The Far North Prescribed Wells Area Groundwater Model

Volume 7 – Water use and balance estimates

Department for Environment and Water
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Government of South Australia

Department for Environment and Water

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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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Internal review of the report was provided by:

- project hydrogeology lead Mark Keppel, Principal Hydrogeologist, Department for Environment and Water (DEW)
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- 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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- Paul Howe Principal Hydrogeologist, CDM Smith Pty Ltd
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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 7) provides a description of estimated groundwater usage as well as a preliminary water balance within the package of strata being represented within the groundwater model.

Current and historical groundwater use is an important primary input for groundwater model construction and history matching phases. Such data represents a major groundwater system output as well as the major human-based stress on the groundwater system. Aquifer responses to variations in groundwater use may be used to refine other aquifer property values in the numerical model. A variety of data sources, estimation methodologies and related assumptions were used to evaluate water use data. In many cases, these methodologies and assumptions are employed in the absence of high quality and accurate water use data, such as metering.

Groundwater use data was collated from various sources and then summarised in annual, bi-annual or monthly volumes per well and maintained within a database. If no pumping rates or volumes were available for stock and domestic use, water use is based largely on conservative estimates for stock consumption based on observable infrastructure or reported yield rates. Where available, metering information for town water supply bores was used. Likewise, extraction logs and estimates for privately managed bore fields were also used where available. For oil and gas co-produced water extraction, rates were obtained either from government-maintained databases or from private industry. The volume of oil and gas abstracted from the aquifer was also considered for with the aid of industry-sourced conversion factors. For all other wells where a water use was identified, extraction rates were estimated from water licence information.

From this water use assessment, stock and domestic use was found to be the oldest modern economic use of groundwater in the study area. Extractions are estimated to have begun in the late 19th century, peaking around the mid-1970s (Figure 1). Water efficiency and well-capping works commencing around this time have seen water extractions decline to around one third of the 1970s peak in the South Australian (SA) artesian portion of the study area. In the SA non-artesian portion of the study area, groundwater extraction has steadily increased for the better part of the 20th century, eventually stabilising at near current day levels around the early 21st century (Figure 1).

Groundwater extraction related to mining and energy industry developments in the artesian portion of the basin began around the mid-1980s. Mining-related groundwater use is dominated by the Olympic Dam mining operation and since the early 21st century have largely remained stable at around 35 ML/d, reflecting limitations imposed by current mining activities. Co-produced water extraction has largely remained between 15 and 25 ML/d from the mid-1990s until about 2010 and has since risen closer to the 60 ML/d licensed volume limit (Figure 1).

The preliminary water balance developed is designed to provide a basic ‘sanity check’ of the numerical modelling approach being developed. Such information can give a broad overview of the various significant inputs and outputs to a groundwater system and ensure that they are treated with appropriate respect during the numerical modelling phase. The water balance calculated here is for the SA portion of the study area, as this is the primary management and regulatory focus of the groundwater model. Similar to water use, the preliminary water balance has been developed with a number of important assumptions and has a number of consequent limitations.

The predominant groundwater system input is lateral inflow from Queensland and the Northern Territory, although the volume is estimated within a level of uncertainty spread over about two orders of magnitude. In contrast, direct recharge is about an order of magnitude lower than the median lateral inflow, although the relative variance is much smaller. With respect to outflow, lateral outflow, spring discharge, well extraction and vertical leakage are all estimated within about an order of magnitude, although with a reasonably high degree of uncertainty.

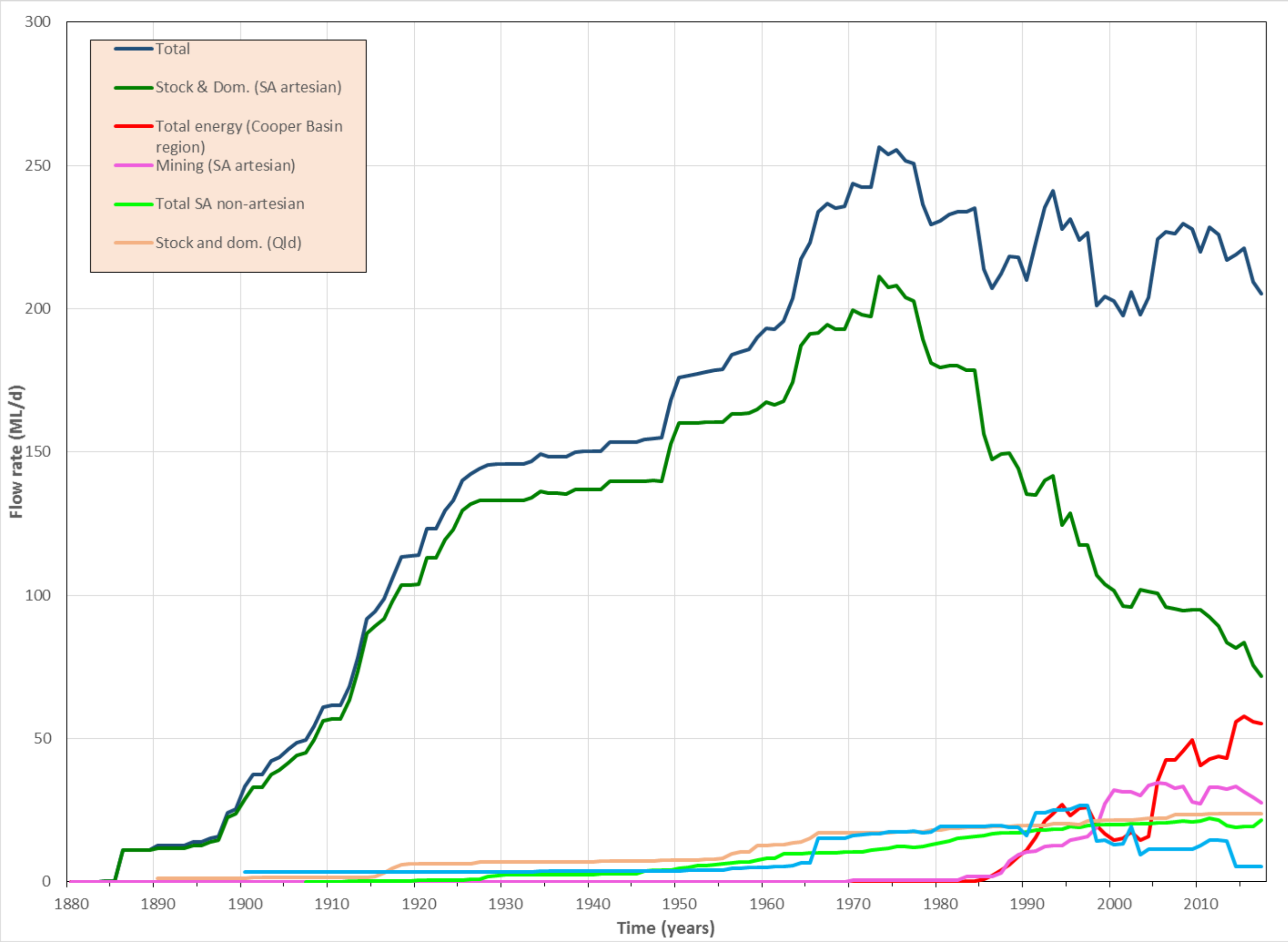

Figure 1: Estimated total groundwater use over time within the study area

The conceptual water balance suggests that the J-K aquifer within SA is not in steady state, but rather in a state of transience where outflows are currently estimated as being greater than inflows. The change in storage of the system reflects the difference between inflow and outflow, shown by changes in groundwater levels. Given current extractions and groundwater flow, such changes in storage may be concentrated in semi-regional areas where extraction is concentrated, such as the Western Flank of the Cooper Basin region or the Olympic Dam wellfield areas. Further work could improve the certainty in this conceptual water balance. Consequently, this water balance should be re-evaluated as new knowledge becomes available.

During the compilation of datasets and information used to develop the conceptual model, a number of material data gaps and uncertainties became apparent. In brief, these include:

- Currently, stock usage is estimated to be 0.3 L/s per trough feed point and 0.4 L/s per small dam, based upon the estimates used in past Far North Water Allocation Plan FNWAP calculations. The resultant water use estimates are considered conservative and represent a maximum use estimate. In the future, more nuanced ways to measure or calculate use would be highly recommended.
- Inherent data issues, such as lack of data or different data format requirements between jurisdictions have led to necessary simplifications as to how some water use data is imported into the model.
- Much of the uncertainty around the preliminary water balance estimates is related to the size and inherent heterogeneity found within the study area. There is further uncertainty related to temporal variations in recharge that may not be interpretable using potentiometric surfaces alone, as head data measurable today may be still representative of paleo-recharge events.

Table 1: Conceptual water balance for the J-K aquifer within SA

Inflow (ML/d)	Median value (ML/d)	Uncertainty range (ML/d)	∆ Storage (ML/d)	Net Uncertainty range (inflow minus outflow (ML/d)	Outflow (ML/d)	Median/ adopted value (ML/d)	Uncertainty range (ML/d)
Lateral inflow	475	(59 to 4219)			Lateral outflow	73	(8 to 443)
Recharge	20	(10 to 30)			Wells	134	(134 to 160)
					Spring discharge	66	(64 to 76)
Vertical leakage	not quantified				Vertical leakage (incl. diffuse discharge near springs)	274	(20 to 690)
Total Inflow	495	(69 to 4,249)	−52	(−159 to 2,880)	Total outflow	547	(226 to 1,369)

1 Introduction

Groundwater in the Far North Prescribed Wells Area (FNPWA) is vital for the success of the mining, energy, 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 water allocation plan (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 oil and gas), stock and domestic use, bore-fed wetlands and other quantities. Demand on the groundwater resources is expected to grow, particularly in response to growth in the mineral and energy 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 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.

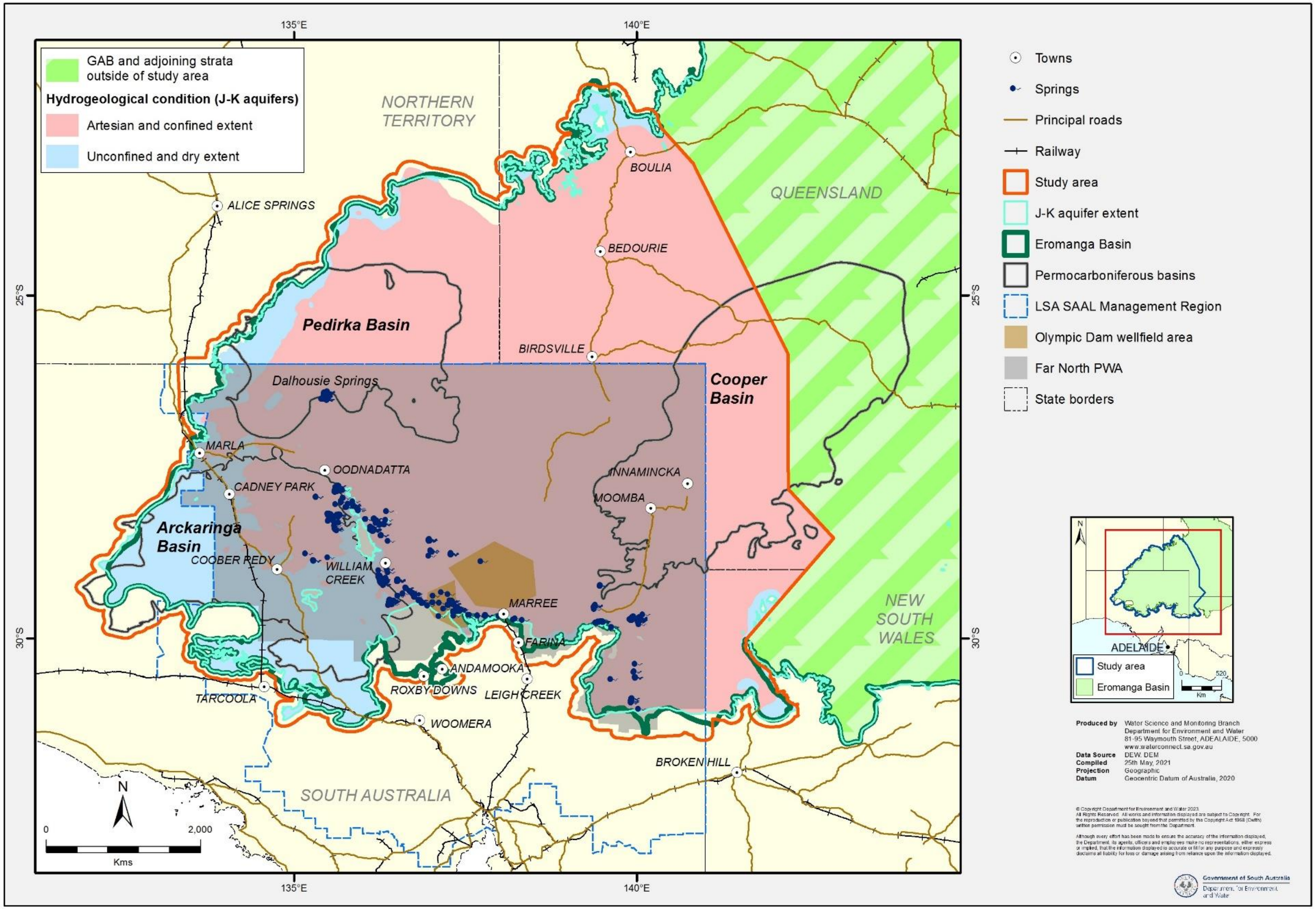

Figure 1.1: Location map of the Far North Prescribed Wells Area and study area

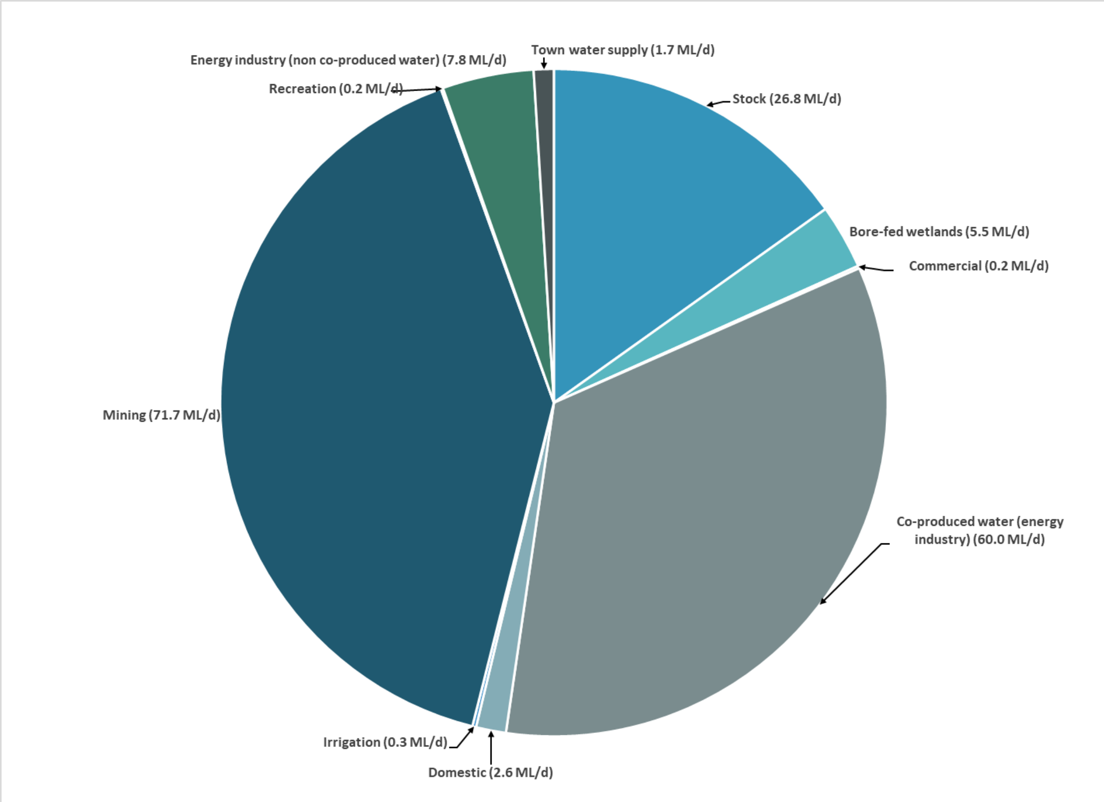

Figure 1.2: Total licensed volume (176 ML/d) presented by licence purpose description, FNPWA.

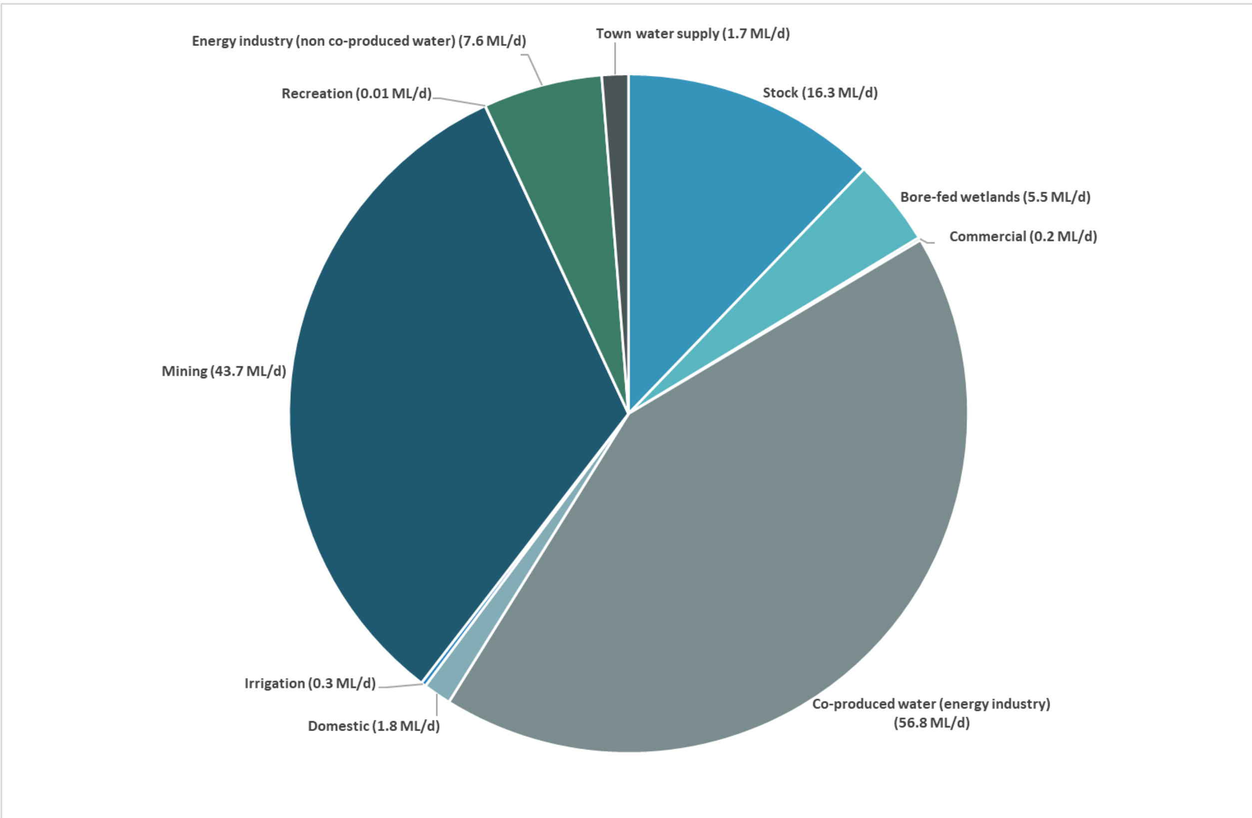

Figure 1.3: Licensed volume sourced from the GAB hydrogeological super-basin (134 ML/d) presented by licence purpose description, FNPWA.

To address the gaps identified in the existing models and to provide a tool to inform management of groundwater resources in the FNPWA, DEW has developed a numerical groundwater flow model that is consistent with the latest science and knowledge and is able to 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 estimations
8. Model construction and history matching
9. Model sensitivity and uncertainty analysis.

1.5 Volume Objective

This volume (Volume 7) describes estimated groundwater usage as well as provides a preliminary water balance within the package of strata being represented within the study area.

Current and historical water use is an important primary input for groundwater model construction and history matching phases. Such data represent a major groundwater system output as well as the major human-based stress on the groundwater system. Aquifer responses to variations in groundwater use may be used to refine other aquifer property values in the numerical model.

Preliminary water balance estimates are primarily designed to provide a useful 'sanity check' of the later numerical model approach (Barnett et al. 2012). Such information can give a broad overview of the various significant inputs and outputs to a groundwater system and ensure that they are treated with appropriate respect during the numerical modelling phase.

An important objective of this volume is to describe in detail the methodology used to derive the water use estimates, given the associated high level of uncertainty. In the absence of extensive well metering, water use estimates for the pastoral industry are based on conservative approximations, which are described in the volume. For other water uses, metered or reported water use data or water licence information was employed where verification against licensed wells could be established. Likewise, aquifer heterogeneity across the study area and the related uncertainty about hydrodynamic processes (discussed in previous volumes) mean that water balance estimates are considered accurate to an order-of-magnitude level only.

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. Future modelling programs may involve extensions to other groundwater flow systems, such as the Cooper, Arckaringa and Pedirka Basins.

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 off isopach interpolation. [b] Maximum thickness was interpolated in close vicinity to a mapped fault but cannot be confirmed. Confirmed thickness of 357 m based off intersection found in Well Unit no. 684200195.

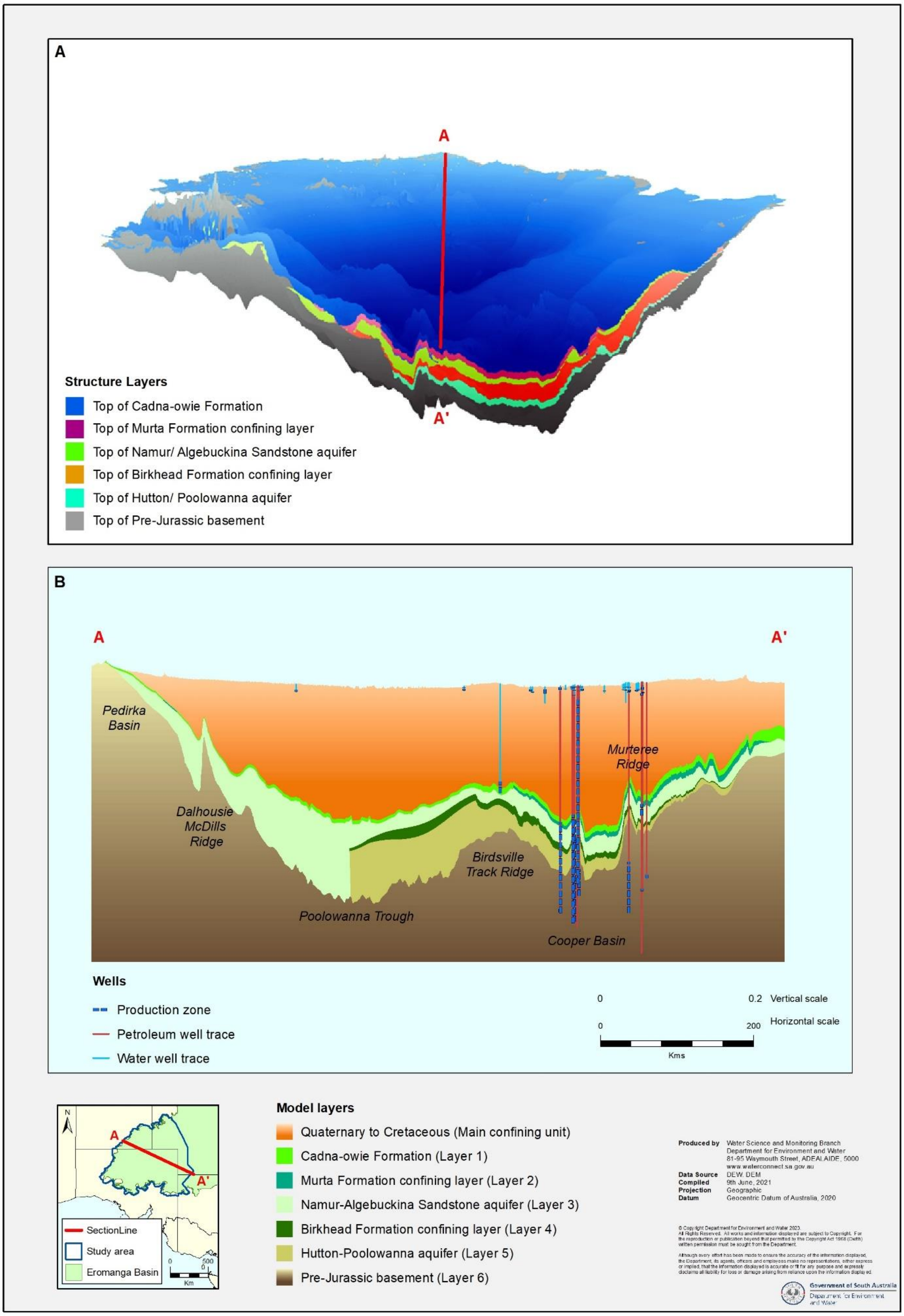

Figure 1.4: A) 3D projection of structure surface used in numerical model B) Cross-section through study area showing model layers and key structures

2 Methodology

Current and historical water use is an important primary input for groundwater model construction and history matching phases. A variety of data sources, estimation methodologies and related assumptions were used to evaluate water use data for this model. In many cases, these methodologies and assumptions are employed in the absence of high quality and accurate water use data, such as metering. As such, these data have important limitations, which are discussed.

The preliminary water balance developed is designed to provide a basic sanity check of the numerical modelling approach being developed (Barnett et al. 2012). The water balance calculated here is for the SA portion of the study area, as this is the primary management and regulatory focus of groundwater model. The preliminary water balance was developed using a number of broad assumptions and using an idealised version of the hydrogeological system described in previous volumes. Therefore, similar to water use, the preliminary water balance has been developed with a number of important assumptions and has a number of subsequent limitations.

2.1 Water use

Water use data was collated from various sources within the study area then summarised in annual, bi-annual or monthly volumes per well, and per formation within the Eromanga Basin sequence where data was available, for direct input into the numerical groundwater flow model. Water use data was collated in a database maintained outside the public domain to ensure the confidentiality of closed file data provided for the development of the groundwater model.

2.1.1 Assumptions and limitations

When estimating water use where measured statistics are unavailable, a conservative approach was generally employed. This typically involved applying the following assumptions in the absence of more reliable data:

- Wells currently reported as not located were assumed to be operational, unless there was other evidence to suggest otherwise, such as prior recorded status. The reasoning for this was to account for the potential of database error with historical reporting of coordinate location.
- Wells that have no well condition status were assumed operational.
- Where there is no drill date the earliest monitoring record date was used.
- Wells with a purpose of observation or monitoring were assigned a flow rate of 0 L/s.
- Abandoned wells were assigned a flow rate of 0 L/s.
- All other ‘purpose’ codes were assigned a measured yield.

Most wells that were listed as either not located or had an unreported status were actually known to be located in the western, non-artesian portion of the study area, based on the historical focus of monitoring and audit works in the artesian portion of the study area.

These assumptions are likely to lead to an overestimation of water usage and are therefore thought to represent the maximum usage estimate. The implications may be at least partially addressed during the history matching phase of model construction. Further, water use data estimates may be expected to improve over time as new information is collected, new techniques to estimate water use developed, and the database is updated.

Furthermore, water use data is limited to that derived from the Main Eromanga Aquifer Sequence, and specifically the J-K Aquifer. The other non-Main Eromanga Aquifer Sequence groundwaters make up 42 ML/d of the 176 ML/d, or 24% of the licensed volume to be extracted in the FNPWA (see Chapter 1). In particular, the Boorthanna Formation in the underlying Arckaringa Basin is a significant source of groundwater for mining operations within the south-western corner of the study area. However, none of these non-Main Eromanga Aquifer Sequence groundwater sources are being represented in the model at this time and so are not being considered in the following groundwater use estimates.

Data sources used to estimate water use and to calculate time series data are described below:

2.1.2 SA oil and gas co-produced water

Volumes of gas, oil and co-produced water production from within SA were sourced from Petroleum Exploration and Production System – South Australia (PEPS-SA) (Figure 2.1). PEPS-SA stores monthly gas, oil and co-produced water production per wellfield, per well, per formation and per month including all historical records. However, there is typically an 8-month lag from the collection of data by industry to the availability of that data in the public domain via PEPS-SA, in accordance with confidentiality agreements. Gas and oil production volumes were also considered as extraction volumes from the groundwater system. Conversion factors were used to relate the volume of gas and oil produced at surface to the volume of gas and oil removed at depth due to expansion (Table 2.1 and Table 2.2) (DEM 2019; T. Hill, personal communication, 26 July); we note that the conversion factors vary between wellfields. Where no conversion factor was available, a factor of 1 was assumed for oil production, while a factor of 189 was assumed for gas production; 189 is the median conversion factor for gas in the study area.

Table 2.1: Volume conversion factors for gas (Bg), Cooper Basin region

Field	Formation	Bg (in situ/surface volume)	1/Bg (surface/in situ volume)
Della	Hutton Sst	0.00678	147.48
Dullingari	McKinlay/Namur	0.00472	211.72
Dullingari	Murta Fm	0.00472	211.72
Gidgealpa North	Poolowanna Fm	0.00615	162.56
Marabooka	Namur Sst	0.00791	126.39
Merrimelia	Hutton Sst	0.00472	211.72
Mirage	Murta Fm	0.00472	211.72
Mudera	Coorikiana Sst	0.00795	125.75
Mudera	Namur/McKinlay	0.00795	125.72
Namur	Namur Sst	0.00775	129.10
Nanima	Poolowanna Fm	0.00656	152.51
Nappacoongee East	Murta Fm	0.00938	106.65
Strzelecki	Hutton Sst	0.00472	211.72
Strzelecki	Namur Sst	0.00472	211.72
Ventura	McKinlay/Namur	0.00472	211.72

2.1.3 SA stock, domestic, commercial and industrial extraction

For the purposes of providing an initial estimate, a simple yet conservative approach was adopted given the size, number and quality of data available. Further, due to the numbers of data points available, water, stock, domestic, commercial and industrial (including mining) groundwater extraction in SA, non-artesian and artesian wells were processed separately (Figure 2.1).

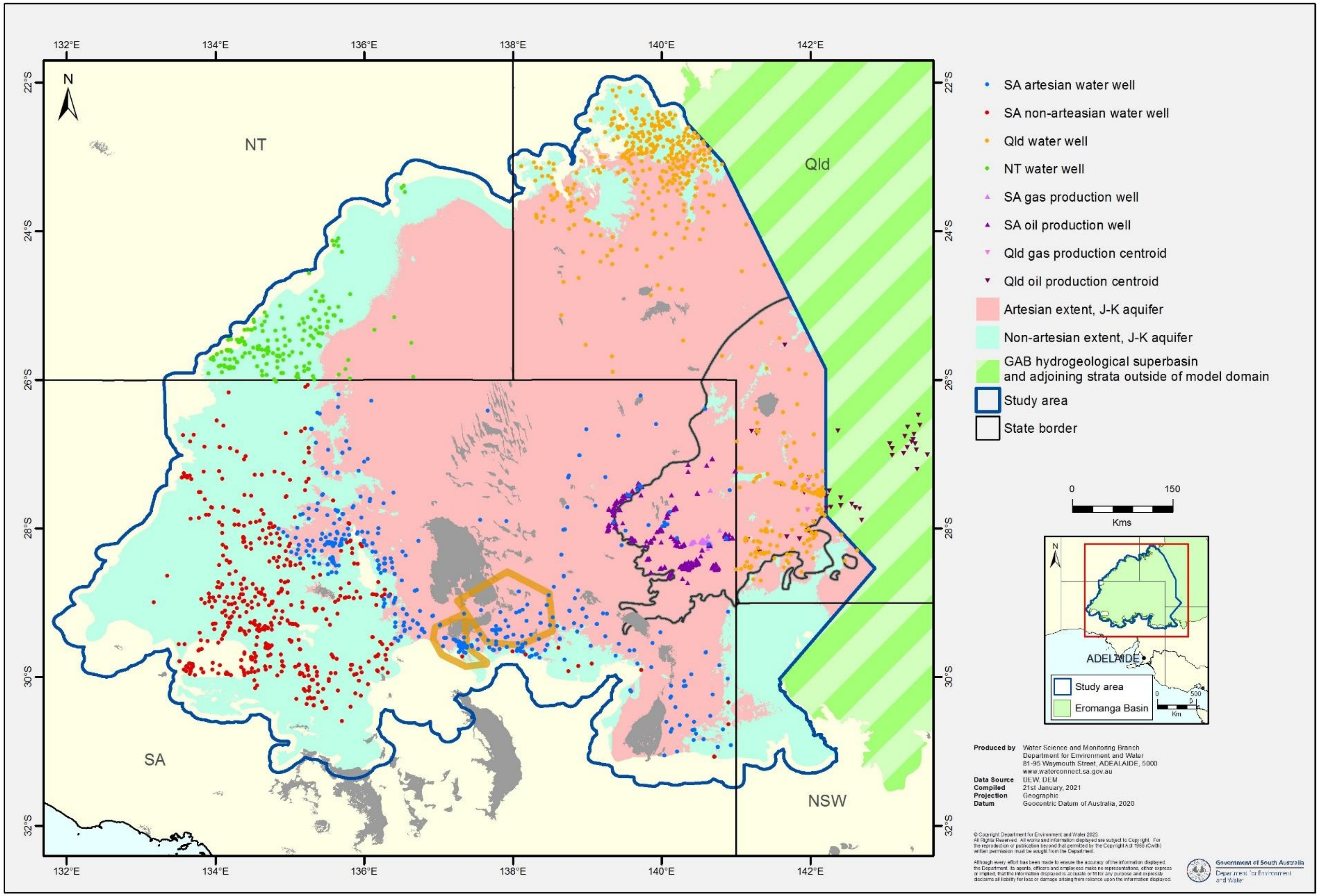

Figure 2.1: Location map of wells used in groundwater use estimates

Table 2.2: Volume conversion factors (Bo) for oil, Cooper Basin region

Field	Formation	Bo (in situ/surface volume)	1/Bo (surface/in situ volume)
Alwyn	Murta	1.08	0.93
Big Lake	Birkhead	1.15	0.87
Big Lake	Hutton	1.15	0.87
Big Lake	Namur	1.15	0.87
Bookabourdie	Birkhead/Hutton	1.10	0.91
Calamia West	Hutton	1.10	0.91
Charo	Birkhead	1.10	0.91
Cuttapirrie	Poolowanna	1.17	0.85
Dirkala	Birkhead	1.10	0.91
Dullingari	Namur	1.16	0.86
Dullingari	Murta	1.17	0.85
Gidgealpa North	Hutton	1.14	0.88
Gidgealpa South	Middle Namur	1.09	0.92
Gidgealpa South	Upper Namur	1.09	0.92
Gidgealpa South	Birkhead	1.10	0.91
Gidgealpa South	Hutton	1.14	0.88
Jena	Murta	1.09	0.92
Keena	Namur	1.10	0.91
Kerinna	Hutton	1.10	0.91
Limestone Creek/Biala	Murta	1.08	0.93
Limestone Creek/Biala	Namur	1.10	0.91
Mawson	Lower Poolowanna	1.10	0.91
Mawson	Upper Poolowanna	1.10	0.91
Mckinlay	Namur	1.10	0.91
Meranji	Namur	1.10	0.91
Merrimelia	Namur	1.09	0.91
Merrimelia	Hutton	1.15	0.87
Merrimelia	Birkhead	2.98	0.34
Moorari	Birkhead	1.12	0.89
Muteroo	Hutton	1.10	0.91
Narcoonowie	Namur	1.10	0.91
Narcoonowie	Murta	1.18	0.85
Nungeroo	Namur	1.08	0.93
Spencer South	Birkhead	1.08	0.92
Spencer West	Birkhead	1.10	0.91
Spencer West	Namur	1.10	0.91
Strzelecki	Birkhead	1.10	0.91
Strzelecki	Hutton	1.10	0.91
Strzelecki	Namur	1.15	0.87
Ulandi	Murta	1.08	0.93
Wancoocha	Birkhead	1.07	0.93

The method used to estimate extraction volumes from pastoral bores in the SA portion of the study area where no measured flow or metering data were available was based on the number of troughs and small dams (not on waterways) supplied by each well. The first step was to identify the number of assets supplied by each well. As a first cut, ArcGIS (Geographic Information System software) was used to link pastoral wells to water supply infrastructure from the 'water points' shapefile using a spatial join. This linked pastoral bores to troughs and small dams that either were connected directly via pipelines (also shown in the water points shapefile) or were within 1.5 km of the GAB well location.

Following this, each location was reviewed to quality check the number of assets assigned to each well using the spatial join. This included a review of aerial photography and satellite imagery at each site (ArcGIS Base Map) to identify the presence of any troughs or small dams not included in the water points shapefile. For the artesian portion of the study area, this also linked pastoral wells to troughs and small dams that were either connected to the well either directly via pipelines (also shown in the water points shapefile) or were within 1.5 km of the GAB well location. Site photos and monitoring notes on SA Geodata were also reviewed for each site to identify any assets missing from the water points shapefile or an over-allocation of assets by the spatial join. Overall, the audit notes and frequency of monitoring is greater for the artesian portion of the study area compared to the non-artesian portion.

In total, 465 well sites in the artesian portion of the study area were reviewed as part of this process and assigned a total 750 troughs and 233 small dams. For the non-artesian portion of the study area, 527 well sites were reviewed and a total of 119 small dams and 498 troughs assigned to these locations. We note that not all the assets contained within the water points shapefile were assigned to wells. The method used to assign water supply assets to wells is more effective in identifying assets that are near the well location and some troughs and/or dams located remotely from the supply well may not have been identified. In some cases, infrastructure may be serviced by wells pumping from Tertiary and Quaternary sedimentary rocks. In other cases, the location troughs and or small dams were remote from a well location (that is, 10 km or more) and could not be linked to a specific well without any documented pipework. However, we consider that the best available data has been applied in this process.

Once the number of water supply assets serviced by each well was identified, well status and well purpose codes were used to estimate extraction volumes and generate time series data for the model.

Well status codes, documented during monitoring events and stored on SA Geodata, were reviewed to identify active and non-active extraction times for each well. The following assumptions were applied:

- The status is continuous between monitoring events, even if they are many years apart. For example, if the well was recorded as 'operational' in 1940, was then monitored again in 2012, and was logged as abandoned, it was assumed that the well has been operational between 1940 and 2012. This may overestimate water use.
- The status from the most recent monitoring event is applied to 2019. That is, if the status of a well was operational in 2013 and it has not been monitored since, then the flow rate for the operational well was extended to 2019.
- The flow rate was applied from the time of construction, even if there was no status recorded at the time. This may overestimate extraction volumes.
- A status of; backfilled, collapsed, abandoned, blocked or unequipped, was used to indicate a well was not active and a flow rate of 0 L/s was applied from the year of the status record. All other status codes, even if no status had been recorded at a site, were used to indicate a bore was active.
- The status was applied in the year it was recorded, regardless of the month in which it was recorded.
- Where wells have no completion date, the first survey date has been assumed to be the completion date.

Well purpose codes were then used to assign pumping rates to each well according to the decision tree shown below (Figure 2.2). A flow rate of 0.3 L/s per trough was based on assumed stock type and stocking rates. The extraction rate for small dams was slightly higher at 0.4 L/s to arbitrarily account for a slightly higher water loss through increased evaporation and some potential leakage. To assign an extraction rate, the status and purpose of each bore was reviewed. For artesian wells, extraction rates were then assigned (from 2003 onwards) based on the rules summarized in Table 2.3 below.

These estimates of water use are based on allocation provisions for stock and domestic groundwater use found within the current FNWAP (SAAL NRM 2009). These rates are considered conservative, being predominantly based on what cattle require in times of little surface water availability. Such rates are unlikely to be applicable during times of destocking or where sheep are the primary livestock. Consequently, these estimated flow rates will only form an initial condition for stock and domestic water use and are acknowledged to represent the maximum water use and may be subject to modification during model calibration. How to address such inherent uncertainties is discussed further in Chapter 5.

Table 2.3: Summary of rules applied to assign extraction rates to bores in the artesian portion of the study area

Status/purpose	Water Supply Infrastructure	Post-2002 Flow Rate Troughs (L/s)	Post-2002 Flow Rate Small Dams (L/s)
Controlled shut in	Trough with float and/or small dam	0.3*Number of troughs	0.4*Number of dams
Controlled shut in	Trough without (or not documented) and/or small dam	0.3*Number of troughs	0.4*Number of dams
Controlled flowing	Trough with float and/or small dam	0.3*Number of troughs	0.4*Number of dams
Controlled flowing	Trough without float (or not documented) and/or small dam	2002 flow rate	2002 flow rate
Controlled flowing	Flow to swamp or drain	2002 flow rate	N/A
Controlled flowing	Flow to amenities/house	2002 flow rate	N/A
Uncontrolled flowing	Trough and or small dam	2002 flow rate	2002 flow rate
Uncontrolled flowing	Flow to swamp or drain	2002 flow rate	N/A
Backfilled/abandoned /collapsed/suspended	N/A	0	0
Not located/unknown	N/A	2002 flow rate	N/A
Town water supply	N/A	SA Water data if available or measured yield	
Industrial	N/A	2002 flow rate	N/A
Uncontrolled flowing	Infrastructure unknown	2002 flow rate	N/A
Controlled	Infrastructure unknown	2002 flow rate	N/A
New bore	Status unknown	0	N/A
Controlled shut in	Flow to swamp or drain	0.3	N/A
Controlled shut In	Infrastructure unknown	0.3	N/A
WMC bore	N/A	0	N/A

Does the bore supply a trough(s) and or small dam(s)?

Yes

Extraction Rate = (Number of Troughs*Flow rate based on purpose) + (Number of small dams*Flow rate based on purpose)

Purpose	Extraction Rate Trough (L/s)	Extraction Rate Small Dam (L/s)
Stock	0.3	0.4
Exploration	0.3	0.4
Observation	0.3	0.4
Monitoring	0.3	0.4
Industry	0.3	0.4
Domestic	0.3	0.4
General	0.3	0.4
Irrigation	0.3	0.4
Investigation	0.3	0.4
Town water supply	SA Water data if available or measured yield	
Road construction	0	0
Unknown	0.3	0.4

No

Assign extraction rate based on purpose code.

Purpose	Extraction Rate (L/s)
Stock	Most recent measured yield or 0.3
Exploration	0
Observation	0
Monitoring	0
Industry	Most recent measured yield or 0.3
Domestic	Most recent measured yield or 0.3
General	Most recent measured yield or 0.3
Irrigation	Most recent measured yield or 0.3
Investigation	0
Town water supply	SA Water data if available or most recent measured yield or 0.3
Road construction	0
Unknown	0
Mine water supply	Most recent measured yield or 0.3

Figure 2.2: Flow rate decision tree

2.1.4 Water use data from the SA mining industry.

The operators of Olympic Dam mining operation provide monthly water extraction data from Wellfield A and Wellfield B for inclusion in the groundwater model. This data was sourced from a bore audit conducted in 2019 within their general field of operation. Additional water extraction data from the J-K aquifer from the mining industry has been collated from annual compliance reporting as part of the statutory reporting obligations for each development. Where current information is unavailable, extraction is based upon yield information provided at the time of well construction and stored within SA Geodata. Water use for recreational, commercial, irrigation, industrial and town water supply, camp water and bore fed wetlands was estimated based on annual water licensing data held by DEW or provided by SA Water. For stock and domestic bores, an estimate of water use was generated for artesian and non-artesian bores based on stock type, stocking rates and the number of watering points associated with an individual bore.

2.1.5 Queensland oil and gas co-produced water

The study area encompasses parts of south-west Queensland to ensure the model boundaries do not influence the areas of focus. Co-produced water production data is collated by the Queensland Government, Department for Natural Resources, Mines and Energy (Queensland Government 2019a) (Figure 2.1) as bi-annual records per well from 2005 to 30 June 2018. Although the reservoir rock and field are described, extraction and production numbers are provided by licence number rather than well. To produce time series data using this dataset, a centroid for each licence was created in ArcMap^{TM} and production and extraction numbers for each field were linked to this centroid. As for SA, gas and oil production volumes were also considered as extraction volumes from the groundwater system. A default conversion value of 1 was assumed for oil production, while a factor of 189 was assumed for gas production. Additionally, production values for condensate and liquid petroleum gas (LPG) were also available; these values were processed with oil data but were handled as separate data points for each licence number.

2.1.6 Queensland stock, domestic, commercial and industrial extraction

Water use data for the south-west Queensland portion of the study area was extracted from data sets compiled for and discussed within KCB (2015a) and KCB (2015b) and provided under creative commons licence by the Queensland Government Department for Natural Resources and Mines (Figure 2.1). Bore integrity, estimated yields for stock and domestic bores and ascribed aquifer interpretation from these data were used in this model. KCB (2015a) also provide entitlement volumes for town water supplies at Boulia, Birdsville and Bedourie; for the purposes of modelling, the full entitlement has been factored into water use calculations. Finally, a separate estimate was made per modelling cell for water used to supply bore drains from controlled bores. This figure was estimated separately from stock and domestic water use to provide an estimate of potential water savings. These per cell estimates were distributed within water use estimates here by ascribing a percentage of the total estimated amount amongst bores within each cell classified as ‘existing’. A total of 570 well sites in the south-west portion of Queensland included in the study area were reviewed as part of this process.

2.1.7 Northern Territory stock, domestic, commercial and industrial extraction

Water use data in the Northern Territory portion of the GAB was based on well survey data collected in 2013 (for the Pedirka Basin) and quality checked using well completion reports and monitoring data, where available, from Natural Resource (NR) Maps (nrmaps.nt.gov.au) (Figure 2.1). Conservative assumptions as detailed earlier were employed for wells. However, the following additional assumption that stock and domestic wells followed the same decision tree as for SA non-artesian and artesian wells was applied (Figure 2.2). Two hundred and fifty-six (256) well sites in the NT portion of the GAB were reviewed as part of this process and assigned a total 37 troughs and 24 small dams.

2.1.8 New South Wales

An estimation for New South Wales water use was not made at this time as sufficient information about extraction from the targeted aquifers in question could not be procured in time. This is currently not considered a critical data gap given the low number of total wells found within the NSW portion of the study area and lack of any non-pastoral industry. However, this data gap will be reviewed periodically and if modelling suggests more importance than currently assigned.

2.2 Preliminary estimates of water balance

A semi-quantitative water balance and a preliminary estimate of groundwater volumes in the Main Eromanga Aquifer Sequence were developed to provide a useful sanity check of the later numerical model approach (Barnett et al. 2012). Such information can give a broad overview of the various significant inputs and outputs to a groundwater system and ensure that they are treated with appropriate respect during the numerical modelling phase.

With respect to the J-K aquifer, a number of groundwater flow systems (GFSs) within the study area can be interpreted on the basis of head and hydrochemistry data. Each of these interpreted GFSs may have their own sub-zone water balance that may be intertwined with neighbouring GFS's. However, given the groundwater model being constructed is of regional scale with an initial focus on the artesian component, a single water balance for SA has been produced. This is because the vast majority of the water balance components, including most of the artesian and sub-artesian components in SA, are interpreted to occur within the Central GFS (Figure 2.3).

2.2.1 Estimating groundwater flow for water balance calculation

Groundwater flow, both inflow to and outflow from the study area for both the J-K aquifer and the underlying Hutton–Poolowanna aquifer has been estimated using potentiometric surfaces to define the relevant hydraulic gradients. For simplicity, we have treated the J-K aquifer as a single unit, and we have not considered intra-aquifer formations for this exercise.

2.2.1.1 J-K aquifer

For the J-K aquifer, one representative potentiometric surface has been selected from each group (as described in Volume 4) to illustrate the large potential uncertainty in subsequent water balance estimates and subsequently inform model calibration. The 4 potentiometric surfaces used to estimate groundwater flow into, and out of the J-K aquifer (Figure 2.4) were:

- Group 1. Minimum Curvature, Internal Tension = 0, Boundary Tension = 0 (*Surfer*, 50 m grid)
- Group 2. Minimum Curvature, Internal Tension =1, Boundary Tension = 1 (*Surfer*, 50 m grid)
- Group 3. Least Square Binomial, Bilinear interpolation, 1st order Taylor series (*Petrosys*, 100 m grid)
- Group 4. Minimum Curvature, Bicubic interpolation, 1st order Taylor series (*Petrosys*, 100 m grid).

To re-iterate from Volume 4, each group of potentiometric surfaces represents a broadly similar conceptualisation of groundwater flow and scale within themselves but with notable differences between groups. In general, differences between groups are broadly related to the employment of different contouring algorithms and gridding assumptions. As discussed in Volume 4, potentiometric surfaces within Group 3 most closely resemble the adopted conceptualisation of groundwater behaviour, with Group 2 providing the most disparate alternative. The most important difference between these two groups is the direction and volume of groundwater inflow originating from the east and north. Consequently, although at this stage, Group 3 is favoured, all potentiometric surface interpretation options will be considered as a means of capturing and investigating this uncertainty.

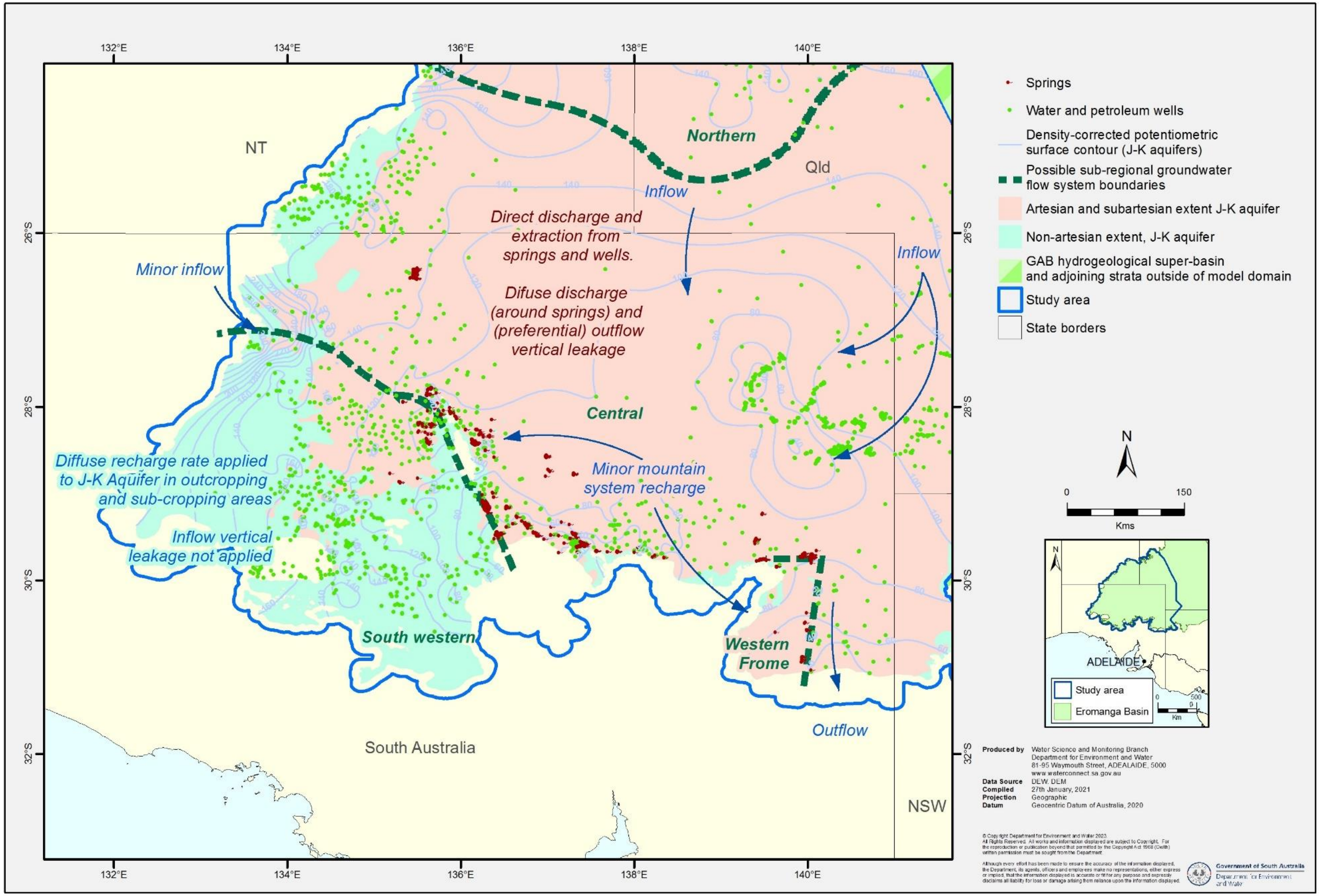

Figure 2.3: Schematic conceptualisation of water balance calculation

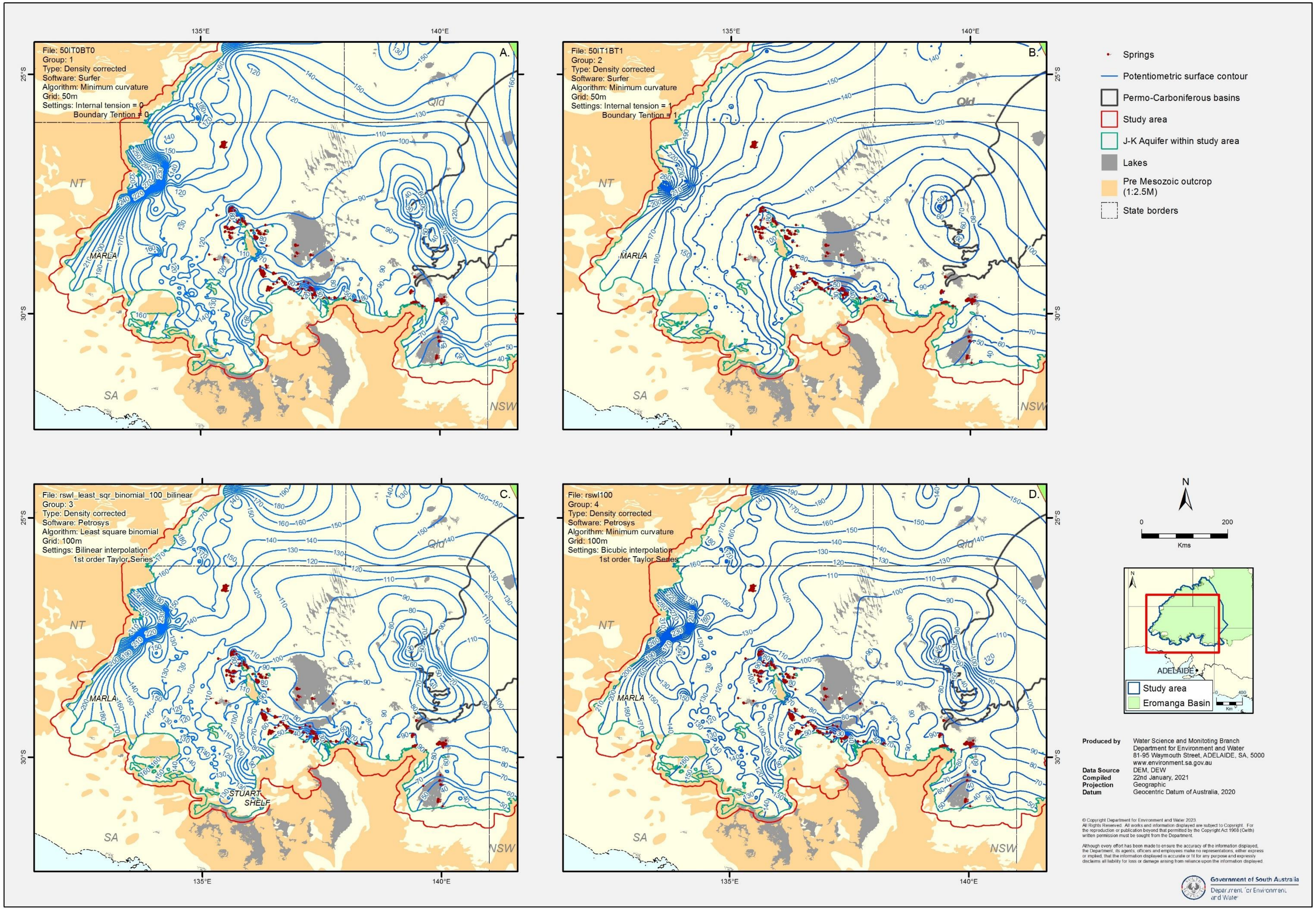

Figure 2.4: Examples of density-corrected potentiometric surfaces developed for the J-K aquifer from each group

Further, as discussed in Volume 4, comparison of these 4 potentiometric surfaces does not suggest that any option definitively describes regional groundwater flow conditions across the basin. However, deriving a regional, density-corrected potentiometric surface of the J-K aquifer to accurately describe all groundwater flow conditions in this complex 3D system is not realistic.

However, based on an assumption that Darcy's Law is valid (which is potentially not the case over some areas of the basin), and that only lateral flow contributes to the development of the potentiometric surface (that is, there are no components of vertical flow for example, no recharge or upward leakage), the total flow through the aquifer is estimated using:

$$\boldsymbol{Q = -K.A.i} \qquad \textbf{1}$$

where Q is the groundwater flow rate through porous medium (m^3/d), K is the hydraulic conductivity (m/d), A is the cross-section area of the aquifer perpendicular to groundwater flow (m^2) and i is the hydraulic gradient (−).The extent of unsaturated J-K aquifer, for each of the 4 potentiometric surfaces, was superimposed over the corresponding density-corrected potentiometric surface to identify the nearest potentiometric contour to the basin margin that was representative of groundwater inflow to, or outflow from the J-K aquifer. Similarly, potentiometric contours occurring along the borders with New South Wales, Queensland and the Northern Territory were classified as presenting groundwater inflow to, or outflow from the SA portion of the J-K aquifer for each of the 4 potentiometric surfaces.

New shapefiles (as lines) were then generated, one for each of the 4 potentiometric surfaces that approximately replicated the position of the identified potentiometric contours. For each new shapefile, a flow-net was defined and subdivided into flow tubes (Anderson and Woessner 1992) bounded by streamline segments representative of similar hydraulic gradients and aquifer thicknesses to facilitate higher accuracy estimates of flow to be calculated. Between 17 and 25 flow tubes were identified for each of the 4 potentiometric surfaces; of those between 4 and 10 were classified as representing outflow from the J-K aquifer.

A multi-step process was used to determine the average thickness and hydraulic gradient of the aquifer along each flow tube. This included:

1. A 'point' file for each of the new line of shapefiles was generated using the 'Locate points along lines' tool in QGIS. Points were generated at 100 m intervals along each line segment.
2. The 'Point Sampling Tool' plugin was used to pick aquifer thickness using an isopach derived from the C horizon (top of the J-K aquifer) and the shallower of the Birkhead Formation (E horizon) and the base of Eromanga (J horizon) stratigraphic surfaces at each of the points generated in step 1. A mean aquifer thickness was then calculated for each line segment.
3. The Point Sampling Tool plugin was used to pick the hydraulic gradient for each point along each line segment for all 4 potentiometric surfaces. An average hydraulic gradient was then calculated for each line segment.

The cross-sectional area (*A*) for each flow tube into, and out of SA was estimated by multiplying the width of each flow tube by its corresponding average height.

An alternative estimate of discharge (flow) would be to estimate spring discharges and groundwater discharge via evapotranspiration. However, given there is a large degree of uncertainty with respect to spring discharge related to the large number of springs located in typically remote areas and difficulty in obtaining sufficiently reliable discharge information, such a methodology may be reserved until such time as a more reliable method for estimating spring discharge over the whole study area can be developed.

2.2.1.2 Hutton–Poolowanna Aquifer

An additional groundwater inflow component was calculated for the Hutton–Poolowanna aquifer using a similar process to what was outlined for the J-K aquifer (Figure 2.5). The differences being:

- Line segments were determined along potentiometric contours of the Hutton–Poolowanna aquifer potentiometric surface that aligned with the South Australia–Queensland border (Figure 2.4).
- Each line segment was assigned points at 100 m intervals.
- The thickness of the Hutton–Poolowanna aquifer was picked at each point using an isopach derived from the Hutton Sandstone (H horizon) and the base of the Eromanga (J horizon) stratigraphic surfaces. An average aquifer thickness was then calculated for each line segment.
- The hydraulic gradient was then estimated along the Hutton–Poolowanna aquifer potentiometric contour.

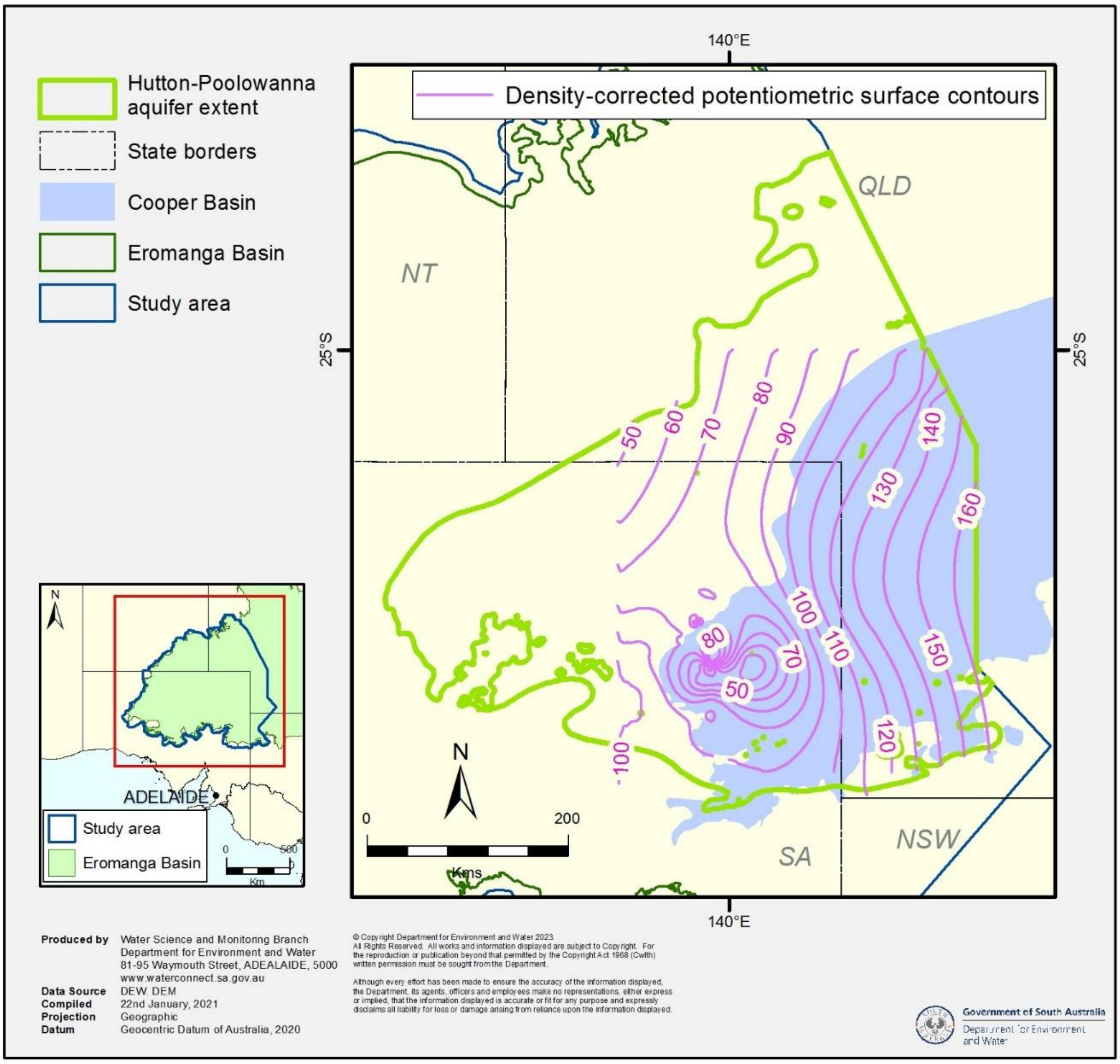

Figure 2.5: Density-corrected potentiometric surface of the Hutton–Poolowanna aquifer

2.2.2 Derivation of hydraulic conductivity (K) values used in water balance estimation

Volume 4 describes a range of hydraulic conductivity (*K*) values for the J-K aquifer and Hutton–Poolowanna aquifer within SA.

K values for the J-K aquifer vary from <0.1 m/d to 248 m/d, determined by artesian well shut-in tests, drill stem tests (DST) and core plug tests. Here, the average, median and 5th percentile *K* values from artesian well shut in tests, as well as the Swanson mean and median DST K values for the Namur Sandstone are used to illustrate uncertainty in groundwater flow estimates for each of the 4 potentiometric surfaces. No calculation of groundwater flow was attempted using hydraulic conductivity values greater than the average (for example, *K* = 107 m/d, 95th percentile from the artesian well shut-in tests) as the higher values were deemed to only represent localised areas and therefore not characteristic of the entire extent.

K values for the Hutton–Poolowanna aquifer were derived from core plug tests and DSTs of the Hutton Sandstone and are discussed in Volume 3. From this work, a Swanson mean value of 1.02 m/d and a DST median value of 0.07m/d were derived.

3 Estimated groundwater use

This chapter describes the initial estimate of current and historical groundwater use within the study area. The method of how water use was estimated, including data sources and assumptions, is detailed in Chapter 2.

These data represent the primary groundwater outflow related to human-activity and therefore represent an important stressor on the hydrogeological system. Further, aquifer responses to water use data may be used to refine other aquifer property values in the numerical model.

3.1 South Australia

Estimates of extraction from the artesian portion in SA (Figure 3.1) show initial sharp inclines from the beginning of groundwater resource development from the late 19th Century to around the mid-1920s, largely in support of the pastoral industry. Since then, the extraction has been generally steady between sporadic increases in total extraction volumes, until a peak in extraction of around 220 ML/d is reached around the mid-1970s. A large percentage of water extraction during this period went to waste, as many unlined bore drains were used as delivery systems and flow was often uncontrolled. From the mid-1970s, a decline in extraction is indicated until an average of around 160 ML/d is reached around the mid-1980s. This decline in usage was largely caused by adoption of more efficient delivery systems, such as troughs and piping, as well as rehabilitation of uncontrolled flowing wells through government, industry and community supported schemes such as the Great Artesian Basin Sustainability Initiative and more recently the Improving Great Artesian Basin Drought Resilience scheme (DAWE 2020). Previously, all extraction from the artesian portion of the basin was for stock and domestic purposes and subsequently, more efficient extraction methodologies employed by the pastoral industry appear to have driven the reduction in volumes extracted from the mid-1970s. Extraction for the pastoral industry has continued to decline to around an estimated 80 ML/d; however, increases in extraction by the energy and mining industries from the mid-1980s has offset this. Extractions by these industries have steadily approached licensed extraction volumes of 60 ML/d and 45 ML/d respectively.

Estimated extraction from the non-artesian portion of the GAB in SA displays a steady increase from the early 20th Century to the early 21st century, where a peak extraction volume of around 25 ML/d was reached around 2010. Since then, extraction has remained constant at around 23 ML/d. Increases prior to 2010 are thought to reflect development of the pastoral and mining industries to current levels as well as population growth during the mid to late 20th Century.

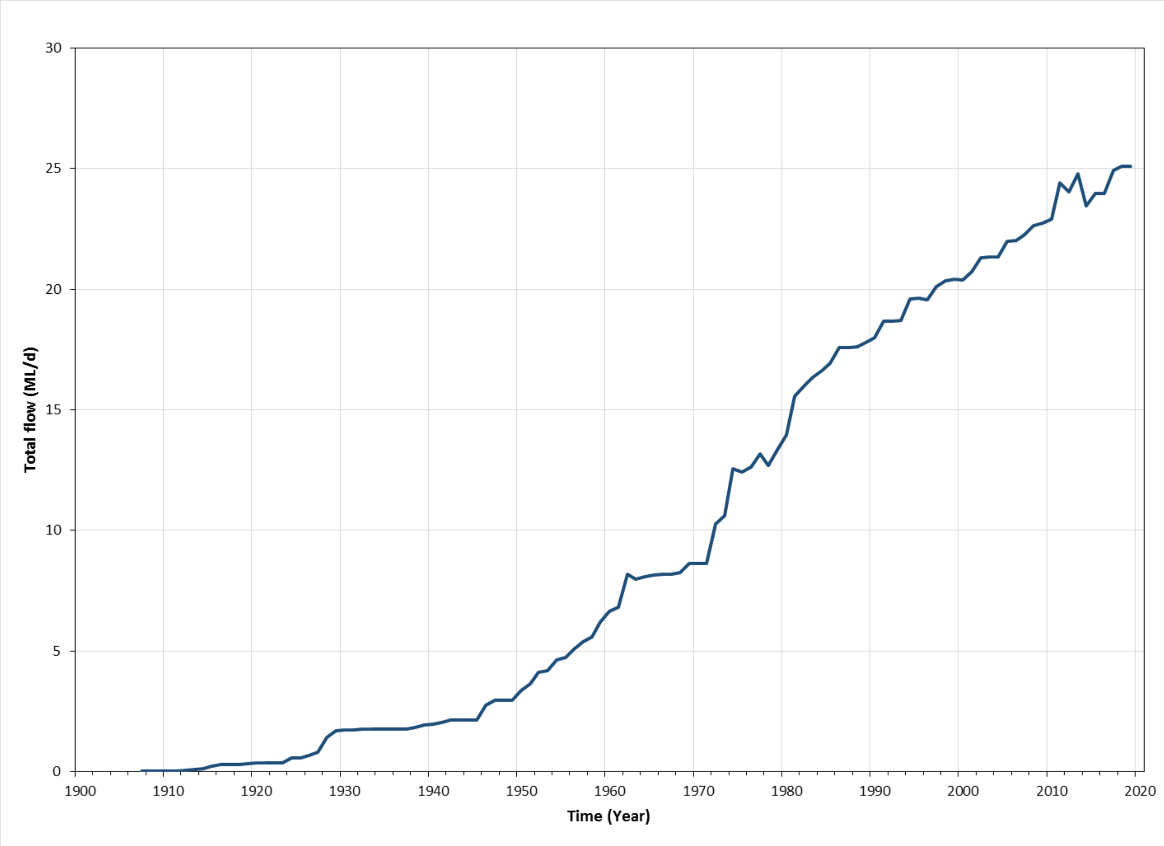

Figure 3.2 graphically presents total annual extraction rate estimates for the artesian and non-artesian components of the J-K aquifer in SA.

3.2 South-west Queensland

Figure 3.3 shows total annual volume estimates for stock, domestic, industrial and co-produced groundwater within the Queensland portion of the study area. The estimations of extraction from within the study area are based on KCB (2015a) and display a largely steady increase to around 23 ML/d from the late 19th century to the early 21st century, with two periods of steeper increases around the late 1910s and in the 1950s to 1960s. A sharp increase in extraction occurs in the mid-2000s when records for co-production from the energy industry commence. It is likely that co-production occurred much earlier than implied by the records. Co-produced water accounts for a near doubling of extraction from the area of south-west Queensland covered by the study area, with a peak extraction of around 47 ML/d in the mid-2000s.

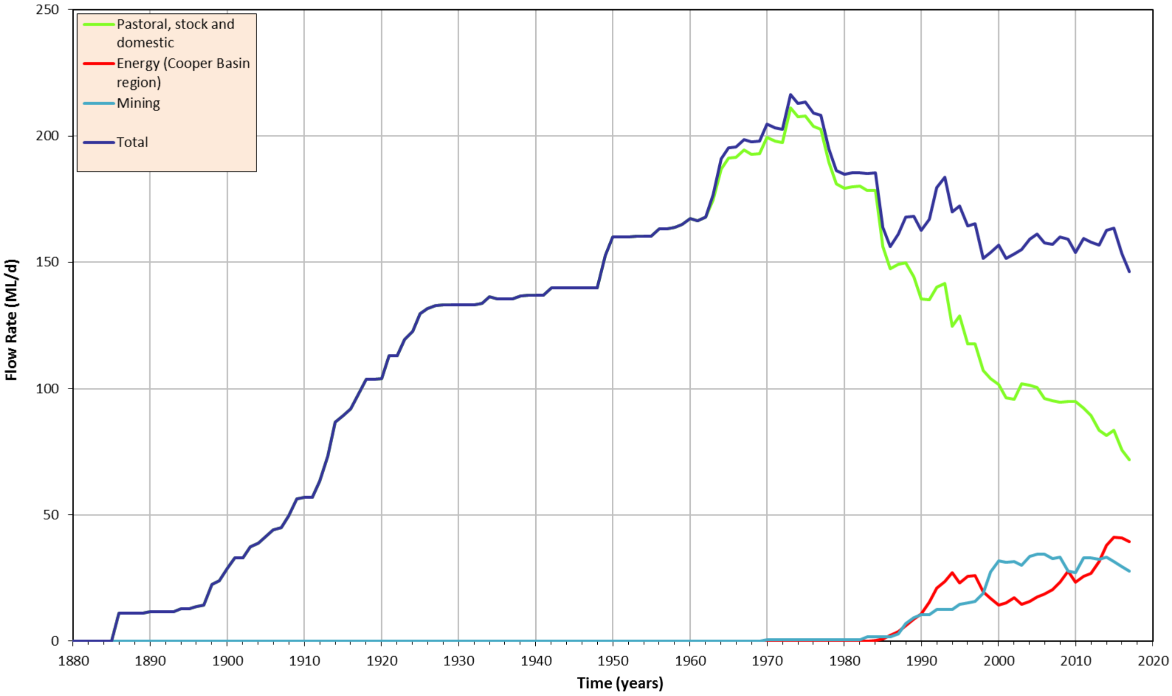

Figure 3.1: Estimated groundwater use over time in SA, Artesian.

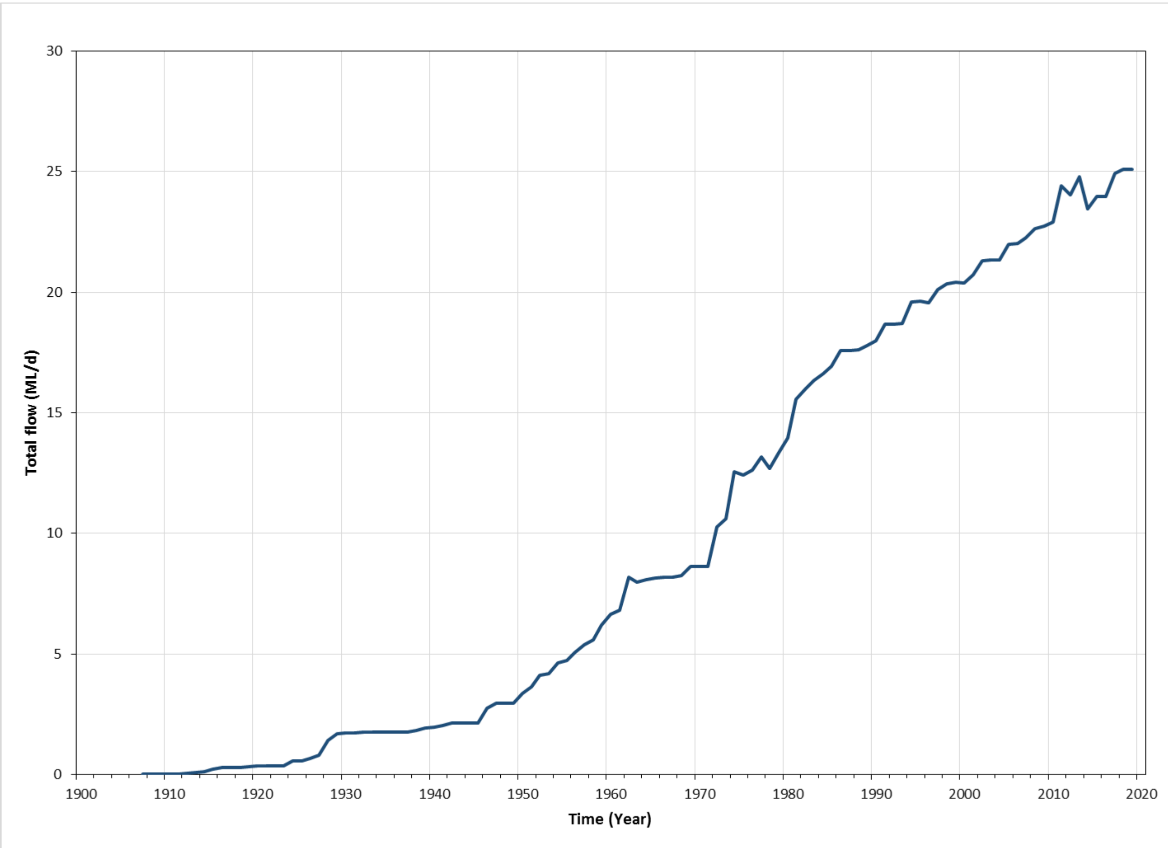

Figure 3.2: Estimated groundwater use over time in SA, non-artesian.

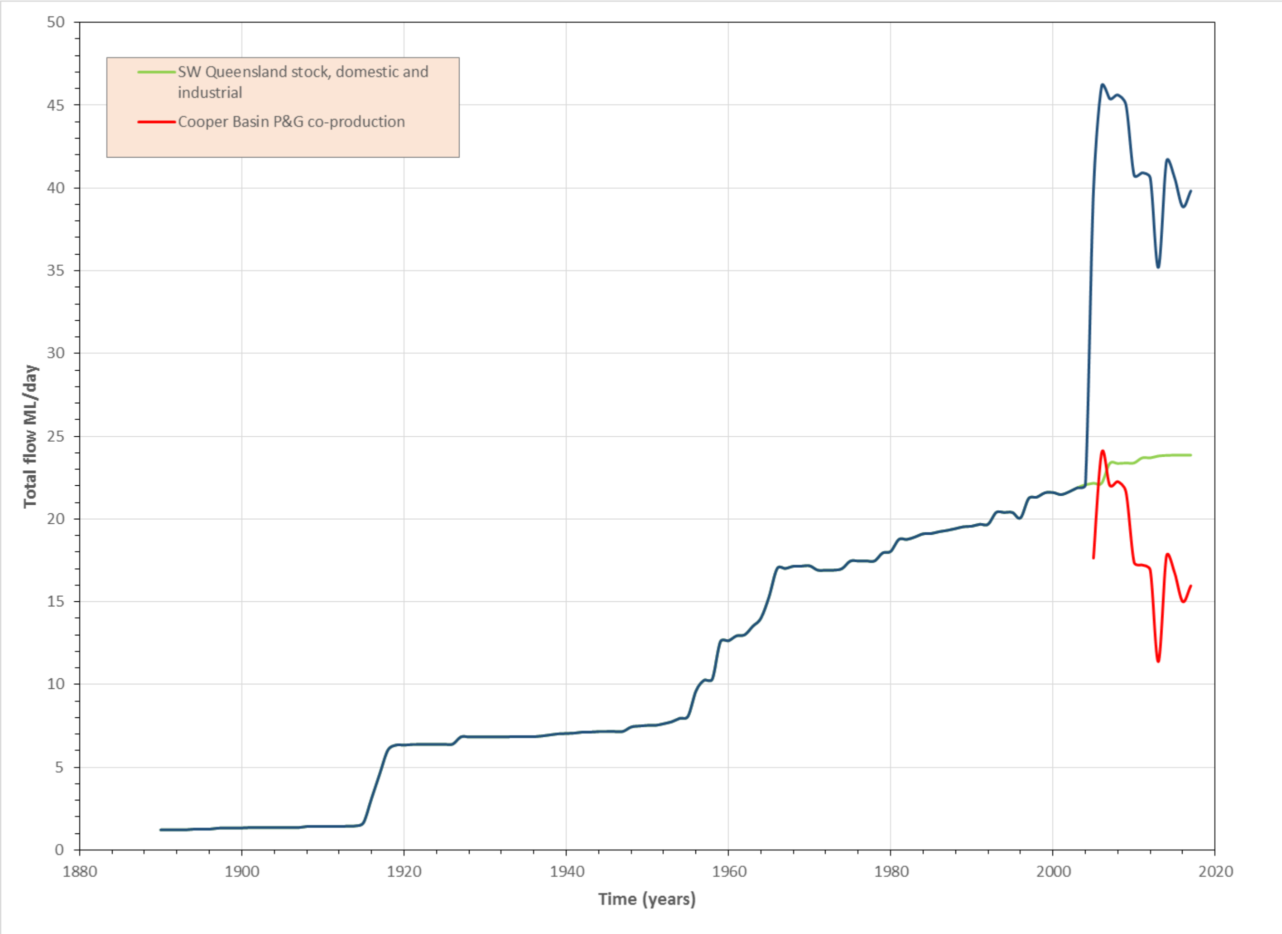

Figure 3.3: Estimated groundwater use over time in the Queensland portion of the study area.

3.3 Northern Territory

Figure 3.4 presents total annual volume estimates for stock, domestic and industrial groundwater within the south-eastern part of the NT that is located within the study area. Extraction volumes are typically small until the 1950s, when a sharp increase in extractions occurs. Extraction increases substantially around the mid-1960s due to the impact of petroleum exploration and associated uncapped bore completions and bore failure. Large variations in total flow after 1990 may be partly attributable to difficulties in estimating flow from these bores (Figure 3.4). Humphreys and Kunde (2004) estimated flow from McDills bore to range between 5.5 and 200 L/s.

The Finke community has a licensed annual allocation of 96 ML, which for water use estimation purposes was assigned to the two main town water supply wells (RN010982 and RN17513) as a proportion based on each well's reported maximum yield. A general stabilisation in water use in the most recent data is attributed to the rehabilitation of several free-flowing wells, including abandoned petroleum exploration wells that were converted to water wells, over the past 20 years. These include Anacoora Bore, Dakota Bore and McDills Bore (Humphreys and Kunde 2004). Flow records as reported by Humphreys and Kunde (2004) were used in the initial calculation of time series data. Bore capping programs and more accurate monitoring after 2010 has seen extraction volume estimates stabilise around 16 ML/d.

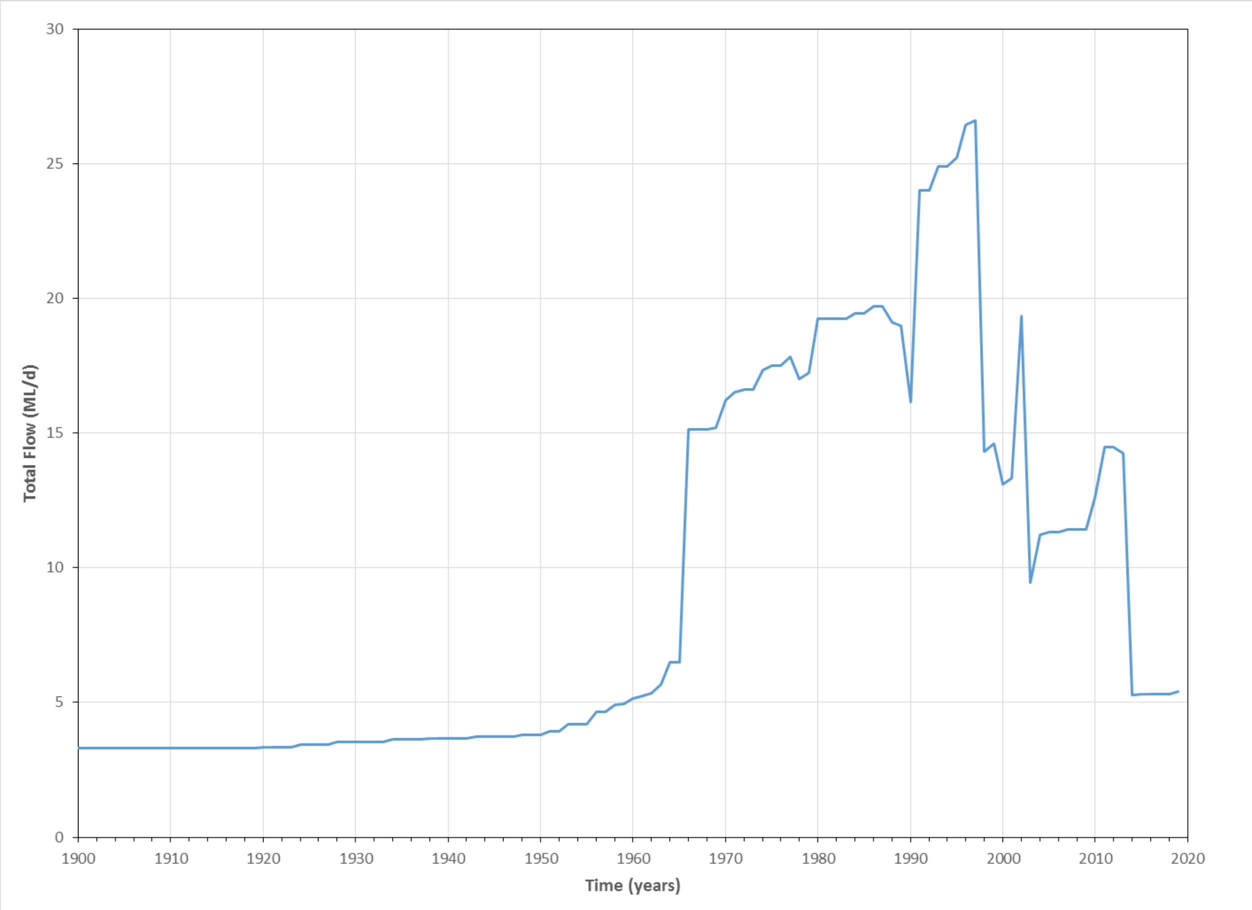

Figure 3.4: Estimated groundwater use over time in NT portion of study area.

3.4 Total water use for the study area

Figure 3.5 presents total annual volume estimates for all groundwater use within the study area. Total values from other figures have also been included to help visualise the proportion that each contributes to the total. Total water usage in the study area is observed to generally increase until the mid-1970s with two periods of more rapid change between 1880 and 1920 as well as between 1950 and 1975. From the mid-1970s, total water use is observed to decline gradually, with large falls in pastoral usage in the artesian portion of SA counterbalanced by increases in usage by the mining and energy industries, as well as increases in water use in other parts of the study area.

As estimated using the methodology described in Chapter 2, stock and domestic use in SA is historically the predominant water user over the period examined. As has been noted previously however, the conservative approach to water consumption estimation employed to generate stock and domestic water use means that this is considered a maximum use estimate and that actual usage is likely to be lower.

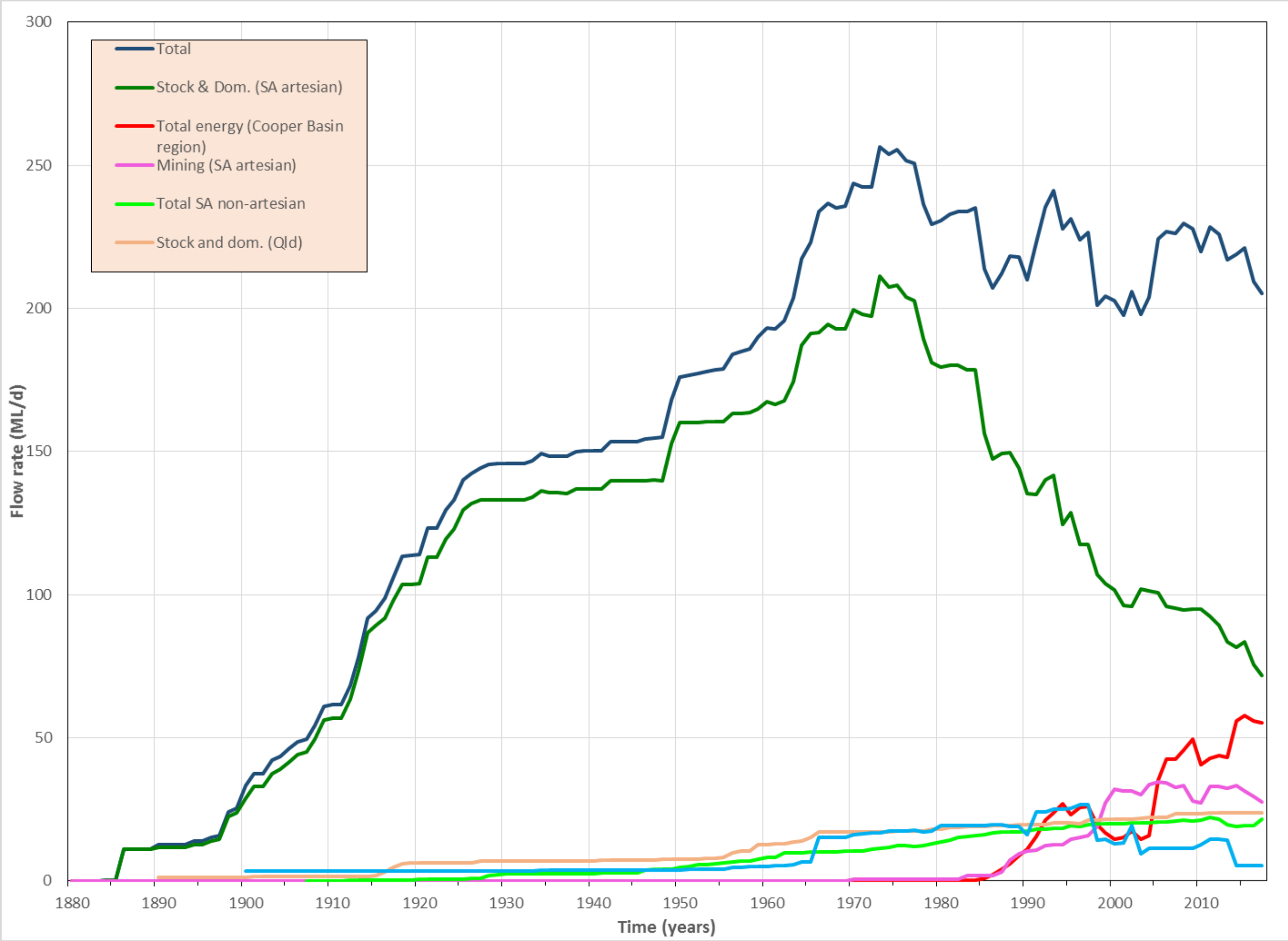

Figure 3.5: Estimated total groundwater use over time within the study area.

4 Estimated water balance

The following chapter provides a description of the preliminary water balance estimates developed to provide a sanity check of the numerical model. Such information is designed to provide a broad overview of the various significant inputs and outputs to the groundwater system. Details of how the water balance was derived are provided in Chapter 2.

4.1 Estimated groundwater flows

Table 4.1 presents the derived groundwater flow (*Q*, ML/d) for 4 representative potentiometric surfaces using a range of *K* values, while Table 4.2 provides the derived groundwater flow (*Q*, ML/d) for the Hutton–Poolowanna aquifer potentiometric surface using *K* values derived from core plug tests and DSTs of the Hutton Sandstone.

Based on the *K* values presented in Section 2.2.2 and on work presented in Volume 3, estimated total groundwater inflow in the J-K aquifer may range from 59 ML/d (Group 1, 5th percentile) to 4,219 ML/d (Group 4, average), while total groundwater outflow from the J-K aquifer may range from 8 ML/d (Group 4, 5th percentile) to 443 ML/d (Group 1, average). This highlights a high degree of uncertainty in actual groundwater flow through the J-K aquifer. As discussed in Section 2.2.1 and Volume 4, Group 3 is considered most representative of the conceptual hydrogeological model (CHM) being employed for model construction and therefore median results from this group are used for the water balance.

Using Group 3 as a basis, and depending on the assumed hydraulic conductivity, net groundwater input to the J-K aquifer may range between 80 ML/d and 2,990 ML/d.

Inflow to the Hutton–Poolowanna aquifer was estimated to range between 2 to 34 ML/d, with groundwater entirely derived from Queensland.

Table 4.1: Estimated groundwater inflow to, and outflow from the J-K aquifer in SA

Group	Flow	Flow rate (ML/d) (*K* derived from artesian well shut-in tests of the J-K aquifer)			Flow rate (ML/d) (*K* derived from core plug tests and DSTs of the Namur Sandstone)	
		Average (22.3)	**Median (5.1)**	**5th percentile (0.6)**	**Swanson mean (3.2)**	**DST median (0.68)**
1	Inflow	2185	500	59	314	67
	Outflow	443	101	12	64	14
	Net	1743	399	47	250	53
2	Inflow	2557	585	69	367	78
	Outflow	338	77	9	49	10
	Net	2219	508	60	319	68
3	Inflow	3309	757	89	475	101
	Outflow	319	73	9	46	10
	Net	2990	684	80	430	92
4	Inflow	4219	965	114	606	129
	Outflow	304	70	8	44	9
	Net	3915	895	105	563	120

Table 4.2: Estimated groundwater inflow to the SA portion of the Hutton Sandstone–Poolowanna Formation

Flow	Flow rate (ML/d) (*K* derived from core plug tests and DSTs of the Hutton Sandstone)	
	Swanson mean (1.02)	**DST median (0.07)**
Inflow	34	2

4.2 Preliminary water balance of the J-K aquifer

Table 4.3 provides a conceptual water balance for the SA portion of the J-K aquifer, although one that is inherently uncertain.

Model inputs for the SA portion of the J-K aquifer include:

- Groundwater inflow is estimated at 475 ML/d assuming Group 3 potentiometric surfaces are the most representative, and adopting the Swanson mean *K* from core tests of the Namur Sandstone (3.2 m/d). The *K* chosen was based on the assessment that it was most representative of where the majority of inflows were occurring in the general Cooper Basin region.
- Notably, the range of uncertainly with respect to lateral inflow is theoretically large if variations in the interpretation of groundwater flow and *K* are considered. Using the potentiometric surfaces and *K* values developed for this study, the theoretical uncertainty range of between 59 ML/d and 4,219 ML/d may be determined (Table 4 1).
- Recharge is estimated to be approximately 20 ML/d using the average diffuse recharge estimate from Love et al. (2000) of 0.16 mm/y and the area over which diffuse discharge is conceptualised as occurring in SA is 4.53 x 10^{10} m^2. This figure is similar to the 6,600 ML/y (18ML/d) estimate of Ransley and Smerdon (2012) produced for the western margin of the GAB hydrogeological super-basin. Using the error range of Love et al. (2000) of ± 0.08 mm/y, an uncertainty of between 10 and 30 ML/d can be estimated. We note that the average estimates of uncertainty by Love et al. (2000) and Wohling et al. (2013) (of 0.15 mm/y) are similar, but the former was favoured, based on the description of an error range accompanying the estimate.
- Although Wohling et al. (2013) found evidence for Mountain System Recharge (MSR) near the Denison and Davenport ranges, the data suggested this occurred between 20 and 30 ka BP (thousand years before the present time) at flux rates comparable to diffuse recharge. While MSR may be occurring over other parts of the study area, such as the Northern Flinders Ranges, the low rates and restricted area suggests overall volumes are likely to be small. Consequently, Rates of MSR are not quantified for this exercise, although they could contribute between 1% and 15% of groundwater flow.
- Likewise, while ephemeral river recharge has been found to occur in small sections of the Finke and Plenty Rivers in the NT (Fulton et al. 2013), evidence for this within the SA portion of the study area is qualitative at best. Considering there is little quantitative assessment of ERR in SA, this has not been included in the water balance assessment.
- Vertical leakage from overlying or underlying units to the J-K aquifer has not been estimated, so these fluxes have been excluded from the conceptual water balance. We note that Welsh (2000) estimated 148 ML/d as a residual volume using the steady state GABFLOW model; however, this estimate involves considerable uncertainty, particularly given recent research suggests the groundwater fluxes of the GAB hydrogeological super-basin are transient in nature and that under current climatic conditions recharge rates are lesser than discharge (see for example, Ransley and Smerdon, 2012; National Water Commission. 2013).

Table 4.3: Conceptual water balance for the J-K aquifer within SA

Inflow (ML/d)	Median value (ML/d)	Uncertainty range (ML/d)	Δ Storage (ML/d)	Net uncertainty range (inflow minus outflow (ML/d)	Outflow (ML/d)	Median/ adopted value (ML/d)	Uncertainty range (ML/d)
Lateral inflow	475[a]	(59 to 4219)			Lateral outflow	73[c]	(8 to 443)
Recharge	20[b]	(10 to 30[b])			Wells	134[d]	(134[d] to 160[e])
					Spring discharge	66[h]	(64[f] to 76[g])
Vertical leakage	not quantified				Vertical leakage (incl. diffuse discharge near springs)	274[h]	(20[i] to 690[j])
Total Inflow	**495**	**(69 to 4,249)**	**−52**	**(−159 to 2,880)**	**Total outflow**	**547**	**(226 to 1,369)**

a Predominantly from Qld and NT. Therefore, based on Swanson mean K from core-derived permeability tests of the Namur Sandstone (3.2 m/d).

b Love et al. (2000).

c Predominantly along the southern margin, into Northern Flinders Ranges. Therefore, based on mean K derived from well-shut-in tests conducted during monitoring (22 m/d).

d Based on licensed volumes estimated to be taken from the GAB hydrogeological super-basin (Chapter 1).

e. Based on water use estimate data and assumptions, Chapters 2 and 3.

f Boucaut et al (1986)

g Golder (2015).

h From SAAL NRM (2009), based on estimates using GABFLOW (Welsh, 2000).

i From Harrington et al. (2013).

j From Costelloe et al. (2011).

Outputs from the SA portion of the J-K aquifer include:

- Lateral outflow from the study area is estimated at 73 ML/d assuming Group 3 potentiometric surfaces are the most representative, and the median *K* from artesian well shut-in tests (Table 4.1). This value was chosen in preference to the Swanson Mean of core derived permeability for the Namur Sandstone because the location of and hydrostratigraphy from which such shut-in tests were conducted, are interpreted to be closer to the location and range where lateral outflow is occurring, namely near the margins and shallower parts of the Eromanga Basin. Interpreted outflow into aquifers bordering the study area is inclusive of fractured rock aquifers predominantly in the Northern Flinders Ranges.

Similar to estimates for lateral inflow, estimates for lateral outflow are also highly uncertain. Using the range of potentiometric surfaces and *K* values developed for this study, a theoretical uncertainty range of between 8 ML/d and 443 ML/d can be estimated.

- Water extraction from pastoral, town water supply and industry wells are estimated at 134 ML/d, based on licensed extraction from wells completed in the GAB hydrogeological super-basin, as detailed in Chapter 1. The uncertainty range of up to 160 ML/d is based on the latest water use estimates using the data and assumptions as described in Chapters 2 and 3 for the SA portion of the study area.
- Spring discharge is estimated at 66 ML/d based on the GABFLOW model (Welsh 2000). This figure is likely to be highly uncertain given the age of the estimate, its derivation using a steady state model assumption with a quite simple aquifer layer structure, and subsequent work (for example, Gotch 2013; Keppel et al. 2016) to map spring vent localities that greatly increased the number of vents. The uncertainty range of up to 76M L/d is based on field assessment works analysed by Boucaut et al. (1986) and a model-derived assessment produced by Golder (2015). Actual spring discharge is anticipated to be higher than this estimate.
- The diffuse vertical outflow leakage estimate of 274 ML/d is the estimate developed for the FNWAP published in 2009 and was derived using the steady state numerical model GABFLOW (Welsh 2000). This number encapsulates both diffuse discharge near springs, as well as into subsurface strata. Although there is a great deal of uncertainty concerning this number, for the reasons detailed above, research conducted since has not been able to provide much additional certainty concerning volumes. Research that has been conducted has better emphasised the idea that vertical leakage is likely to be focussed in areas of preferential flow-path development, such as where faulting has deformed confining units. It is also in such areas of preferential flow-path development where springs are likely to form, hence the correlation between springs and regions where diffuse vertical leakage is interpreted to breach the surface.

  Field based methods such as Woods (1990), Costelloe et al. (2011), Matic (2018) and Matic et al. (2020) used evapotranspiration and landform mapping as a basis to estimate vertical discharge flux. Harrington et al. (2013) in contrast, used laboratory-based determination of flux using core samples of undeformed confining layer as well as noble gas measurements taken from groundwater collected from shallow bores in assumed areas of preferential flow-path development in an attempt to develop a range of fluxes unique to the confining layer (Rolling Downs Group).

  The methods employed by these studies were useful in obtaining a range of fluxes for diffuse vertical leakage; however, when applying these fluxes to calculate volumes, limitations become apparent. For flux estimations based on evapotranspiration estimations and landform mapping, difficulty in accounting for near surface contributions to the water balance, such as localised recharge to the shallow water table become apparent. In contrast, fluxes determined via core and noble gas studies require mapping to constrain their areal extent, otherwise volumes are based on broad approximations of where preferential flow development occurs.

  These limitations were largely recognised; for example, Costelloe et al. (2011) and Matic (2018) presented flux calculations as a percentage of the total diffuse vertical outflow flux (274 ML/d) as determined for SA using the steady state model GABFLOW (Welsh 2000) to describe where vertical leakage was most likely occurring away from the margins of the basin. In contrast Harrington et al. (2013) used arbitrary estimates of 1 and 15% of the total area impacted by preferential flow-path development to describe a range of between 20 to 300 ML/d for the preferential component of diffuse leakage. As selected by Costelloe et al. (2011) and Matic et al. (2020), the upper limit was chosen with consideration to the estimate of total vertical leakage in SA determined using the GABFLOW model.

  For uncertainty purposes, the minimum value of Harrington et al. (2013) (20 ML/d), and the maximum value from Costelloe et al. (2011) (690 ML/d) is used to describe the uncertainty range for diffuse vertical leakage.

The conceptual water balance suggests that the J-K aquifer within SA is not in steady state, but rather in a state of transience where outflows are currently estimated as being greater than inflows. The change in storage of the system reflects the difference between inflow and outflow, as reflected by changes in groundwater levels. Given current extractions and groundwater flow, such changes in storage may be concentrated in semi-regional areas where extraction is concentrated, such as the Western Flank of the Cooper Basin region or the Olympic Dam wellfield areas. Further work would improve the certainty in this conceptual water balance. Consequently, this water balance should be re-evaluated as new knowledge becomes available.

4.3 Water balances and other aquifers

Recent regional scale, steady-state modelling work by Peat and Yan (2015) and Purczel (2015) produced water balances for aquifers and aquitards in the Arckaringa and Pedirka Basins, as summarised in Table 4.4 and Table 4.5. However, due to a paucity of information, there are large uncertainties regarding the understanding of the hydrodynamics, recharge, and discharge characteristics of these basins and consequently the resultant models are highly uncertain. The balances produced by these models are indicative only and are unreliable for management purposes. However, this modelling does highlight areas where more research is required, particularly with respect to vertical leakage into or out of the Main Eromanga Aquifer Sequence.

Purczel et al. (2015) used steady-state modelling of the Arckaringa Basin to estimate an inflow of groundwater from the Mount Toondina Formation to the J-K aquifer of around 135 ML/d (Table 4.4). Fulton et al. (2015) used pumping test data to conclude that there is significant flow connectivity between the Permian aquifers of the Pedirka Basin and the overlying J-K aquifer. However, the steady-state modelling presented by Peat and Yan. (2015) for the Pedirka Basin indicated no flux exchange between the Permian aquifers and the overlying J-K aquifer (Table 4.5). Consequently, existing modelling and empirical evidence suggest that upward vertical leakage may be a more significant contributor to the J-K aquifer water balance in the western portion of the study area where these Permo-Carboniferous basins occur.

The largest extractors of groundwater from the Permian basins are for the mining (Arckaringa Basin) and energy industries (Cooper Basin). In the Arckaringa Basin, the Prominent Hill mining operation is currently licensed for 26.6 ML/d from the Boorthanna Formation. Licensed co-produced water attributable from Cooper Basin strata is approximately 3 ML/d.

Although there has not been an attempt at quantifying groundwater resources in the upper GAB aquifers within the study area, Ransley and Smerdon (2012) considered the Winton and Mackunda formations in their water balance for the Eromanga Basin. In total, Ransley and Smerdon (2012) estimated a total basin recharge of about 164 GL/y into these two formations. They also estimated that recharge to the Winton and Mackunda Formation is currently greater than the equivalent discharge, even if all the evapotranspiration loss estimated for the Eromanga Basin (44 GL/y) is assigned to this aquifer, along with 13.2 GL/y estimated for bore extractions.

No work has been undertaken to examine the water balance of Quaternary and Tertiary aquifers within the study area and consequently this remains an area of uncertainty. Groundwater from Tertiary and Quaternary aquifers is currently estimated to only contribute approximately 3.4% to licensed allocation in the FNPWA; while this number may increase in the future, the small contribution means these aquifers are not of immediate concern to model construction.

Table 4.4: Model water balance (ML/d) for Arckaringa Basin (Purczel et al. 2015)

	To Pre-Permian basement	To Bulldog Shale	To J–K aquifer	To Mount Toondina	To Stuart Range	To Boorthanna	To Stuart Shelf	Discharge via Evaporation	General head boundary
Pre-Permian basement	-	25.3	78.3	5.6	19.2	119.6	16.4	76.7	89 7
Bulldog Shale	0.07	-	6.3	0.03	0.09	0.1	0	241.0	0
J–K aquifer	132	215.8	-	47.1	3.4	18.7	0	0	118.7
Mount Toondina	3.5	1.1	134.7	-	2.6	5.7	0	0.5	0
Stuart Range	2.4	1.8	10.8	55.6	-	5.0	0	0.007	0
Boorthanna	13.4	0	37.4	39.7	50.2	-	0.2	10.4	0
Stuart Shelf	15.7	0	0	0	0	0.04	-	0	0.9
Recharge	0.06	6.8	0	0.001	0.052	2.1	0	-	-
General head boundary	263.7	0	268.1	0	0	0	0	-	-

Table 4.5: Model water balance (ML/d) for Pedirka Basin (Peat and Yan. 2015)

	To Pre-Permian basement	To J–K aquifer	To Permian aquifer	General head boundary
Pre-Permian basement	-	-	-	3
J–K aquifer	-	-	-	153
Permian aquifer	-	-	-	-
River recharge	-	20	19	-
Diffuse recharge	-	44	20	-
General head boundary	9	44	-	-

5 Data gaps and recommendations

Through the process of data compilation, analysis and literature review, a number of critical data gaps were made apparent, both with respect to raw data as well as to conceptual understanding. This section provides a discussion of the data gaps considered important with respect to the development of a CHM and ultimately the numerical model construction.

5.1 Groundwater use estimates

5.1.1 Limitations with estimation methodology

Currently, stock usage is estimated to be 0.3 L/s per trough feed point and 0.4 L/s per small dam, based upon estimates used in past WAP calculations (SAAL NRM, 2009). As previously discussed, the resultant water use estimates are considered conservative and represent a maximum use estimate.

OGIA (2016) developed an alternative methodology for estimating stock and domestic water use within the Surat Cumulative Management Area. This highly detailed methodology takes into account seasonal variations of weather, the moisture content of vegetation, the breeds of cattle found on pastoral stations and other factors. This method determined an average extraction of 0.04 L/s (1.4 ML/y) for stock and domestic bores. Prior to this, OGIA (2012) used an average extraction of 0.13 L/s (4.4 ML/y). Given both numbers are notably lower than the values stipulated previously, the water-use methodology similar to the one employed by OGIA may form the basis of a useful uncertainty test in the future.

Further, the assumption of water extraction based on remotely observed infrastructure is inherently limited. For example, although attempts were made to remove from analysis any dams located in channels, shallow dams used in estimate calculations may still either be partially or wholly supplied by surface water and consequently may be misallocated during this study. Well-audit work will be required to validate these assumptions. For this phase of model construction potential overestimation will be at least partially addressed during the history matching phase of construction.

Ideally, uncertainties related to water use estimates would be better quantified over the longer term with the implementation of water metering or equivalent accounting methodology. Any method needs to be sufficiently robust to cope with the remote and arid environment as well as sufficiently accurate for water accounting purposes.

5.1.2 New South Wales

Groundwater-use estimates for the NSW portion of the study area have not been undertaken at this time. Reasons for this include the low number of total bores in this region, difficulty in ascribing a production zone as well as difficulty in obtaining yield information. Future work may include reviewing the latest status of NSW bores found within the study area, for later inclusion.

5.1.3 South-west Queensland co-production

The Queensland Government (2019a) at the time provided co-production volumes per reservoir rock (Hydrostratigraphic unit equivalent) per petroleum production licence on a 6-monthly basis. An attempt was made to produce an estimate for co-produced water per reservoir rock per well; however, linking production and extraction values to individual wells proved to be difficult. Santos provided biannual extraction and production data dating back to 2007 on a per well basis; however, no concomitant reservoir information was provided. An attempt was made to link reservoir information using stratigraphy and construction data from the Queensland (Government) petroleum Database (QPED) (Queensland Government, 2019b) and supplemented with information from the DataReSources, online database (DataReSources, 2014); however, an adequate linkage for the purposes of the model was not possible Communications with Queensland Government representatives confirmed that validated updating of the QPED database has not kept pace with data acquisition for a number of years, and that more recently, updating has been suspended while a new database is being constructed. Future work may involve updating the SW Queensland portion of the water-use database in anticipation that such updating, and validations issues have been resolved.

5.2 Water balance estimates

As discussed in Chapter 4, there is a lot of uncertainty inherent in the initial water balance calculations. Much of this uncertainty is understandable given the size and inherent heterogeneity found within the study area. Although the range of uncertainty in the initial water balance calculation was partially discussed in Chapter 4 and presented as a description of inflow and outflow ranges, other uncertainties based on conceptualisation also exist.

In particular, the potentiometric surface used to interpret where inflow and outflow may occur cannot entirely account for temporal changes in recharge, particularly given the size of the region it represents. Inflows interpreted by potentiometric surface contours on the western margin may be representative of paleo-recharge events that occurred during the pre-Holocene, and, because of the large scale and slow conductance times, groundwater levels have not had time to sufficiently react to the lack of current-day recharge, and thus the inflows may be overestimated.

Therefore, it is important to re-iterate that the use of the water balance produced here is limited to providing an approximate guide as to the adequacy of water balances produced by numerical groundwater modelling.

Further, the water balance was produced for the SA portion of the study area only. While this provides a useful guide for management and regulatory based modelling, the figures will be less than what might be expected for the entire study area. The area for vertical leakage will be reduced in the absence of the NSW, Qld and NT portions of the study area.

6 Closing remarks, model assumptions and conclusions

This volume presents estimates for groundwater use from the Main Eromanga Aquifer Sequence found within the study area employed for the development of the Far North Groundwater model. Groundwater use estimates are important input data during model construction as they provide a target for history matching and also represent a primary stressor on the hydrogeological system. Further, the preliminary water balance assessment provides a broad sanity check for the numerical modelling approach being developed.

Groundwater use data was either estimated or collected for all the major usage types found in the study area. This includes stock and domestic, co-production of water during petroleum resource development, mining operations and town water supply. In the case of the stock and domestic water use, a lack of metering meant that water use was largely estimated. In contrast, extraction rates for the energy and mining industry were largely sourced from government-maintained records as provided periodically by industry. In the case of the energy industry, consideration was made for the volume of oil and gas also abstracted.

From this water use assessment, stock and domestic water use was found to be the oldest modern economic use of abstracted groundwater in the study area, with extractions estimated to have begun in the late 19th century and peaking around the mid-1970s. Water efficiency and well capping works commencing around this time have seen water extractions decline to around a third of the 1970s peak-extraction-point in the artesian portion of the study area found in SA. In the non-artesian portion of the study area found in SA, groundwater extraction has steadily increased for the better part of the 20th century, eventually stabilising at near current day levels around the early 21st century. Groundwater extraction related to mining and energy-industry developments in the artesian portion of the basin began around the mid-1980s. Mining extraction is dominated by the Olympic Dam mining operation and since the early 21st century has largely remained stable at around 35 ML/d, reflecting limitations imposed by current mining activities. Co-produced water extraction has largely remained between 15 and 25 ML/d from the mid-1990s until around 2010 and has since risen closer to the 60 ML/d licensed volume limit.

From preliminary water balance estimates, it is apparent that the predominant groundwater input is lateral inflow originating from Queensland and the NT, although with a level of uncertainty spread over about two orders of magnitude. In contrast, direct recharge is about an order of magnitude lower than the median lateral inflow. With respect to outflow components, lateral outflow, spring discharge, well extraction and vertical leakage are each estimated within about an order of magnitude range, although with a reasonably high degree of uncertainty. Collectively, inflows are estimated to exceed outflows.

During the compilation of datasets and information used to develop the groundwater use and system water balance estimates, a number of material data gaps and uncertainties became apparent. In brief, these include:

- Currently, stock usage is estimated to be 0.3 L/s per trough feed point and 0.4° L/s per small dam, based upon the estimates used in past FNWAP calculations. Consequently, the resultant water use estimates are considered conservative and represent a maximum use estimate.
- Further, inherent data issues, such as lack of data or different data format requirements between jurisdictions have led to necessary simplifications as to how some water use data is imported into the model.
- Much of the uncertainty around preliminary water balance estimates is related to the size and inherent heterogeneity found within the study area. Further uncertainty relates to temporal variations in recharge that may not be interpretable using potentiometric surfaces alone, as head data measurable today may be still representative of paleo-recharge events.

7 Units of measurement

7.1 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

7.2 Shortened forms

EC electrical conductivity (µS/cm)

8 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 (‰)

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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