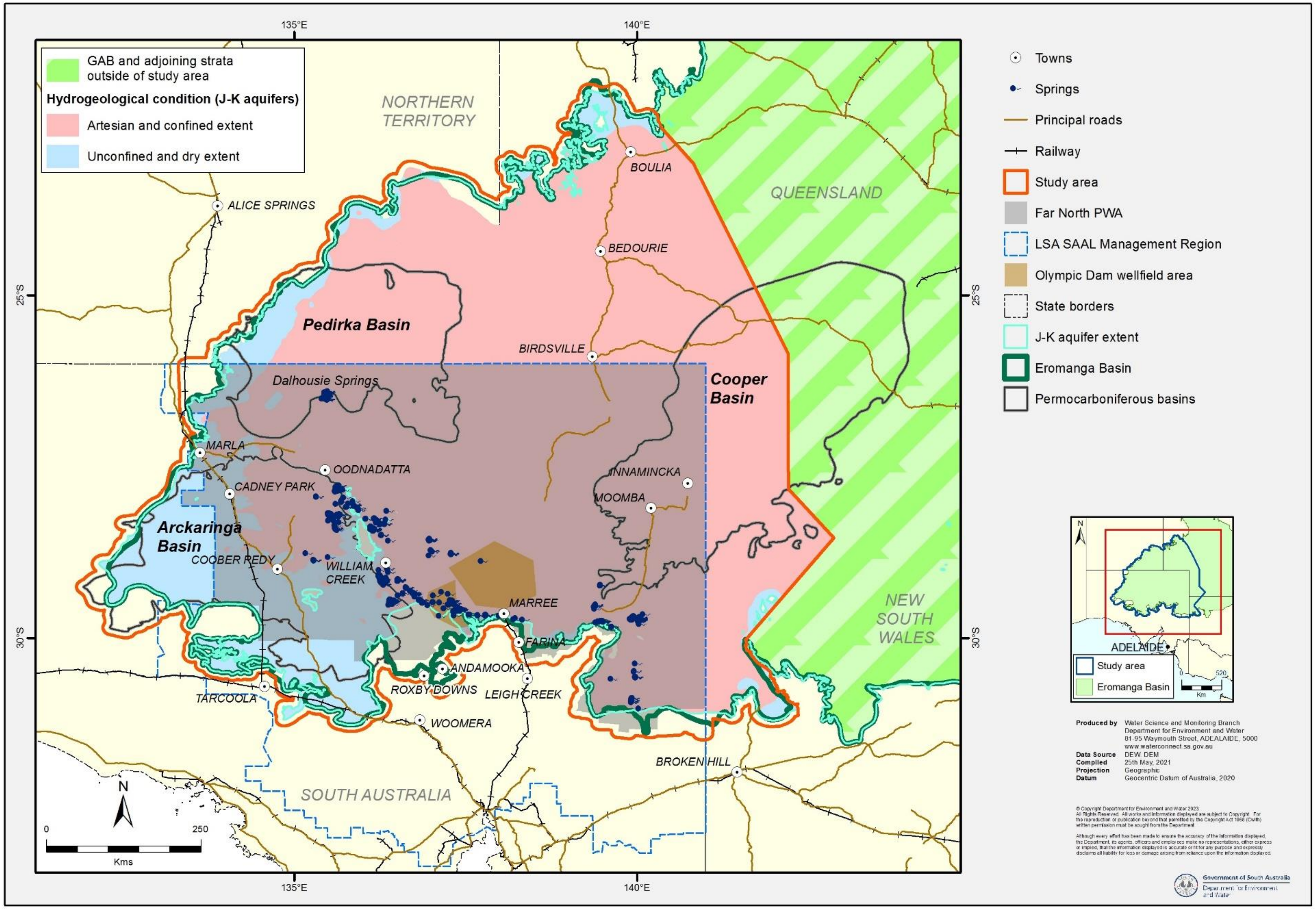

Figure 1.1: Location map of the Far North Prescribed Wells Area and study area

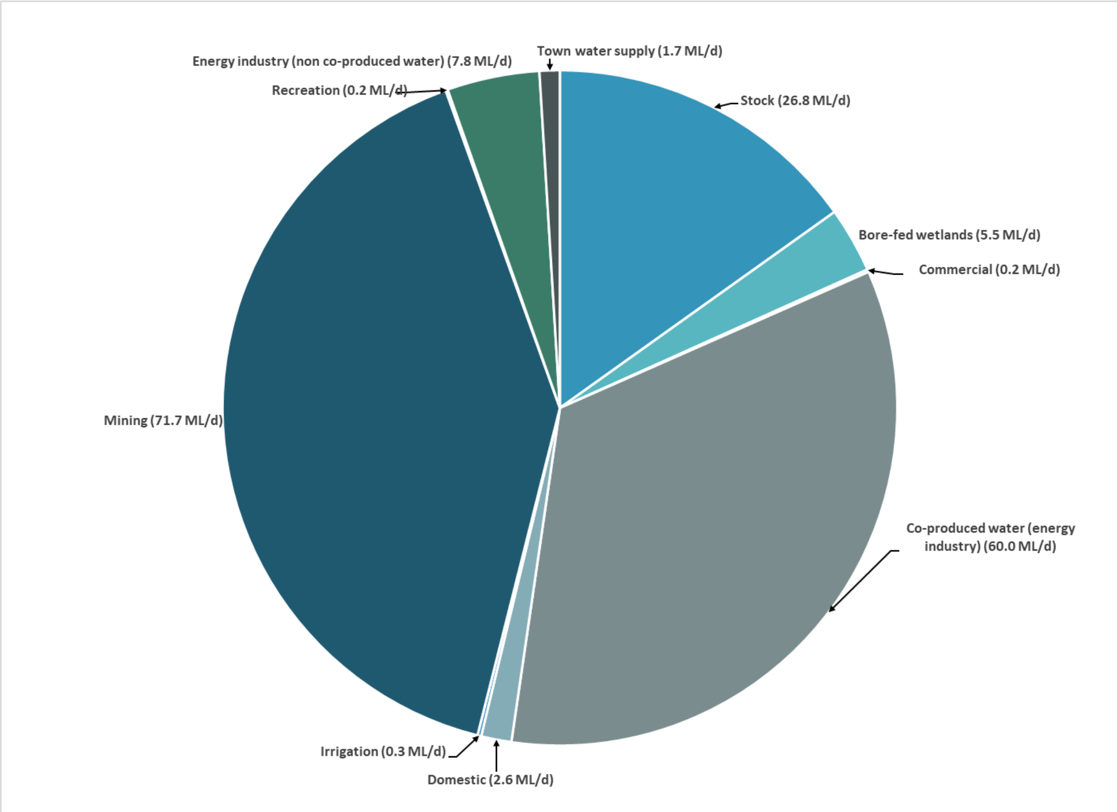

Figure 1.2: Total licensed volume (176 ML/d) presented by licence purpose description, FNPWA

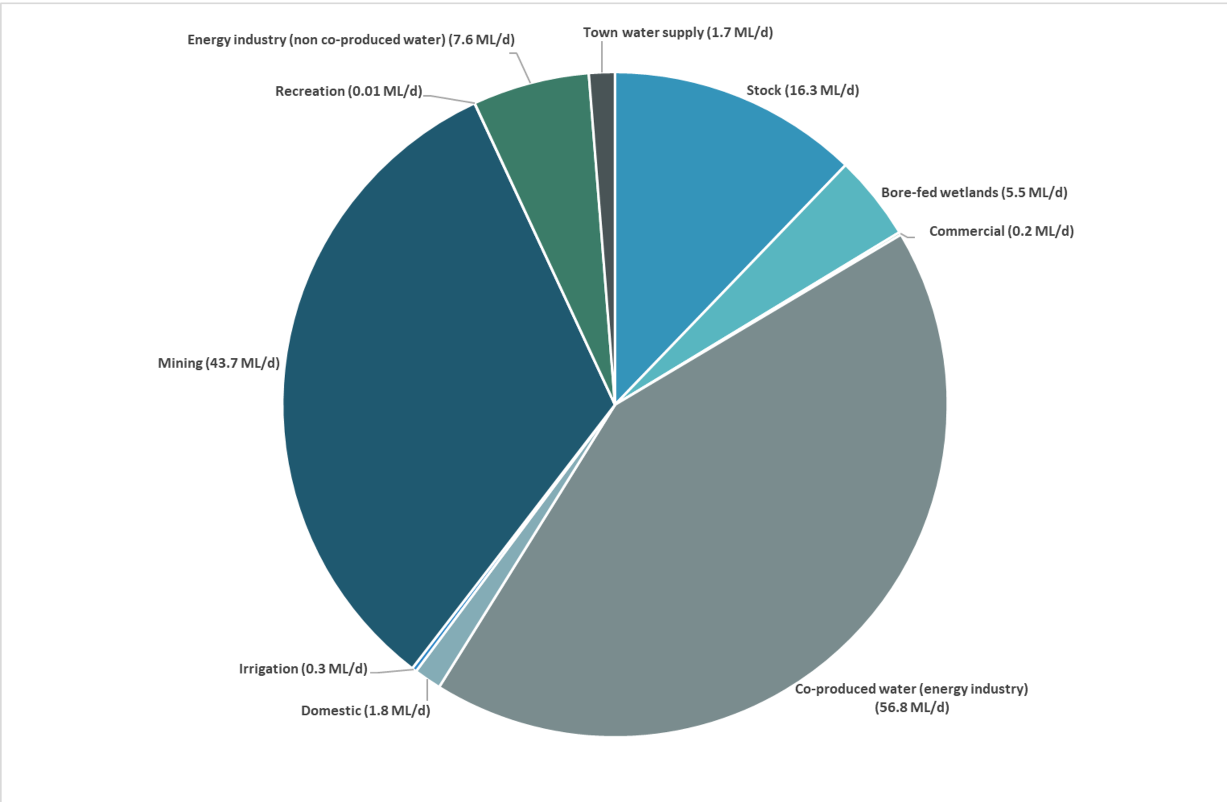

Figure 1.3: Licensed volume sourced from the GAB hydrogeological super-basin (134 ML/d) presented by licence purpose description, FNPWA

DEW has developed a numerical groundwater flow model to address the gaps identified in the existing models and to provide a tool to inform management of groundwater resources in the FNPWA. This model is consistent with the latest science and knowledge and can be updated in the future, providing a quantitative and predictive tool for development assessments and to inform management decisions. Further discussion of previous modelling is provided in Volume 8 of this report.

1.3 The study area

To cover an area of sufficient extent to achieve the model objectives, the study area (Figure 1.1) encompasses portions of the Eromanga Basin in Queensland (Qld) and New South Wales (NSW), part of the Cooper Basin in Qld, and the entirety of the following administrative areas and features of hydrogeological significance:

- Eromanga Bain in SA and the (Northern Territory (NT)
- Cooper Basin in SA
- Pedirka Basin
- Arckaringa Basin
- the Far North Prescribed Wells Area (PWA).

The initial model design is to simulate groundwater flow within the Main Eromanga Aquifer Sequence, with a focus on the Far North PWA in SA. Future modelling programs may involve extensions to other groundwater flow systems, such as the Cooper, Arckaringa and Pedirka Basins.

The study area (Figure 1.1) covers a total area of about 721,370 km^2. A 10 km-wide external buffer encompassing the features described in the above dot points extends beyond the southern, western and northern perimeters of the study area. The eastern boundary extends between 245 km and 420 km from the NT border into Qld; between 125 km and 190 km from the SA border into Qld; and between 60 km and 140 km into NSW from the SA border. The eastern boundary is designed to allow for lateral inflow of groundwater to the study area in some areas and no flow in others, consistent with the groundwater flow system contours interpreted during this project. The spatial extent of the eastern boundary was selected to provide a sufficient distance away from the areas of interest in SA, so that the hydraulic conditions along the boundary do not materially influence simulation results.

1.4 Reporting structure

Given the size and multi-faceted nature of the investigation supporting model development, reporting occurs over several volumes:

1. Simplified technical summary
2. Hydrogeological framework
3. Hydraulic parametrisation
4. Groundwater flow system dynamics
5. Time series data
6. Recharge and discharge processes
7. Water use and balance estimates
8. Model construction and history matching
9. Model sensitivity and uncertainty analysis.

1.5 Volume Objective

This volume (Volume 5) presents time series data for wells and springs located within the study area.

Time series data gives insight into the natural trends and development pressures of groundwater resources as well as providing a stress response by which model calibration can be constrained. This volume presents time series data for water pressures and levels and salinities collected from a number of monitoring networks found within the SA portion of the study area. The volume provides a description of the overall trends observed in these data as well as an assessment of any data gaps pertinent to model conceptualisation and construction.

Time series data is almost entirely derived from the hydrostratigraphic unit described in this study as the 'J-K aquifer'. This aquifer is a combination of layers 1 and 3 in the model construction. There are no time series data for the Hutton–Poolowanna aquifer (Layer 5). For definitions of hydrostratigraphic terms and how they pertain to model construction, please see Section 1.6 or Volume 2 Hydrogeological Framework for more information.

1.6 Relevant hydrostratigraphic background information

Table 1.1 and Figure 1.4, which have been taken from Volume 2, summarise the key stratigraphic, hydrostratigraphic and model layer nomenclature used during this study. The terms discussed below are used throughout this and other volumes.

As stated previously, the study area covers a sizable portion of the Mesozoic Eromanga Basin, including its entire occurrence in SA and the NT. The Eromanga Basin is the largest volumetric component of the GAB hydrogeological super-basin (Krieg 1995), and can be described as having a bowl shape that is partly defined and modified by faulting (Figure 1.4).

In the SA part of the Eromanga Basin, the most important strata sequence is the Cadna-owie Formation, the Algebuckina Sandstone, and their lateral equivalents (primarily the Namur Sandstone and Adori Sandstone). The collective hydrostratigraphic terminology commonly used in SA for aquifers and partial aquifers within these chronostratigraphically and lithologically connected extensive units is the 'J-K aquifer' (Table 1.1). It should be noted that within this general hydrostratigraphic nomenclature there can exist sub-regional scale lithological variation or structural deformation that may promote the development of sub-basinal groundwater flow systems.

The other important aquifer grouping is found in the deeper parts of the Eromanga Basin near the Cooper Basin and is associated predominantly with the Hutton Sandstone and the Poolowanna Formation. In the Cooper Basin region, these aquifer and partial aquifer units and/or groupings are separated from one another by a series of finer grained confining units such as such as the Birkhead, Murta and Westbourne formations (Table 1.1).

The initial design of the model is to primarily simulate groundwater flow within the sequence of strata defined by the top of the Cadna-owie Formation, called the 'C Horizon', to the base of Mesozoic sediments (base of the Poolowanna Formation), or the top of the Pre-Jurassic units, called the 'J-Horizon'. Collectively, this package of aquifers and confining units is called the 'Main Eromanga Aquifer Sequence' (Table 1.1). It is essentially the combination of the extensive J-K aquifer and the sub-basinal Hutton–Poolowanna aquifer, including intervening confining units.

The Main Eromanga Aquifer Sequence is overlain by a confining unit composed of shaly mudstone units of low permeability that are collectively part of the Rolling Downs Group (Vine et al. 1967). The main elements of this group are the Bulldog Shale and Oodnadatta Formations which outcrop extensively near the western margin of the GAB hydrogeological super-basin, whereas the Wallumbilla Formation and Allaru Mudstone occur at depth in the central portions of the basin near the borders of SA and Qld.

Of the strata underlying the Main Eromanga Aquifer Sequence, the most important are the sedimentary rocks of the Permo-Carboniferous Arckaringa, Pedirka and Cooper basins. Not only do the sandstones, siltstones, shales, diamictites and coal beds in these basin sediments contain aquifers themselves, but also significant oil, gas and coal resources under varying degrees of development. Outside of the Permo-Carboniferous basins, metasedimentary rocks of the early Paleozoic Warburton Basin, Precambrian rocks of the Adelaide Geosyncline and crystalline Archaean rock may also be found.

For model construction, the Main Eromanga Aquifer Sequence was discretised into 5 model layers based on regional scale hydrostratigraphy (Figure 1.4). These included the Cadna-owie Formation Aquifer/Leaky Aquitard, the Murta Formation confining layer, the Namur–Algebuckina Sandstone Aquifer, the Birkhead Formation confining layer and the Hutton–Poolowanna aquifer. Underlying these is a layer of nominal thickness representative of the Pre-Jurassic basement.

Table 1.1: Summary of hydrostratigraphic unit nomenclature and relationship to model layer design

Collective term	Western study area					Cooper Basin region, study area					Whole of study area	
	Stratigraphic unit	Hydrostratigraphic unit	Model layer name	Hydrogeological characteristic	Qualitative permeability	Stratigraphic unit	Hydrostratigraphic unit	Model layer name	Hydrogeological characteristic	Qualitative permeability	[a]Max. thick. (m)	[a]Ave. thick. (m)
Main confining units	Rolling Downs Group	Main confining unit		Confining unit	Low	Rolling Downs Group	Main confining units		Confining unit	Low	NA	NA
'C' Horizon												
Main Eromanga Aquifer Sequence	Cadna-owie Formation (and lateral equivalents)	J-K aquifer	Cadna-owie Formation (Layer 1)	Partial aquifer/aquifer	Medium	Cadna-owie Formation	Intra-sequence confining unit	Cadna-owie Formation (Layer 1)	Leaky aquitard	Low	689[b]	42
	Algebuckina Sandstone		Namur–Algebuckina Sandstone aquifer, (Layer 3)	Aquifer	High	Murta Formation and McKinlay Member	Intra-sequence confining unit	Murta Formation confining unit (Layer 2)	Low permeability confining unit. McKinlay Member included initially as conservative option; however, an alternative conceptualisation to include within Layer 3 is an option	Low	122	49
						Adori Sandstone, Westbourne Formation*, Namur Sandstone	J-K aquifer	Namur–Algebuckina Sandstone aquifer (Layer 3)	Aquifer	High	1259	211
						Birkhead Formation	Intra-sequence confining unit	Birkhead Formation confining unit (Layer 4)	Low permeability confining unit	Low	225	72
						Hutton Sandstone and Poolowanna Formation	Hutton–Poolowanna aquifer	Hutton–Poolowanna aquifer (Layer 5)	Aquifer	Medium	855	256
'J' Horizon												
Basement	Pre-Jurassic	Basement	Pre-Jurassic Basement (Layer 6)	Partial aquifer. A designated thickness specified below Layer 3 with variable boundary conditions to allow for broad upward or downward leakage. Base of layer 6 is a no flow boundary.	Variable	Pre-Jurassic	Basement	Pre-Jurassic Basement (Layer 6)	A designated thickness specified below Layer 5 with variable boundary conditions to allow for broad upward or downward leakage. Base of layer 6 is a no flow boundary.	Variable	NA	User defined

Note: Table shading reflects hydrogeological properties of model layers. [a] Depths based on isopach interpolation. [b] Maximum thickness was interpolated in close vicinity to a mapped fault but cannot be confirmed. Confirmed thickness of 357 m based on intersection found in Well Unit no. 684200195.

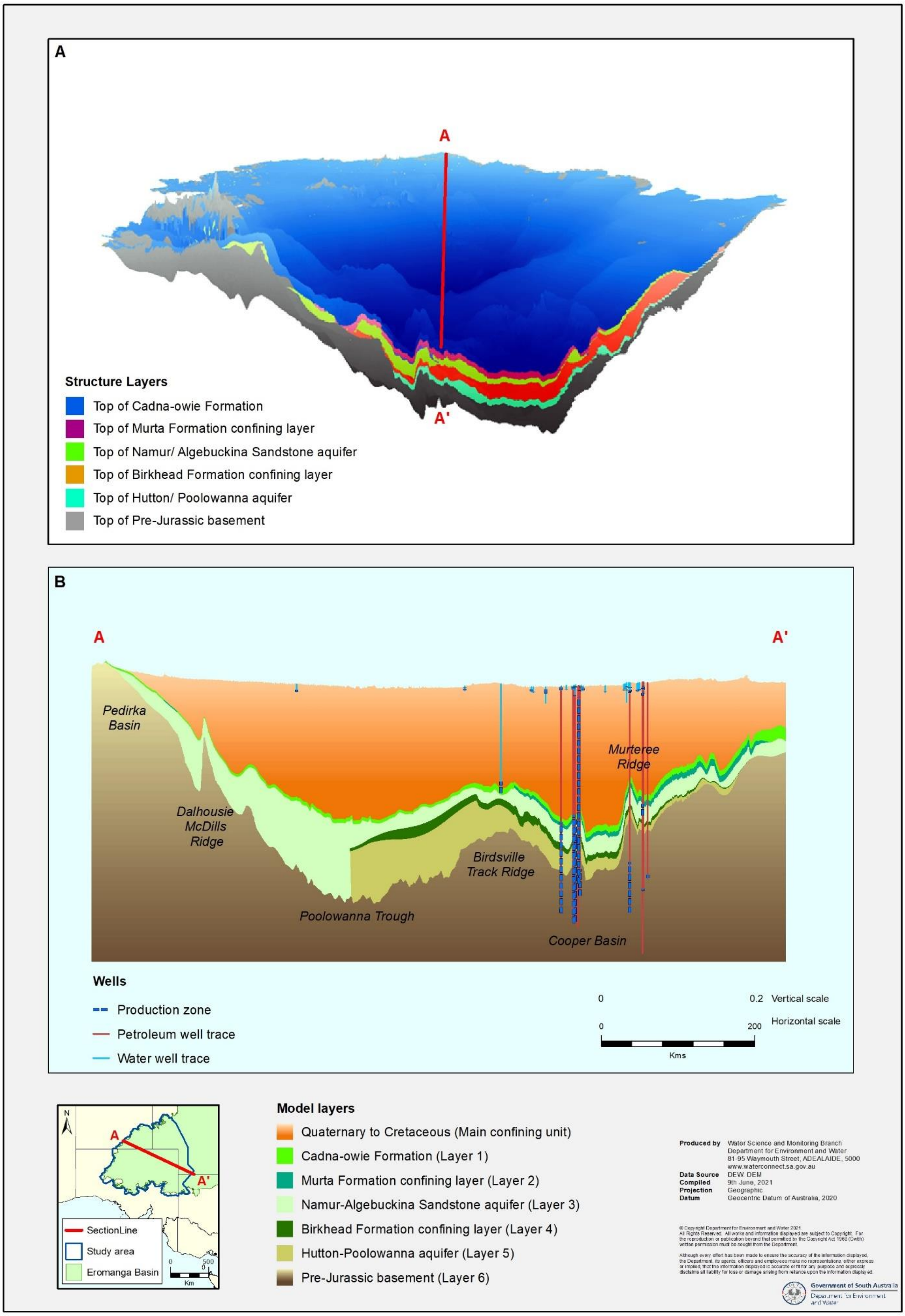

Figure 1.4: A) 3D projection of structure surface used in numerical model B) Cross section through study area showing model layers and key structures

2 Monitoring network data and trend analysis methodology

Data from government and non-government monitoring networks located within the study area were examined to determine trends in water level and (where available) salinity. The largest monitoring network included is the Far North Prescribed Wells Area (FNPWA) monitoring network, which is also the only network designed to examine regional trends. Another large network is the private one around the Olympic Dam mining operation wellfield area. Finally, a number of selected wells from Prominent Hill, Cairn Hill and Peculiar Knob mining operation monitoring networks were also assessed. The wells selected were those completed in the J-K aquifer strata (Figure 2.1).

The Prominent Hill, Cairn Hill and Peculiar Knob monitoring networks cover areas located within the south-western corner of the modelling domain in a region where groundwater conditions in the J-K aquifer are largely unconfined and a limited time range commensurate with mining operations (early 2000's). Wells from the Beverly Uranium Mine monitoring network located within the western half of the Frome Embayment are predominantly completed in Tertiary aquifers and were therefore excluded from this report. Data was largely obtained from the SA Government-maintained database SA Geodata. The exception was publicly available data obtained and used with permission from Olympic Dam operations, from a key area of the confined and artesian portion of the study area, close to springs and with detailed data from a >40 year period. The date cut-off for data compilation and analysis for this study was July 2019; data either collected or entered into SA Geodata after this time has been excluded from this analysis.

Prior to interpretation, anomalous values from the FNPWA monitoring network were investigated using preliminary hydrograph and salinity plots of raw data. Values considered anomalous due to deficient measurement protocols or reading error were removed from the data set after an investigation of field notes.

To assess data from monitoring well networks, water levels are presented as a series of spatially constrained hydrographs or trend graphs on a map of the monitored area. Trends are then described in summary, with notable decreases or increases over time highlighted. Water level results presented are uncorrected for density and so are equivalent to the environmental head found at a given location in time. This presentation was chosen for conceptualisation for 2 reasons:

1. the need to present declining trends in terms of field-based measurement and condition, which is useful with respect to representing risk to springs, other groundwater dependent ecosystems and existing users
2. uncertainty at the time of composition with respect to density-correction methodology, particularly with respect to the choice of reference density (as discussed in Volume 4) and application of salinity and temperature measurement.

Spring-flow monitoring data from two separate monitoring programs were also examined. DEW has historically monitored for flow rates using boxed weirs at 4 springs within the Dalhousie complex approximately every 6 to 12 months on an opportunistic basis, although monitoring of any sort has not been undertaken at Dalhousie since 2010. Additionally, Olympic Dam mining operations monitor spring groups near Wellfield A and along the southern extent of Wellfield B. Historically, springs were monitored monthly for flow and water quality. At present, flow data are available from approximately 40 springs at a minimum monitoring interval of 6 months. Data was obtained from open and closed file data from Olympic Dam mining operations with their permission (BHP Billiton 2009, 2010 and 2018).

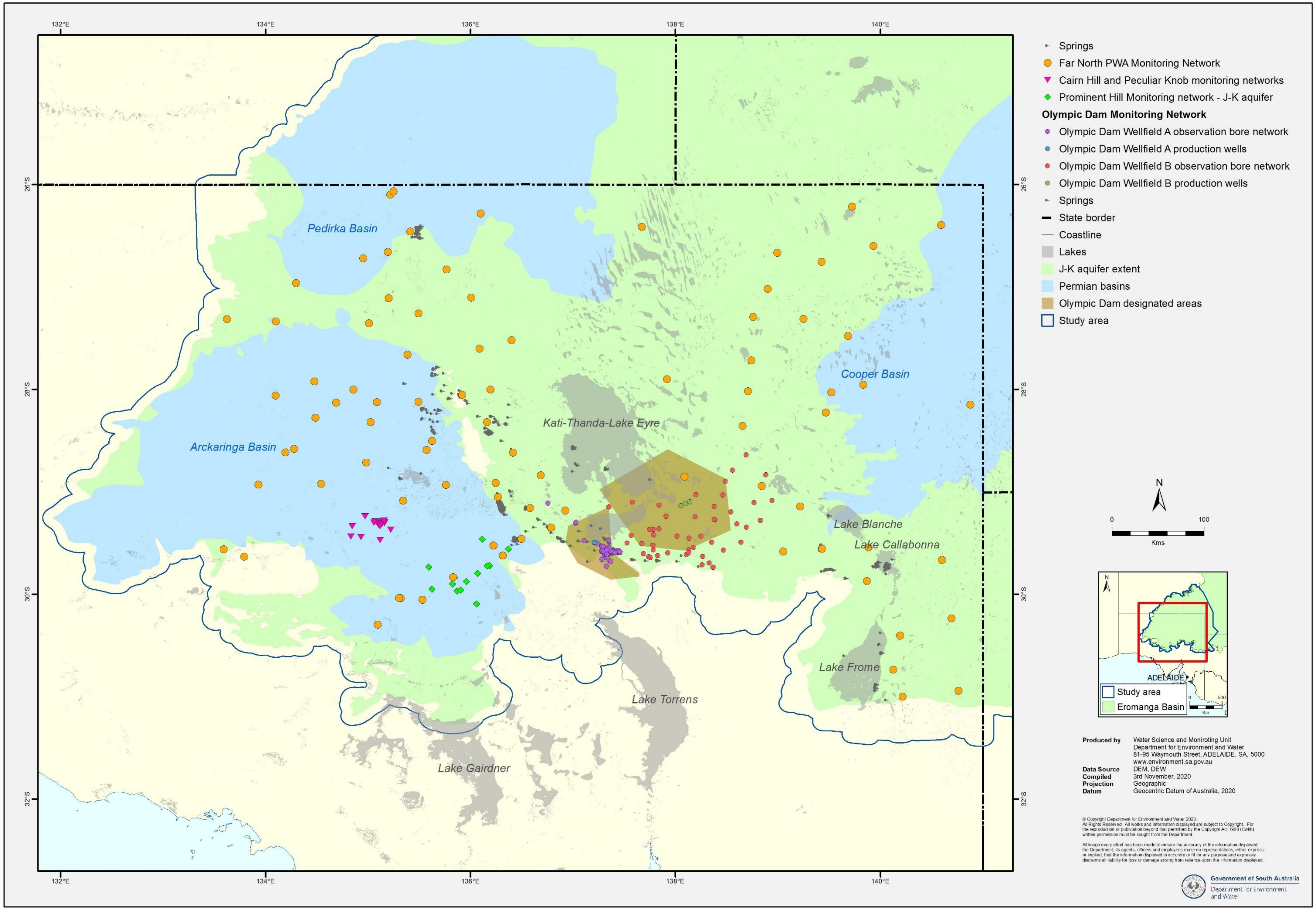

Figure 2.1: Location of monitoring networks examined

3 Water level and pressure trends

This section describes the assessment of environmental groundwater-head trends from the various public and private monitoring networks located within the study area, uncorrected for density. The most important network examined here is the FNPWA monitoring network, which is maintained by DEW. Additionally, measurements from well networks maintained by Olympic Dam, Prominent Hill, Peculiar Knob and Cairn Hill mining operations are also examined. Time series data for the Olympic Dam wellfields monitoring network sourced from the Olympic Dam mining operations annual Environmental Protection and Management Program (EPMP).

Note that because water levels and pressures vary considerably across the study area, the scale of time series hydrographs has been tailored individually to suite the data of a given hydrograph. Therefore, care must be taken with respect to understanding both the time and groundwater level on figures. Further, the figures do not present all wells where timescale data is available, but rather a selection of wells has been made to illustrate broader observations. All time series data will be presented as part of the model construction and history matching report (Volume 8).

Outliers in this report are considered anomalous readings that do not appear to be part of any trend. They are likely to be a data-recording or entry error that were not validated at the time.

3.1 FNPWA monitoring Network

3.1.1 Cooper Basin and Frome Embayment region

Trends in groundwater heads in the J-K aquifer (GAB) near the Cooper Basin region can be defined spatially (Figure 3.1). Declining trends are observed in artesian wells to the west of the Cooper Basin and east of Kati Thanda-Lake Eyre and the Pedirka Basin, such as Goyders Lagoon (664300001/664300011), Parachirrinna Bore (684300006) and Jennet 1 (674100001). Two of the most northerly wells, Claypan Bore (684500008) and Beckwith Bank (684400007), also show generally decreasing trends, although the Claypan Bore decline is less than 1 m in magnitude. Additionally, declining trends are also observed in the wells located to the south-east of the Cooper Basin region at Fortville 3 (703900005) and Tilcha 2 (703800002).

Increasing or stable trends are observed in GAB wells near the border between Qld and SA in the Cooper Basin region. In the south-eastern region, some rising trends were observed in the mid to late 1990s, for example, Woolatchi Bore (683800029) and Connee Creek Bore (703700003), which were rehabilitated in 1994 and 1995 respectively. This was possibly associated with artesian well rehabilitation work as part of the Great Artesian Basin Sustainability Initiative (GABSI) program. Some trends have been stable since the mid-1980s, for example Murnpeowie Homestead Bore (673800002) after rehabilitation in 1986. Similarly, Mungeranie Bore (664100003) and Mirra Mitta Bore (664200002) have declining trends to 2017, at which point they were replaced. Recent pressure levels at these bores were not recorded in time for this assessment.

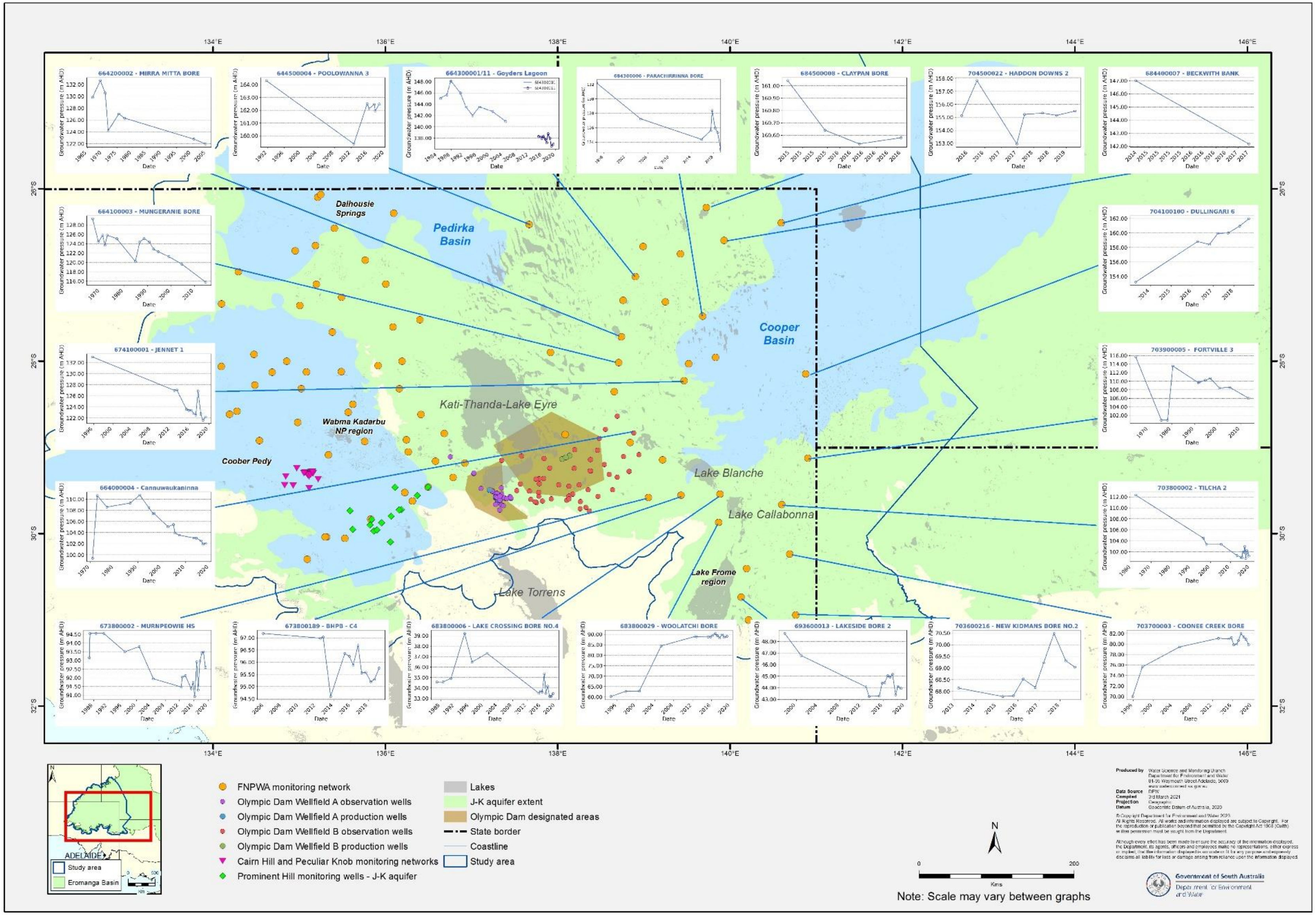

Figure 3.1: Pressure-head trends in the Cooper and Frome regions of the FNPWA monitoring network

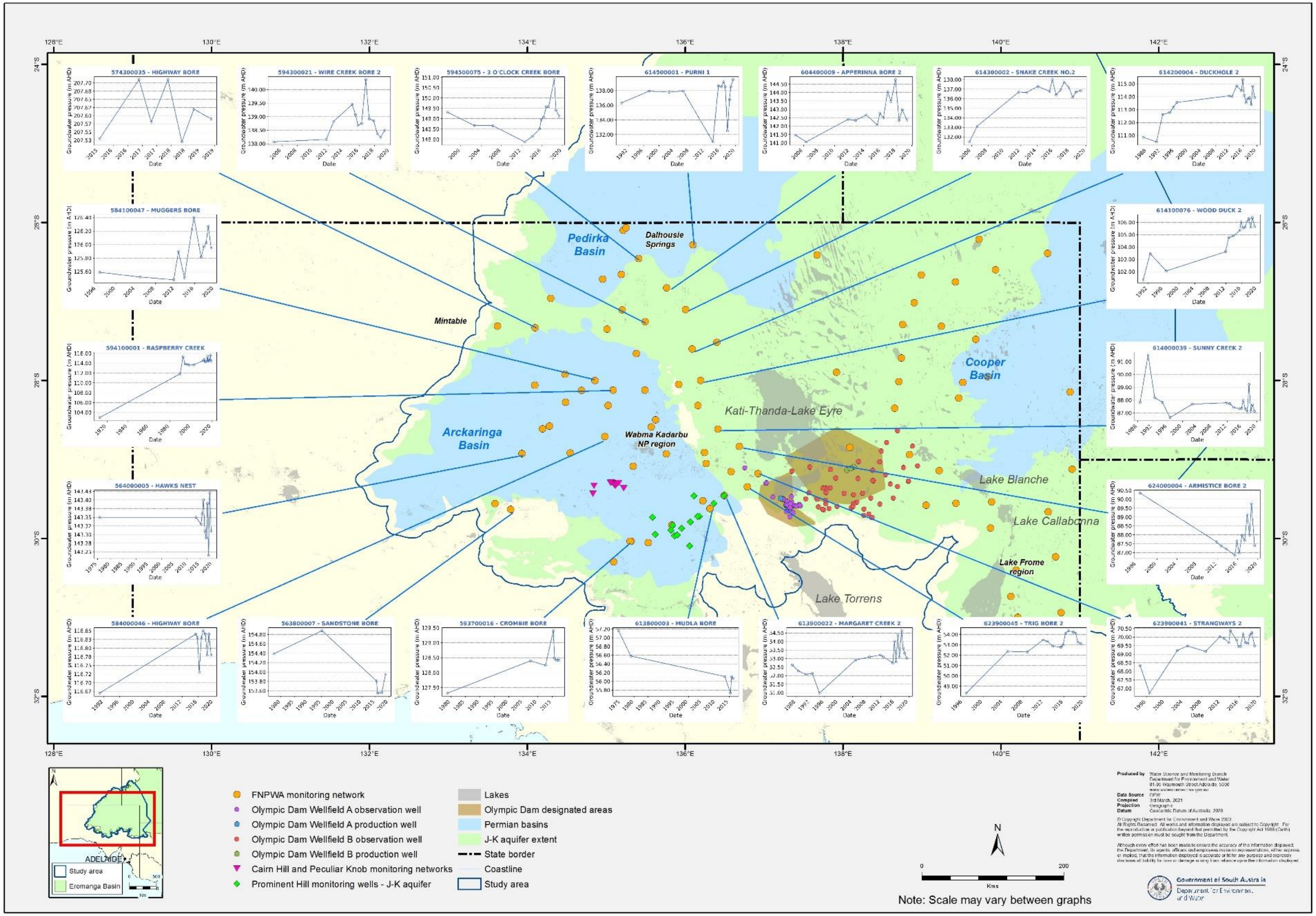

Figure 3.2: Groundwater level and pressure-head trends in the Western region of the FNPWA monitoring network

3.1.2 Western Eromanga Basin region

Groundwater levels have remained relatively stable in the western unconfined, sub-artesian and artesian areas near the southern springs (Figure 3.2). Fluctuations are typically small and within ranges expected from J-K aquifer groundwater in the monitored locations. More specifically, groundwater levels have been relatively stable in non-artesian areas near Hawks Nest Bore (564000005) and Highway Bore (574300035). Elsewhere, the impacts of well rehabilitation and replacement can be seen with increasing pressures in different bores at different times (for example, Raspberry Creek Bore (594100001) in 1989; Wood Duck 2 (614100076) and Duckhole 2 (614200004) bores in 1990; and Snake Creek Bore (614300002) in 2005).

Groundwater levels in the Dalhousie Springs area have remained relatively stable or seen some increase. A consistent increase in RSWL has been noted at wells: Apperinna Bore 2 (604400009), Wire Creek Bore 2 (594300021) and Snake Creek Bore 2 (614300002) (Figure 3.2).

3.2 Olympic Dam Wellfields (Kati Thanda-Lake Eyre South region)

Groundwater pressure trends near the Olympic Dam wellfields can be defined spatially (Figure 3.3). West of the wellfields, groundwater levels have been relatively stable over the past 20 years. Groundwater levels declined in Wellfield A as extraction increased from 1.3 ML/d in the early 1980s, to 10 ML/d in the late 1980s. Extraction continued to increase from Wellfield A to 16 ML/d in 1996 accompanied by continued declines in groundwater level of up to 30 m. In 1996 groundwater levels in Wellfield A started to stabilise and show a small amount of recovery as extraction reduced to at or below 5 ML/d (BHP 2016).

The reduction in extraction from Wellfield A coincided with commenced extraction from Wellfield B in 1996. Wellfield B was established in response to adverse reductions in spring flow observed because of the operation of Wellfield A, with the intention that extraction from Wellfield B would take pressure off Wellfield A. This was intended to allow water pressures at the latter to recover sufficiently to permit partial recovery of spring flow. Extraction increased from 4 ML/day to 12 ML/day between 1996 and 1998 from Wellfield B and continued to increase to 27 ML/day by 2009. Pressure head declines of 15 to 20 m have accompanied extraction from Wellfield B; however, declining trends within the wellfields have stabilised in recent years as extraction has been relatively stable (BHP 2016). Pressure head trends to the north-east and south-east of Wellfield B appear to be in continued decline, particularly at wells Kopperamanna (664000001), Bolcaltaninna (664000020) and Cooryaninna (663900016). This coincides with similar trends observed in the FNPWA monitoring network near the Cooper Basin and may be indicative of a cumulative drawdown impact.

In the area between Wellfields A and B, groundwater levels have been relatively stable (Figure 3.3), although this area coincides with a region where the J-K aquifer is interpreted to be largely absent due to the presence of a relatively impermeable basement high. The trend in hydrographs broadly reflects current compliance conditions enacted following the 1997 Environmental Impact Statement that accompanied the proposal for the development for Wellfield B (Kinhill Engineers 1997).

3.3 Prominent Hill, Cairn Hill and Peculiar Knob (south-west Eromanga Basin)

For the period where data is publicly available, groundwater levels in the J-K aquifer in the Prominent Hill region have remained relatively stable since 2005 (Figure 3.4). For wells completed in Eromanga Basin strata, groundwater levels have varied between 51.45 m AHD (613800071) and 118.721 m AHD (603800207) since 2005.

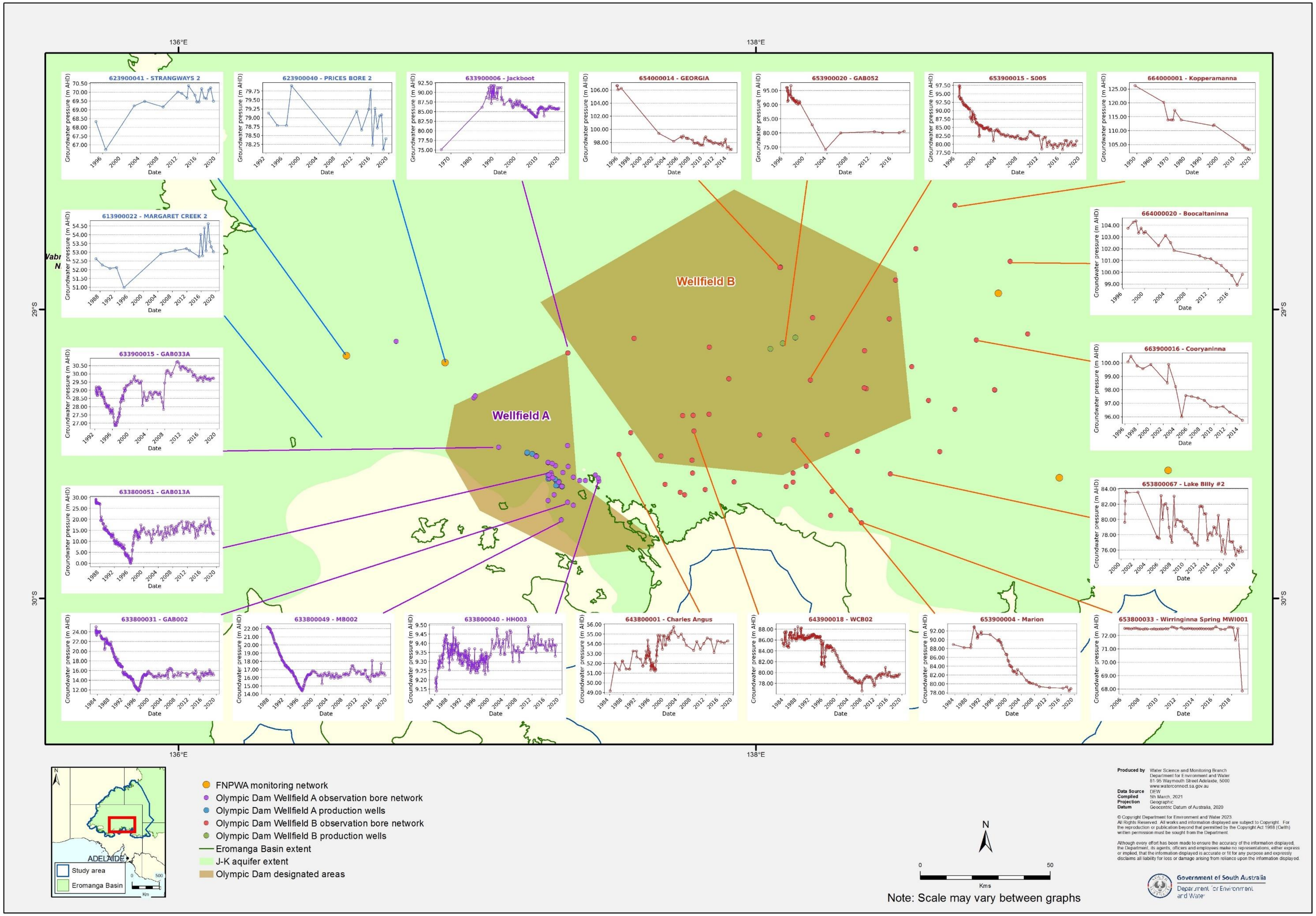

Figure 3.3: Pressure-head trends in and around the Olympic Dam wellfields area

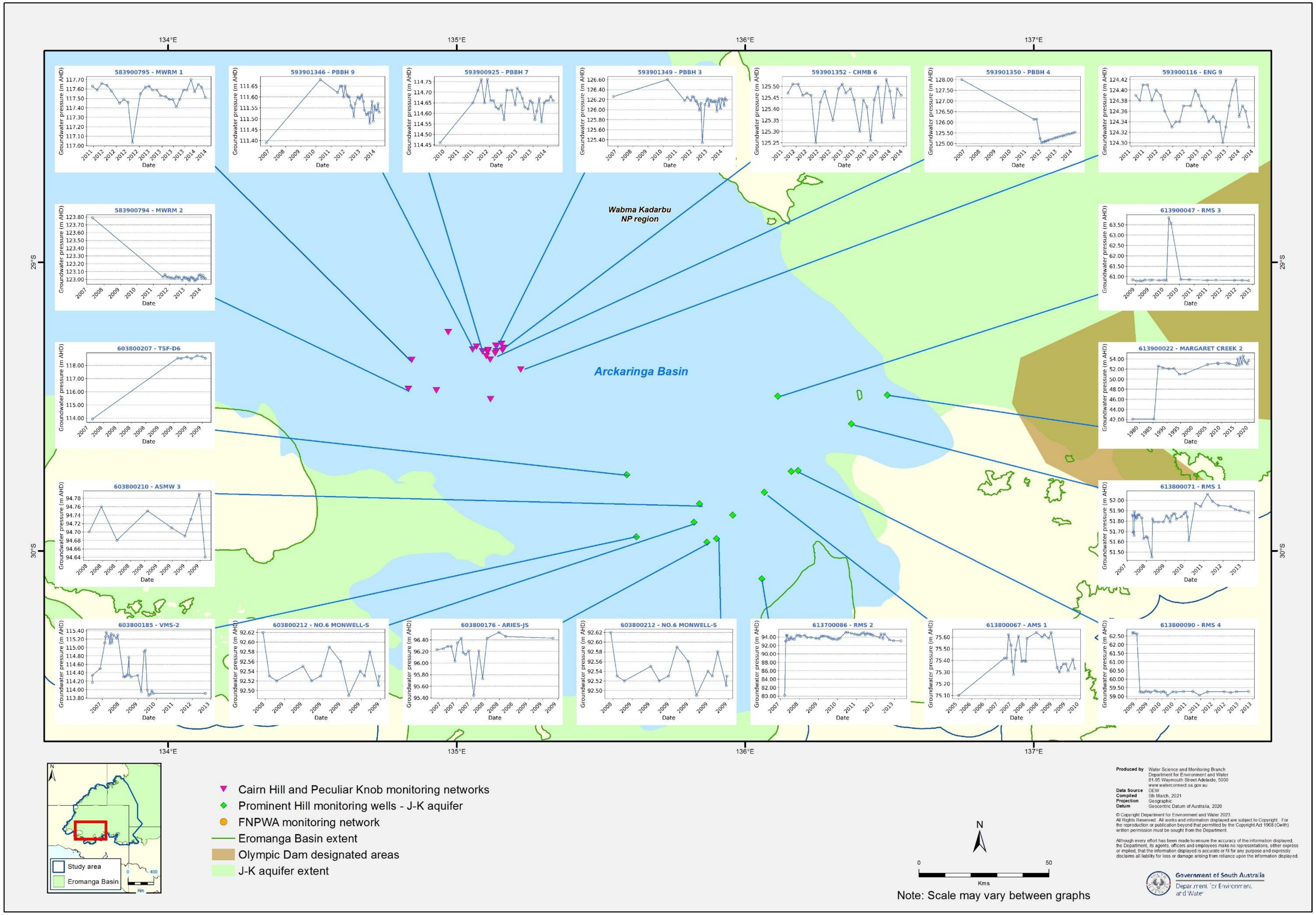

Figure 3.4: Groundwater level trends in the Prominent Hill, Cairn Hill and Peculiar Knob areas.

Likewise, groundwater levels in the J-K aquifer in the Cairn Hill and Peculiar Knob regions have remained relatively stable since 2005 (Figure 3.4). However, publicly available data only extends to early 2014 at which point monitoring ceased due to the mine going into care and maintenance mode. Of note, is that a consistent increase in water level occurred in 593901350 since late 2011, changing from 125.04 m AHD to 125.53 m AHD. Water levels in monitoring wells from the Cairn Hill and Peculiar Knob regions ranged between 105.22 m AHD (59390355) and 128.0 m AHD (593901355) since 2005.

3.4 Trend causation

The main causes for declining trends in groundwater pressures observed in the Cooper Basin and southern Kati Thanda-Lake Eyre region include increases in abstraction to support the energy and mining industries. These trends are reflected in estimated water use data calculated for the SA portion of the study area. Within the artesian portion of the SA Main Eromanga Aquifer Sequence, co-produced groundwater extraction from the Energy industry sector has increased from near zero in the mid-1980s to approximately 40 ML/d by 2018 (Figure 3.5). There was a concomitant increase in groundwater extraction to approximately 30 ML/d by 2018 for use in the mining industry. Consequently, the declines in water pressure discussed above are interpreted to reflect the cumulative impact of groundwater extraction from these operations. Water use estimations are discussed further in Volume 7 of this report.

Well capping and rehabilitation undertaken as part of the GABSI program or other privately funded programs with similar intent are likely to be the reason for pressure head and groundwater level recoveries in certain areas, particularly around the springs in the western Eromanga Basin and around the Olympic Dam wellfields. Likewise, the previously described management of groundwater extraction for the Olympic Dam operations has also seen either stabilised or partial recoveries of pressure head near springs there. This stabilization has been supported by the commissioning and shifting of extractions to Wellfield B, and a concomitant capping of extraction at Wellfield A to less than 5 ML/d.

Further, such recovery trends may also indicate changes in water use trends. For the artesian portion of the SA Main Eromanga Aquifer Sequence, pastoral usage has seen a large overall decline from a peak in the mid-1970s to a portion less than half that in 2018 (Figure 3.5). This decline is in large part driven by well capping, decommissioning, rehabilitation and implementation of water efficiency measures. Although the non-artesian portion of the Main Eromanga Aquifer Sequence has not seen a concomitant decline, usage is estimated to have at least stabilised from the year 2000 onwards (Figure 3.5), consistent with the total artesian bore water use.

Most wells included within the FNPWA monitoring network are extraction bores for stock and domestic purposes. Consequently, there are questions concerning the adequacy of shut-in times applied to artesian wells and recovery times to other wells to obtain accurate measurements. It is possible that shut-in times used during monitoring phases may be inadequate at wells where significant drawdowns are observed or where well construction may be compromised. One such well is Mungeranie Bore (664100003); this well was used for stock, domestic and artificial wetland supply purposes and was recently replaced. A decline in uncorrected head of approximately 14 m was observed between 1966 and 2014 (Figure 3.2). Further, such wells may be used to determine the relative change in storage over time, but hydrograph data will be inadequate to describe pumping impacts, given both the pumping and the monitoring occur simultaneously.

However, areas where multiple bores display similar trends over time are more likely to reflect regional changes in pressure head or groundwater level, rather than a systemic failure of either well construction or measurement error. In the case of Mungaranie Bore (664100003) as well as localised water extraction and well construction deterioration, the well is located approximately 70 km east of the Cooper Basin and approximately 90 km north of the Olympic Dam Wellfield B region. Several bores in this region display long-term declines in pressure and so it is quite likely that this well is also subject to regional declines in pressure.

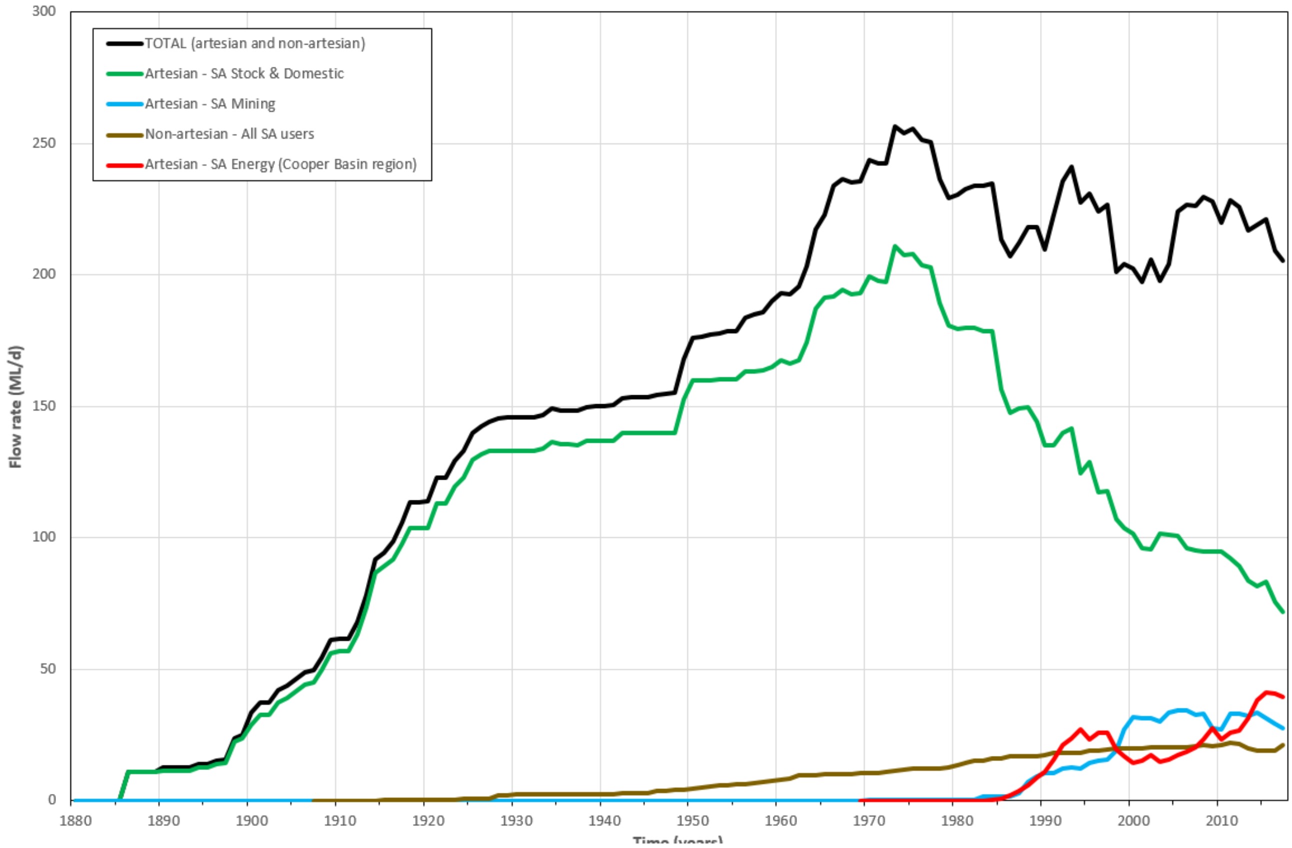

Figure 3.5: Estimated water use over time in South Australia

4 Salinity trends

Salinity data is not as prevalent as water level data. However, from the data available, salinity levels seem to be stable with minor fluctuations throughout the years.

In the eastern, Cooper Basin, Frome Embayment, Olympic Dam wellfields and central-western regions, very little change is observed and is reflective of the predominant artesian conditions and relatively stable hydrochemistry (Figure 4.1, Figure 4.2 and Figure 4.3). Any slight changes may be related to concomitant changes in pressure that could influence temperature and therefore the accuracy of field measurement.

Limited data is available in the south-western margin of the study area, sourced from the Cairn Hill, Prominent Hill and Peculiar Knob monitoring well networks. The data displays very high variance over the limited time monitoring occurred. Typically, salinities further to the west display relatively high values, ranging between 20,000 and 30,000 µS/cm (Figure 4.4). Such salinities are typical for this portion of the J-K aquifer; Ransley et al. (2015) suggested high salinity groundwater in this region was caused by high rates of evapotranspiration within a recharge zone located within an arid environment. Little in the way of a consistent or meaningful trend is observed in this data and the time period over which monitoring data is available further limits usefulness.

Note that because salinity levels vary considerably across the study area, the scale on time series salinographs has been tailored individually to suite the data of a given salinograph. Therefore, care must be taken with respect to understanding both the time and salinity level on figures. Further, the figures do not present all wells where timescale data is available, but rather a selection of wells has been made to illustrate broader observations. Outliers in this report are considered anomalous readings that do not appear to be part of any trend. They are likely to be a data-recording or entry error that were not validated at the time.

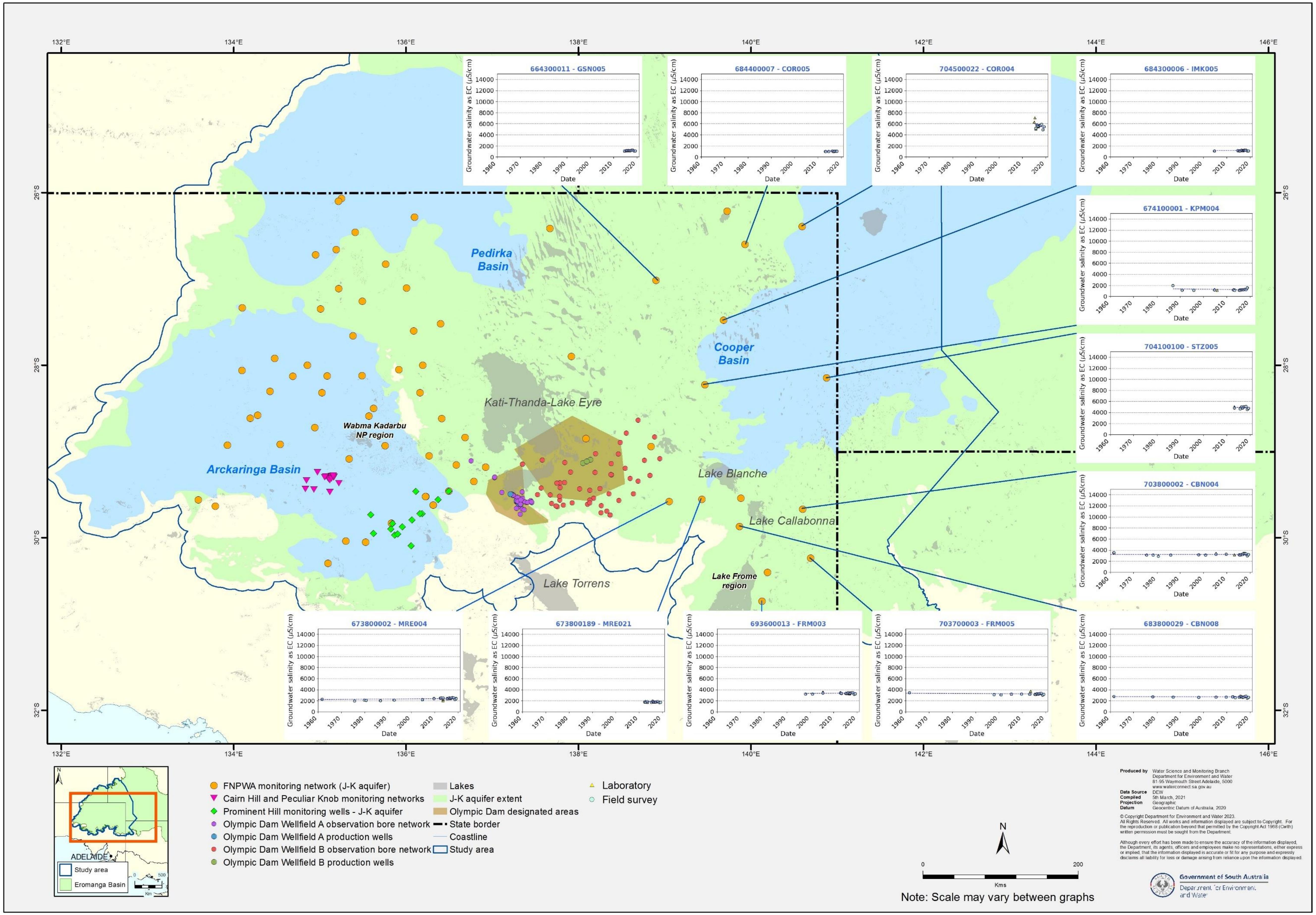

Figure 4.1: Groundwater salinity trends in the Cooper and Frome region of the FNPWA monitoring network

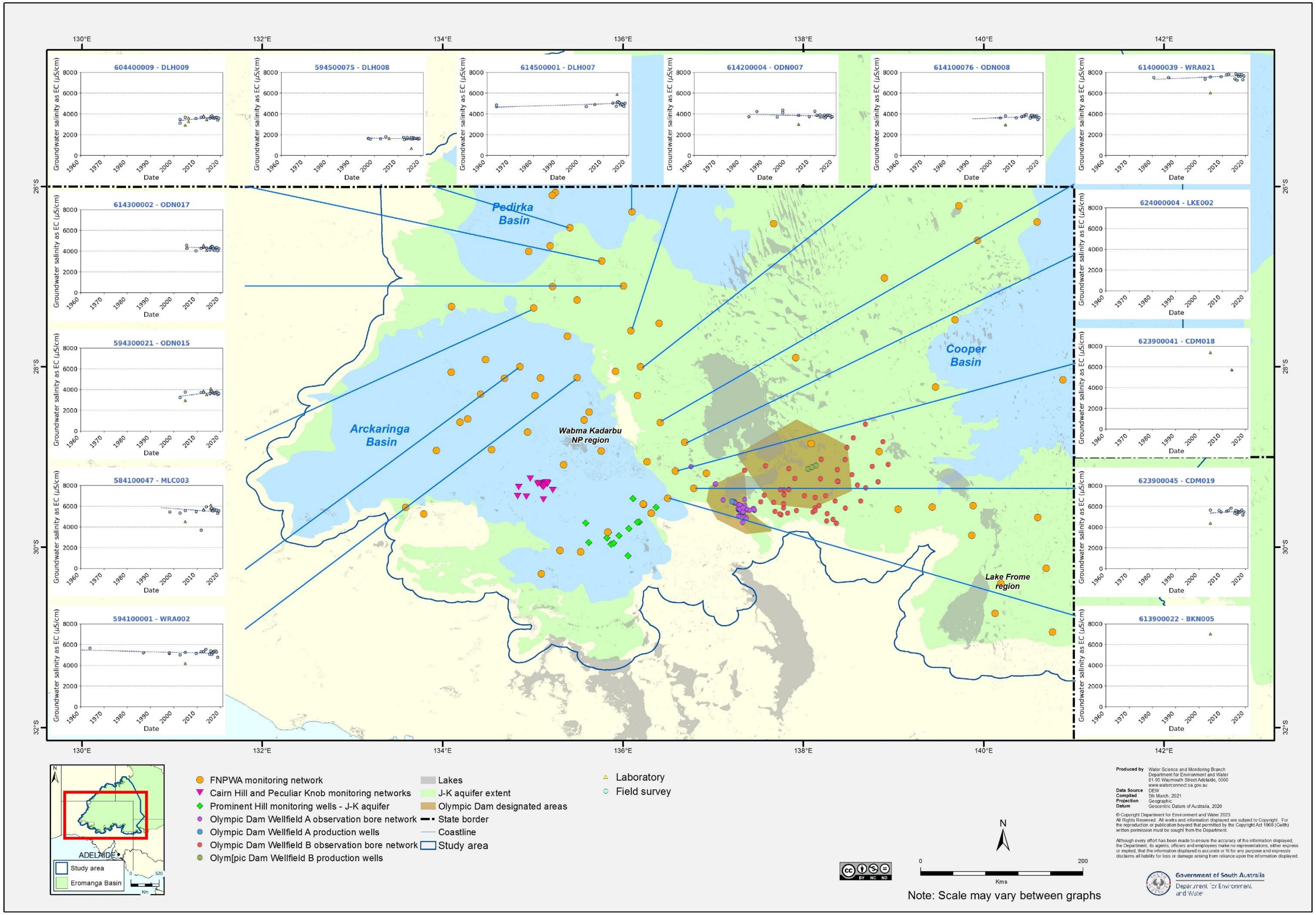

Figure 4.2: Groundwater salinity trends in the western margin of the FNPWA monitoring network

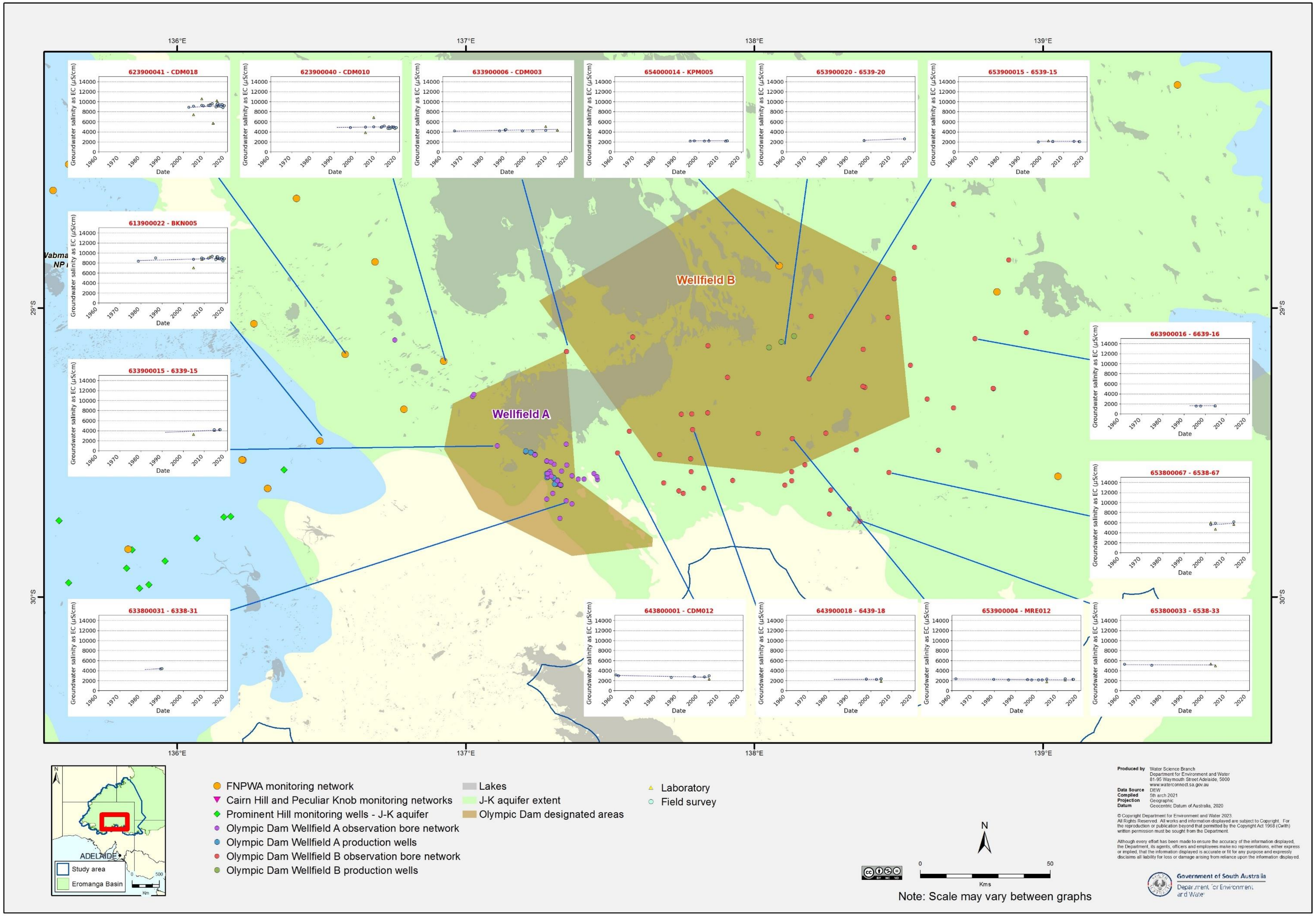

Figure 4.3: Groundwater salinity trends in the Olympic Dam wellfields area

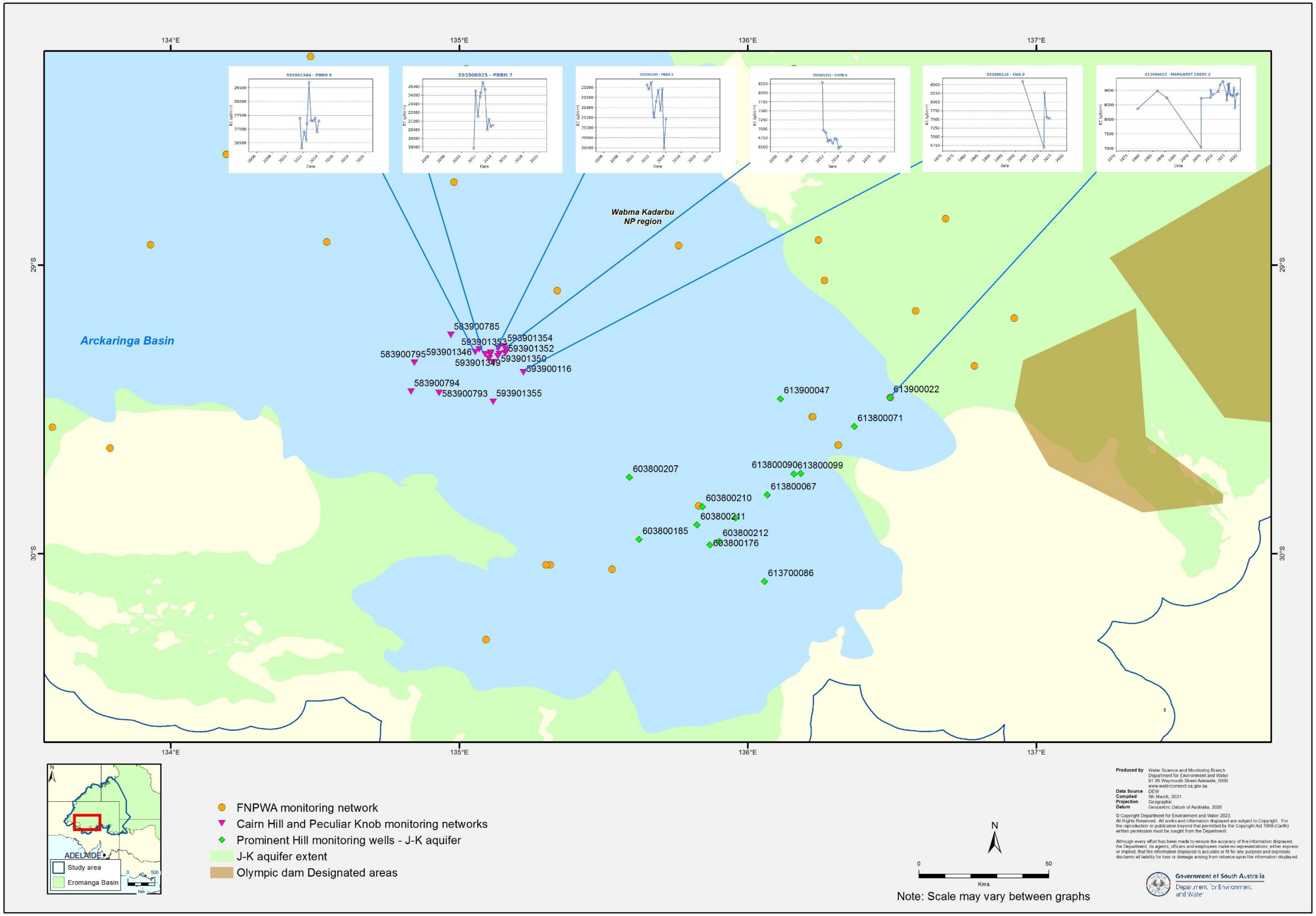

Figure 4.4: Salinity level trends in the Prominent Hill, Cairn Hill and Peculiar Knob areas.

5 Spring flow trends

There are over 5,000 mapped spring vents recorded in the SA Government natural resources database SA Geodata (Figure 5.1) for the study area. The vast majority of these are not regularly monitored, consequently the relationships between spring flow and changes in groundwater pressure are not quantified. Spring flow monitoring programs are largely designed to provide an indication of change to represent impacts on larger spring systems. Spring flow monitoring is not considered sufficient to quantify spring discharge volumes for water balance purposes. A qualitative conceptualisation of spring-related discharge is provided in Volume 7.

Further, although groundwater pressure is a primary controlling feature that enables spring formation, the relationship between pressure and absolute flow is not purely linear, as many other factors, such as conduit permeability and surface conditions, impact the volume of discharge from a given spring vent. This complex relationship is evident in any spring complex or group, where a variety of flow rates can be observed all being supported by generally the same or similar pressure head. Heterogeneous change to spring flow in response to groundwater pressure fluctuations were described by Kinhill Engineers (1997) who noted 'equivocal' spring flow monitoring data following adjustments to the water extraction regimes at the Olympic Dam wellfield. Such heterogeneous changes may be expected as a number of factors may contribute. These include:

- the complexity of spring conduit configuration
- the difficulty in determining the volume of subsurface discharge within spring wetland environments
- the fact that such environments often have multiple points of surface discharge.

Consequently, comprehensive flow monitoring is difficult to achieve and at best long-term semi-qualitative trends may be a more realistic goal of monitoring.

5.1 Dalhousie Springs

The Dalhousie Springs super-group is located near the border between SA and the NT; it is the farthest north of the GAB spring super-groups in SA (Figure 5.1). Estimates of total spring flow from Dalhousie Springs typically range between 50 and 60 ML/d (Alcoe 2015; Boucaut et al. 1986; White and Lewis 2011; Williams 1974). Boucaut et al. (1986) estimated that Dalhousie Springs accounted for approximately 90% of all SA springs discharge. Consequently, Dalhousie Springs is a highly significant spring complex with respect to both total spring discharge and groundwater discharge from the Main Eromanga Aquifer Sequence. There are currently 150 spring vents mapped at Dalhousie Springs.

DEW has historically monitored the flow rates at four springs within the Dalhousie Springs super-group. The monitored springs are located towards the northern end of the spring complex and include Main Spring and Witjirrie Mound Spring. Monitoring occurred approximately every 6 months between 1997 and 2010 and was undertaken on an unfunded, opportunistic basis after the sites were inherited from the former Australian Government Bureau of Rural Sciences. Monitoring ceased after 2010, with monitoring sites in need of repair before recommencement could be considered. Further, a monitoring network of 4 springs is not considered adequate with respect to determining total discharge volumes for the spring complex, but it may provide indicative information concerning any changes in gross discharge.

Total flow rates across the four monitored sites during this time were found to vary between 5 L/s and 180 L/s. Weir 1 (604500005) displays an increase in flow rate from 2004 onwards, from approximately 55 L/s to 63 L/s. Weir 4 (604500016) also appears to have increased in flow over the same period, increasing from 10 to 12.7 L/s, whilst Weir 2 (604500011) and Weir 3 (604500025) display relatively stable flows of approximately 155 and 17.5 L/s respectively within a margin of reading error (Figure 5.2).

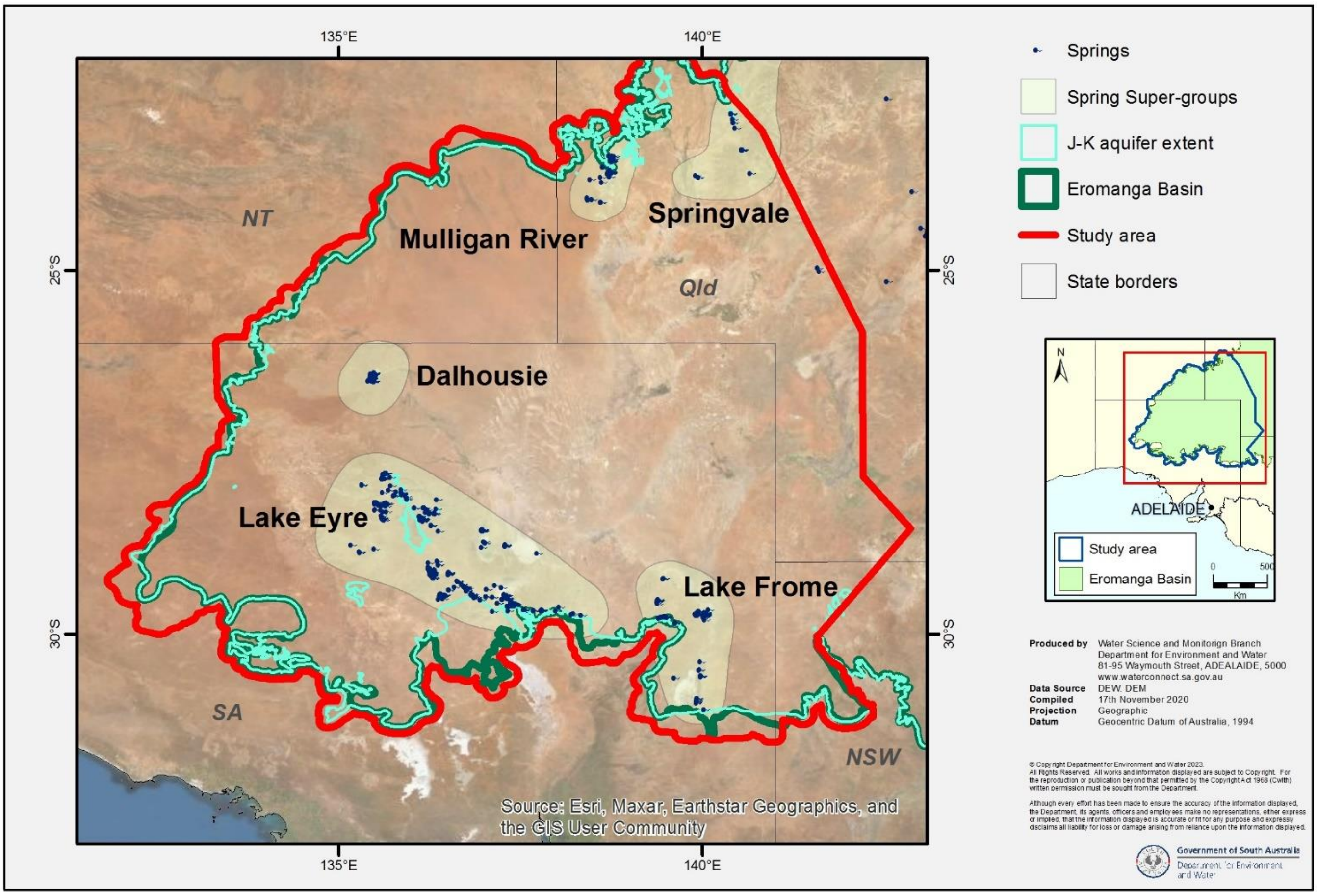

Figure 5.1: Spring super-groups within the study area

5.2 Southern Springs

Approximately 40 springs in the Lake Eyre super-group are monitored every one to six months by Olympic Dam mining operation (Figure 5.3). Spring flow time series data is largely sourced from the Olympic Dam mining operations annual Environmental Protection and Management Program (EPMP). Monitoring is undertaken as part of the indenture covering the development and operation of the Olympic Dam Mine site and Roxby Downs Township (*Roxby Downs (Indenture Ratification) Act 1982*). Monitoring data is reported to the Government of South Australia in the form of an annual report as part of their obligations under the indenture act.

Maximum flows from the surveyed springs varied from 0.15 L/s at Fred's Springs (LES001) to 18.2 L/s at Coward Springs (CBC013). Trends typically reflect the impacts of pumping from Olympic Dam Wellfields A and B, and responses to pumping management protocols designed to stabilize flow reductions. This is more evident after 1998 for monitored springs near or within Wellfield A as a result of a shift in groundwater extraction to Wellfield B and a capping of extraction at Wellfield A to generally less than 5 ML/d. These changes were made after extractions from Wellfield A of up to 16 ML/d were found to be having an adverse impact of spring flows. The location of Wellfield B over a deeper and thicker part of the Main Eromanga Aquifer Sequence and also on the other side of a basement structure (Kinhill Engineers 1997) limits drawdown effects on springs. This allows total groundwater extractions to vary between 30 and 40 ML/d, while spring flows have stabilised and, in some cases, partially recovered since the mid-1990s.

Total spring discharge for the Kati Thanda-Lake Eyre super-group (Figure 5.1), inclusive of those monitored as well as not monitored, has been estimated to be in the range 9 to 17 ML/d (Alcoe 2015; Habermehl 1980). As with the Dalhousie Spring monitoring, the spring monitoring here is designed to indicate change as opposed to determining total spring discharge volumes.

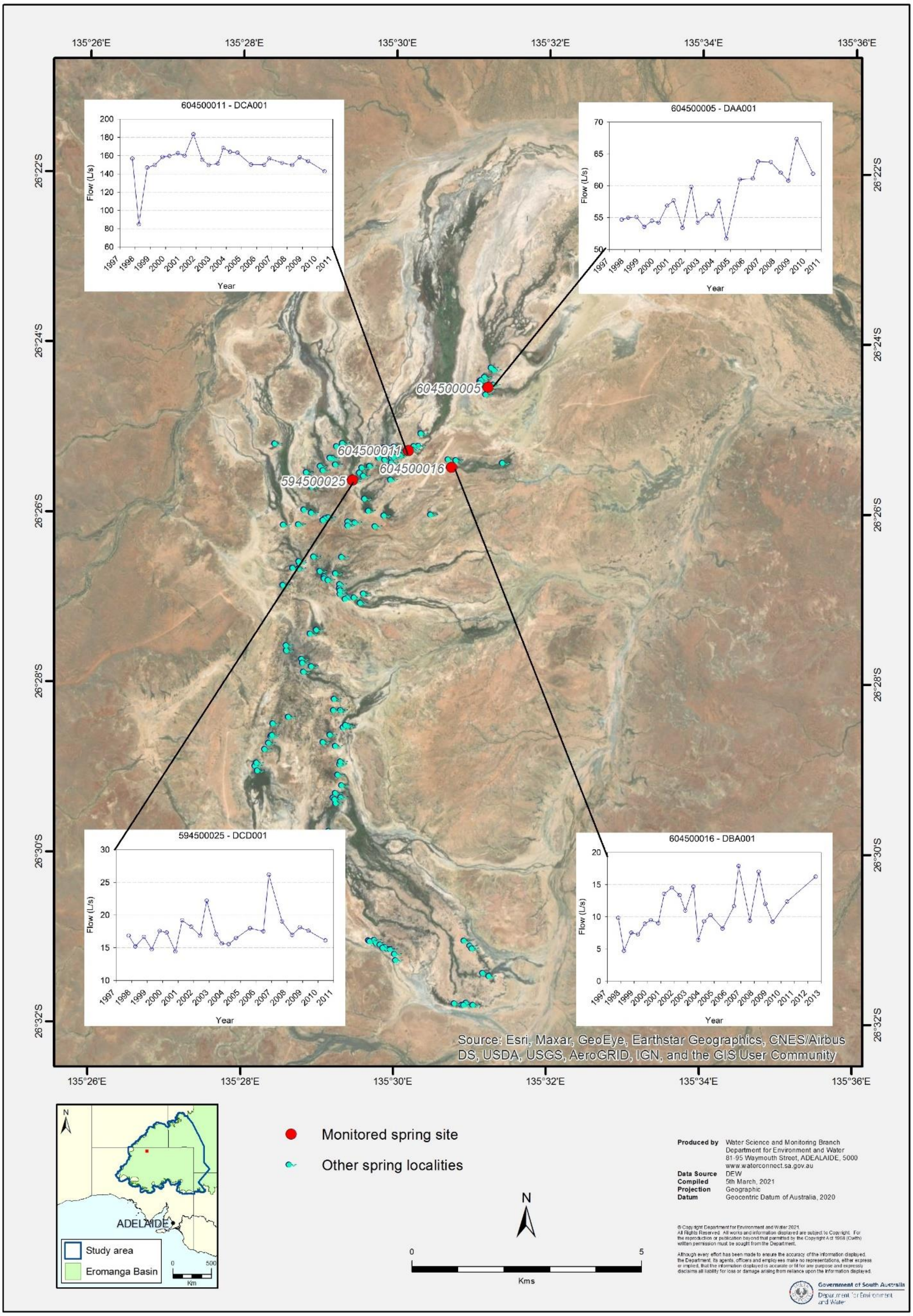

Figure 5.2: Dalhousie Spring monitoring site flow data

5.2.1 Coward and Emerald Springs

These springs are located west of Lake Eyre South and are the furthest away from Olympic Dam wellfield operations (Figure 5.3). Of the 4 vents monitored, flows at CBC001 and CBC002 have remained generally stable over the monitoring period, at approximately 0.3 and 2 L/s respectively. Recorded flows at CBC013 vary considerably compared to other springs, ranging from approximately 4 L/s to 18.2 L/s; however, the long-term trend has been relatively stable from 1999 onwards, with an average flow of 11 L/s. Prior to 1999, CBC013 displayed a generally increasing trend in flow rate.

Flow monitoring at Emerald Springs (LES001) displays a number of relatively high outlier readings, particularly prior to 1991. Between 1989 and 1999, a decline in flow from 3.5 L/s to 1 L/s was observed after a spike in recorded flows. From 1999, a relatively stable flow has been observed, averaging 1.4 L/s (Figure 5.3).

5.2.2 Fred, Gosse and McLaughlin Springs

These springs are located near the southern shoreline of Lake Eyre South, within Olympic Dam Wellfield A area of operation (Figure 5.3). All of the 5 vents monitored show a decline in flow prior to 1998, which can be attributable to drawdowns associated with abstraction in Wellfield A. Since reducing extractions at this wellfield to below 5 ML/d, flow rates appear to have stabilised. Average flow rates from 1998 onwards are 0.1 L/s (LFE001), 0.04 L/s (LFE006), 0.8 L/s (LMS004B), 1.5 L/s (LGS002) and 0.2 L/s (LGS004), respectively.

5.2.3 Hermit Hill Springs

Hermit Hill springs are located between Olympic Dam Wellfield A and Wellfield B areas (Figure 5.3). Of the 6 spring vents monitored, 4 springs have shown relatively stable flow over time, whereas 2 have displayed a decline in flow prior to the year 2000 before stabilising. Overall, flows are all relatively small, ranging from <0.001 (HHS101) to 0.8 L/s. (HHS170). Relatively anomalous increases in flow have been reported at HHS035 (0.03 L/s) and HHS125A (0.02 L/s), although such readings may reflect the difficulty of accurately measuring such very low flow rates.

5.2.4 Old Finniss Springs and Old Woman Springs

Old Finniss and Old Woman springs are located near the Hermit Hill Springs, between Olympic Dam Wellfield A and Wellfield B areas (Figure 5.3). There are 9 spring vents monitored at these locations. Of these, most have recorded stable flow, although HOF096 has displayed a steady increase from approximately 0.15 L/s prior to the year 2000 to a peak of 0.36 L/s in 2016. HOF081 appears to have a more consistently recordable flow of approximately 0.08 L/s since 2010; prior to 2016 flow appears more variable. In contrast, HOW009 appears to be decreasing slightly in flow over the monitoring period; the first 10 years of monitoring had an average flow of 0.17 L/s, compared to the final 10 years that had an average flow of 0.12 L/s, albeit with a large degree of variance inherent in flow measurement (standard deviation of 0.07 L/s). Similar to Hermit Hill, overall flows are all relatively small, ranging from <0.001 (HOF033, HOF094, HOW025) to 0.4 L/s (HOF096, HOW009). Flows at HOW009 appear to be slightly declining, although flow measurements fluctuate greatly, varying between 0.03 (2017) and 0.36 L/s (2011).

5.2.5 Welcome and Davenport Springs

Welcome and Davenport Springs are the most easterly of the spring groups monitored, located to the south of Olympic Dam Wellfield B (Figure 5.3). In total, 7 spring vents are regularly monitored. Most flow measurements are relatively stable, with flows ranging between <0.001 (WDS052) to 1.1 L/s (WDS001). Three of the 4 spring vents monitored at Welcome Springs have shown an increase in flow from the year 2010; the largest change in flow is from WWS001, where prior to 2010 the average recorded flow was 0.07 L/s, compared to the most recent measurement of 0.17 L/s.

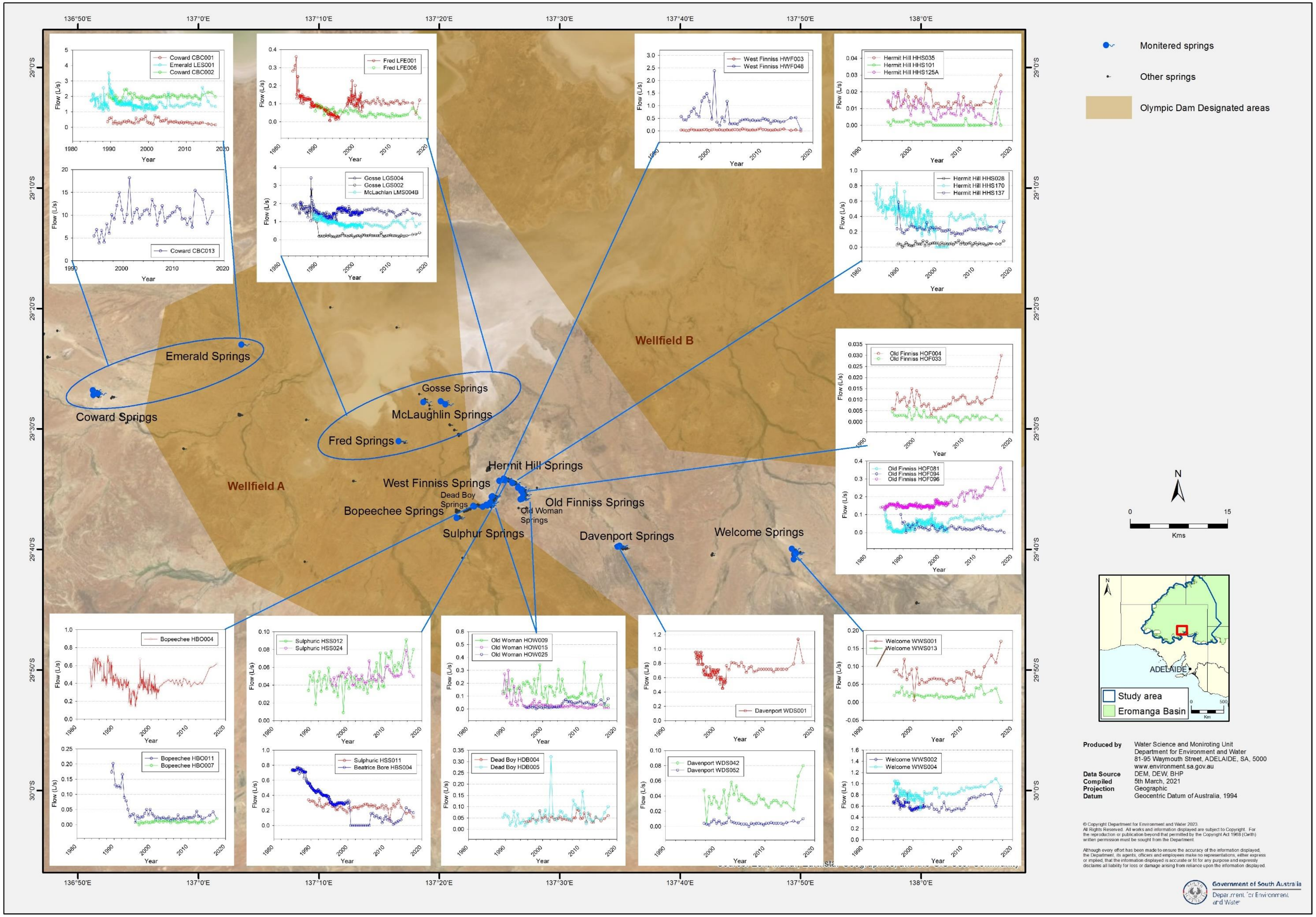

Figure 5.3: Southern Spring monitoring site flow data

5.2.6 Sulphuric, Beatrice and West Finnis Springs

Sulphuric, Beatrice and West Finniss Springs are located between Olympic Dam Wellfield A and Wellfield B areas (Figure 5.3). Of the 6 spring vents monitored, 2 have displayed an increase in flow over time, 3 appear relatively stable and one appears to be in long term-decline.

Of the 3 stable springs reported, 2 may be experiencing recent declines in flow. Of note, HFW048 displays high but very variable flow prior to 2002, with a maximum recording of 2.5 L/s; however, after 2002, flow is typically lower but more stable, averaging 0.4 L/s, before a latest reading of 0.06 L/s. Springs HSS012 and HSS024 have shown an increasing trend over the time, although flows are generally low, with a maximum flow of 0.09 and 0.08 L/s respectively. Finally, HBS004 displays a historically declining trend prior to 2000, with flow decreasing from approximately 0.75 L/s to 0.3 L/s. Further, between 2000 and 2006, no flow was recordable, while after 2006 flows approaching 0.2 L/s have been noted.

5.2.7 Bopeechee and Dead Boy Springs

Bopeechee and Dead Boy Springs are located between Olympic Dam Wellfield A and Wellfield B areas (Figure 5.3). Of the 5 spring vents monitored, 3 display relatively stable flows over the monitoring period. Exceptions include HBO011, which declined from 0.2 L/s to approximately 0.025 L/s prior to 1998 before stabilising, and HBO004, which appears to have declined from approximately 0.6 L/s to approximately 0.4 L/s in the same period. Flow at HBO004 appears to have recently recovered to approximately 0.6 L/s. Spring flow here is typically low, with no flows greater than 0.6 L/s.

6 Data gaps and limitations

During the data compilation and analysis of available time series data, a number of data gaps became apparent. The following section provides a discussion of the data gaps considered important with respect to the development of a conceptual hydrogeological model (CHM) and ultimately the numerical model construction.

6.1 Well distribution

Wells within the FNPWA monitoring network are not evenly distributed. The highest monitoring point densities are near the springs, so areas that are near the margins of artesian groundwater conditions are best represented. As one of the primary purposes of the FNPWA monitoring network is providing an indication of regional groundwater pressure changes near the springs for management and regulatory purposes, this emphasis in distribution is deliberate.

However, for the purposes of determining regional-scale hydrodynamic behaviour and groundwater pressure change for numerical model simulations, areas where there are a relatively sparse number of monitoring points present a data gap. In particular, the region between Kati Thanda-Lake Eyre and the Cooper Basin region could benefit from a greater density of monitoring stations given this is where recent longer term regional declines in groundwater pressure appear to be most sustained. Further, there is a general lack of monitoring points in the unconfined portions of the Eromanga Basin near the western and south-western margins. As these regions are interpreted to be located in potential recharge zones (Ransley et al. 2015), the absence of monitoring data limits the ability to assess the impact of rainfall and flooding on recharge in these areas.

Consequently, this heterogeneous data distribution has rendered parts of the study area reliant on very few data points. As useful time series data requires many rounds of monitoring to become useful, there is currently little redress possible.

6.2 Data quality

Unlike many wells used in the private networks in the study area, the majority of wells included in the FNPWA monitoring networks are working wells; in other words, they serve dual purposes as monitoring wells and as groundwater extraction points for pastoral and other purposes. This presents issues with respect to data quality:

- Although field monitoring protocols require a well to be shut in for a sufficient period of time to allow for a measurement of groundwater pressure as close to natural as possible, there is no guarantee that this will be achieved.
- Maintenance of well condition is the responsibility of the primary users of the well. Normal wear and tear or damage to well infrastructure because of this primary usage may impact the measurement and therefore the reliability of time series data as the well ages.
- Older wells may not be able to be completely shut in. Consequently, all measurements, or the majority of them, may represent flowing or antecedent pressure conditions. While this may provide some relative indication of temporal pressure change, such data is considered less reliable. It also cannot be directly compared to other monitoring sites where shut-in measurement is possible.

- The remoteness of many locations means that measurements may only be taken twice a year at best. Consequently, temporary access issues, such as flooding, may have quite large impacts on the continuity of time series data. Large gaps in data over certain time periods may develop more easily than if access to monitoring wells was less difficult. Similarly, any errors in measurement protocol may have a comparable impact on the completeness of such temporal datasets.
- The size and remoteness of the FNPWA has meant that the monitoring network supporting its management may not have been as comprehensive or monitored as often in the past. Further, expansion of the network has been iterative and so parts of the network, particularly on the western margins, have not been monitored for as long as other parts. This data gap may reduce over time if monitoring regularity is maintained going forward.

Finally, there are data gaps related to the reliance on privately maintained monitoring data. In the case of the Olympic Dam wellfields monitoring network, this is currently not considered an issue due to the quality, consistency, age and coverage of the monitoring assets. In contrast, monitoring data from further to the west are not as complete or comprehensive. This limitation is tied to the requirements for such monitoring data by private concerns, which is largely tied to the life expectancy of their operations.

6.3 Spring flow data

As previously mentioned in Chapter 5, the vast majority of springs in SA are not regularly monitored; consequently, the relationship between spring flow and changes in groundwater pressure over time are not quantified in the majority of instances. Spring-flow monitoring programs are largely designed to provide an indication of change, which is then used as representation for impacts on larger spring systems. Consequently, such monitoring is considered not suitable for calculating discharge volumes for spring environments for water balance purposes.

6.4 Recommendations

With respect to heterogeneous well distribution, this is addressable in the longer term with the addition of monitoring points where well infrastructure is available. Further, the completion of a numerical model may in fact highlight where more time series data is required.

Likewise, data quality issues cannot be rectified easily, with the only current solution being to maintain monitoring as much as possible over the long term so such data gaps may become less important as more data becomes available.

This study identified useful data sourced from privately maintained monitoring networks. In some cases, these monitoring networks are no longer maintained. It is recommended that moving forward, a review is conducted as to whether such networks should be integrated into the FNPWA monitoring network, either wholly or at least partially, to ensure continued monitoring, where deemed necessary for modelling and management purposes.

Finally, this study identified that all current spring monitoring in SA is undertaken by private concerns. The potential for undertaking spring flow monitoring outside of that associated with Olympic Dam mining operations may help elucidate the potential impact of drawdown on spring flow on a more regional scale; however, such monitoring is often time consuming, specialised, occasionally unreliable and has the potential to cause surface damage to the wetland environment. Although the use of remote sensing data as a monitoring tool has been explored (see for example, White and Lewis 2011), to date a practicable technique has not been developed for application within the study area. Spring flow monitoring is therefore reserved to where it may have the greatest and most immediate impact, which is generally where groundwater pressures near springs of significant cultural and ecological significance are under immediate drawdown pressure due to groundwater extraction.

7 Closing remarks, model assumptions and conclusions

Time series data of groundwater pressure reduced standing water level (RSWL) and salinity from within the study area was analysed for conceptual model development purposes. The majority of time series data came from the SA Government-maintained database SA Geodata, primarily from the SA Government monitored FNPWA monitoring network. Other time series data assessed came from a few privately maintained networks, most notably the Olympic Dam monitoring network located in the southern portion of the study area. In addition, selected data from the Prominent Hill mine monitoring network and the Cairn Hill mine and Peculiar Knob mine monitoring networks were also assessed. Spring flow time series data is largely sourced from the Olympic Dam mining operations annual Environmental Protection and Management Program (EPMP). Springs covered by this monitoring program are located in the Kati Thanda-Lake Eyre south region. Additional historical data from 4 springs in the Dalhousie Springs group were also assessed.

Prior to interpretation, anomalous values were investigated using preliminary hydrograph and salinity plots of raw data. Values either considered anomalous due to deficient measurement protocols or reading error were removed from the dataset after an investigation of other field related notes. Data not collected or entered into SA Geodata by July 2019 was not included in this assessment.

Groundwater pressures in the area between the Cooper Basin and Kati Thanda-Lake Eyre have seen declines over the time period monitored, mostly since the 1970s. These declines are associated with petroleum hydrocarbon extraction associated with the Cooper Basin region as well as groundwater extraction from the wellfield areas tied to Olympic Dam mining operations. Ancillary extractions associated with pastoralism in this region have also contributed to the drawdown. Pressures and water levels in other areas generally appear stable, although some localised increases suggest that the impact of well-capping programs can be observed in monitoring data. Localised increases in pressures are particularly notable near the spring zones. The groundwater model is designed with capacity to unpack these various water user effects.

Salinities for the most part have remained relatively steady, varying between <1,000 mg/L in eastern and central regions to >14,000 mg/L near the south-western margin.

In the southern springs region where Olympic Dam mining operations have been monitoring spring flow since the early 1980s, data is generally reflective of impacts associated with groundwater extraction from their wellfields. Notable declines in spring flow were observed at the commencement of extraction at Wellfield A from the early 1980s until the mid-1990s. At that time, the commissioning of Wellfield B enabled mining operations to ease water demand from Wellfield A and cap extraction to approximately 5 ML/day, whereas it had previously approached 16 ML/d. This saw some recovery of spring flow at several monitored spring sites. Over the short period of monitoring record at Dalhousie Springs since the 1990s, no notable trends were observed.

During the compilation of and assessment of time series data, several data gaps and uncertainties became apparent. In brief, these data gaps are generally associated with the following:

- The heterogeneous distribution of monitoring wells leaves some areas reliant on just a few locations and other areas unmonitored.
- Monitoring errors may potentially impact accurate interpretation of water levels and pressures or may exacerbate time gaps between acceptable measurements if outliers are removed from the dataset.
- In the FNPWA monitoring network, maintenance of monitoring points is often left to third parties because the wells are commonly dual purpose, and the dual-use nature of wells may also impact the accuracy of measurement.
- The remoteness of monitoring points means that time gaps between measurements may be relatively long.

- Data from privately maintained monitoring networks may be inadequate for model conceptualisation and construction because such monitoring was never specifically designed for such a purpose.
- Historically, spring flow monitoring is not designed to calculate discharge volumes, but rather to provide an indication of potential changes to flow as a consequence of groundwater pressure stresses associated with extraction. Consequently, only a very small proportion of spring vents found in the study area are routinely monitored, with current monitoring restricted to the southern springs area, although there are some flow monitoring records for Dalhousie spring up until about 2010.

To address these data gaps, the following recommendations are made:

- Heterogeneous well distribution is addressable in the longer term with the addition of monitoring points where well infrastructure is available.
- Likewise, data quality issues can only be addressed through maintaining monitoring for as long as possible, so such gaps become less important as more data becomes available.
- Once private monitoring networks are no longer required by the proponent, a review should be conducted to determine if such networks should be integrated into the FNPWA monitoring network, either wholly or at least partially, to ensure continued monitoring, where deemed necessary for modelling and management purposes.
- Finally, this study identified that all current spring monitoring in SA is undertaken by private concerns. The potential for undertaking spring flow monitoring outside of that associated with Olympic Dam mining operations may help elucidate the potential impact of drawdown on spring flow on a more regional scale.

8 Units of measurement

8.1 Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

8.2 Shortened forms

EC electrical conductivity (µS/cm)

9 Glossary

Act (the) — In this document, refers to the *Natural Resources Management (SA) Act 2004,* which supersedes the *Water Resources (SA) Act 1997*

Ambient — The background level of an environmental parameter (e.g. a measure of water quality such as salinity)

Ambient water monitoring — All forms of monitoring conducted beyond the immediate influence of a discharge pipe or injection well, and may include sampling of sediments and living resources

Ambient water quality — The overall quality of water when all the effects that may impact upon the water quality are taken into consideration

Aquiclude — In hydrologic terms, a formation that contains water but cannot transmit it rapidly enough to furnish a significant supply to a well or spring

Aquifer — An underground layer of rock or sediment that holds water and allows water to percolate through

Aquifer, confined — Aquifer in which the upper surface is impervious (see 'confining unit') and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer

Aquifer test — A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to more accurately estimate the sustainable use of the water resources available for development from the well

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure

Aquitard — A layer in the geological profile that separates two aquifers and restricts the flow between them

ArcGIS — Specialised GIS software for mapping and analysis developed by ESRI

Arid lands — In South Australia, arid lands are usually considered to be areas with an average annual rainfall of less than 250 mm and support pastoral activities instead of broadacre cropping

Artesian — An aquifer in which the water surface is bounded by an impervious rock formation; the water surface is at greater than atmospheric pressure, and hence rises in any well, which penetrates the overlying confining aquifer

Artificial recharge — The process of artificially diverting water from the surface to an aquifer; artificial recharge can reduce evaporation losses and increase aquifer yield; see also 'natural recharge', 'aquifer'

Basin — The area drained by a major river and its tributaries

BoM — Bureau of Meteorology, Australia

Bore — See 'well'

Buffer zone — A neutral area that separates and minimises interactions between zones whose management objectives are significantly different or in conflict (e.g. a vegetated riparian zone can act as a buffer to protect the water quality and streams from adjacent land uses)

^{14}C — Carbon-14 isotope (percent modern Carbon; pMC)

Catchment — That area of land determined by topographic features within which rainfall will contribute to runoff at a particular point

CFC — Chlorofluorocarbon; measured in parts per trillion (ppt)

Climate change — The balance of incoming and outgoing solar radiation which regulates our climate. Changes to the composition of the atmosphere, such as the addition of carbon dioxide through human activities, have the potential to alter the radiation balance and to effect changes to the climate. Scientists suggest that changes would include global warming, a rise in sea level and shifts in rainfall patterns.

CMB — Chloride mass balance

Cone of depression — An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction that exceeds the rate of recharge; continuing extraction of water can extend the area and may affect the viability of adjacent wells, due to declining water levels or water quality

Confining unit — A rock unit impervious to water, which forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also 'aquifer, confined'

CSG — coal seam gas

CSIRO — Commonwealth Scientific and Industrial Research Organisation

δD — Hydrogen isotope composition, measured in parts per thousand (**‰**)

Dams, off-stream dam — A dam, wall or other structure that is not constructed across a watercourse or drainage path and is designed to hold water diverted or pumped from a watercourse, a drainage path, an aquifer or from another source; may capture a limited volume of surface water from the catchment above the dam

Dams, on-stream dam — A dam, wall or other structure placed or constructed on, in or across a watercourse or drainage path for the purpose of holding and storing the natural flow of that watercourse or the surface water

Dams, turkey nest dam — An off-stream dam that does not capture any surface water from the catchment above the dam

DEW — Department for Environment and Water

DEWNR — Department of Environment, Water and Natural Resources (Government of South Australia)

DfW — former Department for Water (Government of South Australia)

dGPS — differential Global Positioning System

DO — Dissolved Oxygen

DOC — Dissolved Organic Carbon

Domestic purpose — The taking of water for ordinary household purposes; includes the watering of land in conjunction with a dwelling not exceeding 0.4 hectares

Dryland salinity — The process whereby salts stored below the surface of the ground are brought close to the surface by the rising watertable. The accumulation of salt degrades the upper soil profile, with impacts on agriculture, infrastructure and the environment.

DSS — Dissolved suspended solids

DWLBC — former Department of Water, Land and Biodiversity Conservation (Government of South Australia)

EC — Electrical conductivity; 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C; commonly used as a measure of water salinity as it is quicker and easier than measurement by TDS

Ecology — The study of the relationships between living organisms and their environment

Ecological processes — All biological. physical or chemical processes that maintain an ecosystem

Ecological values — The habitats, natural ecological processes and biodiversity of ecosystems

Ecosystem — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

Endemic — A plant or animal restricted to a certain locality or region

Environmental values — The uses of the environment that are recognised as being of value to the community. This concept is used in setting water quality objectives under the Environment Protection (Water Quality) Policy, which recognises five environmental values — protection of aquatic ecosystems, recreational water use and aesthetics, potable (drinking water) use, agricultural and aquaculture use, and industrial use. It is not the same as ecological values, which are about the elements and functions of ecosystems.

Ephemeral streams or wetlands — Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

Erosion — Natural breakdown and movement of soil and rock by water, wind or ice; the process may be accelerated by human activities

Evapotranspiration — The total loss of water as a result of transpiration from plants and evaporation from land, and surface water bodies

Fresh — A short duration, small volume pulse of streamflow generated by a rainfall event that temporarily, but noticeably, increases stream discharge above ambient levels

Fully-penetrating well — In theory this is a well-hole that is screened throughout the full thickness of the target aquifer; in practice, any screen that is open to at least the mid 80% of a confined aquifer is regarded as fully-penetrating.

GAB — Great Artesian Basin

GDE — Groundwater dependent ecosystem

Geological features — Include geological monuments, landscape amenity and the substrate of land systems and ecosystems

Geomorphic — Related to the physical properties of the rock, soil and water in and around a stream

Geomorphology — The scientific study of the landforms on the Earth's surface and of the processes that have fashioned them

GIS — Geographic Information System; computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

Groundwater Data — Interactive map and search tool for viewing information about South Australia's wells with access to well details including, graphs showing water salinity and water level. It provides a variety of search methods, including filtering the results. [*waterconnect.sa.gov.au/Systems/GD/]*

Head (hydraulic) — Sum of datum level, elevation head and pressure head. The altitude to which water will rise in a properly constructed well. In unconfined aquifers it is the groundwater elevation, and in confined aquifers it is the potentiometric head.

Hydraulic conductivity (K) — A measure of the ease of flow through aquifer material: high K indicates low resistance, or high flow conditions; measured in metres per day

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers; see also 'hydrology'

Hydrography — The discipline related to the measurement and recording of parameters associated with the hydrological cycle, both historic and real time

Hydrology — The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere; see also 'hydrogeology'

Infrastructure — Artificial lakes; dams or reservoirs; embankments, walls, channels or other works; buildings or structures; or pipes, machinery or other equipment

Injection well — An artificial recharge well through which water is pumped or gravity-fed into the ground

Irrigation — Watering land by any means for the purpose of growing plants

Kati Thanda-Lake Eyre — Lake Eyre was co-named with the name used by the Arabana people in December 2012

Kati Thanda-Lake Eyre National Park — was proclaimed in November 2013 to recognise the significance of Lake Eyre to the Arabana people and co-name the lake Kati Thanda-Lake Eyre.

Lake — A natural lake, pond, lagoon, wetland or spring (whether modified or not) that includes part of a lake and a body of water declared by regulation to be a lake. A reference to a lake is a reference to either the bed, banks and shores of the lake or the water for the time being held by the bed, banks and shores of the lake, or both, depending on the context.

Land — Whether under water or not, and includes an interest in land and any building or structure fixed to the land

Licence — A licence to take water in accordance with the Act; see also 'water licence'

Licensee — A person who holds a water licence

LMWL — Local meteoric water line

m AHD — Defines elevation in metres (m) according to the Australian Height Datum (AHD)

MAR — Managed aquifer recharge (MAR) is a process where water is intentionally placed and stored in an aquifer for later human use, or to benefit the environment.

Metadata — Information that describes the content, quality, condition, and other characteristics of data, maintained by the Federal Geographic Data Committee

Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm runoff, assessing the impacts of dams or predicting ecological response to environmental change

MODFLOW — A three-dimensional., finite difference code developed by the USGS to simulate groundwater flow

Molar (M) — A term describing the concentration of chemical solutions in moles per litre (mol/L)

Monitoring — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things

Natural recharge — The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc). See also recharge area, artificial recharge

Natural resources — Soil, water resources, geological features and landscapes, native vegetation, native animals and other native organisms, ecosystems

NRM — Natural Resources Management; all activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively

NWC — National Water Commission

δ^{18}**O** — Oxygen isotope composition, measured in parts per thousand (**°/₀₀**)

Observation well — A narrow well or piezometer whose sole function is to permit water level measurements

ORP — Oxidation Reduction Potential

Owner of land — In relation to land alienated from the Crown by grant in fee simple — the holder of the fee simple; in relation to dedicated land within the meaning of the *Crown Lands Act 1929* that has not been granted in fee simple but which is under the care, control and management of a Minister, body or other person — the Minister, body or other person; in relation to land held under Crown lease or licence — the lessee or licensee; in relation to land held under an agreement to purchase from the Crown — the person entitled to the benefit of the agreement; in relation to any other land — the Minister who is responsible for the care, control and management of the land or, if no Minister is responsible for the land, the Minister for Sustainability, Environment and Conservation.

Paleochannels — Ancient buried river channels in arid areas of the state. Aquifers in paleochannels can yield useful quantities of groundwater or be suitable for ASR

Percentile — A way of describing sets of data by ranking the dataset and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

Permeability — A measure of the ease with which water flows through an aquifer or aquitard, measured in m/d

Piezometer — A narrow tube, pipe or well; used for measuring moisture in soil, water levels in an aquifer, or pressure head in a tank, pipeline, etc.

PIRSA — Primary Industries and Regions South Australia (Government of South Australia)

Population — (1) For the purposes of natural resources planning, the set of individuals of the same species that occurs within the natural resource of interest. (2) An aggregate of interbreeding individuals of a biological species within a specified location

Porosity — The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment (Middlemis, 2000).

Porosity, effective — The volume of the inter-connected void spaces through which water or other fluids can travel in a rock or sediment divided by the total volume of the rock or sediment.

Porosity, Primary — The porosity that represents the original pore openings when a rock or sediment formed (Middlemis, 2000).

Porosity, Secondary — The porosity that has been caused by fractures or weathering in a rock or sediment after it has been formed (Middlemis, 2000).

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer, measured in metres (m); also known as piezometric surface

Prescribed water resource — A water resource declared by the Governor to be prescribed under the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed well — A well declared to be a prescribed well under the Act

Production well — The pumped well in an aquifer test, as opposed to observation wells; a wide-hole well, fully developed and screened for water supply, drilled on the basis of previous exploration wells

PWA — Prescribed Wells Area

Recharge area — The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. See also artificial recharge, natural recharge

RSWL —Reduced Standing Water Level measured in meters AHD (Australian Height Datum). The elevation of the water level is calculated by subtracting the Depth to Water (DTW) from the reference elevation. A negative value indicates that the water level is below mean sea level.

SA Geodata — A collection of linked databases storing geological and hydrogeological data, which the public can access through the offices of PIRSA. Custodianship of data related to minerals and petroleum, and groundwater, is vested in PIRSA and DEW, respectively. DEW should be contacted for database extracts related to groundwater

Salinity — The concentration of dissolved salts in water or soil, expressed in terms of concentration (mg/L) or electrical conductivity (EC)

SDE — South Australian government dataset containing all other spatially explicit data not housed by SA GEODATA, HYDSTRA, or BDBSA

Seasonal— Pertaining to a phenomena or event that occurs on a on a seasonal basis

Specific storage (S_s) — Specific storativity; the amount of stored water realised from a unit volume of aquifer per unit decline in head; measured in m^{-1}

Specific yield (S_y) — The volume ratio of water that drains by gravity to that of total volume of the porous medium. It is dimensionless

Stock use — The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act)

Storativity (S) — Storage coefficient; the volume of groundwater released or taken into storage per unit plan area of aquifer per unit change of head; it is the product of specific storage Ss and saturated aquifer thickness (dimensionless)

Surface water — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

Sustainability — The ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time

SWL — Standing Water Level (meters) recorded for the water well. This is the distance from the ground surface to the water surface. A negative value indicates that the water level is above ground level.

TDS — Total dissolved solids, measured in milligrams per litre (mg/L); a measure of water salinity

Tertiary aquifer — A term used to describe a water-bearing rock formation deposited in the Tertiary geological period (1–70 million years ago). Also known as the Paleogene to Neogene period.

Threatened species — Any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range

Transmissivity (T) — A parameter indicating the ease of groundwater flow through a metre width of aquifer section (taken perpendicular to the direction of flow), measured in m^2/d

Tributary — A river or creek that flows into a larger river

Turbidity — The cloudiness or haziness of water (or other fluid) caused by individual particles that are too small to be seen without magnification, thus being much like smoke in air; measured in Nephelometric Turbidity Units (NTU)

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground

USGS — United States Geological Survey

Volumetric allocation — An allocation of water expressed on a water licence as a volume (e.g. kilolitres) to be used over a specified period of time, usually per water use year (as distinct from any other sort of allocation)

Water allocation — (1) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence. (2) In respect of water taken pursuant to an authorisation under s.11 means the maximum quantity of water that can be taken and used pursuant to the authorisation

WAP — Water Allocation Plan; a plan prepared by a water resources planning committee and adopted by the Minister in accordance with the Act

Water body — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers

Water column — a section of water extending from the surface of a body of water to its bottom. In the sea or ocean, it is referred to as 'pelagic zone'

Watercourse — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from this definition) into which the water of a watercourse has been diverted; and part of a watercourse

Water dependent ecosystems — Those parts of the environment, the species composition and natural ecological processes, that are determined by the permanent or temporary presence of flowing or standing water, above or below ground; the in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water dependent ecosystems

Water licence — A licence granted under the Act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area; this grants the licensee a right to take an allocation of water specified on the licence, which may also include conditions on the taking and use of that water; a water licence confers a property right on the holder of the licence and this right is separate from land title

Water plans — The State Water Plan, water allocation plans and local water management plans prepared under Part 7 of the Act

Water quality data — Chemical, biological, and physical measurements or observations of the characteristics of surface and groundwaters, atmospheric deposition, potable water, treated effluents, and wastewater, and of the immediate environment in which the water exists

Water quality information — Derived through analysis, interpretation, and presentation of water quality and ancillary data

Water quality monitoring — An integrated activity for evaluating the physical, chemical, and biological character of water in relation to human health, ecological conditions, and designated water uses

Water resource monitoring — An integrated activity for evaluating the physical., chemical., and biological character of water resources, including (1) surface waters, groundwaters, estuaries, and near-coastal waters; and (2) associated aquatic communities and physical habitats, which include wetlands

Water resource quality — (1) The condition of water or some water-related resource as measured by biological surveys, habitat-quality assessments, chemical-specific analyses of pollutants in water bodies, and toxicity tests. (2) The condition of water or some water-related resource as measured by habitat quality, energy dynamics, chemical quality, hydrological regime, and biotic factors

Well — (1) An opening in the ground excavated for the purpose of obtaining access to underground water. (2) An opening in the ground excavated for some other purpose but that gives access to underground water. (3) A natural opening in the ground that gives access to underground water

Wetlands — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial., permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six metres.

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