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Report on

Collation and Synthesis of Evidence to Inform an Assessment of Sustainable Diversion Limits (SDL) and Management Arrangements for Groundwater in the Murray-Darling Basin (ID: BPR202411): Methods Report

Prepared for
Murray Darling Basin Authority

Project No. MDB5000.001
January 2026

ageconsultants.com.au

ABN 64 080 238 642

Document details and history



Document details

Project number	MDB5000.001
Document title	Collation and Synthesis of Evidence to Inform an Assessment of Sustainable Diversion Limits (SDL) and Management Arrangements for Groundwater in the Murray-Darling Basin (ID: BPR202411): Methods Report
Site address	Murray Darling Basin Authority, Canberra
File name	MDB5000.001 Groundwater SDL review method 2025 v05.03.docx

Document status and review

Edition	Comments	Author	Authorised by	Date
v03.02	First draft for client review (partial)	SS/LC/AVV/AB/RR	RR	08/10/2025
V03.03	Second draft released to client (complete)	SS/LC/AVV/AB/RR	RR	30/10/2025
v04.01	Third draft released to client (restructured)	SS/LC/AVV/AB/RR	AB	27/11/2025
v05.02	Final report released to client	SS/LC/AVV/AB/RR	AB	22/12/2025
v05.03	Final report released to client after minor corrections	SS/LC/AVV/AB/RR	AB	28/12/2026

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Collation and Synthesis of Evidence to Inform an Assessment of Sustainable Diversion Limits (SDL) and Management Arrangements for Groundwater in the Murray-Darling Basin (ID: BPR202411): Methods Report

1 Introduction

1.1 Project purpose and policy setting

Australia's largest river system is the Murray–Darling Basin (MDB), spanning five jurisdictions and covering 77,000 km of channels that serve over 2.4 million people. After decades of heavy surface water and groundwater use in the MDB during the 20th century, river ecology and health declined significantly, prompting the introduction of new laws to share water resources between the population and the environment. The Water Act 2007 (*Cth*) established the Murray–Darling Basin Authority (MDBA) to oversee this, leading to the development of the Basin Plan, which aims to create an integrated management plan for the basin's water. The groundwater resources beneath the MDB's rivers are often hydraulically connected to surface water, so integrating both surface and groundwater was essential for the successful implementation of the Basin Plan. The Basin Plan came into effect in 2012, with amendments made in 2018. To balance groundwater use while protecting environmental assets, the Basin Plan established long-term average Sustainable Diversion Limits (SDLs¹) for 80 groundwater resource units (SDLRUs²) in the MDB, which became operational in 2019. In practice, SDLs limit the volume of water that can be extracted for urban, industrial, and irrigation purposes from specific groundwater resource units across the MDB.

The Water Act 2007 (*Cth*) requires that the SDLs reflect an environmentally sustainable level of take (ESLT). The ESLT is defined as the level at which groundwater can be drawn from a resource without risking the values outlined below (MDBA, 2020a):

- productive base of the resource; or
- key environmental functions – surface water – groundwater connectivity; or
- key environmental functions – groundwater-dependent ecosystems (GDEs); or
- key environmental functions – water quality.

The preservation of the productive base means the maintenance of the groundwater resource availability and quality that supports beneficial uses, such as: environmental asset watering; ecosystem uses; irrigation; or drinking water for people and stock (MDBA, 2020a).

Since implementing the plan, the MDBA and MDB communities have improved their understanding of managing water resources among the environment, First Nations, agriculture, towns, and industry. Additionally, advancements in data collection and research have enhanced knowledge of waterways, groundwater, and the climate factors that influence them.

¹ Sustainable Diversion Limits (SDLs) (GL/year): Defined by Basin Plan Schedule 4.

² Sustainable Diversion Limit Resource Units (SDLRUs): Defined by MDBA GIS polygons.

A review of the Basin Plan is required every 10 years under Section 50 of the Water Act 2007 (*Cth*), with the final Basin Plan Review (BPR) report due in December 2026. The BPR focuses on four key themes:

- climate change;
- sustainable water limits;
- First Nations; and
- regulatory design.

A key part of the BPR is assessing the four ESLT groundwater values, and the technical work supporting it provides a basis for the MDBA to determine whether SDLs accurately reflect the ESLT values.

1.2 Project scope and methodology

The MDBA commissioned Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) to undertake the project titled *Collation and Synthesis of Evidence to Inform an Assessment of Sustainable Diversion Limits (SDL) and management arrangements for groundwater in the Murray-Darling Basin* (ID: BPR202411) (the Project). The Project supported the assessment of the SDLRUs as part of the groundwater component of the BPR in 2026 through the best available science. This document outlines the method used by AGE in undertaking the Project (the AGE method).

The development of the method for the Project was documented in the initial method design report delivered by the National Centre for Groundwater Research and Training (NCGRT, 2024). The NCGRT method was used in this Project, but several changes were made to the initial design during the implementation of the Project.

The NCGRT method was designed to use the best available scientific knowledge to assess the level of threat to ESLT values from groundwater extraction under the current management regime. This document outlines the entire method as undertaken by AGE. An important component of the Project methodology was regular engagement with MDBA, state jurisdictions, the NCGRT, and CSIRO to refine and validate the method, as well as to seek advice on the best available science and data informing the method.

The method was applied across the 80 groundwater SDLRUs of the MDB, focusing on the four ESLT values for groundwater: productive base, groundwater-surface water connectivity, GDEs, and water quality (mainly salinity). The scope of work for the Project was to:

- participate in an inception workshop with the MDBA to review the proposed methodology, co-design a multiple lines of evidence (MLE) confidence framework, and sequence jurisdictional and stakeholder engagement activities that will occur across the project;
- evaluate current trends and conditions in ESLT characteristics across the Basin using qualitative and quantitative approaches and, where possible, extrapolate this information to evaluate trends and conditions for use at current SDL levels;
- evaluate the condition of ESLT characteristics under defined future climate scenarios using groundwater recharge modelling outputs from Murray-Darling Basin Sustainable Yields (MD-SY2);
- test and refine the NCGRT (2024) method after the first cycle of implementation in collaboration with the MDBA in a refinement workshop;
- apply the co-designed confidence assessment to quantify the ESLT characteristics by groundwater use at current and SDL levels (where possible) and outline the impact of knowledge gaps or uncertainties on confidence in conclusions;
- utilise existing datasets relevant to groundwater trends and conditions across the Basin; and
- liaise with jurisdictions and other stakeholders to source additional data required for input to the Project as required.

The Project has seven stages that are discussed in this document (Figure 1.1):

1. Updating knowledge of the groundwater flow system and risks to ESLT values in each SDLRU;
2. Sequencing of groundwater SDLRUs;
3. Application of spatial filters for defining ESLT values as “asset areas” in each SDLRU;
4. Analysis of resource condition indicators (RCIs);
5. Consideration of other lines of evidence;
6. Consideration of climate change; and
7. Documentation / reporting.

All stages of the Project method (Stages 1 through 7; Figure 1.1) had to be completed for each SDLRU; however, they did not necessarily need to be completed in sequence. Throughout the implementation of the staged method, engagement with the MDBA, member jurisdictions, the NCGRT, and the CSIRO was critical. This occurred through a series of workshops and feedback loops, leading to the implementation of the Project stages within several engagement Phases: the inception phase, the pilot phase, and the full implementation phase (Figure 1.1). To facilitate this engagement and embed its learnings in an adapted methods framework, the Project stages were first implemented for a small subset of SDLRUs (the Pilot Assessments) and then were implemented for each group of units in turn (details in Table 1.1). Some of the Project stages must be conducted sequentially (Stages 1, 3 and 4; Figure 1.1); therefore, these stages were repeated for each unit, whereas stages were completed for all SDLRUs simultaneously (e.g. Stage 2; Table 1.1). The method implemented for each stage is discussed in detail in Sections 2 through 7.

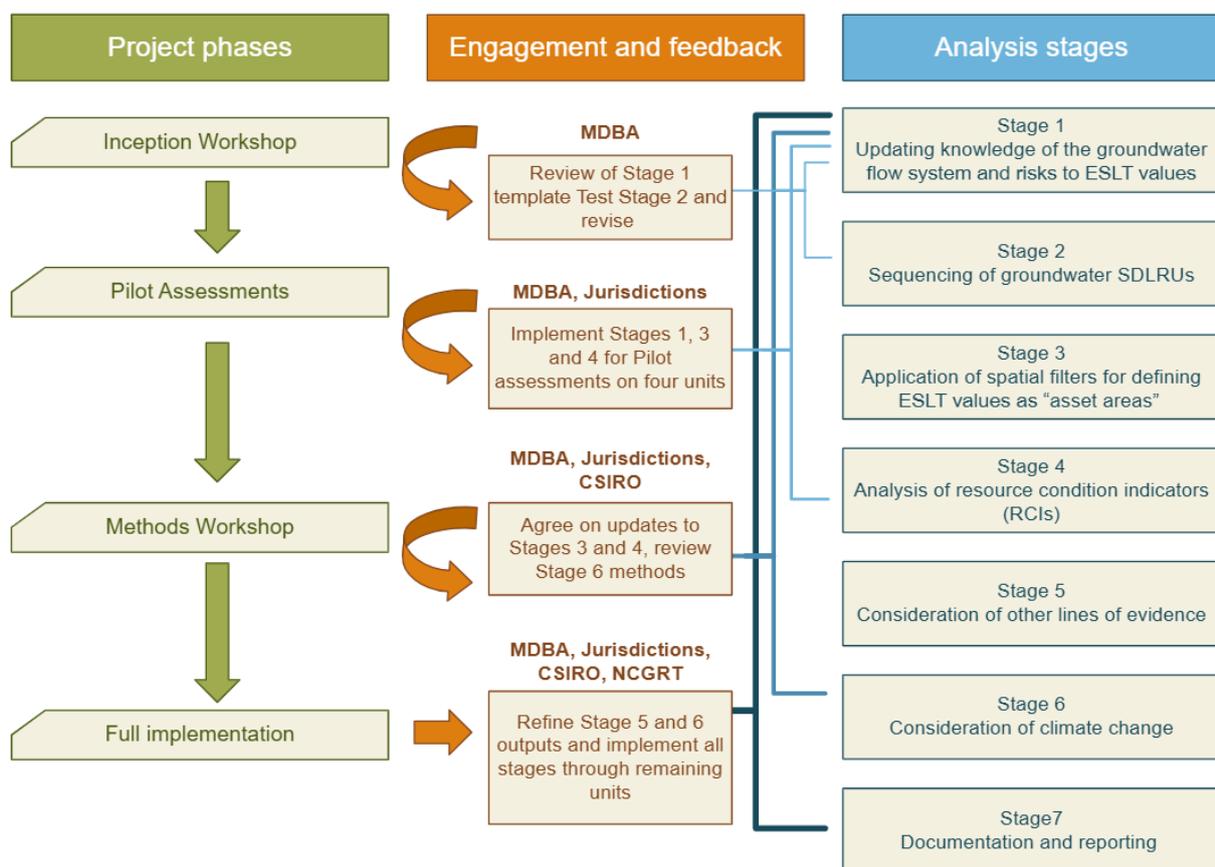


Figure 1.1 AGE project methodology structure (stages) and phases

1.3 Stakeholder engagement overview

The overall objective for engagement with the MDBA, CSIRO, the NCGRT, and state jurisdictions was to deliver the Project with the full benefit of their knowledge and feedback. This information was used to inform and refine the project's methods and improve the outputs with knowledge and data at the jurisdictional scale. The engagement process also enabled advances in the Project to be communicated to stakeholders progressively from Stage 1 to Stage 5, so that they are well informed at the outset of the BPR process in 2026. MDBA included different stakeholders in the discussion of the proposed method of the Project, including the Groundwater Advisory Panel (GAP) and member state departments of water management (SA, VIC, NSW, ACT, and QLD).

The framework for engagement was designed at the Project outset and had two main entry points for refinement of the methods: the inception workshop, and the testing and refinement of the proposed method (the methods workshop). The engagement allowed AGE to further develop the method, and deploy an approach co-designed with MDBA and socialised across jurisdictions.

In addition to regular (weekly or fortnightly) progress meetings between AGE and MDBA, the specific milestones for engagement over the Project were (Table 1.1):

- an Inception workshop between MDBA and AGE (3 December 2024);
- initial engagements with all jurisdictions to present the methodology and request data (December and January 2025);
- a methods workshop with MDBA and AGE (11 February 2025);
- multiple meetings with all jurisdictions to present and discuss preliminary results on each group of SDLRUs;
- several consultations with CSIRO team responsible for the MD-SY2 outputs (May through August 2025);
- engagement with the NCGRT authors who designed the original method of the Project (1 July 2025);
- a final presentation of Stage 5 outcomes for key SDLRUs with all jurisdictions (August 2025); and
- a final presentation of the methods (this report) to the MDBA.

The process of engagement allowed for continuous testing and refinement of the Project methodology throughout Stages 1 through 7. Importantly, the Pilot Assessments (a group of four SDLRUs, including one from each state) were used as the preliminary check on the methods, particularly Stages 3 and 4. Feedback from MDBA was received at regular progress meetings to ensure the quality and direction of outputs. Testing and implementation of the methods were undertaken within each group of SDLRUs in turn (refer to Stage 2 methods for groupings), and results were presented at jurisdictional workshops.

Table 1.1 Chronological implementation of Project Stages for SDL resource units

Timeline	SDL Resource units	Project Outputs	Project Stage	Stakeholder Engagement*
December 2024	All units	Collate take, recharge and SDL data, and determine groupings (sequencing) for SDLRUs	Stage 2	Inception workshop
January 2025	Pilot units (one unit in each jurisdiction, except ACT)	Pilot Assessments: Review knowledge, define ESLT asset areas, and perform spatial analysis of resource condition indicators (RCIs)	Stages 1, 3, and 4	Methods workshop
February 2025	Group 1	Review knowledge, define ESLT asset areas, and perform spatial analysis of resource condition indicators (RCIs)	Stages 1, 3, and 4	Regular progress meetings and engagement with jurisdictions
May 2025	Group 3	Review knowledge, define ESLT asset areas, and perform spatial analysis of resource condition indicators (RCIs)	Stages 1, 3, and 4	Regular progress meetings and engagement with jurisdictions
July 2025	Group 2	Review knowledge, define ESLT asset areas, and perform spatial analysis of resource condition indicators (RCIs)	Stages 1, 3, and 4	Regular progress meetings and engagement with jurisdictions
August 2025	Group 4	Review knowledge, define ESLT asset areas, and perform spatial analysis of resource condition indicators (RCIs)	Stages 1, 3, and 4	Regular progress meetings and engagement with jurisdictions
July 2025	All units	Assess potential pressure from climate change on SDLRUs	Stage 6	Regular progress meetings, engagement with CSIRO and NCGRT
August 2025	All units	Develop charts, maps, and sections to further characterise the resource condition	Stage 5	Regular progress meetings and engagement with jurisdictions
September 2025	Selected units (n = 21)	Interpretive reporting to bring together all lines of evidence	Stage 7	Regular progress meetings, engagement with CSIRO and jurisdictions

1.4 Overarching principles

This Groundwater SDL Resource Unit Technical Review (the Project) was required to balance the need for a deterministic approach that can be implemented consistently across the Basin in a relatively short period with the need to make informed judgments from multiple sources of information. The AGE scope (Section 1.2) was based on the NCGRT method (2024) and was required to collate the best available knowledge, in accordance with the Water Act 2007 (*Cth*). Overall, there are some key differences in the two methods, but the approach remains consistent with the NCGRT design, and the structure of the stages was unchanged. Through interaction with the MDBA and other stakeholders, the following principles were established as essential for the AGE method:

- it is data-driven;
- it follows a multiple lines of evidence approach (and, if possible, independent lines of evidence) in rating the level of pressure on an SDLRU, or its ESLT values;
- it follows a precautionary approach to evaluate pressures and risks on the SDLRU if data is not available;
- it must be based on an integrated approach at all levels (groundwater quality vs. groundwater quantity, surface water–groundwater connectivity);
- it must give due consideration to spatial (e.g. local pressures vs. regional or widespread pressures) and temporal (short-term vs. long-term) scales;
- it should support the BPR decision-making framework, and the Project must transparently document assumptions and uncertainties; and
- it must establish engagement and feedback processes with jurisdictions to inform the method and incorporate jurisdictional knowledge into the Project.

The method focused on the impact of current groundwater extraction (location) on ESLT values and trends observed in key resource condition indicators: groundwater levels and salinity. Such an approach recognised that localised impacts to the ESLT can occur in situations where total extraction is below the SDL value, but the density of extraction is relevant for management of impacts. In these instances, understanding the scale of these impacts is crucial, as this knowledge provides insight into whether local management strategies can be effective in mitigating identified impacts.

1.5 Limitations of the AGE method

The Project was subject to limitations, most importantly a timeframe for implementation spanning less than a year. Through engagement with the MBDA, it was determined that the following components were out of scope for the Project:

- the BPR decision-making framework revolves around the ESLT definition in the Water Act (*Cth*), which is the SDL assessment's guiding principle; as the ESLT values are defined in the Water Act (*Cth*), there was no requirement to redefine them;
- as such, determination or new definitions of cultural values was not included in the scope;
- the sub-division of groundwater resources or their host aquifers beyond the scale of the SDL resources was not mandated by the method or as part of the BPR;
- determination of the causality of observed trends was not plausible, given the conflicting factors of groundwater demand, surface water interaction, and climate variability; rather a clear explanation of observed trends and future pressures was required; and
- the attribution of threat levels and assessment of risk was removed as part of the Technical Review, even though this was originally planned as part of the method (NCGRT, 2024); rather, the Project was limited to a technical study of the pressures on the SDLRUs, providing the best available science to decision makers.

Further limitations of method details are noted specifically for Stage 4 (Section 5) and Stage 6 (Section 7).

2 Stage 1 – Reviewing and updating knowledge

2.1 Methods to review the information

Stage 1 involved reviewing and updating knowledge of groundwater flow systems and threats to ESLT values in each SDLRU.

This stage established the foundational knowledge for later stages of the Project. It also gathered the most current and reliable information and science published for the SDLRUs. The purpose of Stage 1 was to compile the information and summarise it in a proforma, which was incorporated in the NCGRT method (2024). There were no changes made to the original proforma for Groups 1, 2, and 3 (refer to Section 3 for further detail on groupings), which is reproduced in Table 2.1.

For Group 4, the Stage 1 proforma was streamlined due to data paucity. For this group, data discussion was restricted to the productive base, and information on other ESLT values was omitted from the proforma. Likewise, the four ESLT value attributes related to “*Existing condition assessments and findings*” (Table 2.1) were omitted for Group 4 assessments in Stage 1, as the relevant details were included in “*Description of ESLT values and potential threats*” (Table 2.1).

The detailed and data-oriented approach used by AGE to review the information collected in Stage 1 is described in Appendix A of this document. Appendix A contains references to most of the resources accessed, and indicates the basic content required to establish the baseline knowledge for each SLDRU in Stage 1. The Stage 1 method (as per Appendix A) was developed in the Pilot Assessment stage and refined after the methods workshop, and it enabled the consistent application of the method, despite variable authors.

The Stage 1 data were delivered in the reporting proforma as a CSV. The presentation of information for Stage 1 was complemented with outputs from later stages of the Project, such as maps and charts developed in Stage 5.

2.2 Data sources and groundwater studies reviewed

Based on AGE experience, a series of data sources were collected and reviewed as part of Stage 1. The most recent available knowledge and data on specific characteristics of the SDLRUs were gathered, and the corresponding groundwater flow systems were described. Data sources included publicly available information from open repositories and specialised reports provided by MDBA. This characterisation enabled the spatial and temporal description of the groundwater SDLRUs and potential threats to ESLT. The following information was collected:

- a) groundwater levels and salinity;
- b) trends and patterns of groundwater extraction;
- c) intra- and inter-aquifer connectivity with adjacent resources;
- d) water resource plans (WRPs) and risk assessments and associated documentation and reports;
- e) areas of uncertainty;
- f) selected local management rules within WRPs;
- g) groundwater level and monitoring reports for key groundwater sources (NSW);
- h) groundwater resource descriptions associated with water resource plans;
- i) GDE potential using the GDE Atlas (v.2019) published by the Australian Bureau of Meteorology (BOM) (<http://www.bom.gov.au/water/groundwater/gde/>);
- j) Surface water-groundwater (SW-GW) interaction maps from MD-WERP RQ6 (Crosbie *et al.* (2023) have produced maps reflecting the probability of SW-GW interaction based on extensive analysis of data from river reaches and bore levels in the MDB for the period 1970-2019);
- k) Aquifer storage estimates (volumes) provided by the MDBA;
- l) average groundwater extraction rates reported for SDLRUs (extraction reported in the Transition Period Water Take Reports for 2012-2019; and extraction data for 2020-2023 from the Water Take Reports (MDBA, 2024a-c) under the SDL reporting in the MDB); and

m) Diffuse recharge estimates from recent Australia-wide available spatial products (Lee et al. 2024).

For points a, b and c, groundwater levels, salinity, extraction, and GDEs were assessed in Stage 1 for all 80 SDLRUs. AGE used advanced coding to process these large spatial data sets, and AGE's existing catalogue of Python scripts was used to perform standard trend analyses, such as the Mann-Kendall Test, and linear regression, which were applied to varying lengths of data strings across a bore's record (refer to Section 5 for more detail on Stage 4). Results were compared to an existing study, in which data from 22 alluvial groundwater SDLRUs were analysed by Rojas *et al.* (2023), and this work formed an important resource in the Stage 1 description for those units.

For point j, Crosbie *et al.* (2023) examined the surface water-groundwater interactions in the MDB from 1970 to 2019, identifying gaining and losing river reaches using more than 59,000 groundwater level data points from the National Groundwater Information System (NGIS). This regional study served as AGE's starting point to analyse connectivity between shallow aquifers and rivers, as outlined in the NCGRT methodology.

The remaining items were obtained from MDBA, member states, and public repositories where accessible (refer to Appendix A for further details). Spatial data sets were reviewed to evaluate the data density across regions to systematically identify data-poor groundwater SDLRUs. The result was a broad assessment of key gaps in data and knowledge.

Table 2.1 Proforma for Stage 1 reporting (after NCGRT, 2024)

SDL Resource Unit:	ESLT value	Stage 1 - Knowledge collation	References
Climate	N/A		
Land use	N/A		
Groundwater management	N/A		
Hydrogeological system description	N/A		
Groundwater system type	N/A		
Surface water description	N/A		
SDL (GL/year)	N/A		
SDLRU area (km ²)	N/A		
Recharge (GL/year)	N/A		
Extraction (Av. 2013-2021) (GL)	N/A		
Extraction trend	N/A		
Location / density of extraction	N/A		
Description of ESLT values and potential threats	Productive Base		
	Connectivity		
	GDEs		
	Water Quality		
Influence of climate (historical and future projections) on ESLT values	Productive Base		
	Connectivity		
	GDEs		
	Water Quality		
Data availability / uncertainty with respect to ESLT values and threats	Productive Base		
	Connectivity		
	GDEs		
	Water Quality		
Existing condition assessments and findings	Productive Base		
	Connectivity		
	GDEs		
	Water Quality		
Key findings from State-based risk assessment (and risk mitigation measures in place)	Productive Base		
	Connectivity		
	GDEs		
	Water Quality		

3 Stage 2 – Sequencing method

3.1 Overview

Stage 2 methods were created to sequence and group the SDLRUs for further analysis. The approach used two metrics that broadly describe the SDLRU: E/SDL and SDL/R, where:

- *E* refers to groundwater extraction (GL/year) reported through water take reports for each SDLRU from 2012 to 2023;
- *SDL* is the sustainable diversion limit volume (GL/year) for each SDL specified in Schedule 4 of the Basin Plan; and
- *R* is the recharge for each SDLRU (GL/year) as estimated and reported from the most recent science (recharge from numerical flow models or from Lee *et al.* (2024) if a model is not available).

The analysis identified four groups using the NCGRT (2024) method:

- Group 1: SDLRUs where both E/SDL and SDL/R are high (≥ 0.5);
- Group 2: SDLRUs where E/SDL is low (< 0.5) and SDL/R is high (≥ 0.5);
- Group 3: SDLRUs where E/SDL is high (≥ 0.5) but SDL/R is low (< 0.5); and
- Group 4: E/SDL and SDL/R are both low (< 0.5)

The Project method used these groups to sequence the SDLRUs, and the definition of high and low ratios was set as above or below 0.5, respectively (Figure 3.1). The group results of Stage 2 for each SDLRU and the ratio data (E/SDL and SDL/R) are provided in full in Appendix B.

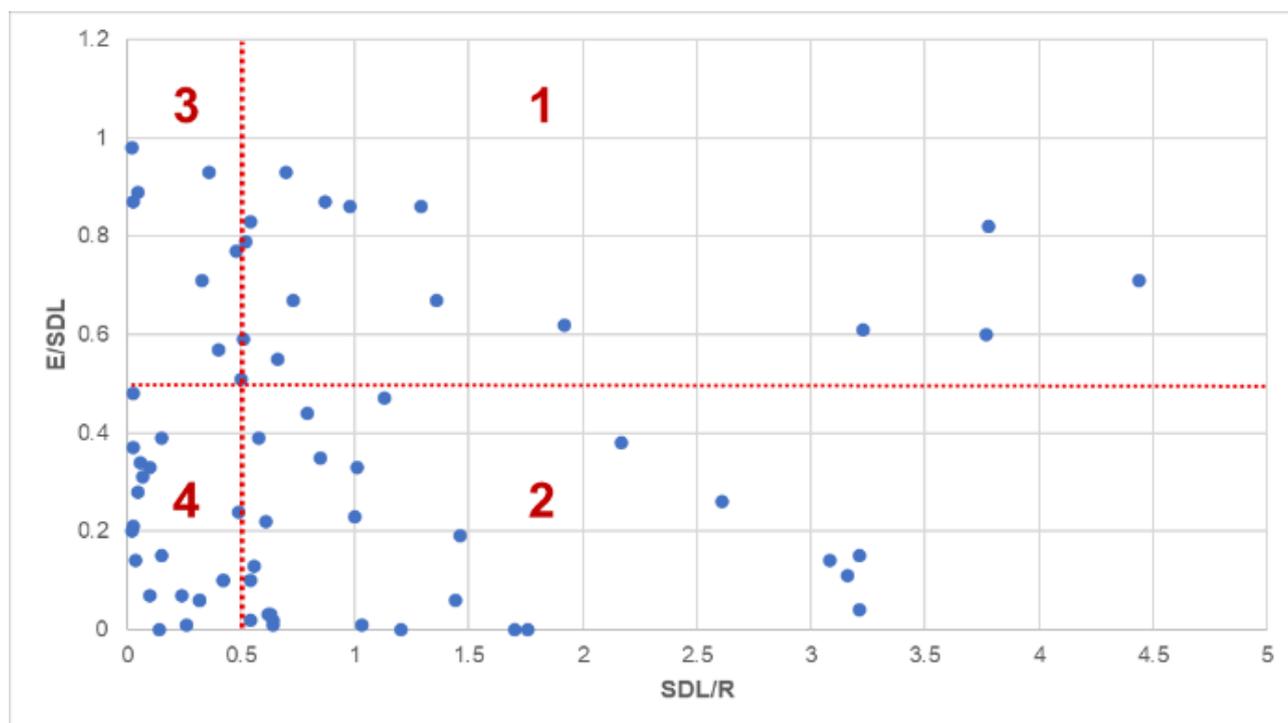


Figure 3.1 Stage 2 groups for the Project

The Project did not make any exceptions to the grouping rules of Stage 2, even though certain aquifer types were recommended for different allocations in the original methods report (NCGRT, 2024), such as limestone aquifers being allocated as high priority. In the AGE method, the same approach was applied to all units in Stages 3 through 6, regardless of their grouping in Stage 2.

Rojas *et al.* (2023) proposed a risk-based approach for prioritising 22 MDB groundwater SDLRUs, including only alluvial aquifers, based on concepts of groundwater stress, resilience, and sustainability. These 22 groundwater SDLRUs account for over 75% of the reported groundwater use in the MDB, placing them mostly in Groups 1 and 2 of the Project methodology. As the data collected by Rojas *et al.* (2023) related to similar but additional metrics to those used in Stage 2, a verification of both methods was conducted (methods stated below, results provided in Appendix B of this document). Furthermore, the additional metrics of Rojas *et al.* (2023) were employed in Stage 5 of the revised method by AGE.

The main outcome of Stage 2 was the four groups of the SDLRUs (Appendix B). This served the method by defining groups of units that could be sequentially assessed using the Project method process. The attributes of the Stage 2 ratios contributed to the contextual understanding of a SDLRU. For example, in Group 2, all units have a diversion limit that is closer to, or potentially exceeding the recharge estimate, but the take from that unit is less than 50% of the SDL. This group typically consisted of SDRUs that have low recharge in semi-arid areas, and take is constrained by naturally occurring low yield and/or high salinity. The common attributes of SDRUs within a group assisted further interpretation in other stages of the Project. The groupings based in Stage 2 results were not used to rank units as high risk or high threat, as was recommended in the NCGRT method (2024). Instead, stakeholder feedback and further interpretation of the NCGRT method led to the outcomes of Stage 4 being used for this purpose in the AGE method (Section 5).

3.2 Recharge data sources

The outcomes of Stage 2 depended directly on the estimates of recharge for the SDLRUs. As recharge estimation is an uncertain science, and there are various estimates available, a review of recharge sources was conducted in Stage 2.

Specifically, the Methods Workshop reviewed the findings of the Murray-Darling Water and Environment Research Program (MD-WERP) and the Murray-Darling Sustainable Yield Project (MD-SY2) Project for major alluvial SDLRUs to provide context for Stage 2 and Stage 6 (impacts of climate change). Figure 3.2 outlines the changes in recharge estimates over time as methods have been updated and available data sources have expanded. The data are shown as total recharge across the entire MDB, with several technical sources developed since 2010 (Figure 3.2). The changes in recharge values from recent studies are mainly decreases compared to early estimates. It is considered that this indicates the 2010 estimates were typically overestimated, and the recent estimates are less uncertain, especially given the general order-of-magnitude agreement among recent studies that the basin-wide volume is about 10,000 GL/y ($\pm 3,000$) (Figure 3.2). The changes in recharge estimates are not due to climate change but rather to method refinements and more or better data. The reduction in recharge estimates from those used in the Basin Plan adds additional pressure on future SDL risk. Therefore, it was determined that Stages 2 and 6 of the Project should rely on recent estimates of recharge as baseline conditions, unless earlier estimates were based on calibrated numerical flow models.

The recharge values used by the Project in this stage to calculate SDL/R differed from those tested by NCGRT (2024). Consequently, the upper range of SDL/R also differed. All available recharge data are supplied in Appendix B of this document. Throughout Stage 2, the most reliable recharge estimates considered were: a) numerical model estimates (if available, the SDLRU data are flagged in Appendix B) that include both localised and diffuse recharge; and b) diffuse recharge estimates from chloride mass balance (CMB) methods (e.g. Lee *et al.*, 2024). Some of these estimates may be superseded by the MD-SY2 modelling recently conducted by using the WAVES model (Crosbie *et al.*, 2025). The new data from MD-SY2 were reported for each SDLRU in Stage 1 and 5 outputs of the Project, but did not influence the ratios for Stage 2, as they were not available at the time of Stage 2 implementation. When the MD-SY2 data became available to the Project, a data validation was conducted (details below).

WAVES (2010) CSIRO	RRAM (2010) MDBA (2020)	CMB Lee et al. (2024)	WAVES (2025) CSIRO MD-SY2	CMB (P50) Crosbie et al. (2025) (MD-SY2)	CMB - 95% CI Crosbie et al. (2025) (MD-SY2)	Stage 2 estimates from this study
25,060.34	23,912.21	11,755.45	8,290.56	10,442.95	7,067.64 to 12,987.98	13,902.72
Defined in the RRAM approach and used to define the GW SDLs			Regarded as the best estimate of diffuse recharge by CSIRO			

Reported extraction (average over 2012-2023) = 1,370.25 GL/year
 Cumulative SDL (total over MDB) = 3,493.65 GL/year

Figure 3.2 Changes in recharge estimates over time (units: GL/y)

3.3 Validation of Stage 2 recharge with WAVES recharge analysis

The following section explains the methodology used to calculate the Stage 2 recharge per SDLRU from publicly available sources. This section outlines the sources of information used, the tools developed, and the multiple criteria considered in the analysis to calculate the diffuse recharge per SDLRU.

3.3.1 Sources of information

A total of 80 shapefiles with the corresponding polygons per SDLRU and their associated information in the attribute table for the Murray-Darling Basin were obtained, as shown in Figure 3.3 and Figure 3.4. The information in the attribute table corresponded to the jurisdiction of the SDLRU, the code, the type of SDLRU (“Groundwater” or “Deep groundwater”), the area of the polygon, and the length of the polygon boundaries.

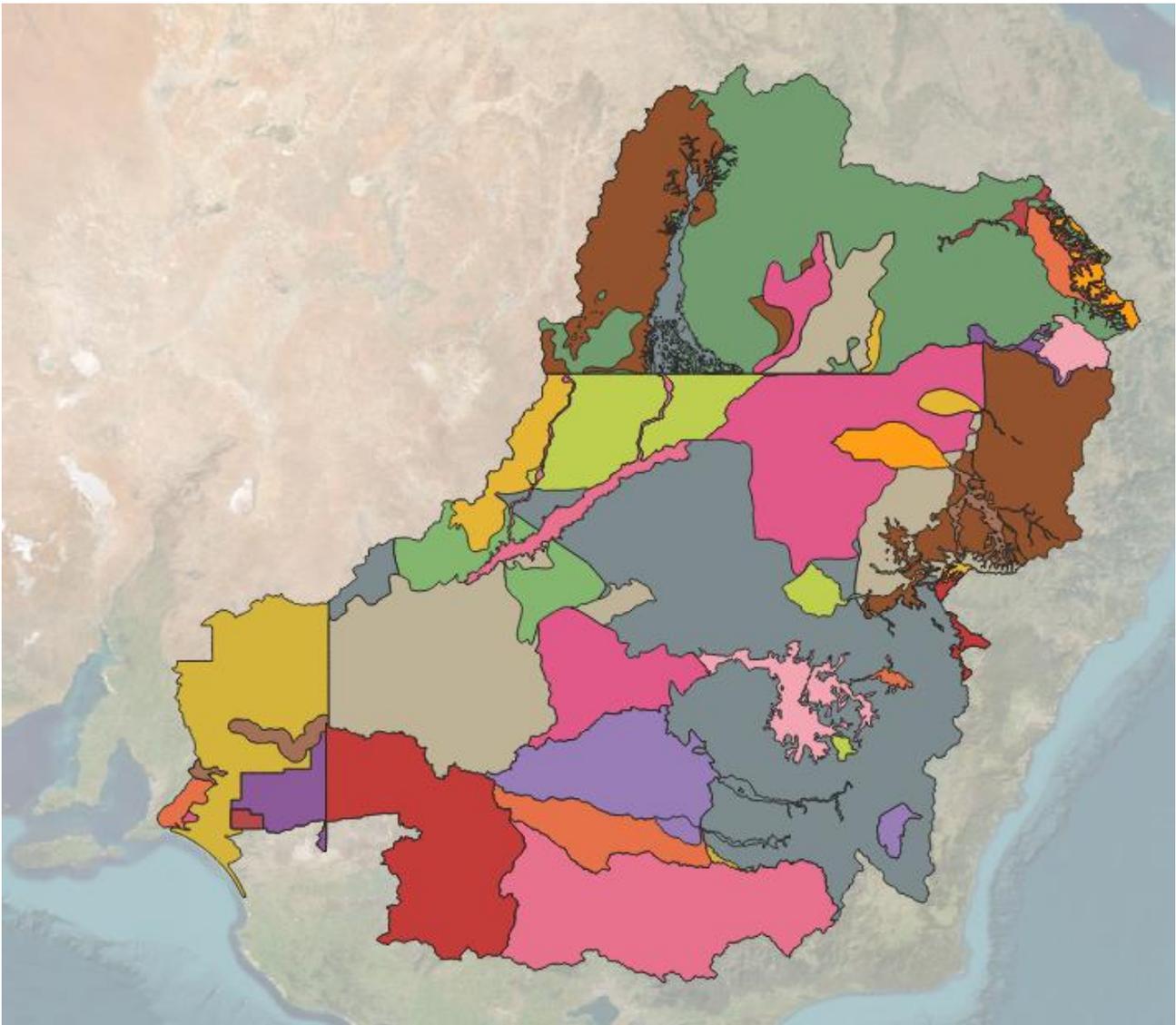


Figure 3.3 Surface outcrop of SDL polygons in the MDB

	JURISDICT	CODE	SDL_TYPE	SDL_NAME	Shape_area	Shape_len
1	NSW	GS11	Groundwater	Bell Valley Alluv...	0.0019884173	0.65178964244
2	NSW	GS12	Groundwater	Belubula Alluvi...	0.00348998291	0.55778826492

Figure 3.4 Example of SDLRU attribute table

The Project used diffuse recharge information from the MD-SY2 study (Crosbie *et al.*, 2025) as detailed below:

- WAVES_baseline_2025:
 - Diffuse recharge modelled in WAVES for current conditions (an updated baseline).
- WAVES_baseline_2010_(RRAM):
 - Diffuse baseline recharge as modelled for the Basin Plan in 2010.
- MDB_cmb_95_RK:
 - The 95th percentile of diffuse recharge derived from CMB modelling.
- MDB_cmb_50_RK:
 - The 50th percentile of diffuse recharge derived from CMB modelling.
- MDB_cmb_05_RK:
 - The 5th percentile of diffuse recharge derived from CMB modelling.

WAVES (Water Vegetation Energy and Solute) is a recharge model that was used as the initial step to estimate rainfall recharge across the Basin in 2010 (although some SDLRUs also had numerical groundwater flow models that estimated recharge). The estimates were achieved using the WAVES model and upscaling techniques developed for the MD-SY1 project, which were further refined for the Basin Plan (CSIRO and SKM, 2010a). The WAVES_baseline_2025 data reflects a more current estimate of recharge, compared to the MD-SY1 analysis (based on the WAVES_baseline_2010_(RRAM) results). The MDB_cmb raster files represent the median, 5th and 95th percentiles of the chloride mass balance method (CMB) implemented by CSIRO, as shown in Figure 3.5 (Crosbie *et al.*, 2025).

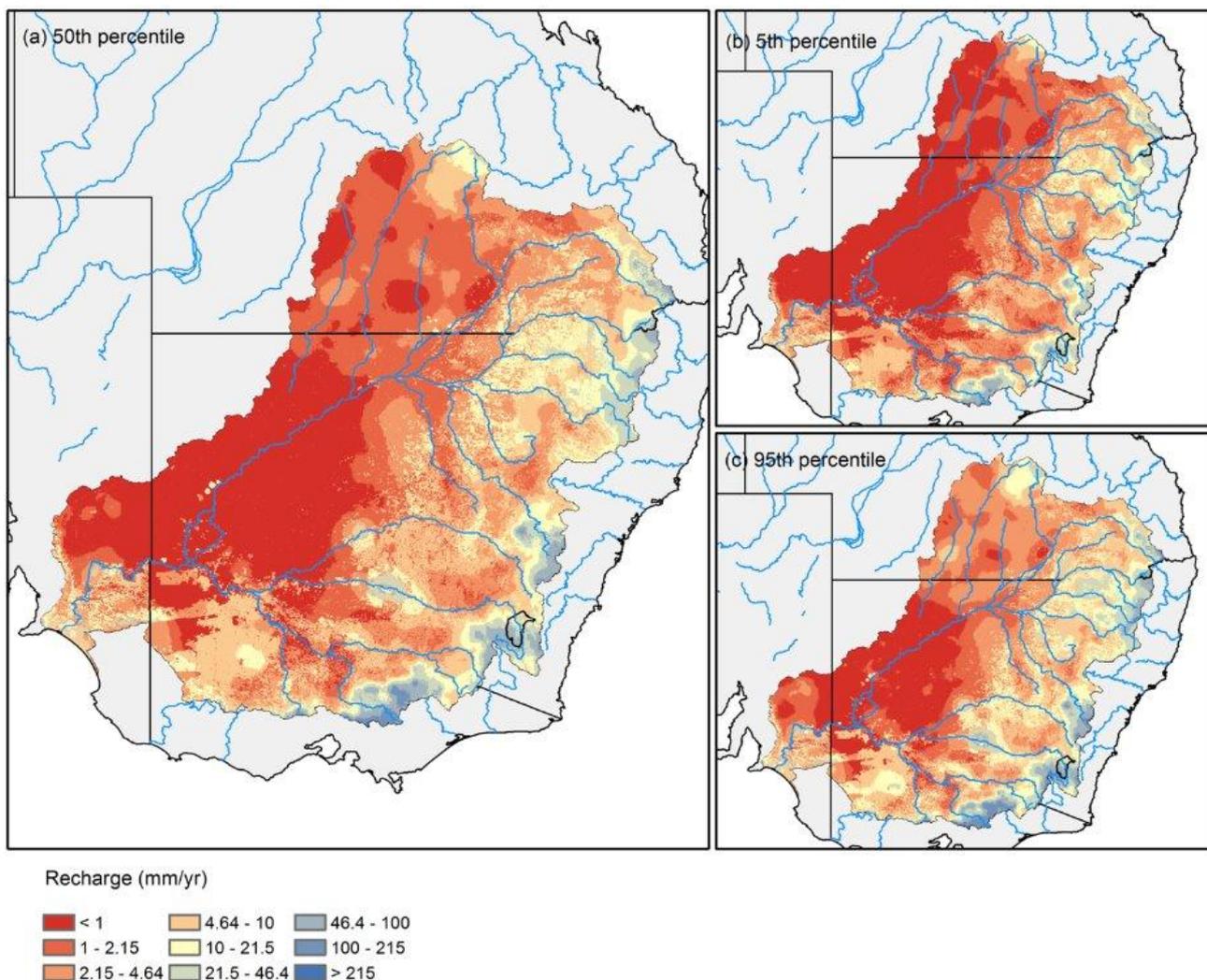


Figure 3.5 Baseline diffuse recharge modelled using CMB (Crosbie *et al.*, 2025)

3.3.2 Assumptions

The basin-wide raster data sets of recharge listed above were converted to recharge totals for each SDLRU using a spatial analysis. To conduct the process, the following assumptions were made:

- The recharge analysis was specifically designed to focus only on diffuse recharge.
- Analysis of polygon areas for each SDLRU:
 - The polygon areas were analysed to determine the accurate outcrop area for each unit.
 - SDRUs classified as “Deep Groundwater” were adjusted to include the outcrop by clipping the original area with shallower units, ensuring that only diffuse recharge was considered for these units.
- SDRUs not classified as “Deep Groundwater”:
 - These units, which corresponded to the same area but are at different depths (e.g., GS3a, GS3b, GS3c), were analysed individually; depths of SDRUs were obtained from their MDBA definitions (2020b).
 - In these cases, only the outcropping areas were taken into account for recharge estimation.
 - Diffuse recharge may have been assigned to a single unit or just a small part of the original area, depending on the outcrop areas.
- Consequences of the methodology:
 - Several SDRUs (those that are completely buried by other SDRUs) lacked direct diffuse recharge under this approach.

3.3.3 Methodology

The following methods were used to calculate the recharge values per SDLRU from the basin-wide rasters:

1. All the SDL files were processed to identify those classified as SDRUs with direct diffuse recharge, as they correspond to outcrop areas based on their characteristics. The process filters the 80 original shapefiles to select only those that will receive direct diffuse recharge. Shapefiles entirely covered by other units are excluded, and areas of deeper units that are partially overlain by other units are clipped accordingly.
2. Once the polygons were obtained, a process was carried out to calculate the recharge for each outcrop unit. Using QGIS and the shapefiles from the previous step, the rasters generated by CSIRO (Crosbie *et al.*, 2025) were clipped with the new polygon shapefiles. From the clipped rasters, it was possible to derive several statistical values from the data in the new area, such as the average recharge, minimum recharge, maximum recharge, and standard deviation for the entire SDLRU. A Python script, intended for use in the QGIS Python console, was developed to automate this process and enhance efficiency. This was done for each raster individually.
3. The result from the previous step was a shapefile containing all the outcrop areas and four new attributes : the average recharge, the minimum recharge, the maximum recharge, and the standard deviation; these data were in mm/year.
4. The area per polygon was recalculated, considering that the outcrop area is not always the same as the initial total area.
5. Using the average recharge value and the area, a recharge rate was converted from mm/year to GL/year for the SDLRU.
6. The results were compared with the recharge values (GL/year) reported by RRAM and estimates derived from the data of Lee *et al.* (2024) for diffuse recharge using the same spatial method described here.

3.3.4 Results

The recharge values from various sources are presented in Appendix B of this document. The values reported in the RRAM align closely with the results obtained from the WAVES_baseline_2010_(RRAM) raster, as expected and validating the spatial method. The values obtained using this methodology demonstrate a similarity between the MDB_cmb_95 recharge values and values from Lee *et al.* (2024). The updated version of WAVES modelling, represented by the WAVES_baseline_2025 raster, indicates a nearly threefold decrease in recharge compared to the results from WAVES_baseline_2010_(RRAM).

4 Stage 3 – Determine asset areas for ESLT values

Stage 3 involved applying spatial analysis to determine areas representing the ESLT values for each SDLRU. The four values from the Water Act 2007 (*Cth*) were examined through this analysis:

- productive base of the resource;
- surface water – groundwater connectivity (connectivity);
- groundwater-dependent ecosystems (GDEs); and
- water quality (mainly salinity).

The areas defined by Stage 3 were called the ESLT asset areas, and they limited the zone within the SDLRU where the RCIs needed to be assessed in Stage 4 (Section 5). The spatial definitions for Stage 3 carried out in the Project is summarised in Table 4.1, and further details regarding the Project method are outlined below.

Table 4.1 Spatial definitions of ESLT asset areas defined in Stage 3

ESLT value	Spatial definitions
Productive Base	<ul style="list-style-type: none"> • Areas within 5 km of a licensed extraction.
River Connectivity	<ul style="list-style-type: none"> • Areas within 5 km from a gauged river reach (Crosbie <i>et al.</i>, 2023) that are also within 5 km of licensed extraction.
Groundwater Dependent Ecosystems	<ul style="list-style-type: none"> • Areas in unconfined or semi-confined aquifers. • Areas within 5 km of licensed extraction sites and 5 km from a relevant potential GDE. • Excluding areas within a 5 km distance of monitoring bores where the groundwater level is reliably >15 metres depth.
Water Quality	<ul style="list-style-type: none"> • Areas within 5 km of licensed extraction. • Excluding areas within a 5 km distance of monitoring bores where salinity exceeds 4,478 $\mu\text{S}/\text{cm}$ at any time.

4.1 Productive base asset area

The productive base asset area was defined as a 5 km buffer zone around licensed extraction bores. The licensed bore data were provided by the jurisdictions in SA, VIC, and NSW, and were downloaded from public databases for QLD and the ACT (refer to Section 4.1.1 for details). The buffer was applied around all licensed bores, regardless of the entitlement allocation size (e.g., Figure 4.1). The licences collated represent entitlements at the particular time of the study (Section 4.1.1). The purpose of applying a buffer zone around licensed bores was to define an area where the groundwater resource may show signs of pressure from consumptive use of the productive base. If a groundwater bore is pumping, it causes drawdown, and the impact of that drawdown could reasonably be expected within 5 km, but would be unlikely beyond 5 km (NCGRT, 2024). In practice, however, this distance is a function of the transmissivity and storativity of the aquifer. It is acknowledged that a variable distance is suitable as a buffer, depending on the type of aquifer of the SDLRU (e.g., confined vs. unconfined, and alluvial vs. fractured rock), although a standard distance was used in the Project.

Where a licensed bore was located within less than 5 km from the boundary of the SDLRU area, the asset area was permitted to extend beyond the mapped boundary of the SDLRU (e.g., Figure 4.1). The basis for this is that: a) a radius of approximately 5 km for influence is considered reasonable and should be consistently applied; and b) there is a reasonable assumption of a margin of error in mapping the extent of the SDLRU, whose boundaries are based on the extent of geological formations, such as alluvia, and can be uncertain.

In SDLRUs where stock and domestic take (basic rights) accounted for more than 75% of the total take on average, the stock and domestic bores were used either alongside licensed bores or instead of licensed bores to define the productive base (e.g., SDLRUs GS22, GS5a). When allocations were for environmental water reserves or the salinity interception scheme (SIS) take, they were not included in the productive base asset area. If no take was recorded for a unit (e.g., GS3a), then no asset area could be defined for the productive base, and Stage 3 and 4 analyses could not be completed for that SDLRU.



Figure 4.1 Example of productive base asset area (blue) based on licensed bores (plus-signs)

4.1.1 Collection and pre-processing of state groundwater licence data

The objective during this stage was to gather and organise state groundwater licence data and attribute each licensed extraction volume to a point location (coordinates, Eastings, and Northings). The level of public access to such data varied. In some states (QLD, ACT), AGE downloaded the data from open-source data portals, while in others (VIC, SA, NSW), the required data was provided by the state government. The groundwater licence data were formatted differently across states, requiring pre-processing, as the format had to be suitable for further spatial analysis.

4.1.1.1 Queensland

The locations and volumes for allocations in Queensland were sourced from the host website. Four types of allocations were assessed: water licences, water permits, interim water allocations, and seasonal water assignment notices (SWAN). All data for Queensland were collected, and allocations related to SDLRUs were identified using the management group and management subgroup (i.e., the water source name). When multiple locations were linked to an allocation, the Nominal Entitlement volume was evenly divided among the locations. If a Nominal Entitlement was listed as a volume per irrigated hectare, the volume of the Nominal Entitlement (ML) was assumed to be six times the area (ha) <https://www.legislation.qld.gov.au/view/pdf/inforce/current/sl-2019-0011>. For allocations with bore numbers, the numbers were used to locate the extraction point, utilising the registered bore coordinates from the NGIS. For allocations without bore numbers, cadastral information was used to derive a coordinate from the lot on plan details of the allocation. Authorisation numbers 622679, 622680, 622681, 622682 refer to water reserved for environmental watering and were not considered part of the productive base.

4.1.1.2 ACT

The ACT groundwater allocation data were obtained from the host website. The data were in PDF format, with one document per allocation. Each document was examined, and the following information was extracted: Water Management Area, water source, licensed groundwater allocation volume (ML), and property address. The property address recorded was that of the groundwater extraction site; these data were converted to coordinates using the 'ACT Addressing' dataset from the ACT Government Open Data Portal on 16 January 2025 (https://www.data.act.gov.au/Land-Planning-and-Housing/ACT-Addressing/rwvc-ci8y/about_data). Where multiple locations were linked to an allocation, the volume was divided equally between the locations.

4.1.1.3 South Australia

The locations and volumes for licences in South Australia were provided by the state on 22 January 2025 and 23 April 2025. The data were supplied separately for each SDLRU, so no separation of the allocations was necessary. When multiple bores were linked to an allocation, the volume was evenly divided among the bores and assigned to the corresponding bore locations.

4.1.1.4 Victoria

The locations for Victorian licences were provided by the state on 22 January 2025. A total of 6,297 bores were detailed, and a very small number of records, which had no coordinates, had to be discarded (4%). The allocation volumes and other details, including the water source, were obtained from the host website by AGE. The groundwater source was used to allocate each licence to the correct SDLRU.

4.1.1.5 NSW

Licence data were provided by the state government on 17 January 2025. The data included locations linked to allocation numbers, allocation shares (indicating a volume when multiplied by the permitted percentage for the share), and the licence Water Resource Plan area and groundwater source. The groundwater source was used to assign each allocation to the correct SDLRU.

4.2 GDE asset area

The ESLT asset area for GDEs was defined as the productive base asset area that intersects with a 5 km buffer zone around relevant potential GDEs, excluding zones where the water level was reliably deeper than 15 m below ground level (mBGL). The process involved four steps:

- mapping the productive base asset area (as mentioned above);
- mapping the relevant potential GDEs with their 5 km buffer (using criteria for two tranches, as explained below);
- identifying the intersection of these two zones; and
- excluding areas with deep water levels (as explained below).

GDEs are ecosystems that depend either partly or entirely on groundwater—either beneath the surface or discharging to it—for their health. For these conditions to occur, a groundwater source generally needs to be near the surface and interact with the unsaturated zone. As a result, confined aquifers are usually not connected to GDEs. The exception is springs formed by deep faults that connect a confined aquifer to the surface, such as many springs in the Great Artesian Basin (GAB). Therefore, this Stage 3 method applies to all units where the SDLRU is at least partly unconfined or semi-confined. Only fully confined SDRUs are excluded from GDE analysis (consistent with NCGRT, 2024). This approach prevents the incorrect mapping of GDE asset areas for SDRUs with no ecological link and is consistent with the view that springs linked to confined aquifers are generally not part of MDB groundwater resource units.

The relevant potential GDEs were identified from the GDE Atlas (BoM, 2025a), which was initially developed and published at a national level (SKM, 2012; Doody *et al.*, 2017). Over time, as jurisdictions created their own methodologies and improved the mapping data at more detailed scales (e.g., DSITI, 2015), the GDE Atlas was updated to include both the national and regional resources. As such, the project incorporated both national and regional mapping by utilising the GDE Atlas. The relevant GDEs for the project, whether aquatic, terrestrial, or subterranean, were defined in two tranches:

- first, including moderate-potential, high-potential, and known GDEs from the GDE Atlas, and
- second, including high-potential, and known GDEs only (for selected SDRUs only – those that were determined from the initial Stage 4 results to be high risk).

Creating two GDE asset areas for those selected SDLRUs by using these criteria allowed a deeper assessment of how uncertainty in GIS mapping could impact the Project outcomes. Therefore, both asset areas were assessed in Stage 4 for the selected SDLRUs. Low-potential GDEs were excluded from both groups because their dependence on groundwater is unconfirmed or unlikely, which could lead to overestimating the asset area if included. A 5 km buffer zone around the mapped polygons meeting these criteria was intersected with the productive base asset area before the deep groundwater areas were removed.

The deep groundwater zones were identified using all available water level data from the Bureau of Meteorology NGIS (BoM, 2025b) related to the SDLRU. Areas where the groundwater level in the unconfined or semi-confined aquifer reliably exceeded 15 mBGL were excluded, in line with NCGRT (2024). Water level thresholds for groundwater use by terrestrial vegetation differ by site and species, with most evidence supporting effective limits of around 10 m or 15 m (SKM, 2012; Doody *et al.*, 2017). Therefore, a precautionary threshold of 15 m was adopted. Water levels were analysed individually for each bore, and if all records showed water levels deeper than 15 mBGL, a buffer zone of 5 km radius around that bore was removed from the asset area, provided the exclusion zone did not contain any bore with shallow groundwater levels (<15 mBGL). This was a conservative interpretation of the NCGRT method (2024) as the document did not specify what constitutes a bore with water levels deeper than 15 m. This exclusion zone modified the initial areas, resulting in refined asset areas specific to GDEs.

4.3 River connectivity asset area

The groundwater-river connectivity area was defined as the productive base area overlapping a 5 km buffer zone around hydraulically connected mapped and gauged rivers. A river that is not hydraulically connected to the aquifer cannot be affected by groundwater extraction in that area. Therefore, the surface water-groundwater interaction data set for stream reaches of the MDB (Crosbie *et al.*, 2023) was used as a basis for defining connectivity. An analysis of all river reaches within the SDLRU was carried out by identifying connected river segments within 5 km of licensed extraction bores. Then, a 5 km buffer was applied around these segments to define the river connectivity asset area for further analysis.

A limitation of the Project is the availability of data relating to stream and river connectivity to groundwater in all SDLRUs. A connectedness condition assessment is available for the units as a whole from the Murray-Darling Water and Environment Research Program (MD-WERP), but not for individual river reaches, which are required for the spatial analysis. In a conservative approach, it was assumed that all reaches assessed as having some losing or gaining relationship with groundwater in MD-WERP Research Question 6 (RQ6) (Crosbie *et al.*, 2022) should be included in the asset area assessment for Stage 3. This provided a conservative assessment for the ESLT of river connectivity to be further evaluated for resource condition in Stage 4. Where the definition of the river connectivity asset area was considered too conservative, it was addressed in Stage 5 with additional lines of evidence.

4.4 Water quality (groundwater salinity) asset area

The water quality asset area was defined as being equal to the productive base area, except for zones where water salinity of the SDLRU exceeds RRAM salinity class 2 (3,000 mg/L; Table 5.2). The higher salinity zones were identified using all available electrical conductivity (EC) data (as a proxy for salinity) from the NGIS database (BoM, 2025b). EC readings were used regardless of the number of readings at each bore or their date, due to limited data availability. These EC data were compared to the Class 2 threshold of 4,478 $\mu\text{S}/\text{cm}$ (derived from 3,000 mg/L salinity using a conversion factor of 0.67; Table 4.2). If a bore had a mean EC value exceeding this threshold, the buffer zone (defined by a 5 km radius) around that bore was subtracted from the asset area. If the exclusion zone included a bore with median salinity readings less than this, then that area was retained within the water quality ESLT asset area for Stage 3.

Table 4.2 Salinity classes for the Project and equivalent EC values

Salinity group	Salinity	Salinity (mg/L)	EC ($\mu\text{S/cm}$)
Fresh	Upper threshold based on the aesthetic guideline for human drinking water (600 mg/L) and close to the freshwater lakes, reservoirs and wetlands of South Central Australia (670 mg/L – default trigger value, ANZECC/ARMCANZ 2000/2018).	0 to 600	350 to 896
Fresh	While the upper threshold is not based on a guideline value, it aligns with the RRAM classification of fresh water, and the water class is suitable for most applications, including irrigation in most settings.	600 to 1,500	896 to 2,239
Brackish	Upper threshold based on the guideline value suitable for most stock without adverse effects (4,000 mg/L ANZECC/ARMCANZ 2000/2018). The upper threshold is also close to the lowland rivers value for South Central Australia (5,000 $\mu\text{S/cm}$ – default trigger value, ANZECC/ARMCANZ 2000/2018). This category contains the 3,000 mg/L threshold in the RRAM classification that divides Class 2 and 3.	1,500 to 4,000	2,239 to 5,970
Saline	Water of limited use, some stock watering with impacts, limited ecological uses.	4,000 to 14,000	5,970 to 20,896
Highly saline	Based on definition of highly saline in RRAM.	Over 14000	Over 20,896

5 Stage 4 – Analysis of resource condition indicators (RCIs)

5.1 Overview

During Stage 4, the Mann-Kendall Test (Kendall, 1975) was used to detect statistically significant increasing or decreasing trends in the selected RCIs, which were groundwater levels and groundwater salinity (EC as proxy). Linear regression analysis was further used to understand trends and their magnitude (rates of change). This analysis was conducted for two key time periods: long-term (1974-2024) and short-term (2012/2024). The Mann-Kendall test is widely used with environmental time-series data because it is suitable for nonparametric data sets (i.e., those that are not normally distributed). It compares each data point to previous readings by taking differences; a high number of positive differences indicates an upward trend, while negative differences indicate a downward trend. Beyond detecting trends, the Mann-Kendall analysis identified some bores with no trend and others with insufficient data (a minimum of 6 measurements over the period was required to assess a bore for trends). An absence of a trend differed from a very gentle trend, which was a low-magnitude but statistically significant change (p -value $\ll \alpha=0.05$). Additional details of the method, including thresholds for defining stable trends, are provided below. The outcomes of Stage 4 are linked to a resource condition ranking, and a trend grouping, both defined below.

5.2 Resource condition rankings

The Methods Workshop was conducted through an online video conference on 11 February 2025, between the MDBA and AGE.

At this workshop, two approaches for resource condition ranking were identified though employing a ternary framework for the data, which allowed three states for RCIs to be acknowledged: improving/stable conditions, deteriorating resource conditions, and uncertain conditions. These approaches regarded resource condition either as a level of pressure on the resource (Table 5.1 or Figure 5.1) or as a trend grouping (Figure 5.2). In the first method, the categories of high and moderate pressure were subdivided according to levels of uncertainty (Figure 5.1); it was considered that up to 30% to 40% of the asset area with insufficient data should be classified as highly uncertain (Table 5.1). A ranking of "Low threat, high uncertainty" was not included (Table 5.1), as it would undermine the precautionary principle applied to Groups 1, 2, and 3 by the method (NCGRT, 2024). Instead, when uncertainty was very high, a moderate ranking was used (Figure 5.1).

Table 5.1 Categories of resource condition ranking (refer also to Figure 5.1)

Colour in Figure 5.1	Resource condition ranking	Basis of condition ranking	Uncertainty level	Basis of uncertainty level
Purple	High pressure on the resource	Asset area is >30% deteriorating RCI	low uncertainty	Asset area is <30% insufficient data
Pink	High pressure on the resource	Asset area is >30% deteriorating RCI	high uncertainty	Asset area is >30% insufficient data
Dark blue	Moderate pressure on the resource	Asset area is <30% and >10% deteriorating RCI	low uncertainty	Asset area is <40% insufficient data
Light blue	Moderate pressure on the resource	Asset area is <30% deteriorating RCI	high uncertainty	Asset area is >40% insufficient data
Green	Low pressure on the resource	Asset area is <10% deteriorating RCI	low uncertainty	Asset area is <40% insufficient data

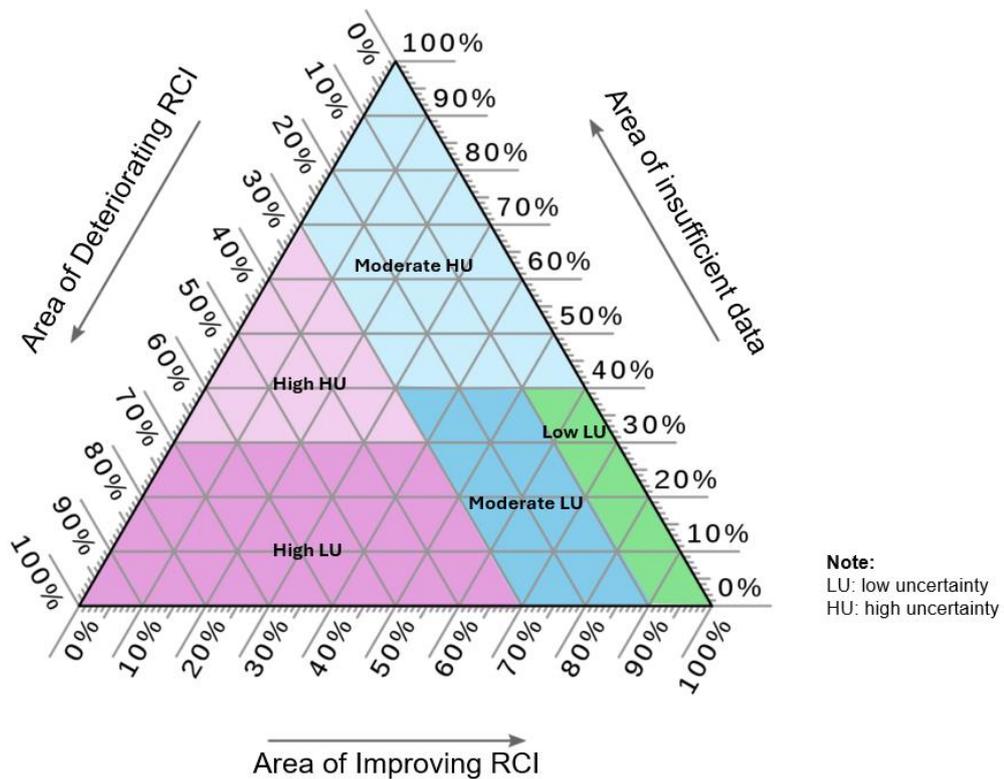


Figure 5.1 Ternary diagram based on resource condition ranking and uncertainty

In the second approach, trend analyses of RCIs grouped the results into four categories. The RCI trend groupings were defined as follows:

- **Improving or stable trends:** >50% of the asset area showing increasing / stable water levels, or decreasing / stable salinity (green; Figure 5.2).
- **Deteriorating trends:** > 50% of the asset area experiencing decreasing water levels or rising salinity (orange; Figure 5.2).
- **Insufficient data:** >50% of the asset area has insufficient data for statistical analysis of temporal trends (blue; Figure 5.2).
- **Variable trends:** the asset area contains less than 50% improving or stable trends, less than 50% deteriorating trends, and less than 50% insufficient data (white; Figure 5.2).

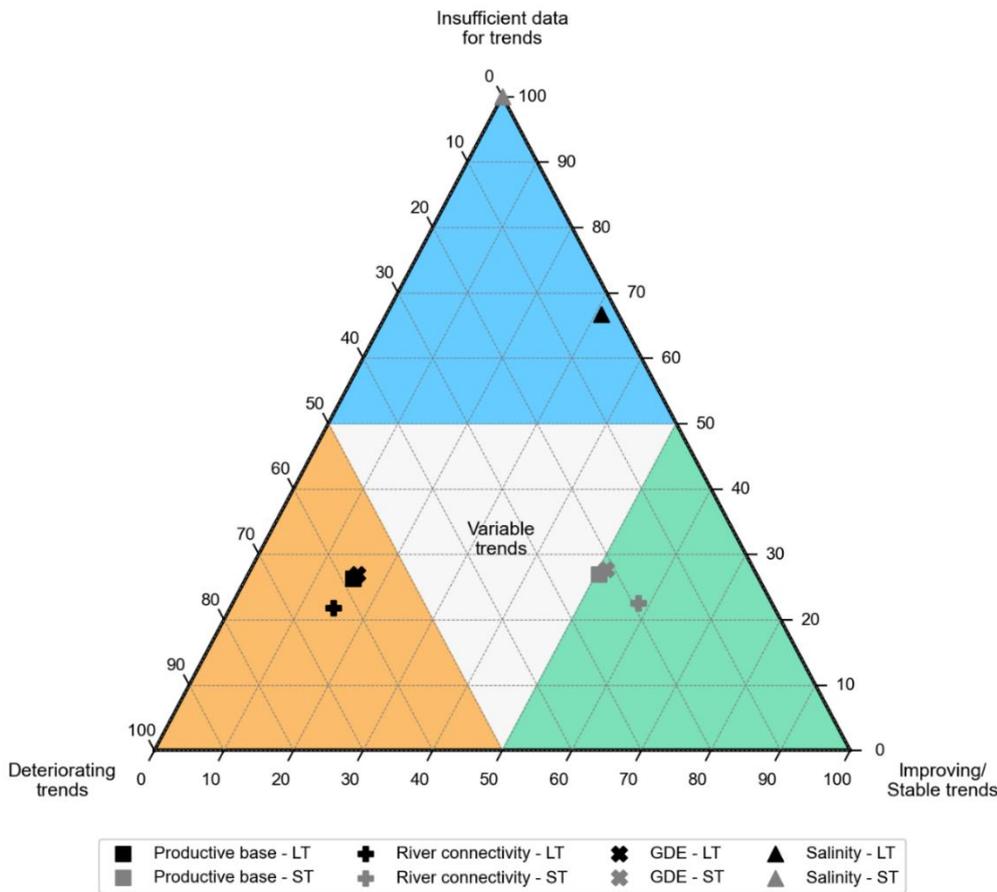


Figure 5.2 Ternary diagram based on trend groupings

5.3 Analysis of resource condition indicators (RCIs)

Groundwater levels and salinity (as EC) were the fundamental metrics used to calculate the RCIs for each SDLRU in the AGE method. The process was as follows:

- the RCIs helped evaluate the status of the SDLRU;
- the RCI temporal trends were associated to each monitoring point and identified as either improving/stable (including no trend), or deteriorating, where increasing salinity or decreasing water level trends were representative of deteriorating conditions;
- if insufficient data were available for temporal analysis, the point was allocated as uncertain;
- then, proportions of the total ESLT asset area were allocated to these RCI categories, according to spatial analysis of the monitoring point locations.

The RCI terms improving/stable and deteriorating applied to areas of the ESLT asset where data trends were confirmed and they were not extrapolated across areas with insufficient data. The results of spatial analysis in Stage 4 were then aligned with a resource condition ranking (Figure 5.1), and a trend grouping (Figure 5.2). The resource condition ranking (defined in Table 5.1) was used to identify SDLRUs suitable for further investigation in Stages 5 and 7. Those units that were identified as high pressure low uncertainty, or high pressure high uncertainty were the focus of detailed reports.

The Project utilised two analytical techniques for RCI trends: the Mann-Kendall (MK) test to identify significant trends, and linear regression analysis. Data processing was conducted using Python scripts to improve efficiency and reduce manual errors. The MK test was performed with an open-source Python toolkit (Hussain *et al.*, 2019).

The MK test results classified bores that had sufficient data based on their RCI behaviour (improving, deteriorating, or no trend/stable); this applied to both water level and salinity using EC data. Besides identifying increasing and decreasing trends, the MK analysis also revealed some bores with no trend (termed stable for the purpose of the study) and others with insufficient data (the minimum number of measurements for a bore to be assessed was 6 over the long-term or short-term period). If the MK test provided an increasing or decreasing trend in water level, but the bore showed a positive or negative linear regression slope within the narrow range of -0.01 m/year to 0.01 m/year, it was classified as “stable” and grouped with improving trends. This threshold was set narrowly to prevent mild trends from being mistakenly labelled as stable RCIs. A similar approach was used for EC data, where stable trends are defined as -5 $\mu\text{S}/\text{cm}/\text{y}$ to 5 $\mu\text{S}/\text{cm}/\text{y}$.

Spatial analyses of the RCI conditions were conducted after the data were analysed for each bore. This process applied in areas identified as asset areas (e.g. dashed line in (A) of Figure 5.3). A buffer zone with a radius of 5 km was applied to each RCI bore and the attribute of that area was determined by the bore’s RCI grouping (e.g., deteriorating shown as red and improving shown as green in (B) of Figure 5.3 and in Figure 5.4). Bores with insufficient data for trend analysis were not the focus of RCI buffer areas (B of Figure 5.3). RCI buffer areas outside asset areas were then discarded (C of Figure 5.3). Where RCI buffer zones of opposing attributes intersected, a tangential mid-point division was drawn (C of Figure 5.3). Asset areas with no intersection with RCI buffer zones were categorised as the insufficient data grouping (e.g. yellow areas in (C) of Figure 5.3, and grey areas in Figure 5.4). The total RCI zones resulting from this analysis (e.g. Figure 5.4) were expressed as a percentage of the overall asset area for an SDLRU, and were provided as the Stage 4 spatial analysis results in a table format for each of the four ESLT asset areas and for the two time periods (results example provided in Table 5.2).

The trend analysis resulted in many adjacent bores showed conflicting RCI trends, with some increasing and others decreasing (e.g. (B) of Figure 5.3). Most of these instances occurred where gentle (low-slope) trends of opposite conditions were adjacent. To address this, the Project adopted a conservative approach, prioritising deteriorating bores over improving or stable ones in the spatial analysis (e.g. Figure 5.4).

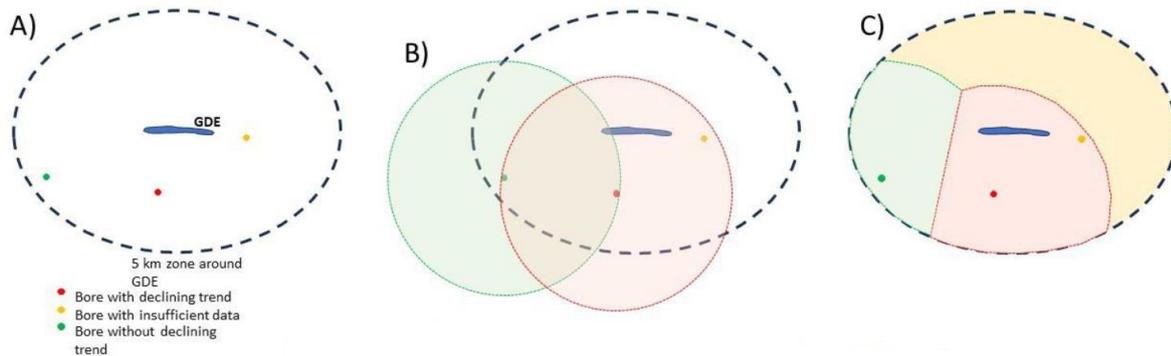


Figure 5.3 Process of RCI buffer zone analysis (after NCGRT, 2024)

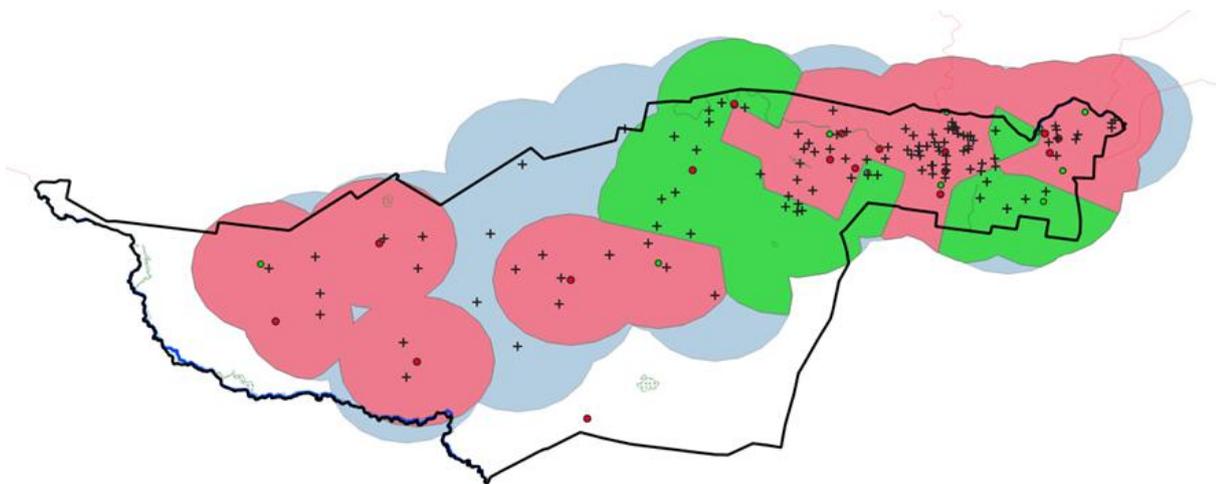


Figure 5.4 Example of outcome for Stage 4 RCI buffer zone analysis for a SDLRU

Table 5.2 Example of Stage 4 results format

ESLT Value	ESLT Asset area (m2)	Proportion of asset area with improving/stable RCI trends	Proportion of asset area with deteriorating RCI trends	Proportion of asset area with uncertain RCI trends	Proportion of asset area with improving/stable RCI trends	Proportion of asset area with deteriorating RCI trends	Proportion of asset area with uncertain RCI trends
		Long term (1974 to 2024)			Short term (2012 to 2024)		
Productive base	5,714,308,493	8%	46%	46%	43%	11%	46%
GDEs (moderate and high)	5,269,445,328	7%	46%	47%	43%	9%	48%
GDEs (high only)	5,158,724,092	5%	45%	50%	39%	11%	50%
River connectivity	4,213,447,458	4%	47%	50%	42%	8%	50%
Water quality	5,678,070,297	0%	0%	100%	0%	0%	100%

5.4 Time periods for trend analysis

Two time periods were assessed in the trend analysis: a long-term period (January 1974 to December 2024) and a short-term period (January 2012 to December 2024). During the pilot assessments, only the long-term period was examined to gather as many records as possible. However, following feedback from the MDBA and jurisdictions, it became clear that exploring recent trends was also necessary, especially to apply an evidence-based approach to assessing the impacts of over 12 years of resource management since the implementation of the Basin Plan in 2012. Consequently, the short-term period was added, and the same Stage 4 methods were used for this period for all SDLRUs.

Quantitative trend assessments over only the past 10 years (as recommended in the NCGRT method, 2024) may not reflect the full historical impact of licensed groundwater extraction on the SDLRU. For example, a bore might show a recent increase in groundwater levels that are still far below pre-development levels, or the effects of extreme climate events, such as the Millennium Drought (MD), might not be captured. Therefore, a longer timeframe was evaluated in the AGE method, especially in comparison to the short-term period. The long-term period for the Project closely matches the analysis period of other studies (Rojas *et al.*, 2023) and includes most of the available data, avoiding unnecessary exclusion of data points. Data records from bores within these periods were accepted, summarised into annual means, and vetted to ensure a minimum number of samples (n=5 annual means for water levels; n=5 for annual EC means). Records shorter than 10 years were accepted in the Project due to limited data in many SDLRUs, although the NCGRT methods suggest this should not be the case (NCGRT, 2024).

5.5 Data sources for groundwater levels and salinity

Groundwater levels and salinity data were sourced from the Bureau of Meteorology (BoM) National database <http://www.bom.gov.au/water/groundwater/explorer/map.shtml>. The BoM collates groundwater data from state and territory agencies in accordance with the Water Regulations 2008 (*Cth*) and publishes it as nationally consistent datasets, including water levels (as elevations and depths), Total Dissolved Solids (TDS), and Electrical Conductivity (EC).

5.6 Allocation of monitoring data to SDLRUs

Once RCI monitoring data were obtained from the Bureau of Meteorology, the information was attributed to the correct SDLRU. This was both a spatial task (constraining the locations of monitoring bores) and a geological task (assessing the hydrostratigraphic unit screened by a monitoring bore).

For the spatial assessment, all bores were compared to the SDLRU extents (<https://data.gov.au/data/dataset/groundwater-sdl-resource-units>) and a list of all possible bores for each unit was obtained. Where SDLRUs have overlapping extents, this meant that a single bore could be listed as a potential bore for more than one unit.

For the hydrostratigraphic screening, the list of potential bores for a unit was refined using one or more filters custom designed to select bore records related to an SDLRU. The filters used were: bore screen depth, bore screen lithology, bore screen stratigraphy (the 'HGU Name' attribute in the Bureau of Meteorology framework), and whether the bore was selected for an underlying or overlying SDLRU. The filters were manually defined and automatically applied for each of the 80 SDLRUs referring to the definitions of the resource in the Groundwater Report Cards (MDBA, 2020b). The full list of filter settings for each SDLRU is provided in Appendix C of this document.

5.7 Limitations

Several additional approaches to method design (NCGRT, 2024) were examined during the Project by AGE. One alternative for Stage 4 methods was to modify the buffer zone distance around observation sites to better characterise resource condition. In the method design (NCGRT, 2024), a fixed distance of 5 km was recommended, and this was used in the Project through AGE's method. However, an alternative was to adopt a risk-based approach to setting the buffer zone distance, allowing for variable distances based on risk factors. For example:

- a) 0 – 500 m: highly likely indicator of condition.
- b) 500 – 1000: likely indicator of condition.
- c) 1000 – 2500: neutral indicator of condition.
- d) 2500 – 5000: uncertain indicator of condition.
- e) > 5000: unlikely indicator of condition.

AGE assessed the feasibility of this method based on the spatial complexity of the data, insights from jurisdiction knowledge, MDBA recommendations, and Project constraints. Although a variable buffer distance was considered unsuitable for the Project due to time constraints and the need for a consistent approach across all SDLRUs, it remains a valuable area for future methods development. This option could frame asset areas from a risk-based perspective, for example, by incorporating information on aquifer properties (e.g., transmissivity) to define buffer zones with a more local and physical basis.

6 Stage 5 – Consideration of multiple lines of evidence

6.1 Context

Stage 5 of the NCGRT (2024) method focused on analysing multiple lines of evidence (MLE) and collecting feedback from jurisdictions on expert knowledge of groundwater SDLRUs. Stage 5 analysis in the Project expanded upon the information gathered in Stage 4 to investigate the specifics of RCIs established for the SDLRUs, particularly where risks had been flagged from the literature review of Stage 1. The Project included both a quantitative component (detailed as Stage 5 methods in this report), and a qualitative (interpretive) component (reporting). The latter was a concise technical memorandum for individual SDLRUs that brought together all the information from all stages of the Project, with interpretation guided by expert knowledge from the jurisdictions. To underpin this reporting, AGE developed a comprehensive suite of quantitative analyses and outputs for Stage 5 in consultation with MBDA and the jurisdictions. Examples of these outputs and their purpose within the Project are discussed in Section 6.2, and their methods of development are provided in Section 6.3.

6.2 Stage 5 outputs

The AGE-revised method produced a large volume of quantitative assessments for all SDLRUs using automated procedures. These included:

- maps of trend magnitudes, and frequency for both long- and short-term;
- cross-sections contextualising historical drawdown, available headroom, and groundwater fluctuation zones;
- correlation between groundwater take and annual rainfall anomaly, long-term CRD;
- spatial interpolation of depth-to-water, groundwater elevation, groundwater salinity;
- spatial overlap with local management zones; and
- numerous (30+) SDLRU-specific metrics based on available data.

The Project undertook primary data analysis to produce the following quantitative assessments as part of Stage 5.

1. A map of ESLTs in the SDLRU

This map was developed to show the productive base per SDLRU, displaying the size of the groundwater entitlement spread across all licensed bores on a given licence, and also showing the other primary data used to determine ESLT asset areas in Stage 3: basic landholder rights bores if they were used in the spatial analysis, rivers, GDEs, and the SDL extent (Figure 6.1). Bore data sources are discussed in Section 2.2.

This map revealed the density and clustering patterns of groundwater entitlements, their proximity to GDEs and river reaches, and the frequency and concentration of larger entitlements (volume).

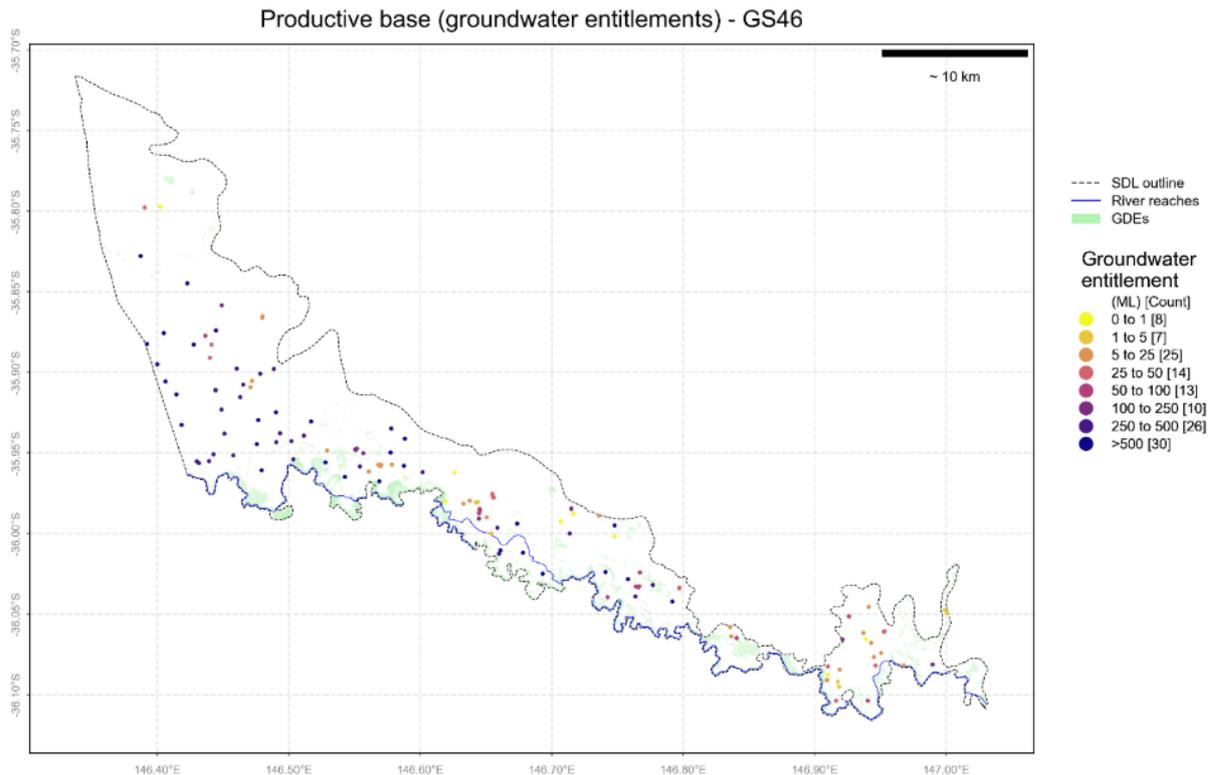


Figure 6.1 Example map of ESLTs in the SDLRU

2. A chart of the annual groundwater take correlated to the annual rainfall anomaly

This chart was designed to show the annual take per water year in comparison to the average take since 2012 (when the Basin Plan was implemented) and the total SDL volume (which came into effect in 2019; Figure 6.2). The plot also displays climate pressures on groundwater take, summarised by calculating the annual rainfall anomaly on the same time scale. The rainfall data were obtained by summarising all rainfall across the SDL area (refer to Section 6.3.1 for more details) and using the 50th percentile of the spatial distribution for each year to compare to the long-term average and obtain the positive or negative anomaly.

This figure revealed the nature of groundwater take to complement surface water supply during years of below-average annual rainfall, short-term trends in groundwater take, the proportion of metered groundwater take with respect to SDL (GL/year), and the average take post-2012.

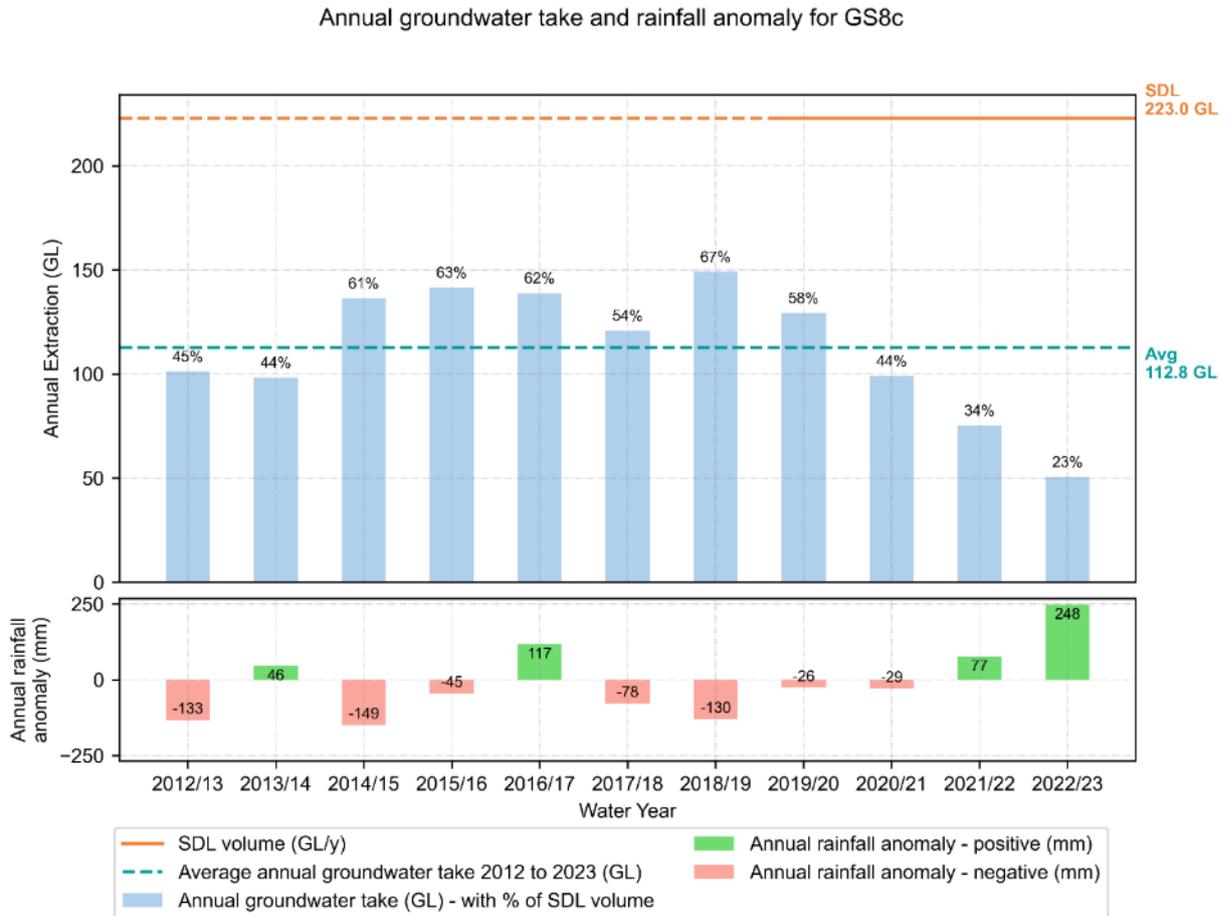


Figure 6.2 Example chart of the annual groundwater take

3. A chart of climate variability

The climate variability chart was plotted to show the cumulative rainfall departure (CRD) and precipitation-evaporation ratio at the temporal scale covering the long-term period of the Project (1974 to 2024; Figure 6.3). The climate data analysis undertaken is outlined in Section 6.3.1, and the data were shown as a distribution (P5, P10, P20, P50, P80, P90, P95) to demonstrate the spatial variability across the SDLRU.

This figure revealed long-term climatic trends, the impact of the Millennium Drought (MD) on rainfall patterns across the SDLRUs, the dominant climate classification, and potential correlation to post-2020 recoveries in water levels observed in numerous hydrographs across the MDB. A secondary outcome was the distinction of SDLRUs located in the northern versus the southern basin.

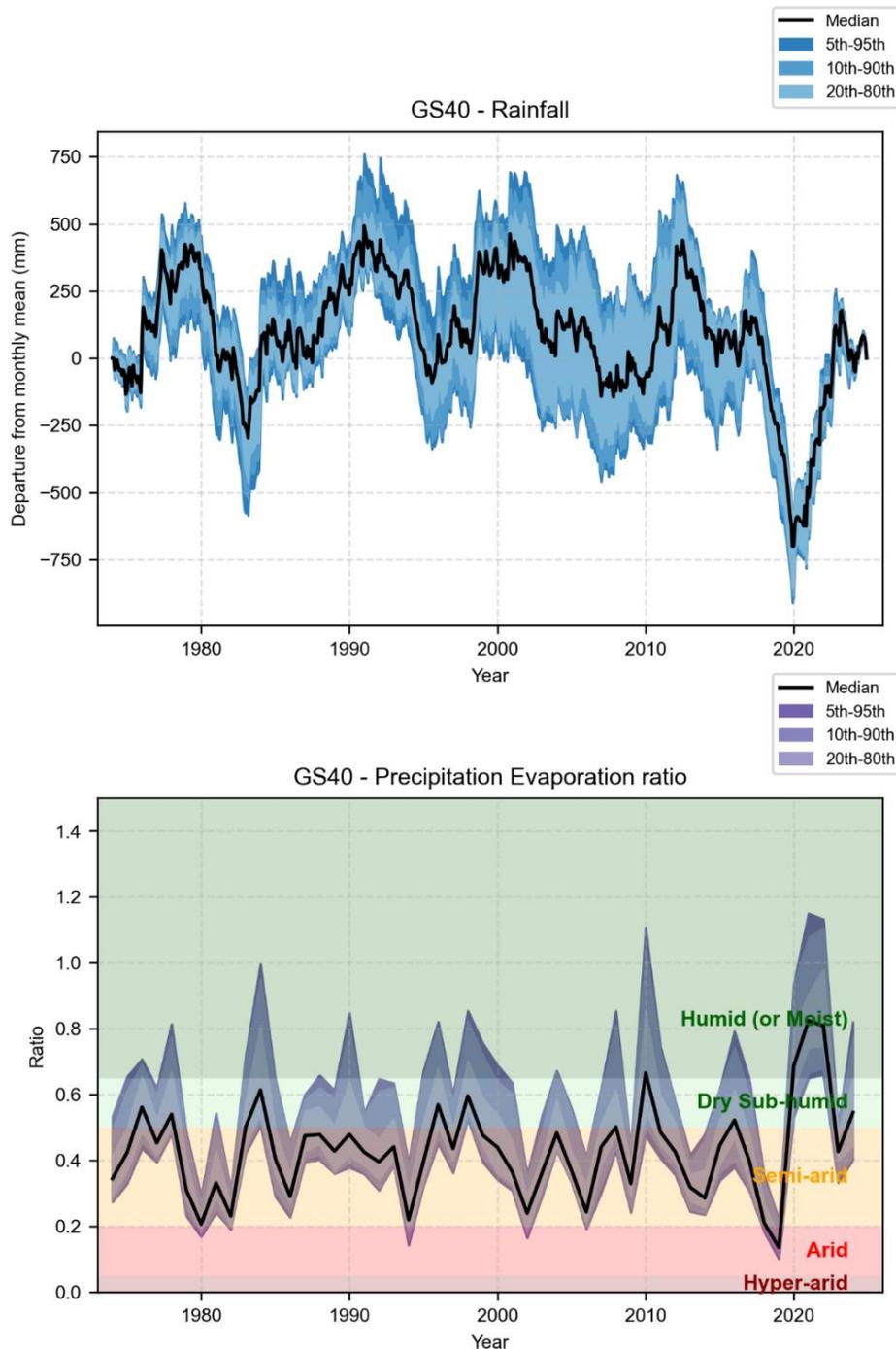


Figure 6.3 Example chart of climate variability

4. A table of key metrics for each SDLRU

This table included 30+ key metrics such as the SDL volume, and also collated historical metrics (e.g. SY1 outputs), and the outputs of the Project for Stage 2 (Table 6.1). The outputs included: E/SDL and SDL/R from Stage 2, and additional metrics for Stage 5, such as aquifer storage volume ratio to recharge (S/R). Sources of S were: a) a recent study from WERP if available (22 units: Rojas et al., 2022); or b) MD-SY1 estimates if no WERP update was available. The statistical trend analysis of Stage 4 underpinned the information on trend magnitudes for water levels and salinity, (mean, P50 of trend magnitude per SDLRU), and provided the number of bores with statistically significant trends (p -value $\ll \alpha=0.05$) in each RCI.

Table 6.1 Key metrics for each SDLRU

Parameter	Unit	Long-term (1974 to 2024)	Short-term (2012 to 2024)	SDL resource unit data
SDL volume	GL/y	-	-	9.3
SDL resource unit area	km ²	-	-	186
Average annual take (2013 to 2023)	GL/y	-	-	5.71
Number of groundwater entitlement bores	-	-	-	550
SDL resource unit storage estimate*	-	-	-	277
Recharge estimate (SY1)	GL/y	-	-	23
Recharge estimate (Stage 2)	GL/yr	-	-	3
Diffuse recharge estimate (SY2 - WAVES)	GL/yr	-	-	4
Extraction/SDL (E/SDL) (Stage 2 result)	-	-	-	0.61
SDL/Recharge (SDL/R) (Stage 2 result)	-	-	-	3.23
Storage/Recharge (S/R)	-	-	-	67
Number of bores in the SDLRU	-	1,232	1,232	-
Number of bores for water level trend analysis	-	46	44	-
Number of bores for water level trend with sufficient data	-	45	43	-
Number of bores with decreasing water level trend	-	9	0	-
Number of bores with increasing water level trend	-	6	3	-
Number of bores with no statistically significant water level trend	-	30	40	-
Mean water level trend magnitude	m/y	0.01	0.07	-
Minimum water level trend magnitude	m/y	-0.34	0.0	-
50%ile water level trend magnitude	m/y	0.01	0.07	-
Maximum water level trend magnitude	m/y	0.07	0.2	-
Number of bores for salinity trend analysis	-	80	N/A	-
Number of bores for salinity trend with sufficient data	-	0	N/A	-
Number of bores with decreasing salinity trend	-	0	N/A	-
Number of bores with increasing salinity trend	-	0	N/A	-
Number of bores with no statistically significant salinity trend	-	0	N/A	-
Mean salinity trend magnitude	µS/cm/y	N/A	N/A	-
Minimum salinity trend magnitude	µS/cm/y	N/A	N/A	-
50%ile salinity trend magnitude	µS/cm/y	N/A	N/A	-
Maximum salinity trend magnitude	µS/cm/y	N/A	N/A	-

5. A groundwater level hydrographs for each bore in the SDLRU

The data processing required for this output involved the identification of bores relevant to the SDLRU (Figure 6.4). This was achieved through a process of filtering the total bore records according to attributes such as bore screened lithology, allocated hydrostratigraphic unit (HGU), location, and depth / or construction (full methods provided in Section 5). Bespoke in-house scripts performed this filtering on the available data from BoM database and charted the data. The water level data were then processed and plotted in timeseries, showing: raw data, annual means, and the ranges of the long- and short-term periods. Two formats were developed for timeseries display: one with multiple bores from an SDLRU on a single page (Figure 6.4), and another with a single bore accompanied by a location map (Figure 6.5).

These figures revealed long- and short-term patterns in hydrographs, seasonality in annual discharge/recharge processes, impacts of the Millenium Drought, recoveries associated with post-2020 increases in the CRD, and potential correlations between the annual water level mean and the annual groundwater take and rainfall anomaly (Figure 6.2).

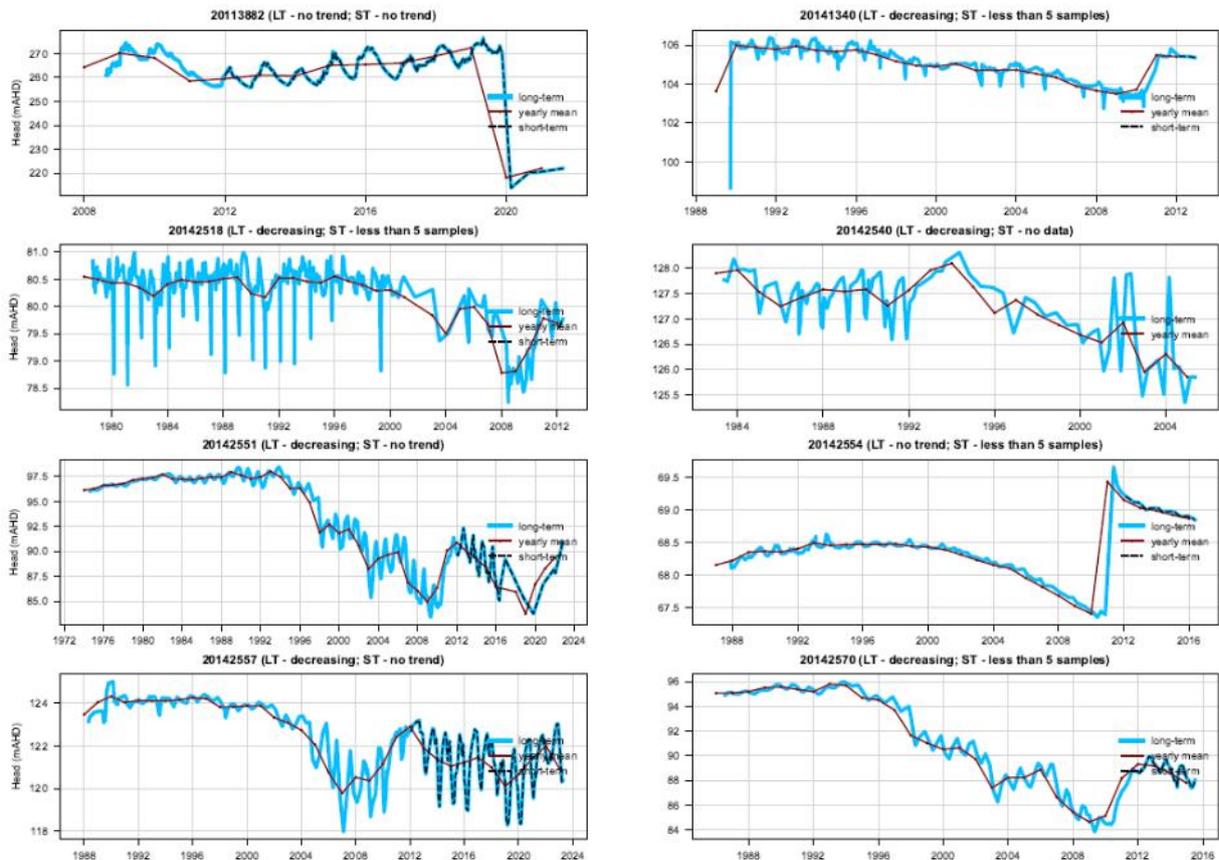


Figure 6.4 Example of groundwater level hydrographs

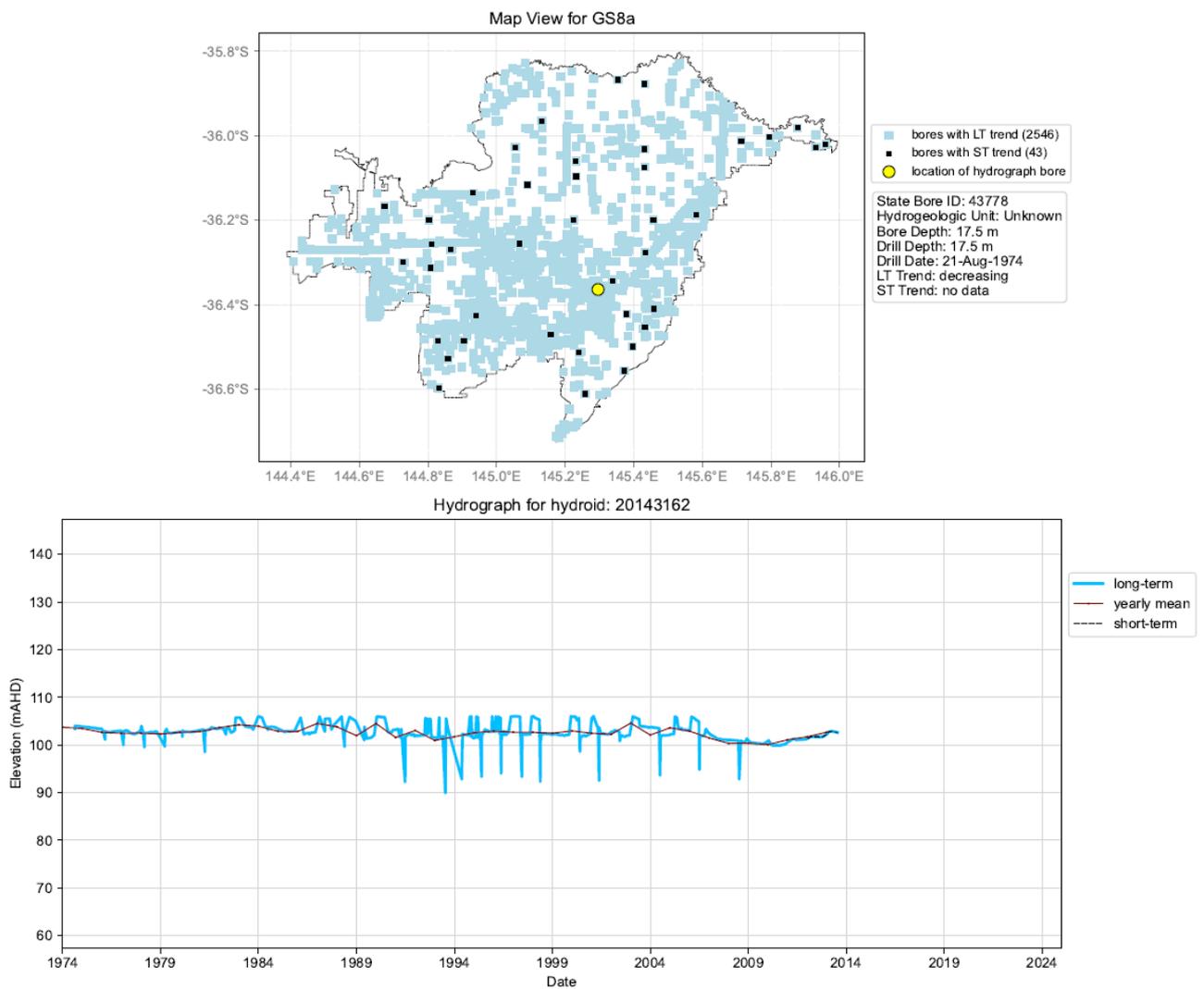


Figure 6.5 Example of groundwater level hydrographs with location map

6. A groundwater salinity (EC) timeseries chart for each bore in the SDLRU

The data process for this output was the same as that for groundwater levels described above, and the data were presented similarly (Figure 6.6 and Figure 6.7).

These figures revealed long- and short-term patterns in salinity trends, and comparative concentrations in groundwater from bores across the SDLRU. However, salinity data availability is considerably lower compared to that of the water level data. The data have poor temporal and spatial density and show substantial variability through time.

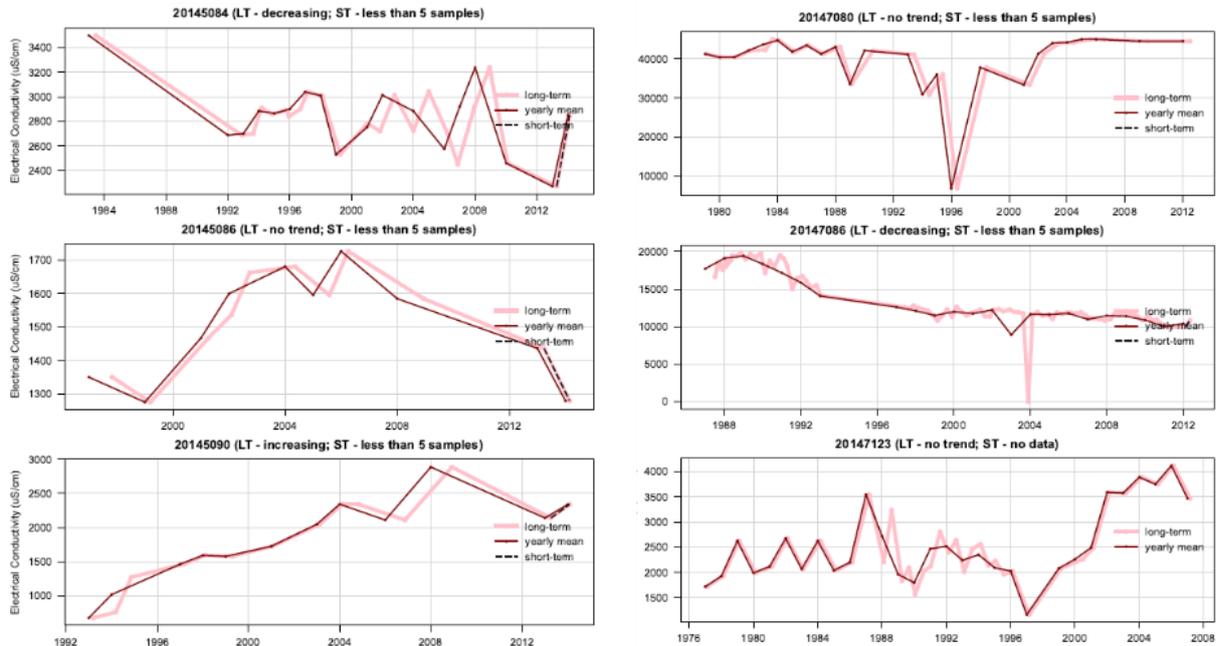


Figure 6.6 Example of groundwater salinity (EC) timeseries

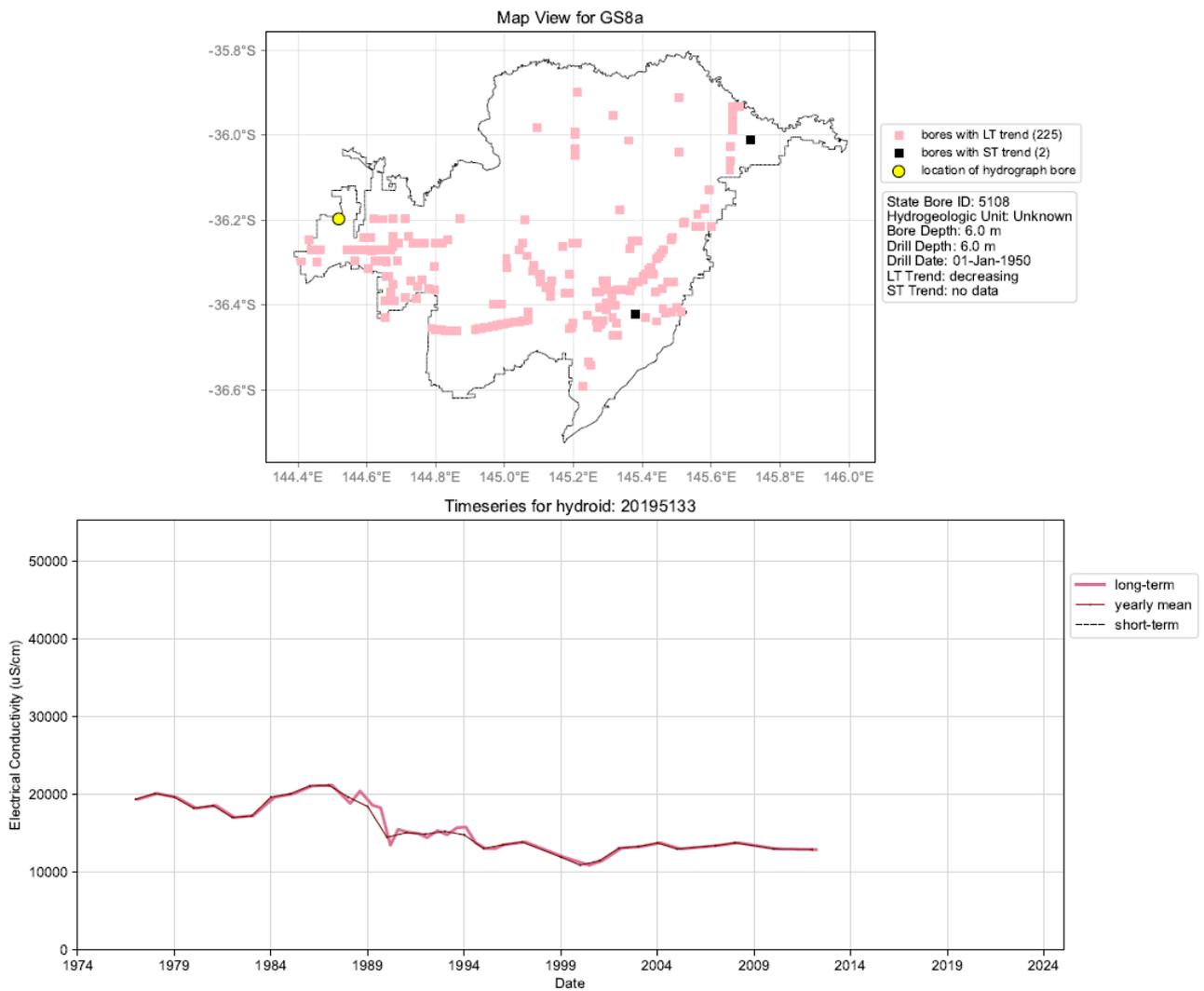


Figure 6.7 Example of groundwater salinity (EC) timeseries with location map

7. A ternary plot showing the long-term and short-term results of Stage 4 spatial analysis

The data needed for the ternary plots (example in Figure 6.8) was developed in Stage 4 and included the asset areas, and the proportional RCI impact areas (improving/stable, deteriorating, or insufficient data for temporal trends). The Stage 4 methods are outlined in Section 5. The ternary plot showed the proportion of the asset area that is improving, deteriorating, or uncertain for each of the four ESLT values, and over the long-term (LT) and short-term (ST) periods of the Project (refer to legend in Figure 6.8). This figure also determined the resource condition ranking (Section 5.2).

This figure showed how insufficient data trends have changed between the long- and short-term periods (assessed by comparing the vertical displacements for the same ESLT asset area). By comparing horizontal displacements, assessments of improving, deteriorating, or variable trend conditions over time were also made. This figure provided a quantitative, objective assessment of SDLRU conditions and uncertainty (due to insufficient data). A striking pattern across most of the SDLRUs analysed was the high levels of insufficient data for the water quality ESLT, which has increased in the short-term. The example situation presented in Figure 6.8 is representative of the situation across many SDLRUs for the salinity ESLT value.

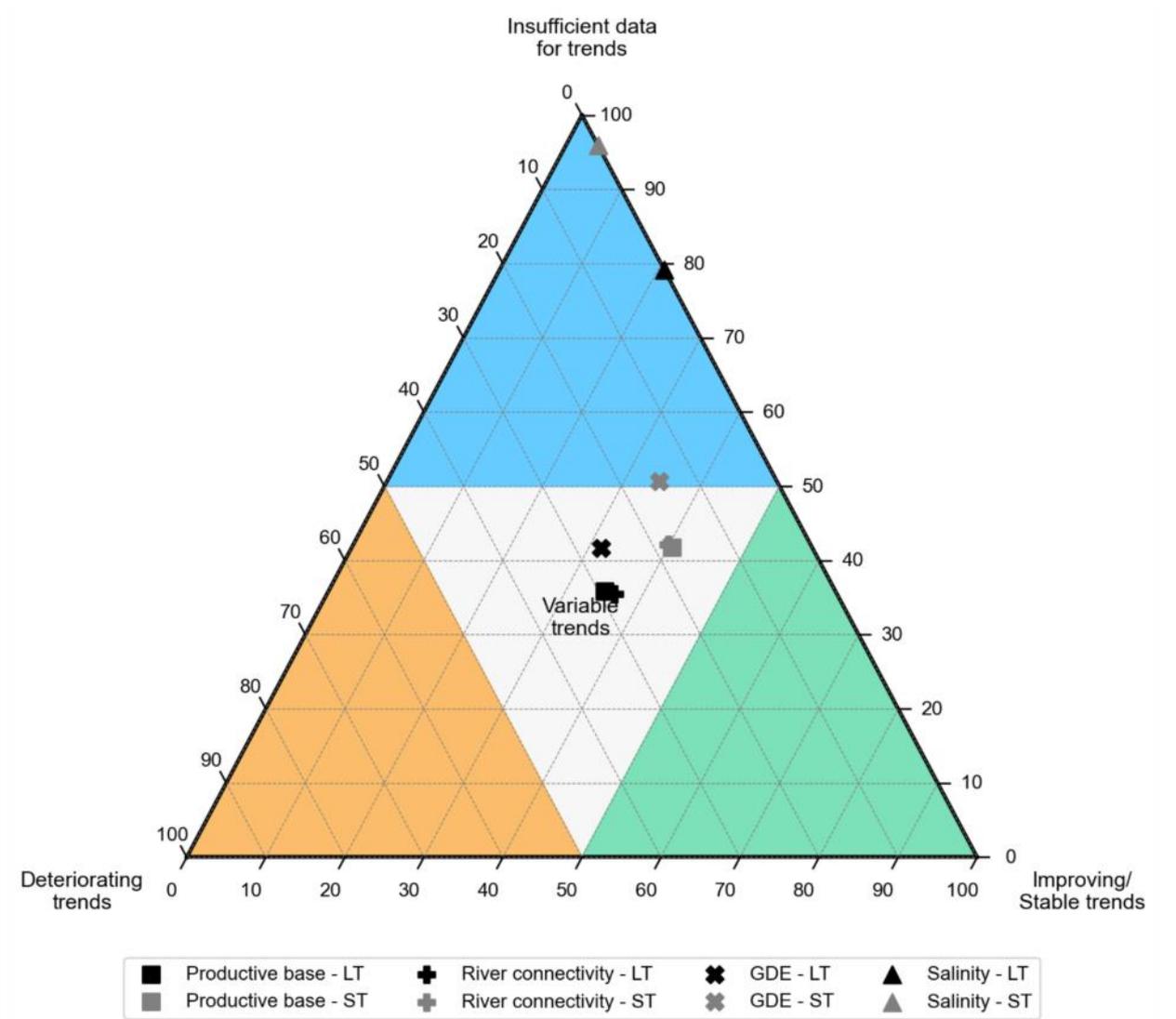


Figure 6.8 Example of a ternary plot

8. Maps of trends in water levels and their magnitude

The processing of Stage 4 data analysis results produced a point data set for each SDLRU, with short- and long-term trend magnitudes for water level. These data were plotted in a map (Figure 6.9), showing trend magnitude where relevant, and also marking locations of no trend or insufficient data. Long-term and short-term data were mapped separately to inform concepts of changes in resource condition over time. A complementary map showed the data density of each monitoring point, displaying the number of years for which the trend was assessed.

This figure also included the frequency of bores with trend magnitudes categorised in specific classes (shown as the bore count in parentheses in the map legend). One trend category is a gentle magnitude trend interval (± 0.1 m/year). This figure revealed potential regional cones of depression, legacy drawdowns at specific locations, potential interactions with river reaches, and the buffering impact with distance (depending on the density of information and the distance to the river reaches).

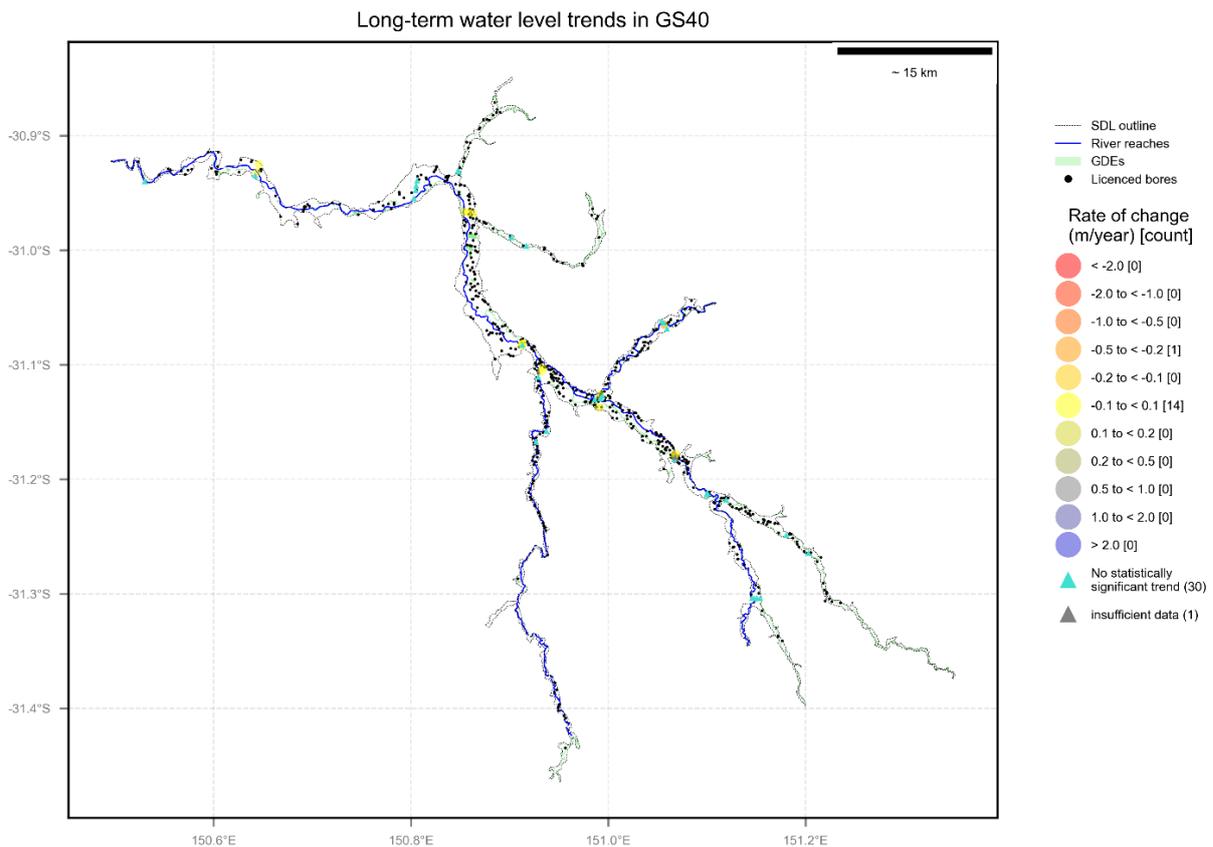


Figure 6.9 Example of map with trends in water levels and their magnitude

9. A salinity class map for each SDLRU

The Stage 4 data for median EC at each bore were interpolated to generate a map of salinity (Figure 6.10). The classes used to present the data were aligned with those of guidelines and informed by the RRAM (Table 4.2). Interpolation methods are discussed in Section 6.3.2. This output was developed to overcome the limitations of salinity records, many of which exhibit poor temporal coverage and are not suitable for temporal trend analysis. This is because the NGIS has considerably fewer records of salinity than water levels, thus limiting a robust assessment of increasing/decreasing trends over time.

The method was informed by the integrated Groundwater Footprint (iGF) (Kourgialas et al., 2018), which Rojas *et al.* (2023b) applied to the alluvial aquifers of the MDB to assess stress levels based on salinity classes defined in the RRAM. The mapped areas of high salinity in the Project outputs are available for future consideration of the freshwater areas and the stress level in the SDLRU due to proximal saline zones.

In many cases of alluvial SDLRUs, salinity maps revealed the impact of localised river recharge on maintaining freshwater pockets along rivers, where most of the groundwater entitlements tend to be spatially concentrated. This figure also provided an indirect assessment of the beneficial use of groundwater, where other classes than freshwater overlapped with groundwater entitlement locations, defining the productive base.

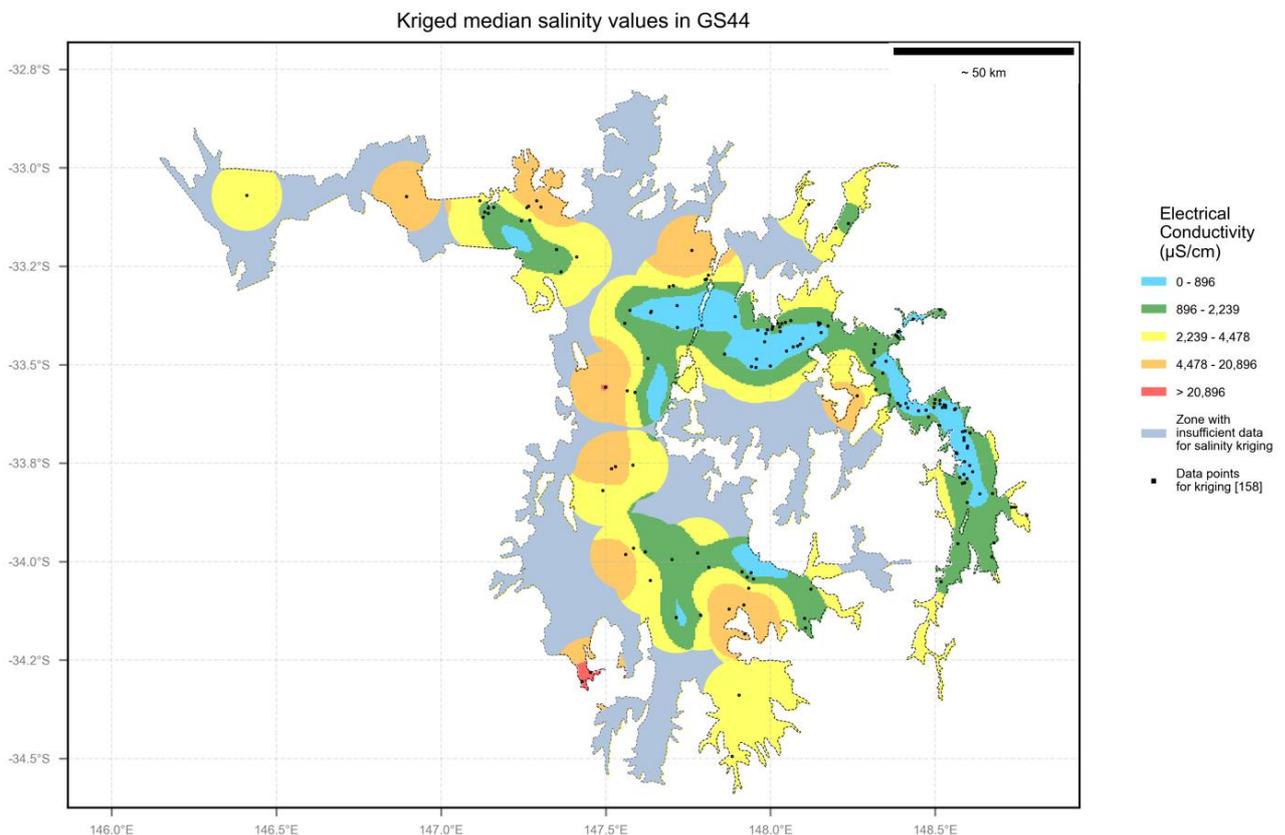


Figure 6.10 Example of salinity class map

10. Trend magnitude as a probability distribution

In Stage 4, the statistical trend analysis provided information on the magnitude of the trend in both RCIs: water levels and EC (salinity). Therefore, these probability distribution charts (Figure 6.11) showed the most likely trend magnitude in both the short- and long-term for the SDLRU. They also provided a picture of the entire data distribution, with broad distributions indicating substantial variability across the SDLRU, i.e., high uncertainty in trend magnitudes. This figure also revealed how the median magnitude of the trend and its associated uncertainty have changed from the long- to the short-term periods.

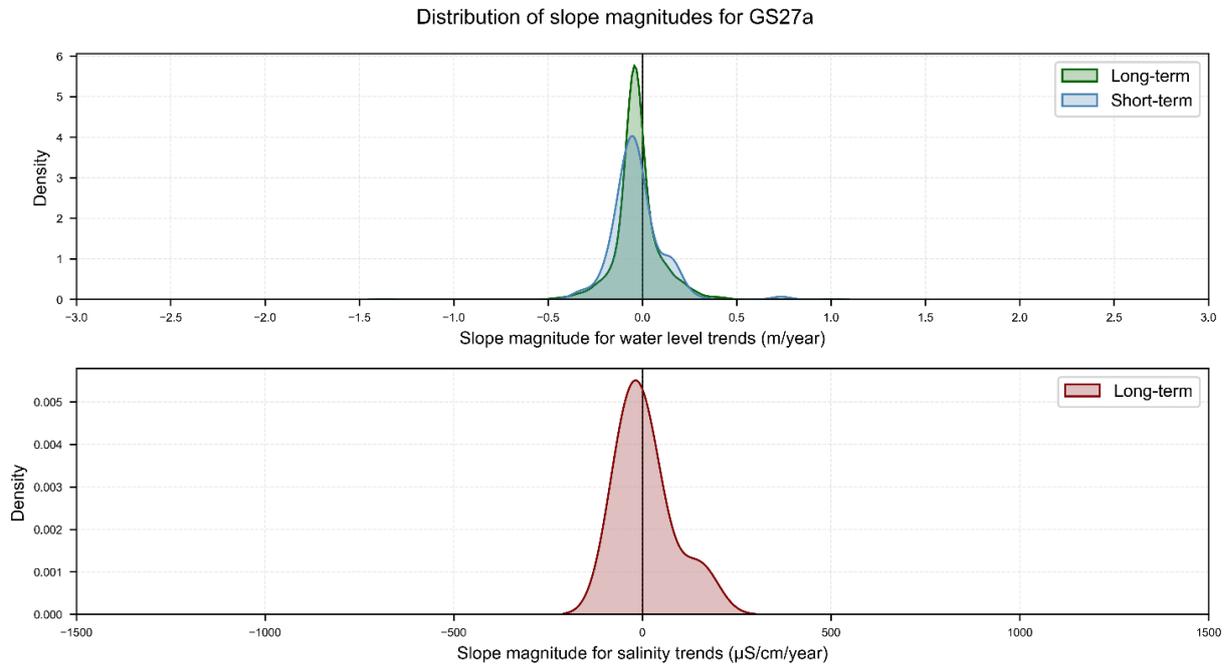


Figure 6.11 Example of probability distribution for trend magnitudes

11. Maps of water level for each SDLRU

The water level data collected in Stage 4 for each SDLRU were interpolated using the methods described below (Section 6.3.2). The data were displayed in maps for both depths below ground (informing GDE and river connectivity ESLTs; Figure 6.12) and elevations (informing productive base assessments; Figure 6.13). The water levels are expressed as statistical summaries of the available temporal records, including the minimum, maximum, and median for short- and long-term periods of the Project.

These maps provided essential insights into depth to water (DTW) and proximity to GDEs, DTW and potential connectivity to river reaches, regional cones of depression, persisting drawdown acting despite more favourable conditions (less groundwater take and above-average rainfall patterns), groundwater flow paths, and broader impacts of groundwater entitlements.

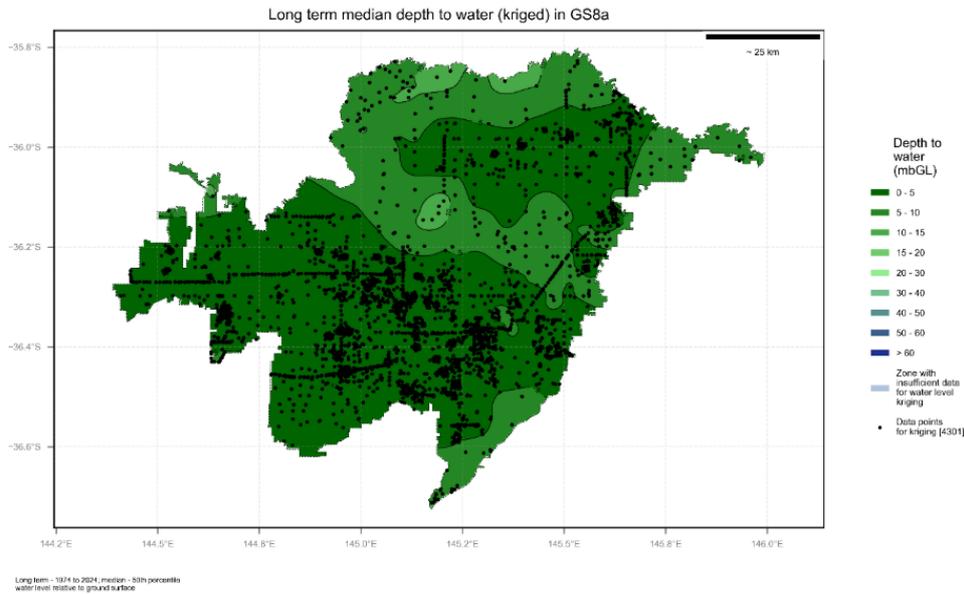


Figure 6.12 Example of depth to water map

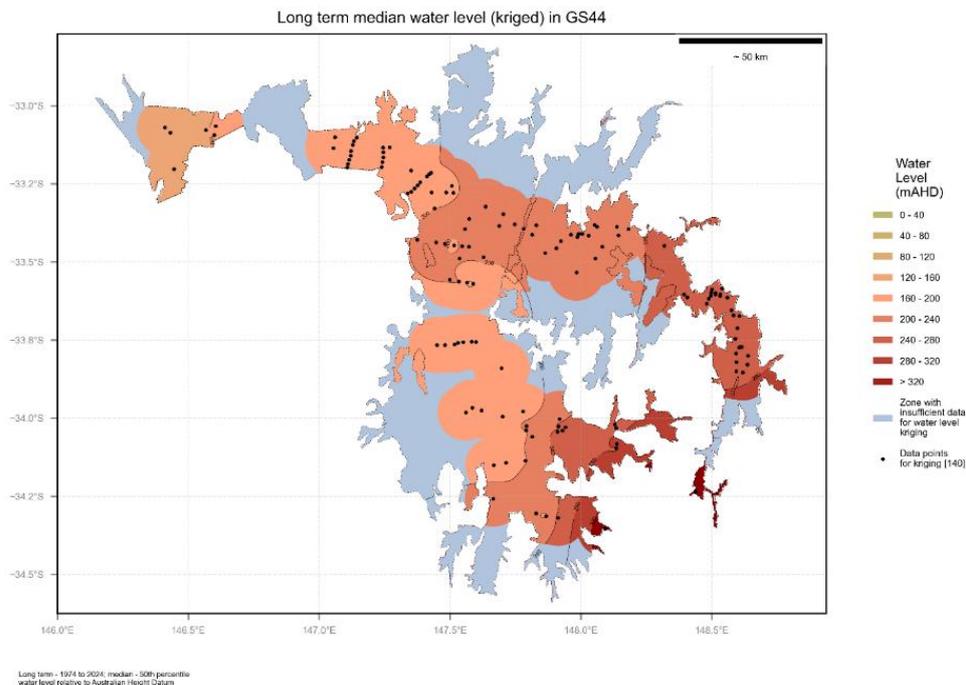


Figure 6.13 Example of water level elevation map

12. Cross sections of selected locations

The scaled cross sections of the Project (Figure 6.14) were constructed to explore groundwater stress in relation to the resource's size and the potential for seasonal drawdown to reach the total available drawdown (TAD). These cross sections were manually positioned at specific locations within the SDLRUs. They were aligned to represent the main hydraulic gradients of the area and display the base of the bores (a proxy for the base of the aquifer or the pressure head zone), along with the interpolated water level elevations on the maps. Additional layers included in the cross sections for context were: the ground surface, the short-term and long-term median groundwater levels, and the long-term fluctuation zone (defined by the 5th and 95th percentiles of groundwater levels over the long-term period).

These figures provided valuable insights into the water level relative to the pressure head zone (analogous to the total available drawdown) from an historical perspective, while accounting for the seasonality of water level variations. In addition, the differences in the average long- and short-term median groundwater levels provided insights into whether the recent groundwater levels have recovered relative to the historical deepest water levels on record, or if declines have continued.

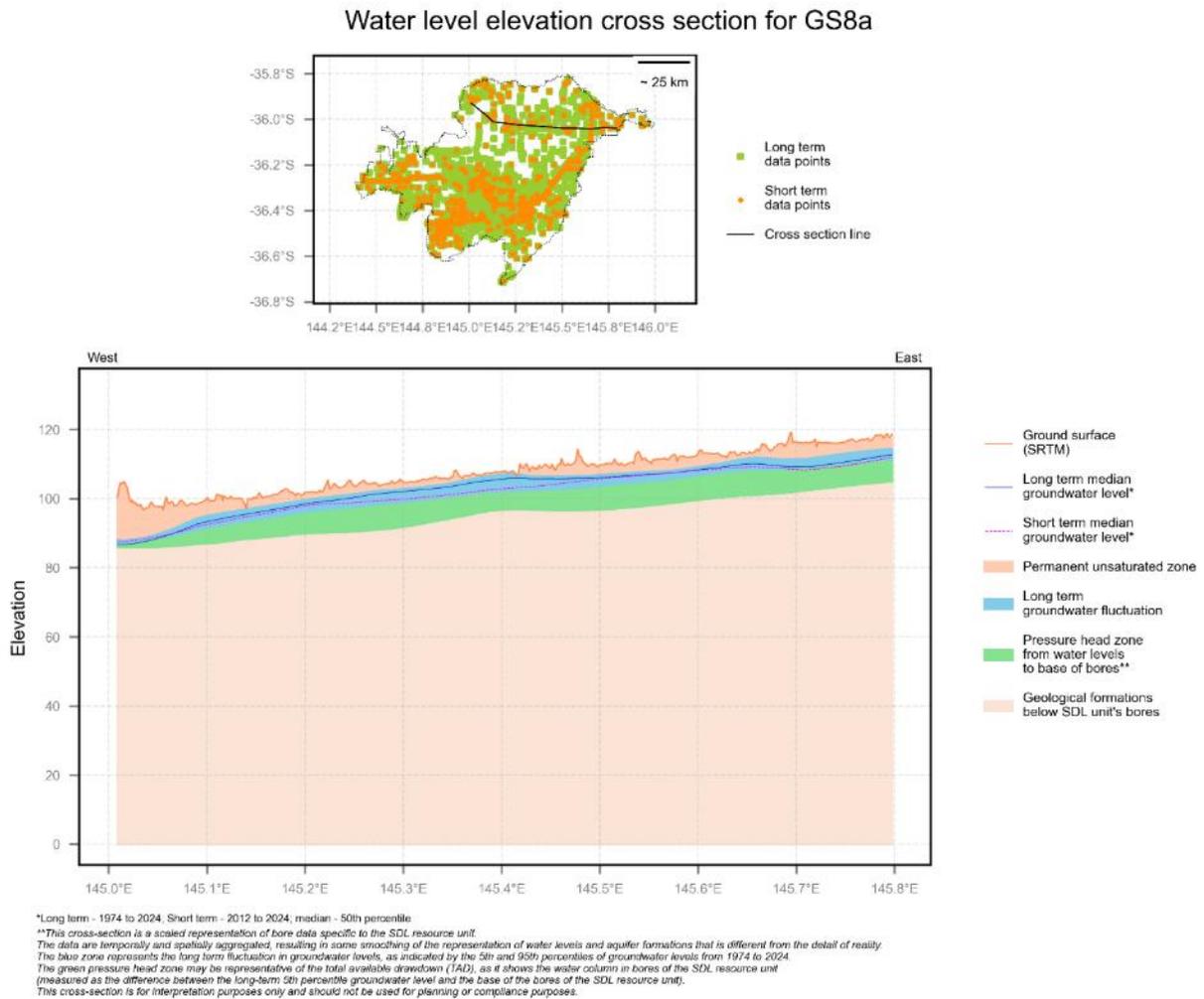


Figure 6.14 Example of a scaled cross-section

6.3 Stage 5 data analysis methods

As stated above, many data sets used in the MLE analyses of Stage 5 were first processed for use in Stage 4. As a result, the method of Stage 4 (Section 5) contains the details of those data sources and analysis methods (e.g. for monitoring bore data, water levels, and salinity data (EC as proxy)).

6.3.1 Climate data analysis

Data from the Scientific Information for Land Owners (SILO; Queensland Treasury and BoM, 2025) database are publicly accessible interpolated rainfall records for the entire MDB. SILO is a database of reconstructed Australian climate data based on observations. The daily rainfall data from SILO were temporally and spatially interpolated from available information, covering the period from 1889 to 2024, the final year of the Project timeframe. For the Project, daily rainfall and evaporation data were downloaded for the period from 1974 to 2024 at a spatial grid approximately 10 km apart. The spatial distribution was then summarised for an SDLRU based on which grid nodes fell within the SDL area. Statistical summaries of the data across the SDLRU were used in the Stage 5 outputs.

6.3.2 Kriging methods

Water level and salinity mapping was performed using kriging for each SDLRU. The kriging process involved calculating summary metrics for all groundwater bores within each SDLRU (Stage 4 data). Before calculating these statistics, anomalies were removed from the water level and salinity (EC) data. Bores with median values below the 5th percentile or above the 95th percentile were excluded to prevent outliers from influencing the analysis, ensuring these bores were not included in the kriging. Subsequently, ordinary kriging was carried out using PyKrige – an open-source Python toolkit (Murphy *et al.*, 2024). A zone of insufficient data was delineated for each map by applying two criteria: a) a 5 km buffer around bores with data; and b) an “insufficient data zone” threshold of 10 km². The 5 km buffer was applied to each bore with data, and the buffered areas were combined and dissolved to create a zone with sufficient data density for reliable kriging results. Areas within the SDLRU that fell outside these zones were classified as zones of insufficient data. These zones might remain fragmented if individual bore buffers connected around a data shortage. Therefore, any insufficient data zones smaller than 10 km² were removed, based on the threshold mentioned above. All procedures were carried out using Python scripts to ensure efficient processing and to minimise manual errors.

7 Stage 6 – Consideration of climate change

7.1 Overview

Stage 6 of the method aimed to assess the robustness of the assessment produced in Stage 5 under future climate change scenarios (NCGRT, 2024). Stage 6 consisted of four main methodologies that were interconnected with each other and the previous stages of the study. The four tasks are explained further below and were:

1. summarising the potential future recharge changes from MD-SY2 studies;
2. estimating the future area of influence using Stage 4 results;
3. estimating future change in SDL/R to further interpret the Stage 2 results; and
4. classification of the pressure from climate change using a decision tree based on Stage 2 and 4 results, and the outcomes of the other Stage 6 tasks.

7.2 Limitations

Ideally, assessing the impacts of climate change on the SDLRUs in relation to ESLT values would involve using a numerical groundwater flow model for each SDLRU; however, models were not available to the study for this purpose. The method undertaken in this study offered an alternative by comparing the temporal trend analysis of groundwater levels in Stage 4 with the potential for drawdown if recharge decreases in the future. The aim of the simplified approach was to provide a high-level interpretation of how climate change might impact the SDLRUs. If climate change reduces recharge for an SDLRU, the affected area is likely to expand, assuming other factors remain constant, and placing greater pressure on the resource. The Project method estimated the future area of influence (Aoi) based on the current Aoi and future recharge projections. The current Aoi was taken to be the observed area of declining trends, as measured in the Stage 4 spatial analysis. AGE recognised that this is a linear method relying on the stationarity of the cone of depression, meaning it assumes groundwater levels will stabilise over time. However, long-term trend analysis indicates that in some bores, declining groundwater levels have not stabilised, despite reductions in extraction across many areas (Fu *et al.*, 2022). Consequently, the key assumption of stationarity in this method is not fully valid. Instead, the method served as a high-level guide to support other evidence in the Project. The study aimed to present the best available science, and some limitations will persist where future knowledge is still evolving.

7.3 Baseline recharge data sources

The recharge rates used to complete Stage 6 were obtained from multiple sources: Stage 2 of this assessment (including rates derived from CMB modelling; Lee *et al.*, 2024); numerical flow models and other SDLRU-specific studies cited in MDBA (2020b); and the baseline recharge rates developed as part of the Murray-Darling Sustainable Yields 2 (MD-SY2) project (draft data provided in January 2025 and derived from with WAVES or CMB modelling; Crosbie *et al.*, 2025). The sources and analyses of baseline recharge data for the Project are detailed in Stage 2 (Section 3), where recharge was estimated in order to analyse SDL/R. In line with the determination in the Methods Workshop (Section 5.2), the data (presented in Appendix B) were also used as inputs for baseline recharge in Stage 6. The variability in baseline recharge estimates contributed to variability in the outcomes of Stage 6 and this was explored as a source of uncertainty.

7.4 Future recharge summary analysis

The first step in considering future climate change impact in this study was to summarise the potential change in recharge relative to current or baseline recharge from the best available science. The current or baseline recharge was characterised as part of Stage 2 and informed this step. The source of data for climate change impact on recharge was the MD-SY2 study (Crosbie *et al.*, 2025), which modelled the projected change in recharge relative to baseline over two time periods: 2030 and 2050. These periods were represented by global warming scenarios of 1.5°C and 2°C, respectively, relative to pre-industrial global temperatures (IPCC³, 2018; pre-industrial representative period of 1850 to 1900). The recharge changes were modelled using WAVES, and predicted potential changes in recharge of three different sources were reported by Crosbie *et al.*, (2025): diffuse recharge, flood recharge (also called over-bank recharge), and in-stream recharge. Predictions were reported as positive or negative percent changes relative to baseline recharge and were provided as distributions for each SDLRU due to the variability of future climates (the P10 provided estimates in dry future conditions; P50 moderate conditions; and P90 wet conditions). For the Project to convert these percentage changes to predicted ranges of future recharge, estimates of current recharge (Table 7.1) and nominal proportions of recharge source contributions (Table 7.2) were used. The two current recharge sources, Stage 2 and MD-SY2, are provided in Appendix B. Overall, these combinations (including the dry, moderate, and wet future conditions represented in the percentage changes) provided 36 permutations of estimates of future recharge in each SDLRU (assumptions for permutations are listed in Table 7.1), which were then statistically summarised.

Table 7.1 Permutations to calculate ranges of future recharge

Recharge change percentile*	Recharge change timeframe*	Current recharge source	R change permutation
Moderate (P50)	2030	Stage 2 recharge	A-Stage 2
Moderate (P50)	2030	MD-SY2 recharge	A-SY2
Moderate (P50)	2050	Stage 2 recharge	B-Stage 2
Moderate (P50)	2050	MD-SY2 recharge	B-SY2
Dry (P10)	2050	Stage 2 recharge	C-Stage 2
Dry (P10)	2050	MD-SY2 recharge	C-SY2
Wet (P90)	2050	Stage 2 recharge	D-Stage 2
Wet (P90)	2050	MD-SY2 recharge	D-SY2
Dry (P10)	2030	Stage 2 recharge	E - Stage 2
Dry (P10)	2030	MD-SY2 recharge	E - SY2
Wet (P90)	2030	Stage 2 recharge	F - Stage 2
Wet (P90)	2030	MD-SY2 recharge	F - SY2

Note: * the change in recharge predictions were from MD-SY2 (Crosbie *et al.*, 2025).

Table 7.2 Permutations for the proportions of recharge sources

Permutation category	Diffuse recharge proportion	Flood recharge proportion	Instream recharge proportion
Balanced	0.6	0.3	0.1
Diffuse	0.8	0.1	0.1
Focussed	0.1	0.8	0.1

³ Note that 1.5°C and 2°C relative to pre-industrial global temperatures (IPCC) are equivalent to 1°C and 1.5°C of warming, respectively as cited in Crosbie *et al.* (2025).

7.5 Area of influence analysis

The Stage 6 output of the Project was an assessment of the potential pressures on the resource from predicted climate change. The objective was to estimate the future expansion or contraction of the area of influence (Aoi) for take (the drawdown area) and compare that to the asset area(s) and the SDL area. The future Aoi calculated in Stage 6 was compared to both asset area and SDLRU area for completeness. The future Aoi was termed A_{dc} (the area of drawdown under future climate). This method relied on a concept of past and future climate change impacting recharge (Figure 7.1) and was dependent on knowing or estimating:

- the area of influence (Aoi) now (A_{dn});
- the rate of recharge in the past (R_0);
- the change in recharge in the past (up to now) due to climate change (ΔR); and
- the future change in recharge predicted due to climate change (δR).

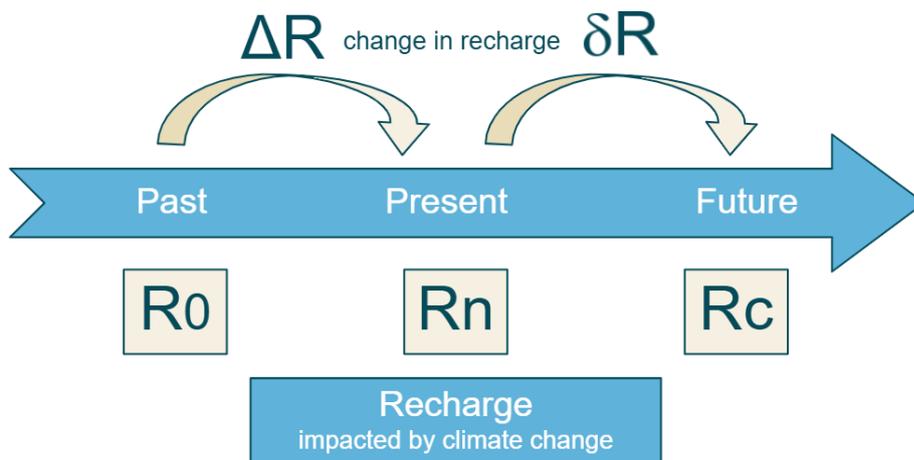


Figure 7.1 Concepts and parameters of recharge change for Aoi calculations

The equation used to estimate A_{dc} was built around the change in drawdown due to future climate change relative to current conditions (NCGRT, 2024):

$$\frac{A_{dc} - A_{dn}}{A_{dn}} = \frac{\delta R}{R_0 + \Delta R + \delta R}$$

The relationship relied on proportional expansion of the Aoi in the future, if recharge were to be decreased (or vice-versa) and used the past relationship between recharge change and Aoi change to determine the magnitude of that proportionality. The NCGRT (2024) method was applied in the Project without changes. The inputs to the equation had various sources and as such twelve permutations were developed using different combinations of source information, as shown in Table 7.3. These were each applied with both long-term and short-term estimates of A_{dn} , and with three permutations for recharge source proportions, if flood or in-stream recharge was known to occur in that SDLRU (Table 7.2; explained further below).

Table 7.3 Permutations for source information to calculate A_{dn}

Permutation number	R_0	ΔR	δR percentile	δR timeframe	R_n
1	CMB*	R_n minus R_0	Moderate (P50)	2030	Stage 2 recharge
2	CMB*	R_n minus R_0	Assumed minimal	N/A	Stage 2 recharge
3	CMB*	δR (P50 at 2030)	Moderate (P50)	2030	Stage 2 recharge
4	MD-SY2	δR (P50 at 2030)	Moderate (P50)	2050	MD-SY2 recharge
5	MD-SY2	δR (P50 at 2050)	Dry (P10)	2050	MD-SY2 recharge
6	MD-SY2	δR (P50 at 2050)	Wet (P90)	2050	MD-SY2 recharge
7	MD-SY2	R_n minus R_0	Dry (P10)	2050	MD-SY2 recharge
8	MD-SY2	R_n minus R_0	Wet (P90)	2050	MD-SY2 recharge
9	CMB*	R_n minus R_0	Dry (P10)	2050	Stage 2 recharge
10	CMB*	R_n minus R_0	Wet (P90)	2050	Stage 2 recharge
11	CMB*	δR (P90 at 2050)	Wet (P90)	2050	Stage 2 recharge
12	CMB*	δR (P10 at 2050)	Dry (P10)	2050	Stage 2 recharge

Note: *Chloride mass balance modelling (Lee *et al.*, 2024).

The application necessitated acceptance of the following assumptions and limitations in the Project:

- An Aol is defined as the area impacted by drawdown caused by groundwater extraction; it expands once pumping commences to cover an area where recharge balances the take. Using the quantitative assessment of Stage 4, the Aol was defined as equivalent to the asset area that showed a deteriorating resource condition, which was a statistically significant declining trend in groundwater level. A_{dn} was therefore assumed to be the deteriorating trend area for the productive base ESLT measured in Stage 4. Due to the structure of Stage 4, this value had two estimates, the long-term and short-term deteriorating areas (e.g. Table 5.2). These assumptions indicated a broad simplification of the concept of groundwater take, drawdown, and the system response to stress. This limitation was noted and explained further in NCGRT (2024).
- There was no clear source of the best information for ΔR , and it was estimated for the SDLRUs based on limited information. The CMB estimate of recharge (Lee *et al.*, 2024) was used as a proxy for past recharge and was compared to the MD-SY2 estimate of baseline recharge (Crosbie *et al.*, 2025) to inform this estimate (refer to Appendix B for values). The nominal time period for the change of ΔR to be applicable was the last 25 years (NCGRT, 2024); however, the estimates may be unintentionally relevant to longer or shorter periods and it is not possible to quantify this error.
- The future change in recharge predicted due to climate change (δR) was provided by MD-SY2 modelling (Crosbie *et al.*, 2025) in the form of proportional increases or decreases in recharge for three main components: diffuse recharge, flood recharge, and in-stream recharge. In order to convert these three components into a single weighted expected change in recharge, the proportions of total recharge were estimated for each recharge type in separate permutations (Table 7.2). The method for this estimation was based on a correlation between recharge factors and annual rainfall (Barron *et al.*, 2012), but was highly uncertain. In response, a range of potential predictions for Stage 6 were provided to communicate potential error and variability in this and other inputs.
- The approach was a linear method and depended on the theoretical future stationarity of the cone of depression (i.e. stabilisation of declining trends in groundwater levels in response to the transient stress of climate change). In reality, the long-term trend analysis of groundwater levels indicates that declining trends have not stabilised in many bores across the basin (Fu *et al.*, 2022). Thus, the main assumption around stationarity in the method to assess the impact of climate change is not completely valid. However, it was employed as a tool to identify those SDLRUs under the most pressure as a result of climate change.

The Aol equation was solved for all possible permutations and the results for A_{dc} (the future Aol) were statistically summarised for the long-term and the short-term. The statistics were graphically represented with the areas from Stage 4 for each SDLRU and the SDLRU area (e.g. Figure 7.2). Where the P50 of the A_{dc} estimates was greater than the A_{dn} from Stage 4, it was interpreted that climate change was more likely than not to reduce recharge and increase drawdown.

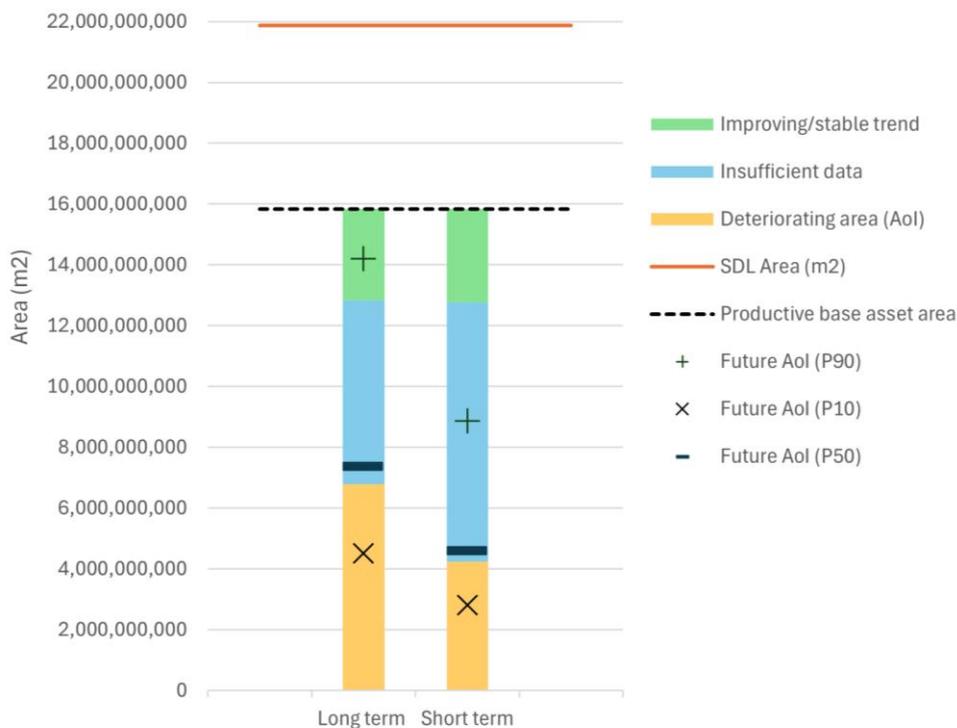


Figure 7.2 Example of Aol analysis chart

7.6 Future SDL/R analysis

In Stage 2 the SDL/R ratio was analysed to determine SDRLU groups. As recharge was an important factor in determining the SDL that took effect in 2019, this ratio is one key measure of the sustainability of the SDL. If recharge were to change in the future, the SDL/R would also change. As part of Stage 6, the future recharge estimates (Section 7.4) were compared to the SDL volumes in predicted SDL/R ratios. The data were compared to the current SDL/R, and it was often the case that the range of predictions bracketed the baseline ratio. This was due to the wet and dry conditions represented in the future recharge modelling (Crosbie *et al.*, 2024; Table 7.1). If the comparison showed that the P50 of the future SDL/R predictions exceeded the current ratio, a negative impact from climate change was inferred as more likely than not.

7.7 Pressure from climate change analysis

As the final component of Stage 6, an assessment that integrated MLE with the predictions of future recharge was developed. The objective of this part of the method was to determine a rating of the pressure likely to be exerted on the SDLRU from future climate change, incorporating the findings of the Project. The method was designed for consistent and objective application to all the 80 SDLRUs of the Basin, and was necessarily simple. A four-tiered decision tree (Figure 7.3) was developed based on Stage 2 results, Stage 4 results, and the outcomes of the other Stage 6 tasks. The questions posed by the four tiers of the tree were:

- Is the rate of groundwater take (E) high or low relative to the SDL?
- Is the SDL volume high or low relative to the rate of recharge that replenishes the resource?
- Is climate change likely to cause an increase or a decrease in recharge for the SDLRU?
- Do RCI trends indicate a deteriorating or improving condition?

The information sources relied on to answer the questions of the decision tree are outlined in Table 7.4. Each tier had two or three possible options as answers, each of which was associated with a point score (Table 7.4). More at-risk options were associated with higher point scores. The points for each SDLRU were totalled to assess the likely pressure from future climate change, with higher totals equating to a higher ranking (Table 7.5).

Table 7.4 Point allocation system used for four-tier decision tree analysis

Tier number	Tier topic	Source of information	Option i – 0 points	Option ii – 1 point	Option iii – 0.5 point	Exceptions
1	Rate of use	Stage 2 – E/SDL	Low use	High use	N/A	N/A
2	Rate of replenishment	Stage 2 - SDL/R	Fast replenishment	Slow replenishment	N/A	N/A
3	Climate change impact	Stage 6 – summary of MD-SY2	Increase in recharge	Decrease in recharge*	N/A	Zero baseline recharge**
4	RCI trends	Stage 4 – Productive base trend grouping	Improving /stable or mixed trends	Deteriorating trends	Uncertain trends	No productive base***

Notes: * Includes uncertain or ambiguous change in recharge.

** If baseline recharge is zero, climate change can only exert minor pressure on the resource, and the level defaults to very low.

*** If there is no productive base, climate change can only exert minor pressure on the resource, and the level defaults to very low.

Table 7.5 Point totals and categories used for four-tier decision tree analysis

Total points from four-tier assessment	Classification of pressure from climate change
0	Very low pressure from climate change
0.5	Very low pressure from climate change
1.5	Low pressure from climate change
2	Moderate pressure from climate change
2.5	Moderate pressure from climate change
3	High pressure from climate change
3.5	Very high pressure from climate change
4	Very high pressure from climate change

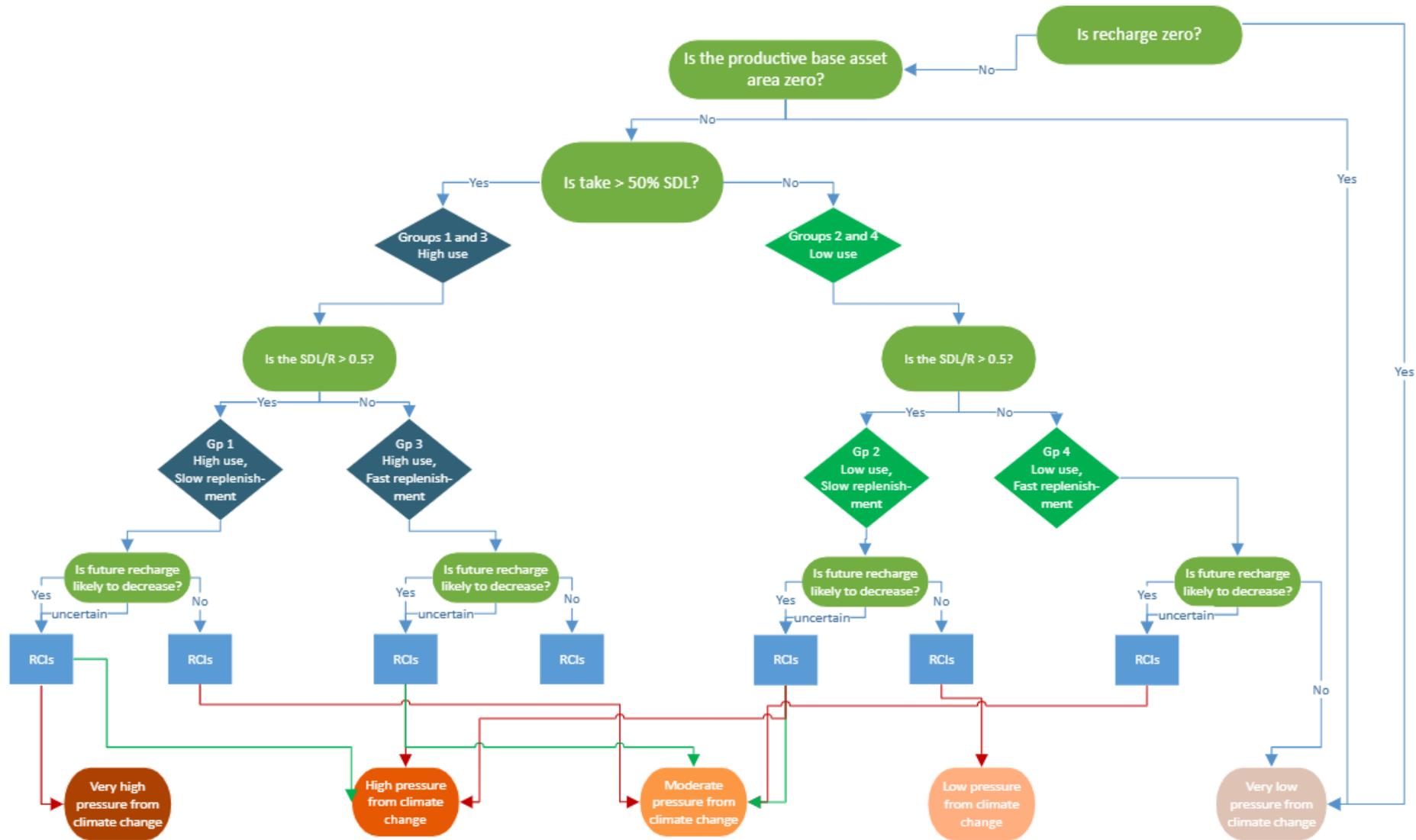


Figure 7.3 Stage 6 decision tree for determination of rank for climate change pressure

8 Concluding remarks and summary

A revised method has been developed and implemented to assess the level of pressure that groundwater extraction in the current Sustainable Diversion Resource Units (SDLRUs) has on the following ESLT values:

- productive base;
- surface water – groundwater connectivity (river connectivity);
- groundwater-dependent ecosystems (GDEs); and
- water quality (groundwater salinity).

The method follows these principles:

- consider the degree of development of SDLRUs for initial screening to identify units requiring further scrutiny;
- balance between consistency and local nuance;
- reliance on best available data and flexibility in terms of the type of data that can be used in the assessment process;
- reliance on a data-driven approach through an assessment of current resource condition inferred from groundwater level and salinity trends;
- conservative approach where information is absent (precautionary principle);
- the use of multiple, independent lines of evidence to increase confidence in outcomes; and
- attributes a high pressure to an ESLT value only where pressures are widespread across the SDLRUs or across the environmental or connected surface water assets within the SDLRU.

The methods present valuable outcomes that inform the Basin Plan review, by providing:

- the most up-to-date available science and information regarding groundwater SDLRUs;
- a substantial amount of quantitative information to assess the level of pressure on the four ESLT values presented in standardised forms such as maps, charts, and tables;
- a graphical tool to evaluate the transition from long- to short-term trends in water levels and salinity, including changes in improving, deteriorating, and variable trend conditions, along with considerations about insufficiency of data for temporal trends and associated uncertainties; and
- a decision tree to systematically assess the pressure from future climate change on ESLT values.

Recommendations are as follows:

- The best way to assess in detail whether the SDL reflects a pressure on the ESLT values is by using groundwater flow modelling to assess those impacts, and make predictions with quantified uncertainty. Suitable scenarios, model performance metrics, and quantities of interest linked to the ESLT values should be defined and tested under different stress conditions (e.g., SDL volume, projected changes in recharge rates). Therefore, it is recommended that groundwater models for SDLRUs be developed (or updated) where pressures are high, imminent, or emergent.
- Evidence from the implementation of the method suggests that groundwater monitoring networks could benefit from an in-depth review. There is a substantial lack of information on groundwater salinity, which precludes temporal trend assessment in many SDLRUs. Even in those SDLRUs with good water level monitoring network coverage, salinity monitoring remains relatively poor.
- Consider the inclusion of other values, such as cultural and spiritual values of groundwater. Similar principles as for the other ESLT values could be implemented through the identification of culturally significant springs or heritage sites and their application to a new ESLT asset area as an extension of Stage 4.
- Group quantitative metrics and outputs of the analysis around formal concepts of groundwater resilience, stress, and sustainability, and frame the analysis of pressure on ESLT values from a multidimensional perspective as suggested by Rojas et al. (2023) for the alluvial aquifers of the MDB.
- Define clear adaptation pathways to manage the SDLRUs under high or imminent pressures, and those where pressures to sustainable management of ESLT values are emerging. The overarching strategy would be to search for robust management strategies as a basis for adaptive management, rather than for strategies aimed at achieving optimal conditions. This will ensure management strategies continue to be well suited to produce satisfactory outcomes across a wide range of uncertain conditions.

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Appendix A

Stage 1 – Approach to Content and Sources

Table A 1 Methods and content for specific items covered in Stage 1

Topic	Methods and content
Climate	<p>Method:</p> <ul style="list-style-type: none"> • Used Water Resource Description (found as one of the documents in the Water Management Plan from the MDB website – usually Appendix A). • If not available, used site-specific data sourced from the BoM climate data online. <p>Content:</p> <ul style="list-style-type: none"> • Annual total rainfall. • Seasonal patterns of rainfall. • Variability of rainfall across the geographical area of the SDLRU. • Potential or actual evaporation (annual total) – seasonal variability. • Seasons where rainfall deficit exists.
Land use	<p>Method:</p> <ul style="list-style-type: none"> • Used Water Resource Description (found as one of the documents in the Water Management Plan from the MDB website – usually Appendix A). <p>Content:</p> <ul style="list-style-type: none"> • Simple, factual, and current land use as percentages. • Mentioned the main population centres if needed. • The focus of land use may have been on what groundwater is used for, but groundwater use was not described here.
Groundwater management	<p>Method:</p> <ul style="list-style-type: none"> • Used the main Water Resource Plan document (For some SDLRUs the WRP had been withdrawn, and thus a preliminary version was used instead). <p>Content:</p> <ul style="list-style-type: none"> • Mentioned the main Water Resource Plan. • Mentioned Water Sharing Plan if needed. • Mentioned any management zones in the plan that relate to the SDL. • Mentioned Water Quality Management plan if needed. • Basin Plan or the Salinity Management plan of 2030 (Basin scale) were omitted as assumed knowledge.
Hydrogeological system description	<p>Method:</p> <ul style="list-style-type: none"> • Used Water Resource Description (found as one of the documents in the Water Management Plan from the MDB website – usually Appendix A). • Used the Groundwater Report Card descriptions (MDBA, 2020b). • Used major publications and peer-reviewed journal articles if they exist for the SDLRU. <p>Content: For all SDLRUs maintained the following content format if possible:</p> <ul style="list-style-type: none"> • Hydrogeological definition and boundaries. • Aquifer material, geometry, hydraulic conductivity/transmissivity. • Recharge/discharge processes. • Connectivity with surrounding aquifer units and surface water. • Groundwater flow direction and gradients (if available). • Groundwater use and associated extraction rates (minimal, as this was also covered in Productive Base). • Groundwater quality.

Topic	Methods and content
Groundwater system type	<p>Method:</p> <ul style="list-style-type: none"> • Used Water Resource Description (found as one of the documents in the Water Management Plan from the MDB website – usually Appendix A). • Used the Groundwater Report Cards (MDBA, 2020b). • Used major publications and peer-reviewed journal articles if they exist for the SDLRU <p>Content: For all SDLRUs identified the following aquifer types as relevant:</p> <ul style="list-style-type: none"> • Unconfined, Semi-confined, Confined. • Fractured rock. • Weathered aquifer. • Unconsolidated, alluvial, valley-fill. • Porous rock, sedimentary.
Surface water description	<p>Method:</p> <ul style="list-style-type: none"> • Used Water Resource Description (WRPs). • Reviewed data from Crosbie et al. (2023) about surface water – groundwater connectivity, available information for assessment, and SDL-based classification (losing, losing- disconnected, variable). • Used major publications and peer-reviewed journal articles if they exist for the SDLRU. <p>Content:</p> <ul style="list-style-type: none"> • High-level description of the surface water system. • Main rivers and tributaries. • Main regulation infrastructure. • Seasonality and other flow regime features.
SDL	<p>Method:</p> <ul style="list-style-type: none"> • Used Basin Plan Schedule 4 to obtain the official SDL volume for each SDLRU. Accuracy as reported by two decimal points in GL/year. (Basin Plan 2012 - Federal Register of Legislation).
SDLRU area	<p>Method:</p> <ul style="list-style-type: none"> • Used official spatial dataset defining the groundwater SDLRUs as defined by MDBA (https://data.gov.au/data/dataset/groundwater-sdl-resource-units). • Used GIS to calculate the SDLRU polygon area.
Recharge	<p>Method:</p> <ul style="list-style-type: none"> • Acknowledged several recharge estimates have been published for the SDLRUs in the MDB. Collected information from the following sources and reported recharge rates: <ul style="list-style-type: none"> • Recharge rates as reported in the Groundwater Report Cards (MDBA, 2020b). Most of these recharge estimates are based on the Recharge Risk Assessment Methodology (RRAM) developed in the framework of the MD-SY project, or results obtained from existing calibrated groundwater models or site-specific studies. • Diffuse recharge estimates as calculated and modelled by Lee et al. (2024) using the Chloride Mass Balance (CMB) method across all of Australia. For this method, recharge rates were only estimated for SDLRUs with a surface expression. That is, SDLRUs defined as deep and completely underlying other units are assumed to have zero diffuse recharge. • Recharge rates as reported by Crosbie et al. (2025) in the context of the MD-SY2 project (WAVES 2025 diffuse baseline modelling). • Confidence in terms of recharge estimates is as follows: recharge estimates including multiple sources and obtained through groundwater model calibration are considered first; recharge estimates considering only diffuse recharge obtained from Lee et al. (2024) (CMB) or the MD-SY2 project (WAVES 2025) are considered second; recharge estimates considering only diffuse recharge obtained from the MD-SY project (WAVES 2010) are considered third.

Topic	Methods and content
Extraction (Av. 2013-2021) (GL)	<p>Method:</p> <ul style="list-style-type: none"> Average annual groundwater extraction rates were obtained from the Transitional Water Take Reports for the period 2012-2019 (https://www.mdba.gov.au/publications-and-data/publications/transitional-sustainable-diversion-limits-water-take-reports) and the Sustainable Diversion Limit Reporting for the period 2020-2024 (https://www.mdba.gov.au/water-use/water-limits/sustainable-diversion-limits).
Extraction trend	<p>Method:</p> <ul style="list-style-type: none"> Described the extraction trend based on annual extraction rates reported at SDLRU-scale. Plots were developed to show annual take since 2012 against SDL volume since 2019. <p>Content:</p> <ul style="list-style-type: none"> Described the number of years with extraction above the SDL level. Described seasonality and correlation with rainfall anomaly. Described most recent trend in groundwater extraction and average percent of SDL.
Location / density of extraction	<p>Method:</p> <ul style="list-style-type: none"> Used the maps in state Water Resource Plans and/or groundwater entitlement locations downloaded from public repositories or shared by the state jurisdictions. Maps were developed to show locations and sizes of licenced extraction. <p>Content:</p> <ul style="list-style-type: none"> Short description of extraction areas in the SDLRU. Clustering and spatial distribution patterns. Density of production bores versus basic landholder rights (stock and domestic). A map of licenced groundwater take points.
Description of ESLT values and potential threats	<p>Method:</p> <ul style="list-style-type: none"> For the Productive Base/River Connectivity/GDEs/Water Quality (Salinity), used the Water Resource Description (found as one of the documents in the Water Management Plan from the MDB website – usually Appendix A). For the Productive Base, referenced the state-based risk assessment. For River Connectivity, used the latest connectivity assessment from Crosbie et al. (2023). Used major publications and peer-reviewed journal articles if they exist for the SDLRU. <p>Content:</p> <ul style="list-style-type: none"> Productive Base: Described licenced extraction, including amount, density, location, and main use if possible. Also described Stock and Domestic or unlicensed use. River connectivity: Described the classification of the SDLRU based on Crosbie et al. (2023), individual reaches as losing, gaining, or variable. GDE: Described the main GDE communities, locations, sites of relevance RAMSAR or HEVAE data, and presence of riverine and terrestrial GDEs. Water quality: mainly focused on salinity only, with other threats (e.g., nutrients, pesticides) being secondary if cited in literature, salinity ranges, spatial distribution, connectivity to surface water, presence of salt interception schemes.

Topic	Methods and content
<p>Influence of climate (historical and future projections) on ESLT values</p>	<p>Method:</p> <ul style="list-style-type: none"> • Referenced limited information available in Water Resource Description (Appendix A). • Used MD-SY2 data for recharge projections to infer changes in diffuse recharge and focused recharge (flooding and in-stream). Three scenarios were available: dry, median and wet conditions; only used P50 values to report on the median conditions (most likely) to occur for the recharge rates. • If no information was available in MD-SY2, acknowledged and reported on residual uncertainty. • Linked impacts of climate change and future projections of recharge rates to each ESLT. For example, changes in diffuse recharge may impact the productive base and terrestrial GDEs, changes in focused recharge may impact river connectivity and riverine GDEs. • Alternatively, referenced NSW-NARClim project predictions of climate change impacts. For consistency, MD-SY2 climate projections results were prioritised. <p>Content:</p> <ul style="list-style-type: none"> • Productive Base: referred to diffuse recharge change of MD-SY2 (1.5°C to 2°C warmer relative to pre-industrial global temperatures – Crosbie et al., 2025), referred to NSW-NARClim as well, if it differed. • River connectivity: referred to In-stream and Flood recharge change of MD-SY2. • GDE: typically poorly documented, thus made inference on impact based on impacts to connectivity and conceptual model. • Water quality: typically poorly connected, thus made an inference on the impact based on connectivity and the conceptual model (e.g., salt flushing and dilution increasing or decreasing based on predicted changes to recharge). Put the importance of this inference in the context of the WQ in the SDLRU, i.e., is it sensitive to change? • All ESLTs: if conflicting climate predictions exist (e.g. NSW-NARClim), acknowledged this and added as residual risk/uncertainty: <ul style="list-style-type: none"> • Regional and long-term studies (States). • Detailed study (SDL zone only) and specific timeline and specific hydroclimates for Basin Plan (SY2). • Acknowledged that changes to the net future recharge due to climate change are uncertain, given conflicting signals in diffuse recharge (increasing) and localised recharge (decreasing) in the results from MD-SY2 (Crosbie et al., 2025).
<p>Data availability / uncertainty with respect to ESLT values and threats</p>	<p>Method:</p> <ul style="list-style-type: none"> • Data availability: <ol style="list-style-type: none"> a. Productive base: High = many bores evenly dispersed across the SDL area with widespread monitoring. Assessed the number of stock and domestic bores (unregulated) observed – if multiple, considered medium data availability, as these are not metered. Assessed monitoring network coverage (spatial and temporal). b. River Connectivity: High = nested bore sites with flow gauges, monitoring connection between aquifers in different geological units and surface water, many bores evenly distributed. Used Crosbie et al. (2023) to assess data quality (bores and river gauges), as this is the most recent and comprehensive basin-scale connectivity assessment. c. GDEs: assessed data availability using the Stage 4 RCI data, the GDE Atlas, and the existing modelling reports. d. Water quality: assessed data availability using groundwater report cards (MDBA, 2020b), and Rojas et al. (2023) for alluvial aquifers in the MDB. • Productive base: state if groundwater take was metered then assumed moderate to moderate/high; if estimated then assumed low; checked monitoring bore network from GIS workspace, assessed coverage and distribution. • River connectivity: assessed how many bores and stream gauges were adjacent to each other. Referred to Crosbie et al. (2023). • GDE: analysed the uncertainty in the GDE assessments for the definitions and descriptions above. If GDEs were listed in Appendix A for the SDLRU, then defined as “moderate” uncertainty. Also refer to Rojas et al. (2021). • Water quality: assessed AGE-compiled files of available salinity data. Also referred to Rojas et al. (2023b). <p>Content:</p> <ul style="list-style-type: none"> • Started with an overall statement on data availability (low, moderate, moderate-high). • Then added statements of supporting information and reasonable levels of uncertainty.

Topic	Methods and content
Existing condition assessments and findings	<p>Method:</p> <ul style="list-style-type: none"> • AGE interpretation based on all the previous lines of evidence. • Collated / combined main findings from the above sections. <p>Content:</p> <ul style="list-style-type: none"> • Mentioned SDLRU description, threats, data availability, climate change and integrated it with a high-level assessment concentrating on the four ESLT values.
Key findings from State-based risk assessment (and risk mitigation measures in place)	<p>Method:</p> <ul style="list-style-type: none"> • Collated all information from State-based risk assessments (found with the WRPs). No interpretation was required, as risk classification is prescriptive and the methodologies of the WRPs are consistent across all SDLRUs. • Refinement of risk statements considered: <ul style="list-style-type: none"> • making sure risks related to the SDLRU (checked SDL definition in relation to WRP area or resource) • making sure that risks were categorised according to the most important ESLT value and not repeated between ESLT values. • Updated the level of assessed and residual risk and verified that the mitigation measures/justification/controls remained appropriate. <p>Contents with formatting:</p> <p><u>Risks to specific ESLTs</u></p> <p>> Preliminary / Inherent Risk</p> <p>> Residual Risk</p> <p>* Justification / Mitigation measures</p>

Appendix B

Stage 2 – Inputs and results

Table B 1 Inputs and results of Stage 2 analysis, with recharge data comparisons

Code	SDLRU name	SDL volume (GL/y)	Average annual take (2013 to 2023)	Recharge (MD-SY1) GL/year	Recharge MD-SY2 diffuse baseline (GL/year)	Stage 2 - Recharge GL/year	Stage 2 recharge source	Stage 2 - Extraction/SDL (E/SDL)	Stage 2-SDL/Recharge (SDL/R)
GS52	Australian Capital Territory (Groundwater) (GS52)	3.16	0.64	150.4	56.95	197.29	Diffuse recharge only	0.2	0.02
GS20	Lachlan Fold Belt MDB (GS20)	259	81.56	8003.2	287.51	3671.12	Diffuse recharge only	0.31	0.07
GS19	Kanmantoo Fold Belt MDB (GS19)	18.7	8.25	91.6	24.44	23.59	Diffuse recharge only	0.44	0.79
GS50	Western Porous Rock (GS50)	226	33.56	395.7	91.93	70.38	Diffuse recharge only	0.15	3.21
GS34	NSW GAB Surat Shallow (GS34)	15.5	2.14	180.2	424.8	379.36	Diffuse recharge only	0.14	0.04
GS17	Gunnedah-Oxley Basin MDB (GS17)	127.5	12.66	624.7	1475.07	302.89	Diffuse recharge only	0.1	0.42
GS37	New England Fold Belt MDB (GS37)	55.1	20.3	2451.5	651.82	1865.72	Diffuse recharge only	0.37	0.03
GS35	NSW GAB Warrego Shallow (GS35)	33.4	0.65	250.6	45.28	61.87	Diffuse recharge only	0.02	0.54
GS28a	Lower Murrumbidgee Shallow Alluvium (GS28a)	26.9	9.12	438	119.74	438	Diffuse recharge, irrigation recharge, river leakage and lateral flows - Numerical Model	0.34	0.06
GS28b	Lower Murrumbidgee Deep Alluvium (GS28b)	273.6	225.69	0	0	0	No Diffuse Recharge	0.82	N/A
GS25	Lower Lachlan Alluvium (GS25)	117	100.52	120	57.21	120	Diffuse recharge, irrigation recharge, river leakage and lateral flows - Numerical Model	0.86	0.98
GS27a	Lower Murray Shallow Alluvium (GS27a)	81.9	6.1	337	138.51	337	Diffuse recharge, irrigation recharge, river leakage and lateral flows - Numerical Model	0.07	0.24
GS27b	Lower Murray Deep Alluvium (GS27b)	88.9	63.03	271	0	271	Diffuse recharge, irrigation recharge, river leakage and lateral flows - Numerical Model	0.71	0.33
GS44	Upper Lachlan Alluvium (GS44)	94.2	55.54	186.5	195.41	186.5	Numerical Model	0.59	0.51
GS36	NSW GAB Central Shallow (GS36)	8.83	0.91	65.9	11.62	16.44	Diffuse recharge only	0.1	0.54
GS17	Gunnedah-Oxley Basin MDB (GS17)	127.5	12.66	624.7	1475.07	302.89	Diffuse recharge only	0.1	0.42
GS42	Upper Darling Alluvium (GS42)	6.59	3.61	14.3	8	10.05	Diffuse recharge only	0.55	0.66
GS29	Lower Namoi Alluvium (GS29)	88.3	76.25	68.2	98.69	68.2	Diffuse recharge, irrigation recharge, river leakage and lateral flows - Numerical Model	0.86	1.29
GS10	Adelaide Fold Belt MDB (GS10)	6.9	2.3	13.1	3.06	6.86	Diffuse recharge only	0.33	1.01

Code	SDLRU name	SDL volume (GL/y)	Average annual take (2013 to 2023)	Recharge (MD-SY1) GL/year	Recharge MD-SY2 diffuse baseline (GL/year)	Stage 2 - Recharge GL/year	Stage 2 recharge source	Stage 2 - Extraction/SDL (E/SDL)	Stage 2-SDL/Recharge (SDL/R)
GS38	Oaklands Basin (GS38)	2.5	0	0	0	0	The Oaklands Basin SDL resource unit is buried underneath other SDL resource units and does not receive rainfall recharge.	0	N/A
GS26	Lower Macquarie Alluvium (GS26)	70.7	33.27	62.8	47.25	62.8	Diffuse recharge, irrigation recharge, river leakage and lateral flows - Numerical Model	0.47	1.13
GS47	Upper Namoi Alluvium (GS47)	123.4	82.71	91	72.27	91	Diffuse recharge, irrigation recharge, river leakage and lateral flows - Numerical Model	0.67	1.36
GS22	Liverpool Ranges Basalt MDB (GS22)	2.16	1.87	88.1	34.62	79.9	Diffuse recharge only	0.87	0.03
GS24	Lower Gwydir Alluvium (GS24)	33	30.54	47.1	38.53	47.1	Diffuse recharge, irrigation recharge, river leakage and lateral flows - Numerical Model	0.93	0.7
GS41	Sydney Basin MDB (GS41)	19.1	1.11	106.6	20.65	59.01	Diffuse recharge only	0.06	0.32
GS18	Inverell Basalt (GS18)	4.15	1.35	110.5	34.38	40.67	Diffuse recharge only	0.33	0.1
GS23	Lower Darling Alluvium (GS23)	2.23	0.79	6.75	1.35	2.61	Diffuse recharge only	0.35	0.85
GS31	Mid-Murrumbidgee Alluvium (GS31)	53.5	35.98	73.2	23.3	73.2	Diffuse recharge, irrigation recharge, river leakage and lateral flows - Numerical Model	0.67	0.73
GS49	Warrumbungle Basalt (GS49)	0.55	0.54	31.3	15.14	28.89	Diffuse recharge only	0.98	0.02
GS39	Orange Basalt (GS39)	10.7	1.59	122.7	25.38	70.32	Diffuse recharge only	0.15	0.15
GS51	Young Granite (GS51)	7.11	1.88	85.8	17.44	2.72	Diffuse recharge only	0.26	2.61
GS13	Billabong Creek Alluvium (GS13)	7.5	2.86	22	12.74	3.45	Diffuse recharge only	0.38	2.17
GS41	Sydney Basin MDB (GS41)	19.1	1.11	106.6	20.65	59.01	Diffuse recharge only	0.06	0.32
GS46	Upper Murray Alluvium (GS46)	14.1	11.51	19.7	8.91	3.73	Diffuse recharge only	0.82	3.78
GS32	NSW Border Rivers Alluvium (GS32)	8.4	5.18	19	5.86	4.37	Diffuse recharge only	0.62	1.92
GS45	Upper Macquarie Alluvium (GS45)	17.9	15.59	20.6	5.97	20.6	Numerical Model	0.87	0.87
GS33	NSW Border Rivers Tributary Alluvium (GS33)	0.41	0.16	4.5	4.56	2.68	Diffuse recharge only	0.39	0.15
GS14	Castlereagh Alluvium (GS14)	0.62	0.08	12.6	2.61	1.11	Diffuse recharge only	0.13	0.56
GS40	Peel Valley Alluvium (GS40)	9.34	5.71	22.9	4.16	2.89	Diffuse recharge only	0.61	3.23

Code	SDLRU name	SDL volume (GL/y)	Average annual take (2013 to 2023)	Recharge (MD-SY1) GL/year	Recharge MD-SY2 diffuse baseline (GL/year)	Stage 2 - Recharge GL/year	Stage 2 recharge source	Stage 2 - Extraction/SDL (E/SDL)	Stage 2-SDL/Recharge (SDL/R)
GS15	Coolaburragundy–Talbragar Alluvium (GS15)	3.47	2.07	4.25	3.2	0.92	Diffuse recharge only	0.6	3.77
GS43	Upper Gwydir Alluvium (GS43)	0.72	0.16	7.5	2.49	1.19	Diffuse recharge only	0.22	0.61
GS21	Lake George Alluvium (GS21)	1.27	0.5	2.05	0.96	2.18	Diffuse recharge only	0.39	0.58
GS48	Upper Namoi Tributary Alluvium (GS48)	1.77	0.2	2.36	0.99	0.56	Diffuse recharge only	0.11	3.16
GS12	Belubula Alluvium (GS12)	2.88	1.14	3.92	1.03	0.3	Diffuse recharge only	0.4	9.6
GS30	Manilla Alluvium (GS30)	1.23	0.17	12.6	0.99	0.4	Diffuse recharge only	0.14	3.08
GS16	Cudgegong Alluvium (GS16)	2.53	1.79	1.38	0.51	0.57	Diffuse recharge only	0.71	4.44
GS11	Bell Valley Alluvium (GS11)	3.29	0.98	2.3	0.39	0.13	Diffuse recharge only	0.3	25.31
GS56	Queensland MDB: deep (GS56)	100	0.03	0	68.62	704.69	infiltration of rainfall into the outcropping sandstone aquifers and leakage through unconsolidated sediments overlying the aquifers	0	0.14
GS60	Sediments above the Great Artesian Basin: Warrego–Paroo–Nebine (GS60)	99.2	0.82	819.1	87.94	96.63	Diffuse recharge only	0.01	1.03
GS57	Sediments above the Great Artesian Basin: Border Rivers–Moonie (GS57)	46.9	0.38	109.4	138.15	73.35	Diffuse recharge only	0.01	0.64
GS61a	St George Alluvium: Condamine–Balonne (shallow) (GS61a)	27.7	0.68	226.5	80.62	43.48	Diffuse recharge only	0.02	0.64
GS61b	St George Alluvium: Condamine–Balonne (deep) (GS61b)	12.6	11.42	0	0	0	No Diffuse Recharge	0.91	N/A
GS66	Warrego Alluvium (GS66)	10.2	0.73	79.2	86.57	107.09	Diffuse recharge only	0.07	0.1
GS63	St George Alluvium: Warrego–Paroo–Nebine (GS63)	24.6	0.09	193	25.77	13.96	Diffuse recharge only	0	1.76
GS58	Sediments above the Great Artesian Basin: Condamine–Balonne (GS58)	18.1	0.55	134.4	43.79	29.32	Diffuse recharge only	0.03	0.62
GS55	Queensland Border Rivers Fractured Rock (GS55)	10.5	9.39	236.6	70.38	207.68	Diffuse recharge only	0.89	0.05
GS64a	Upper Condamine Alluvium (Central Condamine Alluvium) (GS64a)	46	42.93	128	172.46	128	Diffuse recharge, irrigation recharge, river leakage and lateral flows - Numerical Model	0.93	0.36
GS65	Upper Condamine Basalts (GS65)	79	62.24	115	111.46	151.16	Diffuse recharge only	0.79	0.52

Code	SDLRU name	SDL volume (GL/y)	Average annual take (2013 to 2023)	Recharge (MD-SY1) GL/year	Recharge MD-SY2 diffuse baseline (GL/year)	Stage 2 - Recharge GL/year	Stage 2 recharge source	Stage 2 - Extraction/SDL (E/SDL)	Stage 2-SDL/Recharge (SDL/R)
GS64b	Upper Condamine Alluvium (Tributaries) (GS64b)	40.5	31.13	84	88.19	84	Diffuse recharge, irrigation recharge, river leakage and lateral flows - Numerical Model	0.77	0.48
GS54	Queensland Border Rivers Alluvium (GS54)	14	11.56	68.5	22.78	25.69	Diffuse recharge only	0.83	0.54
GS53	Condamine Fractured Rock (GS53)	1.48	0.71	69.4	17.36	49.22	Diffuse recharge only	0.48	0.03
GS62	St George Alluvium: Moonie (GS62)	0.69	0.01	5.2	11.94	2.68	Diffuse recharge only	0.01	0.26
GS6	SA Murray (GS6)	64.8	1.8	483.3	112.74	102.33	Diffuse recharge only	0.03	0.63
GS3a	Mallee (Pliocene Sands) (GS3a)	41.4	0	267.5	80.48	24.39	Diffuse recharge only	0	1.7
GS3b	Mallee (Murray Group Limestone) (GS3b)	63.6	35.38	3.8	3.8	3.8	Barnett & Osei-bonsu (2006)	0.56	16.74
GS3c	Mallee (Renmark Group) (GS3c)	2	0	0	0	0	No Diffuse Recharge	0	N/A
GS7	SA Murray Salt Interception Schemes (GS7)	28.6	11.33	40.4	10.96	3.36	Diffuse recharge only	0.4	8.51
GS2	Eastern Mount Lofty Ranges (GS2)	38.5	7.32	174	37.54	26.3	Diffuse recharge only	0.19	1.46
GS5a	Peake–Roby–Sherlock (unconfined) (GS5a)	3.41	0.19	0	14.24	2.37	The productive aquifers are not recharged via rainfall infiltration or via leakage from overlying/underlying aquifers (Barnett & Yan, 2008)	0.06	1.44
GS5b	Peake–Roby–Sherlock (confined) (GS5b)	2.58	0.97	0	0	0	The productive aquifers are not recharged via rainfall infiltration or via leakage from overlying/underlying aquifers (Barnett & Yan, 2008)	0.38	N/A
GS4a	Marne Saunders (Fractured Rock) (GS4a)	2.09	0.48	4	5.67	2.1	Diffuse recharge, lateral through flow (Palmer Fault), and river leakage.	0.23	1
GS4b	Marne Saunders (Murray Group Limestone) (GS4b)	2.38	1.35	4	0	5.9	No Diffuse Recharge	0.57	0.4
GS4c	Marne Saunders (Renmark Group) (GS4c)	0.5	0	0	0	0	No Diffuse Recharge	0	N/A
GS1a	Angas Bremer (Quaternary Sediments) (GS1a)	1.09	0	6.4	1.92	0.91	Diffuse recharge only	0	1.2
GS1b	Angas Bremer (Murray Group Limestone) (GS1b)	6.57	1.26	0	0	0	Diffuse recharge only	0.19	N/A
GS8d	Goulburn-Murray: deep (GS8d)	20	0.71	0	0	0	No Diffuse Recharge	0.04	N/A
GS9c	Wimmera-Mallee: deep (GS9c)	20	0.13	0	0	0	No Diffuse Recharge	0.01	N/A
GS9b	Wimmera-Mallee: Sedimentary Plain (GS9b)	190.1	8.08	995	439.17	59.31	Diffuse recharge only	0.04	3.21
GS8b	Goulburn-Murray: Highlands (GS8b)	68.7	14.09	3283	2164.66	2319.97	Diffuse recharge only	0.21	0.03

Code	SDLRU name	SDL volume (GL/y)	Average annual take (2013 to 2023)	Recharge (MD-SY1) GL/year	Recharge MD-SY2 diffuse baseline (GL/year)	Stage 2 - Recharge GL/year	Stage 2 recharge source	Stage 2 - Extraction/SDL (E/SDL)	Stage 2-SDL/Recharge (SDL/R)
GS8c	Goulburn-Murray: Sedimentary Plain (GS8c)	223	112.83	450.2	193.08	450.2	Diffuse recharge, irrigation recharge, river leakage and lateral flows - Numerical Model	0.51	0.5
GS9a	Wimmera-Mallee: Highlands (GS9a)	2.75	0.77	102.6	74.31	57.28	Diffuse recharge only	0.28	0.05
GS8a	Goulburn-Murray: Shepparton Irrigation Region (GS8a)	244.1	58.3	498	54.04	498	Diffuse recharge, irrigation recharge, river leakage and lateral flows - Numerical Model	0.24	0.49

Appendix C

Stage 4 – Filter settings for monitoring bores

Table C 1 Filter settings to allocate monitoring bores to an SDLRU in Stage 4

SDL code	Groundwater SDL resource unit	Item number (MDBA, 2020b)	Groundwater covered by groundwater SDL resource unit (MDBA, 2020b)	All groundwater filter	HGU filter	Lithology filter	Depth filter	Exclusion filter	HGU terms allowed	Lithology terms allowed	Upper depth (m)	Lower depth (m)	Exclusion terms
GS17	Gunnedah-Oxley Basin MDB (GS17)	23	all groundwater contained within: (a) all rocks of Permian, Triassic, Jurassic, Cretaceous and Cenozoic age within the outcropped and buried areas; and (b) all unconsolidated alluvial sediments within the outcropped areas; excluding groundwater in items 45, 47, 49, 53, 54, 57, 60, 61 and 62	No	Yes	No	No	Yes	Unknown;	clay;sand;gravel;clay;sandy;gravell y;	60	3950	GS34;GS24;GS29;GS22;GS49;GS14;GS45;GS48;GS47;
GS18	Inverell Basalt (GS18)	44	all groundwater contained within all basalt of Cenozoic age and all unconsolidated alluvial sediments	Yes	No	No	No	No	-	-	-	-	-
GS1b	Angas Bremer (Murray Group Limestone) (GS1b)	17	groundwater in the Murray Group Limestone, and all other groundwater, excluding groundwater in item 16	No	Yes	Yes	Yes	Yes	Unknown;Murray Group;	sand;sandy;sands;gravel;gravels;gravelly;limestone;calcareenite;marl;arenite;calcareous;glauconitic;fossiliferous;coral;carbonaceous;	20	150	GS1a;
GS8c	Goulburn-Murray: Sedimentary Plain (GS8c)	4	all groundwater from the land surface to 200 metres below the surface or 50 metres below the base of the Tertiary sediments, whichever is the deeper, excluding groundwater in item 2	No	Yes	No	Yes	-	Unknown;Lower Shepparton Formation;Undifferentiated Upper Tertiary/Quaternary Aquifer;Undifferentiated Upper Tertiary Aquifer (fluvial);Upper Shepparton Formation;Calivil Formation;Upper Renmark Group;Undifferentiated Lower Tertiary Aquifer;Undifferentiated Quaternary Basalt;Urana Formation;Various fluvial/lacustrine/alluvial/colluvial sediments;Undifferentiated Quaternary Aquifer;Loxton Parilla Sand;Geera Clay	-	25	317	-
GS20	Lachlan Fold Belt MDB (GS20)	41	all groundwater, excluding groundwater in items 23, 24, 25, 26, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 42, 45, 47, 48, 49, 50, 51, 52, 53, 57, 60 and 62	No	Yes	No	No	Yes	Unknown;	-	-	-	GS17;GS41;GS38;GS42;GS13;GS27a;GS27b;GS46;GS21;GS28a;GS28b;GS31;GS12;GS25;GS44;GS39;GS22;GS49;GS11;GS14;GS15;GS16;GS26;GS45;GS29;GS47;GS24;GS50;GS35;GS36;
GS27a	Lower Murray Shallow Alluvium (GS27a)	29	all groundwater contained within all alluvial sediments below the surface of the ground, to a depth of 20 metres	No	Yes	No	Yes	No	Unknown;Loxton Parilla Sand;Undifferentiated Upper Tertiary/ Quaternary Aquifer;	-	0	20	
GS9b	Wimmera-Mallee: Sedimentary Plain (GS9b)	7	all groundwater from the land surface to 200 metres below the surface or 50 metres below the base of the Tertiary sediments, whichever is the deeper	No	Yes	Yes	No	-	Blanchetown Clay;Bookpurnong Formation;Calivil Formation;Ettirk Formation;Pliocene Sands aquifer;Quaternary alluvial aquifer;Duddo Limestone;Geera Clay;Loxton Parilla Sand;Undifferentiated Lower Tertiary Aquifer;Undifferentiated Upper Tertiary Aquifer;Undifferentiated Upper Tertiary/ Quaternary Aquifer;Unknown;Undifferentiated Quaternary aquifer;Upper Shepparton Formation;Various Aeolian Deposits;Various fluvial/lacustrine/alluvial/colluvial sediments;Winnambool Formation;Lower Renmark Group;Renmark Group (younger aquitard);Renmark Group aquifer;Upper Renmark Group;	clay;clayey;clays;sand;sands;sandy;silt;silts;silty;gravel;gravels;gravell y;sandstone;siltstone;alluvium;aluvium;	-	-	-
GS28a	Lower Murrumbidgee Shallow Alluvium (GS28a)	33	all groundwater contained within the alluvial sediments to a depth of 40 metres or to the bottom of the Shepparton Formation, whichever is the deeper	No	Yes	No	Yes	-	Unknown;	-	0	40	
GS3a	Mallee (Pliocene Sands) (GS3a)	9	groundwater in the Pliocene sands	No	Yes	Yes	No	-	Pliocene Sands aquifer;	sand;sands;sandy;gravel;gravels;gravelly;grvl;sandstone;clay;clayey;clays;	-	-	-

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GS3b	Mallee (Murray Group Limestone) (GS3b)	10	groundwater in the Murray Group Limestone	No	Yes	Yes	No	-	Unknown;Murray Group;	limestone;sand;sandy;sands;gravels;gravel;gravelly;travertine;clay;gambier;grained;fine;soft;clayey;fossil;fossils;sandstone;	0	140	-
GS33	NSW Border Rivers Tributary Alluvium (GS33)	65	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	No	Yes	No	Unknown;	sands;gravels;silts;clays	0	50	-
GS5a	Peake–Roby–Sherlock (unconfined) (GS5a)	12	groundwater in: (a) the unconfined Murray Group Limestone comprising the Coomandook and Bridgewater Formations; and (b) the unconfined Quaternary limestone	No	Yes	No	No	-	Murray Group;Undifferentiated Quaternary sediments;Quaternary Limestone aquifer;	-	-	-	-
GS34	NSW GAB Surat Shallow (GS34)	54	all groundwater contained within: (a) all geological formations to a depth of 60 metres below the surface of the ground; and (b)all unconsolidated alluvial sediments; excluding groundwater in items 57 and 62	No	Yes	No	Yes	Yes	Unknown;	-	0	60	GS24;GS29;
GS6	SA Murray (GS6)	14	all groundwater	Yes	No	No	No	-	-	-	-	-	-
GS7	SA Murray Salt Interception Schemes (GS7)	15	all groundwater	Yes	No	No	No	-	-	-	-	-	-
GS1a	Angas Bremer (Quaternary Sediments) (GS1a)	16	groundwater in Quaternary sediments	No	Yes	Yes	No	-	Quaternary aquifer;Unknown;Undifferentiated Quaternary sediments;	clay;clayey;clays;sand;sands;sandy;silt;silts;silty;gravel;gravels;gravelly;alluvium;alluvial;	0	30	-
GS37	New England Fold Belt MDB (GS37)	46	all groundwater excluding groundwater in items 44, 45, 58, 59, 60, 61, 63, 64 and 65	No	Yes	No	Yes	Yes	Unknown;	sandstone;shale;	0	200	GS18;GS33;GS22;GS32;GS40;GS30;GS48;GS43;GS47;
GS2		18	all groundwater	Yes	No	No	No	-	-	-	-	-	-
GS38	Oaklands Basin (GS38)	25	all groundwater contained within all rocks of Permian and Triassic age	NA	NA	NA	NA	NA	Unknown;	-	0	370	-
GS4b	Marne Saunders (Murray Group Limestone) (GS4b)	20	groundwater in: (a) the Murray Group Limestone; and (b) Quaternary sediments	No	Yes	Yes	No	-	Unknown;Undifferentiated Quaternary sediments;Murray Group;Quaternary aquifer;Quaternary alluvial aquifer;Blanchetown Clay;	limestone;limestones;sand;sands;clay;clays;sandy;clayey;	-	-	-
GS39	Orange Basalt (GS39)	42	all groundwater contained within all basalt of Cenozoic age and all unconsolidated alluvial sediments	Yes	No	No	No	No	-	shale;basalt;clay;gravel;shales;basalts;clays;gravels;sandy;clayey;gravelly;	-	-	-
GS50	Western Porous Rock (GS50)	22	all groundwater contained within all sediments of Cenozoic age, excluding groundwater in items 26 and 27	No	Yes	Yes	No	Yes	Unknown;Pliocene Sands aquifer;Renmark Group aquifer;Quaternary alluvial aquifer;	sand;sandstone;marl;limestone;lignite;mudstone;carbonaceous;clay;	-	-	GS23;
GS3c	Mallee (Renmark Group) (GS3c)	11	groundwater in the Renmark Group, and all other groundwater, excluding groundwater in items 9 and 10	No	Yes	No	Yes	Yes	Unknown;Renmark Group aquifer;	-	200	1000	GS3a;GS3b;
GS41	Sydney Basin MDB (GS41)	24	all groundwater contained within: (a)all rocks of Permian, Triassic, Jurassic, Cretaceous and Cenozoic age within the outcropped and buried areas; and (b)all unconsolidated alluvial sediments within the outcropped areas	No	Yes	Yes	No	No	Unknown;	sand;sandstone;clay;shale;basalt;water;sandy;clayey;loam;gravel;coarse;conglomerate;alluvium;rock;silt;siltstone;	0	170	-
GS4a	Marne Saunders (Fractured Rock) (GS4a)	19	groundwater in fractured rock	No	Yes	No	No	Yes	Kanmantoo Group;Keynes Subgroup;Undifferentiated Cambrian rocks;Undifferentiated Delamerian igneous rocks;	-	-	-	GS4b;

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GS15	Coolaburragundy–Talbragar Alluvium (GS15)	50	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	No	Yes	-	Unknown	-	0	105	-
GS23	Lower Darling Alluvium (GS23)	27	all groundwater contained within alluvial sediments of Quaternary age below the surface of the ground	No	Yes	Yes	Yes	-	Unknown;	sand;sands;sandy;loam;clay;clays; clayey;coarse;silty;gravel;gravelly;silt;mud;	0	100	-
GS13	Billabong Creek Alluvium (GS13)	28	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	No	-	Unknown;	sand;gravel;clay;shale;sandy;gravel;coarse;conglomerate;alluvial;silt;silty;drift	0	100	-
GS4c	Marne Saunders (Renmark Group) (GS4c)	21	groundwater in the Renmark Group, and all other groundwater, excluding groundwater in items 19 and 20	No	Yes	No	Yes	Yes	Renmark Group aquifer;Unknown;	-	60	1000	GS4b;GS4a;
GS27b	Lower Murray Deep Alluvium (GS27b)	30	all groundwater contained within all unconsolidated alluvial sediments deeper than 20 metres below the ground surface	No	Yes	Yes	Yes	-	Unknown;Loxton Parilla Sand;Undifferentiated Upper Tertiary/ Quaternary Aquifer	sand;gravel;sands;gravels;gravelly;sandy;	20	350	-
GS16	Cudgegong Alluvium (GS16)	51	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	No	Yes	-	Unknown	coarse gravel;sand;silt;clay	0	64	-
GS21	Lake George Alluvium (GS21)	32	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	No	-	Unknown;	sand;clay;gravel;sandy;clayey;gravelly;gravels;sands;clays	-	-	-
GS52	Australian Capital Territory (Groundwater) (GS52)	1	all groundwater	Yes	-	-	-	-	-	-	-	-	-
GS28b	Lower Murrumbidgee Deep Alluvium (GS28b)	34	all groundwater contained within the Calivil Formation and Renmark Group unconsolidated alluvial sediments greater than a depth of 40 metres	No	Yes	Yes	Yes	-	Unknown;	clay;clayey;clays;sand;sands;sandy;silt;silts;silty;gravel;gravels;gravelly;	40	400	-
GS24	Lower Gwydir Alluvium (GS24)	62	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	No	-	Unknown	clay;silt;sand;sandy;gravel;gravels; gravelly;clayey;silty;alluvial;coarse;	0	90	-
GS12	Belubula Alluvium (GS12)	36	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	No	-	Unknown;	clay;silt;sand;gravel;gravels;sands; clays;sandy;clayey;gravelly;silt;silty; topsoil;	0	40	-
GS25	Lower Lachlan Alluvium (GS25)	37	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	Yes	-	Unknown	clay;silt;sand;gravel;	0	428	-
GS29	Lower Namoi Alluvium (GS29)	57	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	No	Yes	-	Unknown	sand;gravel	0	231	-
GS10	Adelaide Fold Belt MDB (GS10)	39	all groundwater, excluding groundwater in item 22	No	Yes	No	No	-	Unknown;	-	-	-	-
GS19	Kanmantoo Fold Belt MDB (GS19)	40	all groundwater, excluding groundwater in items 22, 26, 27, 33, 34 and 37	No	Yes	No	No	Yes	Unknown;	-	-	-	GS50;GS42;GS23;GS28a;GS28b; GS25;GS36;
GS53	Condamine Fractured Rock (GS53)	70	all groundwater contained within all igneous and metamorphic rocks	No	Yes	No	No	No	Wildash Group; Unknown; Triassic felsic intrusives; Texas beds / Ashford Limestone; Silverwood Group; Permian felsic intrusives; Main Range Volcanics;	granite;andesite;slate;	-	-	-
GS56	Queensland MDB: deep (GS56)	71	all groundwater in aquifers below the Great Artesian Basin	No	Yes	No	No	No	Timbury Hills Formation;	-	-	-	-
GS51	Young Granite (GS51)	43	all groundwater	Yes	No	No	No	-	-	-	-	-	-

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GS5b	Peake–Roby–Sherlock (confined) (GS5b)	13	groundwater in: (a) the confined Renmark Group; and (b) the confined Buccleuch Group; and all other groundwater, excluding groundwater in item 12	No	Yes	No	No	Yes	Unknown;Renmark Group aquifer;	-	-	-	GS5a;
GS22	Liverpool Ranges Basalt MDB (GS22)	45	all groundwater contained within all basalt of Cenozoic age and all unconsolidated alluvial sediments	Yes	No	No	No	-	Unknown;	-	-	-	-
GS62	St George Alluvium: Moonie (GS62)	69	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	No	Yes	No	Unknown;	-	0	80	-
GS49	Warrumbungle Basalt (GS49)	47	all groundwater contained within all basalt of Cenozoic age and all unconsolidated alluvial sediments	Yes	No	No	No	-	Unknown;	-	-	-	-
GS11	Bell Valley Alluvium (GS11)	48	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	No	-	Unknown;	gravel;sand;silt;clay;sandy;gravelly;clayey;silty;silts;sands;clays;gravels;	0	50	-
GS14	Castlereagh Alluvium (GS14)	49	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground, except water contained within the unconsolidated alluvial sediments between the top of the high banks of the river	No	Yes	Yes	No	-	Unknown;	gravel;sand;sandy;gravelly;alluvium;silt;silts;silty;sands;gravels;	0	80	-
GS31	Mid-Murrumbidgee Alluvium (GS31)	35	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	No	Yes	-	Unknown	-	0	145	-
GS32	NSW Border Rivers Alluvium (GS32)	64	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	No	-	Unknown	cobbles;gravels;gravel;sand;sands;sandy;clay;coarse;clayey;silts;clays;claybound;water;shale;	0	100	-
GS26	Lower Macquarie Alluvium (GS26)	52	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	No	-	Unknown;	sand;sands;sandy;clay;clays;clayey;gravel;gravels;gravelly;loam;pug;coarse;silt;silty;silts;	0	90	-
GS40	Peel Valley Alluvium (GS40)	59	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	No	Yes	-	Unknown		0	30	-
GS66	Warrego Alluvium (GS66)	80	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	No	Yes	-	Unknown;Quaternary alluvium;	sand;sandy;sands;gravel;gravels;gravelly;clay;clayey;	0	70	-
GS35	NSW GAB Warrego Shallow (GS35)	55	all groundwater contained within: (a)all geological formations to a depth of 60 metres below the surface of the ground; and (b)all unconsolidated alluvial sediments; excluding groundwater in item 26	No	Yes	No	Yes	No	Unknown;	-	0	60	-
GS36	NSW GAB Central Shallow (GS36)	56	all groundwater contained within: (a)all geological formations to a depth of 60 metres below the surface of the ground; and (b)all unconsolidated alluvial sediments; excluding groundwater in item 26	No	Yes	No	Yes	No	Unknown;	-	0	60	-
GS42	Upper Darling Alluvium (GS42)	26	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	No	-	Unknown	silt;silts;sand;sands;sandy;gravel;gravels;clay;clays;loam;	0	35	-
GS30	Manilla Alluvium (GS30)	58	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	Yes	No	No	No	-	Unknown;	gravel;sand;silt;clay;clayey;clays;silty;sands;sandy;gravelly;soil;topsoil;	0	20	-

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GS44	Upper Lachlan Alluvium (GS44)	38	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	No	-	Unknown	gravel;gravels;clay;clays;sand;sands;sandy;quartz;sandy;	0	150	-
GS45	Upper Macquarie Alluvium (GS45)	53	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	No	Yes	-	Unknown	-	0	80	-
GS48	Upper Namoi Tributary Alluvium (GS48)	61	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	Yes	No	No	No	-	Unknown;	gravel;sand;silt;clay;gravelly;gravels;sandy;sands;silty;clays;clayey;alluvium;conglomerate;topsoil;	0	20	-
GS46	Upper Murray Alluvium (GS46)	31	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	No	Yes	-	Unknown	clay;cobbles;sand;gravel;silt	0	138	-
GS43	Upper Gwydir Alluvium (GS43)	63	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	Yes	No	No	No	-	Unknown;	gravel;sand;silt;clay;gravelly;gravels;sandy;sands;silty;clays;clayey;alluvium;conglomerate;topsoil;loam;	0	30	-
GS47	Upper Namoi Alluvium (GS47)	60	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	No	-	Unknown	gravel;gravels;coarse;clay;interbeds;yellowish;sand;pebbles;	0	170	-
GS8a	Goulburn-Murray: Shepparton Irrigation Region (GS8a)	2	all groundwater in the Shepparton Irrigation Region Water Supply Protection Area to a depth of 25 metres below the land surface	No	Yes	No	Yes	Yes	Unknown;Lower Shepparton Formation;Undifferentiated Upper Tertiary/Quaternary Aquifer;Undifferentiated Upper Tertiary Aquifer (fluvial);Upper Shepparton Formation;Various fluvial/lacustrine/alluvial/colluvial sediments;Undifferentiated Quaternary Aquifer;	-	0	25	GS8c;
GS54	Queensland Border Rivers Alluvium (GS54)	66	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	No	-	Unknown	sand;sands;sandy;gravel;gravels;clay;clays;silt;silts;silty;volcanic;mud;	-	-	-
GS55	Queensland Border Rivers Fractured Rock (GS55)	67	all groundwater contained within all igneous and metamorphic rocks, excluding groundwater in item 66	No	Yes	Yes	No	GS54;	Triassic felsic intrusives;Unknown;	granite;clay;	-	-	-
GS57	Sediments above the Great Artesian Basin: Border Rivers-Moonie (GS57)	68	all groundwater contained within all consolidated sediments above the Great Artesian Basin, excluding groundwater in item 66	No	Yes	No	Yes	-	Unknown; Griman Creek Formation;	gravel;sand;silt;clay;gravelly;gravels;sandy;sands;silty;clays;clayey;alluvium;conglomerate;topsoil;loam;	0	178	-
GS8b	Goulburn-Murray: Highlands (GS8b)	3	all groundwater in the outcropping Palaeozoic rocks (or the in-situ weathered horizon where it is within 5 metres of the surface) from the land surface to 200 metres below the surface	No	Yes	No	Yes	-	Undifferentiated Extrusive Basement Rocks;Undifferentiated Intrusive Basement Rocks;Undifferentiated Mesozoic and Palaeozoic Bedrock;Undifferentiated Metamorphic Basement Rocks;Undifferentiated Quaternary Basalt;Undifferentiated Sedimentary Basement Rocks;Unknown;	-	0	200	-
GS8d	Goulburn-Murray: deep (GS8d)	5	all groundwater, excluding groundwater in items 2, 3 and 4	No	Yes	No	Yes	Yes	Undifferentiated Extrusive Basement Rocks;Undifferentiated Intrusive Basement Rocks;Undifferentiated Mesozoic and Palaeozoic Bedrock;Undifferentiated Metamorphic Basement Rocks;Undifferentiated Quaternary Basalt;Undifferentiated Sedimentary Basement Rocks;Unknown;Urana Formation;	-	200	3000	GS8a;GS8b;GS8c;
GS9a	Wimmera-Mallee: Highlands (GS9a)	6	all groundwater in the outcropping Palaeozoic rocks (or the in-situ weathered horizon where it is within 5 metres of the surface) from the land surface to 200 metres below the surface	No	Yes	Yes	Yes	-	Undifferentiated Mesozoic and Palaeozoic Bedrock;Undifferentiated Metamorphic Basement Rocks;Unknown;	Bedrock;bed-rock;consolidated;elvan;granite;Ironstone;mudstone;quartzite;reef;sandstone;schist;shale;siltstone;sist;slate;	0	200	-

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GS58	Sediments above the Great Artesian Basin: Condamine-Balonne (GS58)	72	all groundwater contained within all consolidated sediments above the Great Artesian Basin	No	Yes	No	Yes	-	Griman Creek Formation;Unknown;	sand;sands;sandy;sandstone;clay; clays;clayey;gravel;gravels;gravelly ;shale;caving;cemented;coarse;course;dark;fine;dirty;siltstone;silt;silts; silty;mudstone;mud;lime;muddy;white;yellow;brown;	0	160	-
GS61a	St George Alluvium: Condamine-Balonne (shallow) (GS61a)	73	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground excluding groundwater in item 74	No	Yes	No	Yes	Yes	Unknown;	gravel;sand;silt;clay;gravelly;gravels;sandy;sands;silty;clays;clayey;alluvium;conglomerate;topsoil;loam;	0	40	GS61b;
GS61b	St George Alluvium: Condamine-Balonne (deep) (GS61b)	74	all groundwater contained within the lower part of all unconsolidated alluvial sediments occupying the Dirranbandi Trough that lies below the middle leaky confined bed	No	Yes	No	Yes	-	Unknown;	-	50	250	-
GS64a	Upper Condamine Alluvium (Central Condamine Alluvium) (GS64a)	75	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	Yes	-	Unknown;	clay;clayey;clays;sand;sands;sandy;silt;silts;silty;gravel;gravels;gravelly;	0	100	-
GS64b	Upper Condamine Alluvium (Tributaries) (GS64b)	76	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	No	-	Unknown;	clay;clayey;clays;sand;sands;sandy;silt;silts;silty;gravel;gravels;gravelly;sandstone;siltstone;alluvium;alluvium;	-	-	-
GS65	Upper Condamine Basalts (GS65)	77	all groundwater contained within all volcanic (basalt) rocks	No	Yes	Yes	No	-	Unknown;Main Range Volcanics;Marburg Subgroup	basalt;basalts;volcanic;volcanics;	-	-	-
GS60	Sediments above the Great Artesian Basin: Warrego-Paroo-Nebine (GS60)	78	all groundwater contained within all consolidated sediments above the Great Artesian Basin	No	Yes	No	Yes	-	Allaru Mudstone / Oodnadatta Formation (SA);Tertiary sediments;Unknown;	bands;sand;sands;sandy;black;shale;limestone;sandstone;sandrock;siltstone;silt;silty;silts;slate;clay;clays; clayey';mud;muddy;mudstone;cemented;coarse;soil;gravel;gravels;gravelly;	0	110	-
GS63	St George Alluvium: Warrego-Paroo-Nebine (GS63)	79	all groundwater contained within all unconsolidated alluvial sediments below the surface of the ground	No	Yes	Yes	Yes	-	Unknown;	bands;silt;silty;silts;clay;clays;clayey;sand;sandy;sands;soil;topsoil;course;gravel;gravels;gravelly;	0	220	-
GS9c	Wimmera-Mallee: deep (GS9c)	8	all groundwater, excluding groundwater in items 6 and 7	No	Yes	No	Yes	Yes	Unknown;Undifferentiated Quaternary Basalt;Phase 2 Basalts;Undifferentiated Mesozoic and Palaeozoic Bedrock;Undifferentiated Metamorphic Basement Rocks;	-	200	2400	GS9a;GS9b;