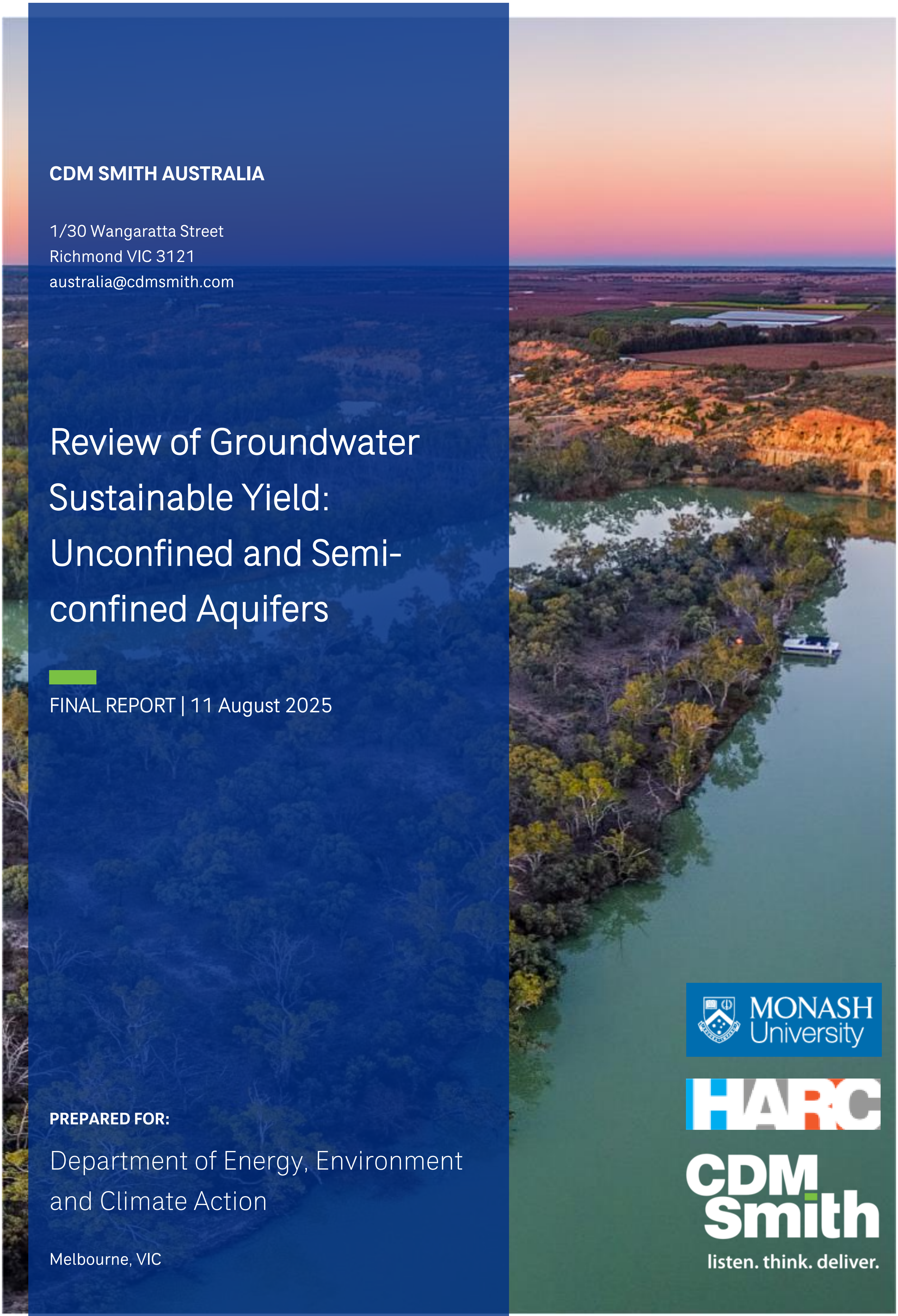

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Review of Groundwater Sustainable Yield: Unconfined and Semi-confined Aquifers

FINAL REPORT | 11 August 2025

PREPARED FOR:

Department of Energy, Environment and Climate Action

Melbourne, VIC

Executive Summary

Project context

The Victorian Department of Energy, Environment and Climate Action (DEECA) is undertaking a review of sustainable yield for groundwater resources in Victoria. The wider review comprises assessment of both confined and unconfined aquifer systems across Victoria, undertaken separately by different organisations. The outcomes of these assessments will be compiled by DEECA to provide guidance relating to groundwater resource management decisions in Victoria into the future and under a changing climate.

CDM Smith were engaged to develop estimates of recharge and groundwater elevation for unconfined and semi-confined aquifer systems, considering changing future groundwater use and climate regimes. Two separate assessments considering confined aquifer are reported elsewhere. The unconfined and semi-confined aquifer assessment was not tasked with determining final sustainable yield values, rather produced results for a range of potential future outcomes, including impacts to groundwater receptors, which may be used to inform selection of appropriate sustainable yield volumes by groundwater resource managers.

The approach

The approach to estimating recharge to the watertable and groundwater elevation was designed around providing data to compare to a series of measures which DEECA have developed to assist in the assessment of sustainability of an aquifer, referred to as ‘metrics’.

The analytical approach used in this study is based on the principal that the dominate state-wide process that controls groundwater level is recharge, and of the recharge process rainfall recharge is significantly the most dominant on regional groundwater levels. Therefore, the dominant regional control on the watertables into the future will be changes in recharge to aquifers; groundwater extraction will exert more control within localised areas of intensive groundwater use.

A key component of the methodology was the estimation of recharge rates based upon:

- A geostatistical interpolation of point estimates that derives recharge values based upon changes in groundwater levels, using groundwater monitoring bores (with HydroSight).
- Combining point estimates with a state-wide recharge dataset (from SoilFlux).

The fusion of the two datasets was based on the uncertainty inherent in the two different estimates of recharge, such that the final product will represent the strengths of each method.

The approach, which was developed through the project with consultation from DEECA, comprised the following key elements, which were brought together to form project outputs:

- Development of GMU-scale hydrogeological conceptual models
- Statistical modelling of individual bore hydrographs using HydroSight (with and without the influence of groundwater extraction), producing over 2,200 bore point estimates of recharge and groundwater elevation
- Incorporation of results from previous relevant HydroSight studies
- Estimation of baseflow statistics at 63 regulated and unregulated stream flow gauges
- Mapping of groundwater levels across Victoria from individual bore models using HydroMap, with uncertainty
- Mapping of groundwater recharge using modified outputs from the SoilFlux model
- A merge of recharge estimates from HydroSight and SoilFlux studies to produce a final maps of recharge to the watertable, with uncertainty
- Review of recharge and groundwater elevation results for GMUs against sustainable yield metrics.

The study area comprised the state of Victoria (gridded products), with reporting of average results for 51 unconfined and semi-confined Groundwater Management Units (GMUs) across Victoria. The assessment ran from 1950 to 2065 and considered four future climate change scenarios and four future groundwater extraction scenarios. The baseline period for the study was 1950-1974.

The recharge estimated in this project is bulk recharge to the watertable, which includes rainfall recharge, irrigation infiltration, surface water accessions and aquifer throughflow.

Sustainable yield metrics assessment

The sustainable yield metrics cover consumptive users (licensed groundwater extraction bores), wetland, terrestrial and waterway groundwater dependant ecosystems (GDEs), stream flow and seawater intrusion. These metrics form the foundation of the assessment to determine if a volume of groundwater take under certain climate conditions is likely to impact on values that are supported by groundwater. Insufficient data meant that the additional metrics of subsurface GDEs (stygofauna), offshore GDEs and cultural elements of groundwater value were not within the scope of the assessment.

Project outputs

Key project outputs included:

- GMU conceptual models
- Maps of groundwater elevation, for average maximum and minimum annual elevation (state-wide)
- Maps of bulk recharge to the watertable (state-wide)
- Streamflow assessment
- Summarised results for each GMU, for groundwater level and recharge
- Metrics assessment for consumptive users, high value wetland, terrestrial and waterway GDEs, stream flows and seawater intrusion.

The results indicate many parts of Victoria will observe significantly less bulk recharge to the watertable (>-30%) when compared to the baseline period (1950-1974) under medium and high climate scenarios into the future, although with high local variability across landscapes. GMUs with the largest estimated reduction in recharge were located in the central northern and highlands of Victoria. Reduction in the elevation of the watertable is expected to be greatest in central-northern Victoria into the future, with around 40% of GMUs estimated to an average drawdown in the watertable across the GMU from baseline levels of more than two metres at 2021-40 under medium climate change. These potential impacts to the watertable transfer to wetland, terrestrial and waterway GDEs in these areas. The seawater intrusion assessment estimated that half of the coastal GMUs assessed show at least 50% of the coastal area (within one kilometre of the coast) with average annual minimum groundwater elevation at or below 1.5 mAHD at 2021-40 under medium climate change.

Uncertainty and limitations

Uncertainty in the results was reported as uncertainty in the mean of recharge and groundwater elevation (separately), statistics that do not cover all potential errors and uncertainties in the data and methods. Because of this, uncertainty reported in this project should be considered indicative of relative uncertainty (i.e. higher in some areas and lower in others) rather than as a band of uncertainty within which the real result lies. Uncertainty was highest in areas where there was no or very sparse bore data, namely in the highlands and far-east Gippsland. The use of low and high climate change results bounding medium climate change results (as an average) for future time periods in the metrics assessment does provide a useful indication of the potential range of results a region may observe in the future.

The approach of combining HydroSight, HydroMap and SoilFlux methodologies to simulating future recharge and groundwater elevation was relatively successful, albeit with a number of limitations. These include the issues with the assumptions made to include unmodelled groundwater extraction bores in watertable mapping, kriging average water levels across highly variable topography, and limitations of the uncertainty estimates accompanying outputs. In general, however, the approaches provide a novel and promising method of modelling recharge and groundwater elevation across both large and small regions from sparse groundwater monitoring data with wider potential application.

The recharge interpolation shows that the uncertainty is spatially variable and highly dependent upon the proximity to groundwater observation bores. Hence, caution should be applied when using the results to examine individual receptors where the uncertainty is high.

The temporal averaging approach used here to provide estimates of recharge for future time periods requires careful interpretation. Specifically, for the period 2021-2040 the annual recharge estimates were averaged over the whole period and do not represent recharge in 2040 (and similar for 2041-2065 representing 2065). Consequently, the approach likely underestimates the impact of climate change on recharge modelled at the end of these future periods.

The regional scale of the assessment means that results should be interpreted at a state-wide or regional scale. Estimated changes to recharge and groundwater elevation at individual groundwater receptors or at local scales are considered to have high uncertainty.

Acknowledgement of Country

The authors of this work acknowledge the Traditional Custodians of the Boonwurrung, Woiworung and Djadjawurung lands upon which this work was undertaken. We pay our respects to Elders' past, present and emerging. We celebrate the stories, culture and traditions of Aboriginal and Torres Strait Islander People of all communities who work and live on these lands.

Acknowledgement of Project Team

We acknowledge and thank a large team of people who contributed to this project.

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Glossary

Baseflow	Flow in a waterway which arises from groundwater.
Bulk recharge	Water flow into an aquifer from all sources, including rainfall, irrigation infiltration, surface water accessions and groundwater throughflow.
Cap	A colloquial/general term for an upper limit of the total water that can be taken from a waterway, catchment basin or groundwater area. Specifically, it could apply to Permissible Consumptive Volumes: the upper limit of licensed entitlements that can be issued in an area considering water shortage declarations and seasonal allocations, restrictions applied to existing licensed entitlements.
Consumptive use	Water removed from the available supply without return to the water resource system for extractive uses, e.g., water used for agriculture, industry and commerce, including stock and domestic purposes.
Domestic and stock	Water taken for household use and watering of livestock. Victorians have basic rights to water for under the Victorian *Water Act* 1989. These rights allow a person to take water from a bore, dam, river or stream to use for domestic and stock purposes.
Drawdown	Term referring to the lowering of groundwater levels from extraction.
Error	Difference between the actual values of a dataset and measured, estimated or modelled values.
Entitlement	A right to use water (and supply) in a waterway, water in storage works of a water corporation, and groundwater. Water entitlements include bulk entitlements (issued to water corporations), environmental entitlements, water rights, surface water and groundwater licences. The term also can be used to mean the volume of water authorised to be taken and used by the holder.
Groundwater Management Area (GMA)	An area where groundwater has been or has the potential to be intensively developed Groundwater Management Areas generally have a Permissible Consumptive Volume set.
Groundwater Management Unit (GMU)	Means both Groundwater Management Areas and Water Supply Protection Areas.
Licensed use (water)	The volume of water taken under a licence(s) to take and use water (groundwater extraction) for consumptive use. i.e., it excludes volume of water taken for domestic and stock purposes.
Licence to take and use	A fixed-term entitlement to take and use water from a waterway, catchment dam, spring, soak or aquifer. Each licence is subject to conditions set by the Minister for Water and specified on the licence.
Mean annual flow (MAF)	The average daily stream flow observed over a year for a waterway.
Permissible Consumptive Volume (PCV)	The maximum volume of water licensed entitlements that can be allocated in an area or a water system.

Q90 flow	Stream flow that is exceeded on 90 percent of days in an annual record.
Stygofauna	Fauna that lives below the earth's surface, e.g. in cave systems or aquifers. Stygofauna are, to some degree, groundwater dependant.
Suite	Distinct and common patterns in groundwater level trends represented by multiple observation bores. See also 'Normalised hydrograph'.
Sustainable Diversion Limit (SDL)	Volume of surface water that can permissibly be taken set surface water catchment areas in Victoria.
Sustainable yield	The groundwater extraction regime, measured over a specified planning timeframe, that allows acceptable levels of stress (if any) and protects dependent values.
Terrestrial groundwater dependant ecosystem (GDE)	Terrestrial plants dependent on groundwater.
Unincorporated area	Groundwater areas which are not defined as groundwater management units and do not have a defined permissible consumptive volume.
Uncertainty	An estimate of the range of values the actual value of a dataset may sit within. Uncertainty in a dataset can come from a number of sources, for example, measurement error, the conceptual model, structure of the modelling approach and estimated parameters used in modelling.
Use (water)	The volume of water taken (for example groundwater extracted) for consumptive use.
Victorian Aquifer Framework (VAF)	Classification of groundwater units in Victoria. VAF units are classified as either an aquifer or an aquitard, and are mapped in three dimensions across Victoria.
Water Supply Protection Area (WSPA)	A Water Supply Protection Area is an area declared under section 27 the Victorian *Water Act 1989* to protect the groundwater or surface water resources through the development of a statutory management plan.
Watertable	A groundwater aquifer above which is unsaturated rock or soil to the ground surface. There may be confined aquifers sitting below the watertable aquifer at any point in the landscape.
Waterway groundwater dependant ecosystem (GDE)	Surface water bodies which have a component of flow sourced from groundwater, such as rivers and streams.
Wetland groundwater dependant ecosystem (GDE)	Surface water ecosystems dependent on groundwater, such as wetlands and springs.

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Section 1 Introduction

1.1 Purpose

The overall objective of the Groundwater Sustainable Yield Project is to better understand groundwater through improved groundwater resource assessments and modelling, including up-to-date information on catchment characteristics, use and climate change.

This element of the wider project provides estimates of recharge and groundwater elevation under future use and climate scenarios for unconfined and semi-confined groundwater management areas (GMUs) in Victoria, and assesses sustainable yield metric values against modelled changes to the watertable resource.

1.2 Background

The Department of Energy, Environment and Climate Action (DEECA) is undertaking a state-wide review of the sustainable yield of groundwater resources (the SY project). The SY project will quantify for particular areas the volumes of groundwater available under different climate scenarios. It will also assess the levels of likely impact on the environment and consumptive users from drawdown of the watertable from different volumes of use and climate change scenarios. Two other concurrent but separate projects consider the confined aquifers across the state. The assessments of flux volumes for assessed GMUs from all three projects will inform development of sustainable yield volumes to assist with groundwater decision making (DELWP, 2021a).

DEECA have developed a series of measures with which to assess the sustainability of the aquifer, referred to as 'metrics', that form the foundation of the assessment to determine if a volume of groundwater take will impact on values that are supported by groundwater.

This report presents the assessment of sustainable yield for Victoria under various climate change and groundwater extraction scenarios to 2065.

1.3 Project area

The project covers the watertable aquifer across the state of Victoria. In particular, the project considers sustainable yield for 51 unconfined and semi-confined GMUs. These are shown in Figure 1-1. GMUs are either Groundwater Management Areas (GMA) or Water Supply Protection Areas (WSPA). The GMUs are listed in Appendix A.

1.4 Project outputs

The following outputs were produced to assess groundwater metrics and inform sustainable yield development:

- GMU-scale conceptual hydrogeological summaries
- State-wide gridded recharge (mm/yr) – absolute values and change from baseline
- State-wide gridded groundwater elevation – absolute values and change from baseline
- Relationship between groundwater use and drawdown for GMUs and metrics values
- Gauged streamflow analyses (mean annual flow and flow exceeded on 90 percent of days (Q90 flow)).

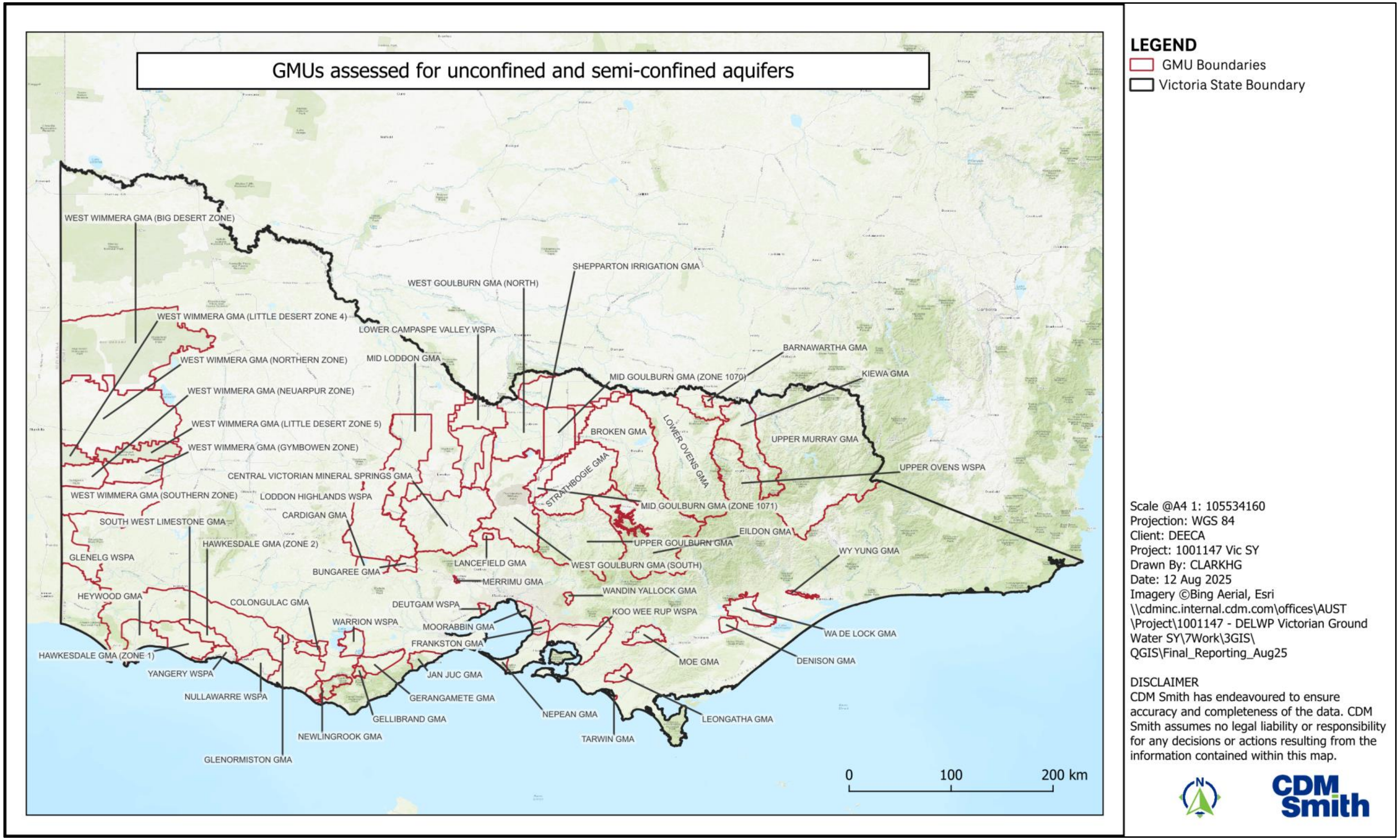

Figure 1-1 **Unconfined and semi-confined GMUs covered by this project.**

1.5 Metrics

The method aims to provide data to enable the development of a sustainable yield for GMUs. The sustainable yield is an estimate of the groundwater available for use that will have limited (if any) adverse impacts on assessed values. The sustainable yield measures, or metrics values, describe the magnitude of potential changes to assessed values. The proposed metrics are presented in Table 1-1 below.

Offshore and cave system (stygofauna) GDEs and cultural values related to groundwater are not considered in the study.

These metrics may be reviewed and revised in the future as the project progresses and a clearer understanding of the project outcomes is gained.

Table 1-1 Proposed groundwater Sustainable Yield metrics (DELWP 2023)

Assessed Value		Metric values
Consumptive use	***Watertable decline***	*Change in annual maximum groundwater level* [1]
	Consumptive use bores	<1 m 1 to 2m 2 to 5m
Environmental	***Watertable decline***	*Change in annual maximum groundwater level* [1]
	Waterway GDEs, Wetland GDEs, and Terrestrial GDEs	<0.1 m 0.1 to 1m 1 to 2m
	Stygofauna (including cave system GDEs) [2]	Not assessed
	Offshore GDEs [2]	Not assessed
	Cultural	Not assessed
	Surface flow	*Groundwater extraction*
	Mean annual flow	<10%
	Q90 flow	<10%
	Cultural	Not assessed
Sea-water intrusion	**Maintenance of elevation**	*Annual minimum groundwater elevation*
	Coastal areas (within 300 m)[5]	>1.5 mAHD

[1] Also known as 'recovered level'.

[2] Stygofauna and cave system, and offshore GDEs are not being assessed in this project due to lack of data.

[3] MAF – mean annual stream flow.

[4] Q90 flow – stream flow that is exceeded on 90 percent of days in the record.

[5] Modelling resolution limits the sea-water intrusion results to 1 km of the coast.

1.6 Approach

The general approach in this project was to use statistical modelling of individual bore hydrographs to estimate the groundwater elevation and recharge to the watertable, using the program HydroSight (Peterson, *et al.*. 2014, 2019). This point data was then spatially interpolated across Victoria for a range of future scenarios relating to groundwater use and climate change using a kriging approach with the HydroMap (Peterson, *et al.*. 2023) code. The mapped drawdown was then used to develop relationships between groundwater extraction rates, climate scenarios and levels of impact to the watertable using the metric values. Recharge was estimated using a merge approach that brought together recharge point data from the HydroSight analysis with modified outputs of the water balance model SoilFlux to map recharge across Victoria into the future under climate scenarios. These outputs provide data to inform development of sustainable yield volumes. The approach is applied consistently across all unconfined and semiconfined GMUs.

1.6.1 Principle behind approach

Within unconfined and semi-confined aquifers, the rate of groundwater recharge significantly controls the volume of groundwater within an aquifer, and therefore the elevation of the watertable.

A diagrammatic conceptualisation of unconfined groundwater aquifer processes is presented in Figure 1-2. This figure demonstrates the key terminology used in this project, importantly recharge and groundwater level.

While it is acknowledged that groundwater flow systems are truly three dimensional, the approach assesses changes in recharge volumes and the interaction of the watertable with existing users, groundwater dependent ecosystems (GDEs) including baseflow to waterways, wetlands (including springs), terrestrial GDEs within the riparian zone and the risk of seawater intrusion into costal aquifers. The approach assumes that understanding the total volume of groundwater within any given aquifer, as with a complete water balance approach, is not necessary to assess the changes to the watertable and impacts to assets under future scenarios.

The modelling uses the statistical hydrograph modelling program HydroSight..

HydroSight is a Monash University peer-reviewed research output that aims to simulate an observed groundwater hydrograph by weighting historic daily forcing data. The forcing data is user-defined and here included rainfall, areal potential evapotranspiration and, within GMUs and WSPAs, metered extractions. Importantly, to account for the nonlinear partitioning of rainfall to recharge (and other fluxes) HydroSight uses a vertically lumped unsaturated soil model. This enables the conversion of daily meteorological inputs to a daily free-drainage out of the bottom of the soil zone. This daily flux is then weighted such that values many years ago still have some influence on the head today, but far less than the more recent flux. More formally, HydroSight achieves this through numerical integration of a convolution of a given flux (e.g. soil drainage) and a parametric weighting function. When only climate forcing is examined, such a model structure typically includes three model parameters for the weighting function, four parameters for the soil model and one for the serial correlation in the model errors. Combined, there are typically eight unknown model parameters. All of these are joined estimated (using global optimisation) to achieve the best fit to the observed hydrograph.

Once such a model is calibrated, the unsaturated zone drainage can be summed to provide an estimate of annual gross recharge (i.e. excluding phreatic ET). Prior DEECA funded trials, however, identified that this approach often produces implausibly high estimates of recharge (as a percentage or mean annual rainfall), despite achieving an exceptionally good fit to observed hydrographs. Peterson and Fulton (2019) resolved this approach by incorporating well-established estimates of long-term mean rainfall partitioning between runoff and actual evapotranspiration. Specifically, they used the Budyko relationship between aridity (mean annual PET divided by precipitation) against mean annual rainfall divided by actual ET. Given that the HydroSight input meteorological data allows estimation of the aridity, the Hydrosight estimate of rainfall divided by actual ET (from the soil model) can be compared against plausible bounds from the Budyko (for the site aridity). If the model is outside these bounds, the calibration rejects the trial parameter set and continues until all parameter sets produce a plausible actual ET. The relevance here is that that approach produces an estimate of actual ET that honours both the observed hydrograph and the long-term partitioning of rainfall.

When pumping is considered at a WSPA or GMU, the model is extended to account for pumping drawdown. The drawdown was simulated using the Thies analytical drawdown equation regulated to allow for time-varying pumping and numerical downscaling of infrequent metered usage (typically annual) to a weekly time-step (Peterson and Fulton, 2019). For such bores, the drawdown parameters were jointly estimated with the other HydroSight parameters and enabled the decomposition of each observed hydrograph into that influenced by climate and that influenced by each pumping bore. That said, when pumping is included in a model the standard Thiess assumptions apply; namely the Dupuit–Forchheimer assumption that groundwater only flows horizontally and that the aquifer is homogenous and of an infinite extent.

Consequently, for such models, groundwater flow near surface water bodies is estimated using horizontal hydraulic gradients and flow into production bores is assumed to be lateral. Additional notable assumptions are that (i) the groundwater can be assumed fresh and that the salinity does not influence the groundwater head; (ii) the measured groundwater head within an unconfined aquifer equals the elevation of the top of the watertable (which is likely to be acceptable when vertical pressure gradients are very low) and (iv) that the aquifer saturated thickness is sufficiently large that any change does not alter the drawdown for a given pumping rate.

Whilst the model aims to determine the rainfall driven component of changes in the watertable, the outputs estimate an upper estimate of bulk recharge, that will include:

- Rainfall recharge
- Surface water accessions, leakage from water bodies
- Irrigation accessions, and
- Throughflow, especially where vertical groundwater flow occurs.

While numerical models can provide a detailed assessment of the entire aquifer including its response to changes in recharge and other stressors such as groundwater extraction, the application of these models introduces considerable technical resources and significant uncertainty of outputs, particularly considering the scale of this project. Most notably, such models require a prior estimation of time-varying recharge, a priori downscaling of annual metered use, and many assumptions about the aquifer geometry and properties (e.g. saturated thickness, specific yield, lateral and vertical hydraulic conductivity). Considering that the dominant control on unconfined groundwater level across Victoria is recharge, the approach adopted does not require a prior input of recharge but rather estimates recharge over time from available input data. Given that recharge is also often very dependent upon nonlinear interactions between soil moisture and daily rainfall, any approach needs to account for these high frequency dynamics. Additionally, the approach honours available groundwater level observations and quantifies the spatial variability in recharge and groundwater level response across the State. The approach also enables prediction of how current and future climate changes influence recharge and groundwater level.

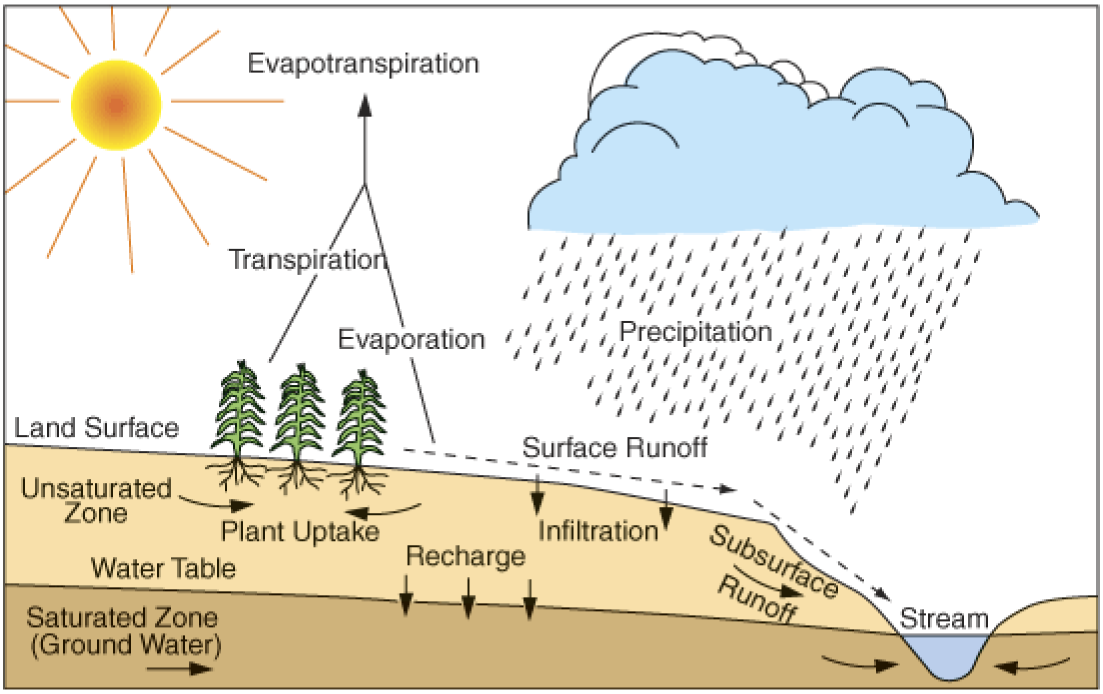

Figure 1-2 Groundwater recharge in the hydrological cycle. Groundwater level is indicated by 'Watertable' (Sophocleous and Buchanan, 2003).

Using this data driven approach, the sustainable yield assessment will evaluate the likely risks and potential impacts to selected aspects of the environment using current and future volumes of licensed groundwater extraction based upon different climatic scenarios into the future. This is undertaken by considering the impact of groundwater extraction on recharge and groundwater elevation under various climate scenarios.

1.6.2 Key project outputs and tasks

The approach of this study can be broken into a number of steps, as presented in Figure 1-3, which underpin the derivation of estimates of recharge and groundwater elevation which inform assessments of sustainable yield metrics for Victoria's unconfined and semi-confined GMUs.

These steps, are described in detail in Section 2 below.

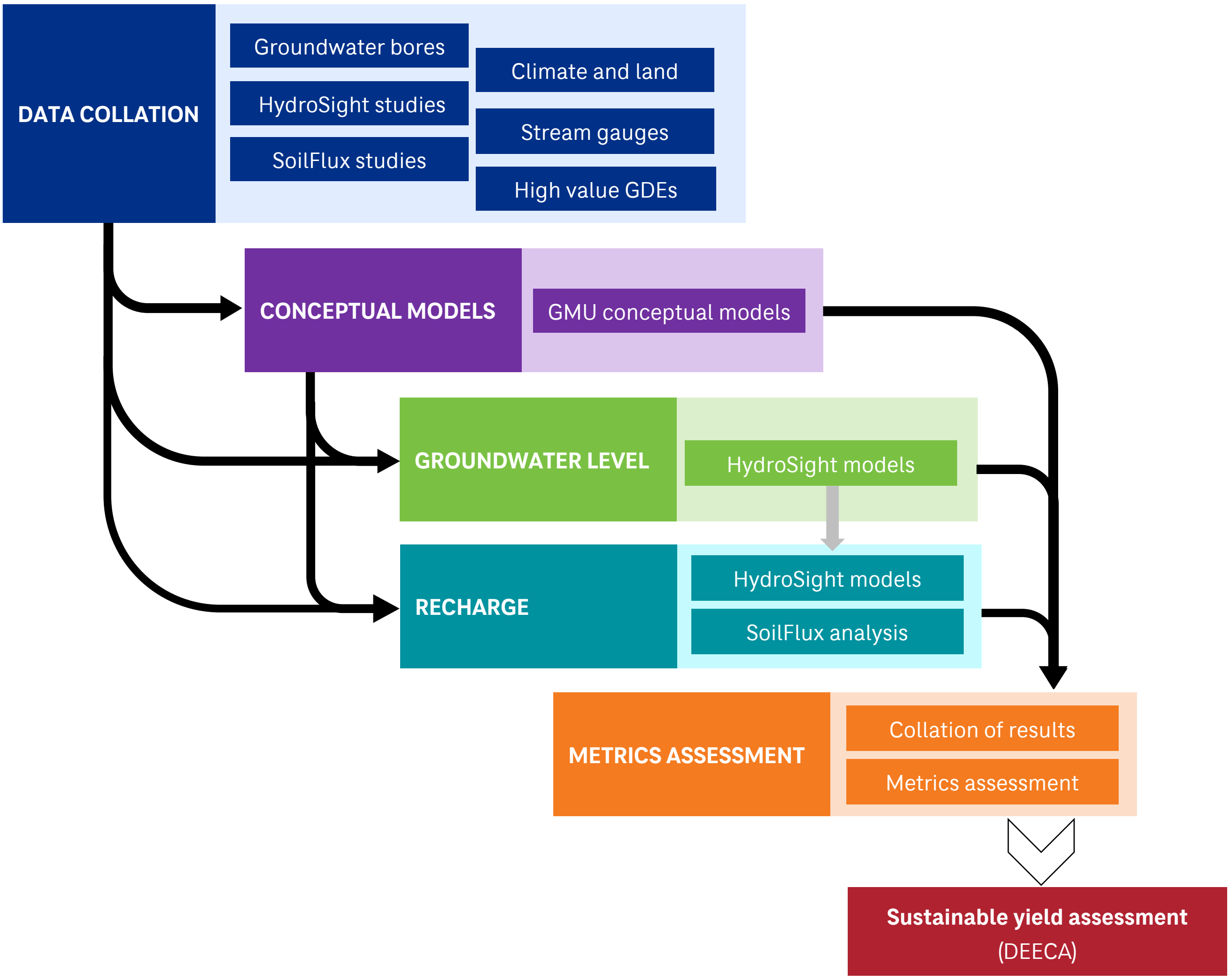

Figure 1-3 Workflow for development of sustainable yield assessments for unconfined and semi-confined aquifers

Section 2 Sustainable Yield Assessment Method

2.1 Method overview

The general approach of the project involved using a range of collated datasets to develop individual bore hydrograph models which were used to map groundwater elevation and recharge across Victoria. This data was then used to consider potential impacts of watertable drawdown at groundwater receptors and estimated recharge volumes for management areas. This approach was developed and improved throughout the initial stages of the project.

An overview of the general approach and project steps is depicted in Figure 1-3 above. These steps consisted of:

1. Project scenarios were defined, in discussion with DEECA – **Section 2.2**
2. A range of datasets were collated – **Section 2.3**
3. Conceptual models for each GMU were developed to frame the analysis – **Section 2.4**
4. HydroSight statistical models of (a few thousand) individual bore hydrographs were built, calibrated and run for scenarios to provide estimates of both climate-only and groundwater pumping-driven groundwater elevation and recharge into the future – **Section 2.5.3**
5. Relevant previous studies were mined for results of HydroSight modelling of to provide additional bore results – **Section 2.5.3.4**
6. Individual bore groundwater elevation results were mapped across Victoria using the kriging code HydroMap to provide a number of state-wide gridded products for project scenarios – **Section 2.5.4**
7. Gridded recharge estimates for Victoria were obtained from the water balance model SoilFlux and modified for project climate scenarios – **Section 2.6.4.2.2**
8. Individual bore recharge results from HydroSight modelling were merged with gridded SoilFlux results to develop state-wide gridded results for recharge for project scenarios – **Section 2.6.4.2**
9. Stream gauge data was analysed to estimate baseflow statistics under future climate scenarios – **Section 2.6.5**

The results from the groundwater elevation, recharge and stream flow analyses were then collated to consider impacts to metrics values by GMU (refer Section 6 below).

2.2 Project scenarios

A number of project scenarios were used to model groundwater level and recharge that considered climate change, groundwater extraction and time period. The project scenarios are as follows:

- **Climate scenarios**[1]:
    - No climate change (*NB not per DELWP guideline*)
    - Low climate change (10th percentile[1])
    - Medium climate change (50th percentile[1]), and
    - High climate change (90th percentile[1])
- **Timeline**, results averaged over the periods (calendar years)

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[1] Climate scenarios were defined as per the 5 km CSIRO downscaled climate change projections for two greenhouse gas emission pathways, medium emissions (RCP8.5) from the *Guidelines for assessing the impact of climate change on water availability in Victoria* ('Climate Change Guidelines'; DELWP, 2020)

  - 1950-1974 - ‘baseline’ period
  - 1975-1997
  - 1998-2020 - ‘current’ period
  - 2021-2040 – period to first prediction date, as per Climate Change Guidelines (DELWP, 2020), and
  - 2041-2065 - period to second prediction date, as per Climate Change Guidelines (DELWP, 2020).
- **Groundwater extraction rates**
  - No use
  - Current use
  - Permissible Consumptive Volume (PCV)[2], and
  - 200% PCV[2].

Project analyses for groundwater elevation considered 35 individual scenarios which correspond to a combination of the relevant scenario alternatives above. Analyses for watertable recharge will consider nine individual scenarios which correspond to a combination of the relevant scenario alternatives above. The recharge results will be used to inform sustainable yields for the state. The predictive groundwater extraction scenarios are not considered for recharge results because groundwater recharge is independent of groundwater extraction. A matrix of how the scenarios relate to project analyses is presented in Table 2-1 below.

Table 2-1 Project scenarios modelled for groundwater level (WL) and recharge (Re) parameters

Scenario	CLIMATE CHANGE															
	Current / No change				Low				Medium				High			
	GROUNDWATER EXTRACTION															
TIME PERIOD	No use	Current use	PCV	200% PCV	No use	Current use	PCV	200% PCV	No use	Current use	PCV	200% PCV	No use	Current use	PCV	200% PCV
1950-1974		WL Re														
1975-1997		WL Re														
1998-2020		WL Re														
2021-2040	WL	WL	WL	WL	WL	WL Re	WL	WL	WL	WL Re	WL	WL	WL	WL Re	WL	WL
2041-2065	WL	WL	WL	WL	WL	WL Re	WL	WL	WL	WL Re	WL	WL	WL	WL Re	WL	WL

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[2] PCV rates were estimated for each GMU as the total of all bores of the average of the most recent five years of data (2015-2020) on licenced groundwater entitlement per bore that was classified as unconfined for the purposes of the project within each GMU. This data was estimated due to the lack of individual bore data on the PCV for unconfined bores (PCV is published per GMU and does not specifically consider the confinement of bores within each GMU).

2.3 Data collation

A number of datasets were gathered for the project, including Victorian databases on groundwater level and use data, stream flow and groundwater receptors, as well as relevant previous modelling work. A summary of the data requirements for each element of project analysis is presented in Table 2-2. The details of the datasets are included in Appendix B.

Table 2-2 Summary of data use on the project

	Project analyses				
Dataset	**HydroSight recharge**	**SoilFlux recharge**	**Groundwater level mapping**	**Streamflow analysis**	**Metrics assessment**
Digital Elevation Model (ground surface elevation)	X	X	X		
Land use mapping		X			
State-wide soil mapping		X			
Groundwater bore records	X		X		
Groundwater level data (manual and telemetered)	X		X		
Groundwater extraction data	X		X		X
Stream gauge records				X	
High value GDEs					X
Climate data (rainfall and potential evapotranspiration (PET))	X	X	X	X	
Previous SoilFlux studies		X			
Previous HydroSight studies	X		X		

2.4 GMU conceptual models

2.4.1 Purpose and rationale

Two types of conceptual models were developed for the project; a high level, schematic description of Victorian aquifer systems, and a more detailed conceptualisation of each GMU. Conceptual models for the GMUs assessed in this project were developed primarily to establish an overview of the primary hydrogeological processes (rainfall, irrigation accessions or stream leakage).

2.4.2 Approach

DEECA have defined a set of 'aquifer systems' across Victoria which relate to hydrogeological settings (Figure 2-2); Highlands, Sedimentary Upland Valleys, Sedimentary Valleys, Volcanics and Sedimentary Plains. These aquifer systems are described in a set of high-level, schematic (two-dimensional) standard models in Appendix C. The models describe the general landscapes and major hydrogeological processes present in each of the aquifer systems. An example of a conceptual diagram and processes is included in Figure 2-1.

Each GMU assessed in the project is assigned to a primary aquifer system type to which the GMU conforms most closely. More detailed conceptual models developed for each GMU are based on the standard model for the assigned primary aquifer system type, to which specific attributes and processes are quantified where possible. The processes specific to that aquifer system type and individual GMU are described based on best available information at the time of reporting, and are sourced from local groundwater management group publications and technical studies from available literature.

The models for all GMUs are included in 2.7.7 and further detailed in Appendix L.

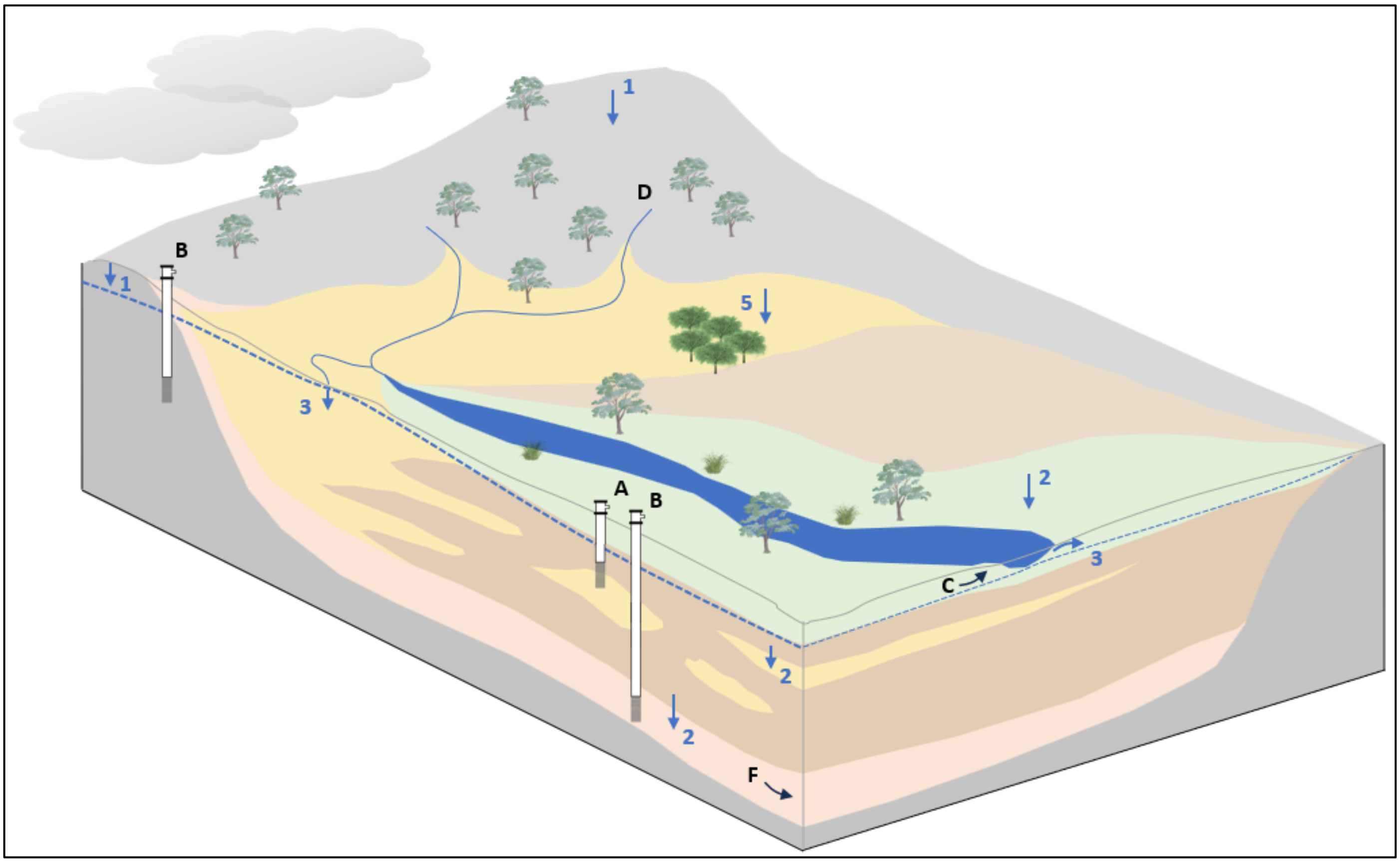
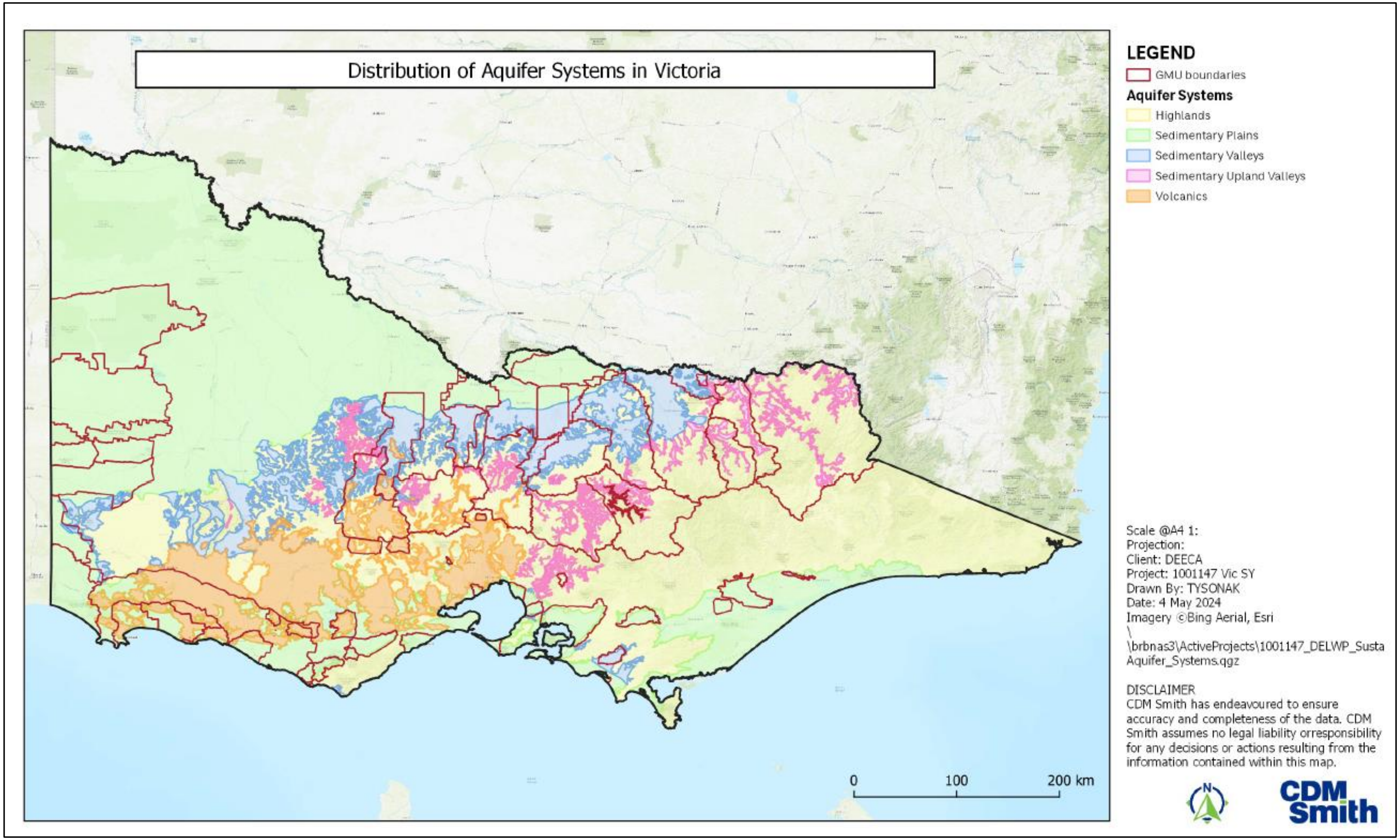


Figure 2-1 Conceptual diagram for Sedimentary Valley GMUs, where 1 – high rainfall recharge, 2 – low rainfall recharge, 3 – surface water leakage, A/B – pumping, C – groundwater discharge to surface water.



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Drawn By: TYSONAK
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Figure 2-2 Victoria's Aquifer Systems

2.5 Groundwater level maps

2.5.1 Purpose and rationale

Maps of groundwater elevation derived in this project are a fundamental output to assessing sustainable yield metrics. Specifically, maps that represent the change in groundwater elevation caused by changes to recharge and groundwater extraction, both historically and into the future.

2.5.2 Approach

Development of groundwater elevation (watertable) maps involved:

- Undertaking statistical modelling of observation bore hydrographs using the program HydroSight to model groundwater level under project scenarios, for
  - Over 3,000 observation bores where only climate impacts to groundwater level were modelled, and
  - 27 extraction bores across eight GMUs where the influence of groundwater pumping was modelled
- Collating results from previous HydroSight studies to provide additional results to the bore dataset
- Mapping individual bore groundwater elevation results across Victoria using the kriging code HydroMap, to develop a number of state-wide gridded products for project scenarios

The results, collated from mapping outputs, were then used to estimate the potential change to groundwater levels into the future as part of the metrics assessment (Section 6).

2.5.3 Bore point groundwater elevation

2.5.3.1 Overview

HydroSight is a statistical package designed to extract quantitative information (such as recharge estimates and predicted groundwater levels) from groundwater level monitoring data. The program calibrates weighting functions with water level observations and climate data, informed by simple soil models, then simulates hydrographs for each modelled bore and provides estimates of groundwater level and recharge together for scenarios of climate change and changes to groundwater extraction volumes into the future. Elements of the package have been extended for use on this project by Dr Tim Peterson. The approach statistically weights input data in the prediction of the groundwater heads. Figure 2-3 is a simplified example of the weighting process used to simulate a timeseries of groundwater levels. Further detail on the concepts behind HydroSight and its uses is presented in Appendix D.

Figure 2-3 (A) shows the time series of the simulated head, which is derived from the weighting of observed past rainfall. Figure 2-3 (B) shows the daily rainfall prior to the time point to be simulated (t2) and Figure 2-3 (C) shows a smooth weighting function with a zero weight at time t2 and a maximum weight after some time lag. Figure 2-3 (D) shows the rainfall after being weighted. Summing this historic weighted rainfall gives the head displacement produced from the historic rainfall and by repeating this process for each head time-point (using the same weighting function) and adding a datum, provides the final simulation of the groundwater hydrograph.

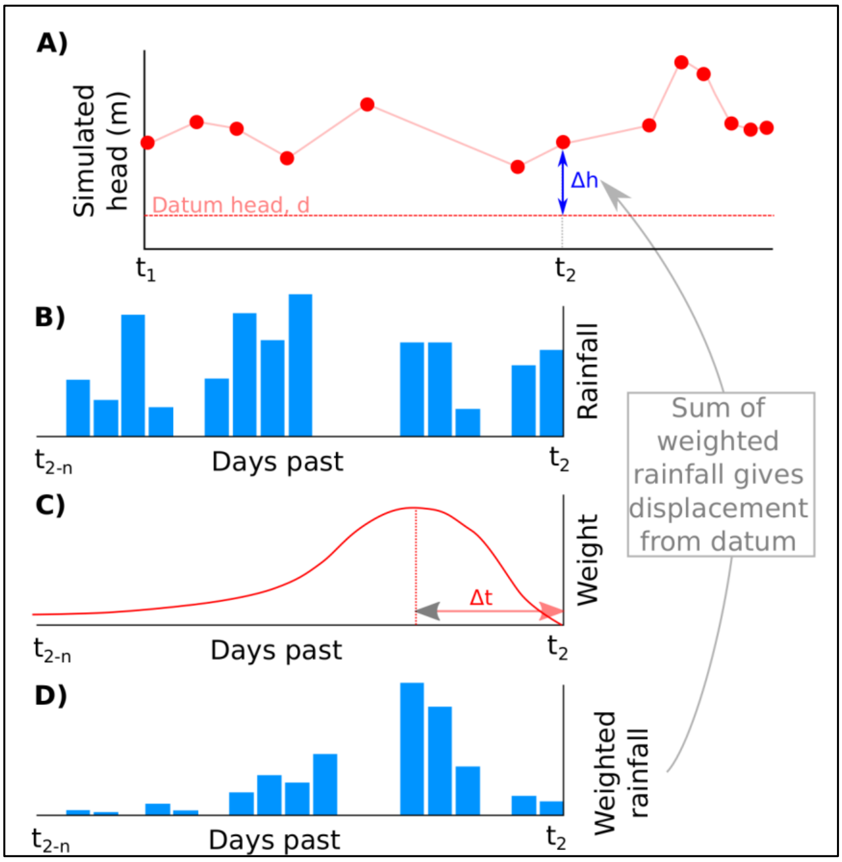

Figure 2-3 Example of the weighting process behind HydroSight

Within the HydroSight analysis for this project, differentiation was made between bores with hydrographs driven mainly by climate-only processes (i.e. rainfall and evapotranspiration) and those that are also driven by local groundwater extraction. These two types of sites are assessed differently in HydroSight, with the latter including data on proximal groundwater extraction bores alongside climate as a factor driving groundwater levels.

Climate-only driven analysis in HydroSight is significantly less time consuming, both in dataset up and model processing requirements. This is because downscaling of infrequent metered usage is not required in climate-only analyses. This fact drove the decision to undertake dual analyses in the project using HydroSight, as follows:

- Climate-only driven models run for all bores (selected on data availability) across Victoria
- Pumping models (where local groundwater extraction is included in each model) undertaken for a limited number of bores in selected high pumping areas and priority GMUs across Victoria
    - To estimate the influence of groundwater extraction on bores which could not be modelled individually, the relationship between groundwater use and drawdown from modelled groundwater extraction bores was assigned to un-modelled bores to provide estimated groundwater level results for all un-modelled groundwater extraction bores in Victoria (described in detail in Section 2.5.3.3 below).

The results of the analyses were combined to produce a spatially continuous dataset of estimated groundwater level at all available bores across Victoria. These two approaches are described below.

It is acknowledged that processes apart from climate influence groundwater levels across the landscape, including irrigation, stream accessions to groundwater and aquifer throughflow. HydroSight does account for aquifer discharge through lateral flow, via the weighting functions, but it does not account for change in the aquifer flowrate or recharge sources other than that from climate (e.g. irrigation, stream accessions). Consequently, HydroSight attributes a given change in head exclusively to climate driven recharge. Where a site is influenced by another source or recharge, such as irrigation, the omission of it from the modelling will result in either the modelled recharge being over-estimated or the fit to the observed hydrograph being reduced.

2.5.3.2 Climate-only driven bores

2.5.3.2.1 Data collation and pre-processing

The following datasets were collated for use in the climate-only driven bore HydroSight modelling.

Groundwater bores with water level records

The databases of groundwater bore monitoring records (manual and telemetered records; DELWP, 2021a; refer Section 2.3) was further refined to include only bores which satisfied the following criteria:

- Groundwater level observations which began after 1 January 2010 (records commencing after this date are considered too late to be a useful bore for modelling)
- Groundwater level observations which ceased after 30 December 2014 (records stopping before this date are considered too early to be a useful bore for modelling)
- Greater than a total of 20 individual monitoring points
- Greater than a minimum of four monitoring points per year.

In addition, the water level time-series were edited in the following manner:

- Telemetered data with a measurement frequency less than daily was reduced to a daily value using the average of the day's data (
- Water level elevations were converted from recorded depth below natural surface using a project DEM (refer Appendix B) so that the outputs of the analysis would be consistent with the DEM to be used in mapping (refer Section 2.5.4 below)
- Where multiple bores had identical locations, the shallowest bore was retained and deeper bore/s were removed from the dataset.

Erroneous groundwater level records were identified and removed using a feature of HydroSight (Peterson *et al*. 2017) to remove a number of identifiable types of data errors and outliers ('Outlier Removal'), including:

- Head deeper than bore depth
- Head shallower than casing stick-up
- Water level rate of change (more than a threshold value of 5 m per day)
- Constant head (longer than a threshold value of 7 days)
- Statistically outlying data points.

This automated process was used because the number of hydrographs to be interrogated for the project was too great to undertake a water level data quality control process manually. This type of approach to data validation is widely used, reproducible and within HydroSight, was developed in collaboration with the Bureau of Meteorology (BoM) and Victorian Department of Primary Industries (DPI).

The final list of 3,406 bores collated for use in climate-only driven HydroSight analysis (spatial distribution of these bores is shown in Figure 2-6 below).

Climate data

Historic record daily rainfall and PET time-series were obtained for each bore location for use in model calibration. The data was collated using AWAPer (Peterson *et al*, 2019), which collates BoM 5x5 km gridded climate data and, here, was used to calculate the Morton's areal potential PET and rainfall at each observation bore. Importantly, the rainfall and PET influencing the groundwater level at a bore was assumed to be that at the bore location and not at some distant location, for example the upper slopes of a catchment.

The predictive HydroSight modelling scenarios required generation of a continuous daily time-series of project rainfall and PET for each individual bore location, for the three project climate change scenarios (refer Section 2.2 above). These products were not available elsewhere and so was created for the project. The result was a timeseries from 2020 to 2085[3] of rainfall and PET specific for future scenarios, for each modelled bore for low, medium and high climate change projections for use in predictive modelling.

Bore locations, effective bore depth, bore construction date and casing stick-up above ground surface were also collated for each bore (primarily for the outlier removal process in HydroSight).

2.5.3.2.2 Model construction

A HydroSight model was built for each individual bore to model groundwater level (and estimate recharge; refer Section 2.6.3 below) driven by climate-only processes (i.e. rainfall and evapotranspiration). The models were based on a single-layer soil model (refer Figure 2-4) using a transfer function-noise (TFN) time-series model and a Pearsons response weighting function at a daily timestep, following Peterson and Western (2014).

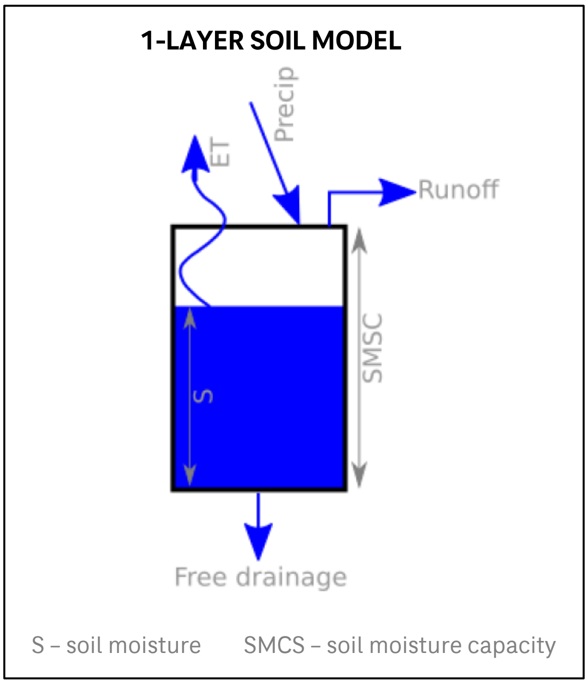

Figure 2-4 Components of a one-layer HydroSight soil model (Peterson, pers. comm., 2022).

A uniform model structure was adopted for all bores in the analysis. HydroSight does allow for many alternate model structures (e.g. a two layer soil model). However, given that this selected one-layer model has been found by others to generally perform very well across Australia (Fan *et al*, 2023) and in blinded tests of the model predictive skill (Collenteur *et al*, 2024), and the scale of this study, this assumption is considered reasonable. The selection of model settings was informed by the experience of HydroSight's lead developer (Dr Tim Peterson) and provided a simple, well performing model that suited project objectives. In summary, the soil model assumed the following in the partitioning of rainfall:

- Infiltration linearly declined with catchment wetness
- Actual soil ET (AET) is a function of soil wetness such that when the soil is saturated the AET equals PET and when empty equal zero
- The long-term mean AET is within plausible bounds as defined by the Budyko curve and the aridity at the observation bore (Greve *et al*. 2015, Peterson and Fulton, 2019). This results in the long term recharge being a plausible fraction of the annual rainfall

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[3] This date is a remnant of method development. The datasets were generated and predictive modelling was undertaken beyond the project reporting date of 2065 so that there was a buffer of results beyond the project reporting date in case project reporting date range extended past 2065 (e.g. if the '2065' project result was decided to be an average of 2055-2075).

- Recharge is event driven such that it only occurs when soil moisture exceeds a threshold. When the soil is saturated, recharge equals the saturated vertical hydraulic conductivity of the soil (which is a calibrated parameter).

2.5.3.2.3 Model calibration

The bores' models were calibrated in HydroSight the using a global calibration scheme called *covariance matrix adaptation evolution strategy* (CMA-ES). Models were calibrated in batches in multiple HydroSight files due to the limitations of the software in practically handling more than a few hundred bore models at a time.

Model calibration resulted in one of two outcomes for bore models:

1. Models calibrated, with calibration quality determined primarily by the coefficient of efficiency (CoE) statistic for each model - the CoE provides an unbiased assessment of calibrated head fit to observed data, and ranges from '0' (or a negative value) - extremely poor calibration, to '1' - perfect calibration. A zero values indicates that the model produced an estimate no better than simply taking the mean head. For reference, the CoE is simple one minus the variance in the model residuals divided by the variance of the observed head. To illustrate the range of CoE values, Figure 2-7 below shows six observed and modelled hydrographs. It shows that the head at some bores had a reasonable CoE (bores 86666 and 117418) while others had a very poor CoE (bores 64013 and 86140). However, it is important to acknowledge that CoE was developed for streamflow modelling and not groundwater head analysis. An implication of this is that, unlike streamflow, groundwater head rarely has a lower bound and hence can experience long term trends. This issue is shown at bore 86140 where a long-term trend occurs. HydroSight explains this trend very well but, because the denominator of the CoE is the variance in the observed head, the relatively low error (i.e. the CoE numerator) is divided by a large number and produces a low CoE. Hence bores with a long term trend like 86140 are likely to be excluded from the subsequent analysis.
2. Calibration failed, where the model failed to calibrate any set of model parameters to the observed data with the given forcing data and model settings. Only 34 of the 3,243 modelled bores failed. This generally occurred when no parameter set could be identified that met the AET constraints discussed above.

Of the 3,209 bores which calibrated to some degree, 68% had a calibration CoE at or above 0.3, and 40% had a calibration CoE at or above 0.7. Refer to Figure 2-5 below for a summary of CoE results, and Figure 2-6 for a spatial distribution of results.

The HydroSight calibration also provides a time-series estimate of the annual watertable recharge for each bore as a product of the model. This component is described separately in Section 2.6.3.2 below.

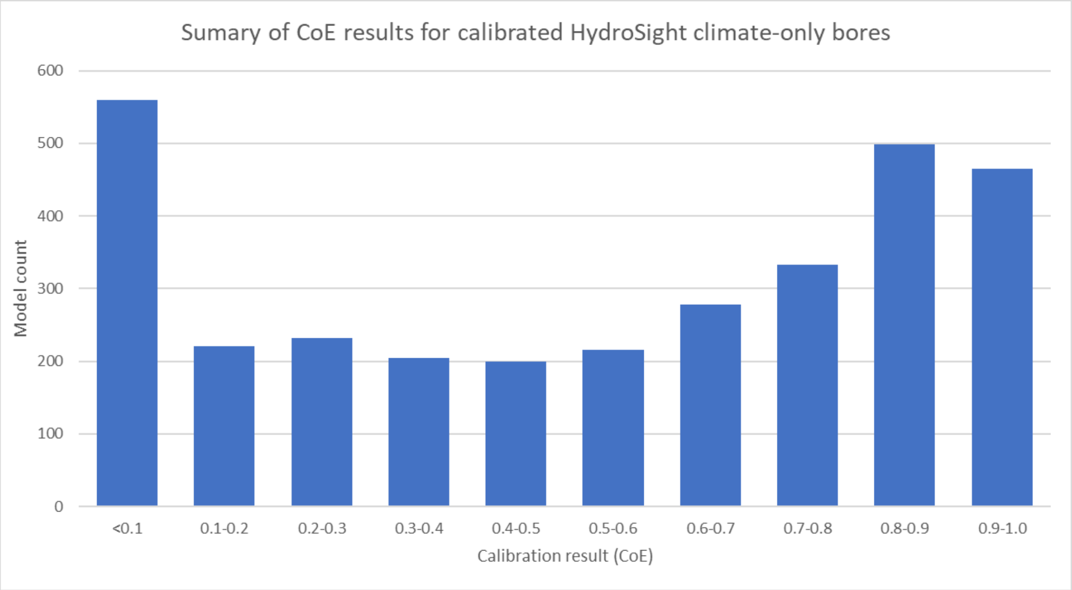

Figure 2-5 Histogram of CoE results for climate-only calibrated bores in HydroSight.

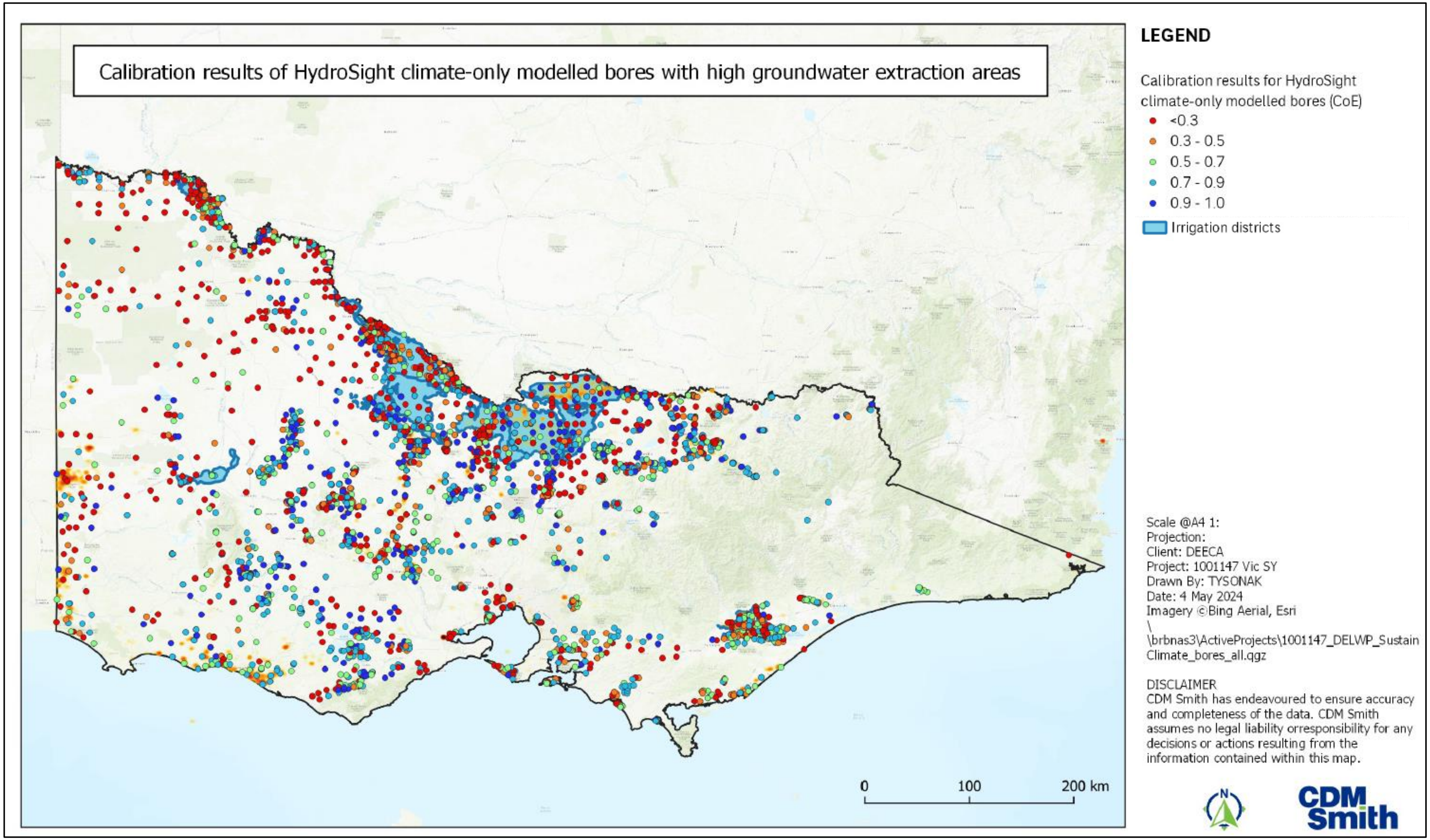

Figure 2-6 Unconfined groundwater observation bores analysed in HydroSight for the SY project , showing irrigation districts and density of watertable extraction

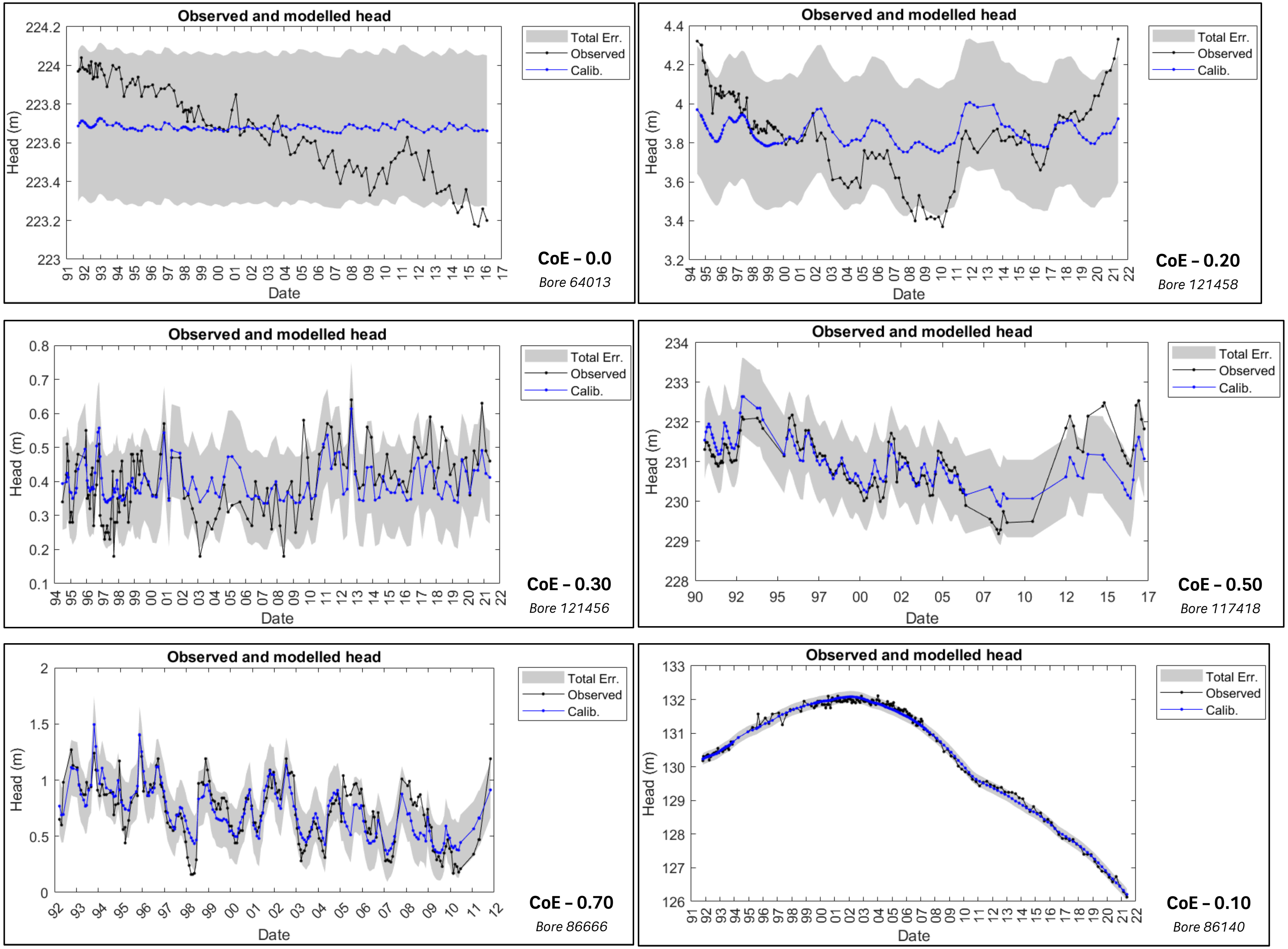

Figure 2-7 Examples of typical HydroSight climate-only modelled results for a range of CoE values.

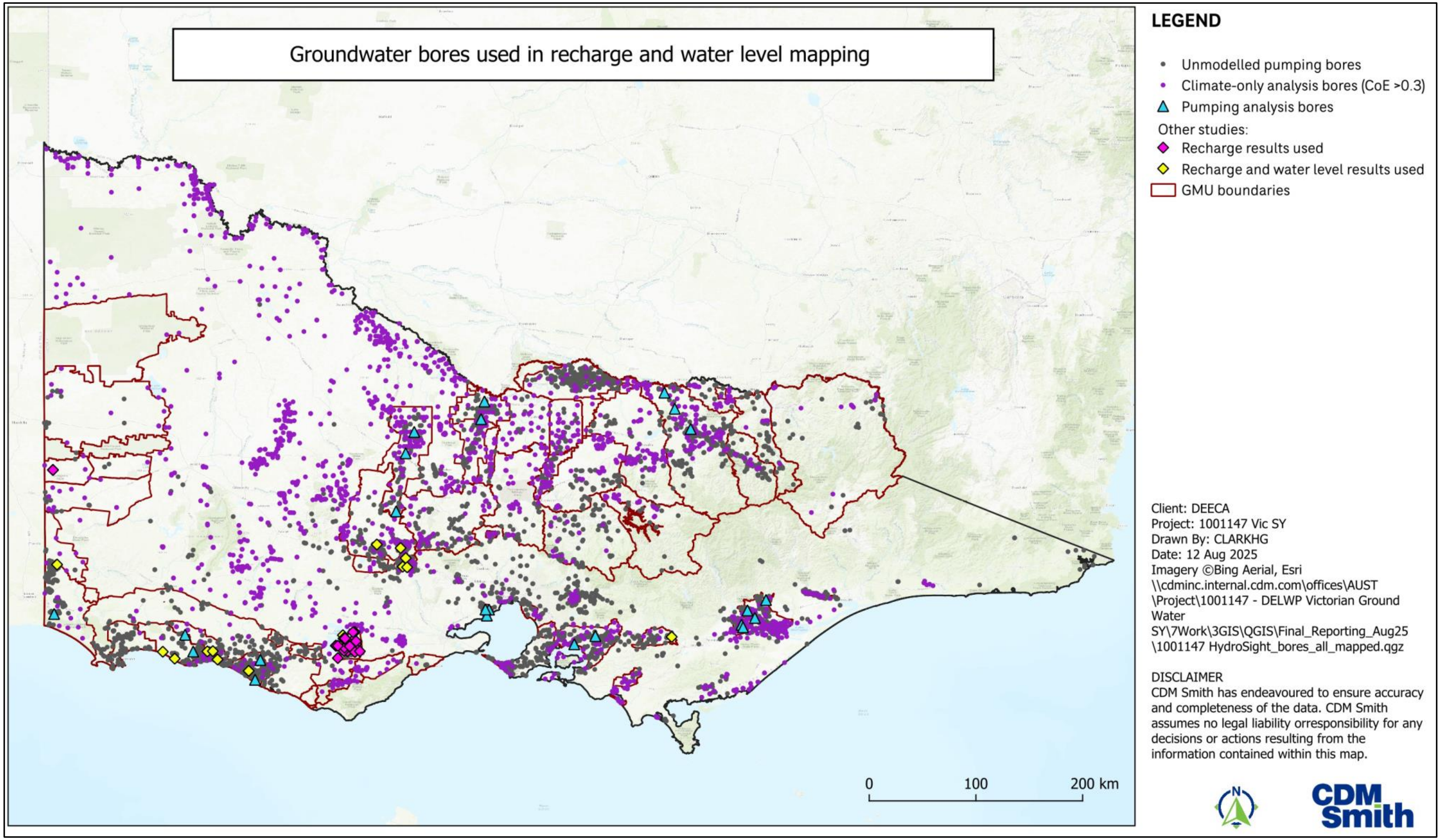

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Figure 2-8 Groundwater bores used in water level and recharge mapping, including HydroSight modelled bores from climate-only and pumping analysis, and from other studies, and unmodelled groundwater extraction bores.

2.5.3.2.4 Model simulation

The scenarios modelled using the calibrated HydroSight models for each bore were based on the three reporting climate scenarios of low, medium and high climate change (refer Section 2.2). The two-reporting time-steps of 2021-2040 and 2040-2065 (refer Section 2.2) were encompassed within the simulation duration of 1 January 1950 to 30 June 2085. The modelled time-step was set to 7 days to control total run times for the modelling.

Each calibrated bore model was run four separate times using the climate change projected data specific to each bore (no climate change/current climate, low, medium and high climate change). The quality of the predictive simulations was dependent on the quality of the original calibration. An example of the simulation of groundwater level under moderate climate change for a 0.91 CoE calibrated bore is presented in Figure 2-9.

The HydroSight predictive simulations also provide a time-series estimate of watertable recharge for each bore as a product of the simulation. This is described separately in Section 2.6.3.2.

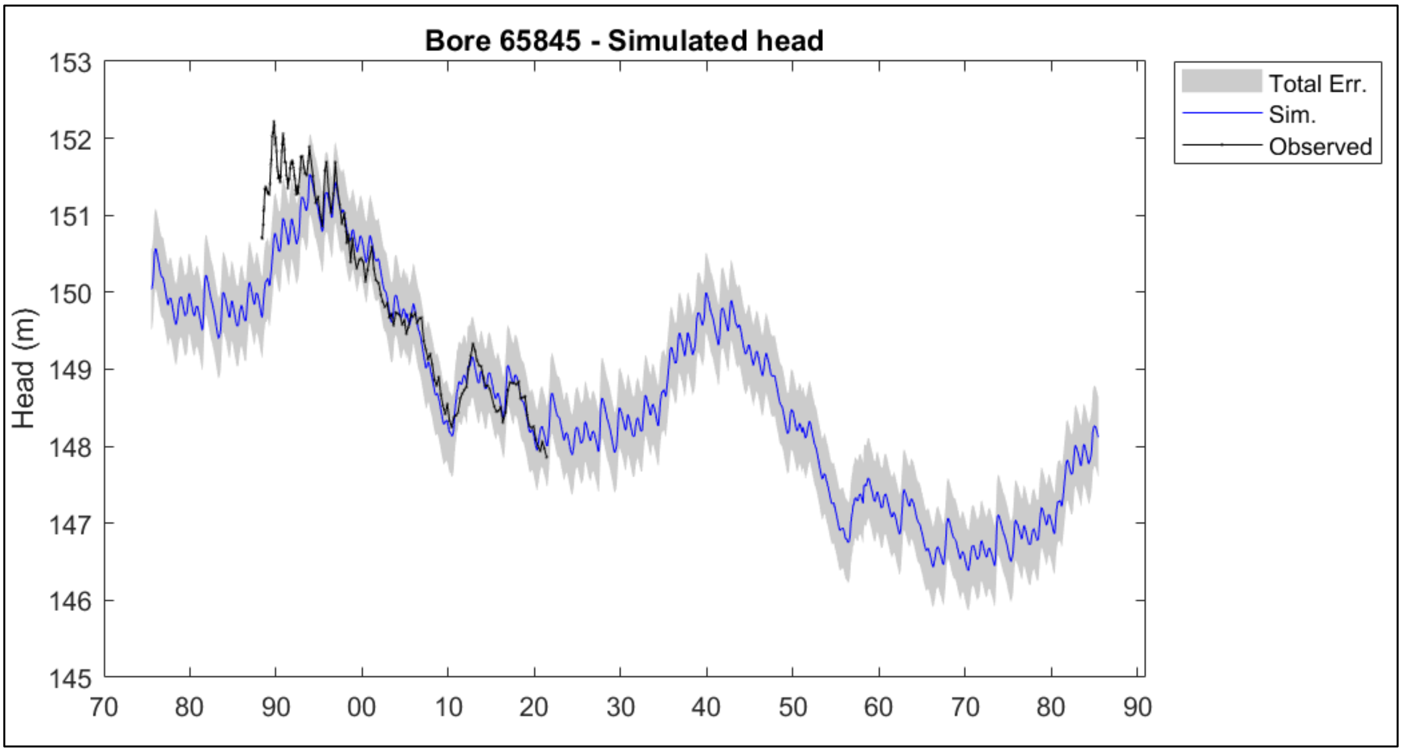


Figure 2-9 An example simulation for a climate-only calibrated model for bore 65845 under a future medium climate change scenario (calibration CoE – 0.91).

2.5.3.2.5 Result post-processing

The modelling results for climate-only driven bores were reviewed for quality of calibration based on the calibration CoE result (refer Section 2.5.3.2.3). A review of a number of calibration hydrographs was undertaken to determine the cut-off CoE value which would be considered suitable for the purposes of the project. A typical range of CoE values like that considered are included in Figure 2-7 above.

The review considered the correlation between CoE value and the modelled water level fit to observed data based on a visual assessment. This review concluded that a CoE value of ≥0.3 indicated a suitable calibration for the purposes of this study, considering the precision appropriate for a state-wide scale study. The CoE value is less strict than a localised, bore-specific HydroSight investigation might use, because of the regional nature of the project analysis and the desire to include as many useful (if not perfect) data points as possible. This CoE cut-off value is consistent with that used in other HydroSight studies (Fan *et al.*, 2024). The hydrograph results from calibration (bore 121456 in Figure 2-7) demonstrate that a typical calibration with a CoE of 0.3 is considered a reasonable prediction of groundwater level, especially when considering results are averaged over decades for project output statistics.

The filtering by CoE resulted in 2,196 bores (68% of all calibrated bores) likely to be highly influenced by climate, and hence, suitable for use in groundwater level mapping (Figure 2-8). Also included in Figure 2-8 are the bores used in mapping from the HydroSight pumping analysis, as well as from previous projects.

The results from the model simulations were then post-processed to provide a single result value for the maximum and minimum head at each bore and for each project scenario. Specifically, for each bore and simulation, the annual minimum and maximum simulated head was identified and then each was averaged over the entire simulation duration. The following scenarios were calculated for each bore, in line with project reporting requirements (refer Section 2.2):

- Baseline - 1950-1974
- 1975-1997
- Current - 1998-2020
- 2021-2040 – no climate change, low, medium and high climate change
- 2041-2065 – no climate change, low, medium and high climate change.

The climate-only bore modelling did not consider groundwater extraction, so the project scenarios around groundwater pumping are not relevant (refer Section 2.2).

2.5.3.2.6 Uncertainty

The uncertainty in the average maximum / minimum groundwater level at each bore was considered to consist of:

1. An error in the HydroSight estimate of the maximum and minimum head each year, and
2. The variability in the maximum / minimum groundwater level from year to year.

Expressing both as a variance, and assuming them to be independent, allows both to be summed. This provided a measure of total uncertainty and this was accounted for in the groundwater level mapping.

To illustrate the uncertainty in the HydroSight estimates, Figure 2-10 shows a modelled and simulated hydrograph. In 2006 the maximum observed groundwater level was 172.5 m AHD while the simulated at this time point was 171.6 m AHD. As shown in the figure, the error in the estimate of the maximum head in 2006 was around 0.9 m. Repeating this for all years in the observed record produces a time-series of annual residuals. To estimate the population variance of this measure or error, jack-knifing was then adopted. This involved the repeated extraction of a single residual value from the time series and calculation of the sample variance from the remaining observations. The removed observation was then reinserted and the next residual value was replaced. At the end of this approach a set of sample variance estimates were obtained and the estimate of the population variance was derived by taking their mean.

To estimate the variability in the modelled maximum / minimum groundwater level at each bore, a similar approach was adopted whereby the HydroSight maximum / minimum groundwater level each year was obtained (refer Figure 2-11). Jack-knifing was again applied whereby a single value was removed and the variance calculated. Repeating for all years and averaging then gave an estimate of the population variance in the maximum / minimum groundwater level at a bore.

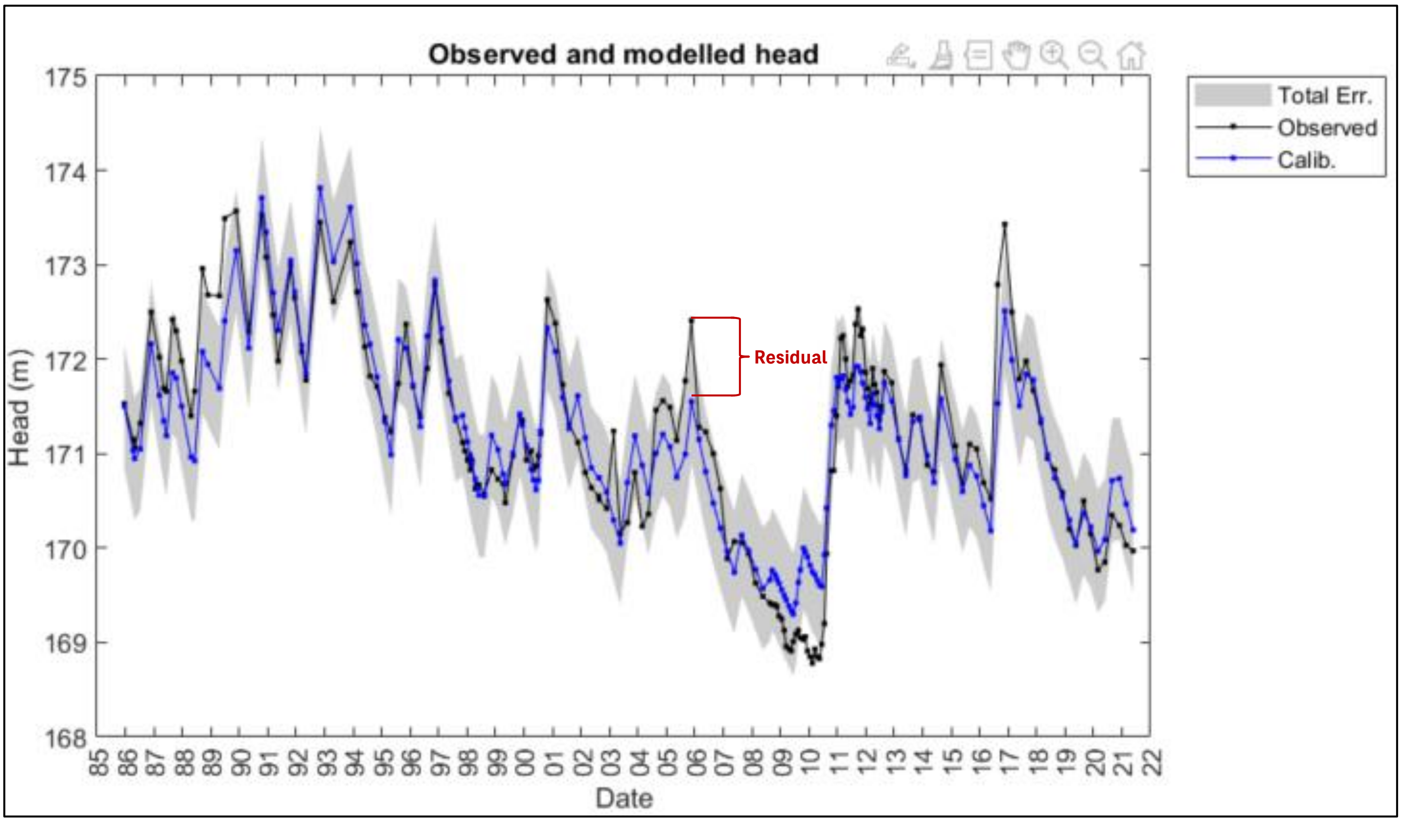


Figure 2-10 **Result of calibration in HydroSight for an example climate-only driven bore showing the observed and calibrated water level data, indicating the residual.**

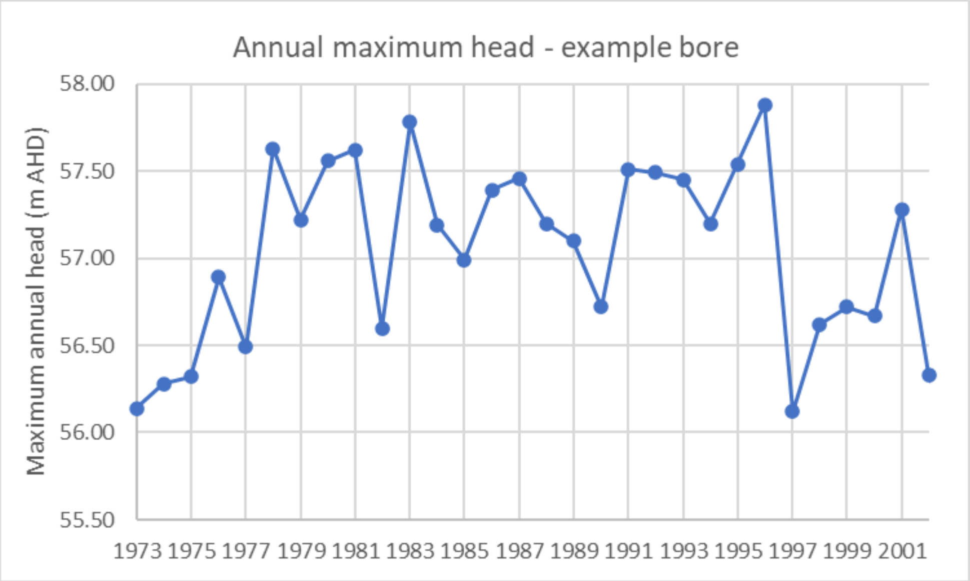


Figure 2-11 **Variability in annual maximum water levels for an example climate-only driven bore.**

The two population variances were then summed to give an estimate of total uncertainty in the mean maximum and minimum groundwater elevation for each bore. This additive approach is based on the statistical principal (and inherent assumption) that uncorrelated variances are additive. This component of the estimate of uncertainty of the mean groundwater elevation at each bore is assumed to be time-invariant and independent of reporting period and predictive scenario. This measure of uncertainty is incorporated into the results through the mapping approach in HydroMap (refer Section 2.5.4.2.6). The combined estimate of uncertainty is considered for the purposes of this project to be considered an estimate of uncertainty in the mean of groundwater elevation.

2.5.3.3 Pumping analysis bores

Analysis of bores influenced by pumping was targeted at selected observation bores in eight priority GMUs where groundwater extraction is significant, namely: Lower Campaspe Valley WSPA, Koo-Wee-Rup WSPA, Lower Ovens GMA, Mid Loddon GMA, Deutgam WSPA, Denison WSPA, Wa De Lock GMA, and the following GMUs in the region of the South West Limestone GMU: Nullawarre GMA, Glenelg WSPA, Hawkesdale GMA and Yangery GMA (see Figure 2-12). The priority GMUs were selected as they are key groundwater use areas where recharge has not been investigated in depth previously.

A limited number of pumping bores (5) were modelled with each observation bore. This is discussed further below.

2.5.3.3.1 Data collation and pre-processing

The following datasets were collated for use in the pumping analysis modelling using HydroSight.

Groundwater bores with water level records

The dataset of groundwater bore water level records (as described in Appendix B) was reviewed to identify 27 observation bores within the eight priority GMUs which would represent groundwater extraction in each area. Three observation bores were selected within each priority GMU, except for the South West Limestone GMU, where a total of six bores were selected across the four sub-zones. The selection of the observation bores was based on proximity to groundwater extraction density, spatial spread across a GMU, bores that are screened in the watertable and availability of data. For example, bores with fewer than 10 years of groundwater observations were not considered. The observation bores selected for use in the analysis are show on Figure 2-12.

Groundwater extraction and entitlement

In order to provide groundwater pumping data as an input to the pumping analysis modelled in HydroSight for each observation bore, the collated database of groundwater bore use and licenced volume records was examined (refer Appendix B). The location, use and entitlement data for the five closest groundwater extraction bores to each observation bore was obtained. Importantly, only the five closest extraction bores were selected because each has incomplete (i.e. observations started years after pumping likely commenced) and infrequent usage observations (i.e. biannually as best). To estimate the drawdown from such a partially metered extraction bore requires estimation of the usage prior to metering and between the meter readings.

A prior DEECA project (Peterson and Fulton, 2019) developed an approach to resolve this issue and implement it within HydroSight. Details are discussed below, but the relevance here is that the approach requires estimation of unmetered usage is undertaken during the model calibration (to honour the observed hydrograph and any usage data) and is enormously computationally intensive. In comparison to the climate-only models, the calibration of these pumping and climate models with downscaling takes approximately 100 times longer and the addition of each additional extraction bore significantly further increases the calibration time. More importantly, the addition of each extra extraction bore reduces the probability the calibration reproducible finding the global solution (i.e. the very best overall parameter values).

The selection of only the five closest extraction bores was therefore considered an acceptable compromise between run-time and calibration reliability, and having sufficient extraction bores to capture the dominate drivers of drawdown. Furthermore, and as shown in Table 2-3, this approach often produced a very high CoE (up to 0.98). For such sites, the addition of an extra extraction bore is only able to improve the CoE by 0.02 and hence offers little marginal value.

Regarding the extraction bore selection processes, extraction bores with use below around 1 ML/yr for the period 2015-2020 were not considered. This was done to ensure other higher rate pumping bores (i.e. those more likely to influence water level) could be included in the analysis. Where more than one of the five closes extraction bores were within 50m of each other, the bores were combined to a single nominal pumping bore with a cumulative effective use. Priority bores and associated pumping bores for each GMU are listed in Table 2-3 and mapped for each GMU in Appendix F.

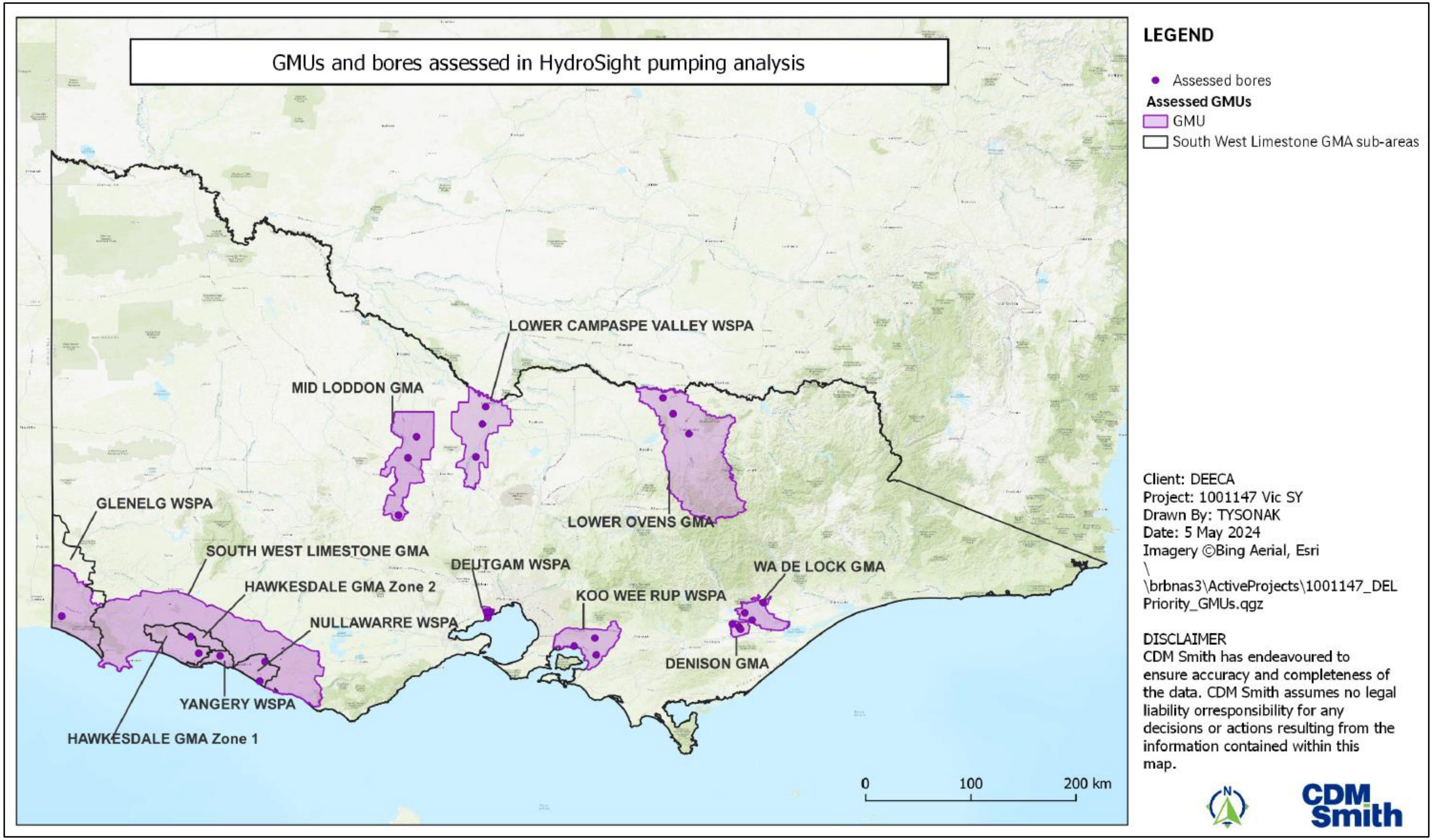


Figure 2-12 Pumping analysis undertaken at 8 selected priority GMUs, showing modelled observation bores.

HydroSight aims to downscale the metered usage to a daily timestep. To ensure the downscaling is plausible (and efficient), knowledge of irrigation practices was used to constrain the processes; specifically:

- Prior to bore construction, usage was zero
- Outside of the irrigation season, usage was fixed at zero
- Between the period of the annual registered extraction dataset (2009-2020), the downscaling was undertaken such that the total extractions over an irrigation season equalled the metered usage.

Climate data was projected and collated for the current climate and climate change scenarios for each modelled observation bore as detailed in Appendix B. Bore locations, effective bore depth (refer Section 2.5.3.2.1), bore construction date and casing stick-up above ground surface were also collated for each bore (primarily for the outlier removal process in HydroSight).

2.5.3.3.2 Model construction

When groundwater level is influenced by both recharge and pumping, reliable prediction of the level under alternate climate and pumping scenarios requires that both drivers be reliably estimated over the calibration period – not just their sum. Ideally, observations would be available for each of these components, against which the modelled components could be compared. However, given recharge is not observable and metered usage is infrequent and incomplete – and pumping test estimates of aquifer properties are unavailable – and alternative approach is required to assess prediction reliability. Alternatively, the prediction of the groundwater level beyond the calibration periods – that is, split sampling – would be informative, especially if pumping and recharge occur at different times of the year. Unfortunately, though, this option is also unavailable because the downscaling of metered usage within HydroSight can only be done over the calibration period and not over a prediction period. The only option currently available is therefore to trial alternate HydroSight model structures and selecting the structure producing the best fit with the observed hydrograph. This does introduce structural uncertainties into the analysis. But given that the latter assessment of the climate-only recharge is reasonable, and was also deemed reasonable by Peterson and Fulton (2019), and that joint estimation of pumping drawdown and climate using HydroSight was also found acceptable by Shapoori *et al*. (2015), this approach is considered acceptable.

Therefore, here four alternative model structures were developed that explored alternatives for both the recharge estimation and the pumping. Specifically, models were developed using a one or a two-layer soil model (see Figure 2-13). For the two-layer model, the layers had uniform hydraulic properties and differed only in their thickness and that evaporation occurs from the top layer first. The implication of this is that the two-layer is anticipated to produce more episodic recharge. For the pumping, models were developed using the closest two extraction bores and the closest five extraction bores.

Like for the climate-only models, here the partitioning of rainfall was constrained by the Budyko curve estimate of long-term mean actual evaporation. For the drawdown, a reformulated version the Thies drawdown equation for a confined aquifer was used. Importantly, drawdown equations for a leaky and unconfined aquifer were considered. However, multiple studies have shown shown that the unconfined approach is only able to be calibrated only when the drawdown at the observation bore is a very large fraction of the saturated thickness (Peterson and Fulton, 2019 and Shapoori *et al*. 2015) and that the additional parameter for a leaky aquifer does not improve the reliability of the calibration (Peterson and Fulton, 2019).

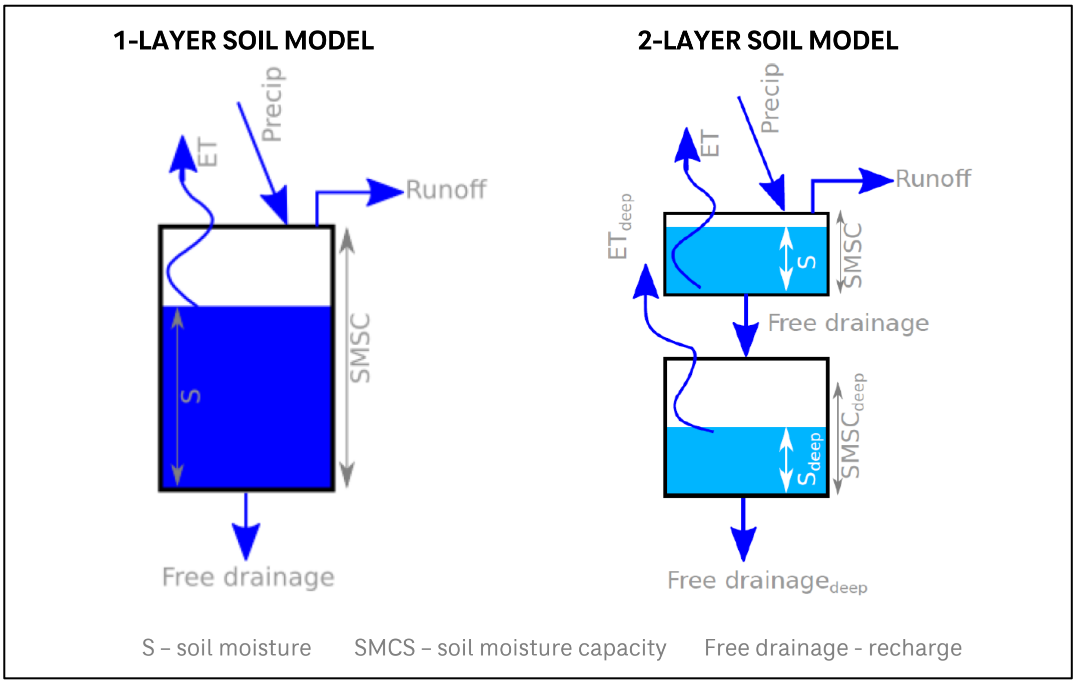


Figure 2-13 Components of one- and two-layer HydroSight soil models (Peterson, pers. comm., 2022).

2.5.3.3.3 Model calibration

The four models for each observation bore were calibrated in HydroSight using a variant of the shuffled complex evolution with principle component analysis (SP-UCI) method that downscales the infrequent metering (Peterson and Fulton, 2019)..

Results of these calibrations are included in Table 2-3. Model calibration for the pumping scenarios returned CoE results typically within 0.1-0.2 of each other. The model with the highest CoE result was selected as the optimal and used in predictive simulations. A number of bores did not result in sufficient calibration (bores in Denison, Koo Wee Rup, Lower Campaspe Valley and Yangery) and these were excluded from further analysis. The hydrographs of the optimal calibrations for each modelled bore are included in Appendix G.

Table 2-3 also provides the calibration CoE results for the climate-only model for the same observation bores which were part of the climate-only modelling in Section 2.5.3.2 above, where the influence of pumping on groundwater level at these bores was not considered. For 13 of the modelled observation bores (48% of bores modelled, identified in Table 2-3), the climate-only model provided comparable (or slightly better) calibration when considering CoE result. In these cases, the pumping models were retained in further analysis because they were considered as valid as the climate-only calibrations for the bores, and allowed for scenarios of variable future pumping rates to be simulated and used in mapping processes.

Table 2-3 Results of HydroSight pumping bore model types for GMU observation bores.

GMU	Observation bore	HydroSight climate-only model result CoE	HydroSight pumping model result CoE by model type			
			Single layer, 2 pumps	Single layer, 5 pumps	Double layer, 2 pumps	Double layer, 5 pumps
Denison	42069	0.73	**0.91**	0.85	Failed	Failed
	42074*	0.03	0.03	0.07	0.07	0.03
	42095	0.08	**0.66**	0.57	0.54	0.60
Deutgam	59522	0.76	0.806	0.807	**0.813**	0.812
	112804	0.75	0.771	0.772	0.775	**0.777**

GMU	Observation bore	HydroSight climate-only model result CoE	HydroSight pumping model result CoE by model type			
			Single layer, 2 pumps	Single layer, 5 pumps	Double layer, 2 pumps	Double layer, 5 pumps
	145270	0.57	0.61	**0.81**	0.63	0.69
Koo Wee Rup	71194	0.52	**0.53**	^	^	^
	71851	0.09	**0.80**	^	^	^
	145259*	0.09	0.08	Failed	0.06	Failed
Lower Campaspe Valley	79329	0.59	**0.51**	^	^	^
	89576	0.12	**0.55**	Failed	0.4	Failed
	WRK953018*	0.02	0.27	0.41	0.39	0.46 *
Lower Ovens	62864	0.20	^	^	^	**0.9**
	WRK054545	Not modelled	0.88	0.92	**0.95**	0.82
	WRK957262	0.34	0.07	0.04	**0.974**	0.971
Mid Loddon	51640	0.05	0.95	0.93	**0.98**	Failed
	88214	0.29	0.80	**0.82**	0.80	0.81
	138653	0.25	**0.78**	0.74	0.75	0.73
SWL - Glenelg	87537	0.38	**0.44**	0.40	^	^
SWL - Hawkesdale	111523	0.86	0.73	0.85	0.87	**0.89**
	WRK988734	0.87	^	**0.89**	^	0.84
SWL - Nullawarre	141235	0.77	Failed	0.65	0.66	**0.68**
	141239	0.89	**0.90**	^	^	^
SWL - Yangery	141310*	0.14	-0.005	0.29	0.36 *	0.32
Wa De Lock	76888	0.55	0.40	0.47	0.42	**0.48**
	110171	0.83	0.54	0.81	0.72	**0.91**
	130372	0.21	0.15	**0.76**	0.41	0.06

Notes: * Insufficient calibration.
^ Suboptimal model.
underline – climate only model result comparable to pumping model.

2.5.3.3.4 Model simulation

The scenarios modelled using the calibrated HydroSight models for each observation bore were based on the four climate and four pumping scenarios. Simulations were run from 1 Jan 1950 to 30 Jun 2085 to address the two project reporting future time-steps of 2040 and 2065. The sixteen primary simulations run for each observation bore were:

- No climate change (current climate) with no extraction, current, 100% PCV and 200% PCV extraction
- Low climate change with no extraction, current, 100% PCV and 200% PCV extraction
- Medium climate change with no extraction, current, 100% PCV and 200% PCV extraction
- High climate change with no extraction, current, 100% PCV and 200% PCV extraction

To develop estimates of use for the predictive simulation extraction rate scenarios for each pumping bore, current pumping (as an average of 2015-2020 use data) was increased to an effective 100% and 200% PCV extraction rate. This was estimated by considering the current percentage contribution of each extraction bore to each GMU total current use, then factoring that use up to 100% and 200% PCV for each GMU. This gave an annual volume of potential future extraction for the two future extraction rate scenarios for each pumping bore. The no pumping scenario data was constructed using historic pumping rates up to 2020 and then no pumping to 2085.

As well as predicted water levels, the simulations also provided a time-series prediction of watertable recharge for each bore as a product of the simulation. This is described separately in Section 2.6.3.3.

2.5.3.3.5 Result post-processing

The results from the 23 successfully calibrated bore calibrations and predictive simulations were processed to provide a single resulting value for maximum and minimum groundwater elevations separately for each bore, project scenario and time period. The resulting value for each bore was calculated as an average of the timeseries maximum / minimum head for each year in the period. The following sets of results of average annual groundwater elevation (maximum and minimum) were calculated for each bore:

- Baseline - 1950-1974
- 1975-1997
- Current - 1998-2020
- 2021-2040 – no climate change, low, medium and high climate change
- 2041-2065 – no climate change, low, medium and high climate change.

An example resulting hydrograph for Mid Loddon bore 88214 is given in Figure 2-14 for the medium climate change and multiple pumping scenarios.

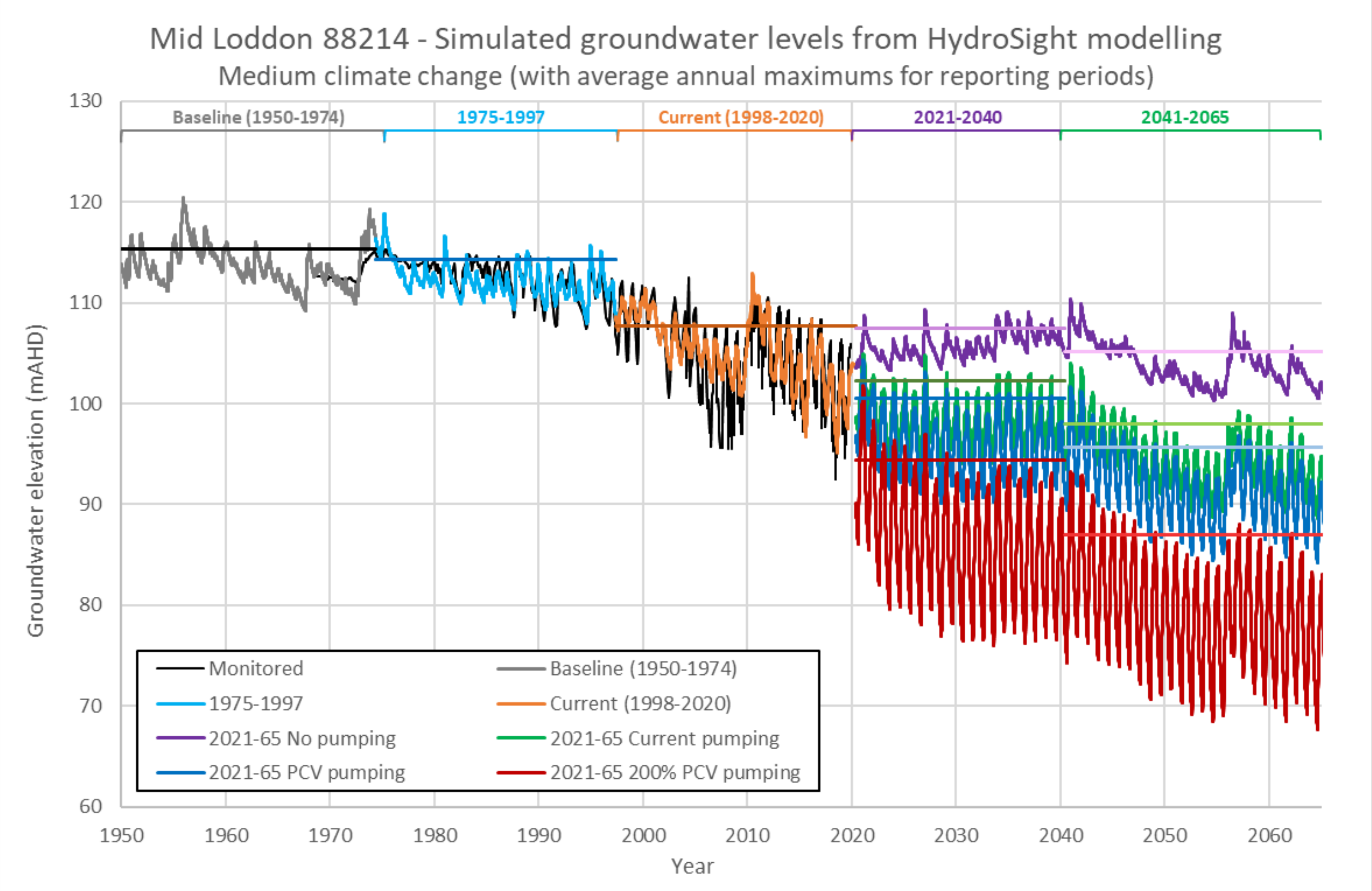


Figure 2-14 Observed and modelled water levels for bore 88214 in the Mid Loddon GMA for a medium climate change scenario, with average of annual maximum results for reporting periods.

2.5.3.3.6 Uncertainty

Estimates of uncertainty were derived for each bore in the same manner as for climate-only driven models, as detailed in Section 2.5.3.2.6.

2.5.3.4 Previous studies

Previous work from Cheng, and Peterson and Fulton was used to add to the dataset of bores analysed for pumping influence across Victoria for use in recharge and watertable mapping. These studies undertook HydroSight studies in a number of areas across Victoria, modelling pumping influence on observation bore groundwater levels. Refer Appendix B for further details on data collation.

2.5.3.4.1 Data collation and pre-processing

The results of these previous analysis using HydroSight were interrogate and model results which matched this study's scenarios (climate and timesteps) were brought into this assessment's dataset. Data used is summarised in Table 2-4, with bores mapped in Figure 2-8. However, the studies by Cheng were undertaken using an early version of the HydroSight pumping downscaling approach and should be interpreted with some caution.

Table 2-4 Observation bores analysed for pumping influence in previous studies for inclusion in project mapping

GMU	Bore ID	Easting*	Northing*	Scenarios	Source
Loddon Highlands	64879^	2408588	2454871	WL + Recharge (all periods)	Cheng
Nullawarre	141232^	2298167	2337953	WL + Recharge (all periods)	Cheng
Glenelg	83447^	2153209	2432747	WL + Recharge (all periods)	Cheng
Wa De Lock	110171^	2679974	2404783	WL + Recharge (all periods)	Cheng
Bungaree	119329^	2410405	2437441	WL + Recharge (all periods)	Cheng
	119332^	2412522	2445429	WL + Recharge (all periods)	Cheng
	119337^	2413635	2436918	WL + Recharge (all periods)	Cheng
Hawkesdale	WRK988724^	2234455	2354057	WL + Recharge (all periods)	Cheng
	WRK988726^	2243410	2347901	WL + Recharge (all periods)	Cheng
Warrion	142671^	2366525	2363992	WL + Recharge (all periods)	Cheng
Yangery	141306^	2267278	2355376	WL + Recharge (all periods)	Cheng
	141308^	2271297	2355723	WL + Recharge (all periods)	Cheng
	141314^	2274959	2347981	WL + Recharge (all periods)	Cheng
Loddon Highlands	116382	2390843	2457960	WL + Recharge (all periods)	Cheng
Moe	107970	2609635	2371472	WL + Recharge (all periods)	Cheng
Neuarpur	129744	2146458	2521013	WL + Recharge (all periods)	Cheng
	129745	2146450	2521060	WL + Recharge (all periods)	Cheng
Warrion	142691	2366871	2372690	WL + Recharge (all periods)	Cheng
	110985^	2361863	2362819	Recharge (current)	Peterson & Fulton
	142666^	2370445	2357777	Recharge (current)	Peterson & Fulton
	142668^	2367858	2358115	Recharge (current)	Peterson & Fulton
	142696^	2373859	2367546	Recharge (current)	Peterson & Fulton

GMU	Bore ID	Easting*	Northing*	Scenarios	Source
	142699^	2376736	2364586	Recharge (current)	Peterson & Fulton
	142702^	2372363	2364498	Recharge (current)	Peterson & Fulton
	142712^	2376020	2357100	Recharge (current)	Peterson & Fulton
	142714^	2372084	2362428	Recharge (current)	Peterson & Fulton
	142717^	2372089	2362427	Recharge (current)	Peterson & Fulton
	26686^	2363306	2362725	Recharge (current)	Peterson & Fulton
	26687^	2379630	2357861	Recharge (current)	Peterson & Fulton
	36058^	2375549	2375872	Recharge (current)	Peterson & Fulton
	57694^	2376691	2367293	Recharge (current)	Peterson & Fulton
	57697^	2374294	2375751	Recharge (current)	Peterson & Fulton
	110984	2361865	2362818	Recharge (current)	Peterson & Fulton
	142670	2368248	2361140	Recharge (current)	Peterson & Fulton
	142720	2372098	2362427	Recharge (current)	Peterson & Fulton
	146931	2363497	2351235	Recharge (current)	Peterson & Fulton
	WRK963394	2367965	2370091	Recharge (current)	Peterson & Fulton
	WRK963395	2368510	2369754	Recharge (current)	Peterson & Fulton
	WRK963396	2368514	2369750	Recharge (current)	Peterson & Fulton

* VicGrid 94.

^ Replaces a climate-only HydroSight analysed bore in the final bore dataset for mapping.

Results from analysis of four other bores that are considered were included from Peterson & Fulton's work in Warrion WSPA, , as listed in Table 2-5 below.

Table 2-5 Observation bores analysed as climate-only driven sites in previous studies for inclusion in project mapping

GMU	Bore ID	Easting*	Northing*	Scenarios	Source
Warrion	142689	2367885	2369612	Recharge (current)	Peterson & Fulton
	142693	2370017	2367692	Recharge (current)	Peterson & Fulton
	142705	2376194	2361097	Recharge (current)	Peterson & Fulton
	WRK963392	2367381	2369596	Recharge (current)	Peterson & Fulton

* VicGrid 94.

2.5.3.4.2 Uncertainty

An estimate of uncertainty for each of the bore datasets incorporated from previous studies by Cheng and Peterson & Fulton was calculated. This used modelling result statistics to estimate the population standard deviation and then variance.

2.5.4 Water level mapping

2.5.4.1 Overview

Mapping of groundwater elevation using the bore point data modelled in HydroSight was undertaken using a kriging package called HydroMap.

HydroMap is geostatistical kriging package developed specifically for mapping the groundwater elevation. In collaboration with the BoM, DEECA and DPI. The package was developed to produce groundwater head contours that honour all point groundwater level observations while also being smoother than the land surface and having appropriate dynamics around waterways and the ocean, but deviating from such when observations suggest otherwise. For the latter this means that groundwater generally flows into lakes and the ocean and that the contours are parallel to the boundaries of both. For rivers, this means that the contours cross streamlines at 90 degrees and that groundwater generally flows into rivers.

To achieve these outcomes, the interpolated head is considered as the sum of a deterministic component arising from local land surface shape and a random component informed by the error at neighbouring bores (i.e. the component of head not explained by the deterministic component). For the deterministic component, the state digital elevation model (DEM) is used to derive maps of *valleyness* and *ridgetopness* using MrVBF (Gallant *et al*, 2003), a measure of land surface roughness and the land surface elevation at each point. These components each have unknown parameters and, combined with the parameters for an isotropic variogram for the spatial correlation of the random errors, they are jointly estimated using a formal likelihood mixed data-type calibration scheme (i.e. continuous and integer parameters) whereby 75% of the data is used to predict the remaining 25% of data points – for which the calibration scheme aims to minimise the error.

2.5.4.2 Water level mapping

2.5.4.2.1 Data collation and pre-processing

The results from the modelling of each individual bore point using HydroSight, including climate-only bore analysis, pumping bore analysis and data incorporated from previous studies, were collated to generate one overall dataset of bore maximum and minimum water level estimates. This was used for mapping of average annual groundwater elevation for each project scenario and time period.

Only 38 of the 2,234 bores modelled in HydroSight considered the influence of groundwater pumping. This meant that the impact of groundwater extraction across Victoria would not be effectively represented with this modelled dataset without the additional of further data points to estimate the wider impact of pumping on Victorian groundwater levels into the future. To introduce an influence of pumping across Victoria that was related to the locations were pumping was occurring (i.e. existing licensed groundwater extraction bores), additional unmodelled bore data was generated for each current active licensed groundwater extraction bore and added to the wider bore dataset for mapping.

To enable this, a relationship between drawdown from baseline (1950-1974) and pumping volume were determined for each unmodelled groundwater extraction bore for each climate scenario and timesteps 1998-2020, 2021-2040 and 2041-2065 when pumping was assumed to be active across Victoria. The modelling results naturally determined a linear relationship where the drawdown-axis generally did not intercept zero use. The exception to this was 1998-2020 where only one pumping data point required forcing the 0,0 point to generate a slope. An example of this approach for bore 112804 in Deutgam GMA is included in Figure 2-15 below. This relationship was developed separately for the average annual maximum and minimum levels for each bore.

Each of the 4,654 unmodelled licensed pumping bores that had a recent (2015-2020) registered use were assigned a relationship based on the closest modelled bore (or average or multiple modelled bores) of a similar aquifer system and climate region. Using the registered use for each unmodelled bore and this relationship, a drawdown at each bore under each scenario could be assigned. In the absence of PCV pumping rates for these individual bores, entitlement and 200% entitlement volumes were used in place of PCV and 200% PCV pumping rates respectively. To determine a baseline groundwater level to which to apply the drawdown, groundwater elevation at each unmodelled bore was extracted from the baseline period groundwater elevation map (which was produced without these bores). The resulting bore point dataset of estimated groundwater elevations for these 4,654 unmodelled pumping bores for each relevant scenario was added to the 2,234 bores modelled in HydroSight to generate a much larger bore point dataset which would better estimate groundwater elevation across Victoria under groundwater pumping scenarios.

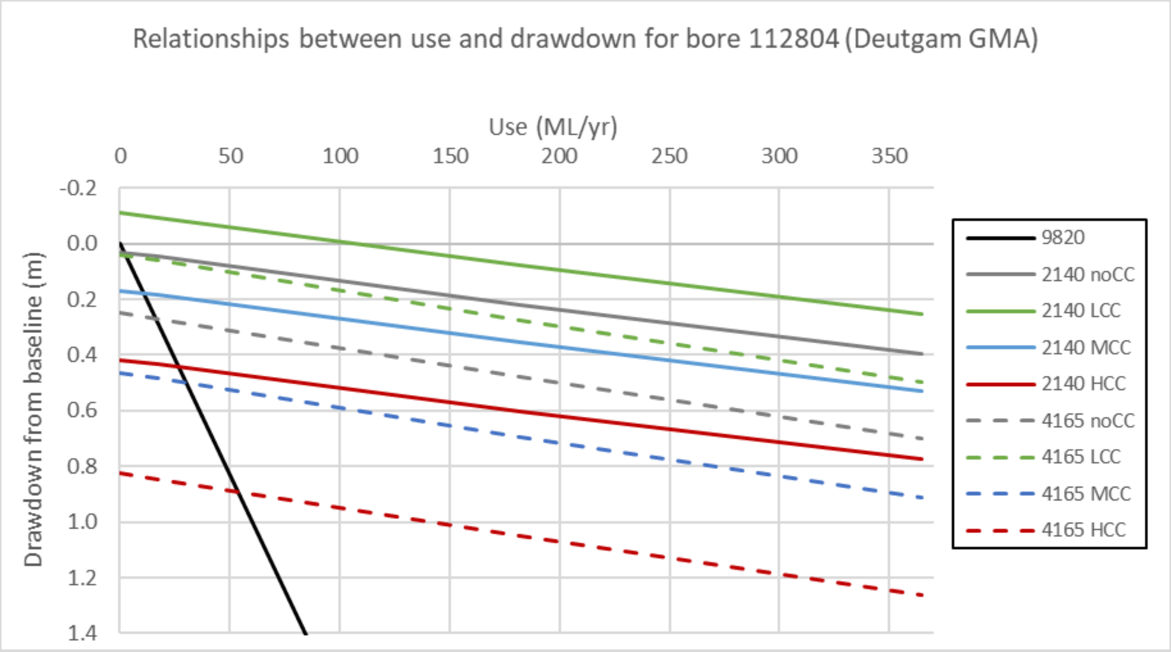


Figure 2-15 Relationships developed between use and drawdown for bore 112804 in the Deutgam GMA for average annual maximum groundwater levels.

2.5.4.2.2 Model set-up

The HydroMap code in *R* was modified to include relevant input data and calibration settings to allow optimal modelling on the available hardware. A combination of the available kriging elements were used for calibration of the krige model including:

- Co-variates of the land surface elevation;
- MrVBF - measure of the valley floor;
- MrRFT - measure of valley bottom flatness;
- Local smoothing between point data and cells.

A 200m x 200m DEM (re-sampled from a 10m DEM; ICSM, 2023) was used for kriging the point groundwater elevation data across space.

Further detail on the HydroMap settings is included in Appendix D.

2.5.4.2.3 Model calibration

Groundwater level mapping parameters were calibrated in HydroMap for maximum and minimum baseline water levels separately, using the collated bore HydroSight model results for the baseline period 1950-1974. This calibration included the input uncertainty (as variance), as described in Section 2.5.3.3.6. Multiple bores sitting within individual cells of the 200m grid were removed within the code.

2.5.4.2.4 Model simulation

Using the calibration parameters for, the maximum and minimum mean head calibrations over the baseline period, the following 35 individual scenarios were simulated across Victoria using HydroMap at the calibrated 200m grid scale to produce state-wide groundwater elevation maps for both average annual maximum and minimum groundwater levels:

- 1950-1974 (Baseline) – historic climate and extraction
- 1975-1997 – historic climate and extraction

- 1998-2020 (Current) – historic climate and extraction
- 2021-2040
    - No climate change (current climate), low, medium and high climate change
    - No use, current use, 100% PCV and 200% PCV
- 2041-2065
    - No climate change (current climate), low, medium and high climate change
    - No use, current use, 100% PCV and 200% PCV

The mapping process also produced an uncertainty gridded output associated with each scenario water level map.

2.5.4.2.5 Result post-processing

In reviewing the maximum and minimum groundwater elevation gridded outputs, it was noticed that for some cells within the rasters (particularly around steep changes in topography), the maximum groundwater elevation mapped result was returning a lower groundwater elevation the result at that grid cell from the minimum groundwater elevation map. This issue arose because the kriging parameters for the mean minimum and maximum heads were calibrated interpedently of each other. To resolve this, the gridded dataset pairs of maximum and minimum groundwater elevation for each scenario were compared and the minimum value for each cell was extracted to produce a final minimum groundwater elevation gridded product for each scenario.

The final raster datasets for groundwater elevation for scenarios between 1975 and 2065 were then subtracted from the results for 1950-1974 for maximum and minimum groundwater elevation separately, to generate values for the change in groundwater elevation from baseline for each scenario.

From these sets of state-wide gridded outputs, statistical results for individual GMUs and surface water catchment areas were calculated to provide results for each project metric.

2.5.4.2.6 Estimating uncertainty

Estimated uncertainty for the water level mapping output results, in the form of a gridded dataset for each scenario at 200 m cell resolution, incorporated the following estimates:

1. Uncertainty estimates from the input point water level data (as described in Section 2.5.3.2.6; for maximum and minimum water level calibrations separately), which included calibrated head fit to observed head and variability in the annual head results over the averaged periods. This measure of uncertainty was used explicitly in the kriging within HydroMap from the calibrated HydroSight model for the baseline period only (1950-1974). The other scenarios did not produce this estimate of uncertainty and so it couldn't be used in kriging for those mapped outputs.
2. Uncertainty built into the calibration in HydroMap (for maximum and minimum water level calibrations separately) from the use of point data uncertainty estimates (above). Each scenario was mapped (kriged) using the calibrated model which was formed using estimates of baseline period uncertainty. This was inherently brought into the kriging of all other scenarios when mapped.
3. Kriging error, built into the mapping process in the HydroMap program, which extends the point dataset and calibration estimates of uncertainty using estimates based on a grid cell's proximity to input point data.

The combined measure of uncertainty (for each raster cell) was exported as a product of the HydroMap process in a state-wide grid at the 200m grid resolution, separately for each of the 35 modelled scenarios. This is considered, for the purposes of this project, an estimate of uncertainty in the mean of groundwater elevation in the unit of metres. This term is used in place of 'uncertainty' and 'error' in this project, and is not proposed to represent all elements of uncertainty within the results, nor intended as a measure of total error (e.g. one standard deviation of the mean) for the results.

2.6 Watertable recharge maps

2.6.1 Purpose and rationale

Estimates of recharge from this project will form the basis of the sustainable yield volumes derived from project outputs. Variability in climate is likely to significantly alter rates of recharge and subsequently, the availability of groundwater in unconfined aquifers.

2.6.2 Approach

Recharge to the watertable was produced for modelled bores as an output in the HydroSight analysis described in, from the separate process of climate-only models, pumping models and the outputs of previous studies. Recharge estimates were generated in SoilFlux which were combined with this bore point data from HydroSight to develop a state-wide recharge estimates for each of the project scenarios. SoilFlux is a one-dimensional, unsaturated zone water balance model which uses land use and environmental parameters to estimate key hydrogeological parameters. The existing data from previous runs of the SoilFlux model was modified for this project to produce estimates of grided recharge across Victoria under future climate scenarios and timesteps. Importantly, unlike HydroSight, SoilFlux parameters are not calibrated against observations.

Development of maps of recharge to the watertable involved:

- Undertaking statistical modelling of observation bore hydrographs using the program HydroSight to model annual recharge under project scenarios (as a product of modelling groundwater level; refer Section 2.5.3), for
  - Over 3,000 where only climate impacts to groundwater level were modelled, and
  - 27 bores across eight GMUs where the influence of groundwater pumping was modelled
- Collating results from previous HydroSight studies to provide additional results to the bore dataset
- Obtaining state-wide gridded recharge estimates from the water balance model SoilFlux, and modify the data for project climate scenarios
- Merge Individual bore recharge results from HydroSight modelling and gridded SoilFlux results to develop final state-wide gridded results for recharge for project scenario

The results, collated from mapping outputs, were then used to estimate the potential change to recharge to the watertable into the future as part of the metrics assessment (Section 6).

2.6.3 Bore point recharge

2.6.3.1 Overview

Recharge was estimated using a merging of two separate recharge datasets; estimate recharge at modelled bores from HydroSight modelling (climate-only and pumping analysis), and gridded recharge extracted from the water balance model SoilFlux. The merge process combined the datasets such that the magnitude of the individual bore model results from HydroSight were prioritised, alongside the spatial variability from the gridded SoilFlux products.

2.6.3.2 Climate-only driven bores

Recharge for climate-only driven bores was modelled as part of the process which produced estimated groundwater levels for the project, as detailed in Section 2.5.3.2 above. This included model construction (Section 2.5.3.2.2), calibration (Section 2.5.3.2.3), simulation (Section 2.5.3.2.4) and results post-processing (Section 2.5.3.2.5).

2.6.3.3 Pumping analysis bores

Recharge for bores influenced by pumping was modelled as part of the water level modelling as detailed in Section 2.5.3.3. This included model construction (Section 2.5.3.2.2), calibration (Section 2.5.3.3.3), simulation (Section 2.5.3.2.4) and results post-processing (Section 2.5.3.2.5).

2.6.3.4 Previous studies

Recharge results from previous studies were incorporated into the dataset used for recharge mapping. The relevant studies and bores are detailed in Section 2.5.3.4.

2.6.3.5 Uncertainty

Uncertainty was estimated using the variability in the total annual recharge results for each bore's calibration period. This varies to the uncertainty estimates for groundwater level (refer Section 2.5.3.2.6), as there are no recharge observations to determine an uncertainty component a comparison of modelled against observed data residuals.

This measure of uncertainty considers the variability in the modelled total annual recharge results for the individual bore calibration period (duration of monitoring data). This is relevant because the modelled recharge results used in metrics analysis are an average of annual results over the reporting time periods (refer Section 2.2). This introduces an uncertainty as this average is trying to represent multiple annual total recharge values over time.

The variability is estimated by calculating a population variance of total annual recharge using a jackknife resampling approach. The result is one value of variance for each bore which is an estimate of uncertainty of the process of averaging annual recharge results across the years in the reporting period. It was observed in the bore results that the variability of recharge within an individual bore results between years is high. An example of the recharge results for bore 69711 (CoE – 0.76) is included in Figure 2-16 below. The calculated uncertainty for this bore is 2,863 mm (compared to a maximum estimated recharge over the same period of 201 mm/yr). This value does not represent the whole uncertainty or error associated with this data.

Additional uncertainty is incorporated into the recharge results through the mapping approach in HydroMap and the merge with SoilFlux (discussed below). The combined estimate of uncertainty is considered, for the purposes of this project, to be an estimate of uncertainty of the mean of recharge.

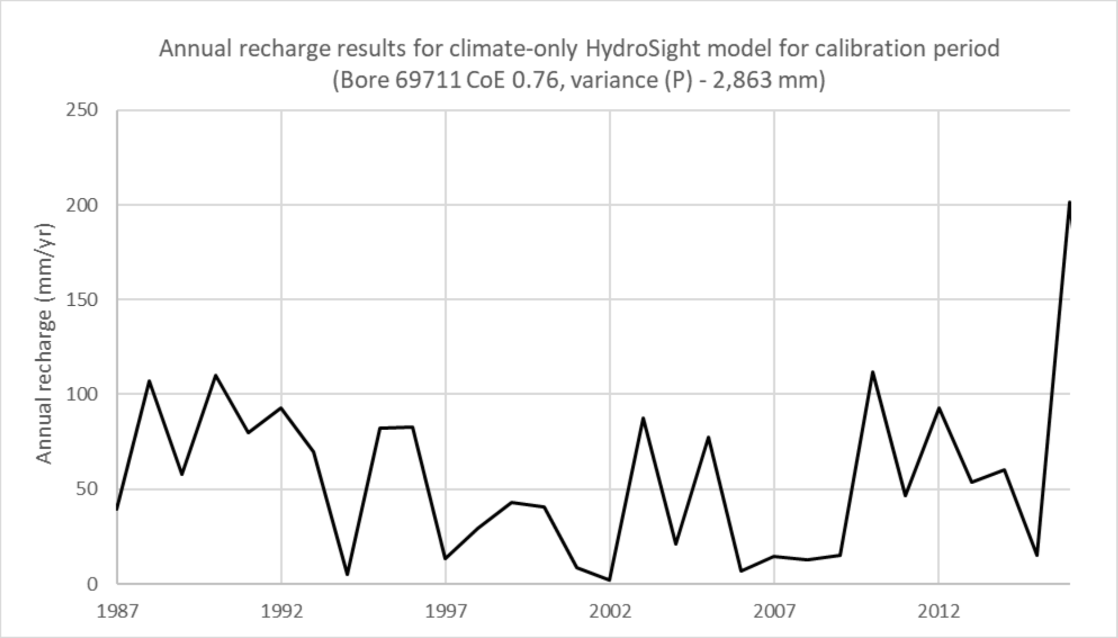


Figure 2-16 Variability in annual recharge for bore 69711 from climate-only HydroSight modelling.

2.6.4 Recharge mapping

2.6.4.1 Overview

Recharge was mapped using an approach that combined individual bore recharge results from HydroSight and state-wide gridded data from the water balance model SoilFlux.

2.6.4.2 Recharge mapping

2.6.4.2.1 Data collation and pre-processing

Two primary datasets were collated to enable recharge mapping: results from individual bores modelled using HydroSight, and state-wide gridded products modified from existing SoilFlux model outputs.

2.6.4.2.2 Recharge mapping

Individual bore models (HYDROSIGHT)

The bore point results of the HydroSight modelling for recharge were collated to generate a dataset of average annual recharge for each climate scenario and time period, noting that no extraction rate scenarios were modelled for recharge.

State-wide grid estimates (SOILFLUX)

Overview

A spatial database of state-wide recharge estimates using the model SoilFlux has been previously developed incorporating landscape features, land use, climate and depth to watertable (SKM, 2011). SoilFlux is a one-dimensional, unsaturated zone water balance model which uses land use and environmental parameters to estimate key hydrogeological parameters (refer Figure 2-17). In this previous study, to populate the database the model was run at a 1 km square grid cell resolution for Victoria, with each grid modelled to estimate monthly recharge for 40 different combinations of vegetation cover (one of ten types) and depth to watertable (for different classes: 5, 10, 20 and >20 metres), over the period 1950-2016. The resulting dataset is currently used to inform the annual Victorian Water Accounts. SoilFlux was not rerun for this project, rather the relevant data was extracted from the existing datasets for a range of scenarios for all grid points across the state. Further detail is provided in HARC's report in Appendix H.

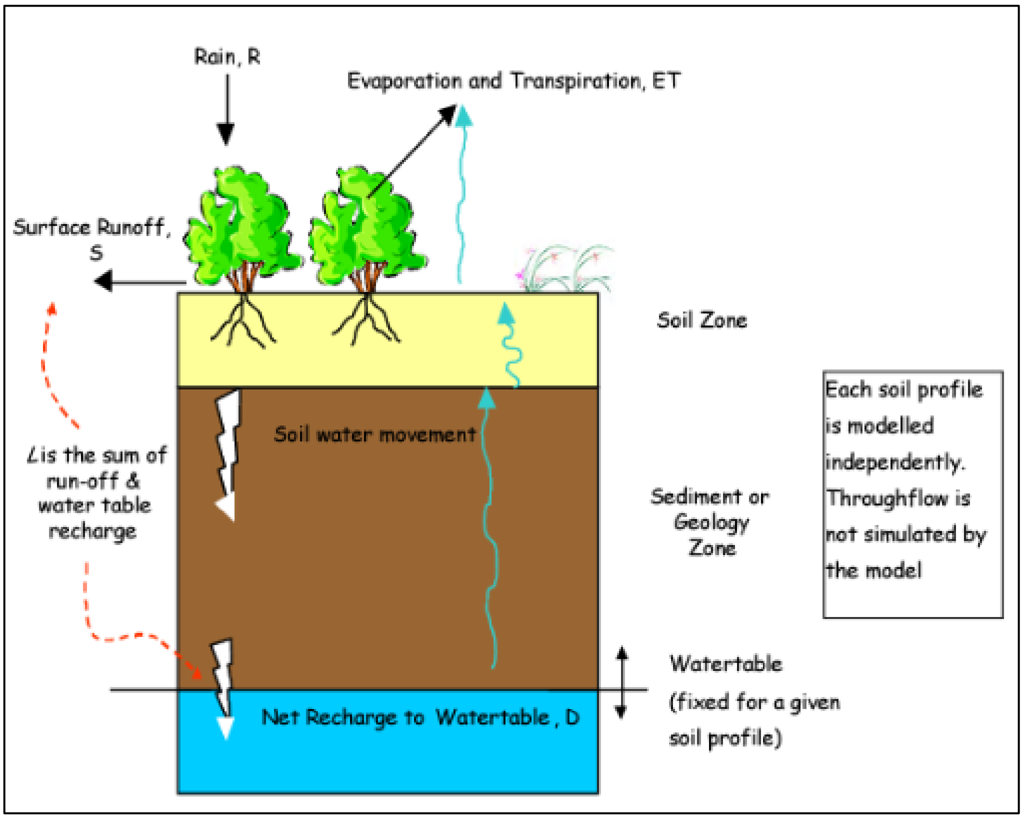


Figure 2-17 Schematic representation of SoilFlux modelled processes (from SKM 2011).

Existing data extracts

HARC (2016, 2017) created a data cube with a set of SoilFlux model outputs generated with different ranges of depth to watertable and land use types. This study used mean annual recharge values corresponding to the depth to watertable values from the DEWLP (2013) watertable mapping outputs and the Victorian Land Use Information System data from 2014/2015 for each 1 km² grid cell.

The DELWP (2013) updated watertable information was then assigned one of four watertable classifications as shown in Figure 2-18. Similarly, the VLUIS (Morse-McNabb et al., 2015) land use data was reclassified within the classes shown in Figure 2-19.

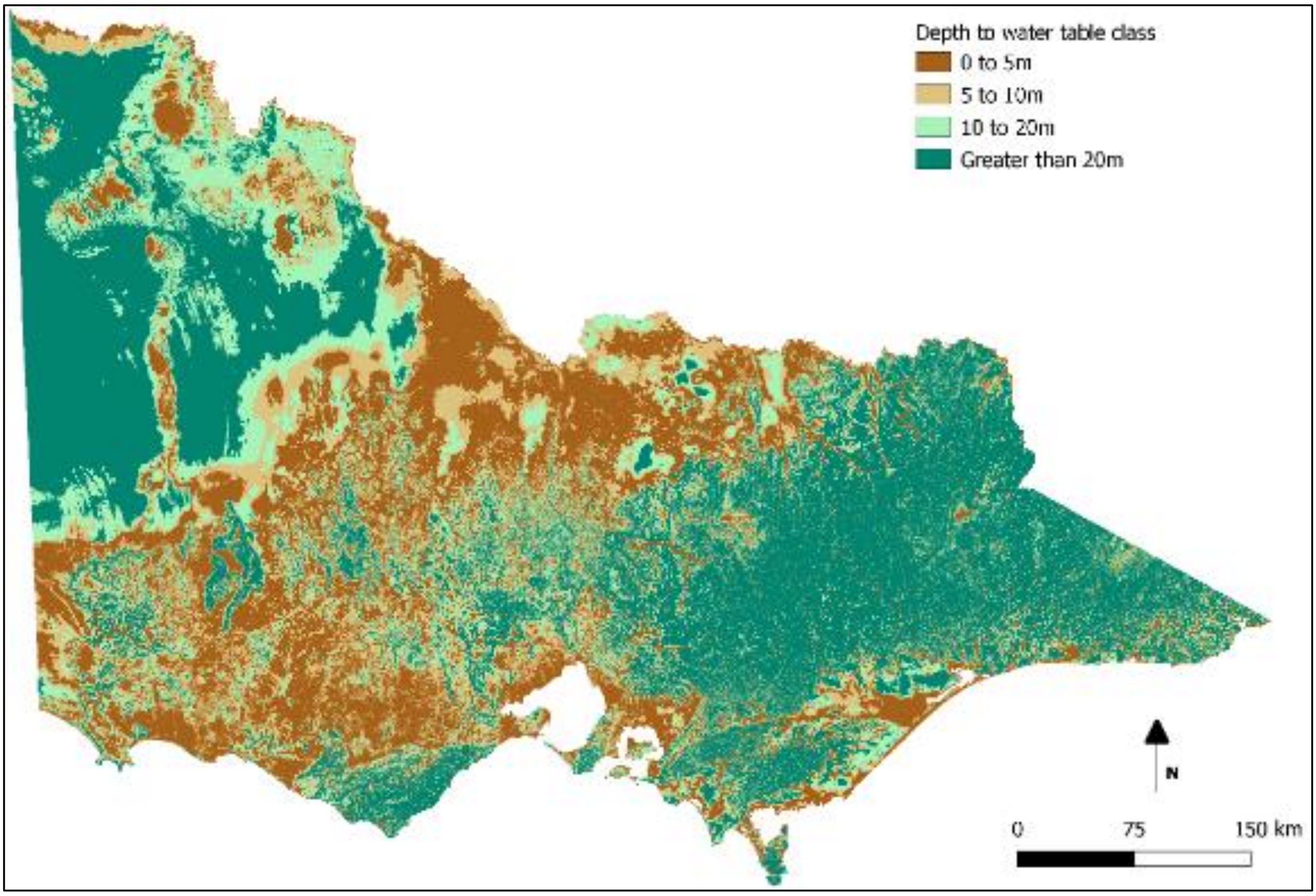


Figure 2-18 Reclassified DELPW (2013) depth to watertable layer (HARC 2023).

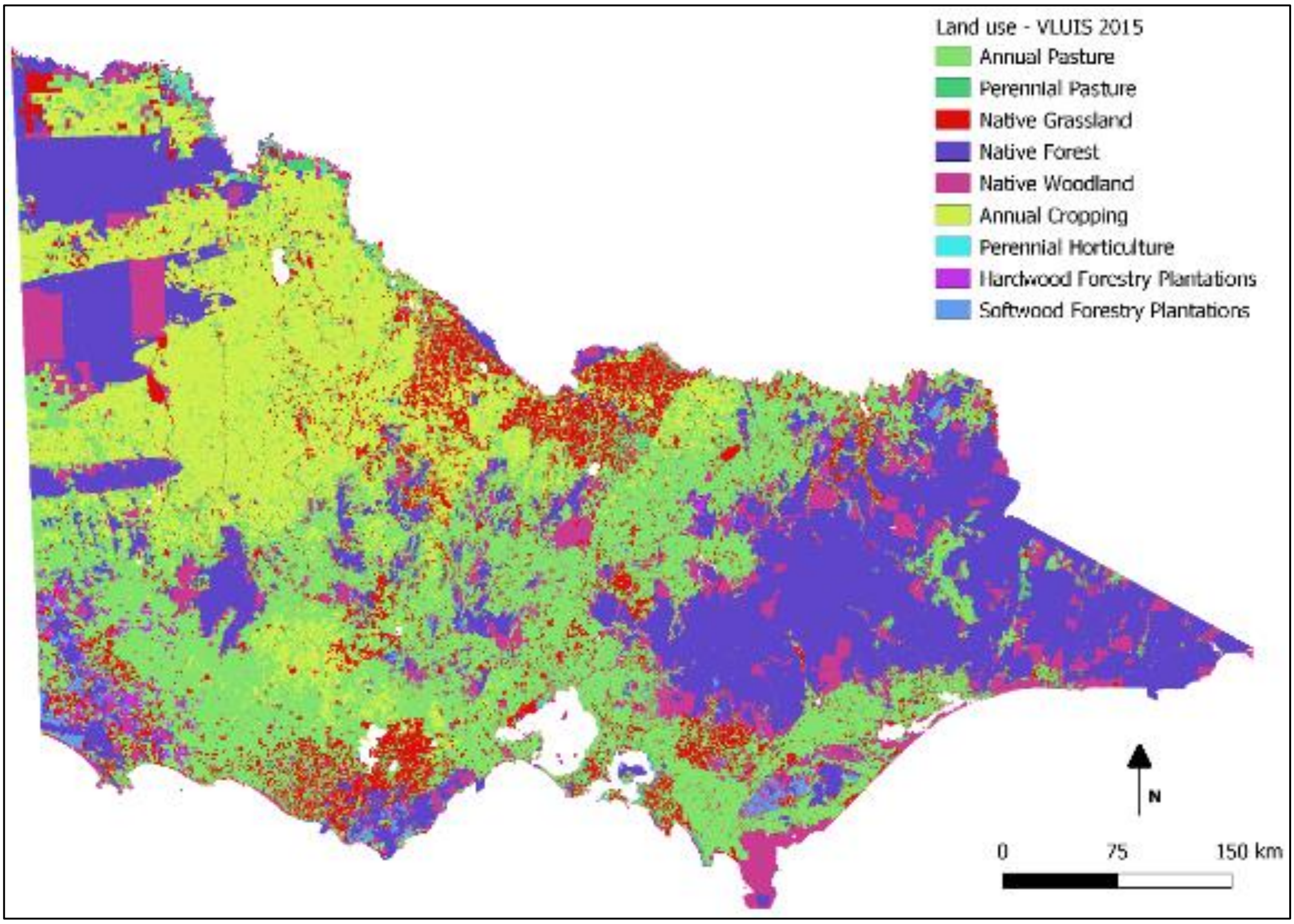


Figure 2-19 Reclassified VLUIS (2015) land use information (HARC 2023).

Mean annual recharge data was then extracted for five historic periods (1961 to 1974, 1975 to 1996, 1997 to 2009, and 2010 to 2016), as mapped in Appendix J.

It is important to note that the warmup period of the model was taken to be from 1/1/1950 to 1/1/1961, so the output data extraction started from 1961 onwards. Upon extraction, the rasters were post-processed so that areas in Victoria where gaps with no data were identified and replaced by the average recharge values of the surrounding grid cells.

Simulating future climate

Recharge estimates modelled in SoilFlux for each grid cell (given an input groundwater level and environment parameters) for future climate scenarios are approximated by developing a relationship between the recharge values from the full record period (1950-2016) result and the Millennium drought period (1997-2009) sourced from the existing SoilFlux database. These points are assigned a linear relationship, and then alternate climate (in the form of a rainfall value) can be calculated. An example of this is shown in Figure 2-20. These results are included in Appendix J for the following estimated scenarios:

- 2040 - Low, medium and high climate change;
- 2065 - Low, medium and high climate change.

Note that unlike the HydroSight analysis for recharge, the future time periods are for individual years (2040, 2065) rather than the average of a period of years (2021-2040, 2041-2065).

The no climate change (current climate) scenario was also not extracted from the SoilFlux data under this project, and is an area where this study could be extended to provide this element of output data for metrics assessment.

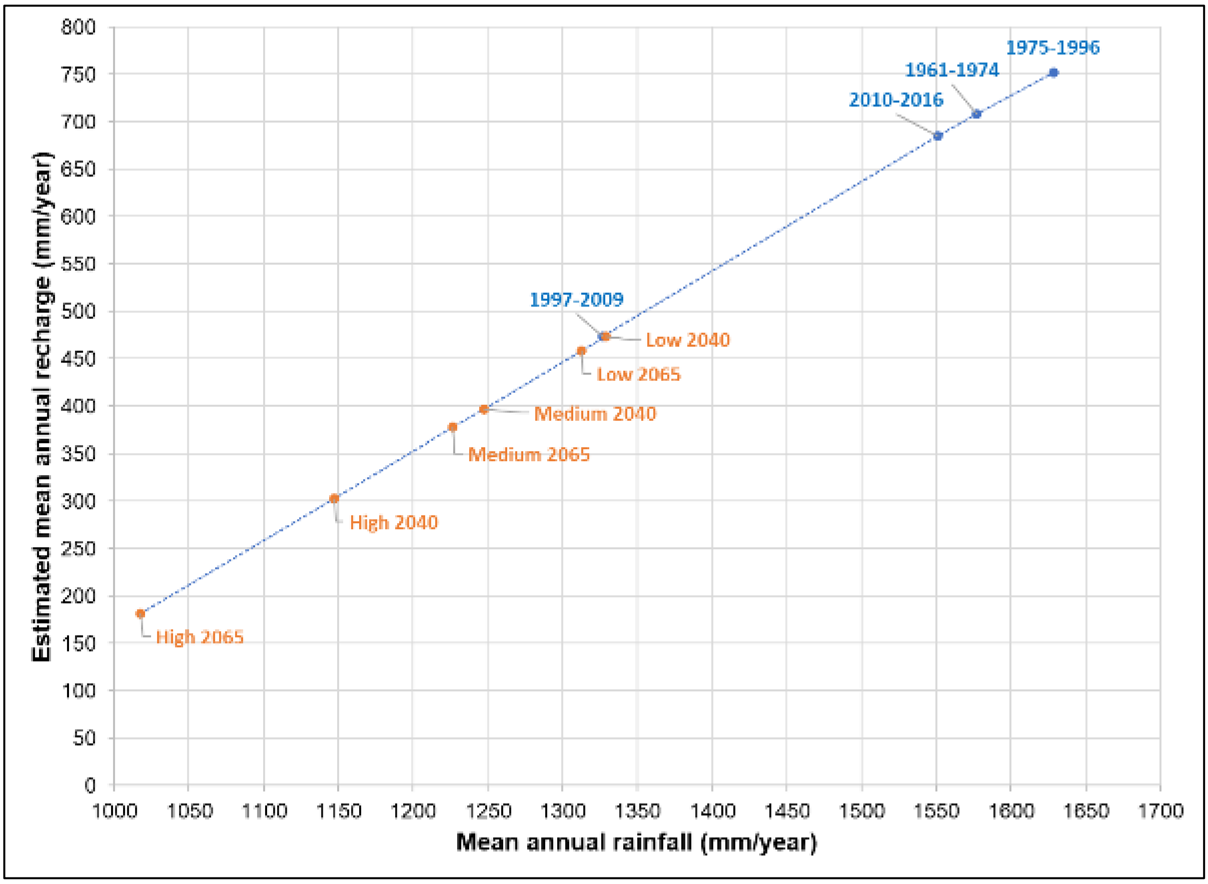


Figure 2-20 Indicative method for estimating SoilFlux recharge for unmodelled climates, for an individual data point (grid cell) (HARC 2023).

2.6.4.2.3 Recharge merge method

The approach to generate a single, combined recharge dataset for each reporting scenario using the datasets from individual bore points (from HydroSight) and the state-wide grid (from SoilFlux) involved the following steps for each scenario separately:

1. Remove the negative values from the SoilFlux dataset (make equal "0").
2. Overlay the bore point recharge data from the HydroSight analysis over the gridded data from SoilFlux.
3. Calculate the difference in value of recharge between the two dataset for each bore point location in the HydroSight dataset (as *HydroSight* minus *SoilFlux*, in mm/yr).
4. Interpolate the bore point dataset of difference in recharge using a kriging approach across the same raster extent as the SoilFlux dataset (state-wide, 1 km x 1 km). Interpolation was achieved with an ordinary kriging approach using an exponential variogram model (using Python).
5. Add the difference raster to the SoilFlux raster. This modified the magnitude of each SoilFlux cell up or down based on the magnitude of interpolated difference to the HydroSight raster.

This approach was based on the assumption that the magnitude of the bore point results for recharge should generally be more accurate than the state-wide gridded values, but the spatial variability across Victoria from the gridded dataset should generally be more accurate than an interpolation of individually modelled bore results. The use of both datasets in the manner described above is a means of maintaining the magnitude of the modelled individual bore results with the spatial distribution of the gridded data.

Data ranges and scenarios available in the two datasets varied slightly. These were paired as near as possible for the merge process, as shown in Table 2-6 below.

Table 2-6 Match between available HydroSight and SoilFlux recharge results as part of the merge approach

Output Scenario	Input HydroSight Scenario	Input SoilFlux Scenario	Notes
Baseline – 1950-1974	1950-1974	1961-1974	No SoilFlux product was available for the exact period 1950-1974, so the closest period was used.
1975-1997	1975-1997	1975-1996	No SoilFlux product was available for the exact period 1975-1997, so the closest period was used.
Current period – 1998-2020	1998-2020	1997-2009	No SoilFlux product was available for the exact period 1998-2020, so the closest period with the most data was used (the other option being 2010-2016).
2021-2040, No Climate Change	2021-2040, LCC	NA	Not produced
2021-2040, Low Climate Change	2021-2040, LCC	2040, LCC	The SoilFlux results were for a specified year only, whereas HydroSight results are an average a period (e.g. 2040 compared 2021-40).
2021-2040, Medium Climate Change	2021-2040, MCC	2040, MCC	
2021-2040, High Climate Change	2021-2040, HCC	2040, HCC	
2021-2040, No Climate Change	2021-2040, LCC	NA	Not produced
2041-2065, Low Climate Change	2041-2065, LCC	2065, LCC	The SoilFlux results were for a specified year only, whereas HydroSight results are an average a period (e.g. 2065 compared 2041-65).
2041-2065, Medium Climate Change	2041-2065, MCC	2065, MCC	
2041-2065, High Climate Change	2041-2065, HCC	2065, HCC	

2.6.4.2.4 Uncertainty

Uncertainty was estimated for each of the recharge datasets (individual bore models from HydroSight and gridded data from SoilFlux) separately based on their approaches, and then combined to generate a single gridded uncertainty dataset that covered all project scenarios.

Individual bore point models (HYDROSIGHT)

HydroMap was used to generate a gridded uncertainty dataset for the HydroSight modelled bore point recharge results. This was undertaken using the uncertainty of the mean of the estimated recharge from the HydroSight model outputs (Section 2.6.3.5) and a gridded baseline period climate dataset (1950-1974) in the form of average annual rainfall at the same resolution of the SoilFlux recharge data (1 km x 1 km; for further detail on the generation of this dataset, refer Appendix H). The approach of kriging bore data across Victoria using HydroMap, as detailed in Section 2.5.4.2, was modified to use climate data in place of DEM, and only the local smoothing between point data and cells calibration element.

This produced a state-wide estimate of uncertainty for the modelled individual bore recharge data in the mean of HydroSight recharge which incorporated the following elements:

1. Uncertainty estimates from the input point recharge data, which was based on variability in the annual recharge results over the calibration period. This measure of uncertainty was used explicitly in the kriging within HydroMap from the calibrated HydroSight model for the baseline period only (1950-1974).

2. Uncertainty built into the calibration in HydroMap from the use of point data uncertainty estimates (above). The bore point data was mapped (kriged) using the calibrated model which was formed using estimates of baseline period uncertainty. This was inherently brought into the kriging of recharge when mapped.
3. Kriging error, built into the mapping process in the HydroMap program, which extends the point dataset and calibration estimates of uncertainty using estimates based on a grid cell's proximity to input point data.

The combined measure of uncertainty (for each raster cell) was exported as a product of the HydroMap process in a state-wide grid at the one kilometre grid resolution for the baseline period. This combined estimate of uncertainty is considered, for the purposes of this project, an estimate of uncertainty in the mean of recharge in the unit of mm/yr. The output is show in Appendix I.

State-wide grid estimates (SOILFLUX)

Uncertainty in the gridded recharge values (from SoilFlux) was estimated through a comparison between the mean annual recharge and runoff estimates obtained from the Victorian Winterfill Period Sustainable Diversion Limits (SDL) project from 1961 to 2000 was also undertaken for each SDL catchment. The 1961-2000 period was chosen for comparison between the SoilFlux mean annual flow and recharge estimates and the SDL estimates of mean annual flow, because the SDL project was undertaken in 2001-03 and provided estimates of mean annual flow that were estimated using streamflow data collected up to the year 2000. Use of SoilFlux estimates for 1961-2000 would therefore be reasonably consistent with the mean annual flow estimates in the SDL spatial dataset.

The scatter plot of the mean annual recharge and runoff estimated by SoilFlux against the SDL mean annual flow estimates for the period between 1961 and 2000 is shown in the left side plot in Figure 2-21. As shown in the figure, mean annual runoff is well correlated with the SoilFlux estimates of mean annual recharge and runoff. Mean annual runoff, estimated from streamflow gauging data, is slightly higher than the SoilFlux model values because SoilFlux includes a deep recharge component that would remain in the groundwater. The focus of this investigation was on the uncertainty or scatter in the mean annual runoff and recharge estimates. The uncertainty in mean annual flow is heteroscedastic, in that there is a trend toward increasing uncertainty in mean annual flow estimates for increasing mean annual recharge and runoff estimates in SoilFlux. A Box-Cox transformation of the data was also undertaken with lambda value of 0.4, shown in the right side plot in Figure 2-21. The Box-Cox transformation made the dataset homoscedastic, producing consistent scatter in transformed estimates of mean annual flow and mean annual recharge plus runoff. As shown in the right side plot in Figure 2-21, a regression relationship and plus/minus one standard deviation confidence limits were fitted to the mean annual flow, as a function of mean annual recharge plus runoff. The one standard deviation confidence limits were back-transformed by inverting the Box-Cox transformation to estimate the one standard deviation uncertainty bands in mean annual runoff.

A spatial raster layer (1km resolution) of the estimated standard uncertainty (as one standard deviation) in the SoilFlux recharge estimates was generated for the same period of data. The output is shown in Appendix J. It is noted that uncertainty in recharge is larger (in absolute terms) in areas of the state with larger rainfall, runoff and recharge estimates. In areas with 0 mm/year of estimated mean annual runoff (e.g. Wimmera and Mallee), the standard error range is about 12 mm/year. In the highest runoff areas of the state, the uncertainty is about 180 mm/year (current climate mean annual recharge is >1600 mm/year).

For additional detail, refer to HARC (2023), included as Appendix H.

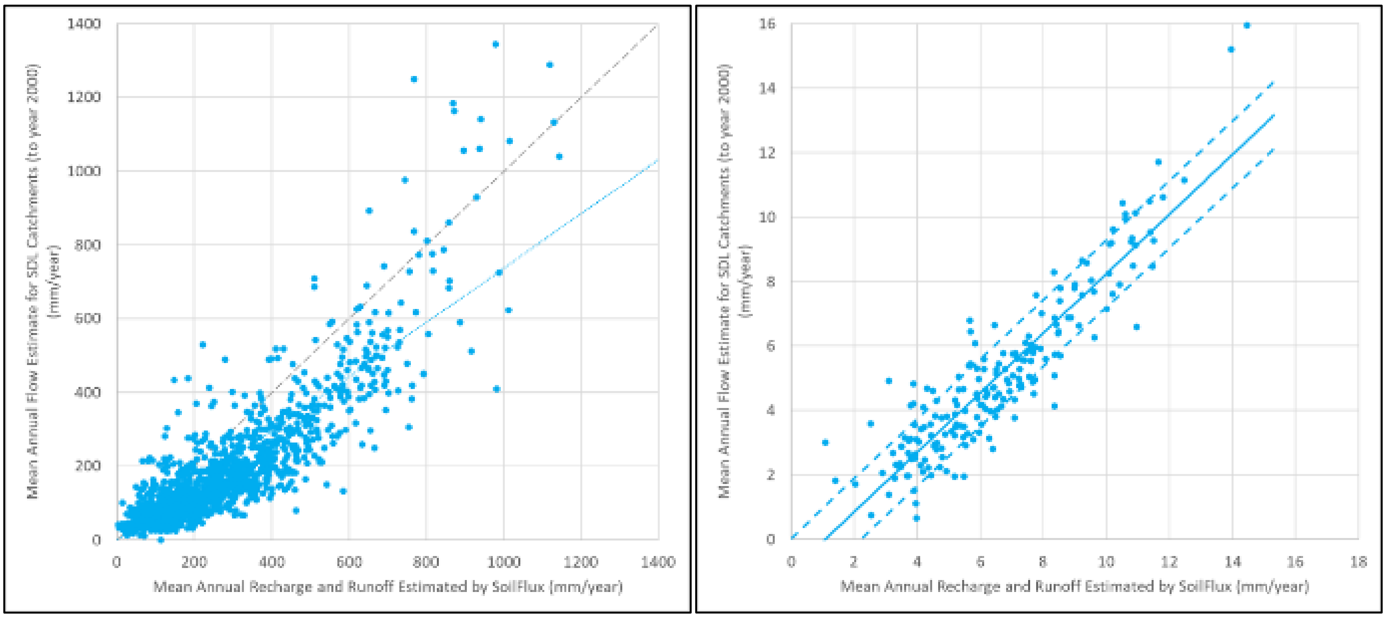


Figure 2-21 LHS: Comparison between SoilFlux mean annual recharge plus runoff and SDL mean annual flow estimates; RHS: Box Cox transformed data - SoilFlux mean annual recharge plus runoff versus SDL mean annual flow estimates (lambda = 0.4 for transformation of values on both axes) (HARC 2023).

Final uncertainty (merged datasets)

The HydroSight and SoilFlux recharge uncertainty outputs were averaged by individual grid cell across the one kilometre resolution raster to generate a final estimate of uncertainty for the merged recharge data. The combined estimate is considered, for the purposes of this project, to be uncertainty in the mean of recharge. This term, uncertainty in the mean of recharge, is used in place of 'uncertainty' and 'error' in this project, and is not proposed to represent all elements of uncertainty within the results, nor intended as a measure of total error (e.g. one standard deviation of the mean) for the results. The map of this data is included in Section 4 (Figure 4-3) below and in Appendix O.

2.6.5 Baseflow and low flow

2.6.5.1 Overview

The impact of climate change on streamflow was derived in accordance with the *Guidelines for assessing the impact of climate change on water availability in Victoria* (DELWP, 2020; 'the DELWP guidelines').

The streamflow gauges with data records pre-1975 were adjusted to derive climate representative of the post 1975 reference climate period. These adjustments make historical droughts more reflective of how they might behave, if they were to occur under current post-1975 levels of greenhouse gas concentrations in the atmosphere.

The DELWP guidelines allow for this transformation to be done using seasonal decile scaling, which picks up on changes in flows at different times of year over recent decades under historical climate change. A four seasons decile scaling transformation was undertaken in this project.

A report has been prepared by HARC for the project and is included as Appendix K.

2.6.5.2 Climate change projections for 2040 and 2065

The climate change projections in the DELWP guidelines are expressed relative to the post 1975 climate reference period, which is approximately centred on the year 1995. Current and future climate change conditions are expressed as a range, which allows for uncertainty in the climate change projections. This range represents the uncertainty in the projections for a given emissions scenario, when using climate models from different research organisations around the world.

The streamflow gauges data series were projected for 2040 and 2065, under low, medium, and high climate change scenarios. In this project, the annual climate change factors were adopted for the RCP8.5 scenario, provided by the DELWP guidelines for each major basin in Victoria. The DELWP guidelines regard the RCP8.5 as a high emissions scenario that is suitably precautionary for water supply planning purposes in Victoria.

Table 2-7 Annual climate change factors for streamflow, RCP8.5 (DEWLP, 2020)

Basin	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Thomson	10.3%	-9.1%	-27.6%	2.0%	-13.9%	-41.9%
Latrobe	8.7%	-10.7%	-31.3%	0.1%	-16.3%	-41.5%
South Gippsland Basin	8.8%	-11.9%	-33.7%	1.6%	-16.9%	-44.8%
Bunyip Basin	10.6%	-13.7%	-33.0%	1.5%	-19.1%	-47.0%
Maribyrnong Basin	15.0%	-13.2%	-33.1%	5.1%	-20.0%	-55.4%
Werribee Basin	11.8%	-7.7%	-28.9%	7.5%	-18.1%	-45.5%
Moorabool Basin	13.5%	-8.0%	-30.4%	-5.5%	-17.3%	-45.6%
Barwon Basin	16.1%	-6.1%	-33.1%	-0.8%	-21.6%	-47.6%
Otway Coast Basin	6.6%	-7.2%	-25.3%	-4.7%	-15.8%	-41.9%
Hopkins Basin	14.9%	-13.0%	-35.7%	-5.2%	-28.5%	-59.8%
Portland Coast Basin	15.5%	-10.8%	-36.0%	-2.7%	-30.4%	-54.8%
Glenelg Basin	7.6%	-13.6%	-37.3%	-3.4%	-31.4%	-60.8%
Upper Murray Basin	17.2%	-8.4%	-23.3%	13.5%	-16.6%	-39.4%
Kiewa Basin	11.2%	-9.1%	-22.4%	1.5%	-12.1%	-39.4%
Ovens Basin	11.7%	-10.8%	-23.3%	1.2%	-15.7%	-43.9%
Broken Basin	18.6%	-9.7%	-35.9%	8.1%	-16.8%	-50.0%
Goulburn Basin	9.9%	-9.5%	-29.1%	1.3%	-13.7%	-41.9%
Campaspe Basin	10.5%	-12.3%	-37.1%	1.0%	-20.7%	-57.0%
Loddon Basin	12.4%	-7.4%	-36.6%	6.9%	-17.6%	-57.6%

2.6.5.3 Baseflow separation and statistical analysis

In streams that are likely to be connected to an unconfined aquifer, baseflow and low flows recorded in the stream are likely to be an indicator of groundwater levels, which, in turn, are an indicator for recharge.

The gauged flow records were analysed to identify indicators of baseflow and low flow. For each gauge, the key statistics that were extracted were:

- Mean flow (ML/y)
- Mean runoff, or mean annual flow per unit catchment area, (mm/y)
- Mean baseflow (ML/y)
- Mean baseflow per unit catchment area (mm/y)
- Baseflow index (BFI), or the mean baseflow divided by mean flow

- Flow exceeded on 90 percent of days in the record (Q90; ML/d).

For unregulated streams, the baseflow volume and baseflow index are likely to be reasonable indicators of baseflow. However, in regulated systems, the gauged flows are influenced by releases from upstream storages. Even though baseflow volumes and baseflow index can be calculated at regulated sites, these statistics are likely to be influenced by regulated releases, rather than an indication of the true baseflow response of the catchment at this location.

The daily baseflow signal was calculated, from the daily gauged flow, by applying the Lyne and Hollick (1979) digital filter. Digital filters are a common means of separating out baseflow from a gauged flow record. Nathan and McMahon (1990) found that applying the Lyne and Hollick (1979) digital filter, with three passes and a filter parameter value of 0.925, provided a reliable, fast and objective method for separating baseflow from gauged flow at streamflow gauges across south eastern Australia. Ladson et al. (2013) also found that the Lyne and Hollick (1979) digital filter worked well for baseflow separation at 178 unregulated gauge sites across the Murray Darling Basin.

For the current analysis, the Lyne and Hollick (1990) digital filter was applied with three passes and a filter parameter of 0.925. This produced a daily time series of baseflow at each gauge site. The daily time series of total flow and baseflow was used to calculate annual and monthly mean statistics for gauged total flow, baseflow and baseflow index.

2.6.5.3.1 Outputs

As the DELWP guidelines only provide mean annual projected changes in streamflow, the future baseflow index (BFI) values are unchanged in the projected data. In comparison, the mean annual flow per unit catchment area, and the mean annual baseflow per unit catchment area (ML/y/km^2) values were developed for gauged data and the climate change adjusted data. These datasets provide a measure of how climate will impact both the volume of flow and baseflow for each catchment.

Changes in mean annual flow volumes and baseflow volumes provide useful context on how different climate scenarios impact stream flow within unregulated streams. Within regulated streams these metrics are less useful, therefore the flow exceeded on 90 percent of the days was adopted to analyse the baseflow component.

2.7 Assumptions and limitations of the method

A range of limitations and assumptions of the input data and the method as described above, are discussed in the section below. A further discussion of the limitations of the results is included in Section 7.

2.7.1 Generic state-wide approach

The underlying goal of this project is to predict changes in watertable levels and recharge rates within a state-wide and generic approach. To achieve this goal, two models were used that were able to:

- Estimate bulk recharge and groundwater elevation from all appropriate groundwater monitoring bores state-wide (HydroSight), and
- Estimate recharge (deep drainage) based upon state-wide land use mapping (SoilFlux).

Whilst this approach provides a state-wide assessment it required several important compromises that included:

- The dominate controls on recharge rates are rainfall and different land use types. Recharge from surface water accessions, leakage from water bodies, irrigation accessions, and throughflow, especially where vertical groundwater flow occurs are not specifically assessed, however they form a component of the final reported bulk recharge.
- Future changes in land use are not considered.
- The current distribution of groundwater monitoring bores is sufficient to assess changes in recharge as they generally exist within landscapes where groundwater is extracted. The approach to estimating impact to unconfined aquifers into the future was designed to be a point location assessment (using HydroSight) applied state-wide. The inherent limitation of this method is that the accuracy of the results will be high at the point of analysis (at individual bores) and much less in between bores where the results are being interpolated. The benefit is that actual field data is used as the basis of the estimates rather than a model which considers a system more abstractly.
- Semi-confined aquifer systems have been assessed as if they were unconfined in this assessment because of the state-wide approach. Care should be taken when using the results in known semi-confined areas as the results are likely to have a higher uncertainty. Understanding the location of semi-confined areas of GMUs would be important. Further investigation into the semi-confined systems and semi-confined areas of GMUs should be considered when using the results of this study to validate the findings.
- The project scoping required the project be undertaken for the three standard climate change projections of 0.5 (low), 0.5 (medium) and 0.95 (high). The additional scenario of no climate change was added and climatologically this would sit between the low and high climate change scenarios. It is assumed that this range of scenarios applied across Victoria covers the likely climate futures of Victorian regions and therefore produce useful project outputs, at least to the best of current (2020) climate research.
- To enable a state-wide approach and due to the number of bores assessed, both HydroSight and SoilFlux apply a single universal ‘best guess’ soil model within each model. It is acknowledged that this approach will not always represent localised soil drainage processes. This assumption likely reduces the quality of the calibration of some bores, and effectively simplifies recharge process state-wide.
- The SoilFlux recharge results, which are used to develop final recharge results in this project, are expected to be an over-estimation of recharge to the watertable, as it is not modelled directly, rather as a remainder of the water balance approach used by SoilFlux. The impact of this limitation on project recharge results is tempered by the use of HydroSight recharge results to modify SoilFlux recharge values in the recharge merge approach.

2.7.2 Groundwater input datasets

- Observation and pumping bores used in this analysis were identified using their reported screen or total depths, and assigned as unconfined, and therefore included in the assessment, based off an intersection with mapped VAF units. This approach was used because of the number of bores requiring assessment for unconfinement. There exist errors within the reported bore depths and screen intervals, and the Victorian Aquifer Framework (VAF) unit mapping, being at a state-wide scale, will not perfectly represent actual extents of different aquifer units. Therefore it is likely that bores may have been included in analyses which were not unconfined, and others excluded which were unconfined. For example, in Gerangamete and West Wimmera GMAs, it is understood that unconfined bore with current extraction were excluded from the final datasets because the VAF layer/bore depth intercept identified them as confined.

- The pumping bore analysis considered only metered groundwater use, and so all licenced unmetered bores (using <10 ML/yr) and stock and domestic bores (assumed <1.5 ML/yr) were not included in the analysis. This means that there is more pumping occurring (by about one quarter) than is being accounted for in the analysis. The exclusion of these bores from the pumping analysis in HydroSight suggests that imperfect calibration of pumping to the hydrographs might be being influenced by a missing pumping component of these unmetered bores.
- Permissible consumptive volume (PCV) rates, as a groundwater use scenario volume, were estimated for each GMU as the total for all bores, of the average of the most recent five years of data (2015-2020) of licensed unconfined groundwater bore registered entitlement. This data was estimated due to the lack of individual bore data on the PCV for unconfined bores (PCV is published per GMU and does not specifically consider the confinement of bores within each GMU).

2.7.3 HydroSight analyses

HydroSight is a statistical model (mathematical optimisation of objective function process informed by a partial mass balance /soil model process) that has a range of structural and data limitations.

- The HydroSight approach to simulating groundwater levels assumes that an aquifer's response (in terms of fluctuations in groundwater and recharge rates) are consistent between historical (calibrated) periods, such that hydrogeological process are a constant through time. This is not necessarily expected to be the case under climate change in Victoria.
- The HydroSight model does not replicate or simulate process associated with aquifer properties or dimensions. The model assumes recharge and predicted groundwater elevation can be adequately assessed using only the primary drivers of recharge which is rainfall and potential evaporation. The hydrological and hydrogeological differences between site are considered through the calibration of the soil and weight function parameters, but are intentionally not required *a priori*.
- In this project, it was not possible to individual assess the quality of each HydroSight model calibration directly. There the assessment relied on the coefficient of efficiency (CoE) result for each calibration. It is likely that some bores were included in the final dataset for mapping which had poor calibrations to observed water level but acceptable CoE results. The number of bores modelled was such that individual calibration hydrographs could not be reviewed individually for calibration quality. This will be a large cause of error in recharge estimations, but only in localised areas where these individual bores are located.
- The sequential change in climate from a no climate change in the past to a climate change impacted future was analysed here to account for the long time lags common in groundwater systems. The project could have, instead, simply applied a given projected impact to the entire observational record. This simpler approach would not have accounted for groundwater time lags and, importantly, would have caused major discontinuities in the simulated head at the junction between the three climate periods. In the approach taken, the historic data is attached to a manufactured timeseries of future climate and climate, and climate change and groundwater use changes are applied to only the future periods, while the historical data is held constant. The future timeseries climate data was developed from taking the historical record from 1975-2020 and tacking it on to the end of the historical record (ending in 2022) to generate a continuous timeseries from 1950-2065, as demonstrated in Figure 2-22. This approach gave rise to uncertainty around the choice of climate period used for the future period. The selection of the climate timeseries to use for future dates is relevant to uncertainty of results, particularly when there are significant medium term features in the signal, such as drought or wet periods. This becomes important when the future periods were averaged across reporting periods, and the results taken have different climate patterns originating from the historic climate data used. In this example in Figure 2-22, from bore WRK054545 in the Lower Ovens GMA, the average rainfall used for 2021-2040 (with no climate change overlain) is slightly higher than for the period 2041-2065. This issue will impact the final groundwater elevation and recharge results coming out of the modelling and mapping processes. This climate timeseries was not sensitivity tested by modelling a range of alternate climate timeseries (a thorough approach may be several hundred climate timeseries) to understand the impact

of the choice of climate timeseries to use for future dates on the results. Despite this limitation, it is considered that the method use in this project provides an acceptable prediction of actual groundwater elevation at a point of time in the future because it considers the cumulative changes to the watertable (influenced by climate and pumping) between baseline and future dates.

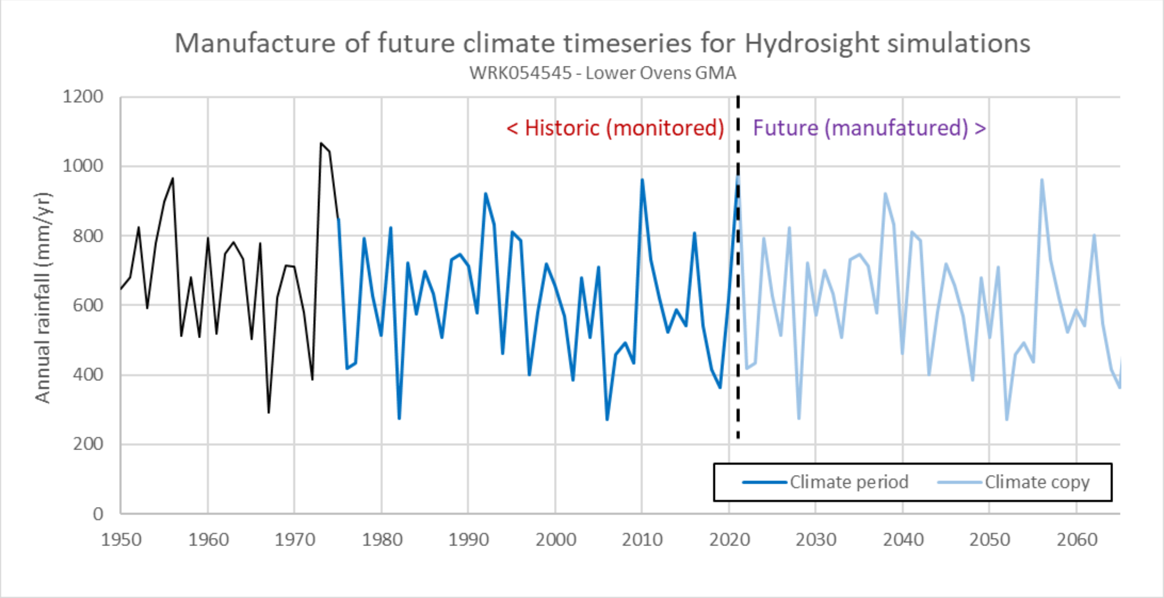


Figure 2-22 Example for an individual bore, of manufacturer of future climate timeseries from historic data, as uses in the groundwater elevation and recharge simulation and mapping approach.

- The number of metered pumping bores with the potential to influence a modelled observation bore was limited in the HydroSight pumping analysis due to the level of complexity at some sites (over 200 pumping bores in the vicinity of some individual observation bores). The radius of influence of an extraction bore on groundwater level at any point is dependent on the local hydrogeological system and previous work in Victoria suggests this radius may range from 1.5 kilometres to 5-10 kilometres (Peterson. & Fulton, 2019) and can vary vastly between geologies. The maximum number of pumping bores used with each modelled observation bore in the HydroSight analysis was limited to five for this analysis (sitting between 100m and around 6 kilometres of observation bores). The exclusion of potentially relevant pumping bores is balanced by the ability of the HydroSight model to provide an assessment of the quality of the calibration (in the resultant calibration statistics, notably CoE). Therefore, the CoE result provided an indication of whether the inputted pumping data, with the climate data and soil model, was sufficient to model a bore's hydrograph to a suitable standard. While the quality of calibration may have been improved by the inclusion of a larger number of local pumping bores for each modelled observation bore, the CoE results from the HydroSight pumping analysis (refer Section 2.5.3.3.3 above and Appendix G) was often approach 1.0 (indicating little improvement could be gained from additional extraction bores) and that the reduced number of pumping bores used to model the selected observation bores, in the majority of cases, produced a comparable CoE to that with many additional extraction bores.
- Decomposition of the impact of pumping and climate on water level is problematic when both occur at the same time. Fortunately, here the recharge often occurs in winter-spring while the pumping occurs in spring-summer. Notwithstanding that this issue in HydroSight can create an over-estimation of recharge, especially within the recovering limb of a hydrograph. the problems with decomposition are considered minor in this project.
- HydroSight is a simplification of groundwater dynamics, such that it does not:
  - Account for no-flow boundaries, or other geological or hydrological structural and sources in the model structure of HydroSight. HydroSight does, however, have the functionality for image wells and so future studies could use this feature to account for no-flow and recharge boundaries.

  - Enforce bounds on hydrogeological parameters when calibrating hydrographs to monitoring data. The lack of enforced parameter bounds beyond physical limits (i.e. aquifer conductivity greater than zero, specific yield between 0 and 1, soil thickness greater than zero) was, however, embedded in HydroSight's design and was included because modelling studies show that the emergence of implausible parameter values are an important clue that the model contains structural errors.
  - Consider the thickness of aquifers in terms of simulating groundwater elevation over time, and whether the water level is being drawn-down below the base of modelled bores or below the depth of the aquifer. The bore models may draw the watertable below the base of the aquifer in any one location, so when this water level is applied in the mapping process across space, the resultant groundwater elevation may sit at or below the elevation of the base of the aquifer. This is clearly not a realistic situation, and in these areas would mean that the available water resource per unit of drawdown is inaccurate.
  - Consider the effective thickness of aquifers and how recharge and watertable variability changes with reducing aquifer thickness, especially when the watertable is drained to the base of the aquifer, and the constraint of available aquifer thickness.
- While the general methodology ignores the presence of semi-confined aquifers and their interrelationship with unconfined aquifers, the HydroSight process can enable modelling of unconfined one and two layer soil models which may include high and varying hydraulic conductivities as part of the calibration process. This may allow for local systems (modelled as bore points) where confined aquifers and confining layers influence the rainfall recharge and groundwater level in a nominally unconfined aquifer so as to be quasi-modelled in the HydroSight process, enabling the influence of semi-confined condition to be incorporated.

2.7.4 HydroMap (watertable mapping)

- It is important to understand the state-wide groundwater elevation maps derived in this project are different in design and purpose than existing static depth to watertable maps. A comparison of project output water level mapping to existing state-wide watertable mapping (e.g. from 2013 used in SoilFlux mapping) is provided in Figure 2-23.
  - The 2013 map is a static representation of average water level over time. Its higher resolution, that reflects topography, is an outcome of the hydrological enforcement of ground surface elevation, where the layer is forced to follow hydrologic controls. Whilst the approach may be considered more correct (in that groundwater elevation is not artesian most places), it can't be used to assess future changes in watertables, as control features are fixed in time and space.
  - In comparison, the HydroMap interpolation approach does not arbitrarily force the groundwater level to be at the elevation of waterways, and as such allows the predicted future watertables to change based upon changes in recharge and pumping. This gives the kriging model freedom to draw-down the watertable below river and wetland levels, enabling the metrics to be assessed.
- An important artifact of the project's approach is that artesian water levels come up consistently throughout the highland valley bottoms in watertable elevation mapping outputs (see an example from the Victorian highlands in Figure 2-24). One of the causes of this is the mapping grid cell size used is 200m. As discussed above, the main cause of this artifact is the HydroMap process not holding groundwater elevation to topographical absolutes (so as to force groundwater level to be at or below stream channels). It might be considered appropriate to remove these negative groundwater elevation values by making them equal to 0 metres below ground level in the mapping, however this ignores areas where groundwater may legitimately be expressing to the ground surface (e.g. baseflow in rivers). It is acknowledged that the extensive areas artesian water levels in the highland may be over-estimated, however, the general approach allows for groundwater elevation change under the waterways to be evaluated into the future. It is noted that additional work on HydroMap calibration parameters may reduce this issue.

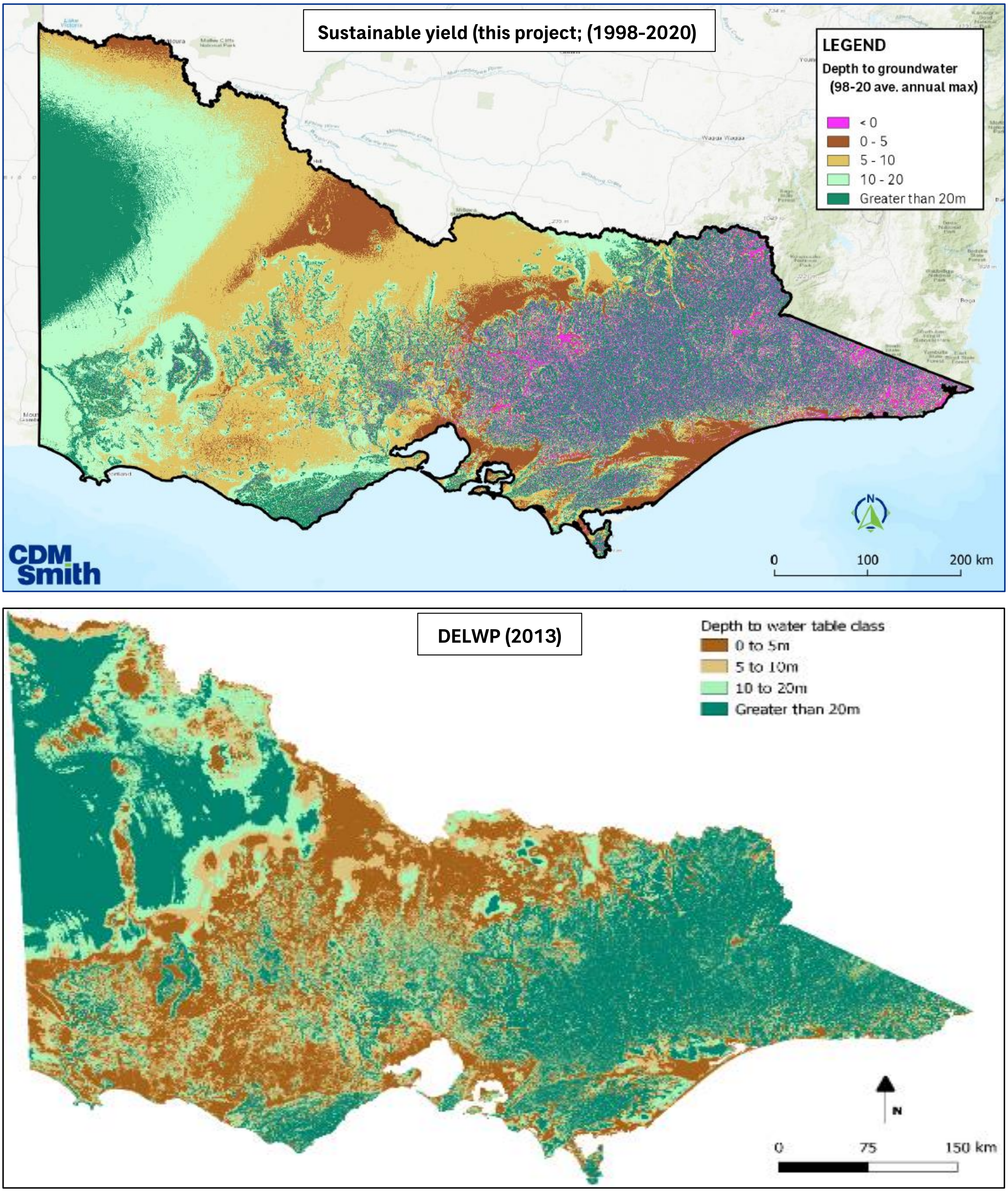


Figure 2-23 Depth to watertable estimates: TOP – Sustainable yields project output (1998-2020 average annual maximum), BOTTOM: Reclassified DELPW (2013) (HARC 2023).

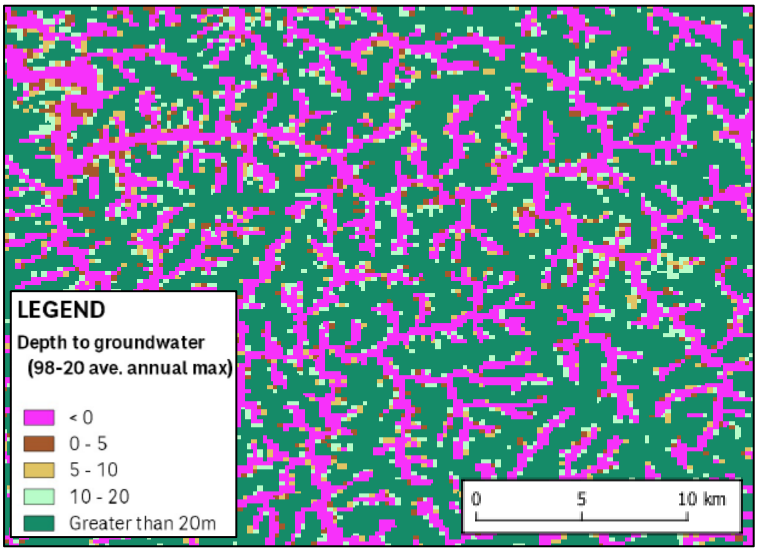


Figure 2-24 Example of depth to watertable from the sustainable yield mapping where the watertable intercepts highland valley lines (excerpt from Victorian Highlands, 1998-2020 average annual maximum groundwater elevation).

2.7.5 SoilFlux recharge

SoilFlux provides a state-wide coverage of recharge estimations by assuming a one-dimensional soil and water balance model of the water cycle. Whilst this is considered appropriate to contribute to a state-wide assessment of recharge, it is based upon the following assumptions, which may not be accurate in many parts of the state:

- The SoilFlux model assumes that the watertable elevation is constant for the entire model run period. While the model allows for water to move between the unsaturated and saturated zones, previous model runs of SoilFlux made relatively generic assumptions regarding the management of plantations (with their known significant impact to watertables over time; HARC, 2023b). The use of a single input watertable elevation is also problematic given the results are providing estimates of recharge a future time points where the watertable will not be consistent with the historic input watertable dataset.
- All SoilFlux runs were undertaken assuming that the only water input is from natural rainfall. SoilFlux does not provide accurate estimates of runoff or recharge for irrigation areas, as it ignores the additional water input from irrigation. As a result, the recharge estimates in irrigation areas represented in SoilFlux would be much lower than would have been the case had irrigation been included (HARC, 2023b).
- The extension of the SoilFlux results developed in this project, to allow estimation of recharge under projected future climate, assumes a linear relationship between mean annual rainfall and mean annual recharge in order to develop the estimated recharge under future climate.
- The uncertainty estimates for SoilFlux recharge data were derived from a comparison with catchment scale mean annual runoff estimates from an external dataset. The scatter, or uncertainty, in the mean annual catchment runoff value compared to SoilFlux estimates of mean annual and runoff and recharge (for a consistent climate period) provides an independent estimate of the uncertainty in the SoilFlux estimates of mean annual recharge, at a catchment level (HARC 2023b). This uncertainty estimation does not represent all uncertainty or error in the SoilFlux method.

2.7.6 Recharge merge mapping approach

The final recharge layers are a process of merging the HydroSight recharge and SoilFlux, this approach introduces several assumptions.

- Ultimately, the point HydroSight recharge estimates are preferred to the SoilFlux results. However the spatial distribution of SoilFlux is considerably greater than HydroSight, and expected to be more accurate than available methods of interpolating recharge across space (i.e. using HydroMap). While considered to provide the best estimates of gridded recharge across Victoria, the merge process undertaken in this study, to combine both approaches to estimating recharge, does introduce potential errors associated with the merging of point data with raster data.

- A comparison between SoilFlux and HydroSight recharge values must consider that HydroSight values are average of annual totals over the reporting periods (e.g. 2021-2040), while SoilFlux values are an annual average for a single reporting year (e.g. 2040) and not informed by observations. With an assumed decline in future water availability under medium and high climate change scenarios, SoilFlux estimates of recharge, which are calculated at the end of the reporting period of HydroSight results, are likely to return universally lower estimates of recharge when compared to the HydroSight results which averages over an earlier and theoretically wetter climate (the opposite is the case for the low climate scenario, with SoilFlux likely to be estimating higher recharge than HydroSight).
- In order to provide some context of this project state-wide recharge data predictions, the outcomes of the two existing datasets are compared to outputs from this project, and the original SoilFlux gridded recharge dataset. This comparison is presented in Figure 2-25 for average results, and Figure 2-26 for maximum/90th percentile results. Comparing the state-wide recharge estimations developed by this project to existing recharge estimations is problematic. The reason being is that there is no formally accepted preferred approach to estimating recharge. CDM Smith (2018b) compiled an extensive list of projects that estimated recharge rates across Victoria, the methods identified included, percent rainfall, Hydrograph fluctuation analysis, Baseflow analysis, Water balance calculation, 1D unsaturated recharge models (e.g. WAVES, Ensym, PERFECT), Empirical models and SoilFlux models (Victorian Aquifer Properties project). The variability in results is evidence that different methods create vastly different recharge estimations.

  CDM Smith (2018b) gridded recharge estimates are based upon a variety existing literature. The outcome of the project was a spatial representation of the range of recharge estimations across watertable aquifers that represent different time periods and methodologies. Lee et al (2024) produced a diffuse recharge based upon the Chloride method.

  When comparing recharge rates to the mean values, it is apparent this project's outputs are consistently higher across the state than both other the Aquifer Properties and Lee et all state-wide datasets. The Lee et al dataset also provided an upper limit (R_{95}), which is more consistent with the recharge estimates developed as under this project. The maximum results from the Aquifer Properties are also more consistent with this project's outputs.

  While a visual comparison of the various study results is simplistic and requires further detailed investigation to determine the data, methodology and landscape drivers of the higher recharge values, the following high level conclusions can be formed:

  - SoilFlux was used in this project as it is one of the only existing state-wide datasets to provide recharge estimation across Victorian landscapes, considering land use, and as discussed, provides a deep drainage estimation as opposed to a direct measure of recharge.
  - The HydroSight point data recharge modelling determines recharge rates based upon the point of truth (monitored groundwater levels) and observed rainfall and PET, and as such cannot be compared to any existing state-wide assessments.
  - The results of this project provide estimates of recharge that includes surface water accessions, leakage from water bodies, irrigation accessions, and throughflow, especially where vertical groundwater flow occurs. Therefore, the rates will be higher than diffuse rainfall estimations produced by other studies.

A comparison of recharge rates for four selected Victorian regions is provided in Table 2-8. What is evident is the extreme variability on recharge values depending on origin. The results from this project ('SY results') are constantly lower than maximum reported recharge rate collated by the Aquifer Properties project, and consistently higher than the Chloride method results – which is widely accepted as providing implausibly low estimates of recharge. Within dryer landscapes, such as the Mallee and Katunga GMA, the results from this project results appear to be an over-estimation compared to other datasets, while they are relatively consistent with other studies within higher rainfall highland regions and coastal regions (e.g. Glenelg and Koo Wee Rup GMAs).

Table 2-8 Comparison of recharge rates for selected GMUs

	Estimated annual recharge (mm/yr)					
Location	SY results	SoilFlux	Lee et al (Chloride) (R50)	Lee et al (Chloride) (R95)	Aq. Properties (mean)	Aq. Properties (max)
	1998-2020	2010-2016	Current	Current	Current	Current
Katunga (North-central Vic)	108	0.1	5	12	15	145
Bright (Vic highlands)	278	685	98	271	220	880
Mallee region	30	2	0.2	0.7	2	60
Koo Wee Rup (port coastal)	188	28	10	27	80	290
Glenelg (South West Limestone coastal)	82	45	66	164	160	270

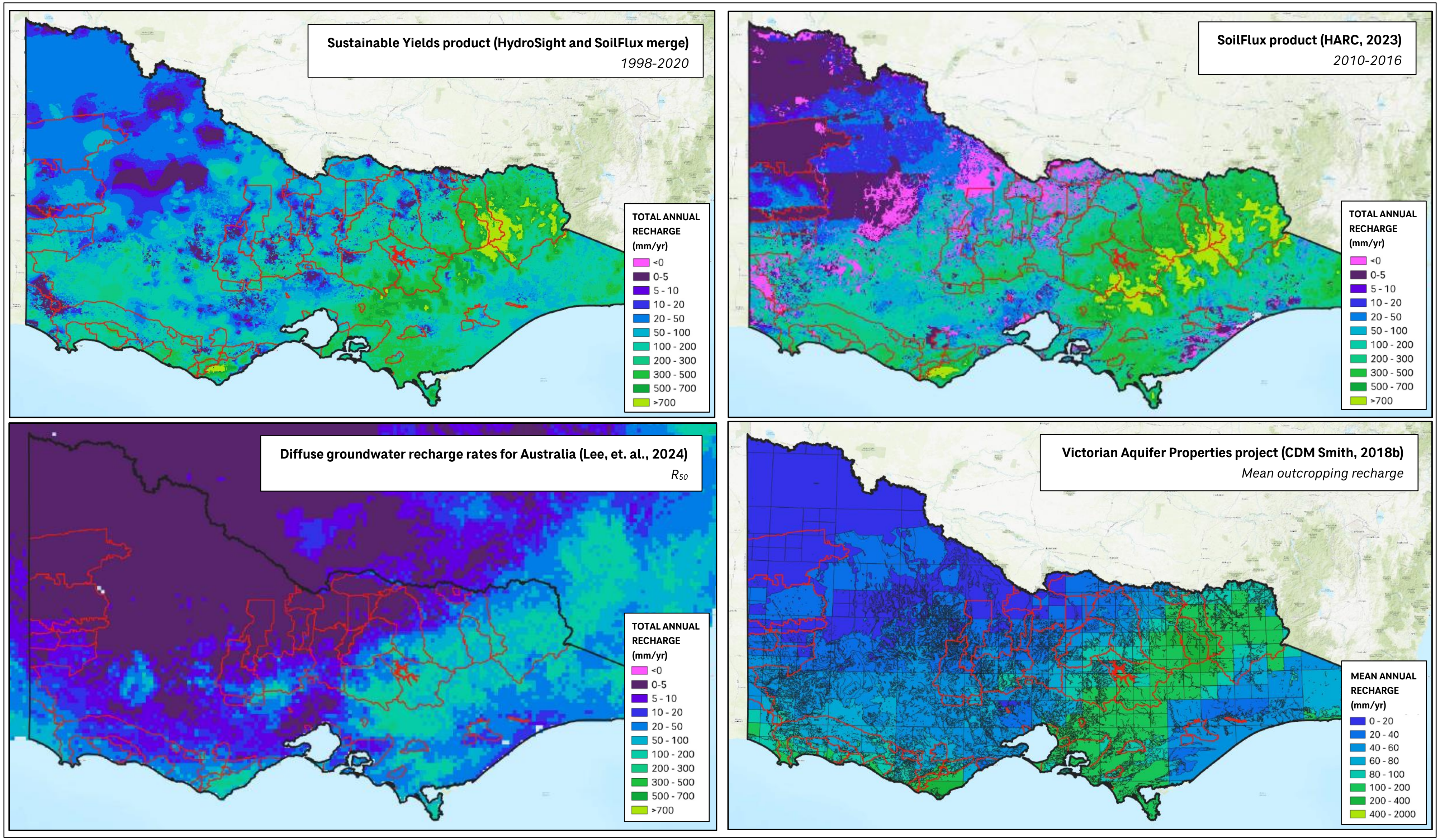


Figure 2-25 Estimated gridded recharge rates (for approx. current period) from available sources. TOP LEFT: Final Sustainable Yield merge results; TOP RIGHT: SoilFlux results; BOTTOM LEFT: Chloride method diffuse recharge; BOTTOM RIGHT: Victorian Aquifer Properties.

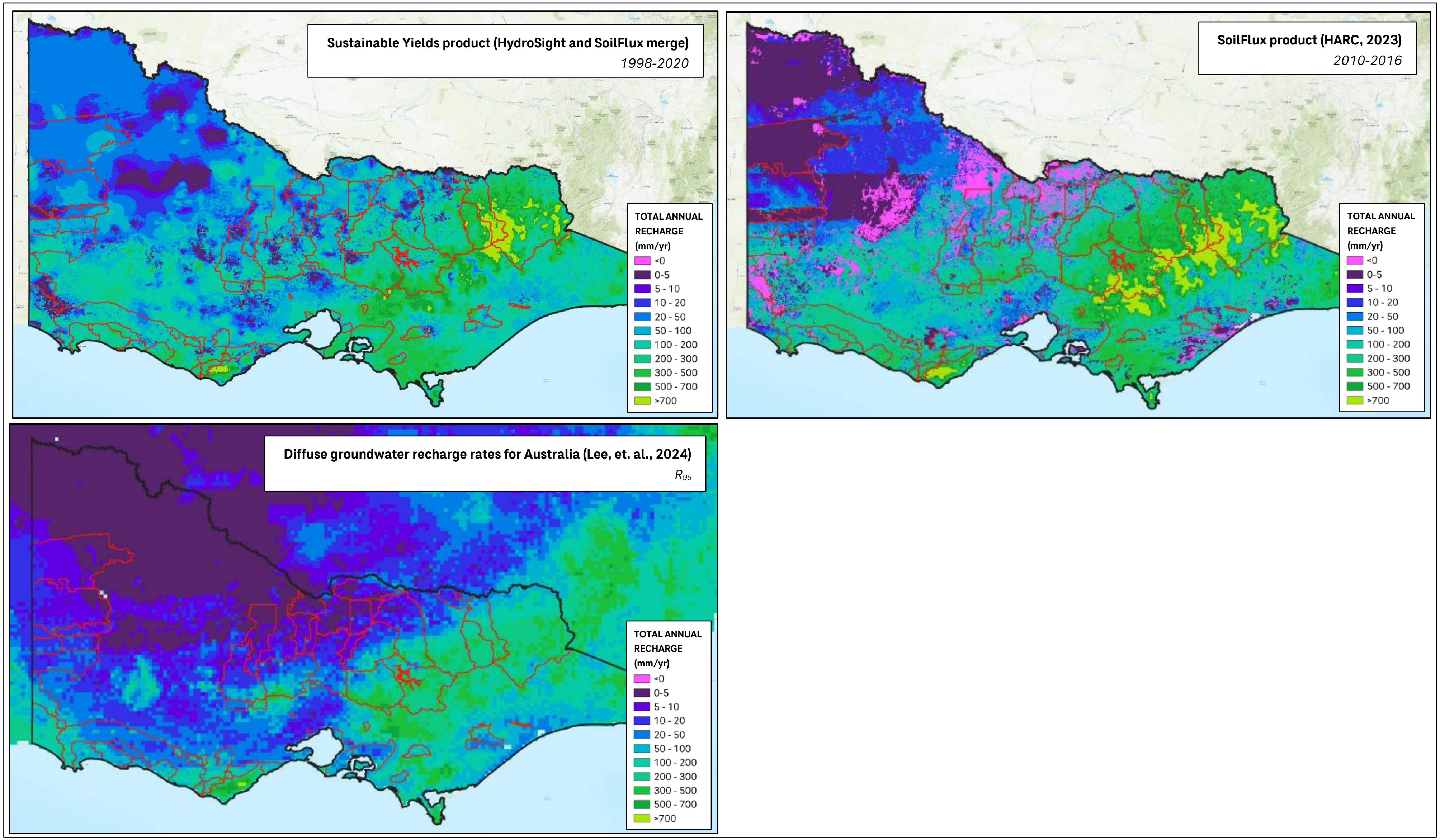


Figure 2-26 Estimated 'maximum' gridded recharge rates (for approx. current period) from available sources. TOP LEFT: Final Sustainable Yield merge results; TOP RIGHT: SoilFlux results; BOTTOM LEFT: Chloride method diffuse recharge.

2.7.7 Estimates of uncertainty

Estimating uncertainty of project results involved multiple complex processes, and included a number of assumptions and limitations. These are described below.

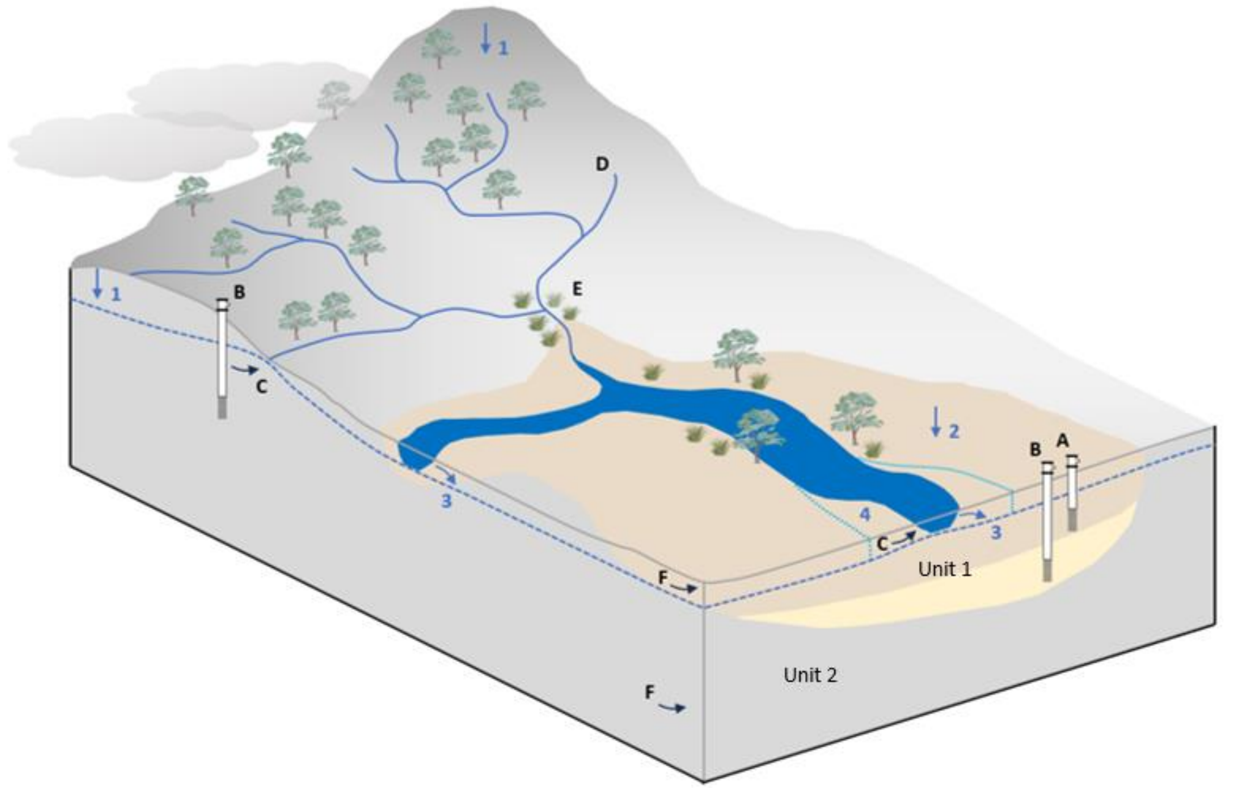
- The approach to estimating recharge and groundwater level used in this study was not able to provide an estimate of the error of the output data, nor an estimate of the whole uncertainty associated with the results. The estimated uncertainty in the mean of recharge and in the mean of groundwater elevation are presented to indicate a differential qualitative estimate of uncertainty across the study area. Specifically, the final presented 'uncertainty in the mean of recharge' results includes both the variability in the estimated recharge results from the averaging process (as the square root of one standard deviation of the population mean) for the modelled recharge results, and the uncertainty band of the fit between results from SoilFlux and the Victorian Winterfill Period SDL project for mean annual recharge and runoff estimates for SDL catchments (as one standard deviation). The 'uncertainty in the mean of groundwater elevation' combines the residual error in the HydroSight model calibration for each bore as well as the variability in the estimated groundwater level results from the averaging process (as the square root of one standard deviation of the population mean). Neither of these estimates of uncertainty constitute an error band or a measure of uncertainty from the average results report within which the actual value of recharge or groundwater elevation will lie, and should be used to identify areas where the results are likely less reliable.
- Another measure of uncertainty that is used in this assessment comes from the estimates of recharge and groundwater elevation under low and high climate change scenarios for future reporting dates (2021-2065). These results, derived from estimated climate of 10th percentile (low) and 90th percentile (high) climate change models projections, are presented alongside the medium climate change scenario (50th percentile climate change models), providing a quasi-upper and lower range. This is not a true upper and lower limit to the uncertainty of the datasets, in that it does not come from a summation of all potential sources of error or uncertainty. For the purposes of interpreting the results, however, the low and high climate change scenario results could be considered a reasonable estimate of the likely range of results for each GMU into the future under climate change.
- HydroSight includes a Differential Evolution Adaptive Metropolis (DREAM) calibration algorithm to provide an estimate of the parameter uncertainty. This can be used to provide an uncertainty range for the results of the bore calibrations. Here however is was not used in this project because the computation effort required and the number of sites to examine. Future studies could have applied this feature to smaller areas. Doing so would then provide an uncertainty in, say, the predicted head or mean annual recharge.
- Mapping uncertainty across space between bore point HydroSight model results was undertaken using a slightly different approach for recharge and groundwater elevation. For both datasets, uncertainty was mapped using the uncertainty functionality in the HydroMap code (modifying the input bore point uncertainty using HydroMap calibration uncertainty and kriging error). For the groundwater elevation mapping in HydroMap, the DEM was used as the interpolation grid dataset, whereas for recharge, average annual rainfall (1950-1974) was used. Given the spatial relationship between ground elevation and the elevation of the watertable is stronger than the relationship between recharge and rainfall (this is the reason HydroMap was not used to produce gridded HydroSight recharge results), the gridded estimate of uncertainty in the mean of recharge produced by the HydroMap process for the HydroSight data is considered less accurate than the uncertainty in the mean of groundwater elevation produced. (This uncertainty estimate for recharge was then combined with the estimate of uncertainty from SoilFlux data to develop a final gridded estimate of uncertainty in the mean of recharge for the final recharge results.

Section 3 Conceptual models

3.1 GMU conceptual models

The conceptual models for all unconfined and semi-confined GMUs are presented in Appendix L. The models contain a conceptual summary of each GMU, including a description of the relevant hydrological processes as well as volumetric estimates of major process contributing to the water budget. An example of the conceptual model for West Goulburn GMA is included Figure 3-1.

WEST GOULBURN GMA ***Highland and Sedimentary Upland Valleys***



Unit description	Unit 1 is the Quaternary alluvial sediments, the Shepparton Formation, the Newer Volcanics and the Deep Lead, Unit 2 is the fractured bedrock
Groundwater levels	Depth to groundwater ranges from <5 m to 190 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (units above the basement) ranges from 5 m to >500 m and averages around 50 m within the GMU. The region is unconfined through to the basement.

Process	Description of Process	Quantification of Process
1 - High Rainfall Recharge	Rainfall recharge occurs in the areas of bedrock outcrop in the south. The zone of greatest recharge is around Puckapunyal.	Total estimated recharge (current period): 488,593 ML/yr
2 - Low Rainfall Recharge	In the north, recharge occurs through rainfall infiltrating the Shepparton Formation then leaking to underlying aquifers.	
3 – River Recharge	NA	

4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	The Deep Lead is high yield relative to the more variable Shepparton Formation. The Newer Volcanics basalt is not considered a significant resource.	Average total extraction (current period): 3,509 ML/yr. Total current entitlement: 95,132 ML/yr PCV: No PCV set
B - Pumping (from unit 2)	Bore yields in the fractured bedrock are variable. This is the main aquifer used in the south of the GMA.	
C - Groundwater discharge to rivers	Groundwater discharge to waterways occurs in this GMU.	Baseflow index: 0.38 Mean annual baseflow: 90.4 ML/y/km^2 (Gauge: 405212 Sunday Creek at Tallarook)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	Groundwater discharge to wetlands occurs in this GMU.	
F - Groundwater throughflow out	The greatest output from the GMU is throughflow to the Murray Valley Deep Lead system.	
References: GMW (2017) West Goulburn GMA Local Management Plan,		

Figure 3-1 GMU conceptual model for West Goulburn GMA.

Section 4 Recharge results

4.1 Summary of results

The results of the mapping of average annual recharge to the watertable across Victoria are presented below. The formulation of these results is described above in Section 2.6.

Estimated average annual recharge from this analysis covers the following scenarios:

- Historical periods: Baseline (1950-1974), 1975-1997 and 1998-2020, and
- Future scenarios 2021-2040 and 2041-2065 for:
  - No climate change (current climate), and low, medium and high climate change.

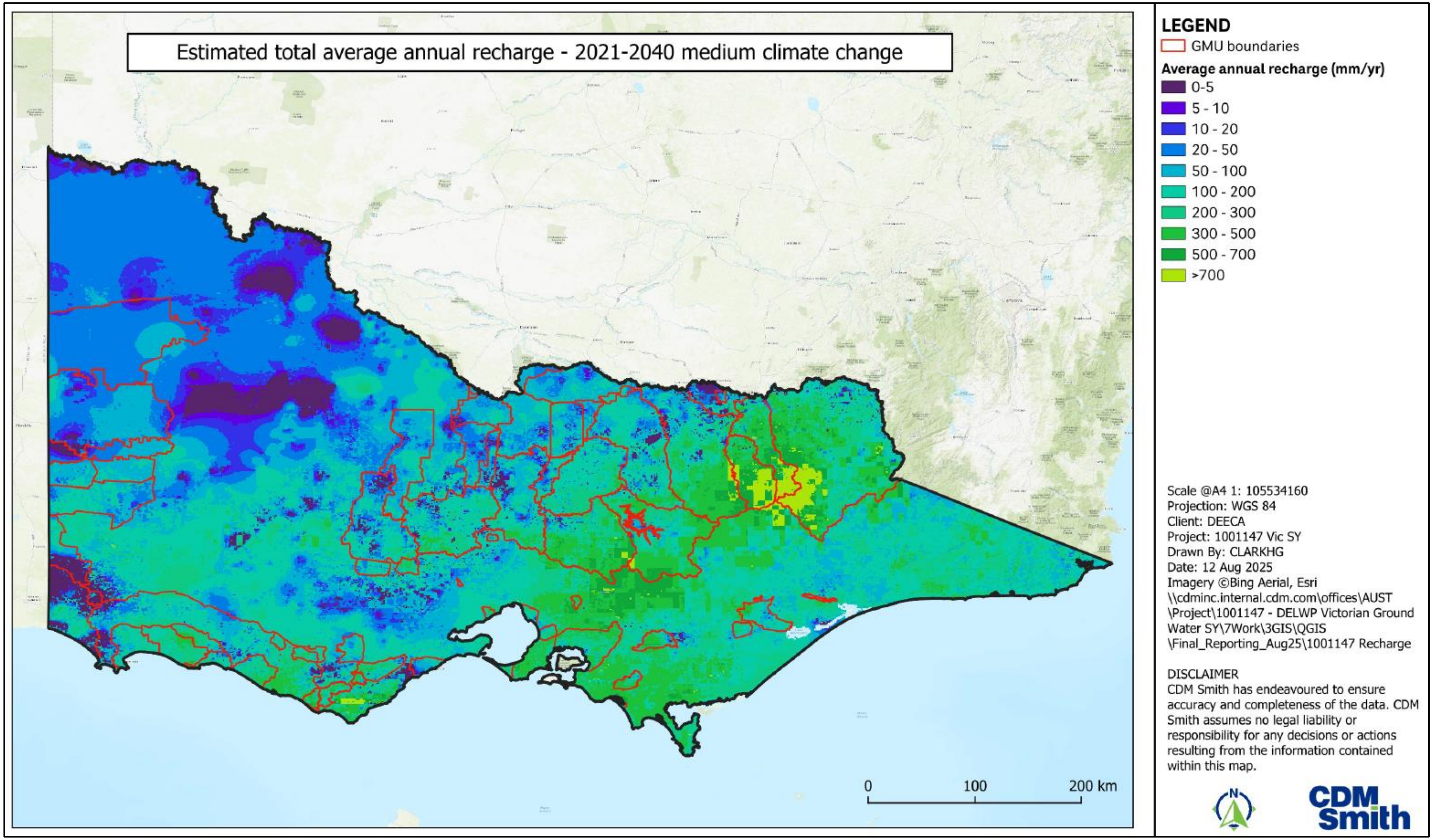
In this assessment, recharge is independent of groundwater extraction. Extraction scenarios therefore are not relevant to recharge results. When converting estimated recharge (mm/yr) to a volume for a management area, each model cell recharge volume was calculated based on the recharge estimate (mm/yr) and cell area (m^2), and then summed for all model cells with a GMU boundary.

Results are presented for Victoria and by GMU as a range of mapped and tabulated datasets, as summarised in Table 4-1.

Table 4-1 Summary of results for recharge

Result dataset	**Results available**				
	Map	**Digital dataset**	**Table of results**	Example map	Summary table
Average total recharge (ML/yr)	State-wide **Appendix M**	Gridded product	By GMU **Table P-1** in **Appendix P**	State-wide **Figure 4-1**	NA
Average total recharge per square kilometre (ML/km^2/yr)	NA	NA	By GMU **Table P-2** in **Appendix P**	NA	NA
Change in average total recharge from baseline (ML/yr)	State-wide **Appendix N**	Gridded product	By GMU **Table P-1** in **Appendix P**	State-wide **Figure 4-2**	By GMU **Table 4-2**
Uncertainty in the mean of average total recharge (m)	State-wide **Appendix O**	Gridded product	NA	State-wide **Figure 4-3**	NA
Use as a proportion of recharge (%)	NA	NA	By GMU **Appendix Q**	NA	By GMU **Table 4-3** **Figure 4-4**
Recharge as a proportion of rainfall (%)	NA	NA	By GMU **Appendix R**	NA	By GMU **Table 4-4**

Additional results are provided for Sustainable Diversion Limit (SDL) catchment areas across Victoria in the form of digital files. Additional recharge related results for GMUs are presented in the metrics assessment (Section 6 below).



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DISCLAIMER
CDM Smith has endeavoured to ensure accuracy and completeness of the data. CDM Smith assumes no legal liability or responsibility for any decisions or actions resulting from the information contained within this map.

Figure 4-1 Estimated average annual recharge (mm/yr) for the period 2021-2040 under medium climate change.

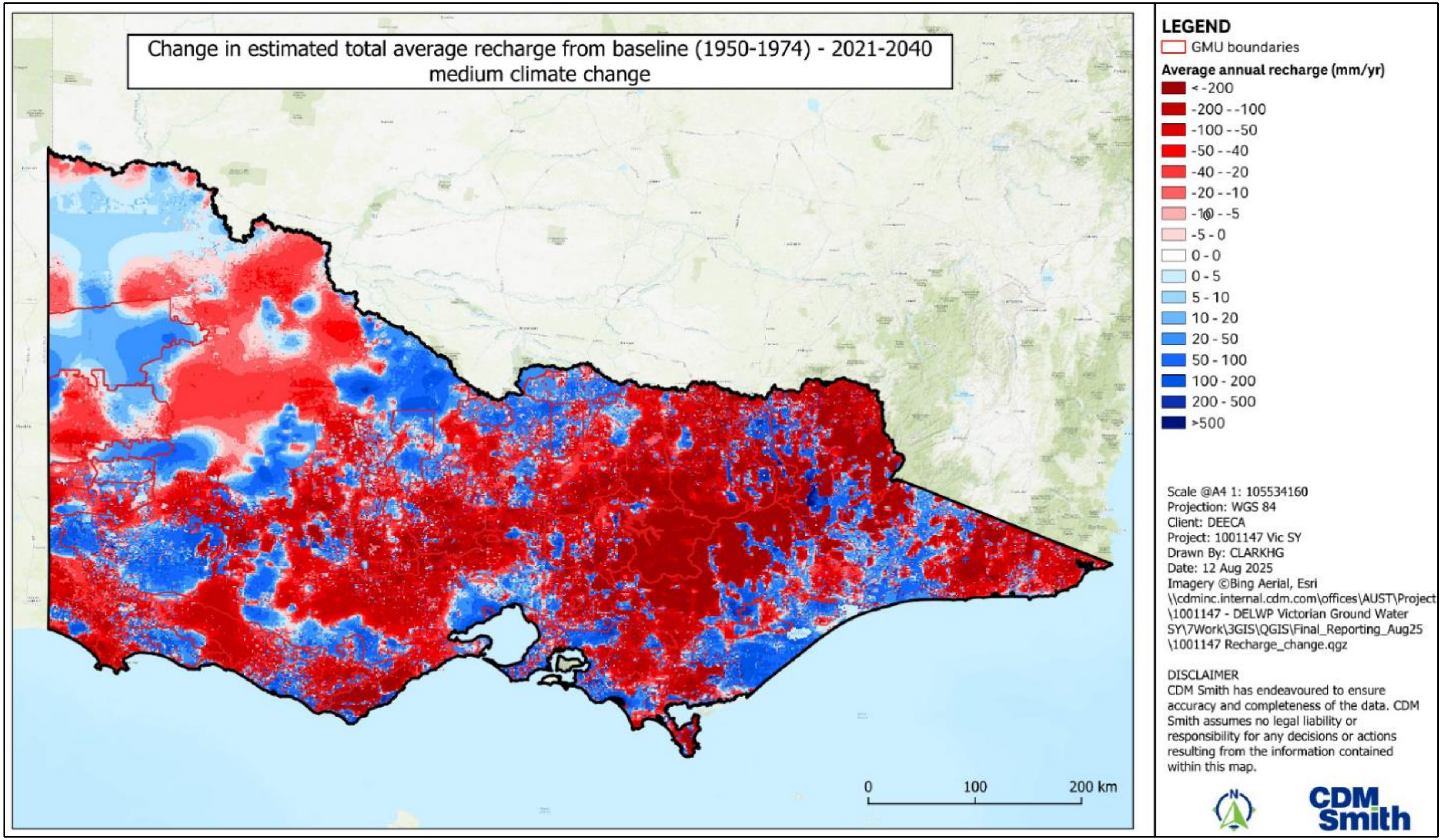

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Figure 4-2 Change in estimated average annual recharge (mm/yr) for period 2021-2040 under medium climate change from baseline (1950-1974).

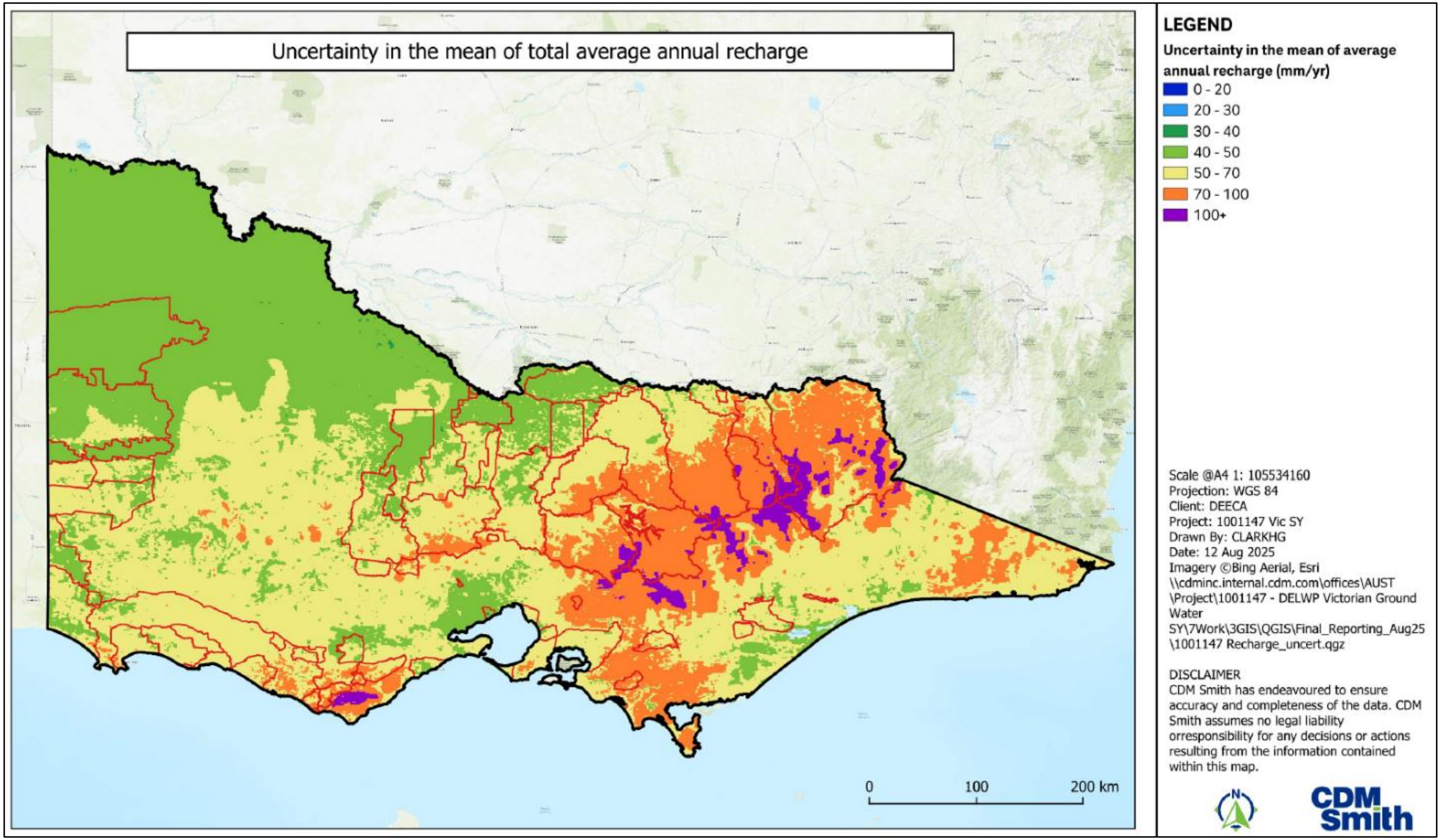


Figure 4-3 Uncertainty in the mean of estimated average annual recharge (mm/yr).

4.2 Discussion of results

A significant reduction from baseline volumes (1950-1974) in bulk recharge reaching the watertable into 2021-2040 and 2041-2065 was modelled for a number of GMUs, as summarised for a medium climate change scenario in Table 4-2. One quarter of GMUs are estimated to have more than a 30% reduction in bulk recharge in 2021-2040, and just over half of GMUs in 2041-2065 (under medium climate change). These GMUs are located primarily in the central northern and highlands of Victoria. Mapping of change of recharge into the future indicates that this change is highly variable, however with some areas of GMUs showing both increases and decreases in recharge (for example see Figure 4-2). Some of this variability is likely to be due to uncertainty in the results. Uncertainty in the recharge estimates is expected to highest in the central and eastern highlands, where there was sparse bore data available. Uncertainty in northern Victoria would be expected to be increased in those areas subject to flooding and irrigation, which contribute substantially to bulk recharge seasonally.

Two GMUs are expected to have groundwater use at current levels comprising more than 10% of annual recharge in 2021-2040 under medium climate change scenario, in the Lower Campaspe Valley WSPA and Denison GMA. A summary of results for all GMUs are presented in Table 4-3 below. An example of groundwater use as a proportion of estimated recharge for the Barnawartha GMA is included in Figure 4-4 below.

Table 4-4 below gives estimated annual recharge as a proportion of annual rainfall (on average) for each GMU. Almost one fifth of GMUs show recharge above 30% of rainfall (2021-2040 under medium climate change). The GMUs with high proportions are not concentrated in areas with high groundwater use or irrigation districts. This number of GMUs reduces into 2041-2065, but this is because of reduced recharge because of reduced future rainfall, rather than an improving trend in recharge volumes.

Table 4-2 Estimated percentage change of recharge from baseline (1950-1974), ranked by highest change for future medium climate change scenarios

GMU	Proportional change in recharge (ML/yr) from baseline (1950-1974)	
	2021-2040 Medium climate change	2041-2065 Medium climate change
Barnawartha GMA	-75%	-81%
Lancefield GMA	-51%	-69%
Eildon GMA	-51%	-62%
Glenelg WSPA ^	-43%	-51%
Loddon Highlands WSPA ^	-42%	-58%
Broken GMA *	-42%	-55%
Central Victorian Mineral Springs GMA	-42%	-60%
Cardigan GMA	-41%	-57%
Bungaree GMA ^	-40%	-55%
Jan Juc GMA	-39%	-54%
Strathbogie GMA	-37%	-52%
Lower Ovens GMA ^	-35%	-48%
Wandin Yallock GMA ^	-32%	-44%
Upper Murray GMA	-29%	-41%
Yangery WSPA ^	-27%	-39%

GMU	Proportional change in recharge (ML/yr) from baseline (1950-1974)	
	2021-2040 Medium climate change	2041-2065 Medium climate change
Upper Goulburn GMA	-26%	-44%
Gerangamete GMA	-24%	-49%
Leongatha GMA	-23%	-34%
South West Limestone GMA ^	-21%	-36%
Neuarpur Zone (West Wimmera) ^	-18%	-38%
Northern Zone (West Wimmera)	-17%	-39%
Heywood GMA	-16%	-35%
Newlingrook GMA	-16%	-28%
Upper Ovens WSPA	-15%	-27%
Southern Zone (West Wimmera)	-14%	-41%
Nullawarre WSPA ^	-14%	-31%
Kiewa GMA	-14%	-25%
West Goulburn GMA * ^	-11%	-33%
Moe GMA	-11%	-27%
Moorabbin GMA ^	-9%	-31%
Lower Campaspe Valley WSPA * ^	-9%	-34%
Mid Goulburn GMA * ^	-6%	-24%
Gellibrand GMA	1%	-26%
Glenormiston GMA ^	2%	-24%
Colongulac GMA	8%	-17%
Frankston GMA	10%	-10%
Hawkesdale GMA ^	12%	-4%
Koo Wee Rup WSPA	16%	-1%
Denison GMA * ^	18%	-10%
Gymbowen Zone (West Wimmera)	22%	-22%
Wy Yung GMA ^	26%	-2%
Warrion WSPA ^	26%	-21%
Mid Loddon GMA * ^	28%	-3%
Wa De Lock GMA * ^	31%	3%
Shepparton Irrigation GMA * ^	36%	10%
Nepean GMA ^	41%	13%
Merrimu GMA ^	48%	8%
Tarwin GMA	55%	31%

GMU	Proportional change in recharge (ML/yr) from baseline (1950-1974)	
	2021-2040 Medium climate change	2041-2065 Medium climate change
Big Desert Zone (West Wimmera)	71%	27%
Little Desert Zone (West Wimmera)	97%	18%
Deutgam WSPA * ^	208%	156%

Notes: * Irrigation district exists within GMU.

^ High density of current groundwater extraction within GMU.

Table 4-3 Licenced current use as a percentage of estimated recharge, with change from baseline (1950-1974), ranked by percentage of recharge for future medium climate change scenarios

GMU	Use as a proportion of recharge and change from baseline (1950-1974)			
	2021-2040 MCC		2041-65 MCC	
	Use as % recharge	% ∆	Use as % recharge	% ∆
Lower Campaspe Valley WSPA	25%	2.2%	34%	12%
Denison GMA	18%	-3.2%	24%	2.3%
Shepparton Irrigation GMA	10%	-3.8%	13%	-1.3%
Mid Loddon GMA	9.7%	-2.7%	13%	0.4%
Nepean GMA	9.4%	-3.8%	12%	-1.6%
Nullawarre WSPA	9.0%	1.2%	11%	3.5%
Yangery WSPA	7.5%	2.0%	8.9%	3.5%
Merrimu GMA	6.9%	-3.3%	9.5%	-0.7%
Glenormiston GMA	6.8%	-0.1%	9.1%	2.2%
Wy Yung GMA	6.7%	-1.7%	8.6%	0.2%
Warrion WSPA	6.4%	-1.7%	10%	2.2%
Wa De Lock GMA	6.1%	-1.9%	7.8%	-0.3%
Bungaree GMA	4.8%	1.9%	6.4%	3.6%
Deutgam WSPA	4.7%	-9.8%	5.7%	-8.8%
Glenelg WSPA	3.7%	1.6%	4.3%	2.2%
Lancefield GMA	3.2%	1.6%	5.0%	3.4%
Wandin Yallock GMA	2.8%	0.9%	3.4%	1.5%
Mid Goulburn GMA	2.2%	0.1%	2.7%	0.7%
Heywood GMA	2.0%	0.3%	2.5%	0.9%
South West Limestone GMA	1.9%	0.4%	2.3%	0.8%
Loddon Highlands WSPA	1.9%	0.8%	2.6%	1.5%

GMU	Use as a proportion of recharge and change from baseline (1950-1974)			
	2021-2040 MCC		2041-65 MCC	
	Use as % recharge	% ∆	Use as % recharge	% ∆
Jan Juc GMA	1.6%	0.6%	2.2%	1.2%
Hawkesdale GMA	1.5%	-0.2%	1.8%	0.1%
Cardigan GMA	1.4%	0.6%	1.9%	1.1%
Koo Wee Rup WSPA	1.1%	-0.2%	1.3%	0.0%
Colongulac GMA	0.9%	-0.1%	1.1%	0.2%
Moe GMA	0.8%	0.1%	1.0%	0.3%
West Goulburn GMA	0.6%	0.1%	0.8%	0.3%
Northern Zone (West Wimmera)	0.5%	0.1%	0.8%	0.3%
Moorabbin GMA	0.4%	0.0%	0.5%	0.2%
Lower Ovens GMA	0.3%	0.1%	0.4%	0.2%
Central Victorian Mineral Springs GMA	0.3%	0.1%	0.4%	0.2%
Southern Zone (West Wimmera)	0.3%	0.0%	0.4%	0.2%
Barnawartha GMA	0.2%	0.2%	0.3%	0.2%
Leongatha GMA	0.2%	0.0%	0.2%	0.1%
Frankston GMA	0.2%	0.0%	0.2%	0.0%
Tarwin GMA	0.1%	-0.1%	0.1%	0.0%
Broken GMA	0.1%	0.0%	0.1%	0.1%
Upper Ovens WSPA	0.1%	0.0%	0.1%	0.0%
Strathbogie GMA	0.1%	0.0%	0.1%	0.1%
Kiewa GMA	0.1%	0.0%	0.1%	0.0%
Upper Goulburn GMA	0.1%	0.0%	0.1%	0.0%
Gymbowen Zone (West Wimmera)	0.04%	-0.01%	0.07%	0.02%
Neuarpur Zone (West Wimmera)	0.038%	0.007%	0.050%	0.019%
Newlingrook GMA	0.025%	0.004%	0.029%	0.008%
Eildon GMA	0.014%	0.007%	0.018%	0.011%
Upper Murray GMA	0.014%	0.004%	0.017%	0.007%
Gerangamete GMA	0.0002%	0.0001%	0.0003%	0.0002%
Big Desert Zone (West Wimmera)	No use			
Gellibrand GMA	No use			
Little Desert Zone (West Wimmera)	No use			

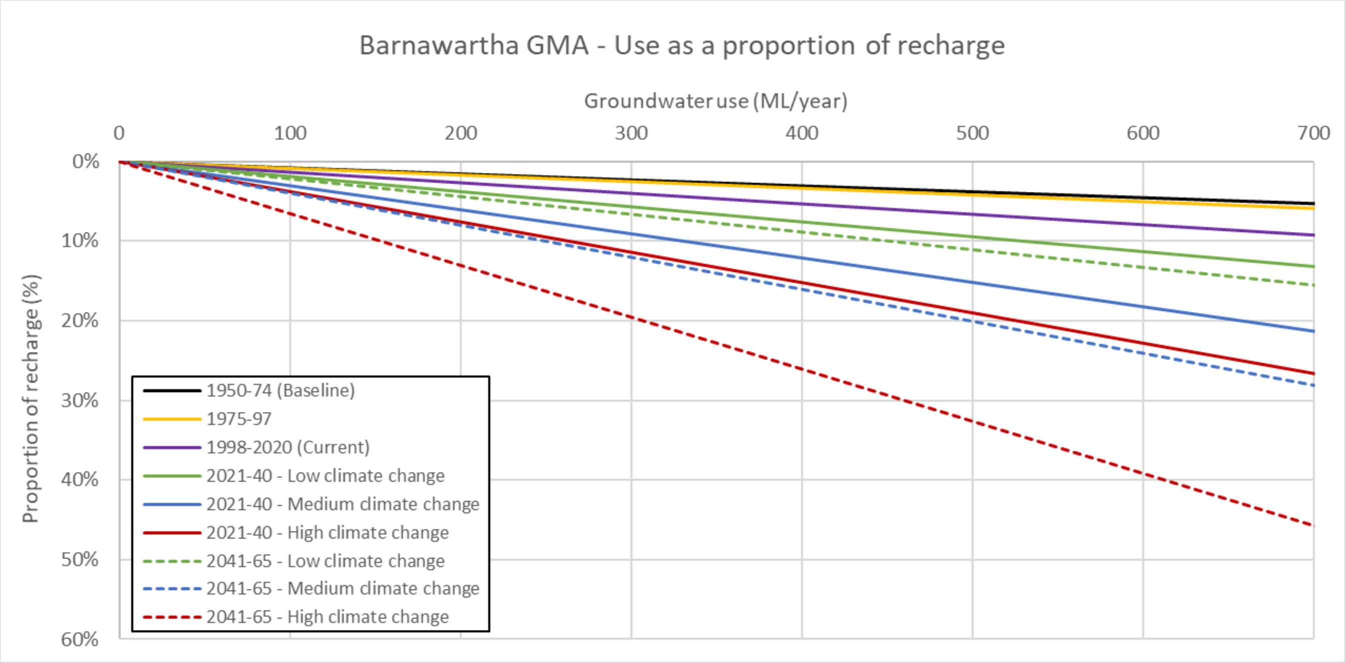


Figure 4-4 Licenced groundwater use as a percentage of average annual recharge for the Barnawartha GMA.

Table 4-4 Estimated total annual recharge as a percentage of rainfall for GMUs, ranked by highest change for medium climate change scenarios

GMU	Recharge as a proportion of rainfall and change from baseline (1950-1974)					
	Current 1998-2020		2021-2040 MCC		2041-65 MCC	
	Recharge as % rainfall	% ∆	Recharge as % rainfall	% ∆	Recharge as % rainfall	% ∆
Tarwin GMA	58%	142%	62%	159%	54%	127%
Nepean GMA	43%	103%	50%	137%	41%	95%
Deutgam WSPA	49%	274%	47%	260%	40%	208%
Upper Ovens WSPA	40%	-17%	44%	-9%	39%	-21%
Kiewa GMA	56%	20%	44%	-6%	39%	-17%
Upper Murray GMA	47%	3%	35%	-22%	29%	-35%
Koo Wee Rup WSPA	31%	18%	34%	28%	30%	11%
Wandin Yallock GMA	36%	-16%	32%	-25%	27%	-38%
Upper Goulburn GMA	29%	-29%	32%	-20%	25%	-37%
Hawkesdale GMA	30%	18%	31%	20%	28%	9%
Frankston GMA	21%	-15%	30%	23%	25%	3%
Leongatha GMA	30%	-18%	30%	-17%	26%	-27%
Moe GMA	33%	8%	30%	-2%	25%	-17%
Denison GMA	29%	22%	29%	23%	23%	-2%

GMU	Recharge as a proportion of rainfall and change from baseline (1950-1974)					
	Current 1998-2020		2021-2040 MCC		2041-65 MCC	
	Recharge as % rainfall	% ∆	Recharge as % rainfall	% ∆	Recharge as % rainfall	% ∆
Wa De Lock GMA	28%	37%	28%	39%	23%	14%
Lower Ovens GMA	21%	-46%	28%	-28%	23%	-41%
Moorabbin GMA	26%	4%	28%	10%	22%	-14%
Wy Yung GMA	23%	20%	28%	44%	22%	17%
Nullawarre WSPA	32%	9%	27%	-5%	23%	-20%
Gellibrand GMA	30%	17%	27%	4%	20%	-20%
Eildon GMA	27%	-45%	26%	-46%	21%	-56%
Colongulac GMA	23%	5%	25%	14%	20%	-9%
Strathbogie GMA	23%	-37%	25%	-32%	19%	-47%
Newlingrook GMA	27%	-1%	25%	-9%	22%	-20%
Glenormiston GMA	24%	8%	24%	8%	19%	-16%
Bungaree GMA	22%	-41%	24%	-36%	18%	-50%
Gerangamete GMA	21%	-30%	24%	-22%	17%	-45%
Yangery WSPA	26%	-4%	23%	-16%	20%	-26%
Central Victorian Mineral Springs GMA	16%	-52%	22%	-37%	16%	-55%
Heywood GMA	25%	19%	19%	-8%	16%	-24%
South West Limestone GMA	21%	-10%	19%	-15%	17%	-27%
West Goulburn GMA	18%	-7%	19%	-1%	15%	-23%
Mid Goulburn GMA	20%	9%	19%	7%	16%	-12%
Gymbowen Zone (West Wimmera)	16%	9%	19%	34%	13%	-11%
Broken GMA	18%	-39%	19%	-35%	15%	-49%
Shepparton Irrigation GMA	19%	64%	18%	61%	15%	33%
Southern Zone (West Wimmera)	18%	-11%	18%	-7%	13%	-33%
Mid Loddon GMA	16%	28%	18%	43%	14%	10%
Merrimu GMA	21%	87%	18%	65%	14%	23%
Lancefield GMA	11%	-66%	18%	-45%	12%	-64%
Cardigan GMA	19%	-29%	18%	-33%	13%	-50%
Warrion WSPA	24%	71%	18%	25%	11%	-19%
Neuarpur Zone (West Wimmera)	15%	-19%	17%	-7%	14%	-26%
Loddon Highlands WSPA	16%	-37%	16%	-36%	12%	-52%
Lower Campaspe Valley WSPA	14%	-4%	15%	3%	11%	-23%
Northern Zone (West Wimmera)	11%	-17%	12%	-6%	9%	-29%
Jan Juc GMA	10%	-44%	12%	-35%	9%	-48%

GMU	Recharge as a proportion of rainfall and change from baseline (1950-1974)					
	Current 1998-2020		2021-2040 MCC		2041-65 MCC	
	Recharge as % rainfall	% Δ	Recharge as % rainfall	% Δ	Recharge as % rainfall	% Δ
Big Desert Zone (West Wimmera)	11%	80%	11%	90%	9%	43%
Little Desert Zone (West Wimmera)	8%	75%	10%	122%	6%	39%
Glenelg WSPA	11%	-14%	8%	-37%	7%	-43%
Barnawartha GMA	17%	-37%	7%	-74%	6%	-80%

Section 5 Groundwater elevation results

5.1 Summary of results

The results of the mapping of average annual maximum and minimum elevation of the watertable across Victoria is presented below. Average annual maximum elevation is defined as the average of annual maximum water levels for the years within each reporting period, also known as 'recovered water level'. Average annual maximum elevation considers the average of annual minimum water levels for the years within each reporting period. The formulation of these results is described above in Section 2.5.

Estimated annual watertable elevation from this analysis covers the following scenarios:

- Historical periods: Baseline (1950-1974), 1975-1997 and 1998-2020, and
- Future scenarios 2021-2040 and 2041-2065 for:
  - No climate change (current climate), and low, medium and high climate change, and
  - No groundwater extraction, current extraction, PCV rate extraction and 200% of PCV rate extraction.

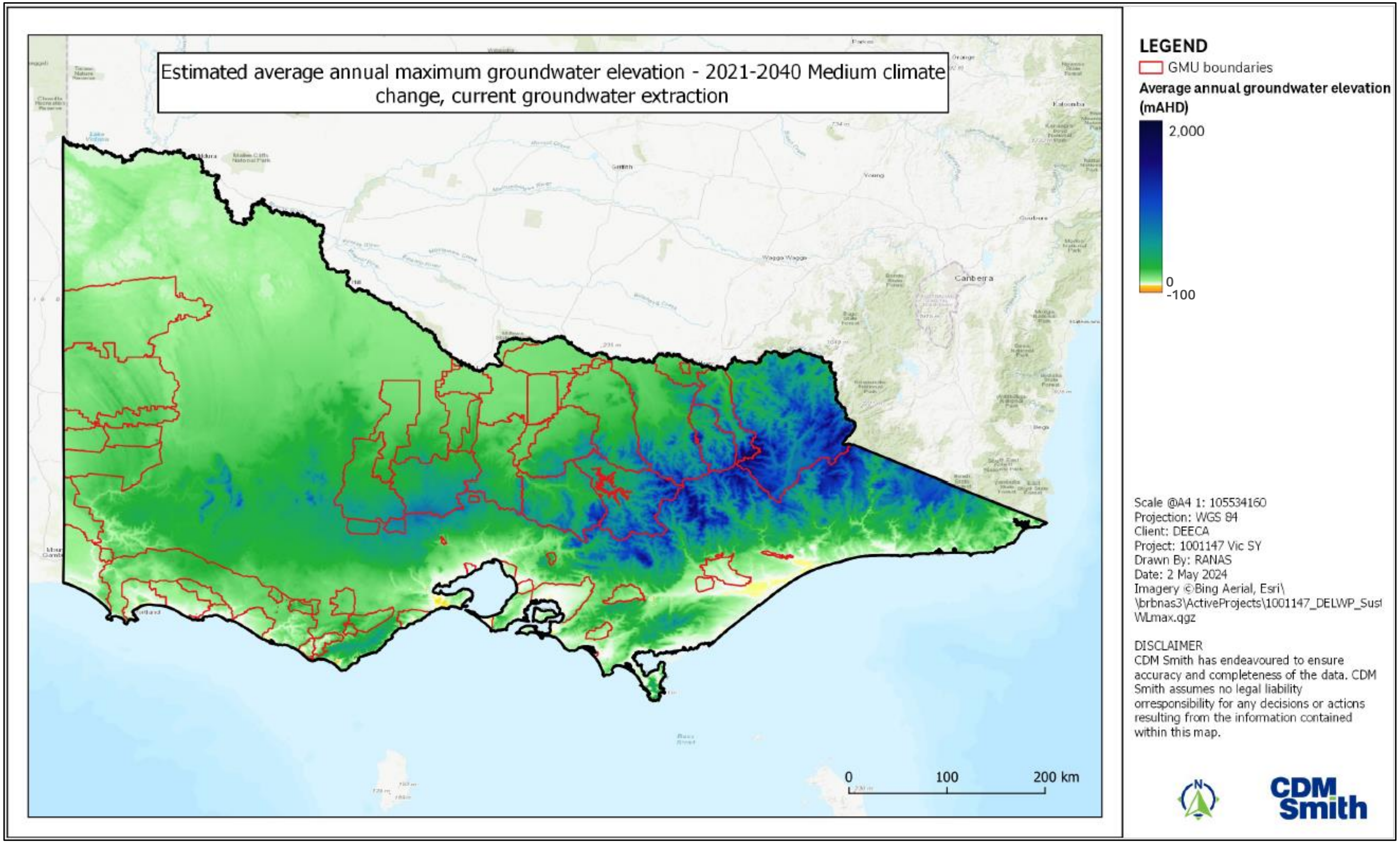
Results are presented for Victoria and by GMU as a range of mapped and tabulated datasets, as summarised in Table 5-1 below.

Results for average annual minimum groundwater elevation are reported for coastal areas as part of the seawater intrusion metrics assessment in Section 6.6 below.

Table 5-1 Summary of results for groundwater elevation

Result dataset		**Results available**				
		Map	**Digital dataset**	**Table of results**	Example map	Summary table
Average annual watertable elevation (mAHD)	Max. elevation	State-wide **Appendix S**	Gridded product	By GMU **Appendix V**	State-wide **Figure 5-1**	NA
	Min. elevation	NA	Gridded product	NA	NA	NA
Change in average total recharge from baseline (ML/yr)	Max. elevation	State-wide **Appendix T**	Gridded product	By GMU **Appendix V**	State-wide **Figure 5-2**	By GMU **Table 5-2**
	Min. elevation	NA	Gridded product	NA	NA	NA
Uncertainty in the mean of average total recharge (m)	Max. elevation	State-wide **Appendix U**	Gridded product	NA	State-wide **Figure 5-3**	NA
	Min. elevation	NA	Gridded product	NA	NA	NA
Relationship between watertable drawdown and use	Max. elevation	NA	NA	By GMU **Appendix W**	NA	NA
	Min. elevation	NA	NA	NA	NA	NA

Additional results are provided for SDL areas digitally. Additional groundwater elevation and drawdown related results for GMUs are presented in the metrics assessment (Section 6 below) where relevant to individual metrics.



Estimated average annual maximum groundwater elevation - 2021-2040 Medium climate change, current groundwater extraction

Scale @A4 1: 105534160
Projection: WGS 84
Client: DEECA
Project: 1001147 Vic SY
Drawn By: RANAS
Date: 2 May 2024
Imagery ©Bing Aerial, Esri\
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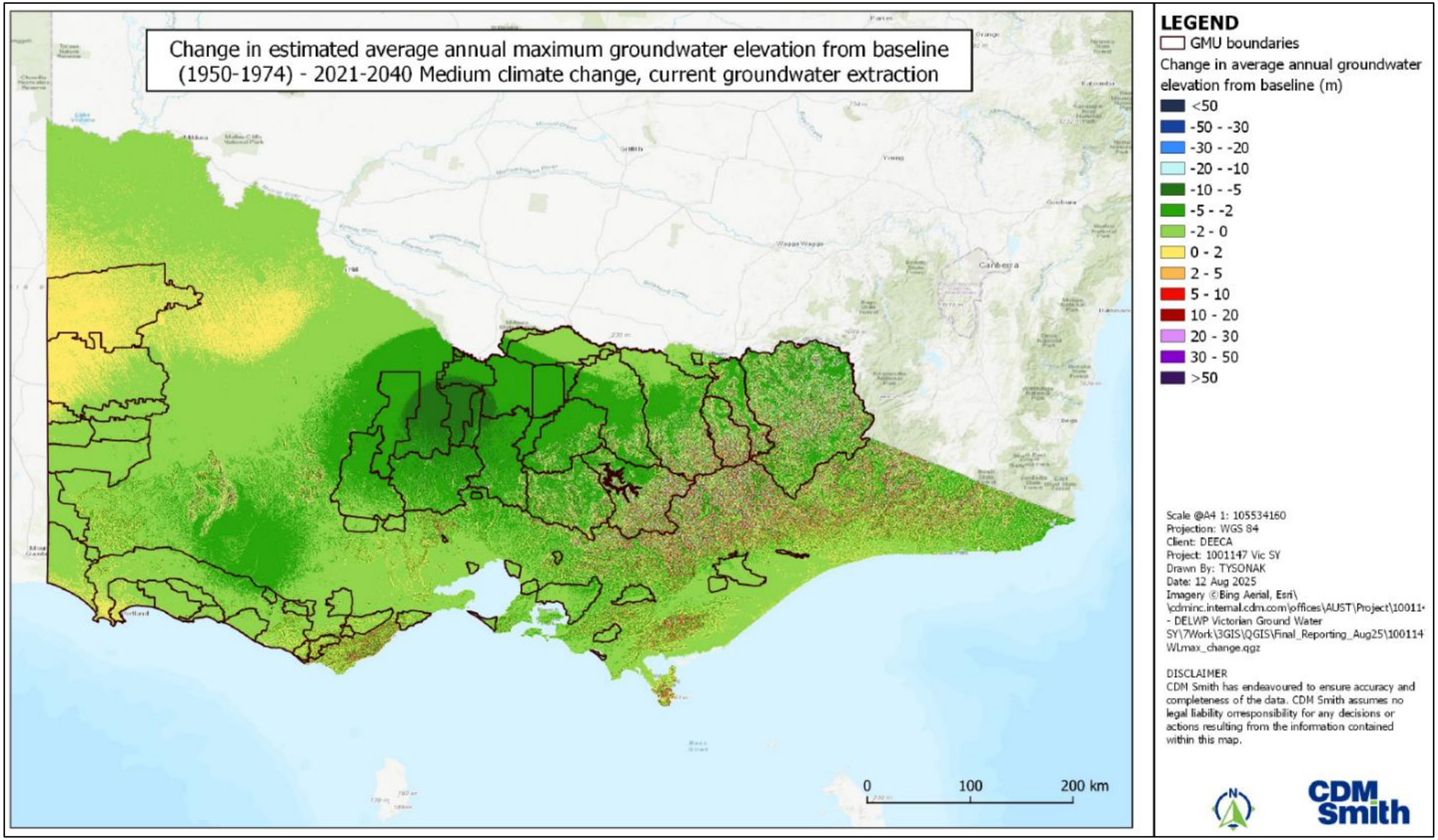
DISCLAIMER
CDM Smith has endeavoured to ensure accuracy and completeness of the data. CDM Smith assumes no legal liability orresponsibility for any decisions or actions resulting from the information contained within this map.

Figure 5-1 Estimated average annual maximum watertable elevation (mAHD) for period 2021-2040 under medium climate change and current use.



Scale @A4 1: 105534160
Projection: WGS 84
Client: DEECA
Project: 1001147 Vic SY
Drawn By: TYSONAK
Date: 12 Aug 2025
Imagery ©Bing Aerial, Esri\
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WLmax_change.qgz

DISCLAIMER
CDM Smith has endeavoured to ensure accuracy and completeness of the data. CDM Smith assumes no legal liability orresponsibility for any decisions or actions resulting from the information contained within this map.

Figure 5-2 Estimated change in average annual maximum watertable elevation (m) for period 2021-2040 under medium climate change and current use from baseline (1950-1974).

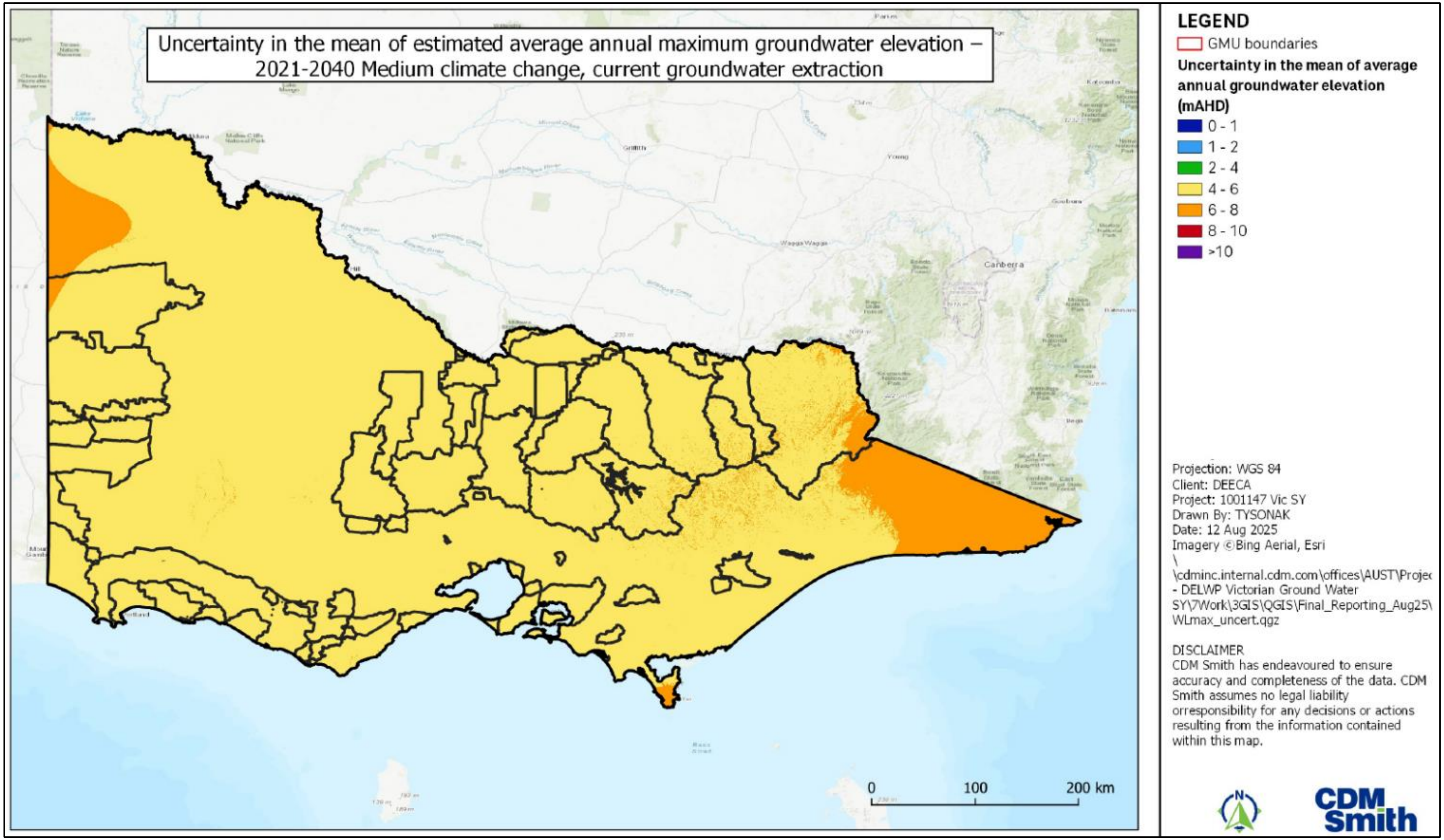


Figure 5-3 Uncertainty in the mean of estimated average annual maximum watertable elevation (m) under medium climate change and current use.

5.2 Discussion of results

One third of GMUs are expected to see an average drawdown in the watertable across the GMU from baseline (1950-1974) of more than two metres at 2021-2040 under medium climate change. This increases to around 40% of GMUs in at 2041-2065. These results are summarised in Table 5-2. These GMUs are located almost universally in the central, central north and highland areas of Victoria. Mapping of change of recharge into the future indicates that this change is highly variable in areas of high topographic relief, however, this is an artifact of the mapping process (for example, see Figure 5-2 above). Uncertainty in the recharge estimates is expected to highest in the highlands and far eastern parts of the state where bore data was most sparce.

An example of the relationship between groundwater use and drawdown in the watertable for the Warrion WSPA is included in Figure 5-4 below.

Table 5-2 Change in estimated average annual maximum groundwater elevation baseline (1950-1974) across each GMU, ranked by highest change, for future medium climate change scenario and current use

GMU	Ave. change in groundwater elevation (annual max.) for GMU from baseline (1950-1974) (m)	
	2021-2040 MCC - current use	2041-2065 MCC - current use
Lower Campaspe Valley WSPA	-5.08	-4.50
Mid Loddon GMA	-4.38	-3.72
Upper Murray GMA	-3.97	-3.62
West Goulburn GMA	-3.94	-3.46
Upper Ovens WSPA	-3.70	-3.48
Central Victorian Mineral Springs GMA	-3.66	-2.80
Eildon GMA	-3.60	-3.51
Mid Goulburn GMA	-3.52	-3.19
Strathbogie GMA	-3.42	-3.09
Kiewa GMA	-3.38	-3.19
Upper Goulburn GMA	-3.29	-2.94
Shepparton Irrigation GMA	-3.13	-2.98
Lancefield GMA	-2.89	-1.93
Lower Ovens GMA	-2.84	-2.73
Broken GMA	-2.69	-2.54
Loddon Highlands WSPA	-2.59	-2.20
Wandin Yallock GMA	-2.25	-2.01
Glenormiston GMA	-1.94	-1.46
Koo Wee Rup WSPA	-1.93	-1.89
Barnawartha GMA	-1.80	-2.07
Moe GMA	-1.70	-1.76

GMU	Ave. change in groundwater elevation (annual max.) for GMU from baseline (1950-1974) (m)	
	2021-2040 MCC - current use	2041-2065 MCC - current use
Frankston GMA	-1.56	-1.44
Nepean GMA	-1.49	-1.84
Leongatha GMA	-1.41	-1.54
Colongulac GMA	-1.38	-1.51
Moorabbin GMA	-1.37	-1.17
Bungaree GMA	-1.34	-1.00
Cardigan GMA	-1.33	-0.88
Tarwin GMA	-1.30	-1.38
Denison GMA	-1.29	-1.31
Wa De Lock GMA	-1.21	-1.22
Jan Juc GMA	-1.05	-2.11
Deutgam WSPA	-0.96	-0.99
Nullawarre WSPA	-0.95	-1.19
Southern Zone (West Wimmera)	-0.95	-0.88
Gymbowen Zone (West Wimmera)	-0.95	-1.00
Hawkesdale GMA	-0.89	-0.63
South West Limestone GMA	-0.89	-0.78
Warrion WSPA	-0.89	-1.18
Gellibrand GMA	-0.88	-2.18
Merrimu GMA	-0.84	-0.79
Gerangamete GMA	-0.79	-1.80
Yangery WSPA	-0.78	-0.72
Newlingrook GMA	-0.61	-2.20
Neuarpur Zone (West Wimmera)	-0.43	-0.51
Glenelg WSPA	-0.42	-0.26
Little Desert Zone (West Wimmera)	-0.37	-0.58
Wy Yung GMA	-0.35	-0.30
Heywood GMA	-0.20	-0.13
Northern Zone (West Wimmera)	0.05	-0.41
Big Desert Zone (West Wimmera)	0.25	-0.25

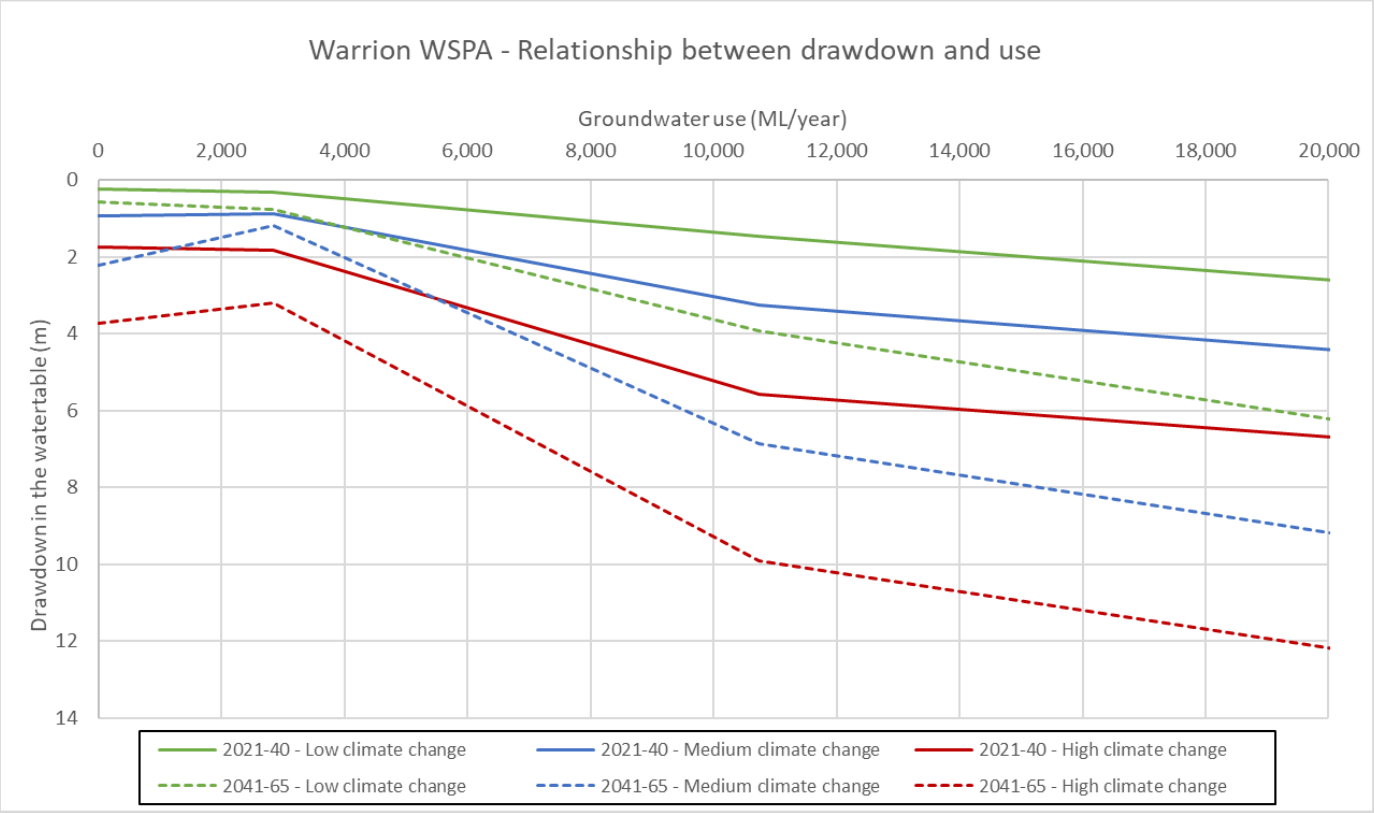


Figure 5-4 Relationship between use and estimated average maximum drawdown for the Warrion GMA.

Section 6 Assessment of metrics

6.1 Structure of assessment

The assessment of sustainable yield metrics was considered for each unconfined and semi-confined GMU for each metric element in Table 6-1. Detail of the metrics for consideration by this project are described in Table 1-1 above. Most of the metrics results datasets were also produced for SDL boundaries.

Table 6-1 Elements of metric assessment reported by metric (reported by GMU)

Metric	Presence/ extent	Metrics elements				
		SY Synthesis data table	Water level results			
			Change in water level by GMU	Change in water level at individual receptors	Proportion of drawdown by metric level	Use-drawdown relationships
Consumptive use	Maps of receptors **Appendix X**	Drawdown at Ave and PCV use Use at metrics levels of drawdown (with % of recharge) **Appendix Y**	Table Average maximum **Appendix Z**	Digital output	Plots by GMU **Appendix BB** Plots by Aquifer System **Appendix CC**	Use (GMU) – drawdown **Appendix AA**
Wetland GDEs	Maps of receptors **Appendix DD**	Drawdown at Ave and PCV use Use at metrics levels of drawdown (with % of recharge) **Appendix EE**	Average maximum **Appendix FF**	Digital output	NA	Use (GMU) – drawdown **Appendix GG**
Terrestrial GDEs	Maps of receptors **Appendix HH**	Drawdown at Ave and PCV use Use at metrics levels of drawdown (with % of recharge) **Appendix II**	Average maximum **Appendix JJ**	Digital output	NA	Use (GMU) – drawdown **Appendix KK**
Waterway GDEs	Maps of receptors/ gauges **Appendix LL**	Drawdown at Ave and PCV use Use at metrics levels of drawdown (with % of recharge) Stream gauge results (BFI, MAF, Q90) **Appendix MM**	Average maximum **Appendix NN**	Digital output	NA	Use (GMU) – drawdown **Appendix OO**
Seawater intrusion	Maps of areas **Appendix PP**	Drawdown at Ave and PCV use Use at metrics level of watertable elevation (with % of recharge and % area impacted) **Appendix QQ**	Average minimum (change and elevation) % area below limit **Appendix RR**	NA	NA	Use (GMU) – elevation **Appendix SS**

6.2 Consumptive use

6.2.1 Summary of results

The metrics assessment for consumptive users (licenced watertable extraction bores) is presented below. Groundwater levels reported for this metric are an annual maximum ('recovered level'). Change in groundwater elevation was calculated as an average of change all bore locations (as opposed an average across the whole GMU), while groundwater use and recharge are for the whole GMU. The metrics levels for drawdown in the watertable for consumptive users are 1, 2 and 5 metres.

Consumptive users are mapped within each GMU in Appendix X. The average use and current bores are summarised for each GMU in Table 6-2. A wide range of use patterns can be observed between GMUs. Mid Loddon GMA and Lower Campaspe Valley WSPA have on the highest consumptive bores (by average annual use).

Table 6-2 Statistics on consumptive users present in GMUs.

GMU	Number of bores*	Total current extraction (ML/yr)^	Mean average current extraction per bore (ML/yr)^
Barnawartha GMA	7	7	1
Big Desert Zone (West Wimmera)	0	0	0
Broken GMA	97	654	7
Bungaree GMA	184	2,037	11
Cardigan GMA	28	537	19
Central Victorian Mineral Springs GMA	145	1,369	9
Colongulac GMA	60	484	8
Denison GMA	171	5,580	33
Deutgam WSPA	212	708	3
Eildon GMA	27	164	6
Frankston GMA	32	56	2
Gellibrand GMA	0	0	0
Gerangamete GMA	1	0.2	0.2
Glenelg WSPA	253	6,068	24
Glenormiston GMA	40	1,253	31
Gymbowen Zone (West Wimmera)	3	37	12
Hawkesdale GMA	185	4,790	26
Heywood GMA	144	2,320	16
Jan Juc GMA	8	370	46
Kiewa GMA	114	666	6
Koo Wee Rup WSPA	445	3,483	8
Lancefield GMA	21	206	10
Leongatha GMA	35	121	3
Little Desert Zone (West Wimmera)	0	0	0
Loddon Highlands WSPA	232	4,954	21
Lower Campaspe Valley WSPA	347	34,733	100
Lower Ovens GMA	333	4,933	15

GMU	Number of bores*	Total current extraction (ML/yr)^	Mean average current extraction per bore (ML/yr)^
Merrimu GMA	12	74	6
Mid Goulburn GMA	230	3,633	16
Mid Loddon GMA	133	17,771	134
Moe GMA	103	782	8
Moorabbin GMA	35	91	3
Nepean GMA	99	2,103	21
Neuarpur Zone (West Wimmera)	1	25	25
Newlingrook GMA	6	29	5
Northern Zone (West Wimmera)	18	1,369	76
Nullawarre WSPA	384	11,103	29
Shepparton Irrigation GMA	1,646	55,314	34
South West Limestone GMA	1,727	30,801	18
Southern Zone (West Wimmera)	19	561	30
Strathbogie GMA	62	412	7
Tarwin GMA	3	11	4
Upper Goulburn GMA	130	715	5
Upper Murray GMA	86	510	6
Upper Ovens WSPA	125	978	8
Wa De Lock GMA	322	6,818	21
Wandin Yallock GMA	226	553	2
Warrion WSPA	187	2,847	15
West Goulburn GMA	392	3,509	9
Wy Yung GMA	89	680	8
Yangery WSPA	288	3,425	12

Notes: * Effective depth of bore mapped in unconfined or semi-confined aquifers.

^ Current average use (2015-2020) for licensed bores.

Table 6-3 below presents a summary of the proportion of consumptive users impacted by more than two metres of drawdown in the average annual maximum watertable under medium climate change at 2021-2040, ranked by highest proportion of impact. Lower Campaspe Valley WSPA, Mid Goulburn GMA and Mid Loddon GMA are all estimated to have 100% of groundwater extracted bores present impacted by more than two metres drawdown, with another 10 GMUs with estimated impacts at above 70% of bores with greater than two metres drawdown. These GMUs are uniformly located in north and central Victoria. The lowest impacted GMUs are all coastal and Wimmera GMUs.

The relationship between average drawdown at consumptive users and groundwater use (as the coefficient (*M*) of the linear equation of *change in groundwater elevation = M*use*) is included Appendix AA by GMU.

Appendix Z presents the average, minimum and maximum change in groundwater elevations as an average of all consumptive users within each GMU.

Appendix BB and Appendix CC present plots by GMU, and by GMU and aquifer system, of the data summarised in this table, of proportion of individual consumptive users impacted by metrics level drawdown for all reporting scenarios. Table 6-3 below gives an example of these plots for the Broken and Wy Yung GMAs, showing the differential impact of watertable drawdown on consumptive users in those areas. Figure 6-2 and Figure 6-3 give an example of the aquifer system differentiated analysis of this data for the Broken GMA, presenting plots for consumptive users in the Highland, Sedimentary Plain, Sedimentary Valley and Sedimentary Upland Valley aquifer systems.

Table 6-3 Proportion of consumptive users impacted by levels of drawdown, ranked by highest impacted above 2m drawdown at 2021-2040 (medium climate change, current use).

GMU	No bores	Proportion of consumptive users impacted by levels of drawdown (DD) for 2021-40 medium climate change, current use		
		DD <1 m	DD 1-2 m	DD >2m
Lower Campaspe Valley WSPA	347	0%	0%	100%
Mid Goulburn GMA	230	0%	0%	100%
Mid Loddon GMA	133	0%	0%	100%
West Goulburn GMA	392	0%	2%	98%
Lancefield GMA	21	0%	10%	90%
Eildon GMA	27	7%	4%	89%
Strathbogie GMA	62	3%	8%	89%
Central Victorian Mineral Springs GMA	145	5%	11%	84%
Upper Murray GMA	86	13%	10%	77%
Upper Goulburn GMA	130	9%	15%	75%
Lower Ovens GMA	333	12%	14%	74%
Kiewa GMA	114	12%	16%	72%
Broken GMA	97	10%	19%	71%
Wandin Yallock GMA	226	17%	13%	69%
Upper Ovens WSPA	125	27%	18%	55%
Shepparton Irrigation GMA	1,646	15%	35%	50%
Barnawartha GMA	7	0%	57%	43%
Koo Wee Rup WSPA	445	0%	68%	31%
Loddon Highlands WSPA	232	9%	61%	30%
Glenormiston GMA	40	0%	70%	30%
Moe GMA	103	12%	66%	22%
Leongatha GMA	35	23%	60%	17%
Frankston GMA	32	9%	78%	13%
Nepean GMA	99	24%	66%	10%
Bungaree GMA	184	25%	66%	9%
South West Limestone GMA	1,727	65%	30%	6%
Nullawarre WSPA	384	67%	27%	5%
Yangery WSPA	288	70%	25%	5%
Warrion WSPA	187	68%	31%	1%
Heywood GMA	144	97%	2%	1%
Wa De Lock GMA	322	19%	80%	1%
Hawkesdale GMA	185	79%	21%	1%

GMU	No bores	Proportion of consumptive users impacted by levels of drawdown (DD) for 2021-40 medium climate change, current use		
		DD <1 m	DD 1-2 m	DD >2m
Cardigan GMA	28	4%	96%	0%
Colongulac GMA	60	37%	63%	0%
Denison GMA	171	0%	100%	0%
Cardigan GMA	28	4%	96%	0%
Moorabbin GMA	35	14%	86%	0%
Gymbowen Zone (West Wimmera)	3	33%	67%	0%
Newlingrook GMA	6	33%	67%	0%
Tarwin GMA	3	33%	67%	0%
Colongulac GMA	60	37%	63%	0%
Merrimu GMA	12	42%	58%	0%
Deutgam WSPA	212	69%	31%	0%
Jan Juc GMA	8	75%	25%	0%
Wy Yung GMA	89	82%	18%	0%
Glenelg WSPA	253	99%	1%	0%
Gerangamete GMA	1	100%	0%	0%
Neuarpur Zone (West Wimmera)	1	100%	0%	0%
Big Desert Zone (West Wimmera)	No bores present			
Gellibrand GMA	No bores present			
Little Desert Zone (West Wimmera)	No bores present			

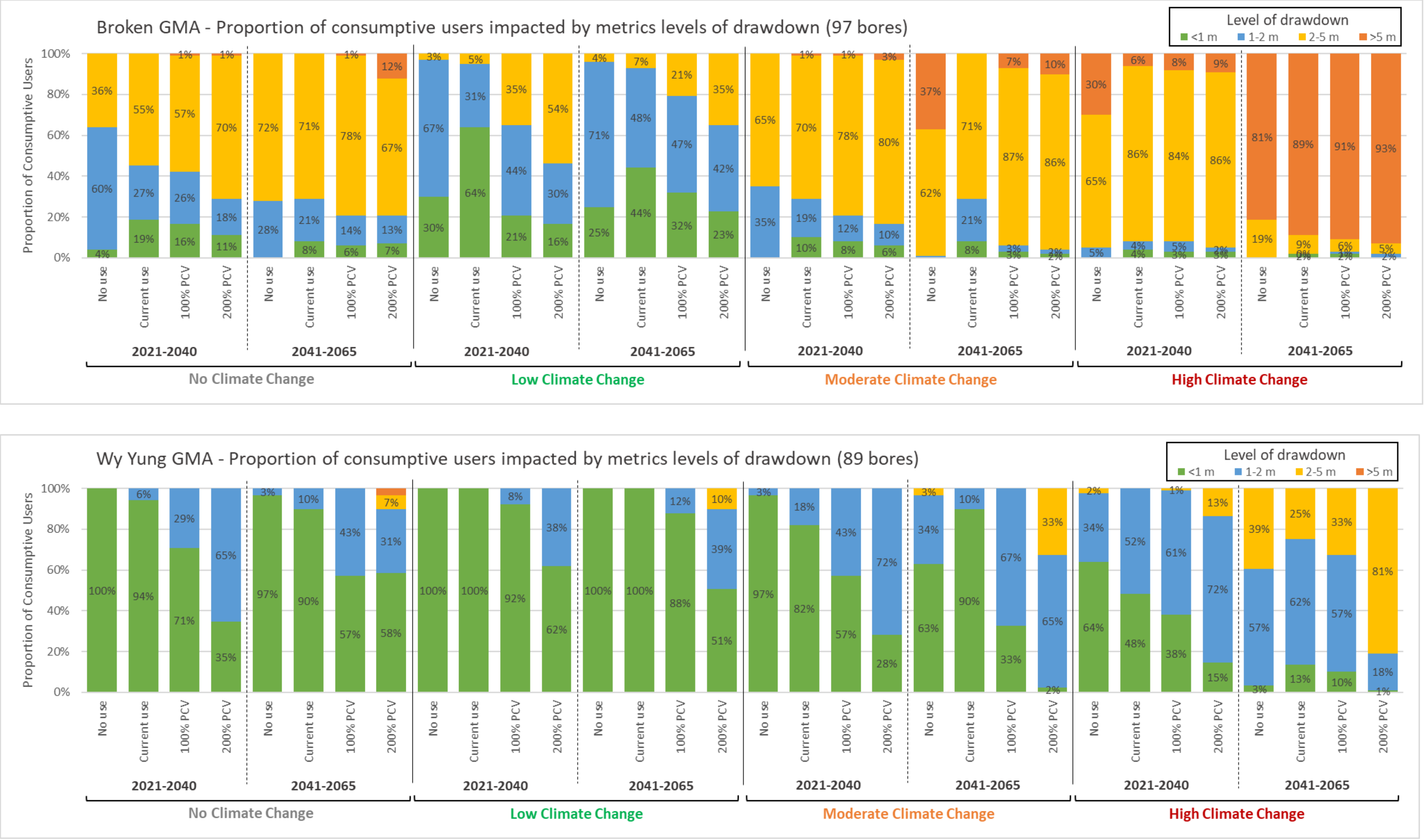
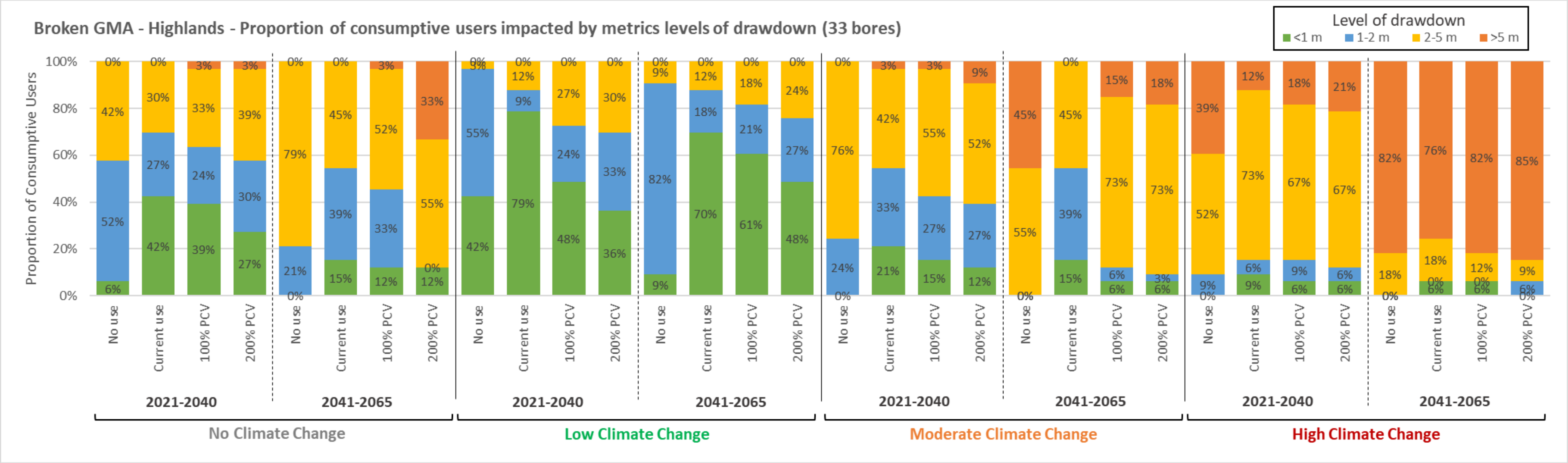


Figure 6-1 Proportion of active groundwater bores which are impacted to metrics levels of drawdown under use and climate scenarios: TOP – Broken GMA, BOTTOM - Wy Yung GMA



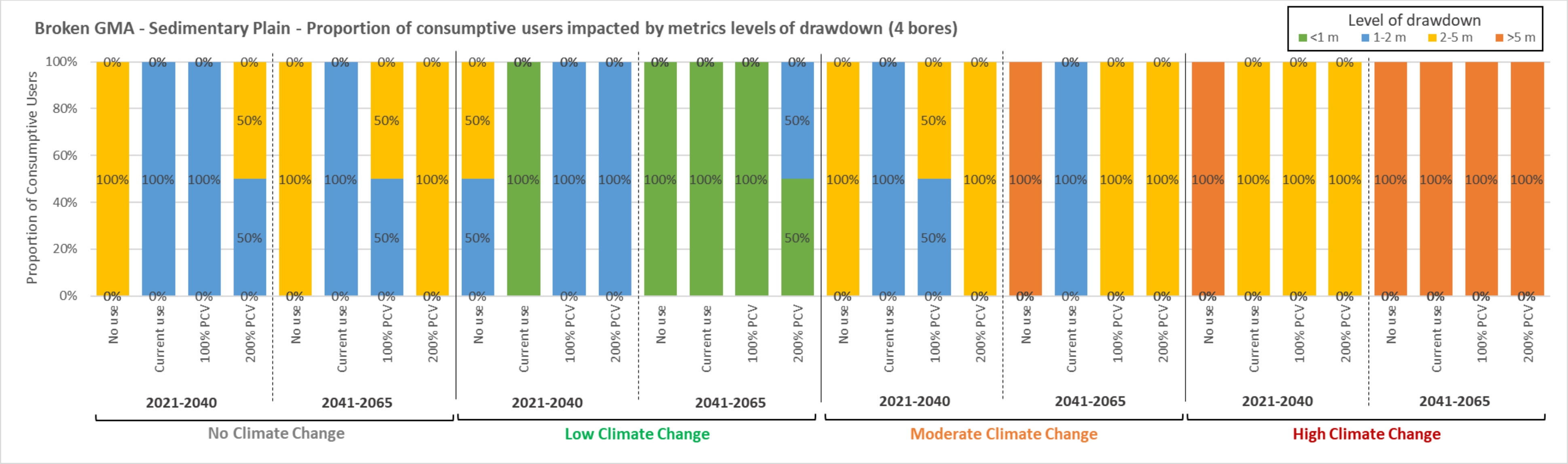


Figure 6-2 Proportion of active groundwater bores which are impacted to metrics levels of drawdown under use and climate scenarios by aquifer systems for the Broken GMA: TOP - Highlands, BOTTOM – Sedimentary Plains.

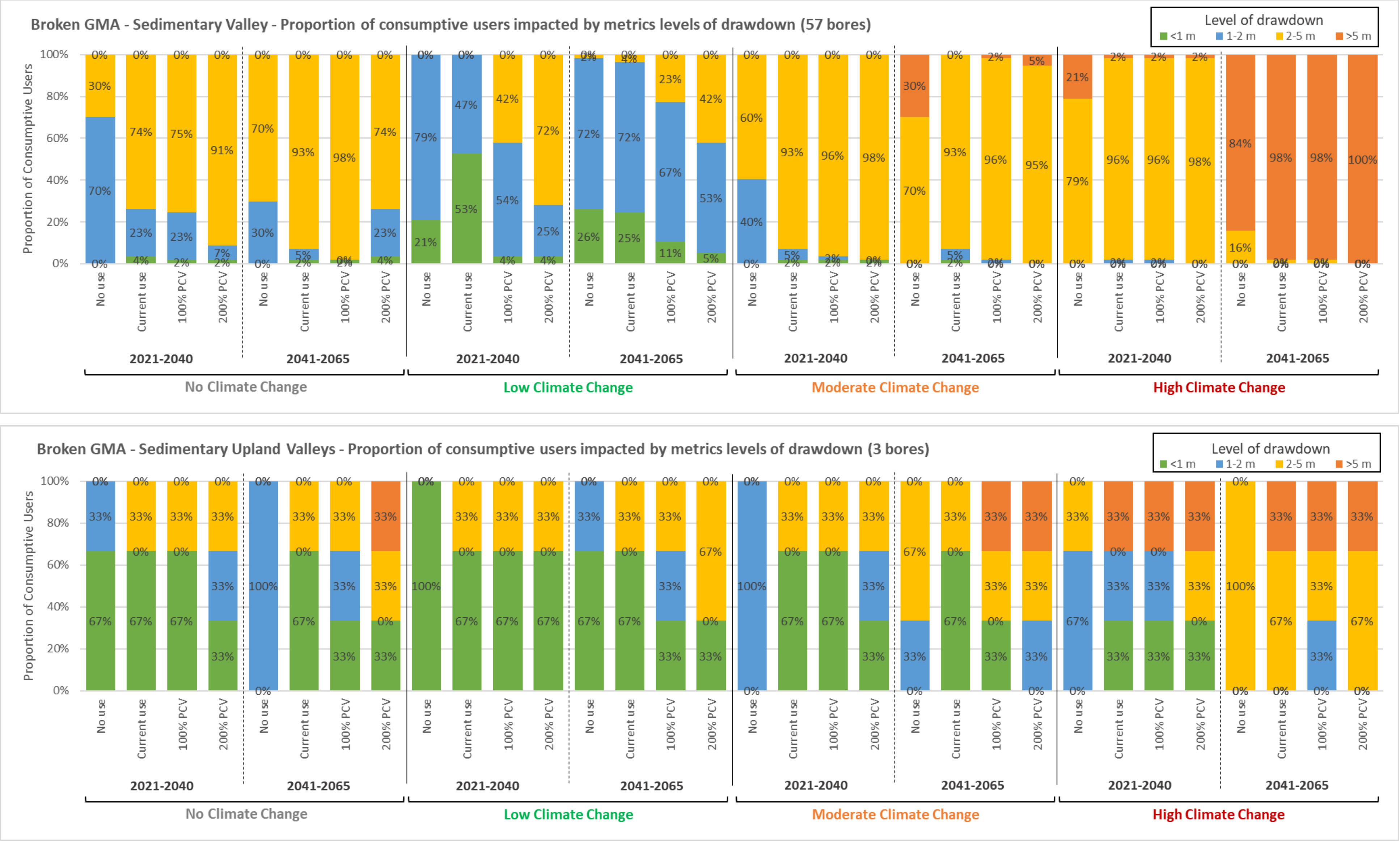


Figure 6-3 Proportion of active groundwater bores which are impacted to metrics levels of drawdown under use and climate scenarios by aquifer systems for the Broken GMA: TOP – Sedimentary Valleys, BOTTOM – Sedimentary Upland Valleys.

6.2.2 Synthesis information

The synthesis information for consumptive users is presented in Appendix Y by GMU. These tables contain:

- Summary information on the GMU (as provided by DEECA [NB Please confirm that CDM Smith will receive this data]);
- Average drawdown of maximum annual elevation of the watertable from baseline (1950-1974) for climate scenarios, and current and PCV rate groundwater extraction scenarios for 2021-2040 and 2041-2065;
- Volume of groundwater extraction under climate scenarios to achieve an average magnitude of drawdown (for average maximum annual watertable elevation) across the GMU, for 1, 2 and 5 metres of drawdown; and
- The proportions of recharge to which the use volumes above correspond.

Results reported as '-' indicate that drawdown in the watertable exceeds the drawdown level with no extraction (from a product of historic take and climate impacts to water level).

An example of the consumptive users synthesis table for Central Victorian Mineral Springs GMA is presented in Table 6-4 below.

Table 6-4 Example synthesis information table for consumptive users Central Victorian Mineral Springs GMA.

	GMU					CENTRAL VICTORIAN MINERAL SPRINGS GMA
Assessment area	Representative Suite/bore					TBC
	Aquifer					TBC
	Water system depth boundary (m below natural surface)					TBC
Catchment	Permissible Consumptive Volume (ML/yr)					TBC
	Licensed Entitlement (ML/yr)					TBC
	Licensed avg use (ML/yr)					TBC
Consumptive use metric	Consumptive users (bores)	Avg Use 1,369 ML/yr	2021-2040	Drawdown from baseline (m)	No CC	2.2
					MCC (LCC - HCC)	3 (0.6 to 3.9)
			2041-2065	Drawdown from baseline (m)	No CC	2.2
					MCC (LCC - HCC)	2.2 (0.9 to 6.6)
		PCV use 4,092 ML/yr	2021-2040	Drawdown from baseline (m)	No CC	4.4
					MCC (LCC - HCC)	5.9 (3.2 to 7.9)
			2041-2065	Drawdown from baseline (m)	No CC	4.1
					MCC (LCC - HCC)	7.6 (1.2 to 13)
		Use at 1 metre drawdown	2021-2040	Volume (ML/yr)	No CC	1,397
					MCC (LCC - HCC)	1,052 (1,938 to 809)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	0.21% (0.36% to 0.25%)
			2041-2065	Volume (ML/yr)	No CC	1,592
					MCC (LCC - HCC)	832 (3,998 to 493)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	0.24% (0.92% to 0.30%)
		Use at 2 metre drawdown	2021-2040	Volume (ML/yr)	No CC	2,794
					MCC (LCC - HCC)	2,104 (3,877 to 1,619)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	0.42% (0.71% to 0.50%)

			2041-2065	Volume (ML/yr)	No CC	3,184
					MCC (LCC - HCC)	1,663 (7,996 to 986)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	0.48% (1.84% to 0.60%)
		Use at 5 metre drawdown	2021-2040	Volume (ML/yr)	No CC	6,986
					MCC (LCC - HCC)	5,259 (9,691 to 4,046)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	1.05% (1.78% to 1.26%)
			2041-2065	Volume (ML/yr)	No CC	7,959
					MCC (LCC - HCC)	4,158 (19,989 to 2,465)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	1.20% (4.60% to 1.51%)

6.3 Environmental – High value wetland GDEs

6.3.1 Summary of results

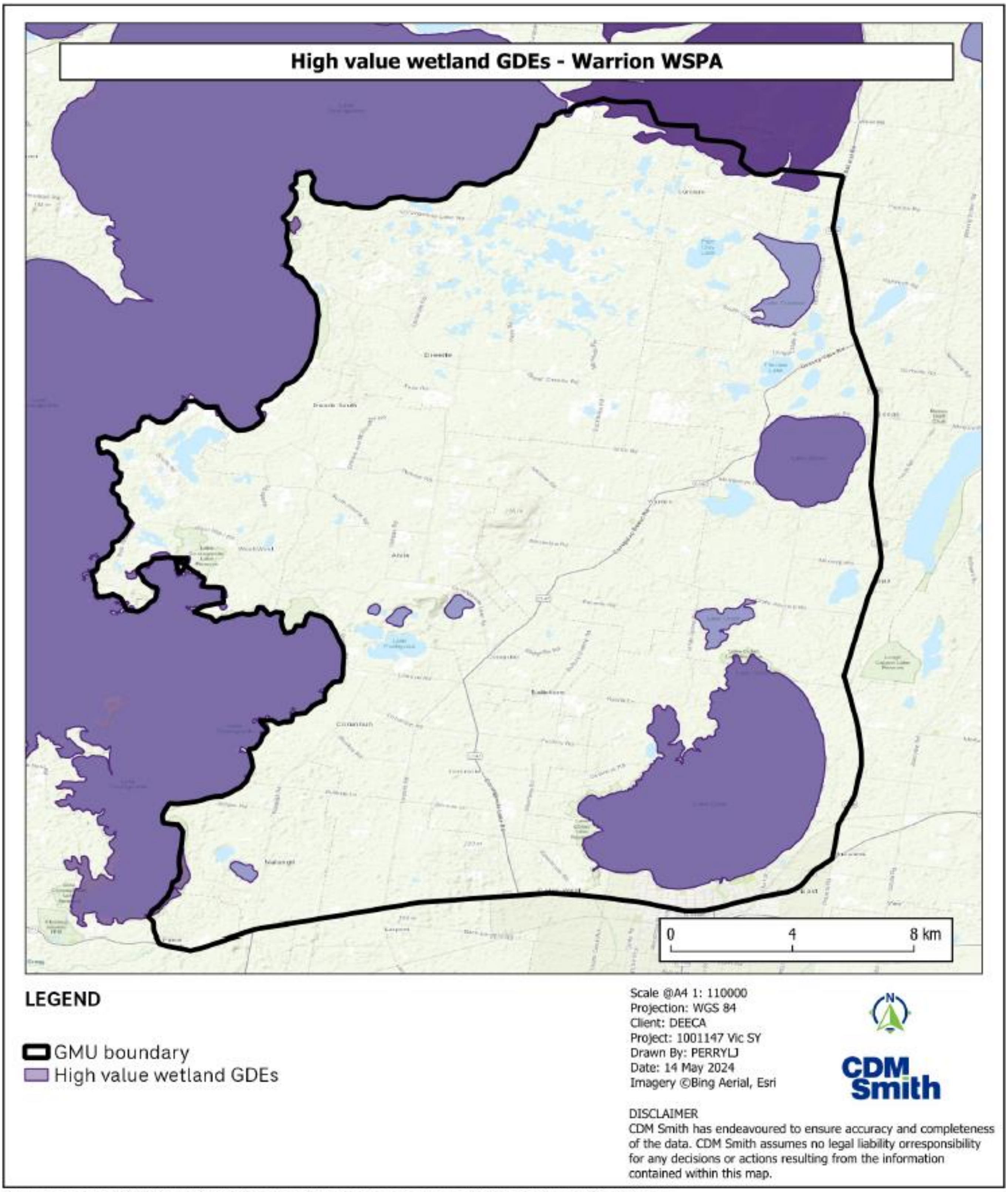
The metrics assessment for high value wetland GDEs is presented below. This metrics value includes springs and wetlands reliant upon or connected to groundwater. Groundwater levels reported for this metric are an annual maximum ('recovered level'). Change in groundwater elevation was calculated as an average of change under all mapped areas of wetland GDEs (as opposed an average across the whole GMU), while groundwater use and recharge are for the whole GMU. The metrics levels for drawdown in the watertable for wetland GDEs are 0.1, 1 and 2 metres.

High value wetland GDEs are mapped across 30 GMUs in Appendix DD, with an example for Warrion WSPA included in Figure 6-4 below.

Table 6-5 below presents a summary of the change in the average annual maximum groundwater elevation at the location of high value wetland GDEs under medium climate change, for current rates of extraction, at 2021-2040 and 2041-2065, ranked by most drawdown. Of the 30 GMUs with mapped high value wetland GDEs, six show an estimated average drawdown at wetland GDEs at 2021-2040 of more than two metres (Lower Campaspe Valley WSPA, Mid Loddon GMA, Mid Goulburn GMA, Shepparton Irrigation GMA, West Goulburn GMA and Loddon Highlands WSPA). Again, these areas are uniformly located in north and central Victoria.

The relationship between average drawdown at mapped high value wetland GDEs and total GMU groundwater use (as the coefficient (*M*) of the linear equation of *change in groundwater elevation = M*use*) is included Appendix GG by GMU.

Appendix FF presents the average change in groundwater elevations as an average of all mapped high value wetland GDEs within each GMU.



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Projection: WGS 84
Client: DEECA
Project: 1001147 Vic SY
Drawn By: PERRYLJ
Date: 14 May 2024
Imagery ©Bing Aerial, Esri

DISCLAIMER
CDM Smith has endeavoured to ensure accuracy and completeness of the data. CDM Smith assumes no legal liability orresponsibility for any decisions or actions resulting from the information contained within this map.

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Figure 6-4 High value wetland GDEs mapped in the Warrion WSPA.

Table 6-5 Change in estimated average annual maximum groundwater elevation at wetland GDEs from baseline (1950-1974), ranked by highest change, for future medium climate change scenario and current use (for GMUs with wetland GDEs present)

GMU	Ave. change in groundwater elevation (annual max.) at wetland GDEs from baseline (1950-1974) (m)	
	2021-2040 MCC - current use	2041-2065 MCC - current use
Lower Campaspe Valley WSPA	-4.0	-3.7
Mid Loddon GMA	-4.0	-3.3
Mid Goulburn GMA	-3.5	-3.3
Shepparton Irrigation GMA	-2.7	-2.6
West Goulburn GMA	-2.7	-2.6
Loddon Highlands WSPA	-2.4	-1.9
Kiewa GMA	-2.0	-1.0
Upper Murray GMA	-1.9	-1.1
Broken GMA	-1.7	-1.6
Koo Wee Rup WSPA	-1.7	-1.6
Frankston GMA	-1.4	-1.4
Nepean GMA	-1.3	-1.6
Lower Ovens GMA	-1.0	-1.2
Deutgam WSPA	-0.9	-0.9
Gymbowen Zone (West Wimmera)	-0.9	-0.9
Tarwin GMA	-0.8	-1.0
Wa De Lock GMA	-0.7	-0.7
Warrion WSPA	-0.7	-1.1
Southern Zone (West Wimmera)	-0.6	-0.6
Upper Goulburn GMA	-0.5	0.1
Colongulac GMA	-0.4	-0.5
Neuarpur Zone (West Wimmera)	-0.3	-0.3
Glenelg WSPA	-0.3	-0.1
South West Limestone GMA	-0.1	0.01
Northern Zone (West Wimmera)	-0.1	-0.2
Wy Yung GMA	-0.04	0.02
Little Desert Zone (West Wimmera)	0.05	-0.1
Upper Ovens WSPA	0.1	0.9
Wandin Yallock GMA	0.1	0.3
Yangery WSPA	1.1	1.0

6.3.2 Synthesis information

The synthesis information for high value wetland GDEs is presented in Appendix EE by GMU. These tables contain:

- Summary information on the GMU (as provided by DEECA);
- Average drawdown of maximum annual elevation of the watertable from baseline (1950-1974) for climate scenarios, and current and PCV rate groundwater extraction scenarios for 2021-2040 and 2041-2065;
- Volume of groundwater extraction under climate scenarios to achieve an average magnitude of drawdown (for average maximum annual watertable elevation) across the GMU, for 0.1, 1 and 2 metres of drawdown; and
- The proportions of recharge to which the use volumes above correspond.

Results reported as '-' indicate that drawdown in the watertable exceeds the drawdown level with no extraction (from a product of historic take and climate impacts to water level).

An example of the high value wetland GDEs synthesis table for Koo Wee Rup GMA is presented in Table 6-6 below.

Table 6-6 Example synthesis information table for high value wetland GDEs for the Koo Wee Rup GMA.

	GMU					**KOO WEE RUP WSPA**
Assessment area	Representative Suite/bore					TBC
	Aquifer					TBC
	Water system depth boundary (m below natural surface)					TBC
Catchment	Permissible Consumptive Volume (ML/yr)					TBC
	Licensed Entitlement (ML/yr)					TBC
	Licensed avg use (ML/yr)					TBC
Environmental metric	**High Value Wetland GDEs**	Avg Use 3,483 ML/yr	2021 - 2040	Drawdown from baseline (m)	No CC	1.2
					MCC (LCC - HCC)	2 (0.5 to 2.9)
			2041 - 2065	Drawdown from baseline (m)	No CC	1.9
					MCC (LCC - HCC)	1.9 (1.1 to 4.7)
		PCV use 11,497 ML/yr	2021 - 2040	Drawdown from baseline (m)	No CC	2.2
					MCC (LCC - HCC)	3.3 (1.3 to 4.7)
			2041 - 2065	Drawdown from baseline (m)	No CC	3.1
					MCC (LCC - HCC)	4.9 (1.7 to 7.5)
		Use at 1 metre drawdown	2021 - 2040	Volume (ML/yr)	No CC	6,737
					MCC (LCC - HCC)	4,892 (10,172 to 3,552)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	1.6% (2.7% to 1.4%)
			2041 - 2065	Volume (ML/yr)	No CC	4,605
					MCC (LCC - HCC)	3,372 (7,614 to 2,235)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	1.3% (2.2% to 1.3%)
		Use at 2 metre drawdown	2021 - 2040	Volume (ML/yr)	No CC	13,474
					MCC (LCC - HCC)	9,784 (20,345 to 7,105)
					No CC	NA

				Proportion of recharge (%)	MCC (LCC - HCC)	3.1% (5.5% to 2.7%)
			2041 - 2065	Volume (ML/yr)	No CC	9,210
					MCC (LCC - HCC)	6,744 (15,228 to 4,470)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	2.5% (4.5% to 2.6%)
		Use at 5 metre drawdown	2021 - 2040	Volume (ML/yr)	No CC	33,684
					MCC (LCC - HCC)	24,461 (50,862 to 17,762)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	7.8% (13.7% to 6.8%)
			2041 - 2065	Volume (ML/yr)	No CC	23,025
					MCC (LCC - HCC)	16,861 (38,069 to 11,174)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	6.3% (11.2% to 6.5%)

6.4 Environmental – Terrestrial GDEs

6.4.1 Summary of results

The metrics assessment for high value terrestrial GDEs is presented below. This metrics value includes terrestrial vegetation upon or connected to groundwater. Groundwater levels reported for this metric are an annual maximum (‘recovered level’). Change in groundwater elevation was calculated as an average of change under all mapped areas of wetland GDEs (as opposed an average across the whole GMU), while groundwater use and recharge are for the whole GMU. The metrics levels for drawdown in the watertable for terrestrial GDEs are 0.1, 1 and 2 metres.

High value terrestrial GDEs are mapped across all reporting GMUs in Appendix HH, with an example for Mid Goulburn GMA included in Figure 6-4 below.

Table 6-5 below presents a summary of the change in the average annual maximum groundwater elevation at the location of high value terrestrial GDEs under medium climate change at 2021-2040 and 2041-2065, ranked by most drawdown. 11 GMUs show an estimated average drawdown at terrestrial GDEs at 2021-2040 of more than two metres. Except for the Glenormiston GMA, these areas are uniformly located in north and central Victoria.

The relationship between average drawdown at mapped high value terrestrial GDEs and total GMU groundwater use (as the coefficient (*M*) of the linear equation of *change in groundwater elevation = M*use*) is included Appendix KK by GMU.

Appendix JJ presents the average change in groundwater elevations as an average of all mapped high value terrestrial GDEs within each GMU.

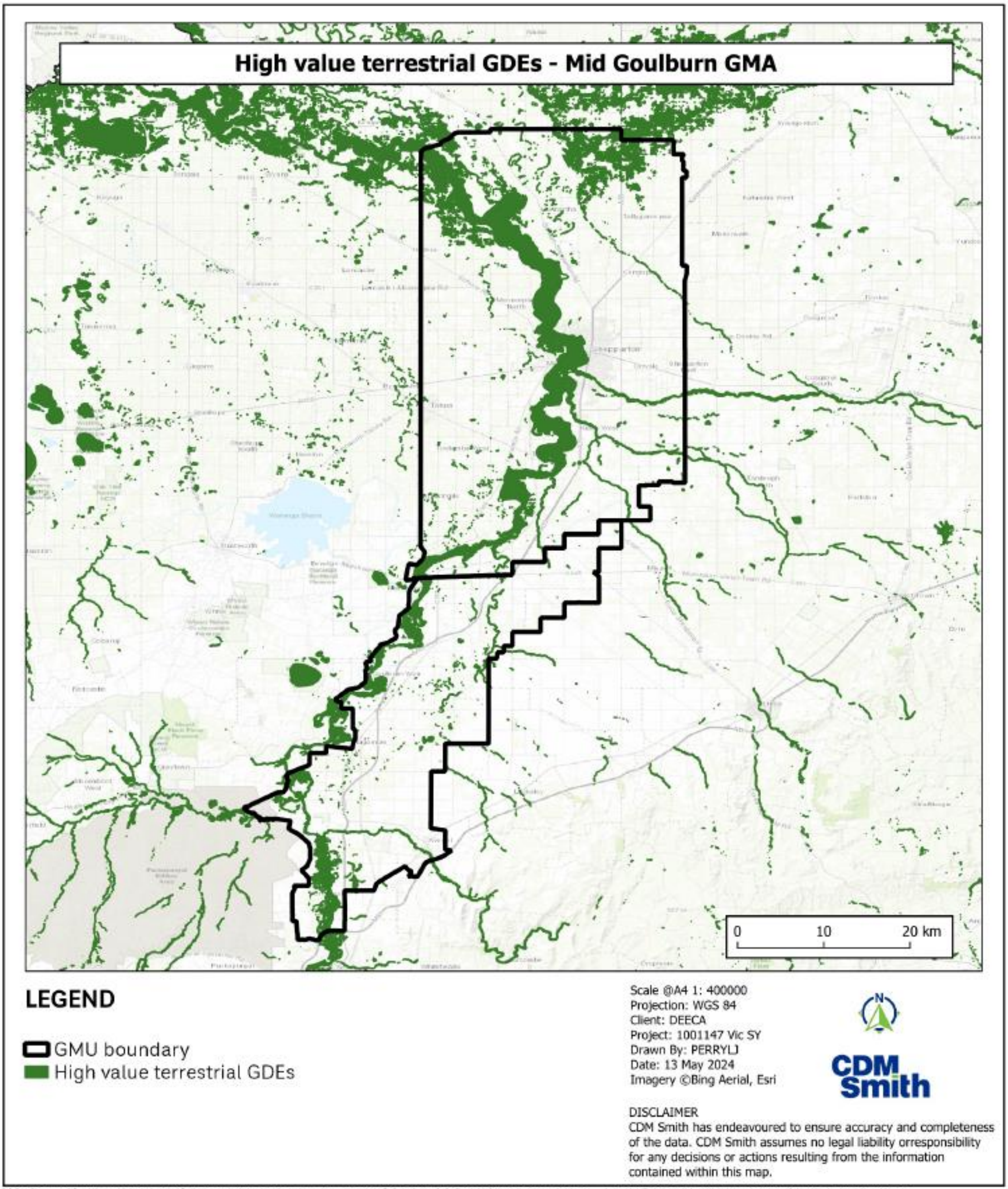

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Figure 6-5 High value terrestrial GDEs mapped in the Mid Goulburn GMA.

Table 6-7 Change in estimated average annual maximum groundwater elevation at high value terrestrial GDEs from baseline (1950-1974), ranked by highest change, for future medium climate change scenario and current use

GMU	Ave. change in groundwater elevation (annual max.) at terrestrial GDEs from baseline (1950-1974) (m)	
	2021-2040 MCC - current use	2021-2040 MCC - current use
Lower Campaspe Valley WSPA	-4.6	-4.1
Mid Loddon GMA	-4.1	-3.4
Mid Goulburn GMA	-3.4	-3.0
West Goulburn GMA	-2.9	-2.5
Lancefield GMA	-2.7	-1.6
Central Victorian Mineral Springs GMA	-2.5	-1.7
Kiewa GMA	-2.4	-2.2
Loddon Highlands WSPA	-2.2	-1.8
Strathbogie GMA	-2.2	-1.9
Shepparton Irrigation GMA	-2.2	-2.1
Glenormiston GMA	-2.2	-1.4
Broken GMA	-2.0	-1.9
Upper Ovens WSPA	-1.9	-1.5
Koo Wee Rup WSPA	-1.7	-1.7
Upper Goulburn GMA	-1.7	-1.3
Upper Murray GMA	-1.6	-1.3
Lower Ovens GMA	-1.6	-1.6
Eildon GMA	-1.6	-1.3
Frankston GMA	-1.5	-1.4
Moorabbin GMA	-1.3	-1.1
Nepean GMA	-1.3	-1.6
Denison GMA	-1.3	-1.3
Barnawartha GMA	-1.2	-1.5
Cardigan GMA	-1.1	-0.6
Tarwin GMA	-1.0	-1.2
Wa De Lock GMA	-0.9	-0.9
Leongatha GMA	-0.8	-1.0
Moe GMA	-0.7	-0.8
Gymbowen Zone (West Wimmera)	-0.7	-0.7
Warrion WSPA	-0.7	-1.1

GMU	Ave. change in groundwater elevation (annual max.) at terrestrial GDEs from baseline (1950-1974) (m)	
	2021-2040 MCC - current use	2021-2040 MCC - current use
Merrimu GMA	-0.6	-0.6
Southern Zone (West Wimmera)	-0.6	-0.5
Bungaree GMA	-0.5	-0.2
Hawkesdale GMA	-0.5	-0.3
Deutgam WSPA	-0.5	-0.5
Neuarpur Zone (West Wimmera)	-0.3	-0.4
Little Desert Zone (West Wimmera)	-0.3	-0.5
Wy Yung GMA	-0.2	-0.2
Northern Zone (West Wimmera)	-0.1	-0.4
Wandin Yallock GMA	-0.1	0.1
Glenelg WSPA	0.001	0.05
Nullawarre WSPA	0.02	-0.2
Yangery WSPA	0.04	-0.03
Heywood GMA	0.1	0.1
Colongulac GMA	0.1	0.01
Big Desert Zone (West Wimmera)	0.2	-0.1
South West Limestone GMA	0.4	0.2
Gerangamete GMA	0.8	-0.4
Jan Juc GMA	1.3	0.1
Gellibrand GMA	1.6	0.1
Newlingrook GMA	2.6	0.9

6.4.2 Synthesis information

The synthesis information for high value terrestrial GDEs is presented in Appendix II by GMU. These tables contain:

- Summary information on the GMU (as provided by DEECA);
- Average drawdown of maximum annual elevation of the watertable from baseline (1950-1974) for climate scenarios, and current and PCV rate groundwater extraction scenarios for 2021-2040 and 2041-2065;
- Volume of groundwater extraction under climate scenarios to achieve an average magnitude of drawdown (for average maximum annual watertable elevation) across the GMU, for 0.1, 1 and 2 metres of drawdown; and
- The proportions of recharge to which the use volumes above correspond.

Results reported as '-' indicate that drawdown in the watertable exceeds the drawdown level with no extraction (from a product of historic take and climate impacts to water level).

An example of the high value terrestrial GDEs synthesis table for Denison GMA is presented in Table 6-8 below.

Table 6-8 Example synthesis information table for high value terrestrial GDEs for Jan Juc GMA.

	GMU					JAN JUC GMA
Assessment area	Representative Suite/bore					TBC
	Aquifer					TBC
	Water system depth boundary (m below natural surface)					TBC
Catchment	Permissible Consumptive Volume (ML/yr)					TBC
	Licensed Entitlement (ML/yr)					TBC
	Licensed avg use (ML/yr)					TBC
Environmental metric	High Value Terrestrial GDEs	Avg Use 370 ML/yr	2021-2040	Drawdown from baseline (m)	No CC	1.2
					MCC (LCC - HCC)	1.7 (1.2 to 3.1)
				Area elev. <1.5 mAHD (%)	No CC	22%
					MCC (LCC - HCC)	23% (23% to 25%)
			2041-2065	Drawdown from baseline (m)	No CC	2.0
					MCC (LCC - HCC)	2.3 (1.3 to 4.6)
				Area elev. <1.5 mAHD (%)	No CC	23%
					MCC (LCC - HCC)	24% (22% to 27%)
		PCV use 4,250 ML/yr	2021-2040	Drawdown from baseline (m)	No CC	6.8
					MCC (LCC - HCC)	7.0 (5.9 to 8.6)
				Area elev. <=1.5 mAHD (%)	No CC	30%
					MCC (LCC - HCC)	29% (27% to 32%)
			2041-2065	Drawdown from baseline (m)	No CC	15
					MCC (LCC - HCC)	16 (14 to 18)
				Area elev. <=1.5 mAHD (%)	No CC	49%
					MCC (LCC - HCC)	50% (46% to 56%)
		Use at 1.5 mAHD	2021-2040	Volume (ML/yr)	No CC	10,563
					MCC (LCC - HCC)	10,320 (11,366 to 9,338)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	45.8% (44.7% to 50.3%)
			2041-2065	Volume (ML/yr)	No CC	4,604
					MCC (LCC - HCC)	4,258 (4,799 to 3,596)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	24.9% (23.3% to 32.0%)

6.5 Environmental – Waterway GDEs

6.5.1 Summary of results

The metrics assessment for high value waterway GDEs is presented below. This metrics value includes rivers and streams connected to groundwater. This metric considers both drawdown in the watertable at waterways, as well as stream flow results for assessed stream gauges. Groundwater levels reported for this metric are an annual maximum ('recovered level'). Change in groundwater elevation was calculated as an average of change under mapped waterways (as opposed an average across the whole GMU), while groundwater use and recharge are for the whole GMU. The metrics levels for drawdown in the watertable for waterway GDEs are 0.1, 1 and 2 metres.

High value waterway GDEs are mapped across 39 GMUs in Appendix LL, with an example for Jan Juc GMA included in Figure 6-6 below.

Table 6-9 below presents a summary of the change in the average annual maximum groundwater elevation at the location of high value waterway GDEs under medium climate change, for current rates of extraction, at 2021-2040 and 2041-2065, ranked by most drawdown. Of the 39 GMUs with mapped high value waterway GDEs, six show an estimated average drawdown at wetland GDEs at 2021-2040 of more than two metres (Lower Campaspe Valley WSPA, Mid Loddon GMA, Mid Goulburn GMA, Shepparton Irrigation GMA, West Goulburn GMA and Strathbogie GMA). Again, these areas are uniformly located in north and central Victoria.

The relationship between average drawdown at mapped high value waterway GDEs and total GMU groundwater use (as the coefficient (*M*) of the linear equation of *change in groundwater elevation = M*use*) is included Appendix OO by GMU.

Appendix NN presents the average change in groundwater elevations as an average of all mapped high value waterway GDEs within each GMU.

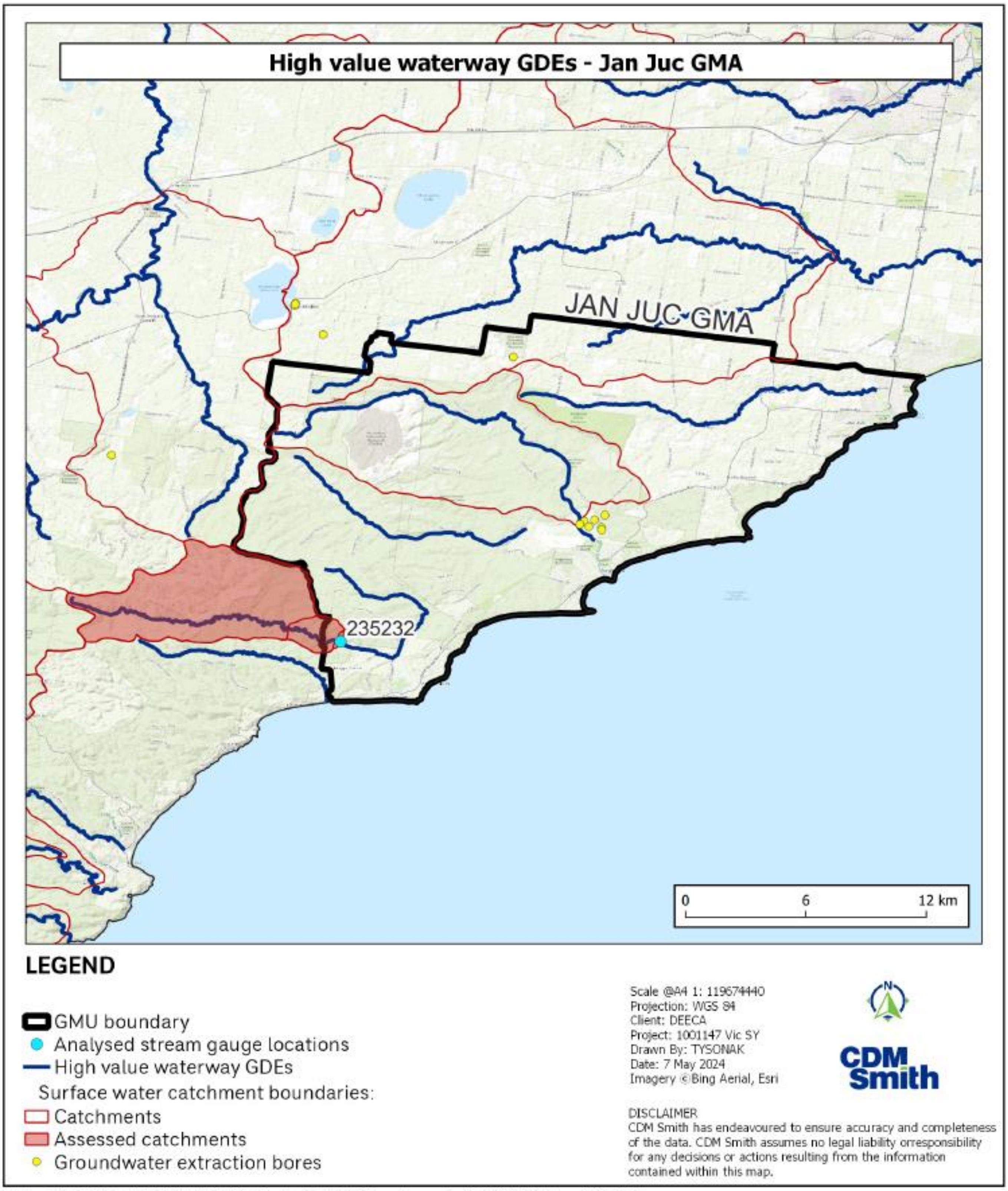

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Figure 6-6 High value waterway GDEs and assessed stream gauges/catchments for the Jan Juc GMA.

Table 6-9 Change in estimated average annual maximum groundwater elevation at waterway GDEs from baseline (1950-1974), ranked by highest change, for future medium climate change scenario and current use (for GMUs with wetland GDEs present)

GMU	Ave. change in groundwater elevation (annual max.) at waterway GDEs from baseline (1950-1974) (m)	
	2021-2040 MCC - current use	2041-2065 MCC - current use
Lower Campaspe Valley WSPA	-5.5	-4.6
Mid Loddon GMA	-4.2	-3.5
Mid Goulburn GMA	-3.3	-3.0
Shepparton Irrigation GMA	-2.9	-2.8
West Goulburn GMA	-2.5	-2.0
Strathbogie GMA	-2.3	-2.0
Lancefield GMA	-1.9	-1.0
Koo Wee Rup WSPA	-1.7	-1.7
Central Victorian Mineral Springs GMA	-1.5	-0.6
Broken GMA	-1.3	-1.2
Denison GMA	-1.2	-1.2
Barnawartha GMA	-1.2	-1.5
Tarwin GMA	-1.1	-1.2
Moe GMA	-0.9	-1.0
Cardigan GMA	-0.8	-0.3
Deutgam WSPA	-0.5	-0.6
Northern Zone (West Wimmera)	-0.5	-0.6
Loddon Highlands WSPA	-0.5	-0.2
Warrion WSPA	-0.5	-1.1
Hawkesdale GMA	-0.4	-0.2
Wa De Lock GMA	-0.4	-0.5
Kiewa GMA	-0.3	-0.1
Bungaree GMA	-0.3	0.0
Wy Yung GMA	-0.2	-0.2
Nullawarre WSPA	-0.1	-0.3
Upper Goulburn GMA	-0.04	0.2
Southern Zone (West Wimmera)	0.05	0.1
Yangery WSPA	0.1	-0.04
Lower Ovens GMA	0.3	0.3
Heywood GMA	0.4	0.4
Jan Juc GMA	0.6	-0.5
South West Limestone GMA	0.6	0.5
Gerangamete GMA	0.7	-0.5
Upper Murray GMA	1.1	1.4

GMU	Ave. change in groundwater elevation (annual max.) at waterway GDEs from baseline (1950-1974) (m)	
	2021-2040 MCC - current use	2041-2065 MCC - current use
Leongatha GMA	1.2	0.8
Glenelg WSPA	1.3	1.2
Upper Ovens WSPA	1.7	1.9
Eildon GMA	2.4	2.3
Newlingrook GMA	4.1	2.3

6.5.1.1 Stream flow

Figure 6-7 and Figure 6-8 below provide a visual display of relative magnitude of mean annual flow and Q90 flow for assessed stream gauges under medium climate change at 2040. Table 6-9 below presents a summary of the change in mean annual flow and Q90 flow for the assessed stream gauges under medium climate change at 2040, ranked by highest change from baseline. 40 (63%) of the 63 assessed gauges show an estimated reduction in mean annual flow of more than 10% compared to the baseline period (1975-2020), and 37 (59%) show an estimated reduction in Q90 flow of more than 10%. These areas a spread across Victoria.

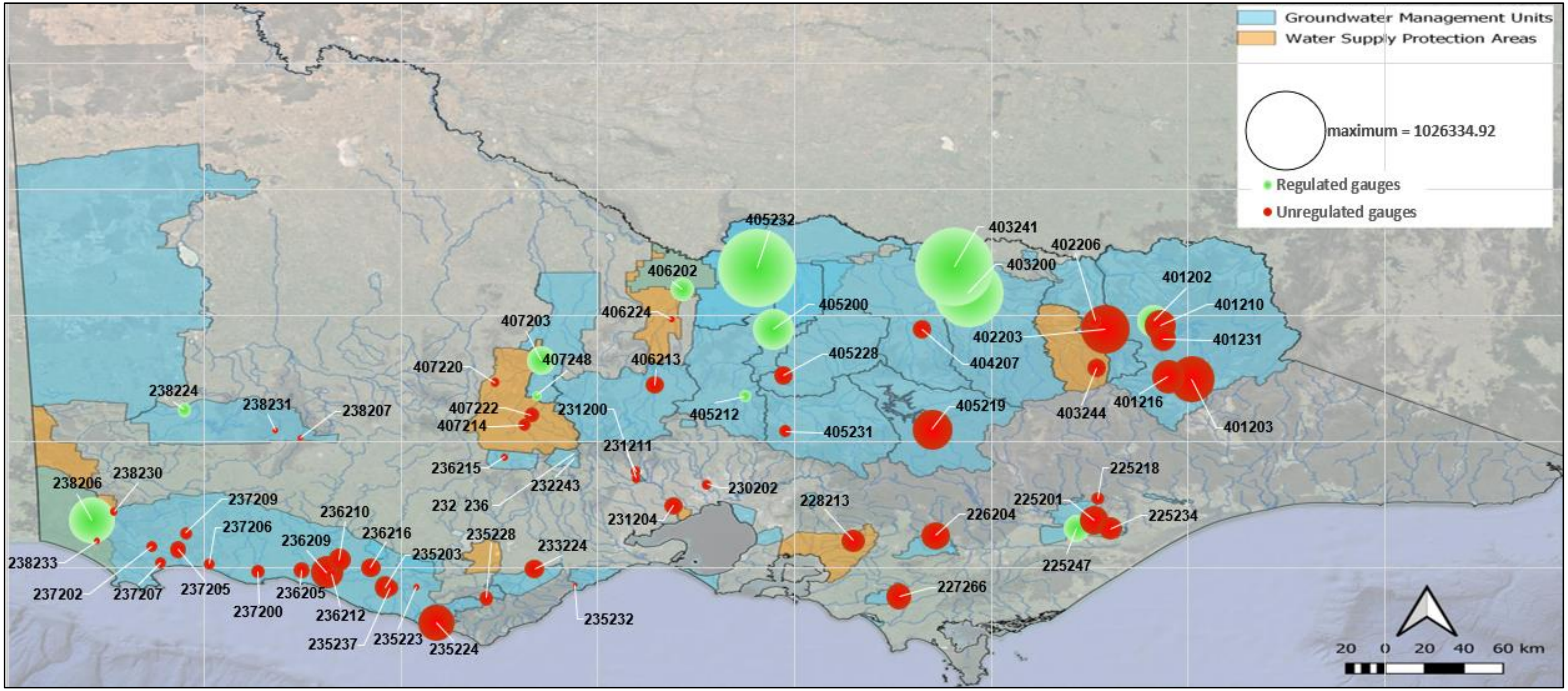

Figure 6-7 Relative magnitude of estimated mean annual flow for assessed gauges, from HARC baseflow analysis (HARC, 2023).

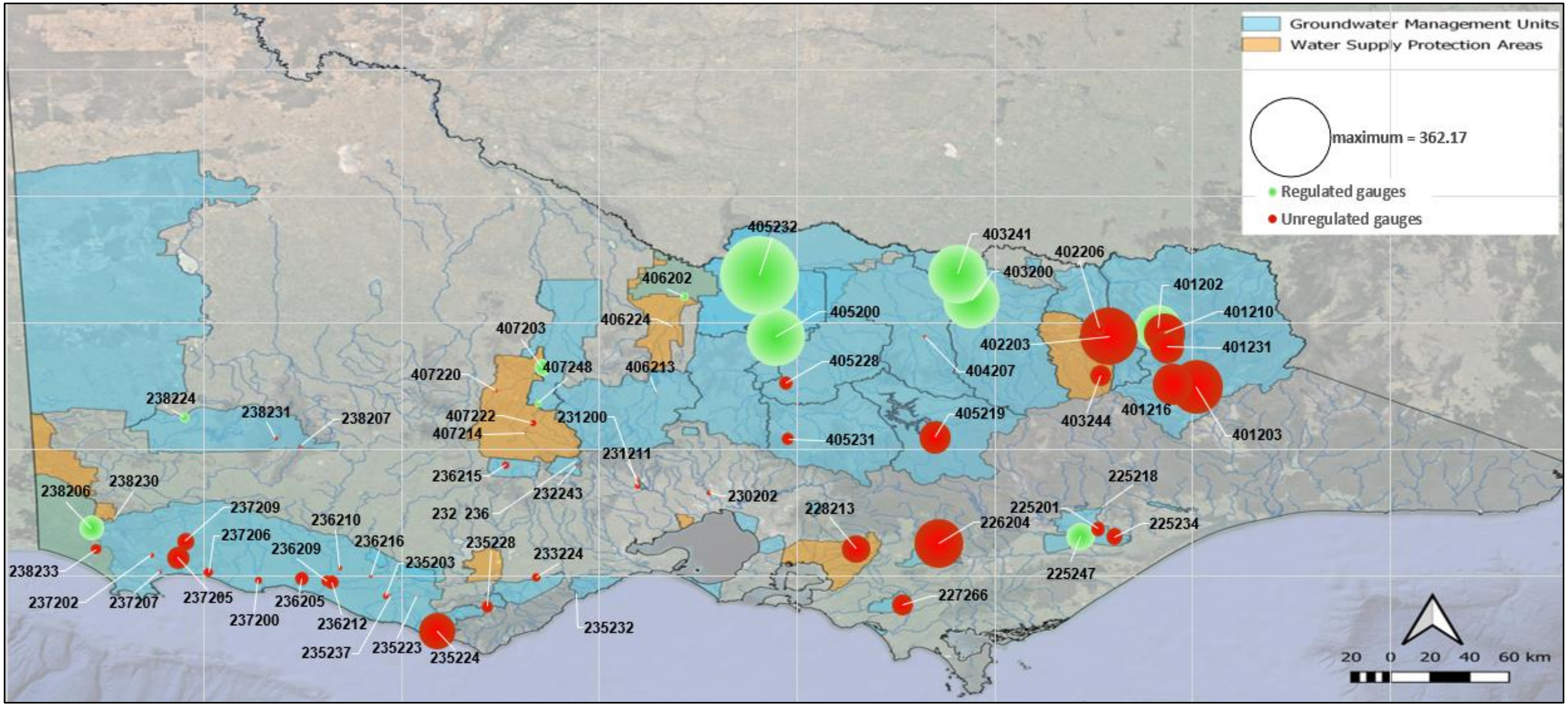

Figure 6-8 Relative magnitude of estimated Q90 flow for assessed gauges, from HARC baseflow analysis (HARC, 2023).

Table 6-10 Estimated mean annual flow (MAF), Q90 and BFI for 2040 medium climate change scenarios and change from baseline (1975-2020), ranked by highest change in MAF

GMU	Stream flow gauge		BFI	2040 Medium climate change			
				Mean annual flow		Q90	
	ID	Name		ML/yr	% ∆	ML/yr	% ∆
Mid Goulburn	405200*	Goulburn River @ Murchison	0.54	87,238	-82%	205	9%
Upper Glenelg	238207	Wannon River @ Jimmy Creek	0.5	6,300	-36%	0.7	-45%
Moe	226204	Latrobe River @ Willow Grove	0.74	33,025	-28%	142	-25%
Lower Campaspe Valley	406202*	Campaspe River @ Rochester D/S Waranga Western Ch Syphn	0.36	01,065	-27%	5.5	-12%
South West Limestone	236209	Hopkins River @ Hopkins Falls	0.44	75,057	-24%	8.6	-21%
Lower Ovens	403200*	Ovens River @ Wangaratta	0.63	14,127	-22%	186	-22%
Wa De Lock	225218	Freestone Creek @ Briagalong	0.22	28,543	-20%	0.1	-82%
Maribyrnong Basin	230202*	Jackson Creek @ Sunbury	0.32	18,038	-20%	1.6	-14%
Broken	404207	Holland Creek @ Kelfeera	0.46	62,177	-18%	1.0	-77%
South West Limestone	237202	Fitzroy River @ Heywood	0.41	21,171	-18%	1.2	-11%
Upper Murray	401203	Mitta Mitta River @ Hinnomunjie	0.64	343,894	-17%	166	-10%
Upper Murray	401216	Big River @ Jokers Creek	0.66	86,485	-16%	98	-11%
Loddon Highlands	407203*	Loddon River @ Laanecoorie	0.46	38,216	-16%	16	-13%
Eildon	405219	Goulburn River @ Dohertys	0.58	262,304	-15%	58	-11%
West Goulburn	405212	Sunday Creek @ Tallarook	0.28	25,871	-15%	0.0	NA
Koo-Wee-Rup	228213	Bunyip River @ Iona	0.57	90,438	-15%	46	-14%
Kiewa	402203	Kiewa River @ Mongans Bridge	0.66	400,022	-14%	191	-10%
Upper Murray	401210	Snowy Creek @ Below Granite Flat	0.7	161,358	-14%	98	-10%
South West Limestone	237205	Darlot Creek @ Homerton Bridge	0.7	47,866	-14%	30	-13%
South West Limestone	236205	Merri River @ Woodford	0.37	44,721	-14%	11	-13%
Upper Glenelg	238231	Glenelg River @ Big Cord	0.56	7,000	-14%	1.1	-14%
South West Limestone	238233	Moleside Creek @ Kentbruck	0.69	7,762	-14%	7.1	-14%
South West Limestone	238230	Stokes River @ Teakettle	0.29	11,684	-14%	0.3	-14%

GMU	Stream flow gauge		BFI	2040 Medium climate change			
				Mean annual flow		Q90	
	ID	Name		ML/yr	% ∆	ML/yr	% ∆
Upper Glenelg	238224*	Glenelg R @ Fulham Bridge (Bottom Ec Probe)	0.45	35,096	-14%	5.9	-14%
South West Limestone	238206	Glenelg River @ Dartmoor	0.46	355,715	-14%	36	-14%
South West Limestone	236210	Hopkins River @ Framlingham	0.4	88,543	-13%	1.3	-13%
South West Limestone	236216	Mount Emu Creek @ Taroon (Ayrford Road Bridge)	0.46	62,625	-13%	0.7	-13%
Cardigan	236215	Burrumbeet Creek @ Lake Burrumbeet	0.44	8,709	-13%	2.9	-13%
South West Limestone	236212	Brucknell Creek @ Cudgee	0.44	22,522	-13%	12	-13%
Lower Campaspe Valley	406224	Mount Pleasant Creek @ Runnymede	0.11	9,010	-12%	0.3	-12%
Central Victorian Mineral Springs	406213	Campaspe River @ Redesdale	0.36	53,054	-12%	0.4	-12%
Leongatha	227266	Tarwin River @ Koonwarra	0.51	107,006	-12%	25	-12%
Gerangamete	233224*	Barwon River @ Ricketts Marsh	0.36	62,626	-12%	4.2	-21%
Newlingrook	235224	Gellibrand River @ Burrupa	0.56	219,214	-11%	77	-11%
South West Limestone	237206	Eumeralla River @ Codrington	0.49	24,435	-11%	5.7	-11%
South West Limestone	237200	Moyne River @ Toolong	0.33	34,953	-11%	3.3	-11%
Lower Ovens	403241*	Ovens River @ Peechelba	0.59	1,024,472	-11%	203	-11%
South West Limestone	237209	Darlot Creek @ Myamyn	0.75	27,092	-11%	17	-11%
Upper Ovens	403244	Ovens River @ Harrietville	0.67	63,092	-11%	26	-11%
South West Limestone	237207	Surry River @ Heathmere	0.4	23,438	-11%	1.4	-11%
Strathbogie	405228	Hughes Creek @ Tarcombe Road	0.5	55,391	-10%	12	-10%
Shepparton	405232*	GOULBURN RIVER @ Mccoys BRIDGE	0.53	1,026,335	-9%	362	-9%
Upper Goulburn	405231	King Parrot Creek @ Flowerdale	0.62	29,267	-9%	8.3	-10%
Kiewa	402206	Running Creek @ Running Creek	0.65	25,323	-9%	8.4	-9%
Wa De Lock	225201	Avon River @ Stratford	0.28	140,574	-9%	12	-9%
Wa De Lock	225247*	Macalister River @ Riverslea	0.58	123,624	-9%	46	-9%
Wa De Lock	225234	Avon River @ Clydebank (Chinn's Bridge)	0.44	89,825	-9%	16	-9%
Upper Murray	401231	Snowy Creek @ D/S Lightning Ck	0.71	100,840	-8%	69	-8%

GMU	Stream flow gauge		BFI	2040 Medium climate change			
				Mean annual flow		Q90	
	ID	Name		ML/yr	% ∆	ML/yr	% ∆
Upper Murray	401202*	Mitta Mitta River @ Mitta Mitta	0.6	176,045	-8%	126	-8%
Bungaree	232236	West Moorabool River U/S Moorabool Reservoir	0.61	875	-8%	0.1	-8%
Bungaree	232243	Whisky Creek At Whisky Creek Diversion Weir	0.62	534	-8%	0.9	-8%
Werribee Basin	231211	Lerderderg River @ U/S Goodman Creek Junction	0.42	15,264	-8%	1.1	-8%
Werribee Basin	231200*	Werribee River @ Bacchus Marsh	0.35	15,861	-8%	2.2	-8%
Loddon Highlands	407220	Bet Bet Creek @ Norwood	0.25	15,795	-7%	0.8	-7%
Mid Loddon	407248*	Tullaroop Creek @ Tullarrop Res. (O'let Meas. Weir)	0.63	18,847	-7%	4.3	-7%
Loddon Highlands	407222*	Tullaroop Creek @ Clunes	0.43	37,332	-7%	2.9	-7%
Janjuc	235232	Painkalac Creek @ Painkalac Creek Dam	0.3	3,841	-7%	0.1	-7%
Gellibrand	235228	Gellibrand River @ Gellibrand	0.52	35,086	-7%	7.9	-7%
South West Limestone	235203	Curdies River @ Curdie	0.34	77,921	-7%	2.4	-7%
South West Limestone	235237	Scotts Creek @ Curdie (Digneys Bridge)	0.29	43,984	-7%	0.4	-7%
South West Limestone	235223	Scotts Creek @ Scotts Creek	0.31	7,783	-7%	0.5	-7%
Deutgam	231204*	Werribee River @ Werribee Diversion Weir	0.36	56,109	-3%	0.0	-100%
Loddon Highlands	407214	Creswick Creek @ Clunes	0.38	27,617	20%	0.3	-53%

Notes: * Regulated stream.

6.5.2 Synthesis information

The synthesis information for waterway GDEs for each relevant GMU is presented in Appendix MM. These tables contain:

- Summary information on the GMU (as provided by DEECA);
- Average drawdown of maximum annual elevation of the watertable from baseline (1950-1974) for climate scenarios and current and PCV rate groundwater extraction scenarios for 2021-2040 and 2041-2065;
- Volume of groundwater extraction under climate scenarios to achieve an average magnitude of drawdown (in average maximum annual watertable elevation) across the GMU, for 0.1, 1 and 2 m drawdown (nothing that use is for the whole GMU);
- The proportion of recharge to which the use volume above corresponds.

And for GMUs with stream gauges (where one or more assessed gauged catchments sits within the GMU boundary):

- BFI for each gauge;
- Mean annual and Q90 flows for climate scenarios 2040 and 2065 for each gauge; and
- Groundwater use in assessed gauged catchments as a proportion of mean annual and Q90 flows for each gauge.

Results reported as '-' indicate that drawdown in the watertable exceeds the drawdown level with no extraction (from a product of historic take and climate impacts to water level).

An example of the high value waterway GDEs synthesis table for Jan Juc GMA is presented in Table 6-11 below.

Table 6-11 Example synthesis information table for waterway GDEs for Jan Juc GMA.

	GMU					JAN JUC GMA
Assessment area	Representative Suite/bore					TBC
	Aquifer					TBC
	Water system depth boundary (m below natural surface)					TBC
Catchment	Permissible Consumptive Volume (ML/yr)					TBC
	Licensed Entitlement (ML/yr)					TBC
	Licensed avg use (ML/yr)					TBC
Environmental metric	Waterway GDEs	Avg Use 370 ML/yr	2021-2040	Drawdown from baseline (m)	No CC	-0.5
					MCC (LCC - HCC)	-0.6 (-1.1 to 0.6)
			2041-2065	Drawdown from baseline (m)	No CC	0.5
					MCC (LCC - HCC)	0.5 (-0.3 to 2.5)
		PCV use 4,250 ML/yr	2021-2040	Drawdown from baseline (m)	No CC	5.3
					MCC (LCC - HCC)	5.4 (4.4 to 7)
			2041-2065	Drawdown from baseline (m)	No CC	13.6
					MCC (LCC - HCC)	14.2 (12.7 to 16)
		Use at 0.1 metre drawdown	2021-2040	Volume (ML/yr)	No CC	75
					MCC (LCC - HCC)	74 (83 to 64)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	0.33% (0.33% to 0.34%)
			2041-2065	Volume (ML/yr)	No CC	30
					MCC (LCC - HCC)	31 (33 to 29)
					No CC	NA

				Proportion of recharge (%)	MCC (LCC - HCC)	0.18% (0.16% to 0.26%)
		Use at 1 metre drawdown	2021-2040	Volume (ML/yr)	No CC	753
					MCC (LCC - HCC)	744 (834 to 641)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	3.3% (3.3% to 3.5%)
			2041-2065	Volume (ML/yr)	No CC	298
					MCC (LCC - HCC)	306 (331 to 285)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	1.8% (1.6% to 2.5%)
		Use at 2 metre drawdown	2021-2040	Volume (ML/yr)	No CC	1,507
					MCC (LCC - HCC)	1,489 (1,668 to 1,282)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	6.6% (6.6% to 6.9%)
			2041-2065	Volume (ML/yr)	No CC	595
					MCC (LCC - HCC)	612 (661 to 571)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	3.6% (3.2% to 5.1%)
		Stream gauge/Catchment:				235232 - Painkalac Creek @ Painkalac Creek Dam
		Base flow index (1975-2020)				0.30
		Mean annual flow (MAF)	2040	Flow (ML/yr)	MCC (LCC - HCC)	3,841 (4,412 to 3,092)
				Change from 1975-2020 (ML/yr)	MCC (LCC - HCC)	-298 (273 to -1,047)
			2065	Flow (ML/yr)	MCC (LCC - HCC)	3,485 (3,945 to 2,405)
				Change from 1975-2020 (ML/yr)	MCC (LCC - HCC)	-654 (-195 to -1,734)
		Groundwater extraction in upgradient catchment as % of MAF flow	2040	Current use (ML/yr)	MCC (LCC - HCC)	No extraction
				PCV use (ML/yr)	MCC (LCC - HCC)	No extraction
			2065	Current use (ML/yr)	MCC (LCC - HCC)	No extraction
				PCV use (ML/yr)	MCC (LCC - HCC)	No extraction
		Q90 flow	2040	Flow (ML/yr)	MCC (LCC - HCC)	0.15 (0.17 to 0.12)
				Change from 1975-2020 (ML/yr)	MCC (LCC - HCC)	-0.01 (0.01 to -0.04)
			2065	Flow (ML/yr)	MCC (LCC - HCC)	0.13 (0.15 to 0.09)
				Change from 1975-2020 (ML/yr)	MCC (LCC - HCC)	-0.03 (-0.01 to -0.07)
		Groundwater extraction in upgradient catchment as % of Q90 flow	2040	Current use (ML/yr)	MCC (LCC - HCC)	No extraction
				PCV use (ML/yr)	MCC (LCC - HCC)	No extraction
			2065	Current use (ML/yr)	MCC (LCC - HCC)	No extraction
				PCV use (ML/yr)	MCC (LCC - HCC)	No extraction

6.6 Seawater intrusion

6.6.1 Summary of results

The metrics assessment for seawater intrusion is presented below. This metric relevant to the 14 Victorian coastal GMUs and only for portions of those GMUs within 300 m of the coast. Groundwater levels reported for this metric are for one kilometre of the coast (limited by model resolution) and are an annual minimum, which is different to the other sustainable yield metrics reported. Change in groundwater elevation was calculated as an average of change within one kilometre of the coast (as opposed an average across the wider GMU), while groundwater use and recharge are for the whole GMU. The metrics level for groundwater elevation for seawater intrusion is 1.5 mAHD.

The seawater intrusion reporting areas of each of the 14 coastal GMUs are shown in Appendix PP with maps showing the areas where the metric level was exceeded for the medium climate change and current groundwater use scenario at 2021-2040 (average annual minimum elevation of the watertable <=1.5 mAHD). An example of these maps for the Nepean GMA is included in Figure 6-9 below.

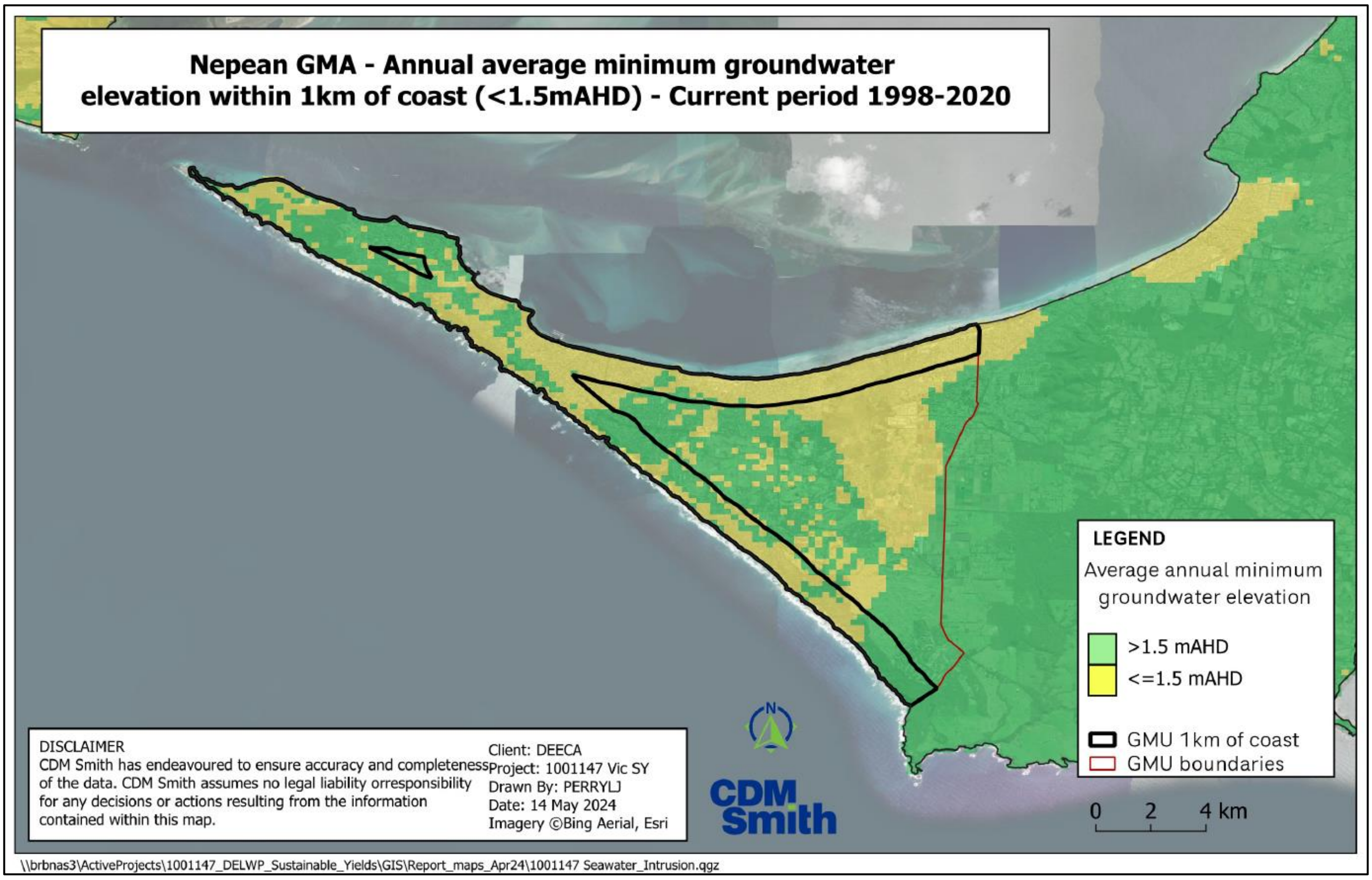

Figure 6-9 Indicative area of potential seawater intrusion risk (as estimated average annual minimum groundwater elevation <> 1.5 mAHD) within 1km of the coast for the Nepean GMA - medium climate change and current use scenario at 2021-2040.

Table 6-12 below presents a summary of the percentage of GMU area with an average annual minimum groundwater elevation at or below 1.5 mAHD under medium climate change and current use at 2021-2040 and 2041-2065, and change from baseline, ranked by highest percentage. Half of the coastal GMUs show at least 50% of the coastal area (within 1 km of the coast) with average annual minimum groundwater elevation at or below 1.5 mAHD for this scenario at 2021-2040. This increase to 64% of GDEs at 2041-2065. Both central and western GMUs show high impacts.

The relationship between average drawdown in coastal areas and total GMU groundwater use (as the coefficient (*M*) and constant (*C*) of the linear equation of *change in groundwater elevation = M*use + C*) is included Appendix SS by GMU.

Appendix RR presents the average elevation and change from baseline of groundwater elevations in coastal areas, as well as the percentage of GMU area with an average annual minimum groundwater elevation at or below 1.5 mAHD for all reporting scenarios.

Table 6-12 Proportion of area of coastal GMU within 1km of the coast with an estimated average annual minimum groundwater elevation below 1.5 mAHD, ranked by average elevation, for future medium climate change and current use

GMU	Proportion of GMU area with groundwater elevation at or below 1.5 mAHD and change from baseline (1950-1974)			
	2021-2040 Medium climate change, current use		2041-2065 Medium climate change, current use	
	% area	% Δ	% area	% Δ
Frankston GMA	96%	16%	97%	17%
Glenelg WSPA	96%	-1%	97%	0%
Koo Wee Rup WSPA	88%	5%	91%	9%
Yangery WSPA	73%	6%	75%	10%
Deutgam WSPA	70%	83%	71%	86%
Heywood GMA	62%	-3%	64%	1%
Nepean GMA	55%	44%	65%	71%
South West Limestone GMA	48%	-1%	51%	5%
Newlingrook GMA	43%	5%	45%	10%
Tarwin GMA	37%	-19%	61%	32%
Hawkesdale GMA	28%	13%	31%	26%
Jan Juc GMA	23%	12%	24%	16%
Moorabbin GMA	17%	132%	15%	102%
Nullawarre WSPA	7%	4%	8%	22%

6.6.2 Synthesis information

The synthesis information for seawater intrusion for each GMU is presented in Appendix QQ. These tables contain:

- Summary information on the GMU (as provided by DEECA);
- Average drawdown of maximum annual elevation of the watertable from baseline (1950-1974) for climate scenarios and current and PCV rate groundwater extraction scenarios for 2021-2040 and 2041-2065;
- Proportion of coastal area with average groundwater elevation at or below 1.5 mAHD for those same scenarios above;
- Volume of groundwater extraction under climate scenarios to maintain an average watertable elevation across the GMU within 1 km of the coast above 1.5 mAHD (minimum annual watertable elevation); and
- The proportion of recharge to which the use volume above corresponds, and
- The proportion of the area of GMU within 1km of coast where metric level is exceeded.

Results reported as '-' indicate that drawdown in the watertable exceeds the metrics level with no extraction (from a product of historic take and climate impacts to water level).

An example of the seawater intrusion synthesis table for Jan Juc GMA is presented in Table 6-13 below.

Table 6-13 Example synthesis information table for seawater intrusion for the Jan Juc GMA.

	GMU					**JAN JUC GMA**
Assessment area	Representative Suite/bore					TBC
	Aquifer					TBC
	Water system depth boundary (m below natural surface)					TBC
Catchment	Permissible Consumptive Volume (ML/yr)					TBC
	Licensed Entitlement (ML/yr)					TBC
	Licensed avg use (ML/yr)					TBC
Seawater intrusion	**Seawater intrusion**	Avg Use 370 ML/yr	2021-2040	Drawdown from baseline (m)	No CC	1.2
					MCC (LCC - HCC)	1.7 (1.2 to 3.1)
				Area elev. <1.5 mAHD (%)	No CC	22%
					MCC (LCC - HCC)	23% (23% to 25%)
			2041-2065	Drawdown from baseline (m)	No CC	2.0
					MCC (LCC - HCC)	2.3 (1.3 to 4.6)
				Area elev. <1.5 mAHD (%)	No CC	23%
					MCC (LCC - HCC)	24% (22% to 27%)
		PCV use 4,250 ML/yr	2021-2040	Drawdown from baseline (m)	No CC	6.8
					MCC (LCC - HCC)	7.0 (5.9 to 8.6)
				Area elev. <1.5 mAHD (%)	No CC	30%
					MCC (LCC - HCC)	29% (27% to 32%)
			2041-2065	Drawdown from baseline (m)	No CC	15
					MCC (LCC - HCC)	16 (14 to 18)
				Area elev. <1.5 mAHD (%)	No CC	49%
					MCC (LCC - HCC)	50% (46% to 56%)
		Use at 1.5 mAHD	2021-2040	Volume (ML/yr)	No CC	10,563
					MCC (LCC - HCC)	10,320 (11,366 to 9,338)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	45.8% (44.7% to 50.3%)
			2041-2065	Volume (ML/yr)	No CC	4,604
					MCC (LCC - HCC)	4,258 (4,799 to 3,596)
				Proportion of recharge (%)	No CC	NA
					MCC (LCC - HCC)	24.9% (23.3% to 32.0%)

6.7 Cave system GDEs (stygofauna)

No data was available on high value stygofauna and cave system GDEs and as such, these values are not considered in this assessment.

6.8 Offshore GDEs

No data was available on high value offshore GDEs and as such, these values are not considered in this assessment.

6.9 Cultural

Preservation of cultural elements related to groundwater (including GDEs) was not considered in this assessment.

Section 7 Limitations and recommendations

The following section discusses limitations in the results, related to the method (assumptions and limitations of which are discussed in Section 2.7, and recommendations to resolve these limitations.

7.1 Recharge

This study's novel approach was to estimate the magnitude of recharge across Victoria using the existing groundwater monitoring network, which was screened for suitability. The current spatial distribution of groundwater monitoring points is concentrated around historical areas of groundwater extraction, and is very sparse in landscapes where little to no groundwater extraction occurs. Even with the addition of SoilFlux gridded recharge as a basis from which to map the point data across space, the requirement to interpolate between point data recharge estimates brings in uncertainty. The results may be considered an upper estimate of bulk recharge to the watertable at a regional scale, and certainly compare to upper estimates of recharge from other studies (refer Section 2.7 above). The interpolation, combined with a 1,000 m grid cell size for the study, confirms that the results are not likely to be accurate at local scales and should not be used to interrogate impacts at individual groundwater receptors. It is therefore considered that the approach of using HydroSight to estimate recharge at individual bore points produces reasonable estimates of recharge at the scales relevant to this project (state-wide and regional).

The recharge results in this study are averages of multiple years of data. The high variability of recharge results between years should be considered when using the recharge results from this project (an element of the uncertainty in the mean of recharge).

The recharge interpolation shows that the uncertainty is spatially variable and highly dependent upon the proximity to groundwater observation bores (see Figure 4-3). Hence, caution should be applied when using the results to examine individual receptors where the uncertainty is high.

The temporal averaging approach used here to provide estimates of recharge for future time periods requires careful interpretation. Specifically, for the period 2021-2040 the annual recharge estimates were averaged over the whole period and do not represent recharge in 2040 (and similar for 2041-2065 representing 2065). Consequently, the approach likely underestimates the impact of climate change on recharge modelled at the end of these future periods. This is because of the trend toward reducing availability of rainfall (and therefore less rainfall recharge) expected under medium and high climate change scenarios, and increasing availability of rainfall (and therefore more rainfall recharge) expected under the low climate change scenario. An estimate of recharge using the 2021-2040 average under medium and high climate change will be, on average, higher (less of a reduction in recharge) than at 2040 (or even an average taken around 2040, like 2030-2050). Similarly, under low climate change, an estimate of recharge using the 2021-2040 average will be, on average, lower (more of a reduction in recharge) than at 2040. If the averages reported in this project are used to estimate recharge at 2040 and 2065, they will effectively be underestimating the impact the future climate is expected to have on recharge to the watertable that the modelling in this assessment is indicating. This point should be considered when using the results of the project.

The process of averaging results across GMUs also removes the detail of areas of higher or lower magnitude or change in recharge. The average GMU result statistics should be considered alongside the distribution of results across a GMU (at a regional level) when considering at the results from this project on recharge to the watertable.

The estimate of recharge as a bulk value in this study, does not distinguish between sources of water interacting with the watertable. Irrigation accessions, river and lake ascension and groundwater through flow are all hydrological processes which are incorporated into the recharge estimate but not distinguished by this study's approach. Consideration will be required when using these results to review management practices and changing landscapes and climates in areas with differing related hydrological processes. For example, for some GMUs, future changes to irrigation patterns and volumes will impact these estimates of recharge, where they would not in other areas with less/no irrigation.

Interaction between confined, unconfined and semi-confined aquifers have not been accounted for in this study, except where HydroSight inherently models a hydrograph which may have inter-aquifer flow components (throughflow and vertical flow to/from confined aquifers) and the model tries to adjust the parameters to reproduce the observed head.

The approach is also not a water balance approach that includes the watertable, only for the unsaturated zone. . Notwithstanding these assumptions, HydroSight does model groundwater bore records true to the water level data, and so the results should be relatively accurate when considering an estimate of bulk recharge for the area of influence of each bore.

The estimates of uncertainty in the mean of recharge produced to accompany gridded recharge data for this project should be viewed as an indication of where recharge uncertainty is greater than others, and not as an error band (i.e. +/- mm/yr) of the recharge results themselves. A key limitation of the recharge results presented in this study is the unavailability of an estimate of error which could be applied to the results at any point to indicate the extremes of a range of potential results for that location. The estimate provided, as uncertainty it the mean of recharge, does not provide a comparable statistic, but it does allow for some understanding of the qualitative uncertainty for data within the dataset.

The results are less certain for the 2041-65 time step than for 2021-40, due to the increased uncertainty of climate change factors, rainfall and extraction predictions that far into the future, but they do provide a useful range of potential outcomes.

The recharge results compared to rainfall available across GMUs show proportions of above 30 and 40% (recharge/rainfall) for a number of GMUs and scenarios (refer to Table 4-4 above). This would indicate that the recharge volumes in these areas may be less accurate than elsewhere, as recharge is typically accepted to range from 5 to 25% in most areas of Victoria.

In the higher altitude, higher rainfall parts of Victoria, where recharge is commonly estimated in excess of 1,000 mm/yr (this study; SoilFlux 2023; CDM Smith 2018b) this volume recharge is not likely to represent the usable resource in the watertable aquifer, as much of this water will quickly move to surface water in valleys and streams. This is consistent with the high percentage of rainfall results for highland areas in this study (e.g. Upper Ovens – 44%, Keiwa 44%, Upper Murray 35% at 2021-40, medium climate change).

The ‘no climate change’ scenario for future recharge was not produced within the project scope, and is missing from the set of results. Recharge results for this scenario could be developed using the project methods if required in future.

Recommendations

- To improve the estimates of recharge at the local scale, particularly away from groundwater bores modelled under this study, additional detailed (pumping) modelling of bores using HydroSight within a study region could be considered. This would reduce the uncertainty around recharge estimates at this scale.
- Use of the DREAM process in HydroSight for estimating modelling uncertainty (more directly than was available at the scale of this project) when undertaking a more localised assessment of recharge, would enable estimation of both the point annual recharge uncertainty and variability..
- Further development of HydroMap in mapping recharge across space, specifically an appropriate gridded dataset to use as a basis for interpolation (like a DEM is for water level mapping in HydroMap), would benefit future projects, to enable sparse bore recharge data to be mapped without using a dataset like SoilFlux, which brings with it additional sources of uncertainty. This could be achieved by extending HydroMap to allow recharge interpolation using gridded land use categories – a feature which is already included for head mapping.
- If an estimate of recharge is required for the no climate change scenario beyond 2021, the SoilFlux model results may be re-interrogated to extract data for that scenario to then be combined with HydroSight data in the same manner as the other scenarios to generate a consistent recharge result for 2021-2040 and 2041-2065 no climate change.

7.2 Groundwater elevation

It is important to understand the state-wide groundwater elevation maps derived in this study are different in design and purpose than existing static depth to watertables maps. This is because they estimate a average of multiple year maximum and minimum water level for periods of time rather than average water level in a single year. A comparison of project output water level mapping to existing state-wide watertable mapping, e.g. DELWP’s 2013 depth to groundwater map used in the SoilFlux model (as shown in Figure 2-18 above).

As for recharge, the process of averaging results across GMUs removes the detail of areas of higher or lower magnitude or change in groundwater elevation. The average GMU result statistics should be considered alongside the distribution of results across a GMU (at a regional level) when considering at the results from this project on watertable elevation.

The groundwater elevation mapping and metric results do not consider unlicensed groundwater use, such as stock and domestic bores, of which there are thousands across Victoria, and from which legal use can be up to 1.5 megalitres per year per bore. However, where an observation bore is nearby then these such extracts will be accounted for in the mapping because the observed head includes drawdown from them and the observed head is honoured in the mapping. However, in regions without observations, stock and domestic drawdown will not be accounted for

Also as mentioned above, interaction between confined, unconfined and semi-confined aquifers, and flow boundaries, have not been accounted for in this study, except where HydroSight inherently models a hydrograph which may have inter-aquifer flow components (throughflow and vertical flow to/from confined aquifers), and where the MrVBF element of HydroMap considers recharge boundaries. Indeed, because HydroSight does not consider aquifer thickness, the watertable estimates in this study may be estimating drawdown below the base of the watertable aquifer in places. In areas where drawdown is significant in an area where an aquifer is known to be thin, care should be taken in interpreting the results of this study. In most areas, and at a regional scale, however, HydroSight does model groundwater bore records true to the water level data (at least for the calibration period), and so the groundwater level results should be relatively accurate close to modelled bores.

Issues with the method of estimating groundwater elevation at unmodelled pumping bores (so as to bring the impact of pumping into the groundwater elevation mapping where pumping was not directly modelled, refer Section 2.5.4.2 above) has brought in significant uncertainty in the groundwater level estimates, particularly in a comparison of the no use and pumping scenarios. In areas of high pumping where the assignment of drawdown has not worked as well, the watertable is estimated to have more drawdown in a scenario of current use in 2021-40 than with extraction ceasing after 2020 (which in reality should be reversed). Refer Figure 7-1 and Figure 7-2 below for an example in the Shepparton Irrigation GMA. This effect is most evident in this section of northern Victoria, west Wimmera and the inland western district.

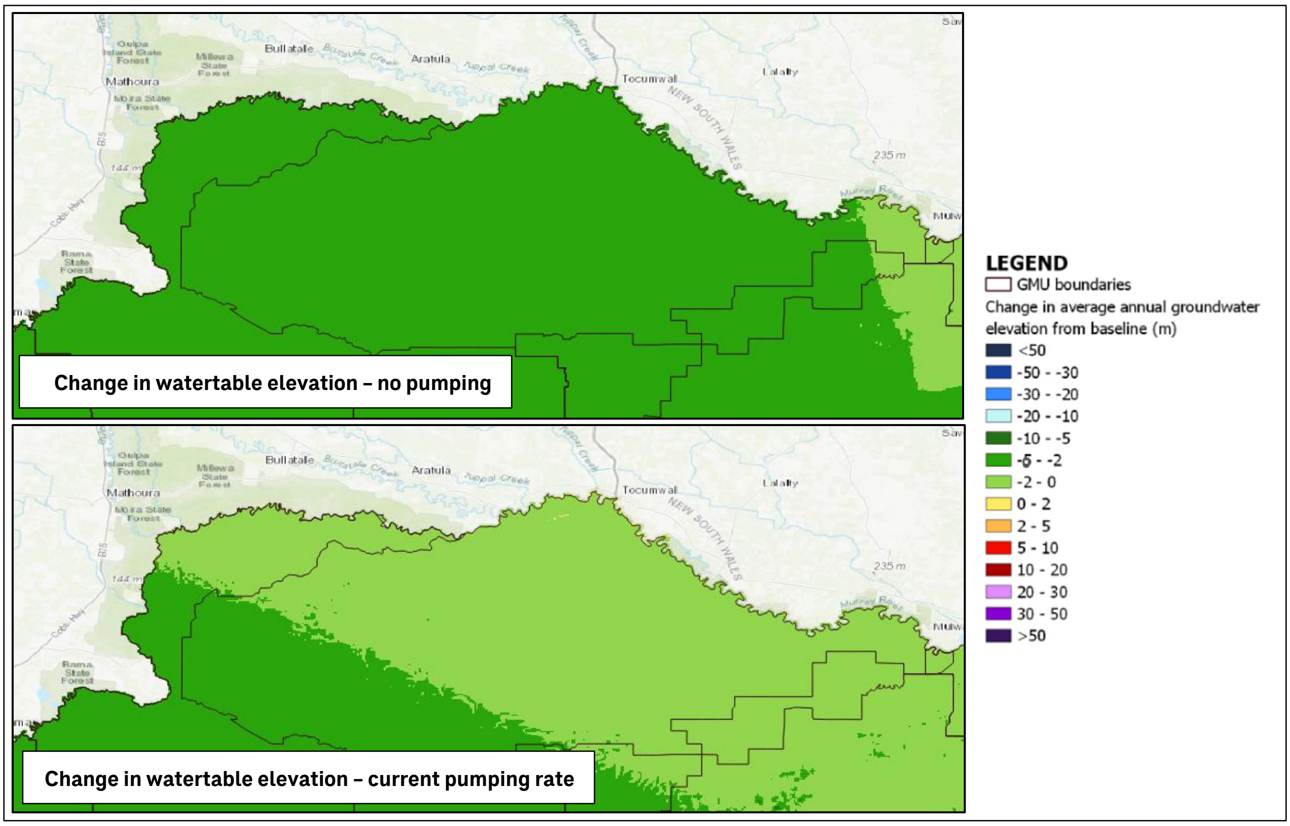

Figure 7-1 Example of inconsistent change in average annual maximum groundwater elevation due to mapping methods in the north of the Shepparton Irrigation GMA (2021-40, medium climate change), with darker red indicating higher change in groundwater elevation.

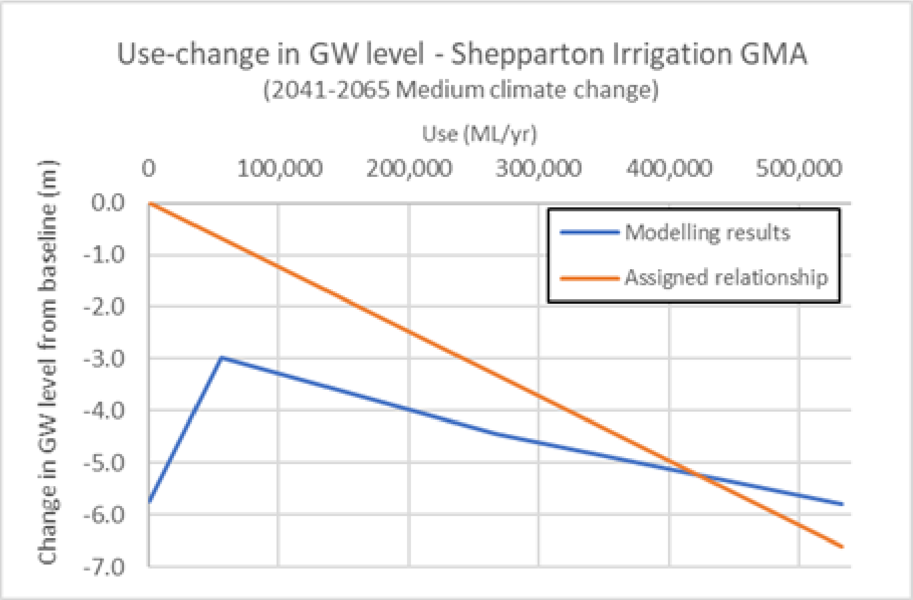

Figure 7-2 Average use-drawdown relationship for the Shepparton Irrigation GMA for 2041-65 medium climate change.

The low magnitude of metrics values around water level change (0.1, 1 and 2 metres for environmental metrics) and the magnitude of the likely uncertainty of the project outputs (due of the method and scale of the project) are inconsistent. The magnitude of likely error in the groundwater elevation results derived in this project is likely to be much greater than the differentiation between metrics levels (i.e. the likely error band (although it has not been determined here) is expected to be much greater than two meters in water level change in most parts of Victoria). This should be considered when using the results, especially the distinguishing between 'above' and 'below' metrics levels.

The groundwater level mapping method (with the embedded uncertainties) did not allow for the level of high resolution groundwater level and stream water elevation data sufficient to determine changing gaining or losing groundwater conditions. The regional approach, the issues around the mapping daylighting groundwater in hilly areas, and the likely magnitude of error across the landscape resulted in difficulty inferring the direct magnitude of impact to surface water bodies. . What can be determined from the results is a relative risk to waterways from the estimated change in groundwater elevation under waterway reaches. Where this is greater than several metres drawdown, it could be considered that a historically gaining stream or transitional streams would likely switch gradients and move to losing conditions, or certainly be put under significant stress in dry periods. Where estimated drawdown is at 0-5 m, historically gaining or transitional streams, it would be reasonable to consider these under risk from reduced groundwater accessions or losing conditions.

Uncertainty in groundwater elevations estimated in coastal areas was increased because of the inability to incorporate the coastal boundary element of HydroMap in the analysis.

The results for groundwater elevation mapping across Victoria (e.g. 1998-2020) should provide a good match to historic bore data, as the bore data was used indirectly (via HydroSight) for mapping. However, while the average result should be representative, the averaging of the bore data over the reporting period will mean individual water level results are not necessarily represented in the elevation mapping.

When generating GMU-scale statistics and metric results in the analysis, groundwater extraction bores only contribute to use within the GMU in which they physically sit, even though use from bores outside of a boundary of a GMU can contribute to drawdown in the watertable inside that GMU if the systems are linked (as they are in many cases, e.g. pumping bores to the north of the northern boundary of the Mid Loddon GMU). This is relevant in the use of GMU averaged use-drawdown relationships developed to assess metrics where use is from bores within each GMU. This should be considered when using the use-drawdown relationships and metrics results for GMUs, especially where a GMU borders an area of high groundwater use.

The approach to select unconfined groundwater bores by depth and VAF mapping missed a number of groundwater extraction bores known to be within unconfined aquifers in the Gellibrand, Gerangamete and West Wimmera GMAs. The results (recharge and water level) will be more highly uncertain than in other areas of the assessment.

The development of the relationships for GMUs between drawdown in the watertable and recharge as part of the metrics assessments should be considered when interpreting the results. The important aspects of the relationships to keep in mind are:

1. They are regional results (consider recharge and drawdown averaged across GMUs), and as such, are not designed to represent groundwater elevations at a local scale or at individual surface features (i.e. wetland).
2. They are designed so that zero groundwater use after 2020 will give zero drawdown (as drawdown from 1950-1974), which is not generally what the HydroSight modelling results show is occurring (at individual bores or on average across GMUs). The impact of climate and pumping between 1975 and 2020 causes a drawdown in the watertable from baseline levels before use is evenly applied from 2021. By forcing the drawdown-use relationships through 0-use/0-drawdown at 2021-40 and 2041-65, drawdown at use volumes below around ~1.5 times PCV use are generally under estimated.

Recommendations

- The mapping of the mean minimum and mean maximum head over large project reporting periods limits the mapping to only those bores with sufficiently long observation records to undertake HydroSight modelling and ignores the many bores with only a few observations. To get the best value out of the observational record, it is recommended that space-time groundwater level kriging be developed. This would enable all observations at all bores to be included in the mapping and would eliminate the need for HydroSight modelling to a develop baseline dataset prior to the mapping (HydroSight would still be required for predictive scenarios). From these maps, if multiple were produced, the annual minimum and maximum heads could then be easily extracted. And, given that these min/max maps are derived from the observations they are likely to be more accurate the those produced here where multiple stages of averaging were required.
- To improve the estimates of groundwater elevation at the local scale, particularly away from groundwater bores already modelled under this study, additional detailed (pumping) modelling of bores using HydroSight within a study region could be considered. For areas where groundwater extraction is present, undertaking HydroSight modelling of many more pumping bores would significantly reduce uncertainty in groundwater elevation results at this scale.
- Refinement of the approach of assigning drawdown to unmodelled pumping bores which cannot be modelled directly should also be considered to reduce uncertainty in groundwater elevation in these areas.
- Modelling a large number of alternative future climate timeseries in HydroSight for each bore would also reduce the uncertainty around future simulated groundwater level, as it provides a measure of the error around the future climate timeseries. This could be achieved by generating daily climate timeseries data for hundreds of replicates that each include climate change scenario gross rainfall volumes and inter-seasonal variability, and increasing probability of high rainfall events.
- Use of the DREAM process in HydroSight for estimating modelling uncertainty (more directly than was available at the scale of this project) when undertaking a more localised assessment of groundwater elevations, would provide a more accurate assessment of the magnitude of likely error in the results.
- Further work is recommended to undertake a thorough evaluation of the existing groundwater monitoring database and accurately assign VAF unit and confined/unconfined status for groundwater extraction bores, and to determine a method of spatially assigning non-metered groundwater extraction to reduce uncertainty in the estimates of groundwater elevation.
- Improvement of the coastal boundary component of HydroMap would benefit the estimate of groundwater elevations along the coast, particularly to reduce uncertainty in the seawater intrusion metric results.

Section 8 Conclusions

8.1 Suitability of the approach

The general approach in this project was to use statistical modelling of individual bore hydrographs to estimate the groundwater elevation and recharge to the watertable, using the program HydroSight, supplemented with recharge outputs from the water balance model SoilFlux. These outputs were then interpolated across Victoria for a range of future scenarios relating to groundwater use and climate change, using a kriging approach that considered elements of topography (HydroMap) for groundwater level, and a merge approach to combine individual bore model results and SoilFlux datasets for recharge. Stream flow analysis was also undertaken to estimate baseflow statistics in gauged rivers under future climate scenarios to inform impacts to waterway GDEs. The estimated drawdown in the watertable and change in recharge volumes from baseline levels (1950-1974) was then used to develop relationships between groundwater extraction rates and levels of impact to defined metric values. This provides a significant dataset to inform development of sustainable yield volumes for unconfined and semi-confined GMUs across Victoria.

The combined approach successfully developed a series of spatial and temporal datasets that have being developed consistently across unconfined and semi-confined GMUs and unincorporated regions, providing a number of statistical and mapped results to inform sustainable yield volume development. A number of limitations and uncertainties are linked with the input data, study approach and outputs, and these should be considered when interrogating the results.

The approach estimates bulk recharge to the watertable, which includes rainfall recharge, irrigation infiltration, surface water accessions and aquifer throughflow. This definition should be considered when reviewing the recharge results, and comparing them to estimates from other sources.

Whilst there is a natural tendency to evaluate results from project such as this at a local asset scale, the reality of existing datasets and state-wide resolution of creating recharge and groundwater elevation maps, the outputs of this study are only suitable for comparative assessments at the regional scale.

8.2 Project Outputs

The approach applied by this project, provided for the first time a statistical evaluation of recharge based upon all suitable groundwater monitoring bores across Victoria (2,234 bores), and combined with SoilFlux, created the first integrated hydrograph and land use/climate analysis of recharge. Estimates of groundwater elevation into the future were also modelled using the statistical evaluation of monitoring bore data (2,234 observation bores plus another 4,654 extraction bores used in mapping), producing predictions of groundwater elevation into the future with changing climate and groundwater extraction regimes. Additionally, stream flow statistics was produced for all Victorian stream gauges with a suitable monitoring record (63 gauges), estimating baseflow statistics for waterways under climate change. These analyses enabled a series of state-wide datasets to de developed, for recharge and groundwater elevation, for a range of time steps, groundwater extraction rates and climate change projections. Results were collated and reported for 51 unconfined and semi-confined GMUs across Victoria, where groundwater receptors, in the form of metrics values (i.e. consumptive users, GDEs and seawater intrusion), were assessed for impact under climate and groundwater extraction scenarios.

The key project outputs are summarised in Table 8-1.

Table 8-1 Key Project Outputs

Result dataset	Output format		
	Produced map	Digital dataset	Summary of results
GMU conceptual models	State-wide	-	By GMU
Groundwater elevation [1]	State-wide	Gridded product	By GMU
Change in groundwater elevation from baseline (1950-74) [1]	State-wide	Gridded product	By GMU
Uncertainty in the mean of groundwater elevation [1]	State-wide	Gridded product	-
Recharge to the watertable elevation [2]	State-wide	Gridded product	By GMU
Change in recharge to the watertable from baseline (1950-74) [2]	State-wide	Gridded product	By GMU
Uncertainty in the mean of recharge [2]	State-wide	Gridded product	-
Streamflow assessment [3]	-	Interactive spreadsheet	By gauge
Metrics assessment:			
Consumptive users [1]	By GMU	-	By GMU
High value wetland GDEs [1]	By GMU	-	By GMU
High value terrestrial GDEs [1]	By GMU	-	By GMU
High value waterway GDEs [1]	By GMU	-	By GMU
Seawater intrusion [1]	By GMU	Gridded product	By GMU

Notes: [1] Produced for 35 project scenarios (time step, climate change, groundwater extraction).

[2] Produced for 9 project scenarios (time step, climate change).

[3] Produced for 7 project scenarios (time step, climate change).

8.3 Recharge to the watertable

Recharge to the watertable is expected to be impacted significantly under most climate scenarios across Victorian regions out to 2065. The results of this project estimate many parts of Victoria will observe greater than 30 percent less recharge to the watertable when compared to the baseline period (1950-1974) under medium and high climate scenarios into the future. Out to 2065 under medium climate change, most unconfined and semi-confined GMUs in Victoria are estimated to see reduction in recharge of more than 10 percent from baseline levels. GMUs with the largest estimated reduction in recharge were located in the central northern and highlands of Victoria, corresponding with areas of significant rainfall reduction under climate change coupled with groundwater extraction.

Comparing state-wide recharge estimations developed under this project to existing recharge estimations is problematic, because of the varying methods used in analyses and the specific components ‘recharge’ being estimated (e.g. rainfall recharge only compared to bulk recharge). Notwithstanding this point, project outputs sit within the range of results of previous studies on state-wide recharge, with an overestimation possible in some parts of Victoria with dryer landscapes.

8.4 Groundwater elevation

As the greatest control on watertables is recharge, it is relatively unsurprising that the marked reduction in recharge from future changes to climate leads to state-wide declines in watertables, across both areas of groundwater extraction and areas of little to no groundwater extraction. This pattern is borne out in project results for groundwater elevation. Combined with groundwater extraction rates, drawdown in the watertable is expected to be greatest in central-northern Victoria into the future, with around 40% of unconfined and semi-confined GMUs across the state estimated to an experience an average drawdown in the watertable across the GMU from baseline levels of more than two metres at 2021-40 under medium climate change. These potential impacts to the watertable transfer to wetland, terrestrial and waterway GDEs in these areas. Gellibrand, Jan Juc, Newlingrook, Leongatha and Gerangamete GMAs were estimated to already have an average drawdown across the GMU of around 2 m from baseline to the current period (1998-2020).

The seawater intrusion assessment estimated that half of the coastal GMUs assessed show at least 50% of the coastal area (within one kilometre of the coast) with average annual minimum groundwater elevation at or below 1.5 mAHD at 2021-40 under medium climate change.

8.5 Assessment of metrics

Project outputs for recharge and groundwater elevation were analysed with respect to the location of metrics values within each GMU, in order to undertake an assessment of sustainable yield metrics for the project. Volumes of recharge and groundwater use associated with metric levels of drawdown in the watertable under project scenarios were determined for the metrics values, and summarised for each GMU. A relationship between groundwater extraction and drawdown at the location of metrics values was determined, so that predictions could be made about likely drawdown under a range of future use scenarios for each GMU and climate scenario.

The development of these GMU-scale summaries of project outputs for metric values enables a consistent state-wide assessment of future sustainable yields, within both areas of current groundwater extraction and areas of potential future groundwater extraction, and with changing climate and consumptive patterns across Victoria.

8.6 Uncertainty and limitations

Uncertainty in the results was reported as uncertainty in the mean of recharge and groundwater elevation (separately), statistics that do not cover all potential errors and uncertainties in the data and methods. Because of this, uncertainty reported in this project should be considered indicative of relative uncertainty (i.e. higher in some areas and lower in others) rather than as a band of uncertainty around reported average values in which the real result lies. Results should be considered at a scale of 10 km+. Uncertainty is highest in areas where there was no or very sparse bore data, namely in the highlands and far-east Gippsland. In these areas the results should be used with more caution. The use of low and high climate change results bounding medium climate change results (as an average) for future time periods in the metrics assessment does provide a useful indication of the potential range of results a region may observe in the future. The results are less certain for the 2041-65 time step than for 2021-40, due to the increased uncertainty of climate change factors, rainfall and extraction predictions that far into the future, but they do provide a useful range of potential outcomes.

The approach of combining HydroSight, HydroMap and SoilFlux methodologies to simulating future recharge and groundwater elevation was relatively successful, albeit with a number of limitations. These include the issues with the assumptions made to include unmodelled groundwater extraction bores in watertable mapping, kriging average water levels across highly variable topography, and limitations of the uncertainty estimates accompanying outputs. In general, however, the approaches provide a novel and promising method of modelling recharge and groundwater elevation across both large and small regions from sparse groundwater monitoring data with wider potential application.

The results for groundwater elevation mapping across Victoria (e.g. 1998-2020) should provide a good match to historic bore data, as the bore data was used indirectly (via HydroSight) for mapping. However, while the average result should be representative, the averaging of the bore data over the reporting period will mean individual water level results are not necessarily represented in the elevation mapping.

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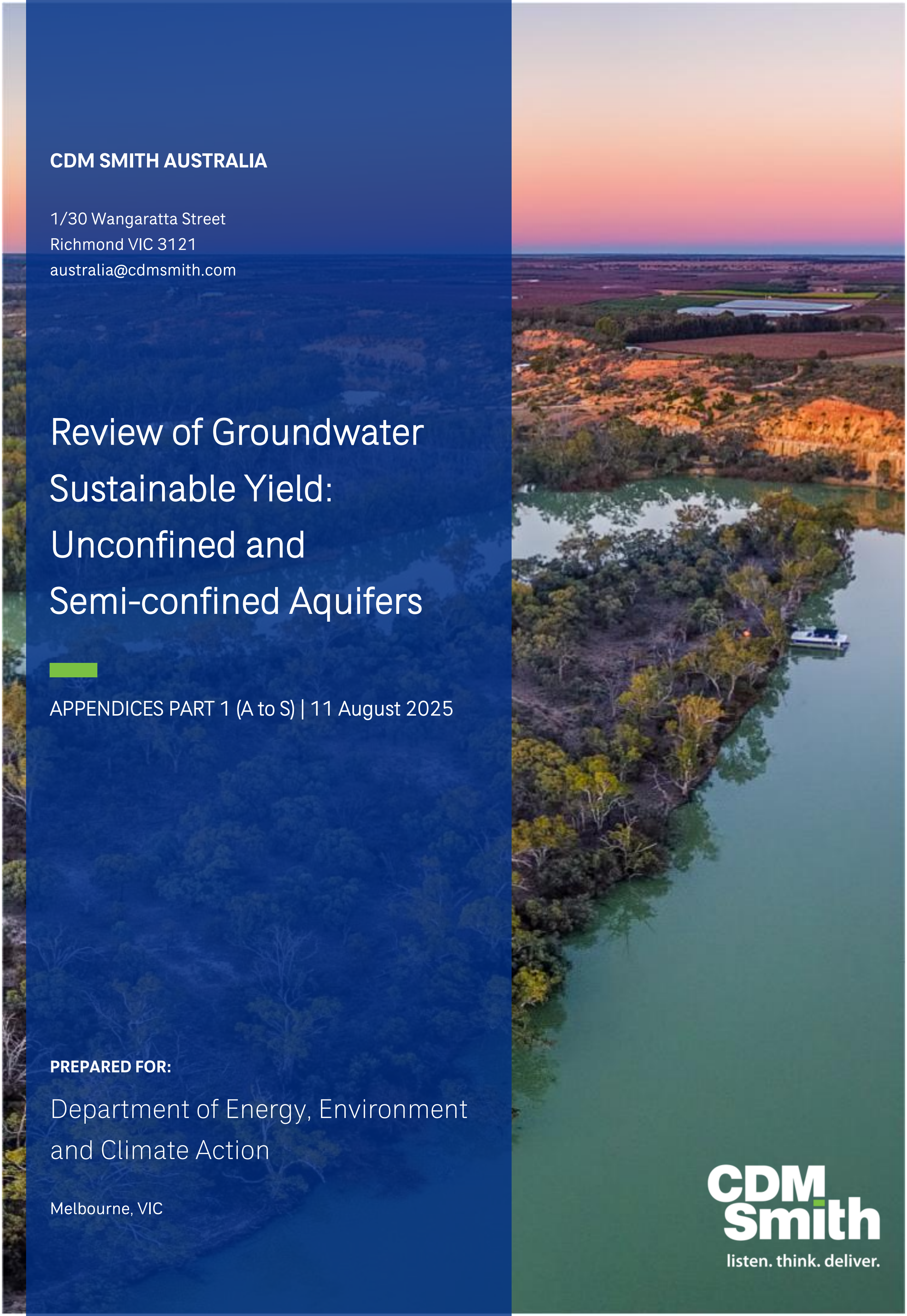

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Review of Groundwater Sustainable Yield: Unconfined and Semi-confined Aquifers

APPENDICES PART 1 (A to S) | 11 August 2025

PREPARED FOR:

Department of Energy, Environment and Climate Action

Melbourne, VIC

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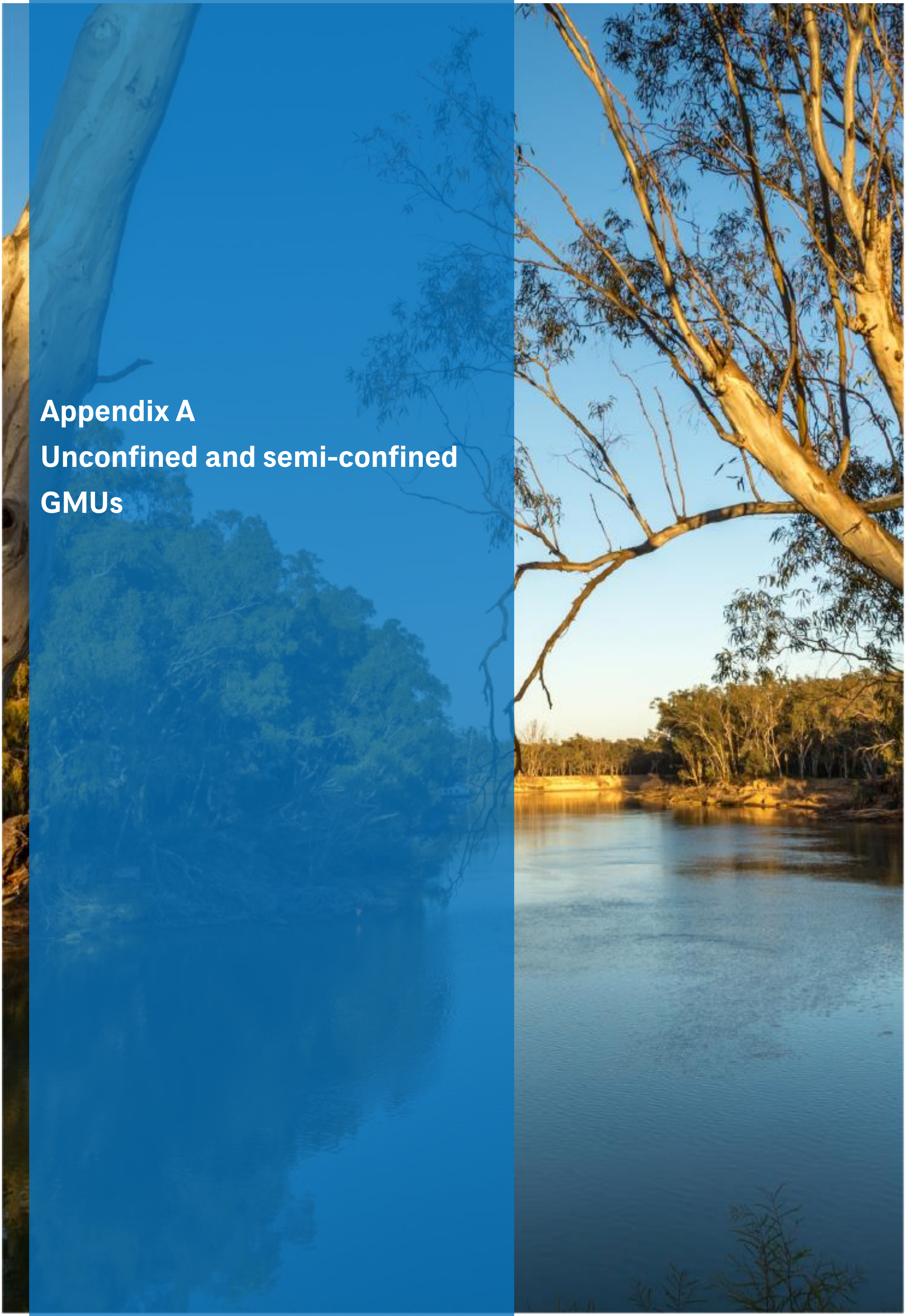
Appendices



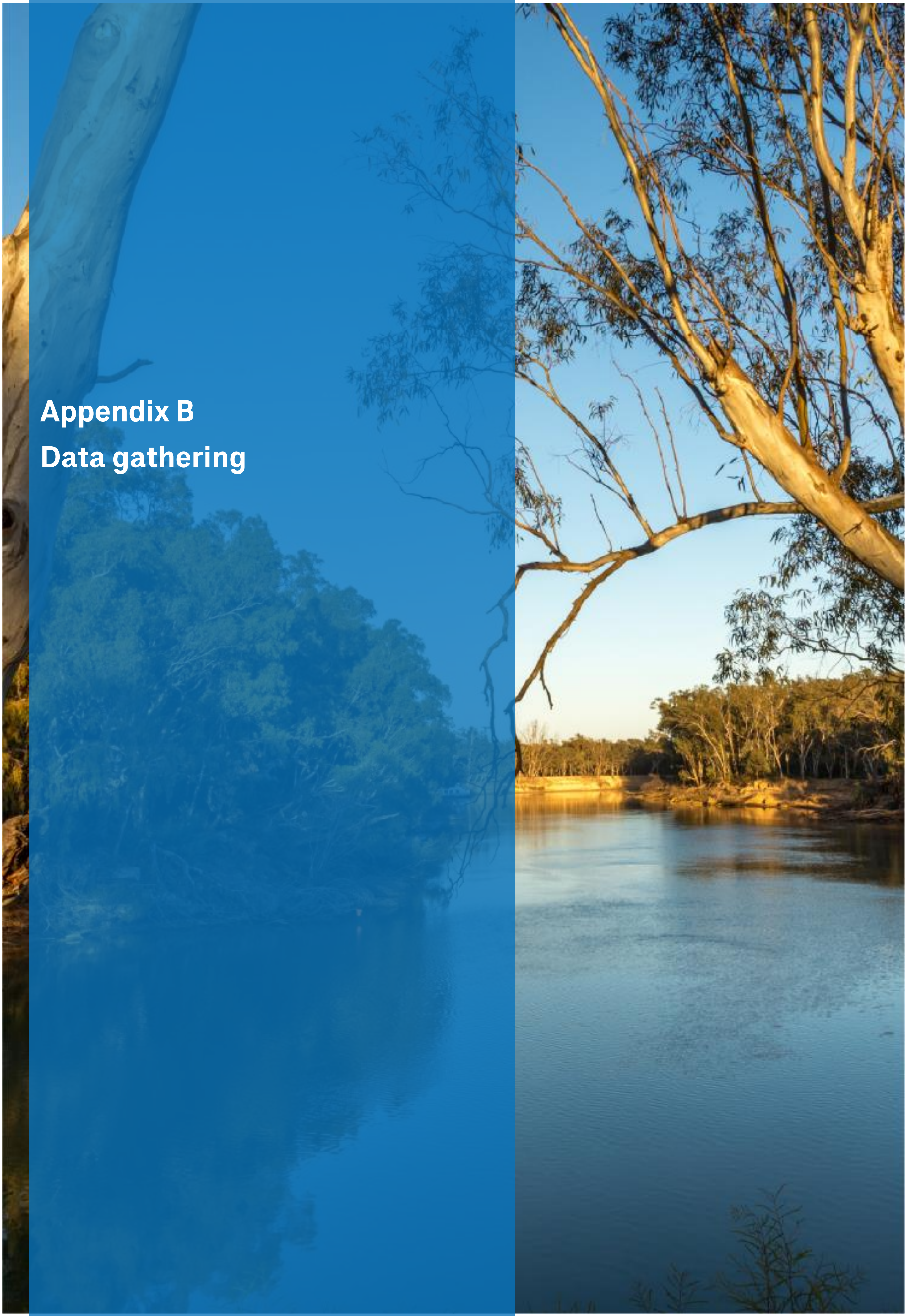
Appendix A

Unconfined and semi-confined GMUs

Table A-1 Unconfined and semi-confined GMUs covered by the project

GMU	Aquifer Type	Area (km^2)
Barnawartha GMA	Unconfined	69
Big Desert Zone (West Wimmera)	Transitional	6,615
Broken GMA	Unconfined	4,373
Bungaree GMA	Unconfined	206
Cardigan GMA	Unconfined	341
Central Victorian Mineral Springs GMA	Unconfined	3,314
Colongulac GMA	Unconfined	284
Denison GMA	Unconfined	172
Deutgam WSPA	Unconfined	65
Eildon GMA	Unconfined	3,801
Frankston GMA	Stacked	142
Gellibrand GMA	Partly Unconfined	83
Gerangamete GMA	Partly Unconfined	484
Glenelg WSPA	Stacked	3,009
Glenormiston GMA	Unconfined	106
Gymbowen Zone (West Wimmera)	Unconfined	931
Hawkesdale GMA	Transitional (Limestone), Stacked (volcanics)	1,414
Heywood GMA	Transitional (Limestone), Stacked (volcanics)	814
Jan Juc GMA	Partly Unconfined	290
Kiewa GMA	Unconfined	1,883
Koo Wee Rup WSPA	Transitional	1,114
Lancefield GMA	Unconfined	46
Leongatha GMA	Unconfined	201
Little Desert Zone (West Wimmera)	Unconfined	1,294
Loddon Highlands WSPA	Unconfined	2,877
Lower Campaspe Valley WSPA	Transitional	2,154
Lower Ovens GMA	Both	5,559
Merrimu GMA	Unconfined	14
Mid Goulburn GMA	Unconfined	1,692
Mid Loddon GMA	Unconfined	2,323
Moe GMA	Transitional/stacked	358

GMU	Aquifer Type	Area (km^2)
Moorabbin GMA	Stacked	137
Nepean GMA	Unconfined	104
Neuarpur Zone (West Wimmera)	Unconfined	786
Newlingrook GMA	Transitional	447
Northern Zone (West Wimmera)	Unconfined	5,371
Nullawarre WSPA	Unconfined	568
Shepparton Irrigation GMA	Unconfined	6,744
South West Limestone GMA	Unconfined	11,321
Southern Zone (West Wimmera)	Transitional	2,253
Strathbogie GMA	Unconfined	2,898
Tarwin GMA	Unconfined	30
Upper Goulburn GMA	Unconfined	3,428
Upper Murray GMA	Unconfined	10,063
Upper Ovens WSPA	Unconfined	1,647
Wa De Lock GMA	Unconfined	630
Wandin Yallock GMA	Unconfined	58
Warrion WSPA	Unconfined	395
West Goulburn GMA	Unconfined	5,315
Wy Yung GMA	Unconfined	55
Yangery WSPA	Unconfined	294



Appendix B

Data gathering

A.1 Groundwater levels

Victoria's groundwater bore database of over 120,000 bores was obtained from the Victorian Water Measurement Information System (WMIS) via DEECA in late 2021 for the purposes of extracting relevant groundwater bore information, including:

- Bore locations
- Groundwater levels – manual
- Groundwater levels - telemetered
- Construction information (depth, screen depth, construction date), and
- Ground surface elevation.

Groundwater level records (time-series) were extracted from the database for all monitored bores through time, and additional telemetered records provided by DEECA where available. This database includes all registered bores in Victoria, including observation and groundwater extraction bores (covering off on all official bore use classifications in the Victorian databases, including stock and domestic, investigation, dewatering, etc).

The timestep of water level records for manual, data logger and telemetered data logger collection ranged from sub-daily to bi-annually, with gaps in many records. Data quality codes were generally supplied with all observations.

The database was reviewed to identify bores suitable for use in the project. Screened interval was identified where data was available, and where not, the effective depth of the bore was given as the total depth of the bore where available. Where no screen or depth data was available, these bores were not used further in this project, as they could not be identified as likely watertable intersecting bores. Bores with an effective depth of less than 1m were also removed from the analysis so as to exclude unrealistically shallow and '0' depth recorded bores.

The effective depths of the bores were then considered in a spatial analysis against the depths of unconfined Victorian Aquifer Framework (VAF) aquifer units to identify likely watertable intersecting (unconfined) bores. A bore was classified for the purposes of this project as unconfined if there was no confining VAF unit overlying the effective depth of the bore at the bore's location.

Additional data validation was undertaken identifying and or removing bores that had incomplete bore construction information. Within this process data quality issues were identified, such as error within telemetry data sets that were either adjusted or the bore removed from the data sets.

This data was used throughout the project, including in HydroSight and HydroMap analysis to estimate recharge and groundwater level across the state, and for assessing potential impacts to existing extraction bores.

A.2 Groundwater use and entitlement

A number of datasets containing information on groundwater bores consumptive use and licenced (entitlement) volumes were obtained from DEECA for the purposes of extracting relevant groundwater use and licence information for groundwater extraction bores. The records included the following data:

- Licence (entitlement) numbers related to bore IDs
- Groundwater use volume per licence number per financial year between 2009 and 2020 (up to 2022 for some licences)
- Groundwater licenced volume per licence number per financial year between 2009 and 2020 (up to 2022 for some licences).

Where a licence had more than one bore assigned to it, and in the absence of any other information to attribute use between bores, the use volume under the licence was assumed to be split evenly between the bores associated with the licence.

Licensed bores in Victoria comprise groundwater bores taking more than 10 ML/yr. Groundwater bores taking less than this volume (e.g. stock and domestic bores) were not captured in the analysis.

The groundwater extraction bores were also identified as unconfined in the same process as described in Section A.1 above.

A collated database of unconfined groundwater extraction bores was used to identify 'active' extraction bores, which were classified as bores with non-zero use in the most recent five years of data (2015 to 2020). Effective recent use was calculated as the average annual use over the same period. This constitutes the list of consumptive users for which impact to groundwater levels is assessed in this project.

This data was used in HydroSight and HydroMap analysis to estimate recharge and groundwater level across the state, and for assessing potential impacts to existing extraction bores.

A.3 Stream flow

In order to perform the baseflow analysis, streamflow data was collated and analysed for a group of gauges selected based on the following criteria:

1. Streamflow gauges within Victoria where there is known to be, or likely to be, a connection between in-stream baseflows and levels in unconfined groundwater aquifers; *where waterways are dependent on groundwater (ie gaining streams*
2. Streamflow gauges with data available from the period post-1975 hydroclimatic baseline; and
3. Streamflow gauges with continuous data, with acceptable quality code flags, for a large proportion of the post-1975 period.

The final selection consisted of a group of 67 streamflow gauges, with 15 of them located in regulated rivers. Their location is shown in Figure B-1.

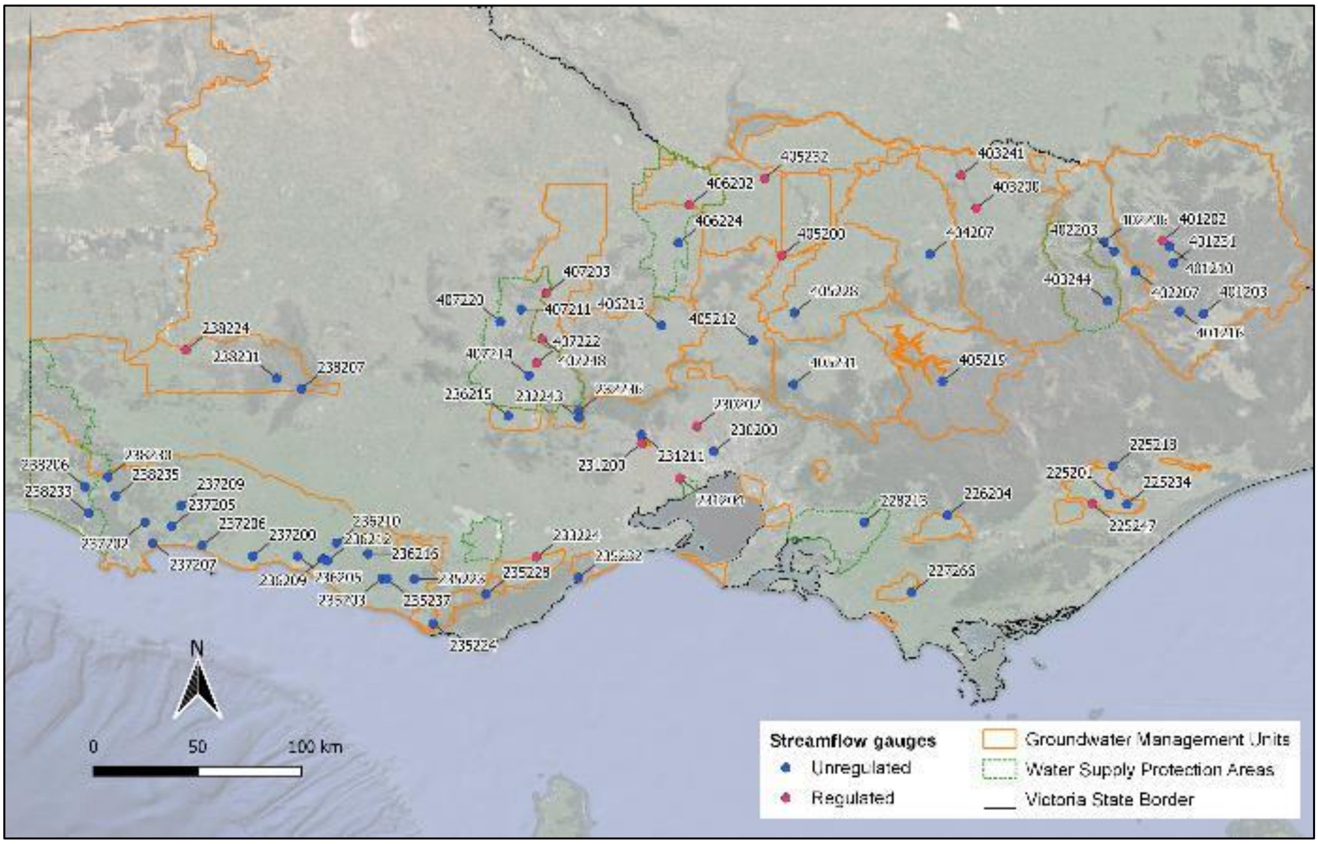


Figure B-1 Stream gauges used in baseflow and low flow analysis (HARC 2023).

Once the streamflow gauges were selected, quality control steps were undertaken for each of the data series, as follows:

1. Data filtering, where any record with quality code indicative of unreliable data (quality code numbers of 150 and greater) was set to missing data
2. Visual inspection of the data series, where periods of time with suspicious behaviour (such as successive flat periods in low flows) were set as missing.

A.4 Waterway connectivity to groundwater

Classification of losing or gaining to groundwater streams was taken from the SAFE project of Victorian groundwater-surface water interaction.

A.5 High value Groundwater Dependent Ecosystems

The dataset used to represent high valued GDEs is taken from the Victorian High Value at Risk GDE Layer developed for DELWP in 2018 (CDM Smith 2018). This project established the location and geometry of wetlands, rivers and terrestrial vegetation in Victoria that are groundwater dependent and are considered high valued.

A.5.1 GDE locations

The base layer geometry that comprise the final High Value at Risk GDE Layer was derived from the following datasets:

- The most recent boundary layer for wetlands - the Victorian Wetland Inventory (Current), which was updated in June 2015 and is held by the Water Division of DELWP. (https://www.data.vic.gov.au/data/dataset/victorian-wetland-inventory-current).
- The Index of Stream Condition 2010 River Centrelines Dataset was used as input for the most accurate current delineation of Victoria’s rivers, and is held by the Water Division of DELWP.
- The GDE Atlas distribution of subsurface ecosystems was used to identify terrestrial vegetation.

These three datasets were reduced in size, based on intersection with features contained in the GDE Atlas dataset for Victoria (the Atlas). Two GDE types were included in the assessment:

- GDEs reliant on the surface expression of groundwater (i.e. surface GDEs)
- GDEs reliant on the sub surface expression (vegetation) and located in riverine (floodplain or riparian) environments (i.e. subsurface GDEs)

Only surface and subsurface GDEs with the following indication of confidence in their GDE attribution were included in the assessment:

- Known GDEs identified in other studies
- Potential GDEs identified in national or other studies – High Potential
- Potential GDEs identified in national or other studies – Moderate Potential.

Ecosystems with “low”, “unclassified” and “not analysed” potential of being groundwater dependent were excluded from the assessment.

A.5.2 GDE Value

Ecosystem value can be defined in a myriad of ways, by using different combinations of existing value datasets and setting rules that determine the value hierarchy. CDM Smith (2018) includes a review of some key approaches to assigning high value to GDEs, used in previous studies within Victoria. This includes the approach adopted by:

- the Victorian Waterway Management Strategy (DELWP, 2013)

- the Ministerial Guidelines for The Licensing and Protection of High Valued GDEs (The Guidelines 2015)
- the Melbourne Water GDE Plan, and
- the Goulburn-Broken CMA.

The review found that the Victorian Waterway Management Strategy is the most comprehensive account of GDE value assessment. The strategies use the Aquatic Value Identification and Risk Assessment (AVIRA) database to inform values for selected rivers (from Index Stream Condition reaches), wetlands (from Wetland Current) and estuaries (from DELWP's estuary layer). *Need to note that basically all waterways are considered "high value" in this context*

Therefore, this project has adopted the high valued ecosystems identified within Regional Water Way Strategies. For Melbourne Water's jurisdiction, such a strategy is not available and instead existing GDE value data provided by Melbourne Water has been used in that area. The high value data acquisition for each CMA area is summarised in CDM Smith (2018).

For terrestrial vegetation GDEs, eleven environmental value datasets were used to inform terrestrial vegetation value. This list provides a comprehensive coverage of terrestrial vegetation across the state, that are both of value and are considered a GDE.

Table B-1 Environmental value datasets for assigning terrestrial vegetation GDEs with value (from CDM Smith, 2018)

Dataset	Attribute	High Score	Low Score
DEPI, Vicmap, Parks and Reserves	N/A	Intersect	No Intersect
RAMSAR	N/A	Intersect	No Intersect
Directory of Important Wetlands	N/A	Intersect	No Intersect
Victorian Biodiversity Atlas (which includes) VBA_FLORA25 VBA_FLORA100 VBA_FLORA_RESTRICTED VBA_FAUNA25 VBA_FAUNA100 VBA_FAUNA_RESTRICTED	EPBC	Critically Endangered	NA
		Endangered	
		Extinct	
		Vulnerable	
	FFG	Listed	Delisted
			Rejected
			Invalid/Ineligible/Rejected
	Flora Victorian endangered species listing	Endangered	Poorly Known
		Rare	Data Deficient
		Vulnerable	
		Presumed Extinct	
		Critically Endangered	
		Endangered	
		Extinct	
		Near Threatened	
		Regionally Extinct	
		Vulnerable	
	TREATY	CAMBA	
		CAMBA JAMBA	

Dataset	Attribute	High Score	Low Score
		JAMBA	
NV2005_EVCBCS Ecological Vegetation Communities Best Case Scenario	EVCBCSDESC	Endangered	Not Applicable
		Vulnerable	Least Concern
		Rare	
		Depleted	
Nature Print	Class value	5	0 to 4 Artificial Impoundment
		6	
		7	
		Wetland habitat recommended	

A.6 Climate

Climate data in the form of rainfall and potential evapotranspiration (PET) was sourced from SILO database of Australian climate (DES, 2023). Data used was daily rainfall (mm) and daily Morton's potential evapotranspiration (mm) for the period 1 January 1950 to 30 June 2020, which was a gridded product generated from observations at 5km resolution across Victoria.

Climate datasets for use in various modelling activities were extracted for historical reporting periods, as an average of total annual rainfall (mm/yr) and PET (mm/yr) of the years in the reporting period. Climate data was also modified by climate change factors to provide input datasets for projected climate under the climate change scenarios modelled for the project. An existing data product was not available in the form required for this project, so one was developed using available datasets.

The climate datasets were used in two ways:

- Rainfall and PET extracted from the grid for each bore used in HydroSight analysis based on that bore's location.
- The gridded datasets for rainfall were also used to estimate rainfall into the future for GMUs (to compare to recharge results), and in HydroMap to estimate the uncertainty in the mean of recharge.

A.6.1 Data requirement

The HydroSight analysis undertaken on this project require daily continuous timeseries data for rainfall and PET to estimate future depth to groundwater and recharge under climate change. The project requires climate change estimates to be consistent with DELWP's 2020 *Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria* (the Guidelines). The Guidelines do not prescribe a method for generating a single continuous daily timeseries of meteorological variables starting in the current climate and tracking the changing climate – instead they describe a method for scaling historical climate data to be climatologically consistent with future climate at specified points in time. The following method was developed for use on the project to generate the required datasets, using methods that are consistent with the Guidelines.

A.6.2 Method for generating climate data

A continuous daily timeseries for rainfall and PET was required for each individual bore analysed by HydroSight (~3,500 bores) and gridded across Victoria, from 1950 to at least 2065, for each of the three (low, medium and high) climate changes scenarios for RCP8.5. Historical data from 1 January 1950 to 30 June 2020 has been sourced from SILO for this project. Daily data from 1 July 2020 until 30 June 2085 needs to be developed and climate change factors applied using the method described below.

This project requires the use of Low (10th percentile), Medium (50th percentile) and High (90th percentile) climate change factors for RCP8.5, so climate change models and individual cell results were selected corresponding to the relevant percentile.

An empirical downscaling method, using the post-1975 historic climate reference period, similar to that which was used to generate the climate projections in the Guidelines, was undertaken, with modifications to ensure the climate change in the downscaled timeseries matches the projected climate change. The following steps were undertaken:

1. Obtain the seasonal and annual gridded hydroclimate projections for Victoria from the CSIRO ("period a" = 2040 (2031-2050), "period b" = 2065 (2056-2075)). The CSIRO dataset contains the change factor results from the full set of CMIP5 global climate models for each grid point, time step (2040, 2065; called periods 'a' and 'b' in the dataset) and RCP4.5 and RCP8.5.
2. Determine which model corresponds to the low (10th percentile), medium (50th percentile) and high (90th percentile) scaling factors for rainfall and PET RCP8.5 scenario for each grid point and each time step.

The historical data scaling method used in Potter et al (2016), on which the Guideline projections are based, recommends that for daily climate projections where intra-annual detail is relevant (such as seasonal variability and infrequent but high intensity rainfall), annual, seasonal and daily climate change factors should be used to scale climate data. This method is used to ensure variability is consistent with the fine spatial scale, and consistent with historical variability while minimising the assumptions and artifacts that can result from other statistical downscaling methods, and avoiding the high computational cost (and potential biases) of dynamical downscaling. It enables the full model ensemble to be used to specify the probability distribution into the future.

Following the Guidelines, aggregated projected rainfall change factors over each basin were used to select a model representative of low, medium and high scenarios, using the following process

1. Once the correct model is identified, the relevant scaling factors for rainfall and PET for each grid point, each of the 4 seasons, the 53 daily scaling values and annual data are extracted
2. Obtain the list of bores to be analysed in HydroSight and their coordinates)
3. Undertake a spatial proximity match between the bore locations and the gridded climate data from CSIRO to identify the closest climate grid cell to each bore location
4. Match the relevant rainfall and PET scaling factors (for 10th, 50th and 90th percentile, and 2040, 2065, 53 daily, 4 x seasonal and 1 x annual) from the closest climate data to each bore
5. Interpolate the scaling factors for each year between 2021, 2040 and 2065. As per the Guidelines (Section 4.3.6) a linear interpolation applied between these years is appropriate. Proposed formulas for scaling factor factors and final scaling factors are below.

Table B-2 Scaling factor factors for climate data projections for any date (daily)

For each day in period	Scaling factor factor (SFF)	Final scaling factor for any day (DATE)
1 Jan 1975 - 31 Dec 2021	0	0
1 Jan 2022 - 30 Jun 2040	$\frac{\text{Scaling factor (1995)} - \text{Scaling factor (2040)}}{\text{30 Jun 2040} - \text{30 Jun 1995}}$	$\text{SFF x (DATE} - \text{30 Jun 1995)}$
1 Jul 2040 - 30 Jun 2065	$\frac{\text{Scaling factor (2065)} - \text{Scaling factor (2040)}}{\text{1 Jul 2065} - \text{1 Jul 2040}}$	$\text{SFF x (DATE} - \text{30 Jun 2040)} + \text{Scaling factor (2040)}$
1 Jul 2065 - 31 Dec 2075	$\frac{\text{Scaling factor (2065)} - \text{Scaling factor (2040)}}{\text{1 Jul 2065} - \text{1 Jul 2040}}$	$\text{SFF x (DATE} - \text{30 Jun 2065)} + \text{Scaling factor (2040)}$

Table B-3 Scaling factor factors for climate data projections for each year, where SF_i = [(YEAR - YEAR0) / (YEARF – YEAR0)] * SF_YEARF (refer the Guidelines, Equations 2, 3 and 4)

For each year in period	Scaling factor factor (SFF)	Final scaling factor for this year
1 Jul 1975 – 30 Jun 2021	0	0
1 Jul 2021 – 30 Jun 2040	$\frac{(\mathrm{YEAR} - 1995\ )}{30\ \mathrm{Jun}\ 2040 - 30\ \mathrm{Jun}\ 1995}$	$\mathrm{SFF\ \ x\ Scaling\ factor\ (2040)}$
1 Jul 2040 – 30 Jun 2065	$\frac{\mathrm{YEAR} - 2040}{2065 - 2040}$	$[\mathrm{SFF\ \ x\ (scaling\ 2065 - scaling\ 2040)}] + scalingfactor\ 2040$
1 Jul 2065 – 30 Jun 2085	$\frac{\mathrm{YEAR} - 2065}{2065 - 2040}$	$\mathrm{SFF\ \ x\ (Scaling\ Factor\ 2065 - scaling\ factor\ 2040\ )}$ $+ \mathrm{Scaling\ factor\ (2065)}$

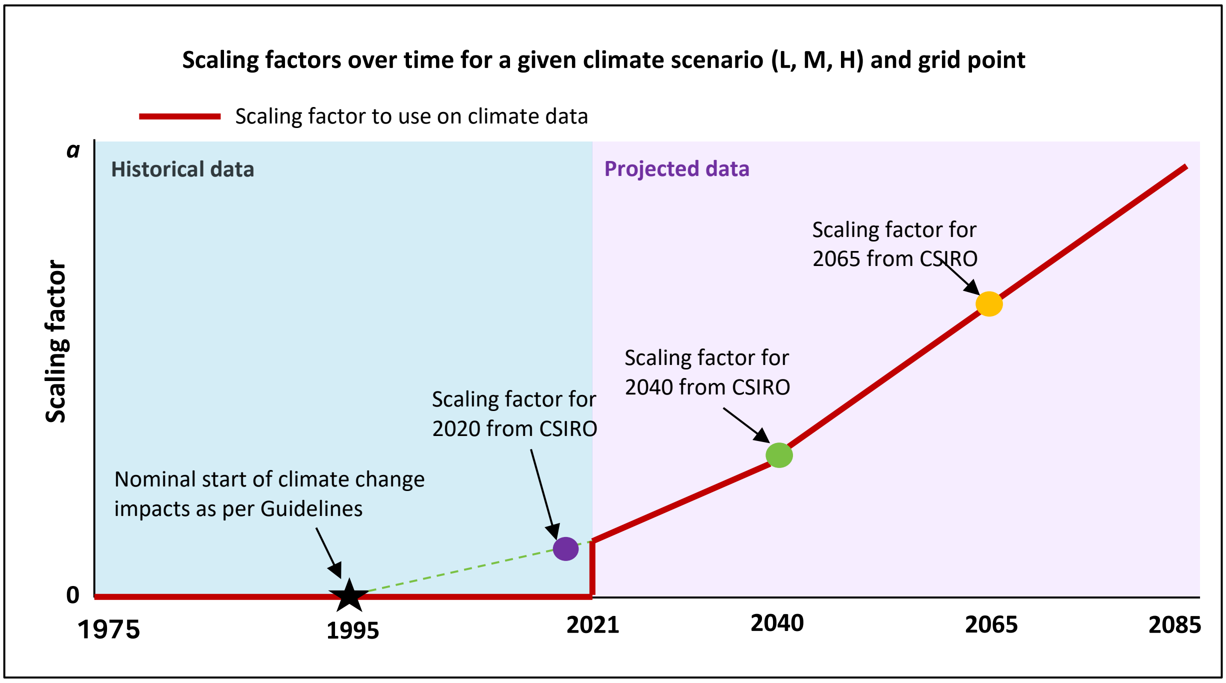


Figure B-2 Depiction of the approach of developing scaling factors for climate data future projections

The end date of analysis of 2085 has been selected to allow for some averaging of results over the years around the reference date of 2065 to accommodate for the uncertainty around the underlying climate timeseries.

Process for developing a projected climate dataset to 2085

1. Obtain a daily 5kmx5km gridded rainfall and PET historic timeseries record from SILO for each bore location over the *post-1975 historic climate reference period*, being 1 Jul 1975 to the most recent year of available data (for this project, 30 Jun 2021) (refer the Guidelines, Section 5.3)
2. This period is chosen in accordance with the guidelines, as a period with a representative degree of variability, numerous ENSO events and both positive and (a partial) negative IPO phases
3. Construct a climate dataset for each of rainfall and PET by joining the 1975-2021, 45 years of historic data, back-to-back three times, to run 1975-2021 > 2022-2067 > 2067-2113, and cut the end of the data to end at 30 Jun 2085

4. If connecting this timeseries 'back to back' is considered undesirable, a longer baseline period could be adopted, e.g. 1950-2014. The advantage of this is that it contains a full negative IPO phase and has the same mean rainfall as the entire BoM record

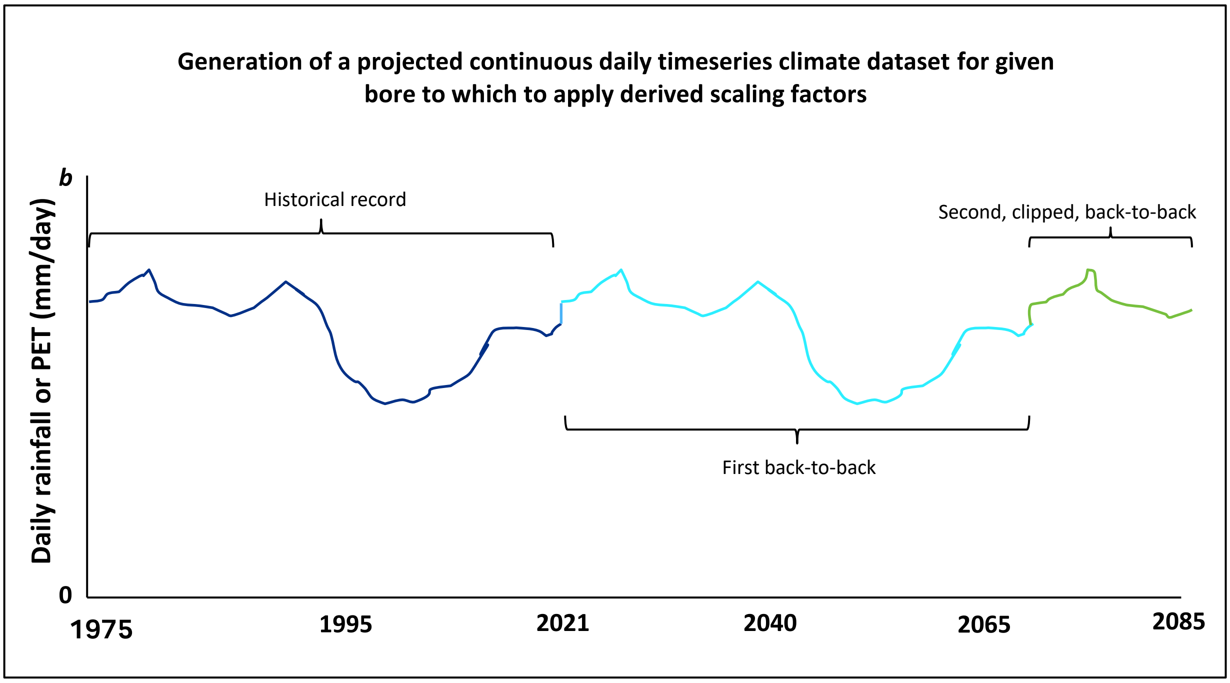


Figure B-3 Depiction of the approach to developing an underlying (no-climate change) climate timeseries from the historical record

Process for developing the climate change factored projected dataset

1. Apply the scaling factors to the climate datasets on a year basis (1975-2075), as described in Potter 2016, generating a projected climate dataset for both rainfall and PET for each bore and for low, medium and high climate scenarios.

   For rainfall

   a. Calculate daily percentiles from 1-50
      i. Apply first daily scaling factor to the day of maximum rainfall, and so on until the 50th highest rainfall day
      ii. Apply the 51st factor to rank 50-100 rainfall
      iii. Apply the 52nd factor to rank 101-200 rainfall
      iv. Apply the 53rd factor to other rainfall days
   b. Apply seasonal scaling to each season ensuring factors are annually adjusted seasonal scaling factors as described in Potter et al equation 2
   c. Apply remaining annual scaling factor.

   For PET - apply steps b and c above.

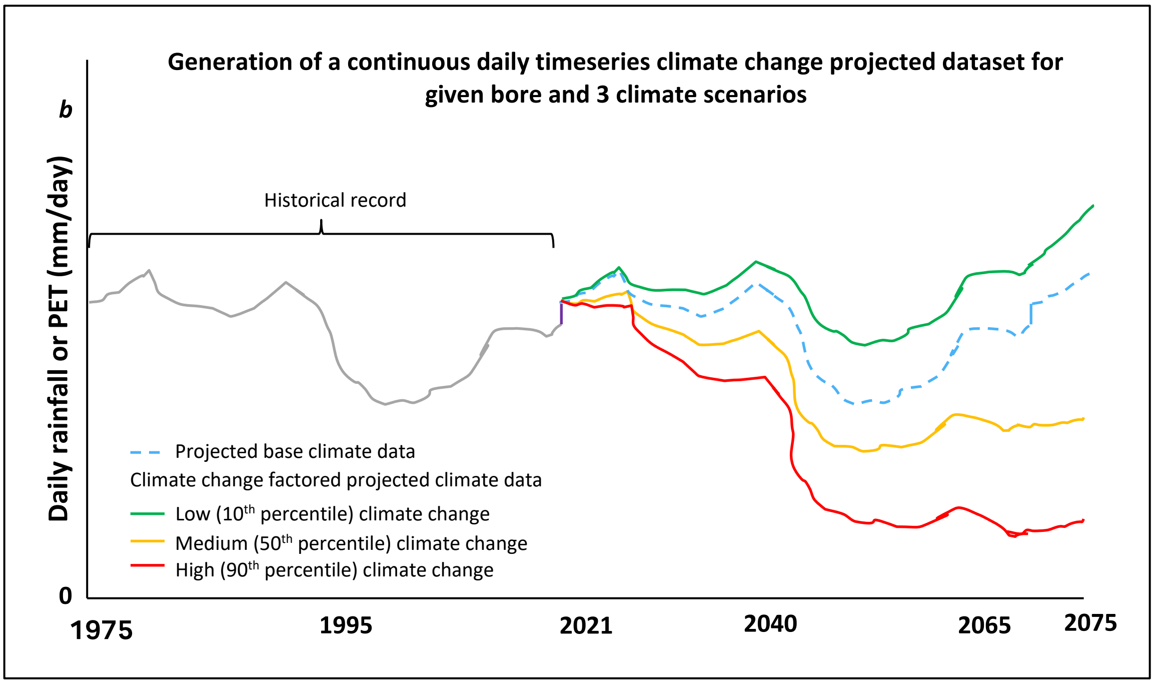


Figure B-4 Example of the final projected future climate timeseries developed using this method

A.7 Ground surface elevation

The 10m Digital Elevation Model (DEM) of land surface was downloaded for the extent of Victoria from ELVIS (ICSM,2023). This data was used in HydroSight analysis and the mapping of water levels across Victoria in HydroMap.

A.8 Previous HydroSight study results

There have been a few previous studies undertaken to examine groundwater pumping using HydroSight, the results of which are useful to include as additional data points in this project. These previous studies were undertaken by Xiang Cheng for the Victorian Department of Jobs, Planning and Resources (DJPR) on a number of bores across several GMUs in 2021, and Dr Tim Peterson and Simon Fulton for DELWP on a number of bores in Warrion GMA in 2019. These studies are summarised below.

Cheng – Multiple GMUs

- Source: *HydroSight Study: Estimation of Aquifer Properties and Recharge in Five Selected Groundwater Management Areas* (Cheng, 2021a, b) *Cheng. (2022). HydroSight study: estimation of aquifer properties and recharge in thirteen selected groundwater management areas. Agriculture Victoria (DJPR) Research Technical Report produced for DELWP.*
- Areas covered: Loddon Highlands WSPA (2 bores), Moe WSPA (1 bore), Nullawarre WSPA (1 bore), Glenelg WSPA (1 bore), Wa De Lock GMA (1 bore), Bungaree (3 bores), Hawkesdale (2 bores), Neuarpur (2 bores), Warrion (2 bores), Yangery (3 bores).
- Method: Relevant results from multiple bores from the HydroSight pumping analyses in the areas above were used as additional bore point inputs (extending the dataset generated under the project) in the mapping of state-wide estimated recharge and groundwater elevation for climate and pumping scenarios. Cheng's results were used for the following scenarios:
    - Baseline (1975-1997)

  - Current (1998-2020)
  - 2020-2040: low, medium and high climate change
  - 2041-2065: low, medium and high climate change

Peterson & Fulton – Warrion GMA

- Source: *VAF Enhancement using HydroSight* (Peterson and Fulton, 2018)
- Areas covered: Warrion GMA (32 bores).
- Method: Relevant results from 32 bores from the HydroSight pumping analysis in Warrion GMA were used as additional bore point inputs (extending the dataset generated under the project) in the mapping of state-wide estimated recharge and groundwater elevation for climate and pumping scenarios. Peterson and Fulton's results used only for the current (1998-2020) scenario because of the limited scenarios modelled in that work.

Selected bores were used alongside project-derived results in the HydroMap analysis to estimate recharge and groundwater level across the state, and for assessing potential impacts to existing extraction bores.

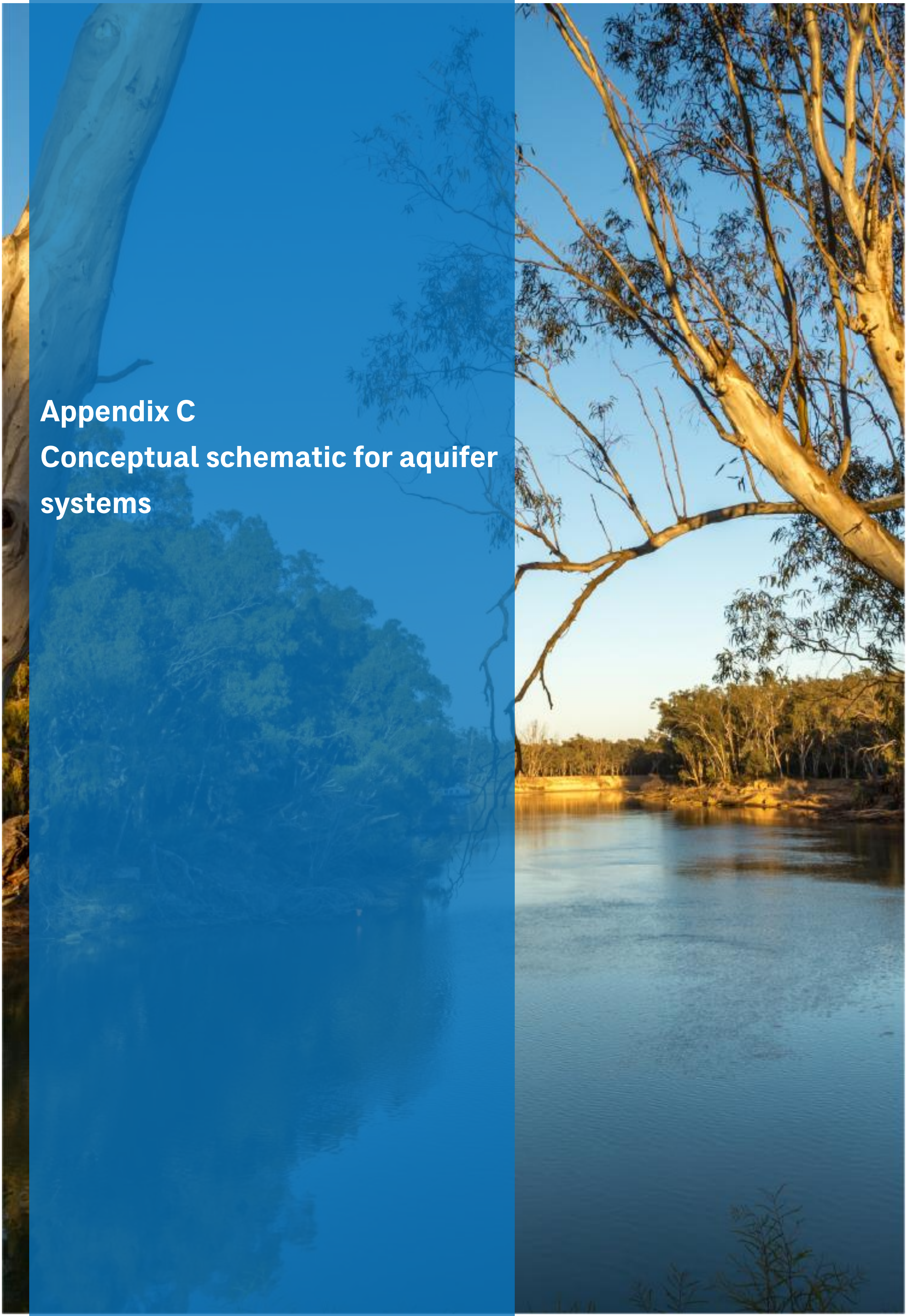
A.9 Previous SoilFlux model results

The results of the 2016 and 2017 runs of the SoilFlux model (HARC, 2016, 2017) were extracted by HARC for this project on a 1km grid for the whole of Victoria. Inputs parameters for each grid cell were determined by the 2013 reclassified depth to watertable data (DELWP, 2013) and 2015 reclassified Victorian Land Use Information System (VLUIS) land use data (Morse-McNabb et al.,2015). Mean annual recharge for the following scenarios were extracted from the previous modelling (HARC, 2023):

- 1961-1974
- 1975-2016
- 1975-1996
- 1997-2009
- 2010-2016

The following future predictions for recharge for the following scenarios were interpolated from primary SoilFlux output data as part of this project, using the correlation to mean annual rainfall for each grid cell:

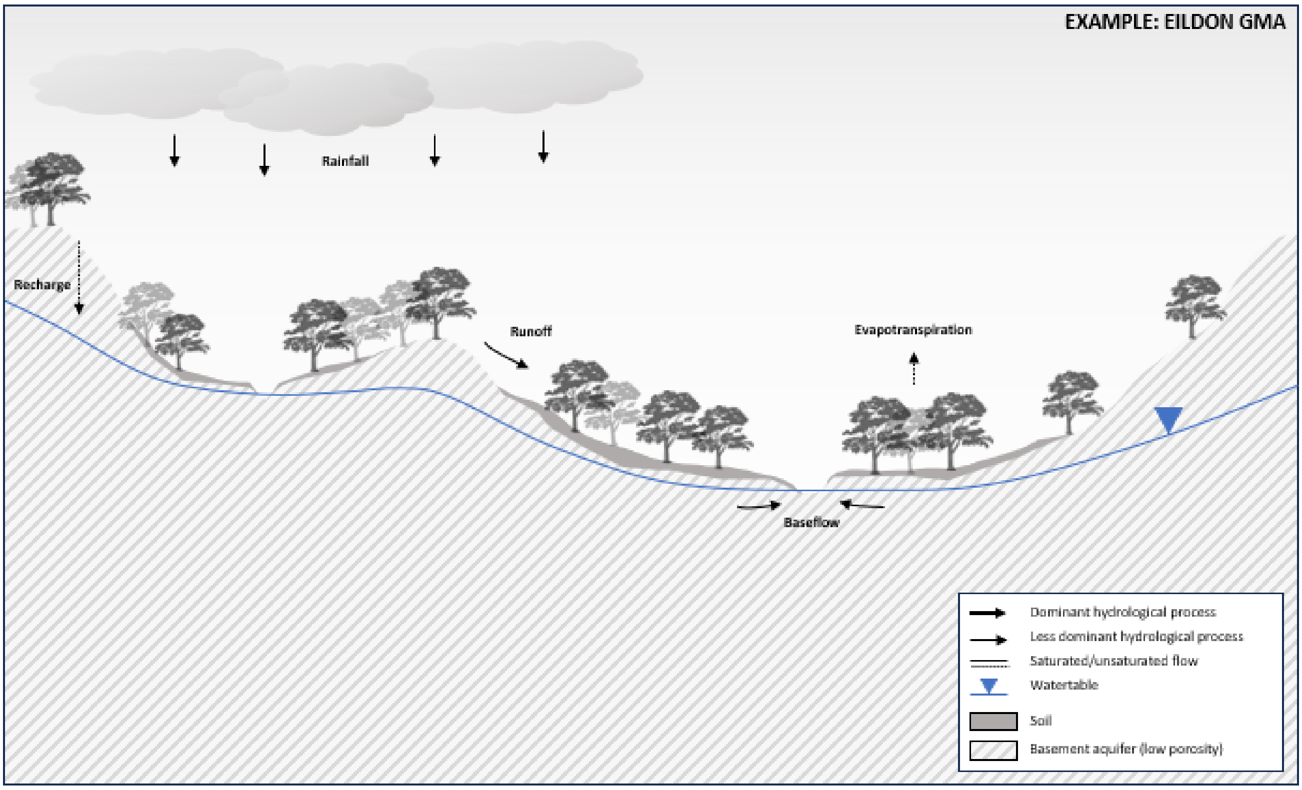
- Climate scenarios as per the 5-km CSIRO downscaled climate change projections for 2 greenhouse gas emission pathways, medium emissions (RCP8.5) from Climate Change Guidelines (DELWP, 2020):
  - Low climate change (10th percentile)
  - Medium climate change (50th percentile), and
  - High climate change (90th percentile)
- Time periods (calendar years)
  - 2040 - first prediction date, as per Climate Change Guidelines (DELWP, 2020), and
  - 2065 - second prediction date, as per Climate Change Guidelines (DELWP, 2020).



Appendix C

Conceptual schematic for aquifer systems

HIGHLANDS



Aquifer description: Outcropping bedrock/basement generally found in mountainous regions or steep and hilly areas. These were originally sedimentary rocks first deposited as thick sequences of alternating layers, generally on an ocean floor. Over time and tectonic activity these deposits were forced upwards forming mountains and hills. The sedimentary rocks can also be mixed with volcanic rocks and/or forced apart by intruding molten rock (granites). The process of weathering and tectonic activity results in cracking of the rocks forming a network of joints, fractures and faults in which groundwater can flow.

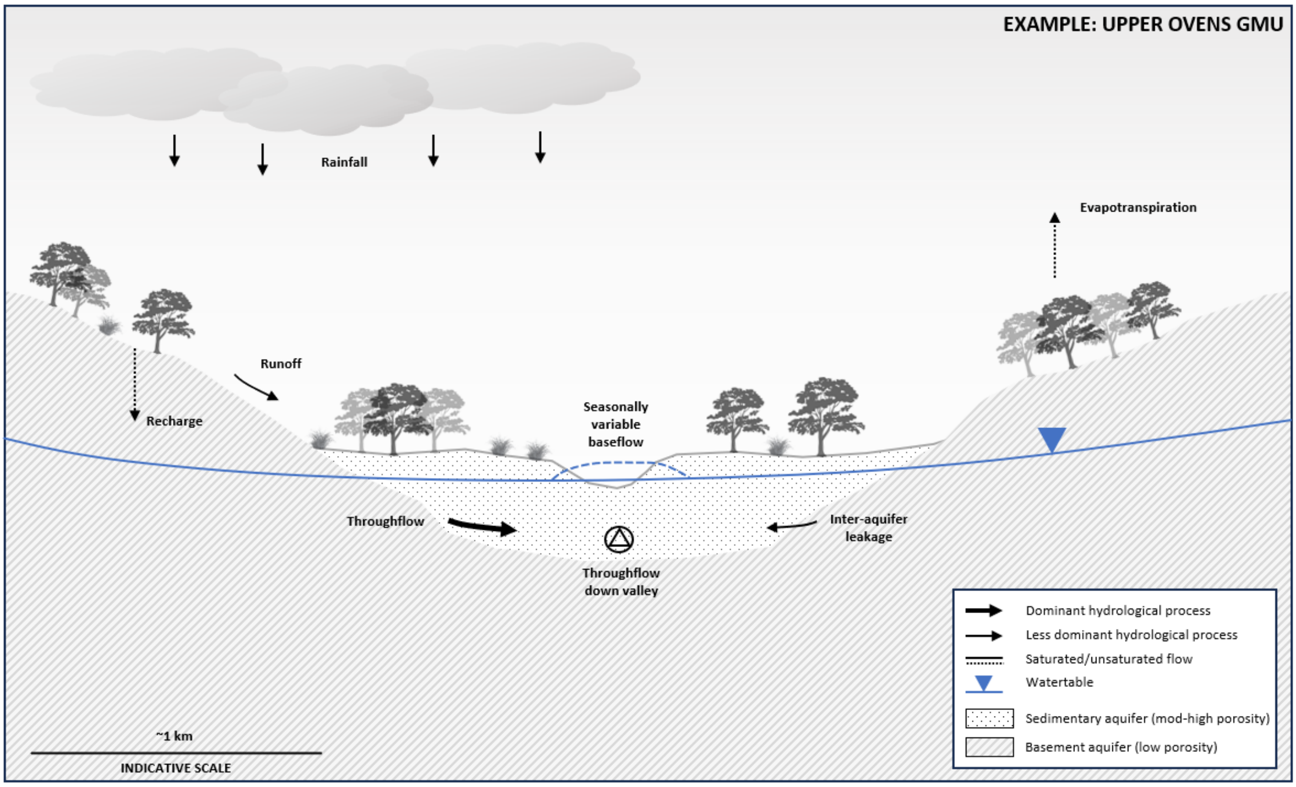
System description: Local flow systems heavily connected to surface waters, with low storage potential and rapid flux.

Connectivity: Interflow occurs via a network of joints, fractures and faults in which groundwater can flow, and the small alluvial deposits alongside waterways which are highly connected and dependent on groundwater for summer flows.

Dominant flow process: Recharge processes from rainfall with high dependency of waterways (>0.7 BFI) and little in-aquifer storage.

Figure C-1 Conceptual schematic for Highlands aquifer systems

SEDIMENTARY UPLAND VALLEYS



Aquifer description: Sedimentary Upland Valleys systems are developed on edges of plateaus, ranges and foothills as small/narrow valleys constrained by bedrock. In these valleys, permeable fine to coarse grained sediments have been eroded from outcropping bedrock and redeposited by water flow forming unconfined aquifers and are closely connected with the local surface water systems.

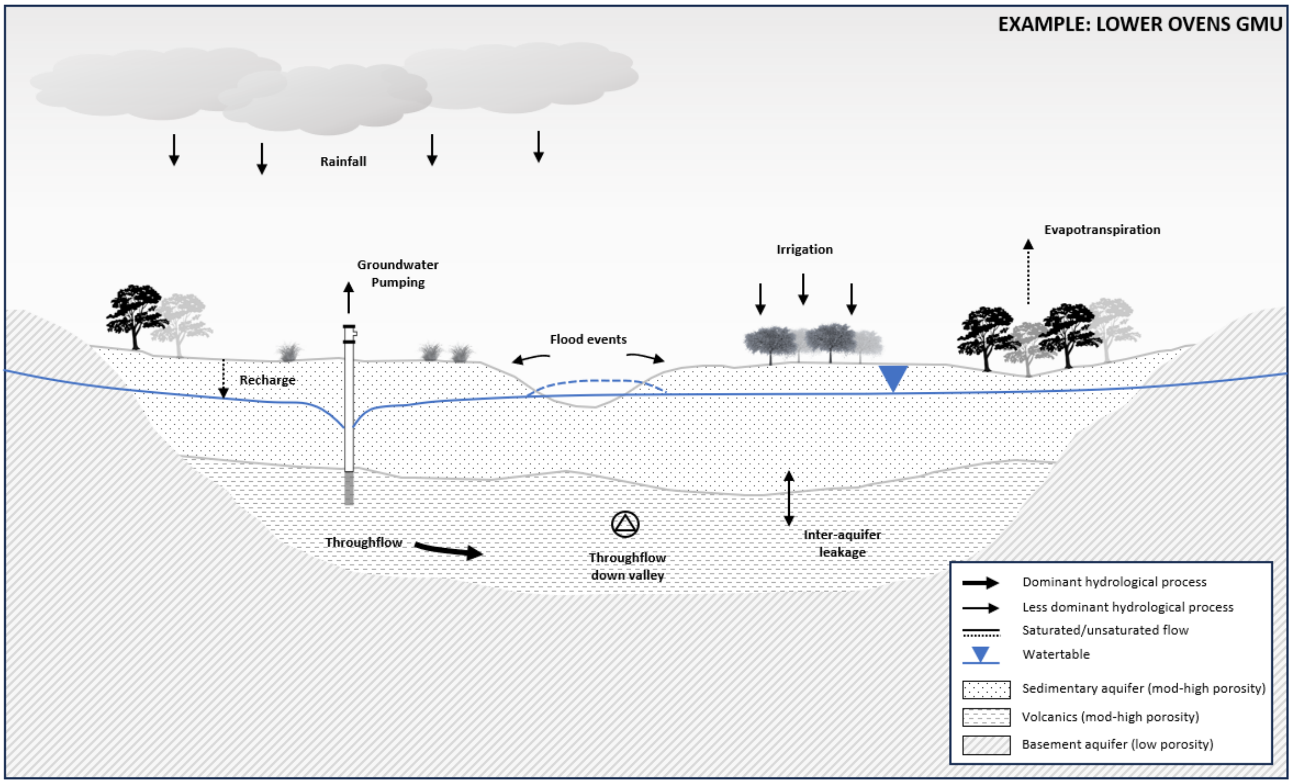
System description: Local flow systems in alluvial aquifers dominate flows and connectivity to streams.

Connectivity: Groundwater flow is determined by the underlying bedrock structures such as faults, folding and/or lithology change and may be restricted or preferentially directed by the underlying bedrock surface

Dominant flow process: Recharge process include surface water interaction, leakage from surrounding bedrock and rainfall.

Figure C-2 Conceptual schematic for Upland Valley aquifer systems.

SEDIMENTARY VALLEYS



Aquifer description: Sedimentary Valleys systems are constrained within a bedrock valley but are deeper and wider than Sedimentary Upland Valley systems. These systems generally have at least two distinct aquifer systems, the surficial aquifer that, generally, follows the surface water feature and there can be ancient buried river valleys (paleovalleys). A third layer may also be present consisting of clays and act as a confining/semi-confining layer to the deeper paleovalley.

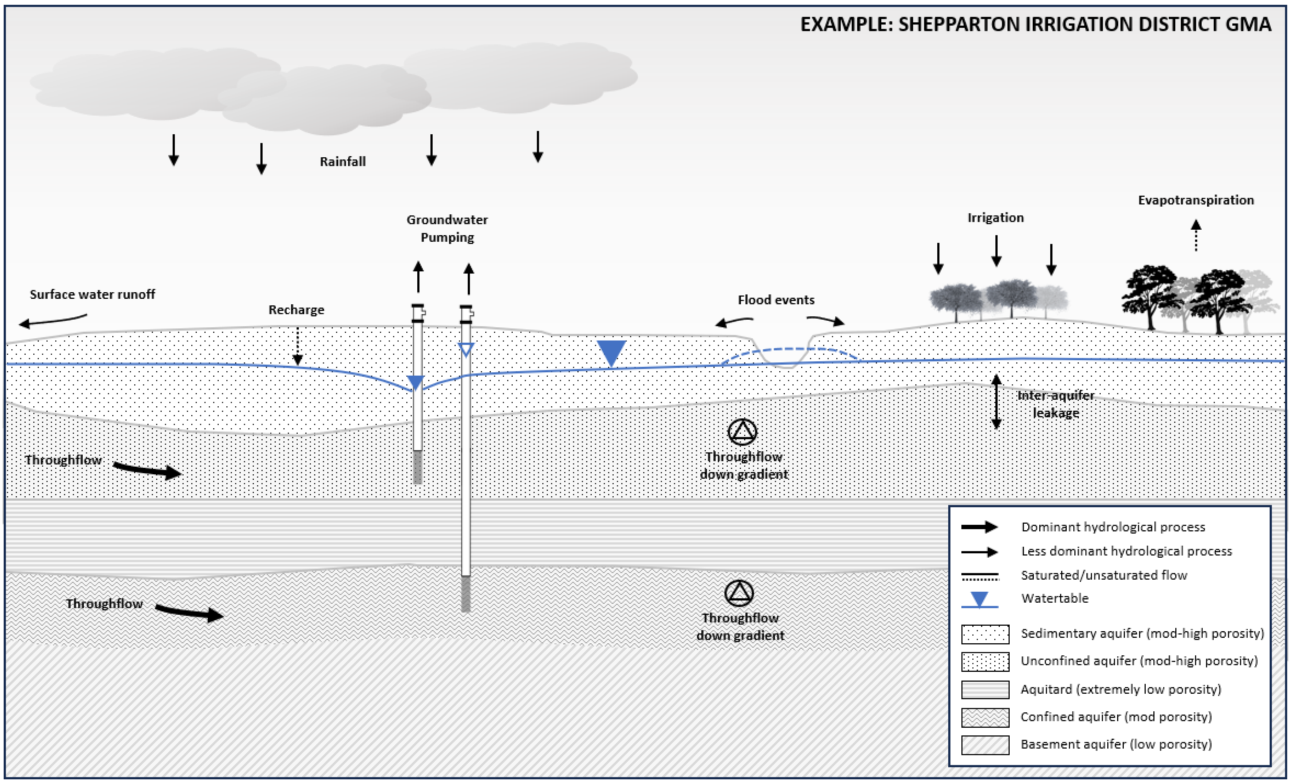
System description: Alluvial aquifer that follows river valleys with either one or two layered connected aquifers overlying bedrock system that bounds the alluvial aquifer extent.

Connectivity: Groundwater flow within the surficial aquifer is directed towards and along the dominant surface water feature and along the axis of the paleovalleys where they are present. In general the two aquifers, where clays do not exist, are considered to be connected and act as one homogenous layer through which groundwater flows, however can behave differently when stressed due to the different hydrogeological properties.

Dominant flow process: Recharge process include surface water interaction, flood events and irrigation, inter-aquifer leakage (including bedrock) and rainfall.

Figure C-3 Conceptual schematic for Sedimentary Valley aquifer systems.

SEDIMENTARY PLAINS



Aquifer description: The Sedimentary Plains system can be defined as a region where groundwater is contained within a complex interbedded sequence of aquifers and aquitards with no outcropping bedrock. The aquifers can be grouped into surficial/watertable systems and buried/confined systems.

SYSTEM 1 (WATERTABLE)

System description The watertable aquifer is unconfined and connected to underlying aquifers (semi-confined to confined systems).

Connectivity: The degree of interaction between the aquifers in the surficial system is dependent on the location, thickness and coverage of the confining layers. No bedrock structure influences on groundwater flow.

Dominant flow process: Recharge processes include rainfall, irrigation, surface water interaction and flooding and inter-aquifer leakage.

SYSTEM 2 (BURIED AQUIFERS)

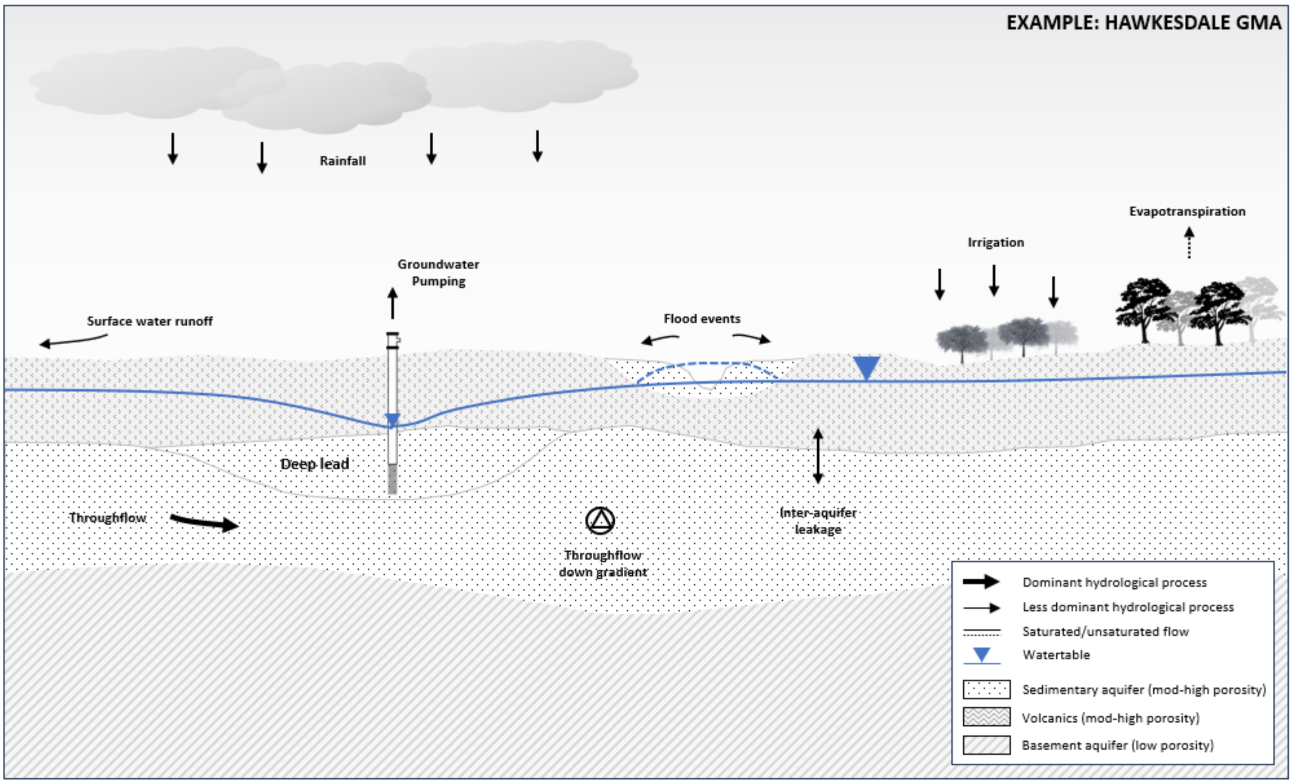
System description: In the buried aquifer systems, all aquifers are confined.

Connectivity: However, the degree of interaction and vertical flow direction of groundwater between aquifers within the buried system is dependent on storage capacity of each aquifer. Bedrock structures may influence groundwater flow.

Dominant flow process: Recharge is dominated by lateral inflow from other aquifers or from basin margins where the aquifer is exposed.

Figure C-4 Conceptual schematic for Sedimentary Plain aquifer systems.

VOLCANICS



Aquifer description: Volcanics consist of large lava flows that extend over hundreds of kilometres and range in thickness from a few metres to more than a hundred. In general volcanics landscapes are relatively flat with slopes that follow the general lay of the land. There are exceptions where there are landscape variations and occur where basalt plains have been incised by rivers and craters, and where volcanoes and scoria cones are present. Lava flows can also be contained within river valleys such as the Upper Loddon Valley.

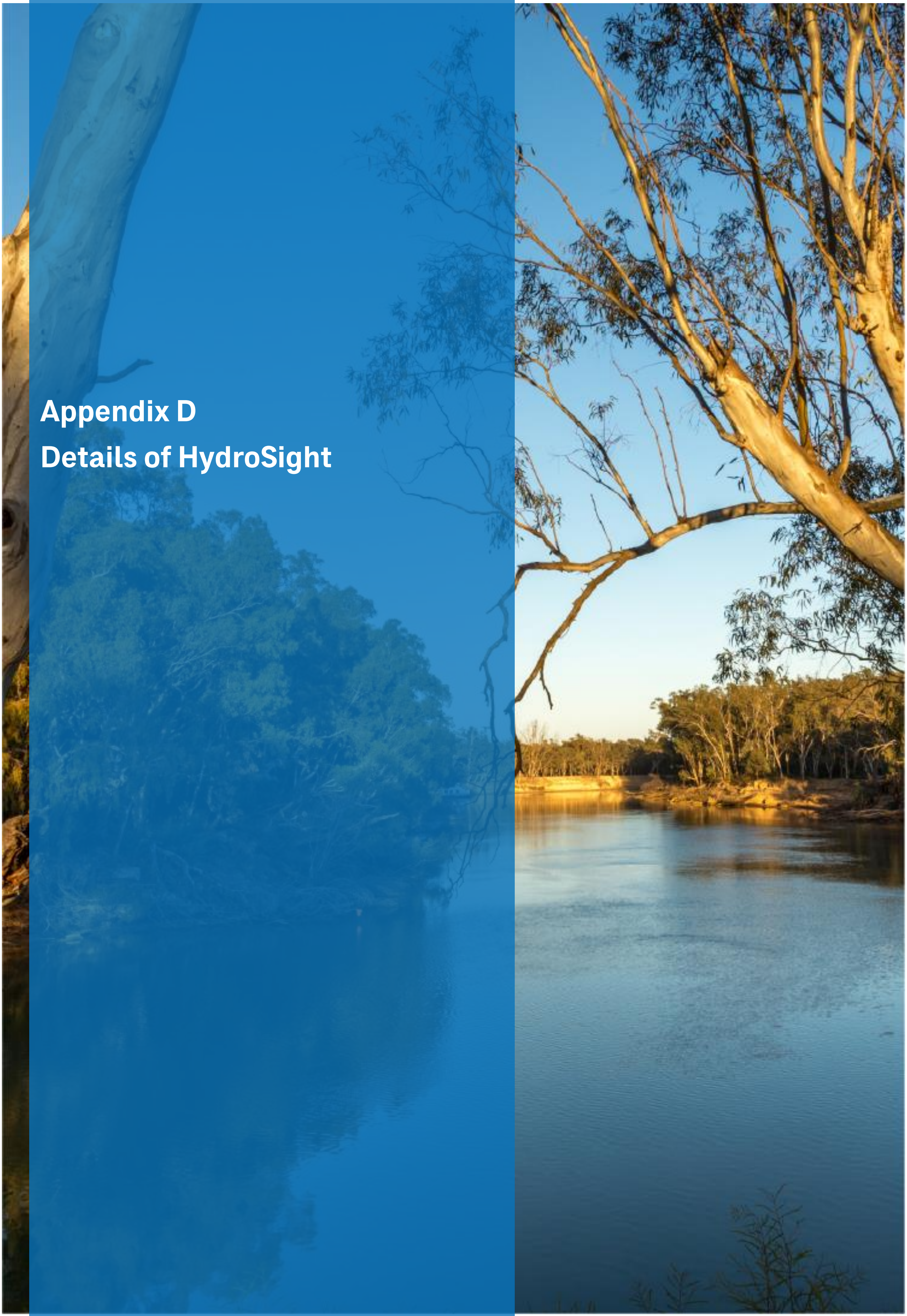
The Volcanics are not actually a ‘groundwater system’ but rather the dominant aquifer material and can occur in Sedimentary Upland Valley, Sedimentary Valley and Sedimentary Plain systems. The variability in permeability of the volcanics leads to high variability in yields and subsequent.

Dominant flow process: The variability in permeability of the volcanics leads to high variability in yields and subsequent development. They can have large volumes of groundwater available where recharge occurs directly through fractures and scoria cones. In other areas with lateral flows they are more impermeable and lower yielding, and restrict recharge to deeper alluvials.

Figure C-5 Conceptual schematic for Volcanics aquifer systems.

Appendix D

Details of HydroSight

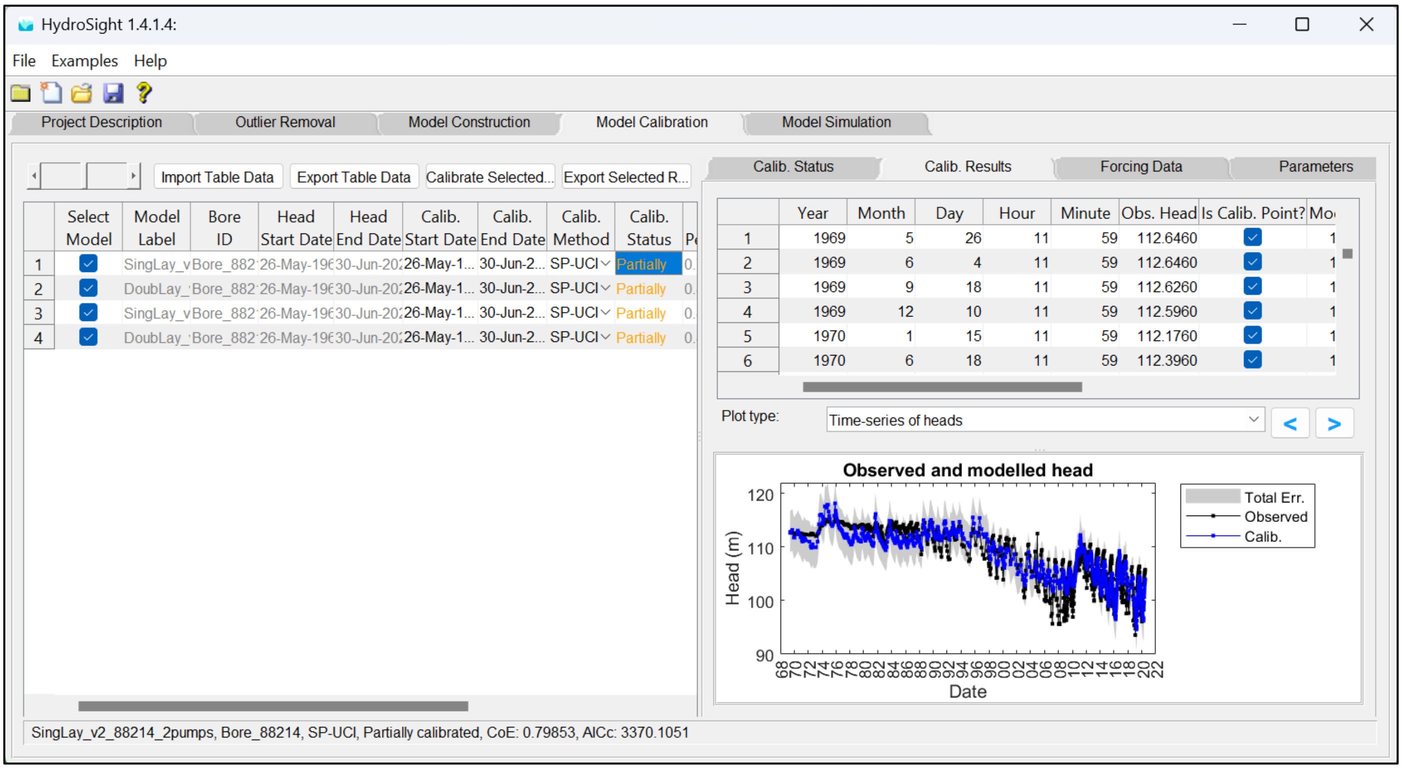


D.1 Introduction

HydroSight is a highly flexible statistical toolbox designed to extract quantitative information from groundwater level monitoring data. The toolbox uses readily available data (groundwater hydrographs, weather and pumping data) to enable data-driven investigations of:

- The driver of observed groundwater level trends
- Interpolation and extrapolation of hydrographs
- Identification of outliers
- Exploration of scenarios (e.g. differing pumping rates)
- Aquifer hydraulic properties; and
- Estimation of recharge;

It includes a power graphical interface (Figure D-1) that enables the efficient construction of hundreds of models and their robust interrogation.



	Select Model	Model Label	Bore ID	Head Start Date	Head End Date	Calib. Start Date	Calib. End Date	Calib. Method	Calib. Status	Pe
1	☑	SingLay_v	Bore_882	26-May-19	30-Jun-20	26-May-1...	30-Jun-2...	SP-UCI	Partially	0.
2	☑	DoubLay_	Bore_882	26-May-19	30-Jun-20	26-May-1...	30-Jun-2...	SP-UCI	Partially	0.
3	☑	SingLay_v	Bore_882	26-May-19	30-Jun-20	26-May-1...	30-Jun-2...	SP-UCI	Partially	0.
4	☑	DoubLay_	Bore_882	26-May-19	30-Jun-20	26-May-1...	30-Jun-2...	SP-UCI	Partially	0.

	Year	Month	Day	Hour	Minute	Obs. Head	Is Calib. Point?	Mo
1	1969	5	26	11	59	112.6460	☑	1
2	1969	6	4	11	59	112.6460	☑	1
3	1969	9	18	11	59	112.6260	☑	1
4	1969	12	10	11	59	112.5960	☑	1
5	1970	1	15	11	59	112.1760	☑	1
6	1970	6	18	11	59	112.3960	☑	1

Plot type: Time-series of heads

SingLay_v2_88214_2pumps, Bore_88214, SP-UCI, Partially calibrated, CoE: 0.79853, AICc: 3370.1051

Figure D-1 HydroSight Data input graphical interface (version 1.4.1.4)

D.2 Background concepts

HydroSight is a statistical toolbox designed to extract quantitative information (such as recharge estimates and predicted groundwater levels) from groundwater level monitoring data. The program simulates hydrographs for each modelled bore and provides estimates of groundwater level as and recharge together for scenarios of climate change and changes to groundwater extraction volumes into the future. Elements of the toolbox have been extended for use on this project by Dr Tim Peterson. The approach statistically weights input data in the prediction of the groundwater heads. Figure D-2 is a simplified example of the weighting process used to simulate a timeseries of groundwater levels.

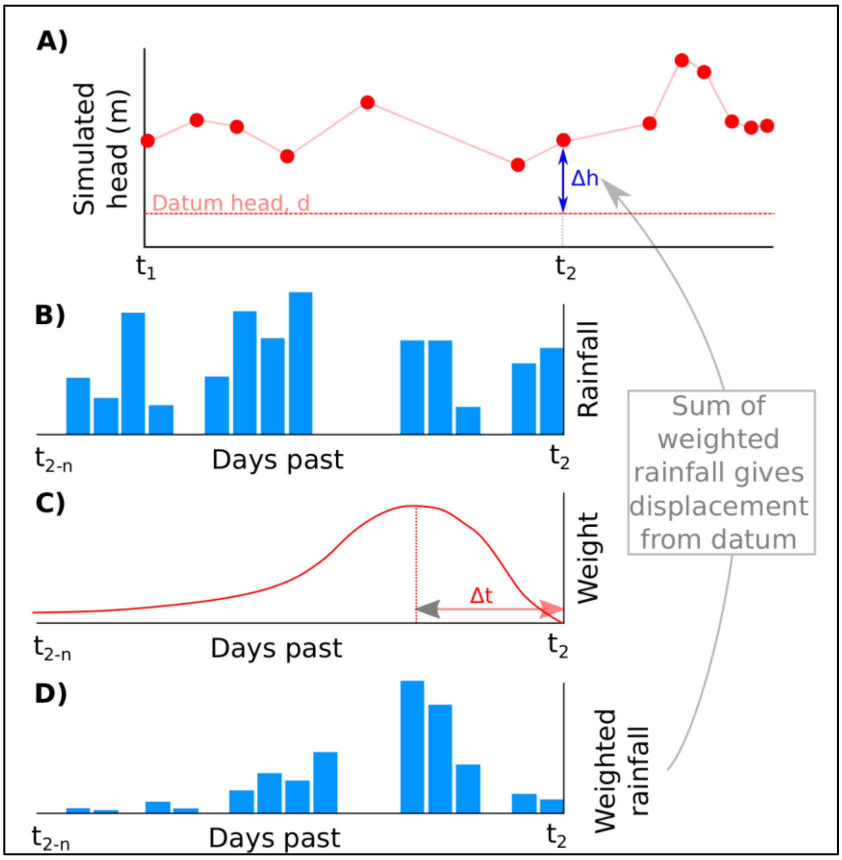


Figure D-2 Depiction of the weighting approach to historical data in HydroSight

HydroSight is an open-source groundwater time-series analysis package that provides hydrograph error and outlier detection (Peterson et al 2015), modelling of groundwater hydrographs using daily observed forcing data (e.g. rainfall and extractions), simulation of hydrographs for alternative climate and extraction scenarios. Common outputs include groundwater head at any time step, interpolated heads that perfectly match all observation and monthly to annual recharge. Each of these aspects of HydroSight have been peer-reviewed in leading international hydrology journals. The HydroSight features most relevant here are the outlier detection, time-series modelling of head and estimate of recharge. Core background concepts of each are detailed below. In the following section their application for this project is detailed.

D.2.1 Error and Outlier Detection

Groundwater hydrographs often contain questionable observation such as unexplained spikes, periods of no head change and apparently displaced head extended periods. HydroSight automatically identifies and removes such questionable observation by first applying a series of simply heuristics that remove extended periods of constant head and those violating physical constrained such as a head below the bottom of a bore screen. Next, a double exponential smoothing equation is fit to the remaining observations. The uncertainty around this curve is then quantified as the standard deviation of the difference between the observed head and the smoothed head. Any observation more than, say, six standard deviations away from the smooth curve is then removed. The double exponential smooth step is the repeated until no outliers are detected. For futher details see Peterson et al. (2017) and at https://peterson-tim-j.github.io/HydroSight/.

D.2.2 Time-series Modelling

The central concept of the modelling is that groundwater level results from past drives summed. For example, a large recharge event significantly influences the head over the subsequent days. Weeks later the recharge event still has some influence on the head, and months later even less. A subsequent recharge events similar influences the head and the observed head is the sum of all historic recharge events. HydroSight implements this concept taking an input time-series driver. In Fig 2-8B this is shown as rainfall. To estimate the groundwater head at time t2, daily rainfall from t2 back to the start of the meteorological record is selected and weighted by some unknown function. In Fig. 2-8C this weighting function applies a low weight to the recent rainfall. After a time of Δt the rainfall receives a maximum weight, thereafter the weight declines to approach zero. To estimate the influence of this historic rainfall on the current head, this time-series of weighted rainfall is then numerically integrated (effectively summed).

In this simple model, the only unknown parameters are three parameters for the shape of the weighting function and a fourth for the observation noise. To estimate the model parameters, they are automatically adjusted using a global numerical calibration scheme to achieve the best fit with the observed calibration. Importantly, all groundwater level observations are used in the calibration no matter the observation frequency or length of record gaps. This feature was implemented to achieve the greatest insights from the observed data.

When the calibration has converged to a robust solution, the modelled groundwater hydrograph is provided, along with any predictions over a user set evaluation period. The solution also estimates the noise in the observations. It is reported as an upper and lower bound around the modelled time-series head and 95% of the observations should be within these bounds. Importantly, theses bounds are not a model uncertainty.

The drivers of the observed head fluctuations are however often more complex than simply a weighting of historic rainfall. For a location known to not be influenced by groundwater pumping or land cover change, meteorological factors such as rainfall and potential evaporation are likely to be the only possible drivers. How they interact to influence groundwater head is, however, highly likely to be very nonlinear. Most notably, recharge often only occurs when soil moisture increases beyond a threshold and the rainfall driving the soil moisture can only infiltrate into the soil if there is capacity within the soil for more water, and if not then saturated excess runoff occurs. The soil moisture is therefore central to the estimation of recharge and hence unconfined groundwater head. HydroSight accounts for this by simulating the unsaturated zone as one or two storages that fill with rainfall and drains with evapotranspiration and recharge (see Fig. 2-9). These storages and fluxes also include unknown model parameters and, depending on which of these parameters the user chooses to calibrate, all model parameters including those for the weighting and noise components are jointly calibrated.

The outcome from including the soil model is a time series of free drainage out the bottom of the root zone. If the root zone is close to the water table then then free drainage is likely to be a plausible estimate of daily recharge. However, if this is not the case then some lag between the free drainage and the head response to it is likely. Also, some of this free drainage may be intercepted by very deep roots. Therefore, the free drainage from HydroSight is best interpreted as a gross recharge and should be reported at a monthly or greater time scale, so at to account for the time lags.

A final challenge in estimating recharge, and other unsaturated zone fluxes, is that the modelled fluxes are by default only constrained by the observed groundwater head. Consequently, situations arise where recharge is an implausible fraction of rainfall (e.g. >50%) and the response of the aquifer per unit or drainage is very low. To overcome this problem, Peterson and Fulton (2019) discovered that the Buydko curve from hydrology could be used to constrain the modelled soil evapotranspiration and hence the free drainage. To expand, the Budyko curve is one of the most well-established principles in catchment hydrology. It explains the long-term steady state annual actual evaporation from a catchment (as a fraction of annual rainfall) for a given aridity (potential evapotranspiration divided by the rainfall). By adopting recent probabilistic bounds for the Budyko curve, Peterson and Fulton (2019) were able to identify upper and lower bounds for the modelled soil evapotranspiration. During the calibration, if a model parameter set produces mean evapotranspiration outside of these bounds then it is rejected. The outcome of this is that the calibrated model always produces plausible actual evapotranspiration for the site, and hence significantly more plausible recharge estimates.

D.3 HydroSight core concept

The core concept of *HydroSight* is that observed groundwater dynamics can be explained using carefully weighted user-defined forcing data, such as rainfall or pumping and requires very few assumptions about the aquifer properties or the vadose zone processes partitioning rainfall to recharge. The data obtained from *HydroSight* is derived directly from observed changes in the aquifer water levels, and therefore, represents aquifer behaviour.

The opportunity *HydroSight* provides is that it rapidly enables all available groundwater monitoring data to be used to explain groundwater processes in the aquifer at the location of the monitoring bore, allowing the user to learn from the data about the hydrological cycle (what is driving the hydrograph response). While other model types (e.g. numerical models) simulate aquifer processes that fit to an observed groundwater trend across the entire model domain, these applications require significantly more labour to achieve results, as they require calibration to consider aquifer geometry and other data inputs that may or not be influencing the hydrograph response.

The strength of HydroSight is its approach to statistically weighting input data in the prediction of the groundwater head. Figure 2 above is a simplified example of the weighting process used to simulate a timeseries of groundwater levels.

Figure D-3 [A] shows the time series of the simulated head, which is derived from the weighting of observed past rainfall. Figure D-3 [B] shows the daily rainfall prior to the time point to be simulated (t2) and Figure D-3 [C] shows a smooth weighting function with a zero weight at time t2 and a maximum weight after some time lag. Figure D-3 [D] shows the rainfall after being weighted. Summing this historic weighted rainfall gives the head displacement produced from the historic rainfall and by repeating this process for each head time-point (using the same weighting function) and adding a datum, provides the final simulation of the groundwater hydrograph.

D.4 Application on Sustainable Yield project

One of the key focuses of the groundwater sustainable yield project is to estimate how changes in climate and the amount of recharge allocated to consumptive use, impacts watertable elevations across Victoria.

The focus of the technical assessment, therefore, is on using all available groundwater monitoring data (within GMUs and also less developed areas of the state) to develop state-wide maps of recharge and depth to watertable surfaces, which are two of the metrics needed to assess the sustainable yield.

The advantages of applying HdyroSight to the sustainable yield project include the following;

- It already has an established library of information around recharge estimation for hundreds of groundwater bores across Victoria
- HydroSight only uses data that is measured (levels, use, climate data)
- HydroSight does not require a full conceptualisation of the aquifer system (removing some assumptions will remove some uncertainty). This also negates the need to estimate aquifer parameters and construct a model replica of the system.

While other models are able to simulate the entire aquifer dynamics, considering the scale and objective of this project, the efficiency of HydroSight makes it an appealing alternative.

The user community of HydroSight has increased significantly since its establishment. The model has transitioned from research-based applications towards a standard tool used within groundwater resource assessments (government agencies, water authorities and consultancies) across a broad range of geographies, aquifers and climates. To date, an estimated 850 downloads of the HydroSight tool-box have occurred worldwide, illustrating the exposure and uptake of its application. Examples of past and current applications of HydroSight (excluding those associated with the Victorian government) include:

- Department of Water, Western Australia. Identification of aquifer properties across the Albany region
- Department of Environment and Water, South Australia. Estimations of recharge across the Eyre Peninsula. Within this application the recharge associated with sink holes was incorporated
- Power and Water Corporation, Northern Territory. Relative contribution of climate and groundwater extraction on declining groundwater levels. Within this project the estimated transmissivities were validated by historical groundwater pumping tests
- International examples include projects in Germany, where HydroSight was applied to determine data outliers and Norway, where the impact of groundwater extraction and climate on groundwater resources was assessed.

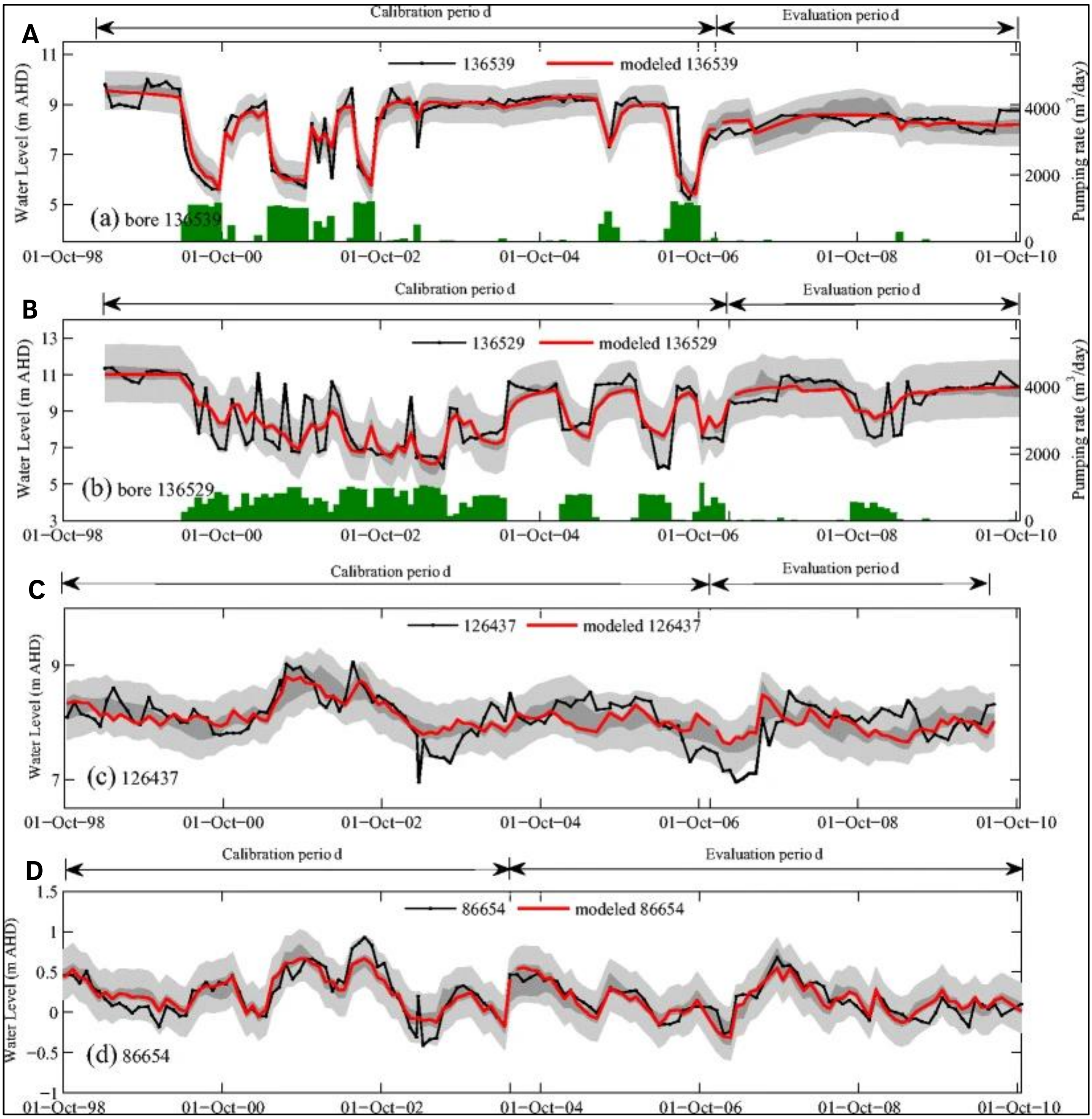


Figure D-3 Examples of HydroSight hydrograph modelling process - Observed (black line) and modelled groundwater levels (red line) for four observation bores. The dark green colour bars shown in A and B represent pumping rate. The dark grey area represents the 90 % uncertainty interval due to parameter uncertainty, while the light grey region shows the additional spread due to remaining residual error. [From Shapoori et al., 2015a]

D.5 *HydroSight* uncertainty

HydroSight can estimate both the variability and uncertainty in aquifer recharge, parameters and groundwater heads, based on the set of model parameters used to calibrate the model. To illustrate, Figure D-3 shows the observed and estimated calibrated heads at four observation bores in Maffra, Victoria. The calibrated head has uncertainties arising from the estimation of the model parameters applied; that is, there are likely many parameters that fit the hydrograph nearly as well as each other. This uncertainty is quantified using Markov Chain Monte Carlo sampling and the 90th percentile uncertainty interval due to parameter uncertainty is demonstrated in this figure by the dark grey band around the calibrated head.

D.5.1 *HydroSight* Non-Uniqueness

Hydrogeological models are valuable when they are able to match reality and subsequently be used to make predictions about future behaviours of the hydrogeological system. However, all hydrogeological models have unknown parameters that we attempt to estimate and adjust to achieve the closest alignment with the observed data (e.g. the groundwater level hydrograph). In hydrogeological models, the initial estimation of model parameterisation is informed by measured data for the system or otherwise, expert opinion. The calibration process involves jointly adjusting all the parameters to eventually produce a model that fits the observed data, better than the original estimation of parameterisation.

The best model solution achieved from the model calibration is referred to as the optima, and any additional changes to model parameters away from the optima, will lead to a degradation in the calibrated solution. To illustrate this idea Figure D-4 below shows the calibration process for two different model parameters plotted on the x and y axis (for context, we could imagine the x axis is hydraulic conductivity and the y axis is porosity). The graph shows the results of 100s of combinations of the two parameters of hydraulic conductivity and porosity. The objective function colour scale shows the error to the observed hydrograph (where a bigger number and a red colour, is further away from the observation) for each value of the two parameters.

Importantly the optima's are depicted in the figure below where the closed ellipsoids appear (there are arrows marking these features) and the initial model parameterisation is depicted by the black star.

This figure shows that while the preferred optima (blue) is possible, another combination of parameters may produce another optima (yellow closed ellipsoid) that may be worse fit; and this is the model non-uniqueness. This non uniqueness occurs when there are multiple optima, in the figure below we can see two such optima (yellow top right and bottom left blue). Ideally the model would converge to the blue ellipsoid and provide the best possible fit to the observed data. This very best optima is called the Global Optima, the others are referred to as Local Optima.

This challenge has been a fundamental development component of HydroSight (with more detail on its solution presented in Peterson & Western [2014]). The HydroSight approaching to dealing with non-uniqueness is common in hydrological modelling (surface water models) and is similar to the principles applied by PEST. In summary, HydroSight applies Global Optima calibration methods to avoid non-uniqueness and as such, avoids the need for an accurate initial parameterisation and also reduces the risk of the outputs representing a Local Optima as opposed to the desired Global Optima. The approach involves hundreds and thousands of random initial parameters estimates and within the model calibration scheme built into HydroSight, each of the parameter sets are estimated jointly in the search for the Global Optima.

D.6 HydroSight limitations and future developments

HydroSight has limitations, including the following.

- Where the groundwater dynamics change significantly with a change in groundwater level. This may occur if groundwater pumping produces sufficient drawdown that surface-groundwater hydraulic gradients reverse or the aquifer transitions from confined to unconfined.
- Groundwater level observation frequency changes within the record (e.g. from a monthly to a daily monitoring frequency). Counter intuitively this scenario is likely to produce a poorer fit to the observed hydrograph than resampling the data (to, say, a weekly time step). This limitation is under investigation.
- Where groundwater pumping occurs from multiple wells and is influenced by a recharge or no-flow boundary. Currently image wells can be manually added and have been found to improve performance, but implementation is limited to scenarios with simple boundaries and few wells. Future developments aim to implement more advanced image well techniques.

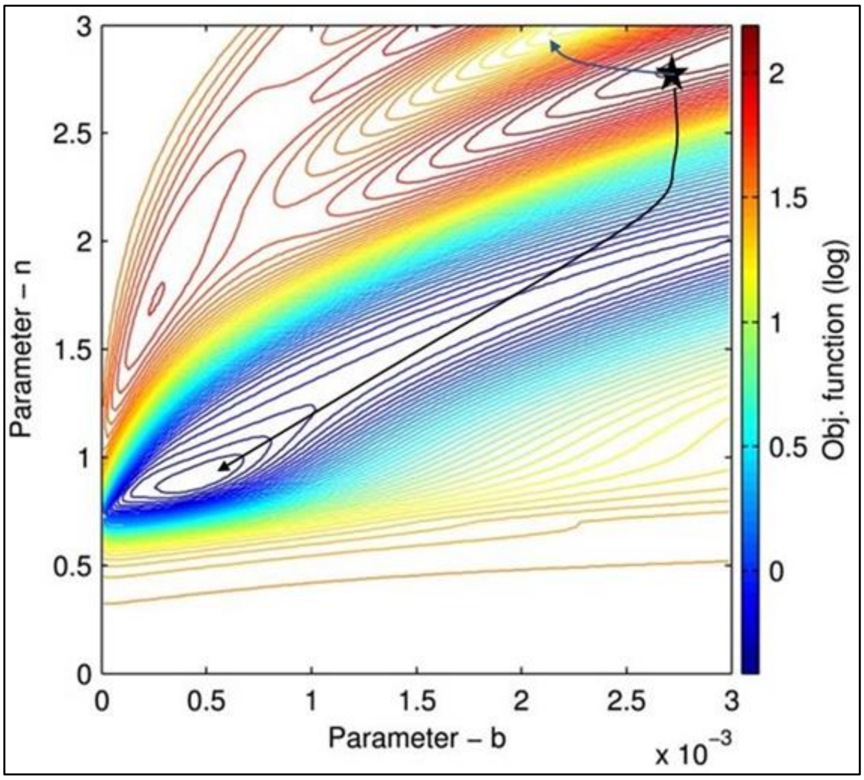


Figure D-4 **Two-parameter response surface illustrating the complexity of the model calibration; specifically, the multiple optima, complex valleys and regions of low sensitivity. It shows three possible optima: (i) blue ellipse at b=0.5, (ii) red ellipse at b=0.3 and (iii) b=2.25. The very lowest error solution is when b=0.5. The response surface was derived using the five parameter linear TFN model. Note, the remaining three parameters were fixed to that at a prior determined optima. (From Peterson & Western, 2014).**

D.7 References

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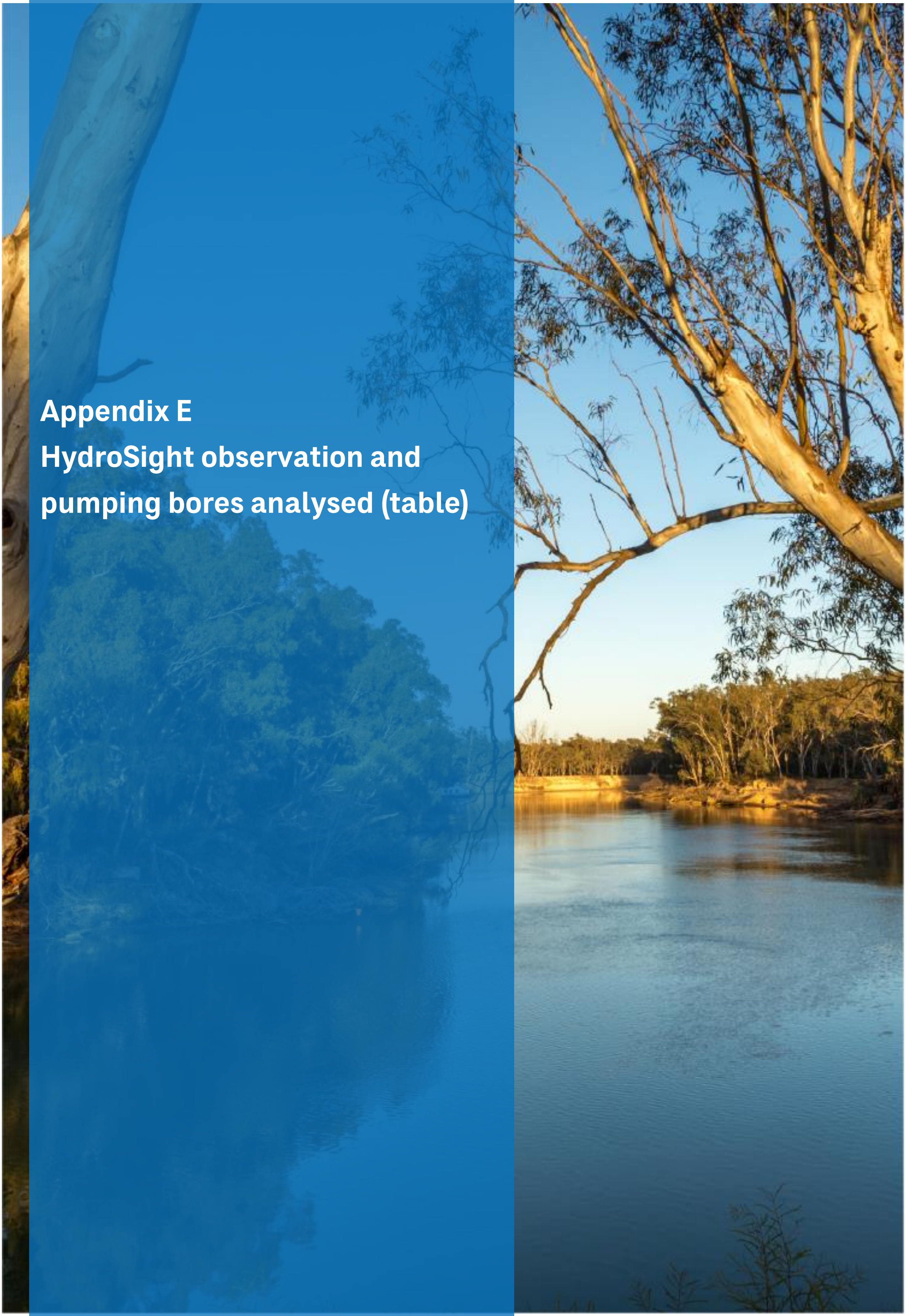


Appendix E
HydroSight observation and pumping bores analysed (table)

Table E-1 Observation and pumping bores used in HydroSight pumping analysis by GMU

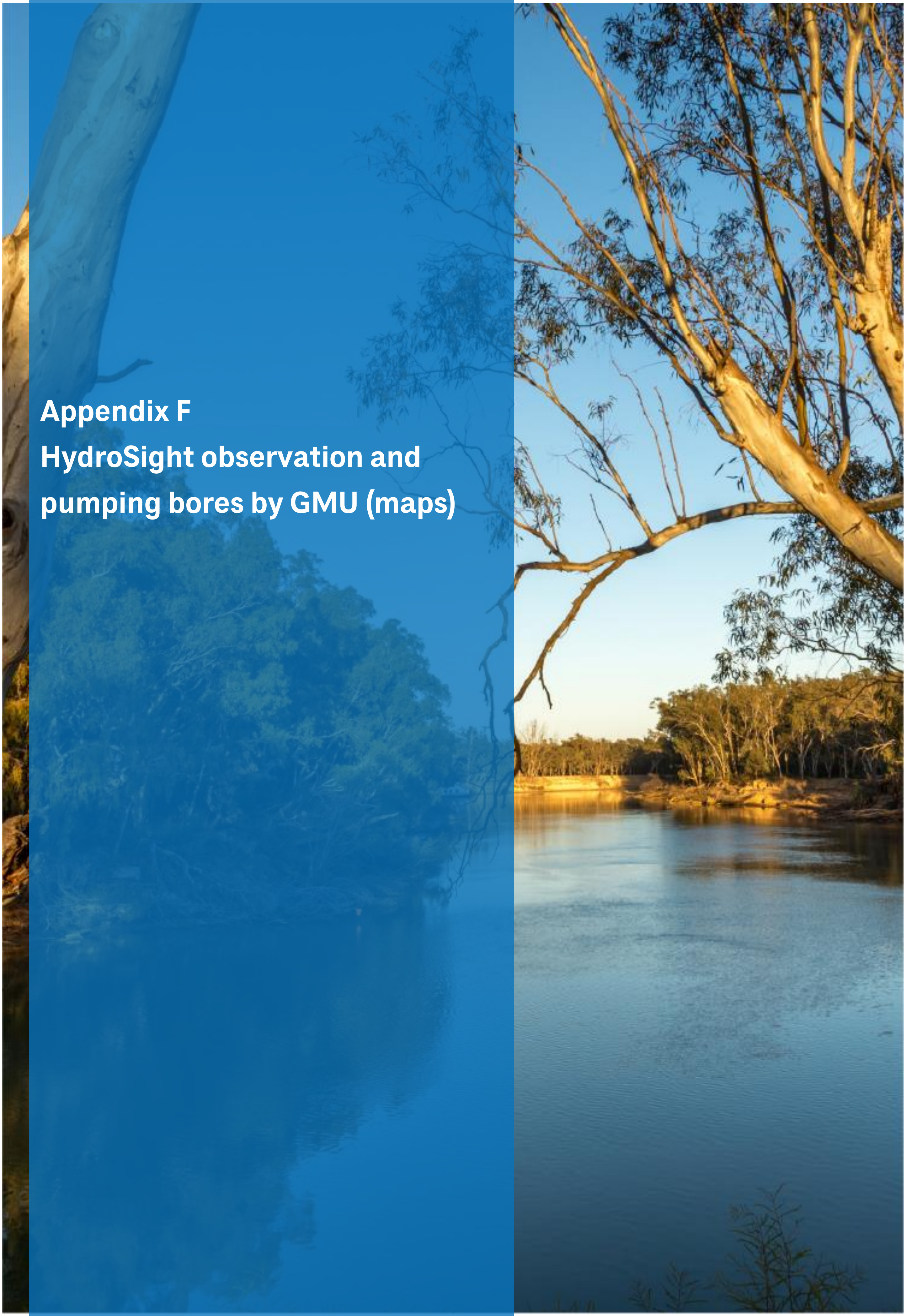
GMU	Observation bore	Pumping bore	Bore type	Included in final calibrated model	Final soil model
Denison	42069	WRK040452	Single	Yes	Single layer
		WRK040507	Single	Yes	
		WRK040574	Single	No ^	
		WRK038517	Single	No ^	
		WRK040547	Single	No ^	
	42095	WRK038519	Single	Yes	Single layer
		WRK040553	Single	Yes	
		WRK040563	Single	No ^	
		WRK052584	Single	No ^	
		WRK038524	Single	No ^	
	42074	WRK031821	Single	Insufficient calibration	NA
		WRK040442	Single		
		WRK040473	Single		
		WRK040418	Combined		
		WRK040419	Combined		
		WRK040416	Single		
Deutgam	59522	WRK057044	Single	Yes	Double layer
		WRK040733	Single	Yes	
		WRK040715	Single	No ^	
		WRK040710	Single	No ^	
		WRK032729	Single	No ^	
	112804	WRK052371	Single	Yes	Double layer
		WRK040705	Single	Yes	
		WRK040704	Single	Yes	
		WRK040651	Single	Yes	
		WRK040617	Single	Yes	
	145270	WRK046682	Single	Yes	Single layer
		WRK040735	Single	Yes	
		WRK040616	Single	Yes	
		WRK040615	Single	Yes	

GMU	Observation bore	Pumping bore	Bore type	Included in final calibrated model	Final soil model
		WRK040498	Single	Yes	
Koo Wee Rup	71851	WRK041614	Single	Yes	Single layer
		WRK041553	Single	Yes	
		WRK041386	Single	No	
		WRK111736	Single	No	
		WRK086868	Single	No	
	71194	WRK041491	Single	Yes	Single layer
		WRK041489	Single	Yes	
		WRK041488	Single	No	
		WRK041441	Single	No	
		WRK041359	Single	No	
	145259	WRK041784	Single	Insufficient calibration	NA
		WRK041828	Single		
		WRK041822	Single		
		WRK041825	Single		
		WRK091174	Single		
Lower Campaspe Valley	79329	WRK011521	Single	Yes	Single layer
		WRK008688	Single	Yes	
		WRK094518	Single	No	
		WRK007679	Single	No	
		WRK005694	Single	No	
	89576	WRK007526	Combined	Yes	Single layer
		WRK088351	Combined	Yes	
		WRK009927	Single	Yes	
		WRK006481	Combined	No	
		WRK010570	Combined	No	
		WRK006330	Combined	No	
		WRK078137	Combined	No	
		WRK007077	Combined	No	
		WRK007816	Combined	No	
	WRK953018	WRK009453	Single	Insufficient calibration	NA
		WRK011924	Single		

GMU	Observation bore	Pumping bore	Bore type	Included in final calibrated model	Final soil model
		WRK076095	Single		
		WRK015688	Single		
		WRK010877	Single		
Lower Ovens	WRK957262	WRK009614	Single	Yes	Double layer
		WRK009615	Single	Yes	
		Pump_WRK009616	Single	No	
		Pump_WRK009617	Single	No	
		Pump_WRK008196	Single	No	
	62864	WRK013629	Single	Yes	Double layer
		WRK013734	Single	Yes	
		WRK104495	Single	Yes	
		WRK110495	Single	Yes	
		WRK006470	Single	Yes	
	WRK054545	WRK071818	Single	Yes	Double layer
		WRK006186	Single	Yes	
		WRK006373	Single	No	
		WRK006185	Single	No	
		WRK006832	Single	No	
Mid loddon	51640	WRK006049	Single	Yes	Double layer
		WRK008976	Single	No	
		WRK015618	Single	No	
		WRK007376	Single	No	
		WRK008048	Single	Yes	
	88214	WRK007779	Single	Yes	Single layer
		WRK094463	Single	Yes	
		WRK006221	Single	Yes	
		WRK008925	Single	Yes	
		WRK007474	Single	Yes	
	138653	WRK065581	Single	Yes	Single layer
		WRK008295	Single	Yes	
		WRK068818	Single	No	
		WRK005849	Single	No	

GMU	Observation bore	Pumping bore	Bore type	Included in final calibrated model	Final soil model
		WRK006636	Single	No	
SWL - Glenelg	87537	WRK032168	Single	Yes	Single layer
		WRK032464	Single	Yes	
		WRK040957	Single	No	
		WRK041029	Single	No	
		WRK047964	Single	No	
SWL - Hawkesdale	111523	WRK041264	Single	Yes	Double layer
		WRK105078	Single	Yes	
		WRK055222	Single	Yes	
		WRK041265	Single	Yes	
		WRK069136	Combined	Yes	
		WRK115670	Combined	Yes	
	WRK988734	WRK110283	Single	Yes	Single layer
		WRK110282	Single	Yes	
		WRK051270	Single	Yes	
		WRK046627	Single	Yes	
		WRK041257	Single	Yes	
SWL - Nullawarre	141235	WRK054441	Single	Yes	Double layer
		WRK043404	Single	Yes	
		WRK040252	Single	Yes	
		WRK039026	Single	Yes	
		WRK038774	Single	Yes	
	141239	WRK043437	Single	Yes	Single layer
		WRK100360	Single	Yes	
		WRK043470	Single	No	
		WRK043432	Single	No	
		WRK043430	Single	No	
SWL - Yangery	141310	WRK048745	Combined	Insufficient calibration	NA
		WRK048814	Combined		
		WRK048743	Combined		
		WRK048745	Combined		
		WRK048711	Combined		

GMU	Observation bore	Pumping bore	Bore type	Included in final calibrated model	Final soil model
		WRK048710	Combined		
		WRK031912	Combined		
		WRK048913	Combined		
		WRK048698	Single		
		WRK048717	Single		
Wa De Lock	76888	WRK039080	Single	Yes	Double layer
		WRK039081	Single	Yes	
		WRK047975	Single	Yes	
		WRK047983	Single	Yes	
		WRK048019	Single	Yes	
	130372	WRK048007	Single	Yes	Single layer
		WRK047981	Single	Yes	
		WRK047970	Single	Yes	
		WRK043673	Single	Yes	
		WRK039502	Single	Yes	
	110171	WRK046453	Single	Yes	Double layer
		WRK046454	Single	Yes	
		WRK046468	Single	Yes	
		WRK062399	Single	Yes	
		WRK057240	Single	Yes	



Appendix F

HydroSight observation and pumping bores by GMU (maps)

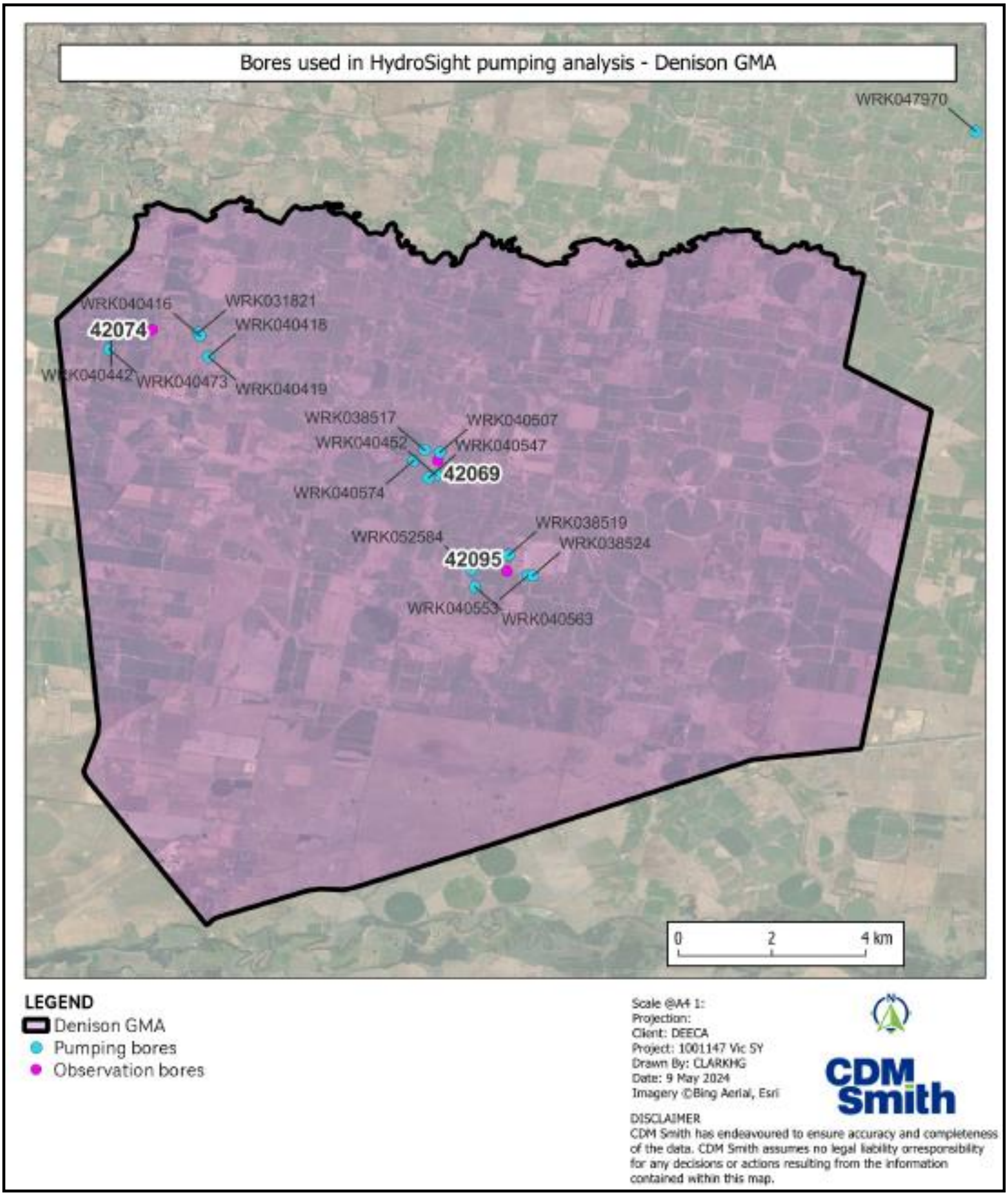


Figure F-1 **Pumping bores analysed in HydroSight for the Denison GMA.**

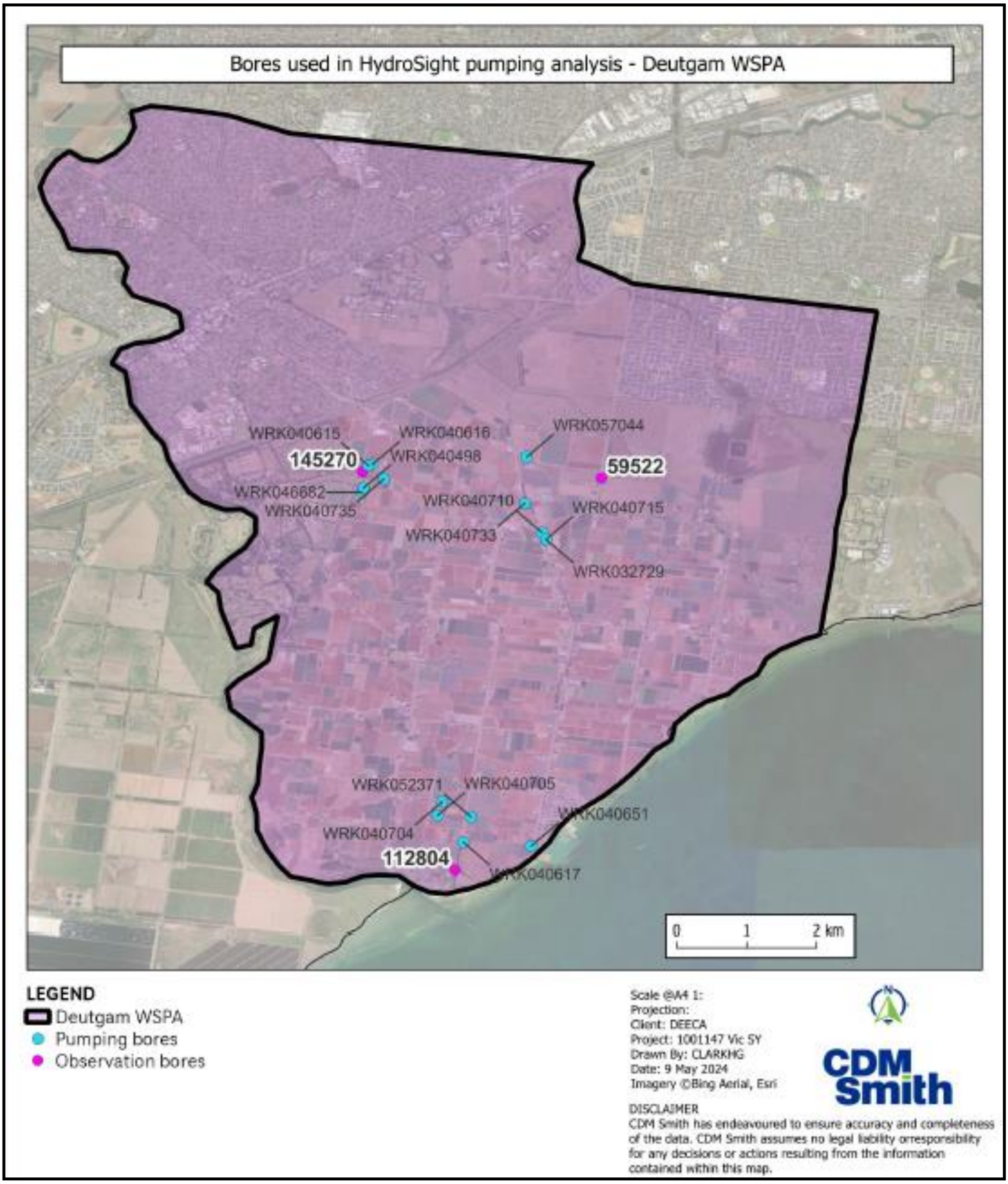
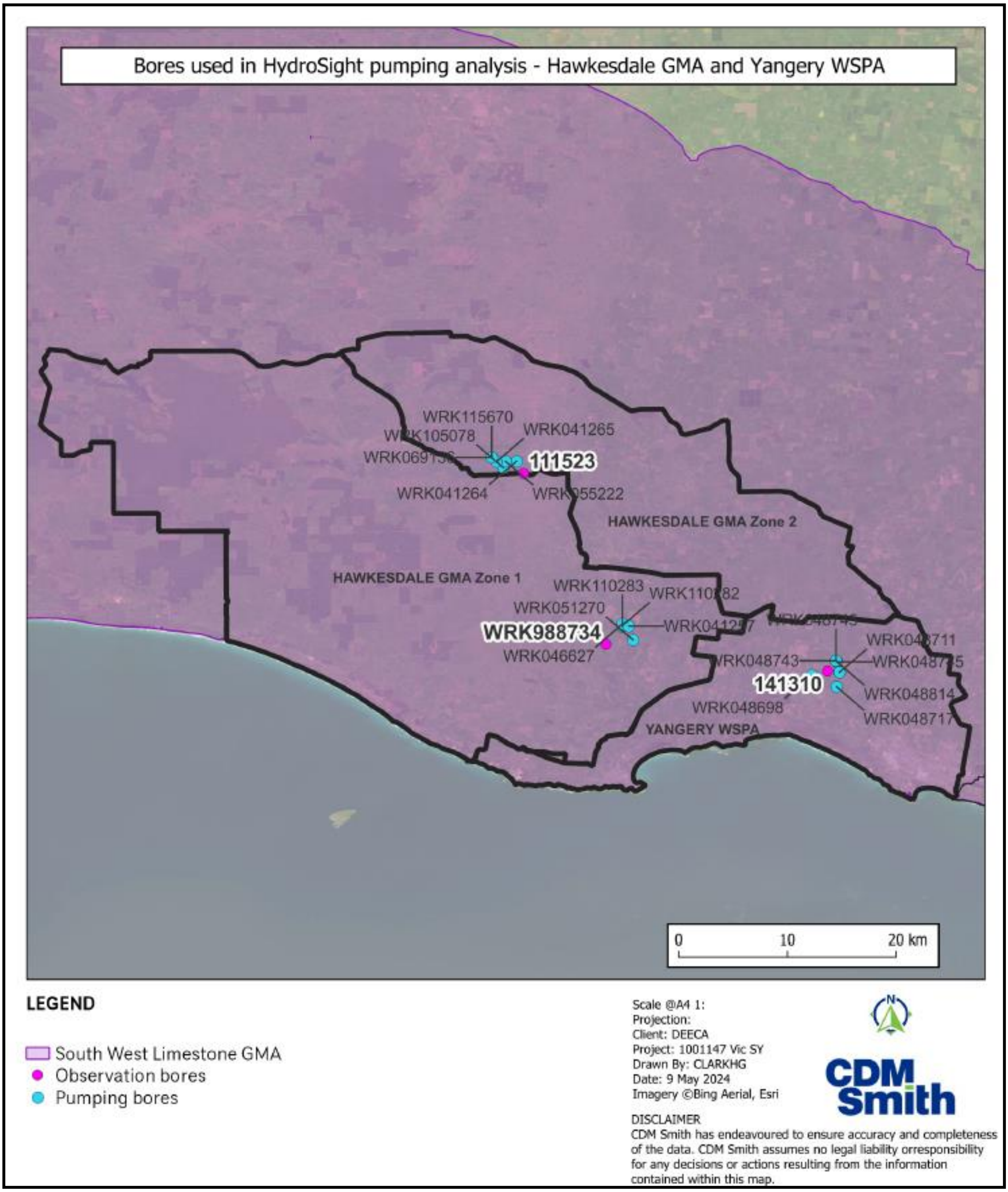


Figure F-2 Pumping bores analysed in HydroSight for the Deutgam WSPA.



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Client: DEECA
Project: 1001147 Vic SY
Drawn By: CLARKHG
Date: 9 May 2024
Imagery ©Bing Aerial, Esri

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Figure F-3 Pumping bores analysed in HydroSight for the Hawkesdale GMA and Yangery WSPA.

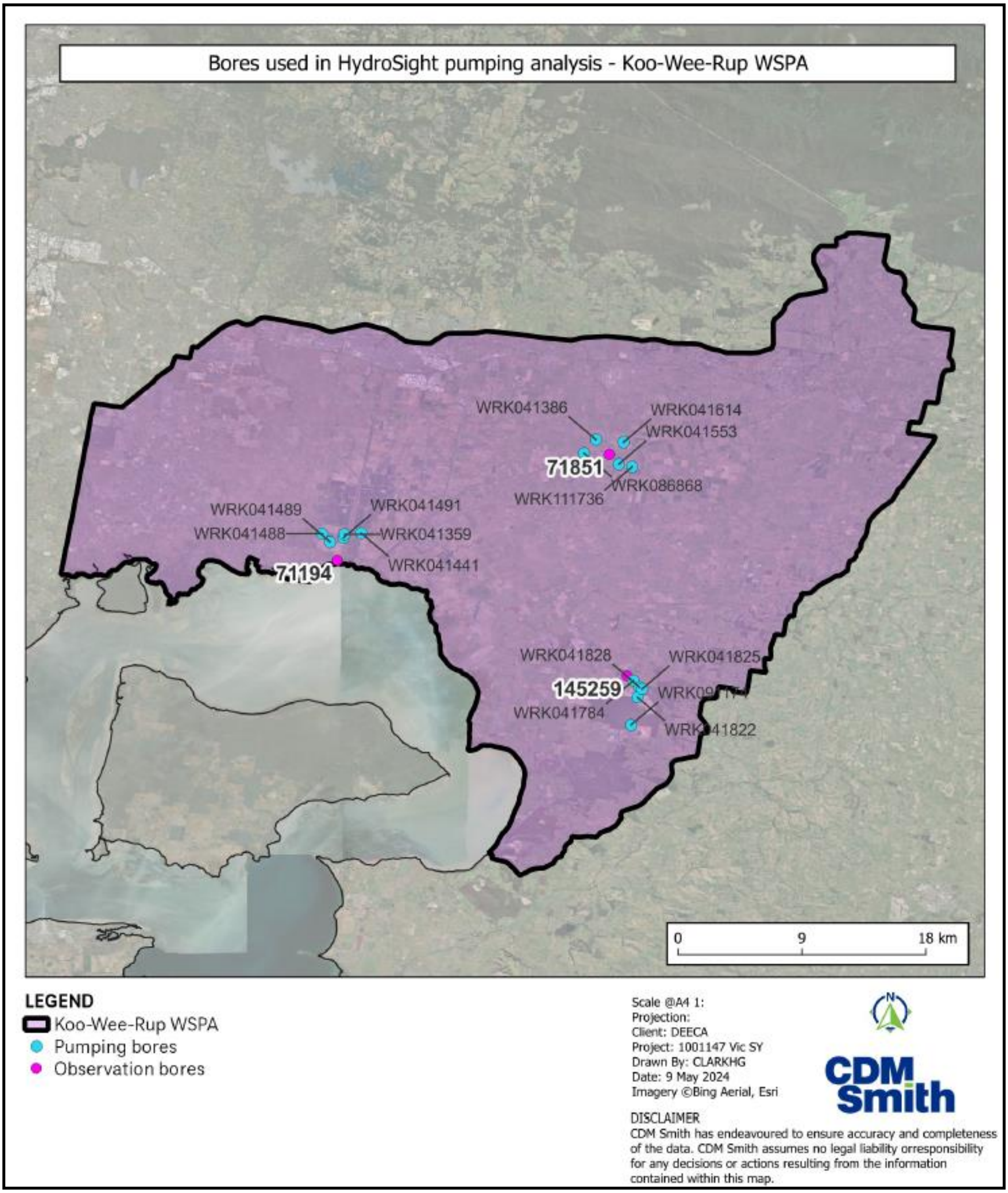

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Figure F-4 Pumping bores analysed in HydroSight for the Koo-Wee-Rup WSPA.

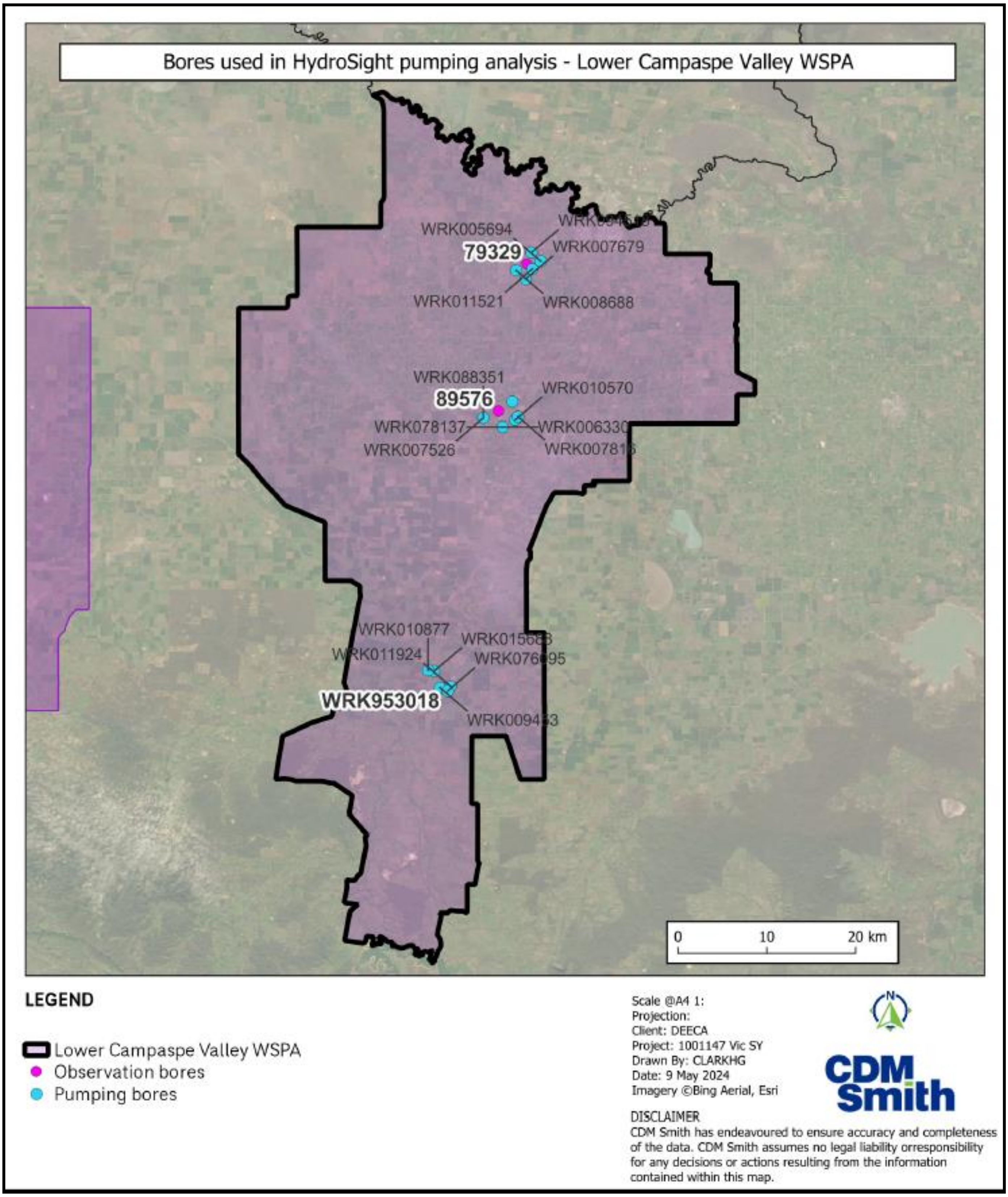


Figure F-5 Pumping bores analysed in HydroSight for the Lower Campaspe Valley WSPA.

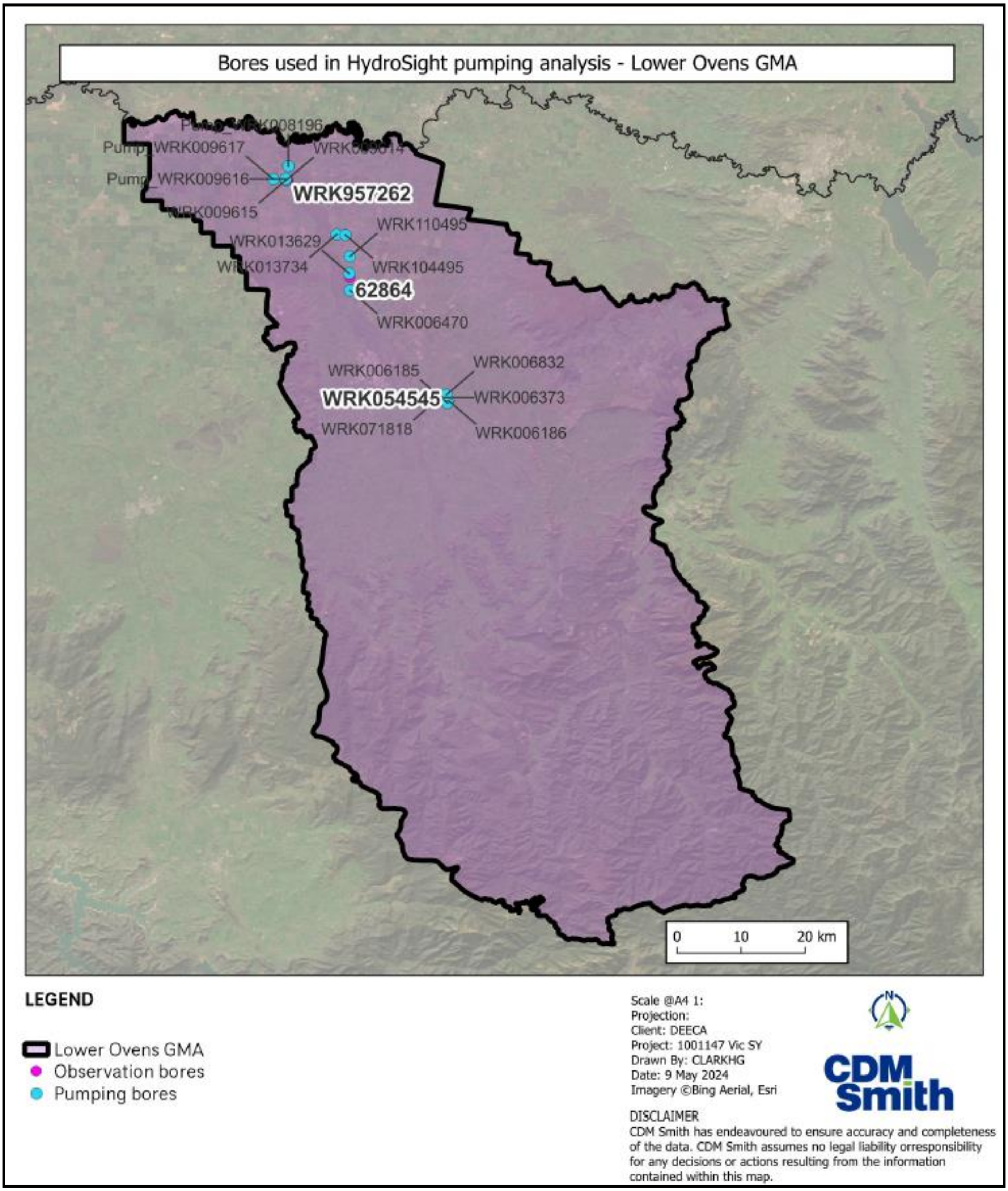
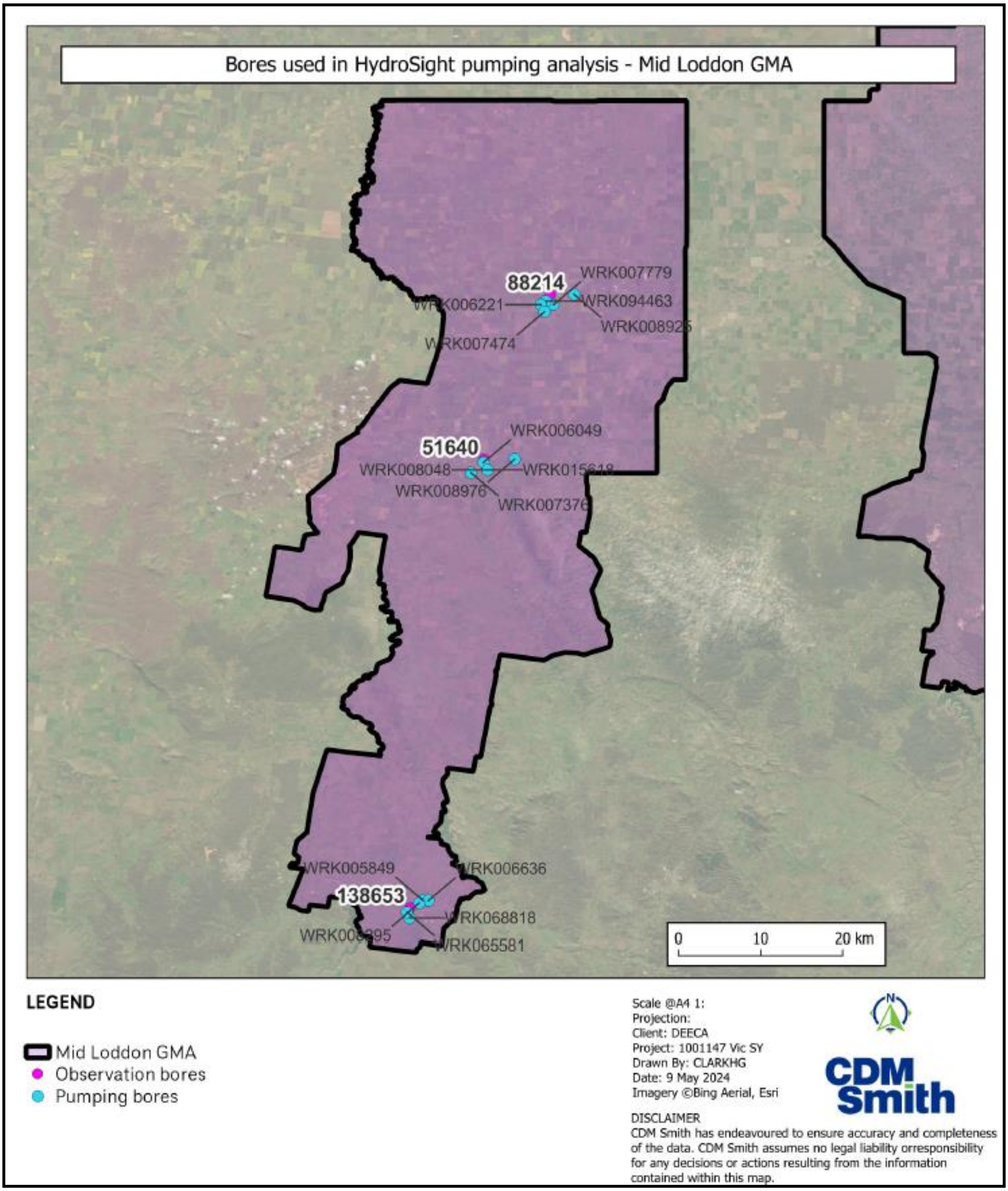


Figure F-6 **Pumping bores analysed in HydroSight for the Lower Ovens GMA.**



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Drawn By: CLARKHG
Date: 9 May 2024
Imagery ©Bing Aerial, Esri

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Figure F-7 Pumping bores analysed in HydroSight for the Mid Loddon GMA.

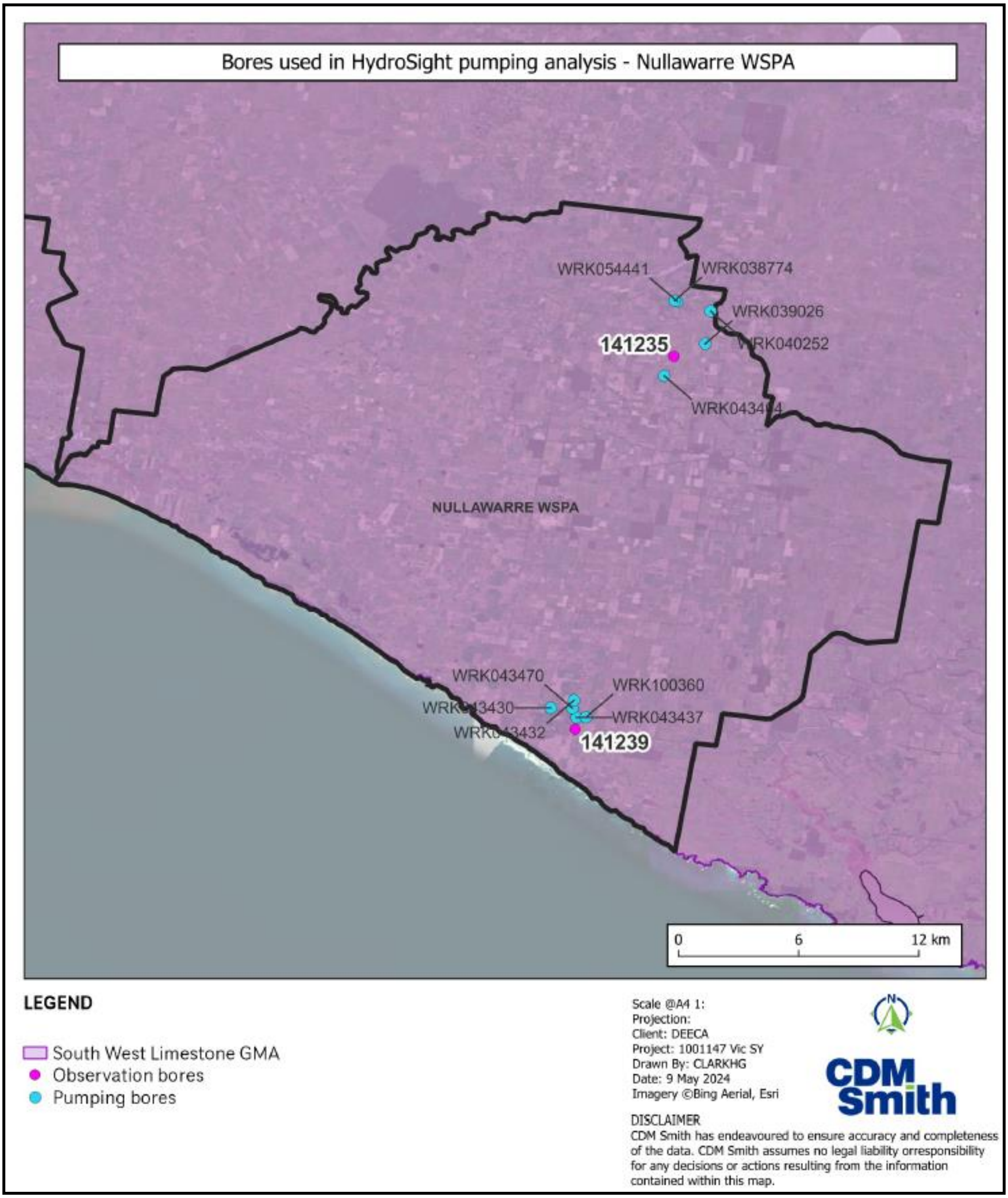


Figure F-8 Pumping bores analysed in HydroSight for the Nullawarre WSPA.

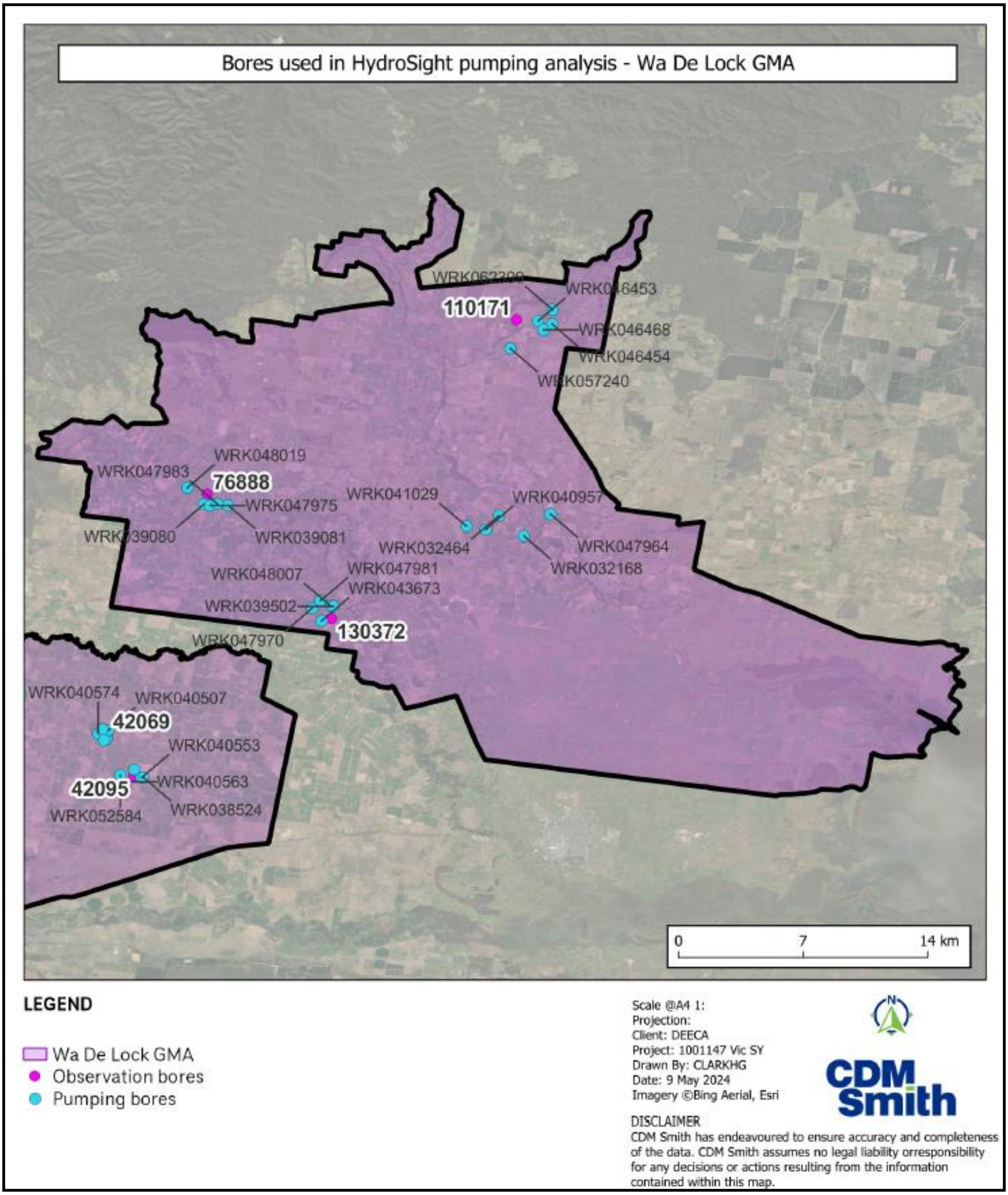
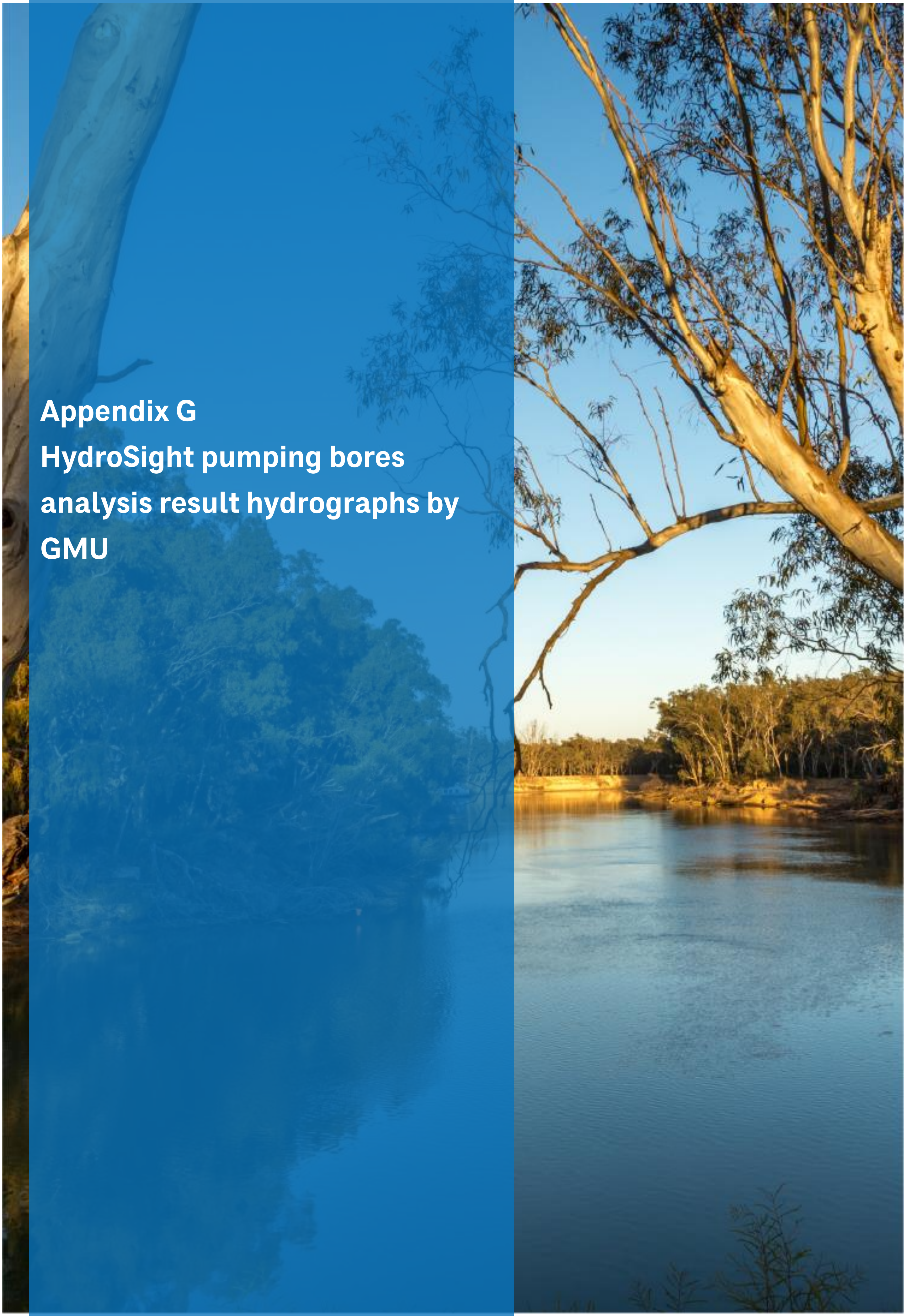


Figure F-9 Pumping bores analysed in HydroSight for the Wa De Lock GMA.



Appendix G

HydroSight pumping bores analysis result hydrographs by GMU

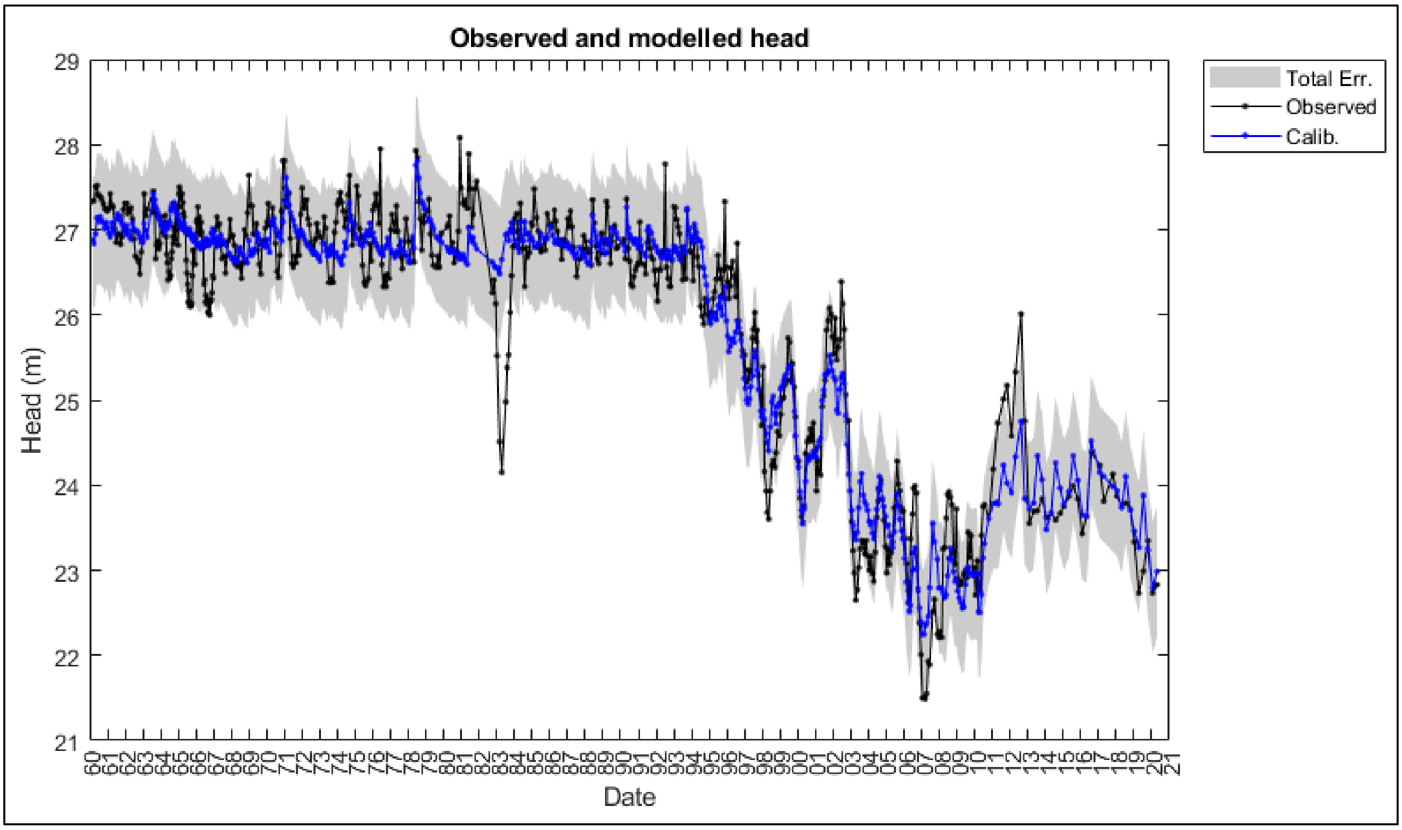


Figure G-1 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 42069 in the Denison GMA – CoE = 0.91.

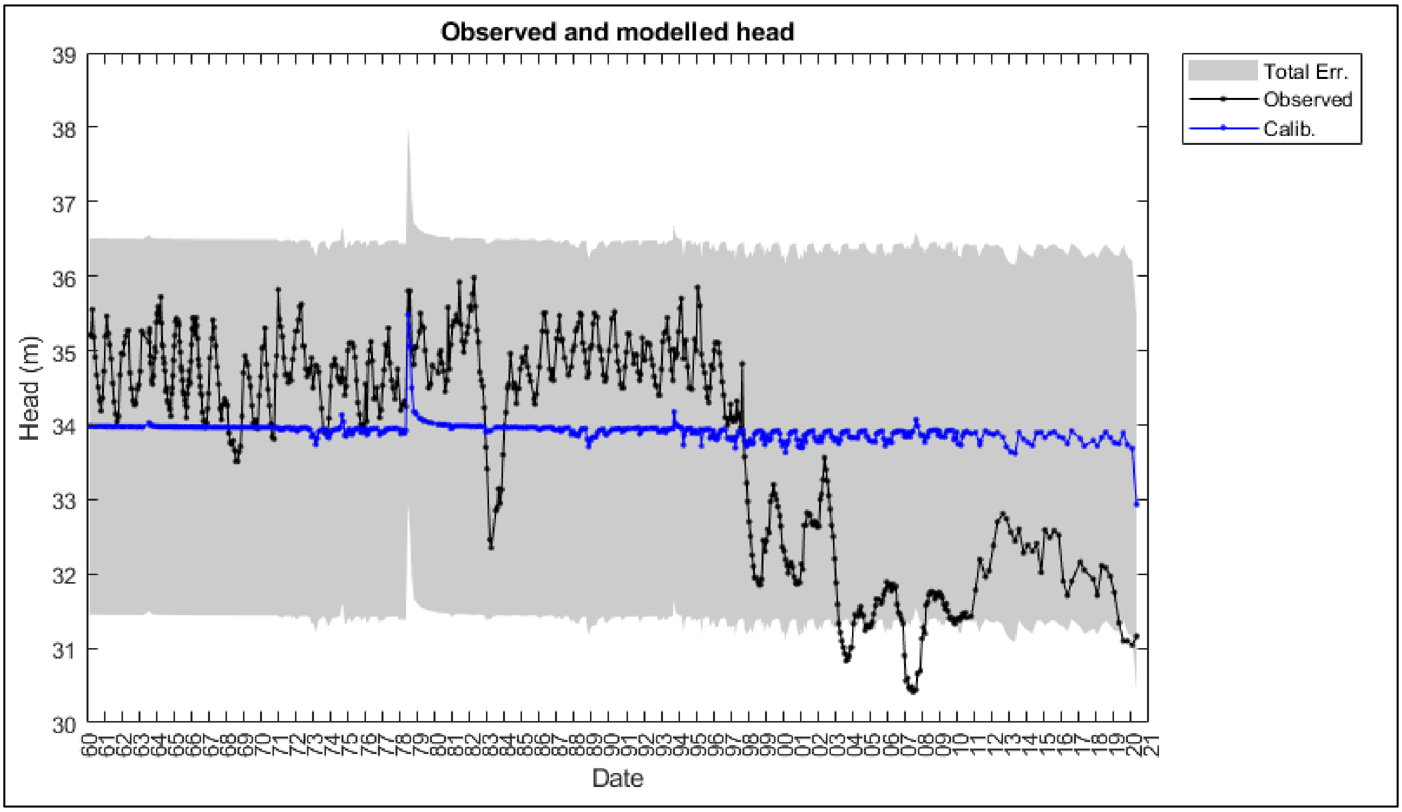


Figure G-2 Hydrograph result of the most optimal HydroSight pumping analysis calibration for observation bore 42074 in the Denison GMA– CoE = 0.07 CALIBRATION FAILED.

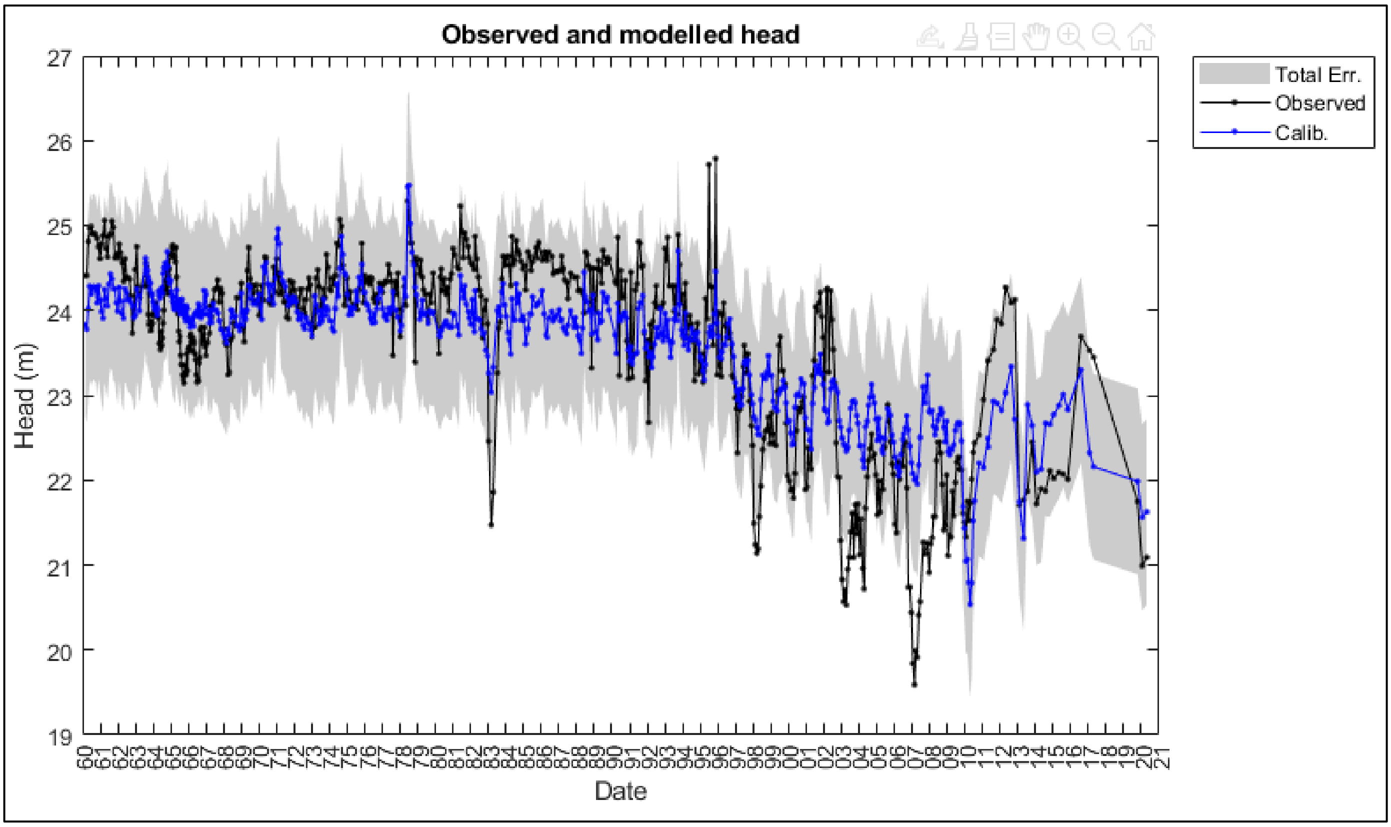


Figure G-3 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 42095 in the Denison GMA – CoE = 0.66.

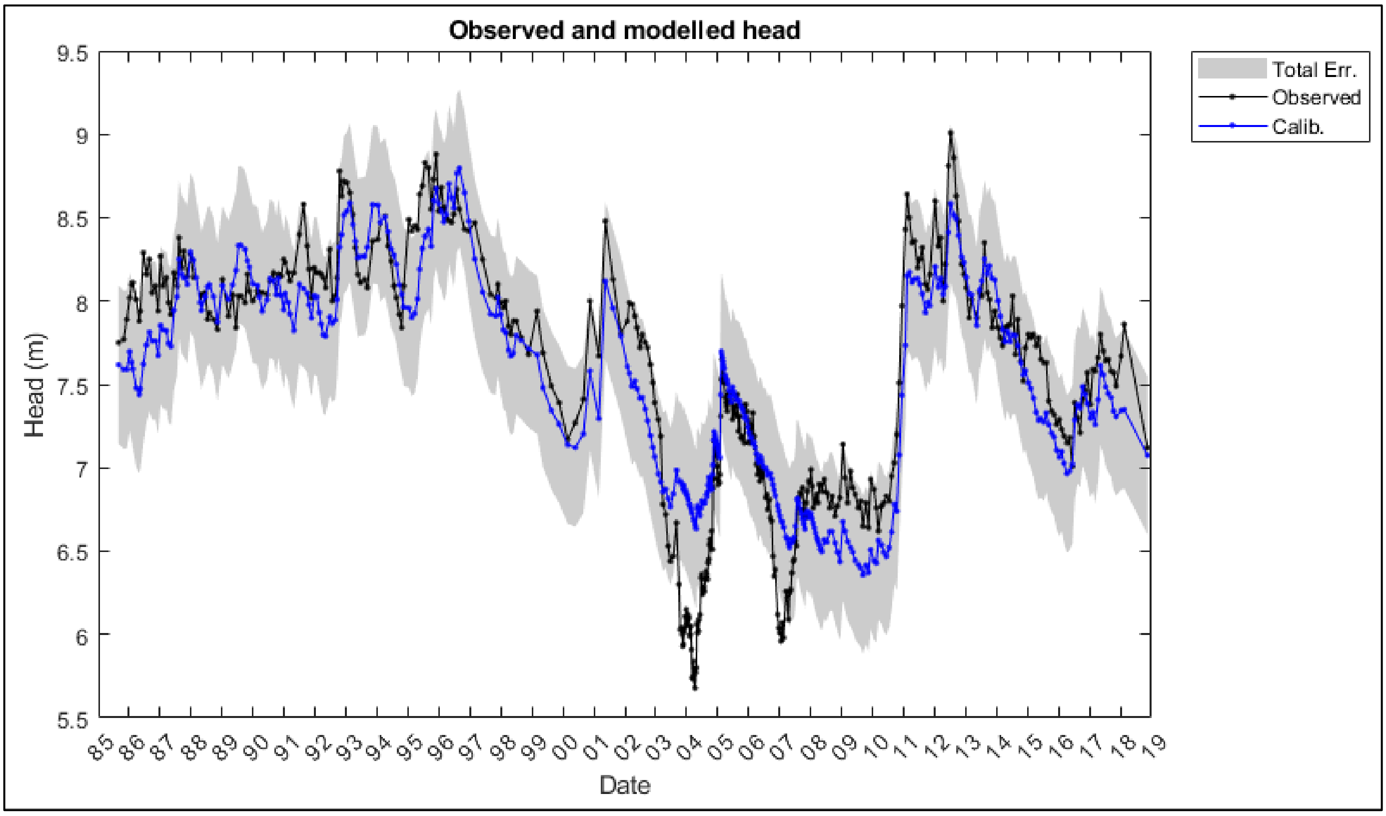


Figure G-4 Hydrograph result of the most optimal HydroSight pumping analysis calibration for observation bore 59522 in the Deutgam GMA– CoE = 0.81.

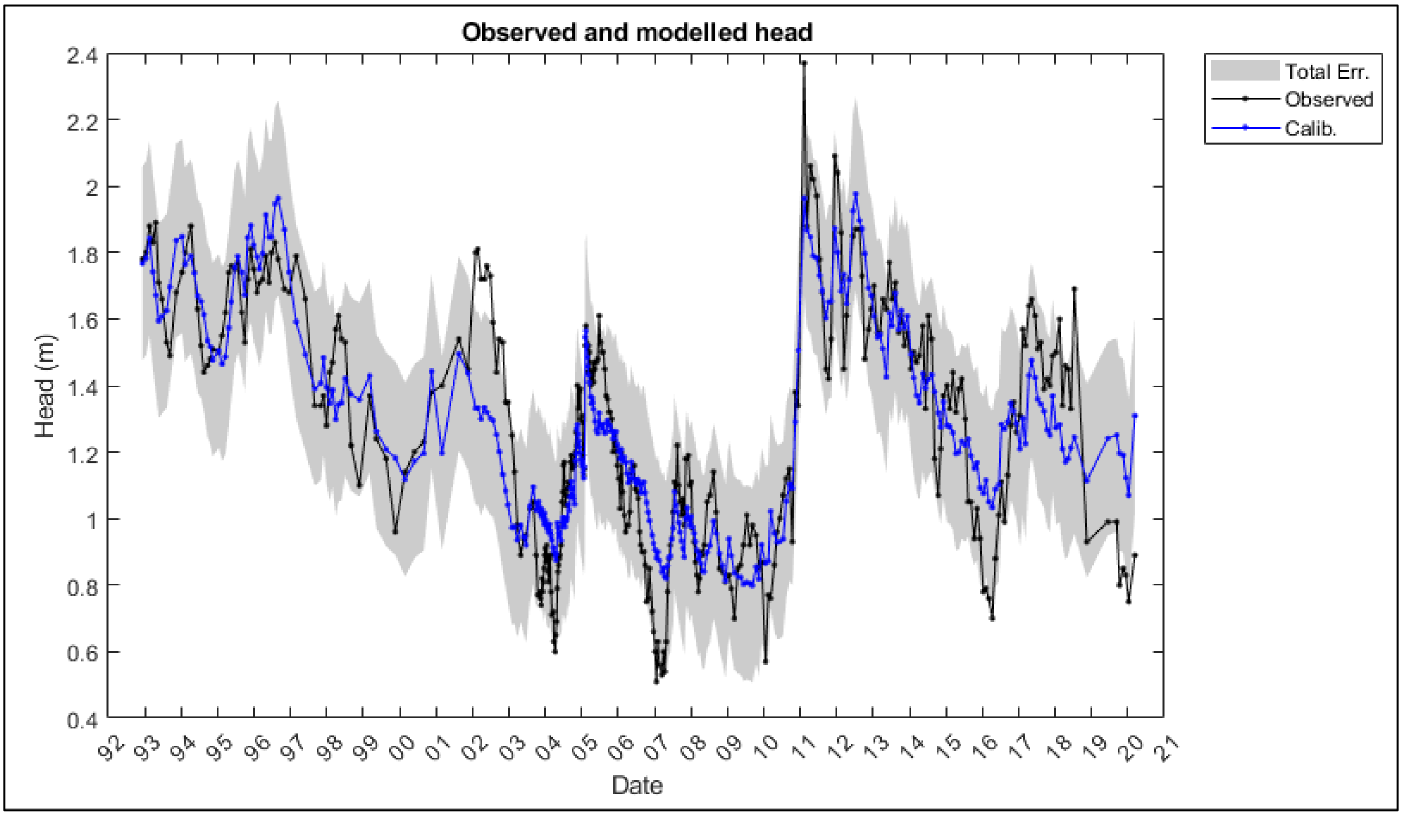


Figure G-5 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 112804 in the Deutgam GMA – CoE = 0.78.

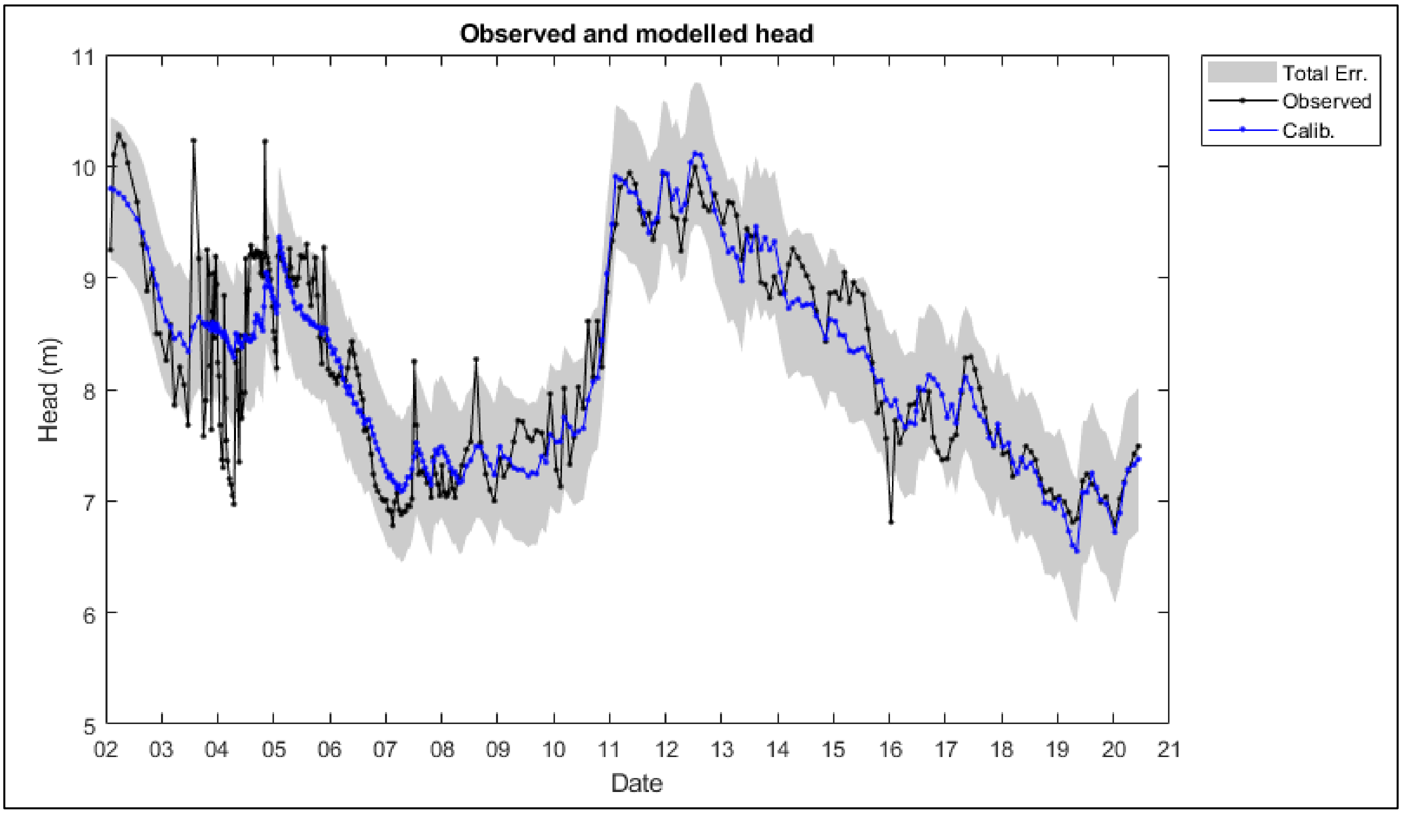


Figure G-6 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 145270 in the Deutgam GMA – CoE = 0.81.

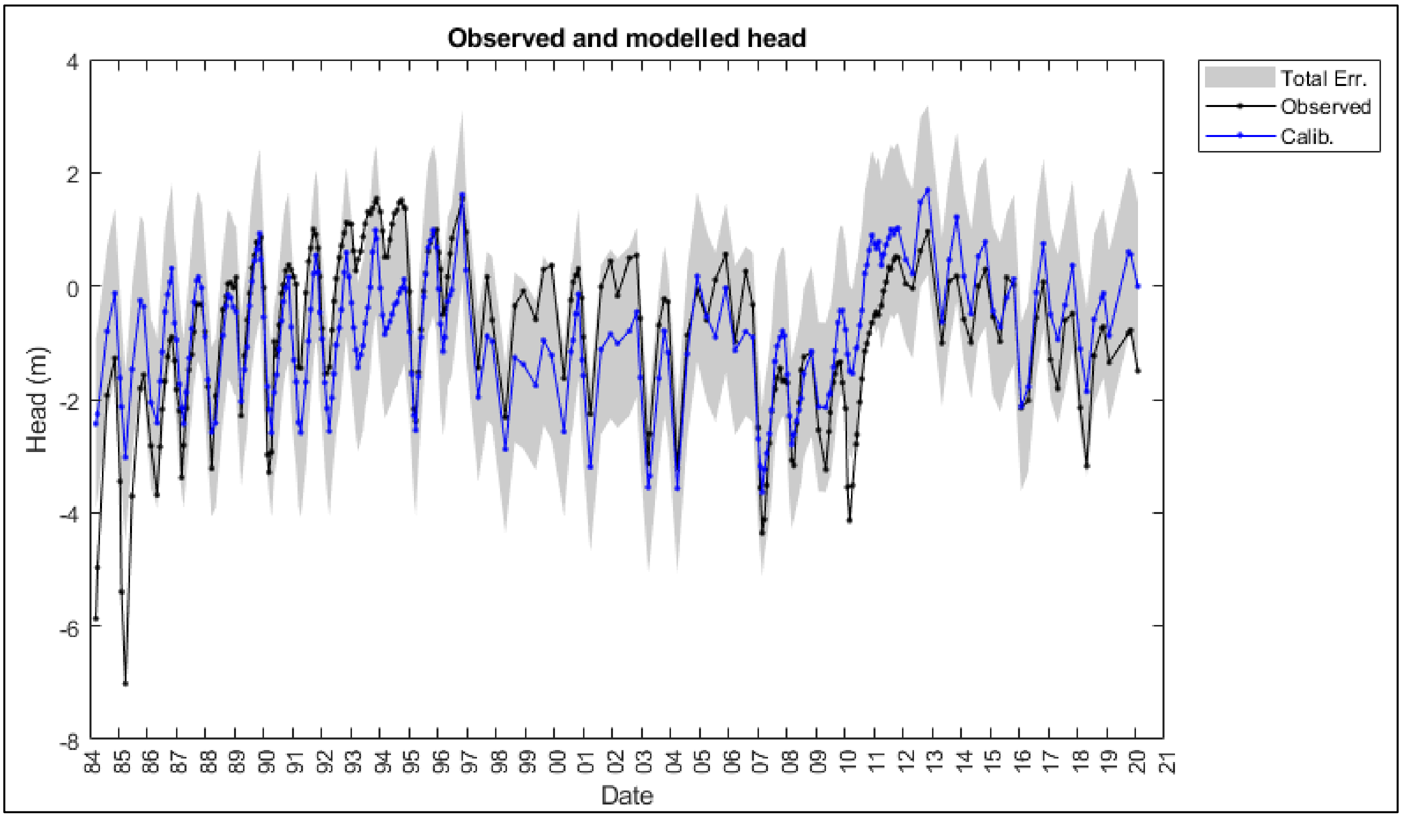


Figure G-7 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 71194 in the Koo Wee Rup GMA – CoE = 0.53.

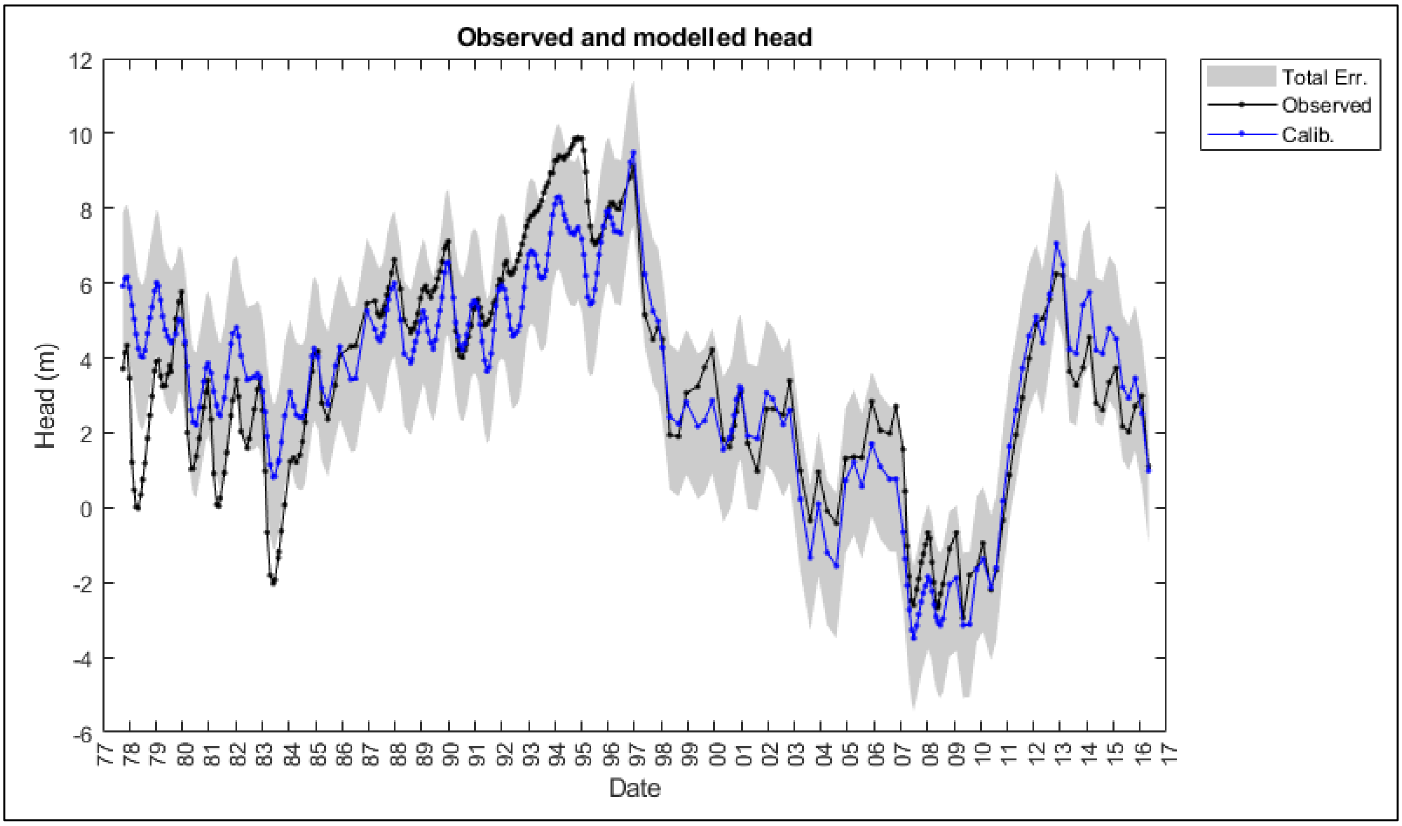


Figure G-8 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 71851 in the Koo Wee Rup GMA – CoE = 0.80.

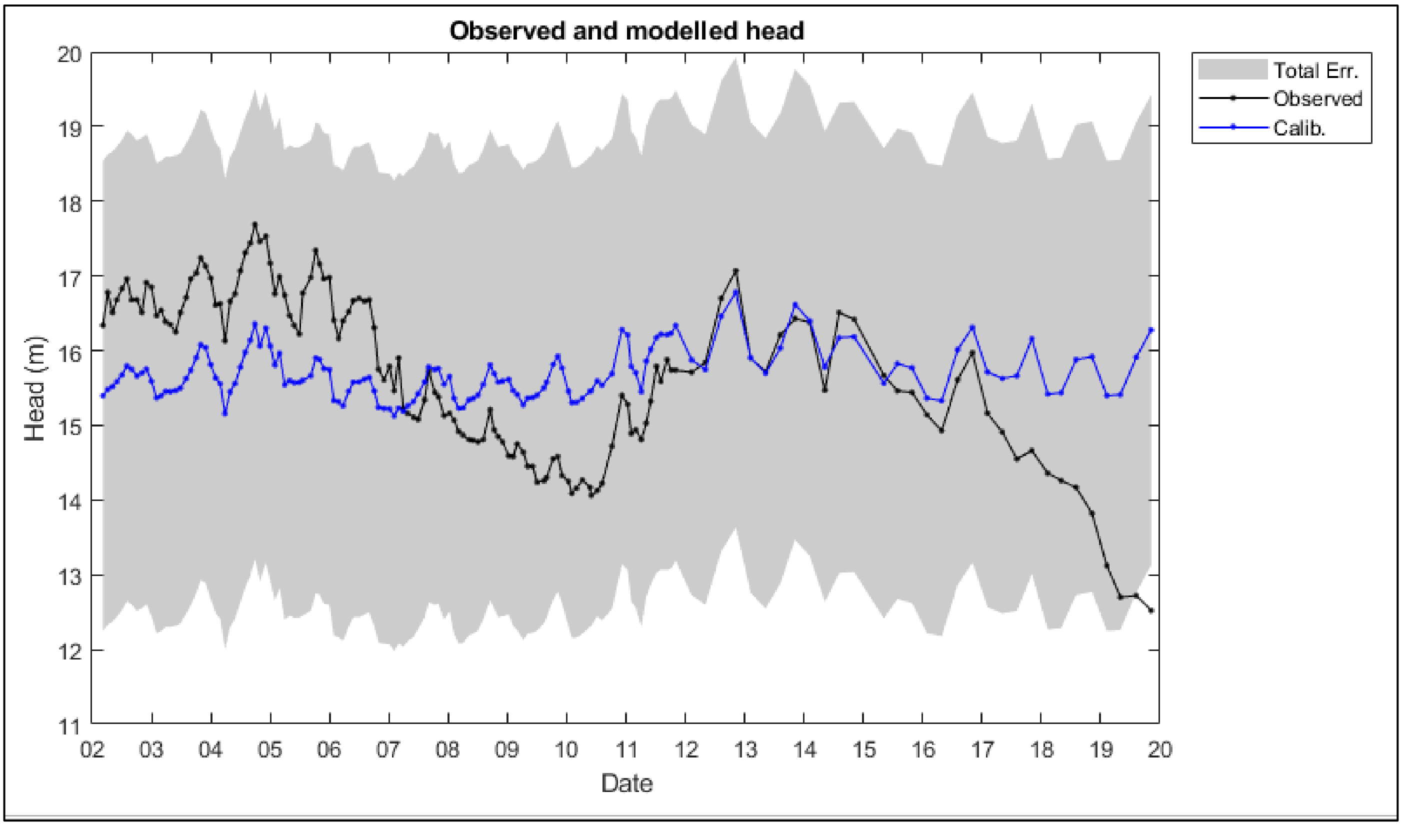


Figure G-9 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 145259 in the Koo Wee Rup GMA – CoE = 0.08CALIBRATION FAILED.

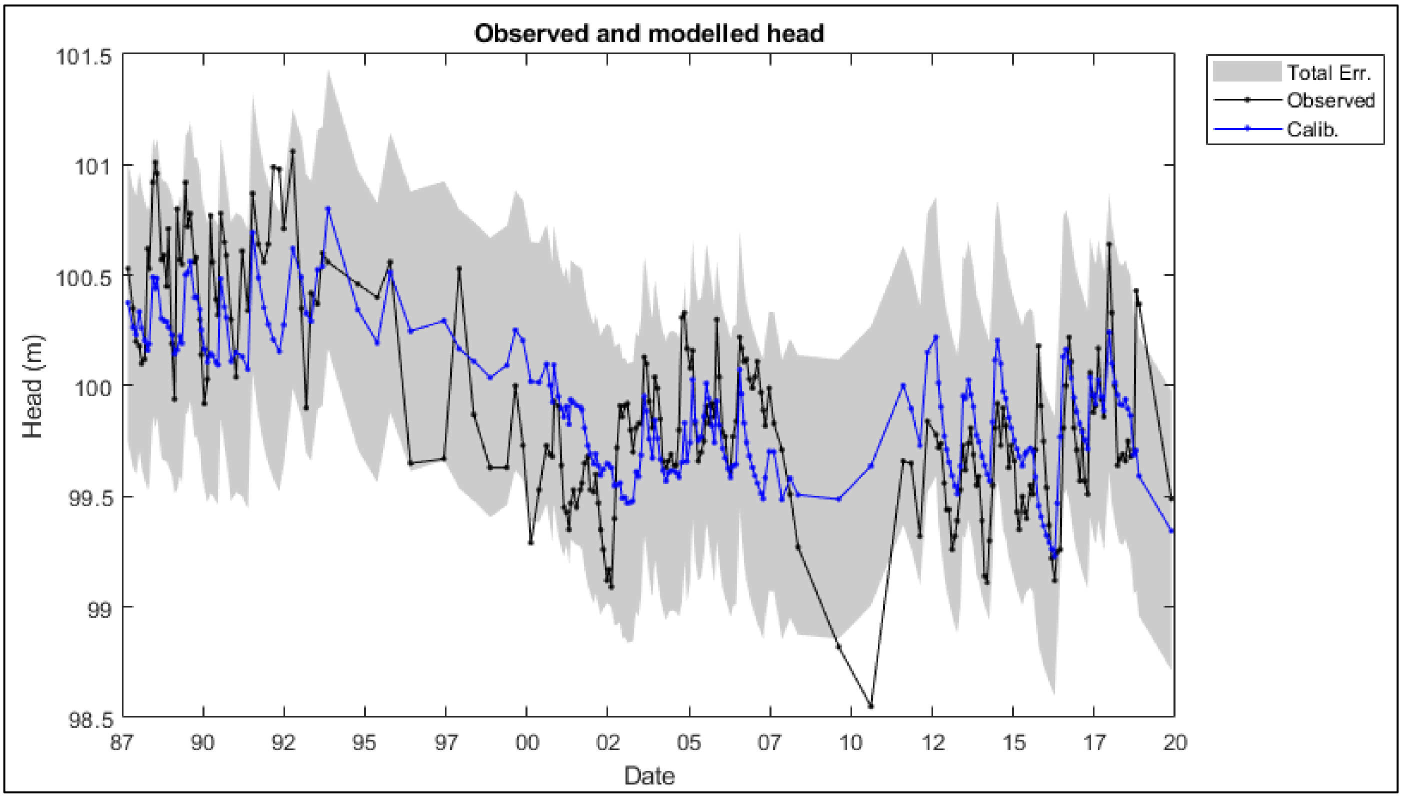


Figure G-10 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 79329 in the Lower Campaspe Valley WSPA – CoE = 0.51.

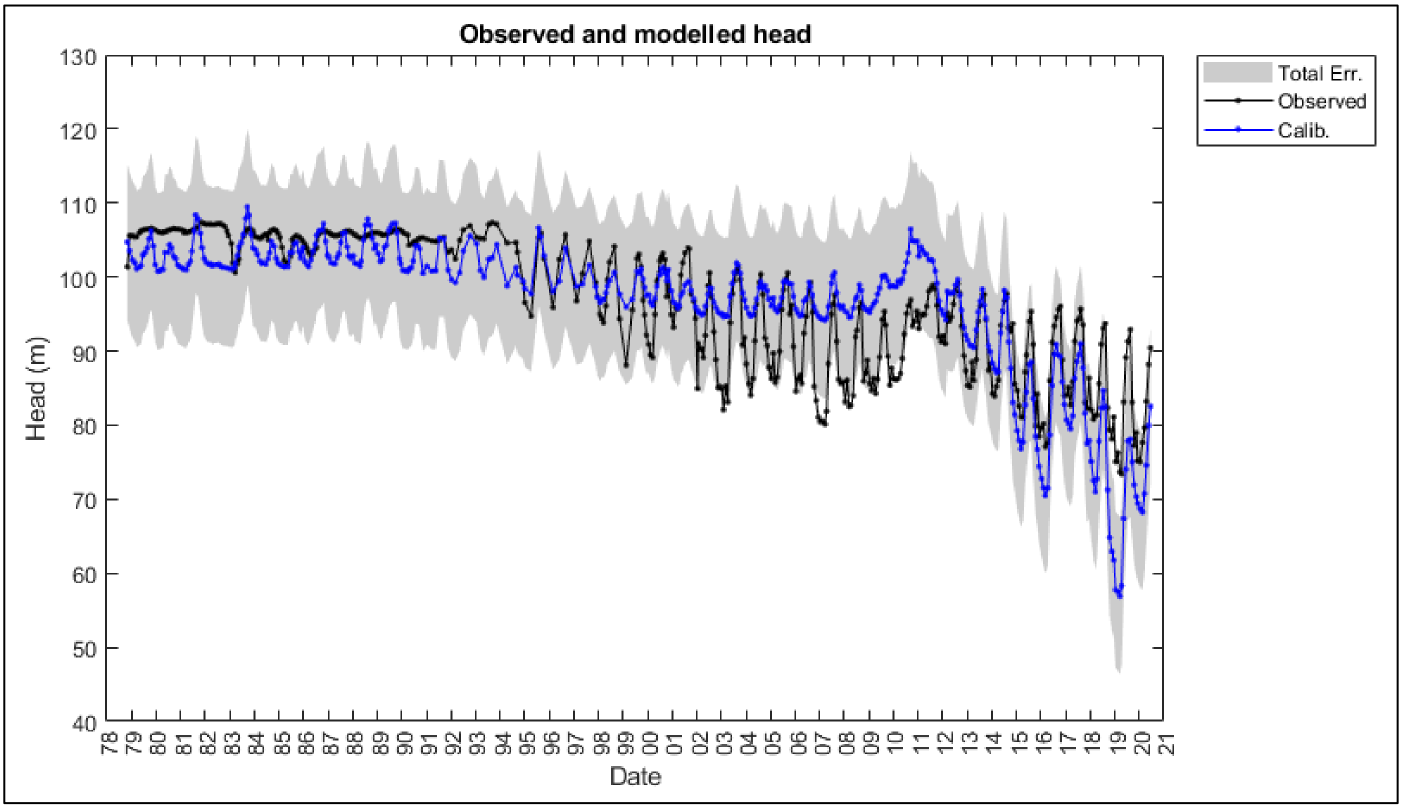


Figure G-11 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 89576 in the Lower Campaspe Valley WSPA – CoE = 0.55.

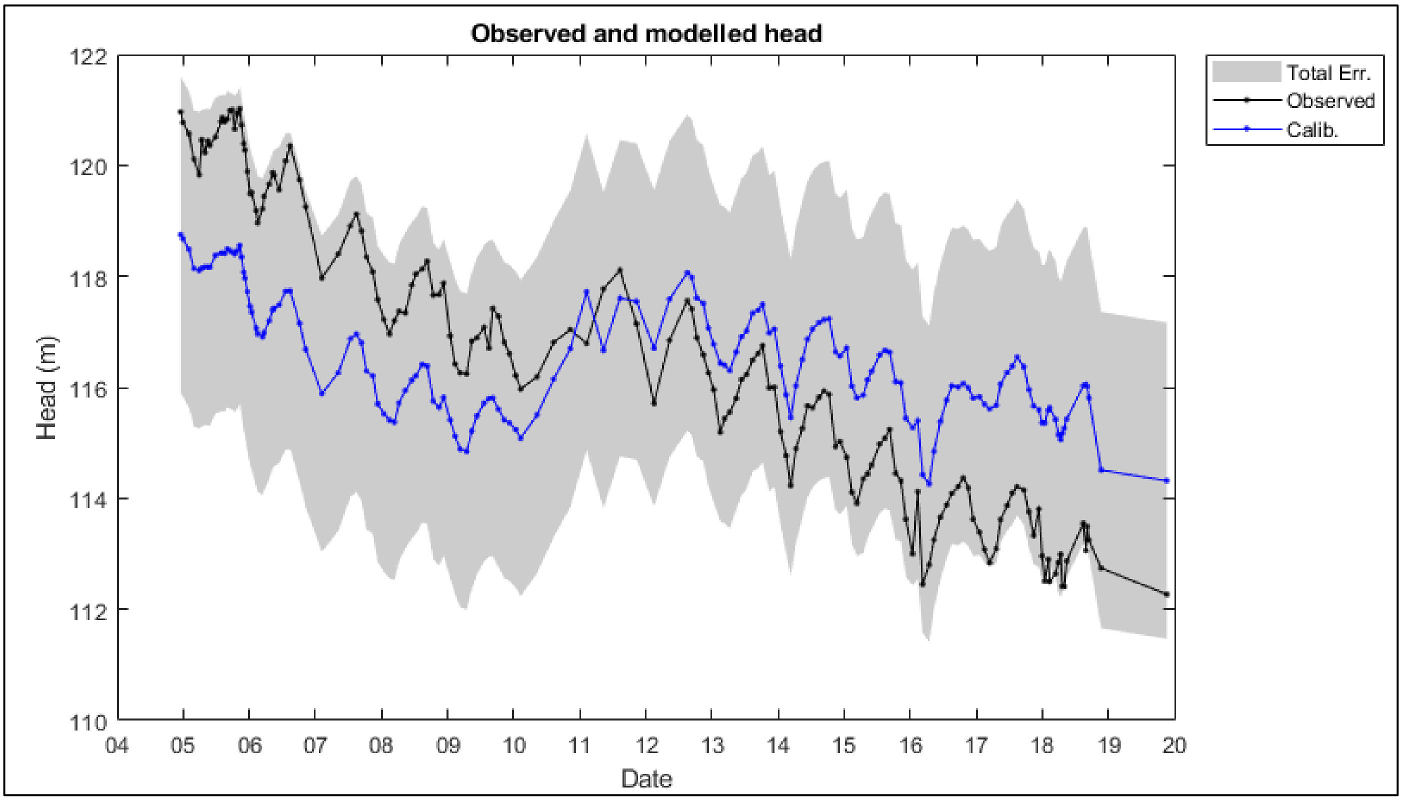


Figure G-12 Hydrograph result of the most optimal HydroSight pumping analysis calibration for observation bore WRK953018 in the Lower Campaspe Valley WSPA – CoE = 0.46 INSUFFICIENT CALIBRATION.

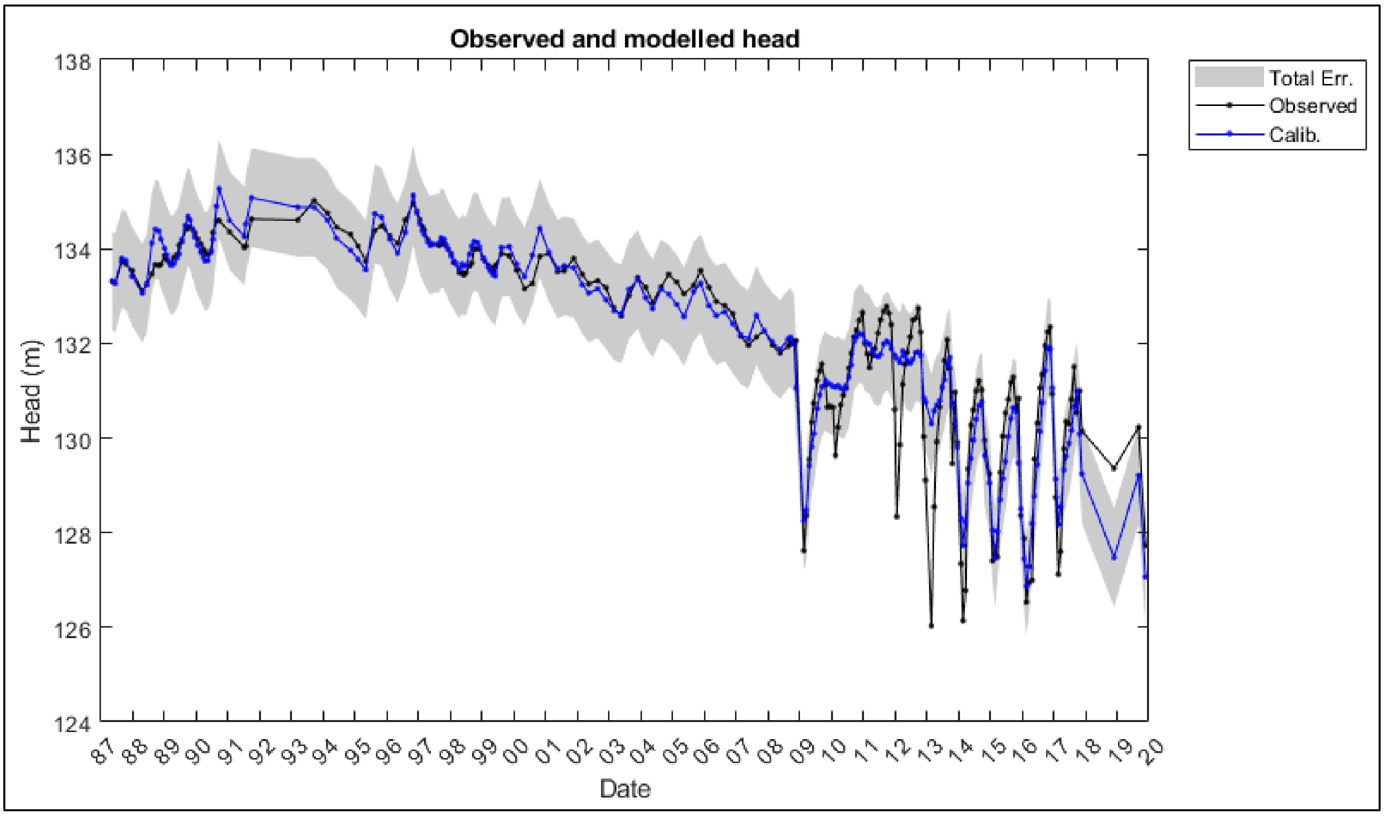


Figure G-13 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 62864 in the Lower Ovens GMA – CoE = 0.90.

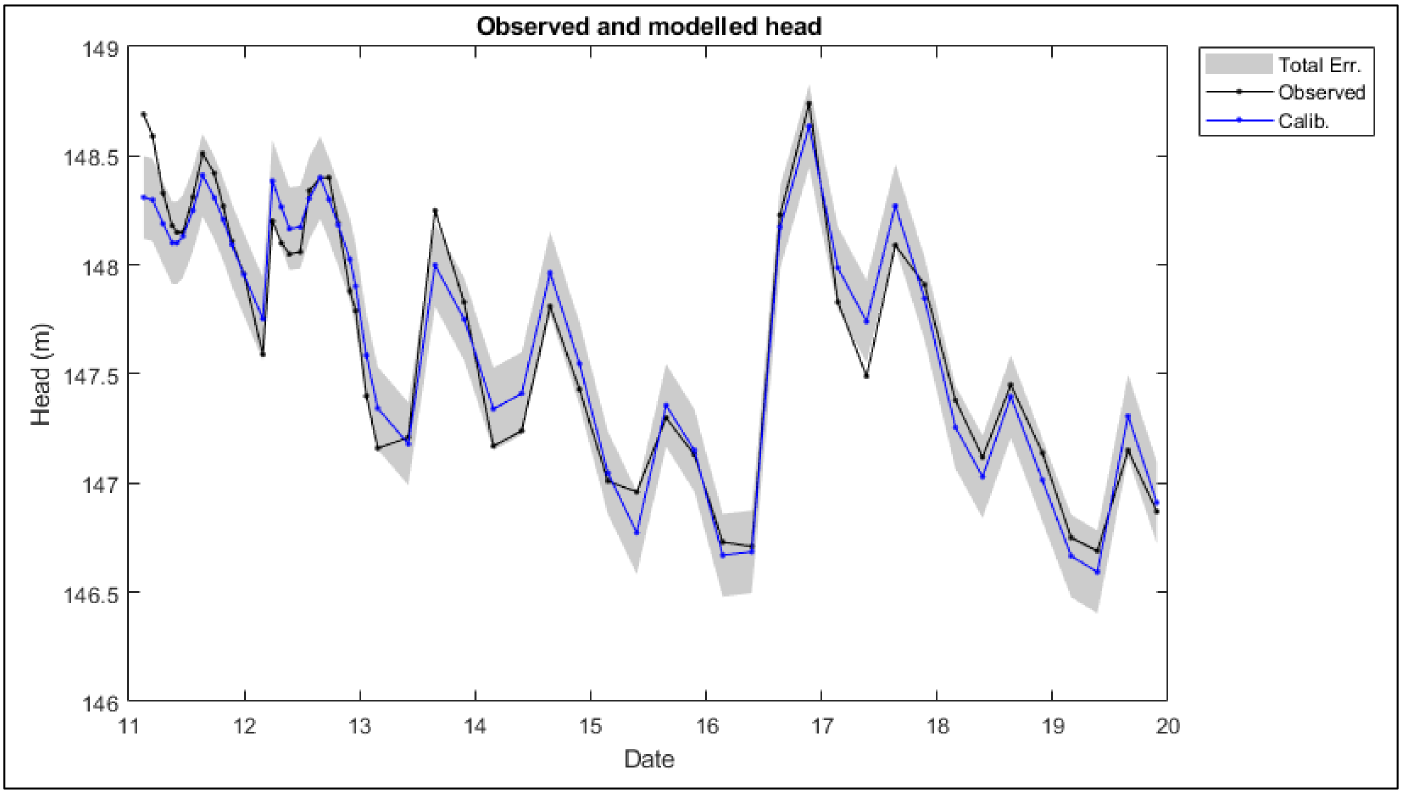


Figure G-14 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore WRK054545 in the Lower Ovens GMA – CoE = 0.95.

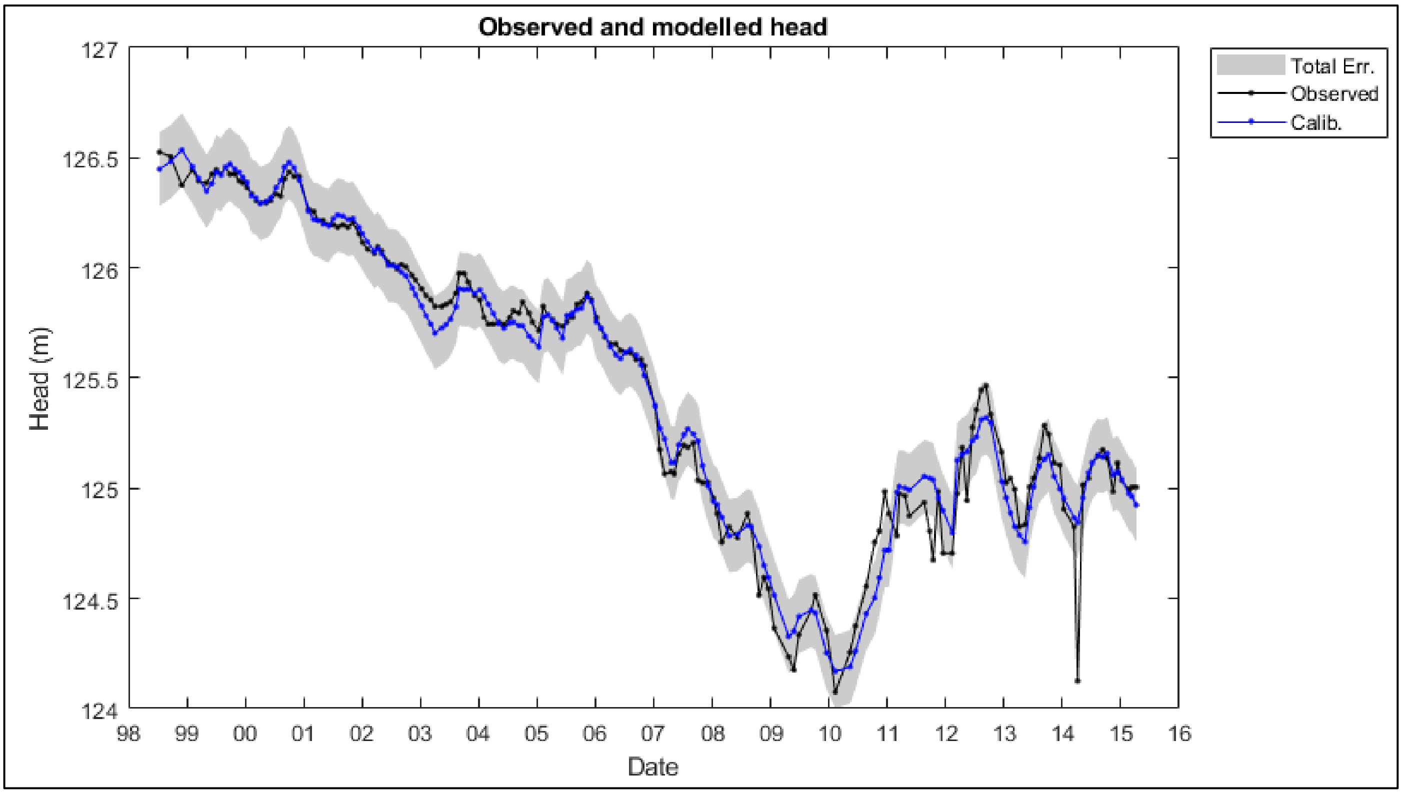


Figure G-15 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore WRK957262 in the Lower Ovens GMA – CoE = 0.97.

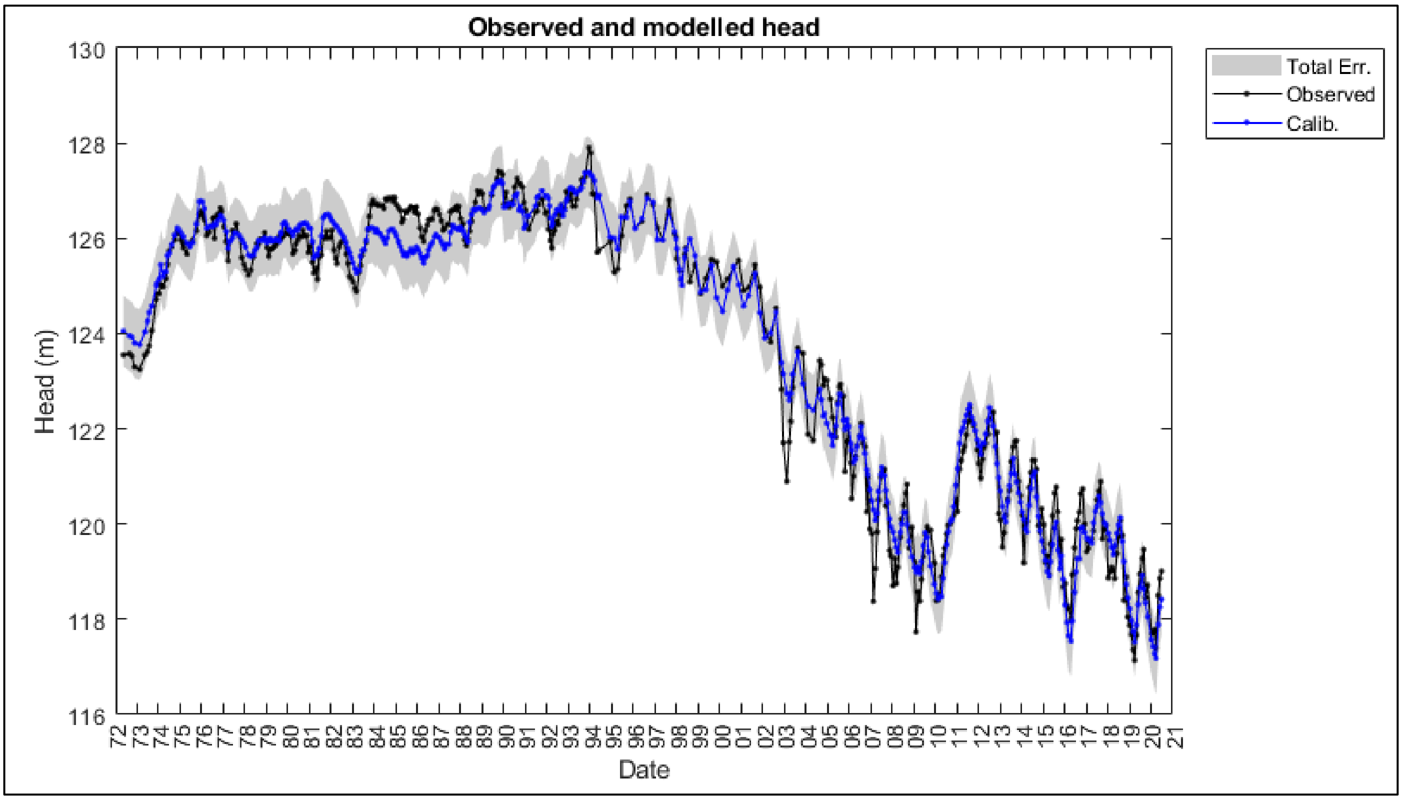


Figure G-16 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 51640 in the Mid Loddon GMA – CoE = 0.98.

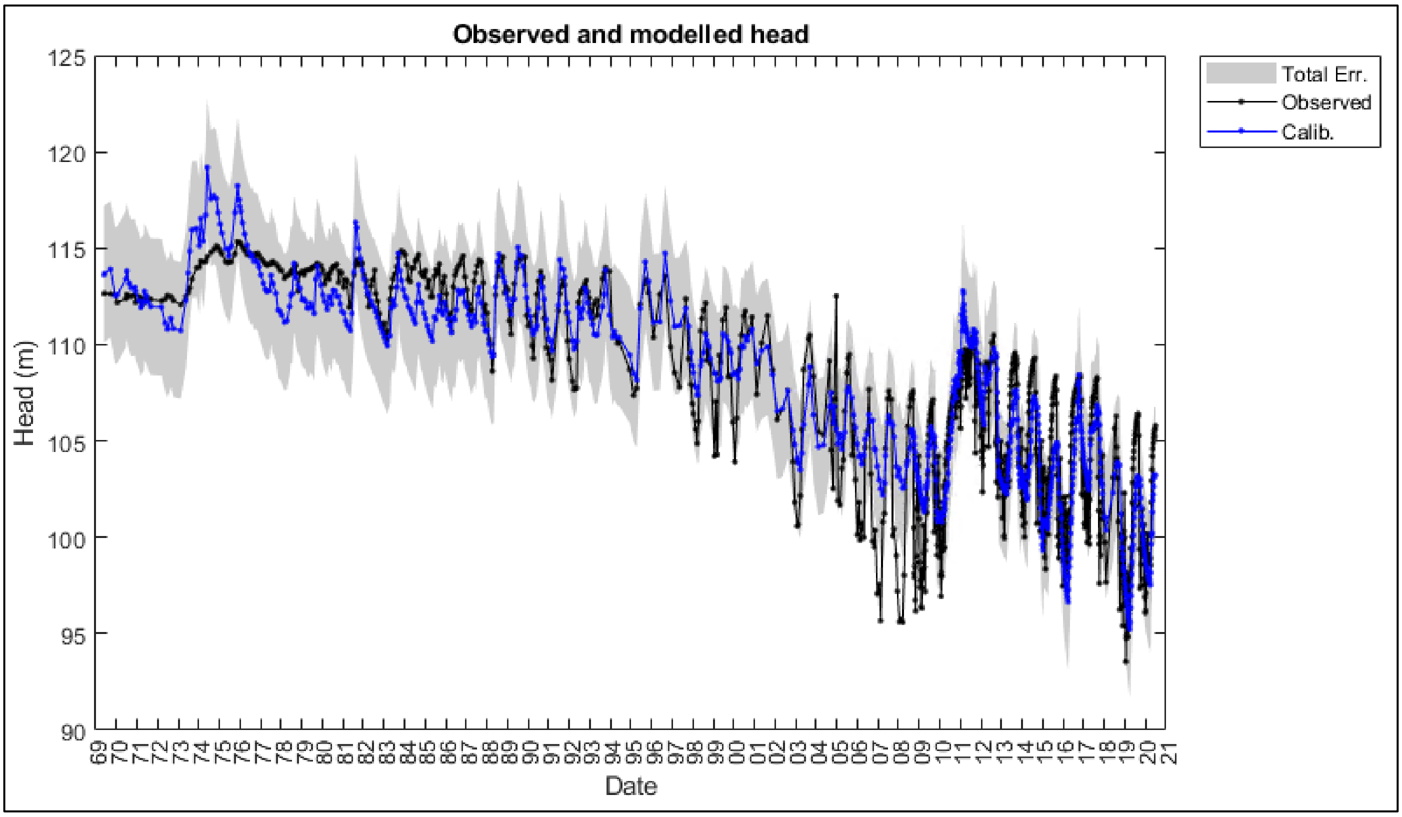


Figure G-17 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 88214 in the Mid Loddon GMA – CoE = 0.82.

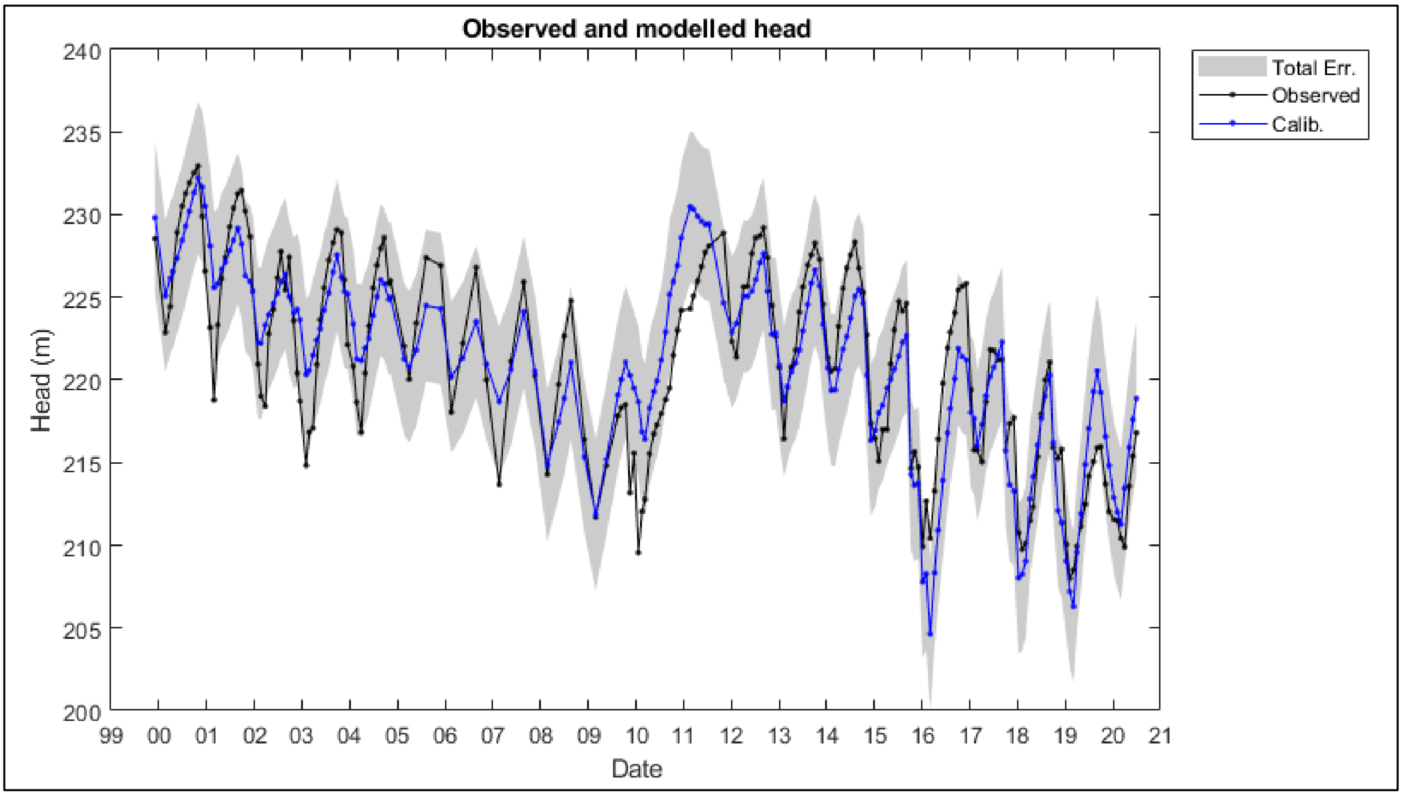


Figure G-18 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 138653 in the Mid Loddon GMA – CoE = 0.78.

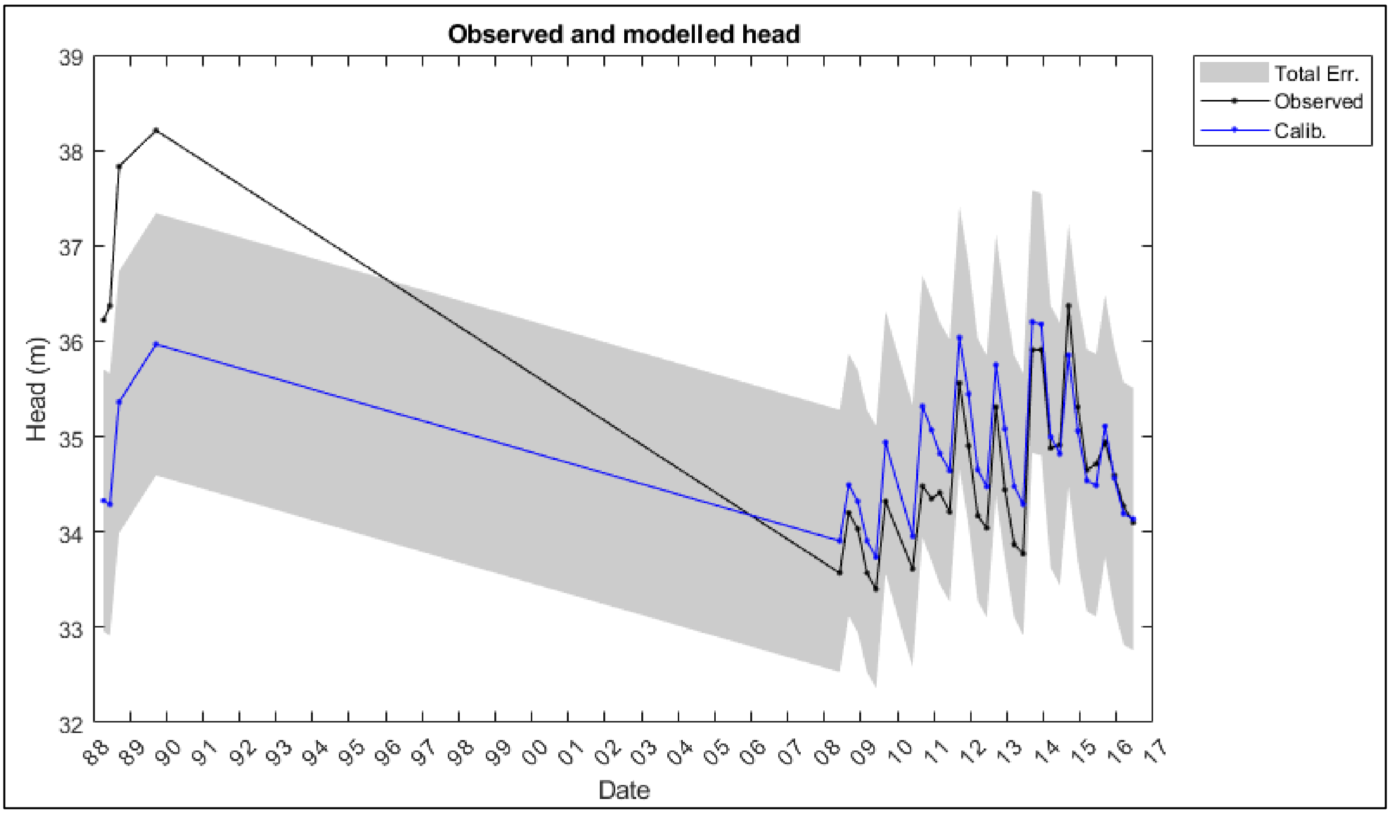


Figure G-19 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 84537 in the South West Limestone GMA (Glenelg) – CoE = 0.44.

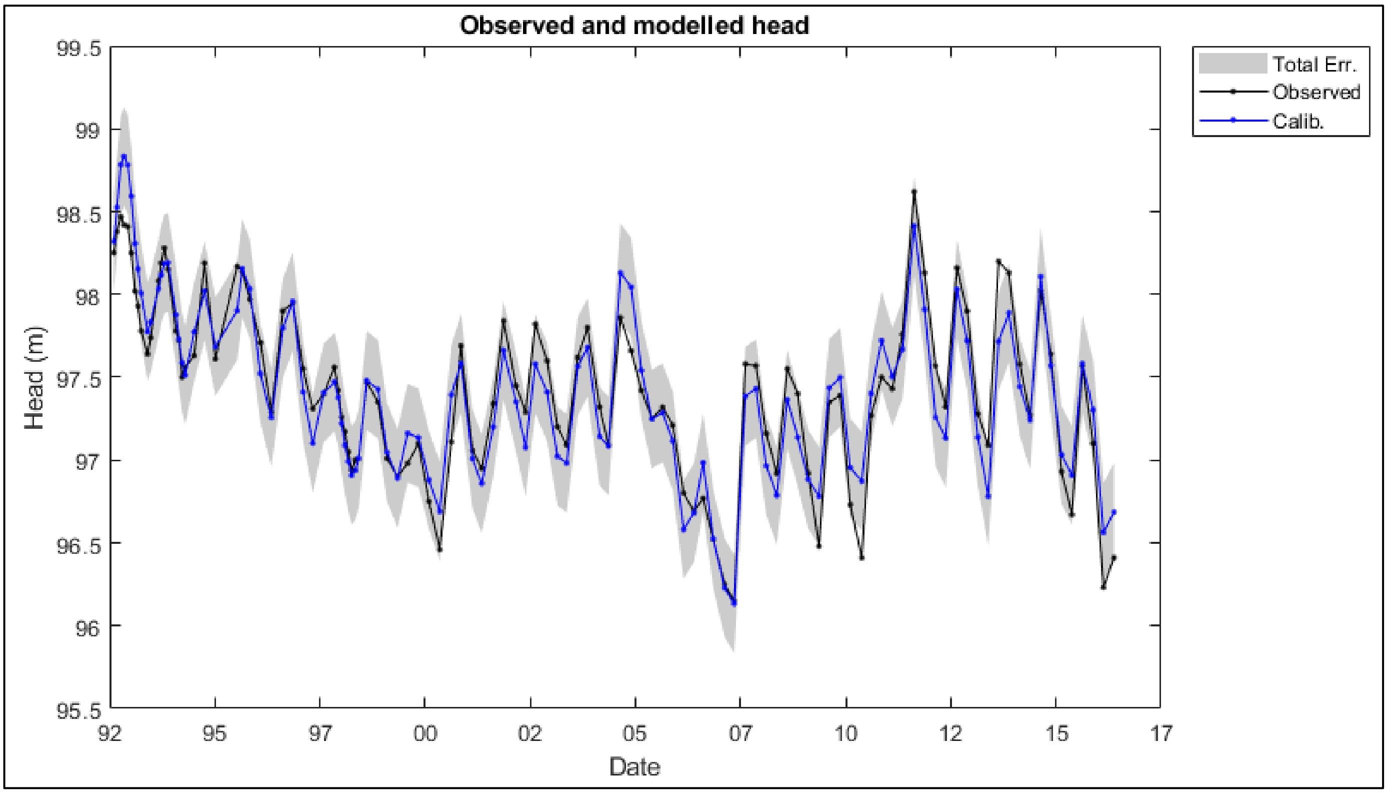


Figure G-20 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 111523 in the South West Limestone GMA (Hawkesdale) – CoE = 0.89.

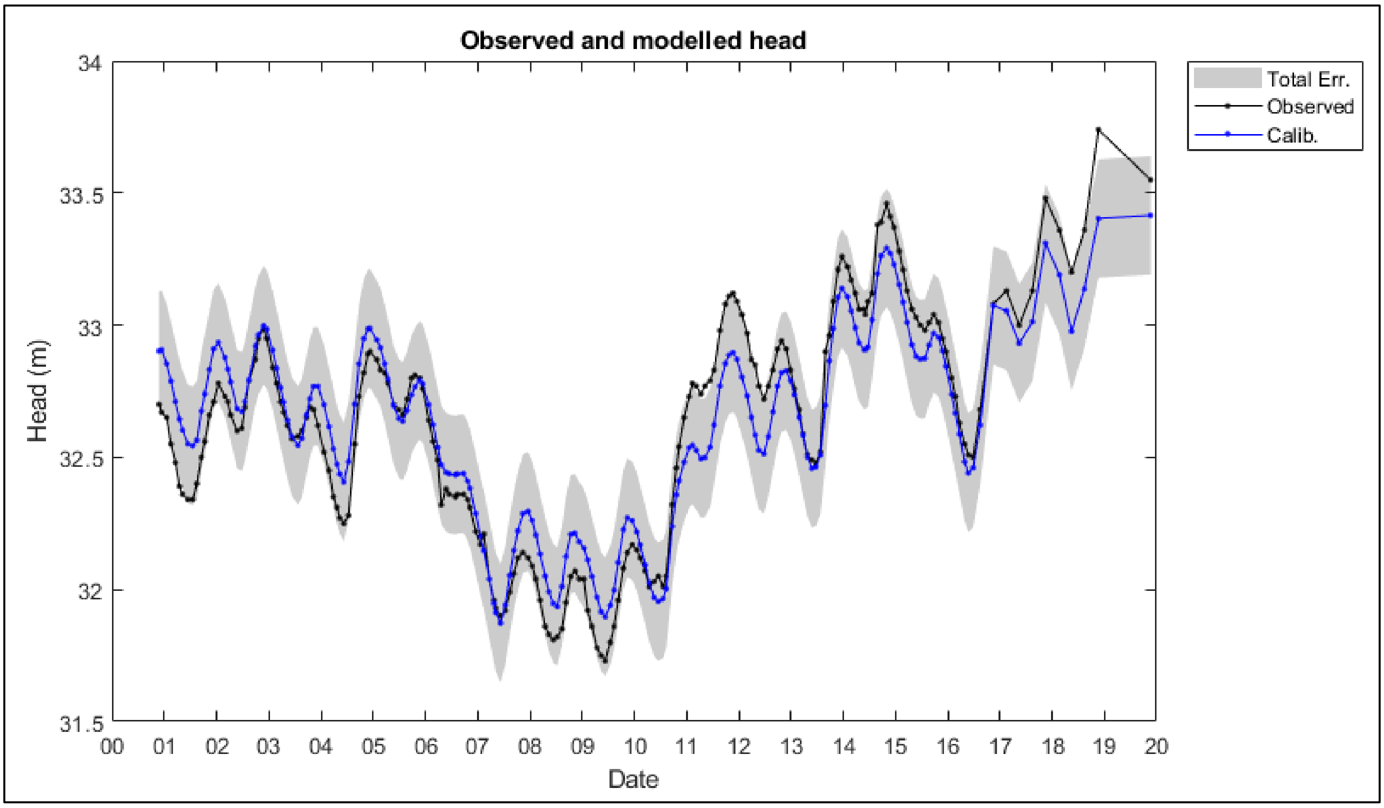


Figure G-21 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 141239 in the South West Limestone GMA (Nullawarre) – CoE = 0.90.

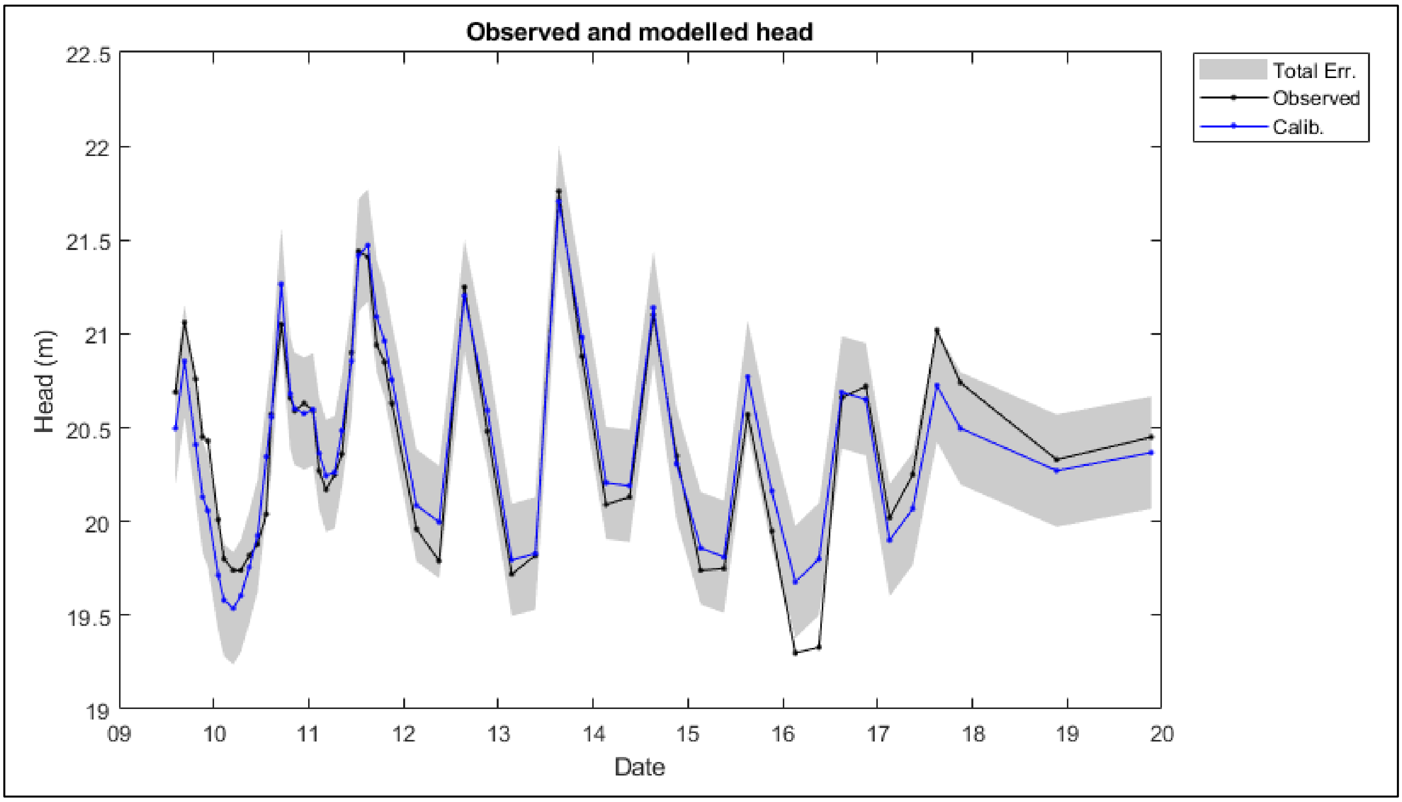


Figure G-22 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore WRK988734 in the South West Limestone GMA (Hawkesdale) – CoE = 0.89.

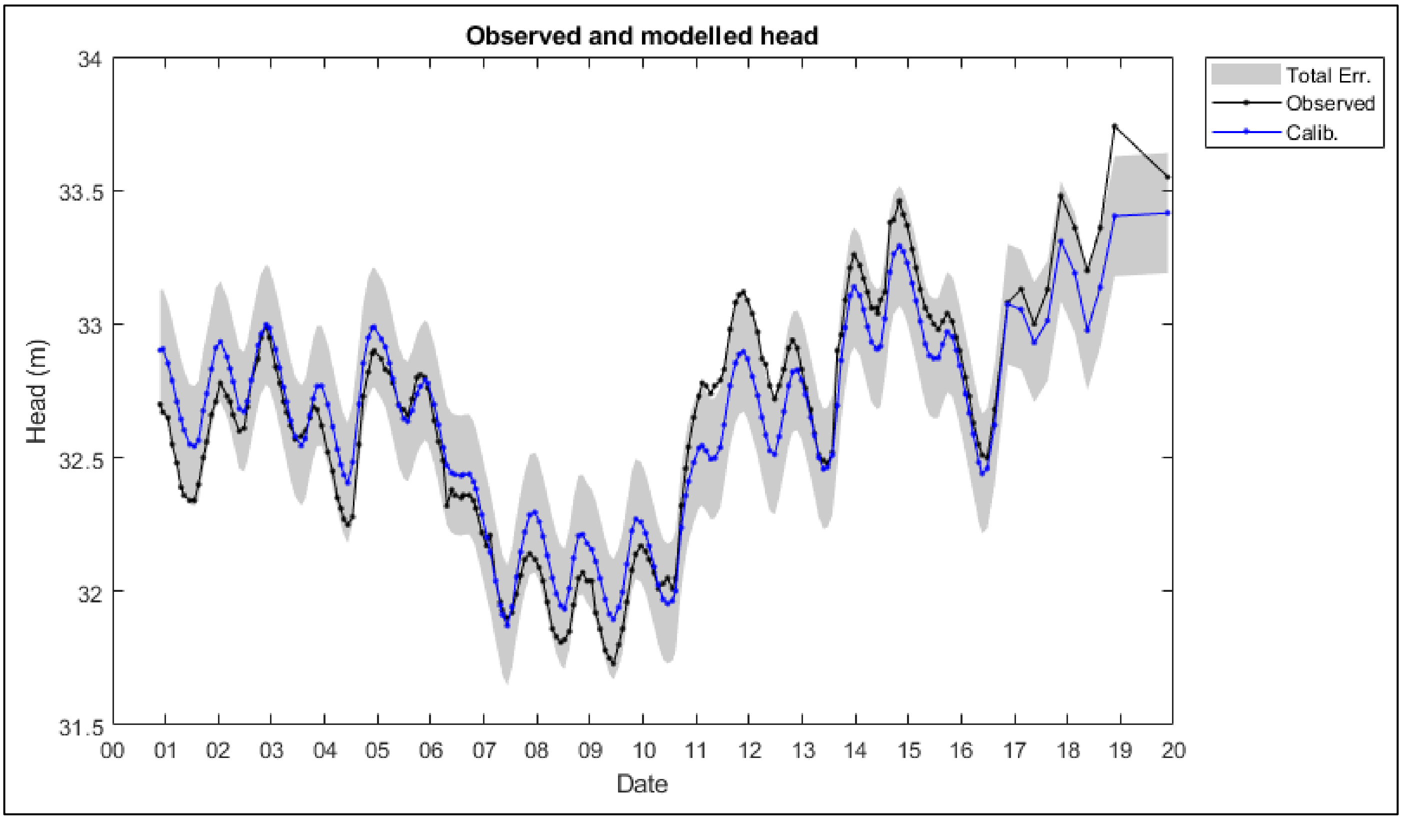


Figure G-23 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 141239 in the South West Limestone GMA (Nullawarre) – CoE = 0.90.

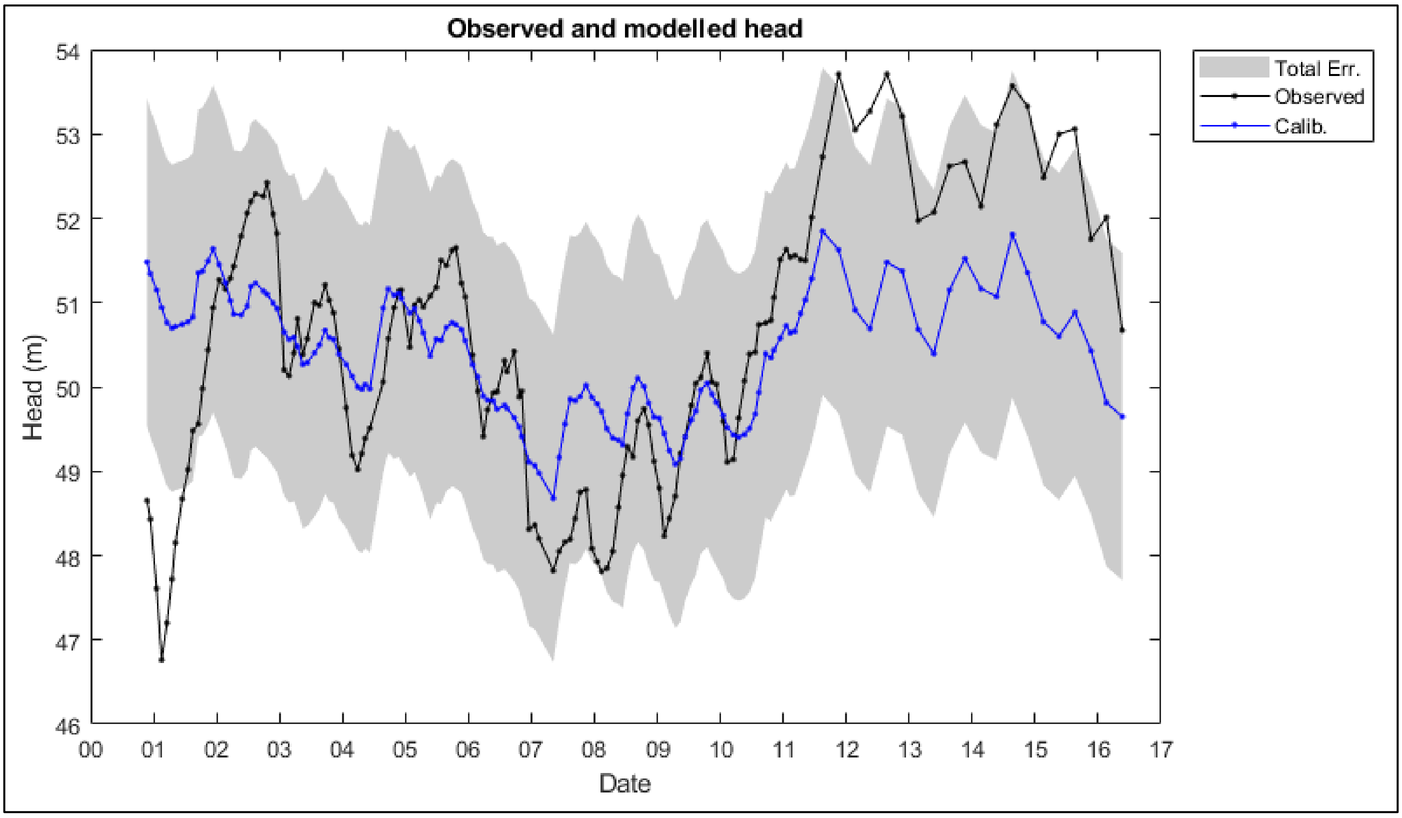


Figure G-24 Hydrograph result of the most optimal HydroSight pumping analysis calibration for observation bore WRK988734 in the South West Limestone GMA (Yangery) – CoE = 0.36 INSUFFICIENT CALIBRATION.

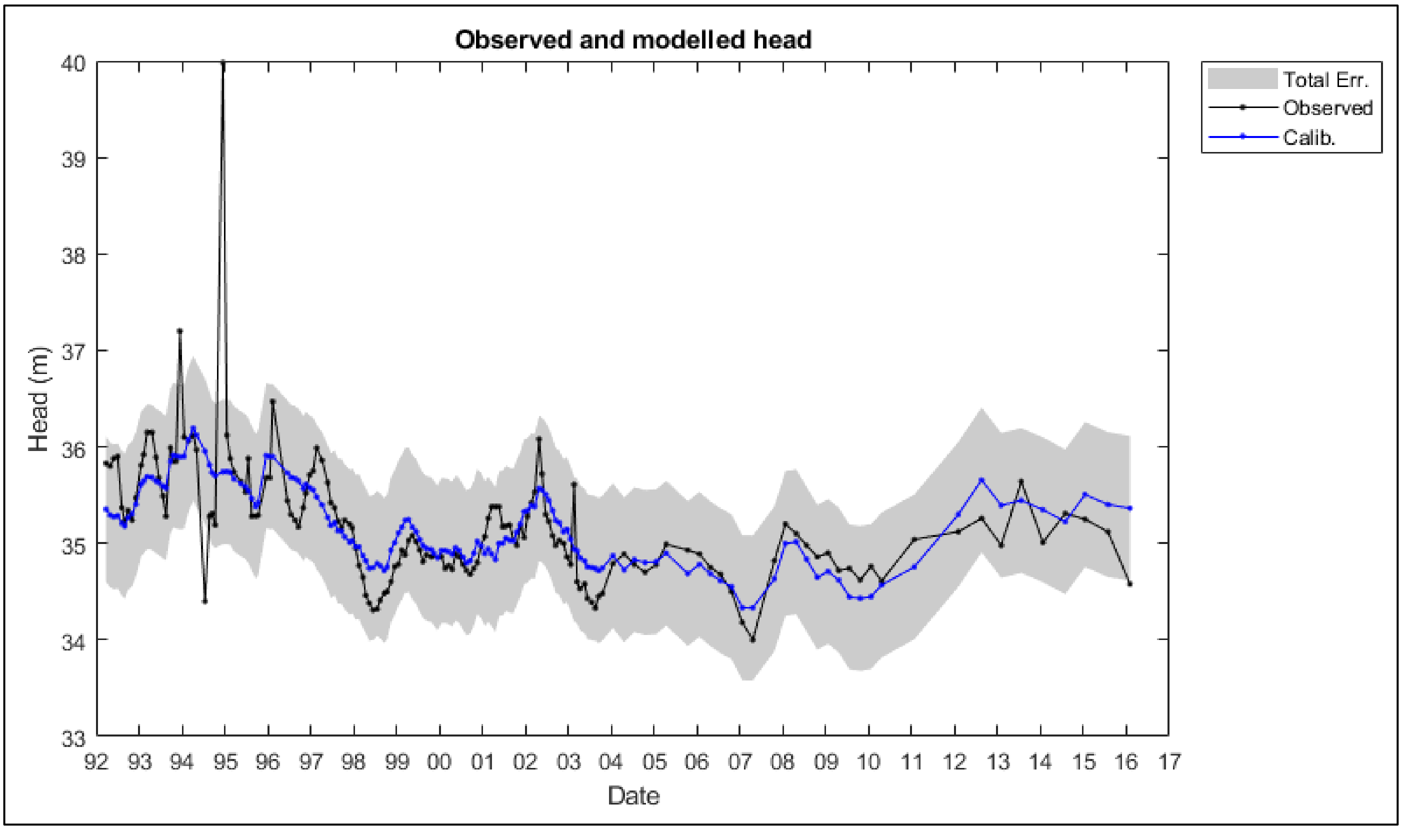


Figure G-25 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 76888 in the Wa De Lock GMA– CoE = 0.48.

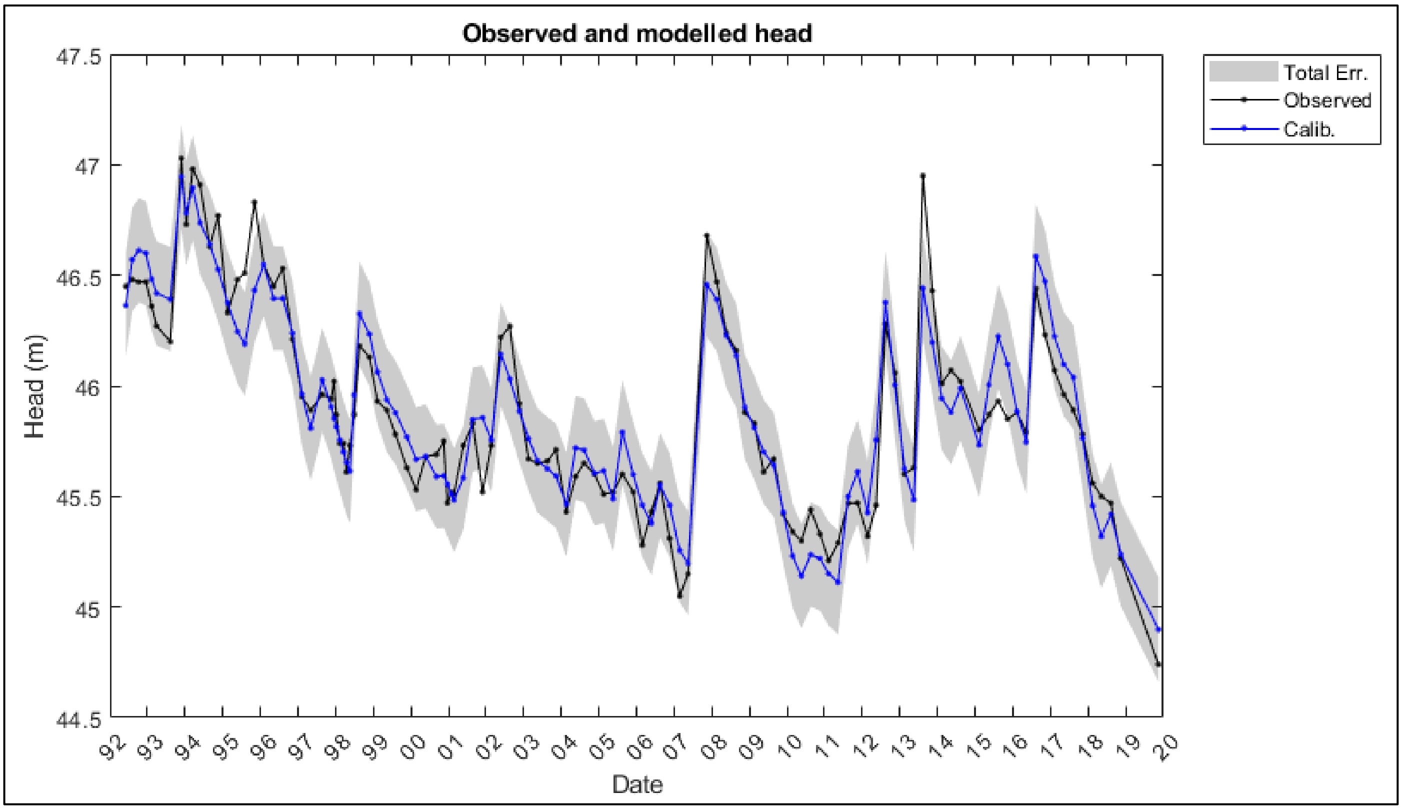


Figure G-26 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 110171 in the Wa De Lock GMA – CoE = 0.91.

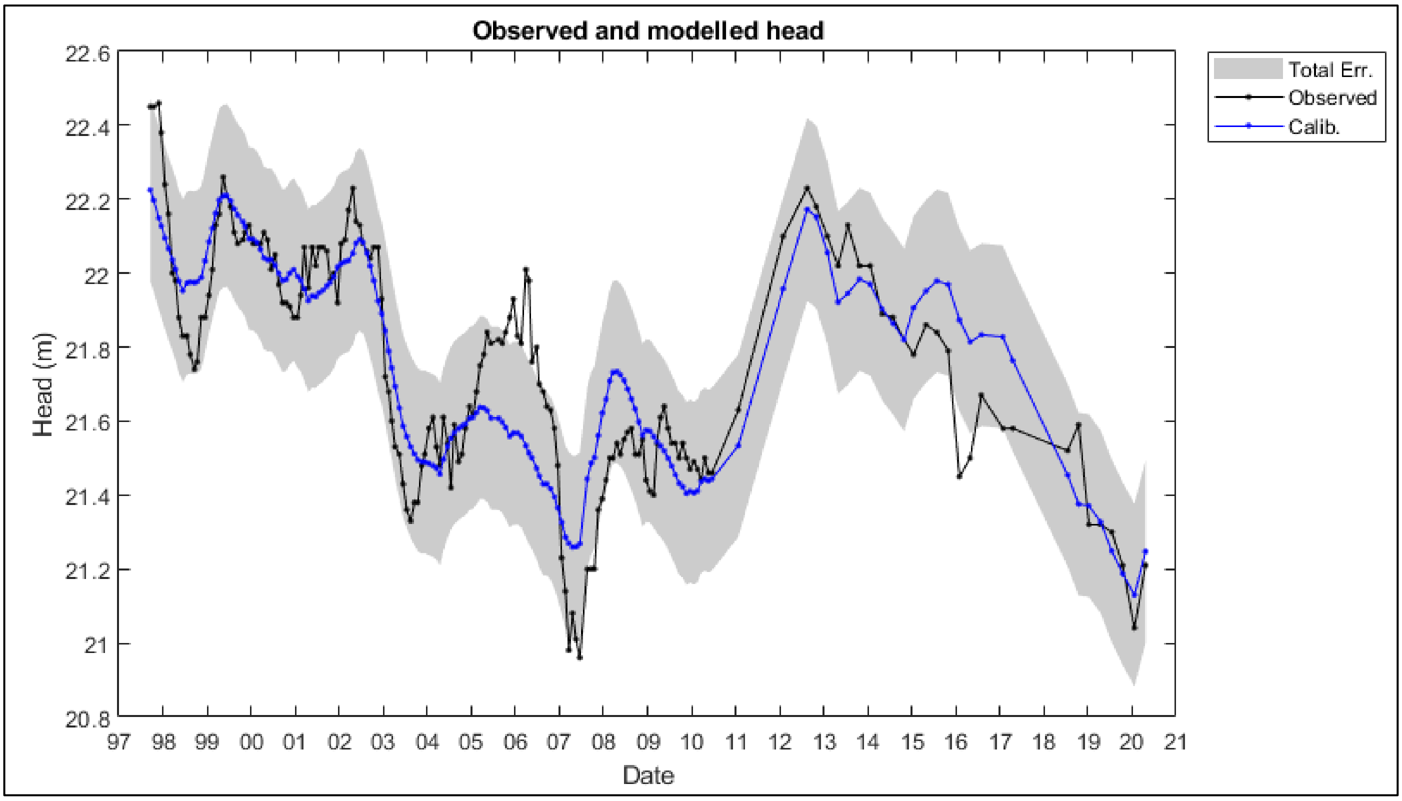
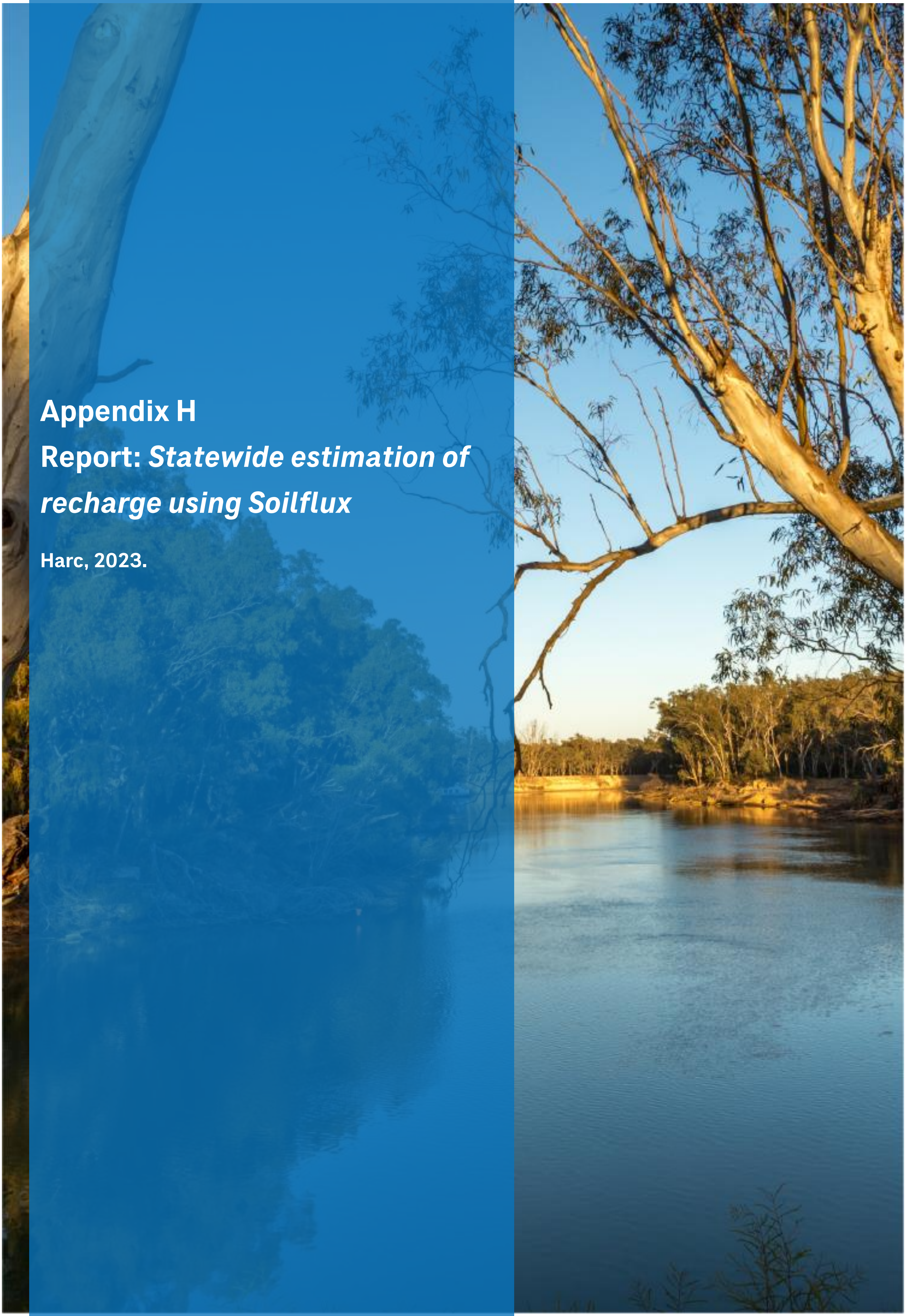


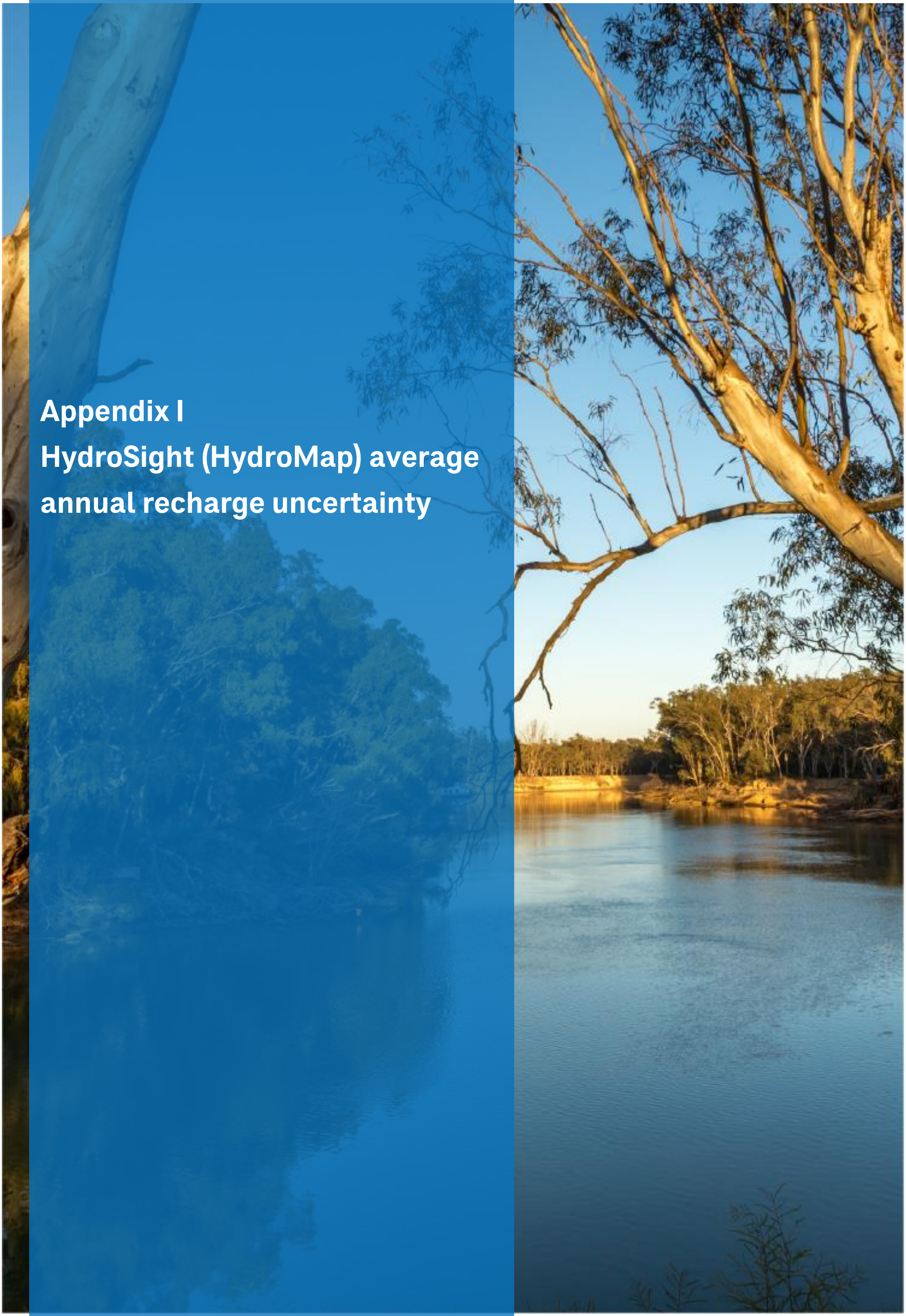
Figure G-27 Hydrograph result of the optimal HydroSight pumping analysis calibration for observation bore 130372 in the Wa De Lock GMA – CoE = 0.76..



Appendix H

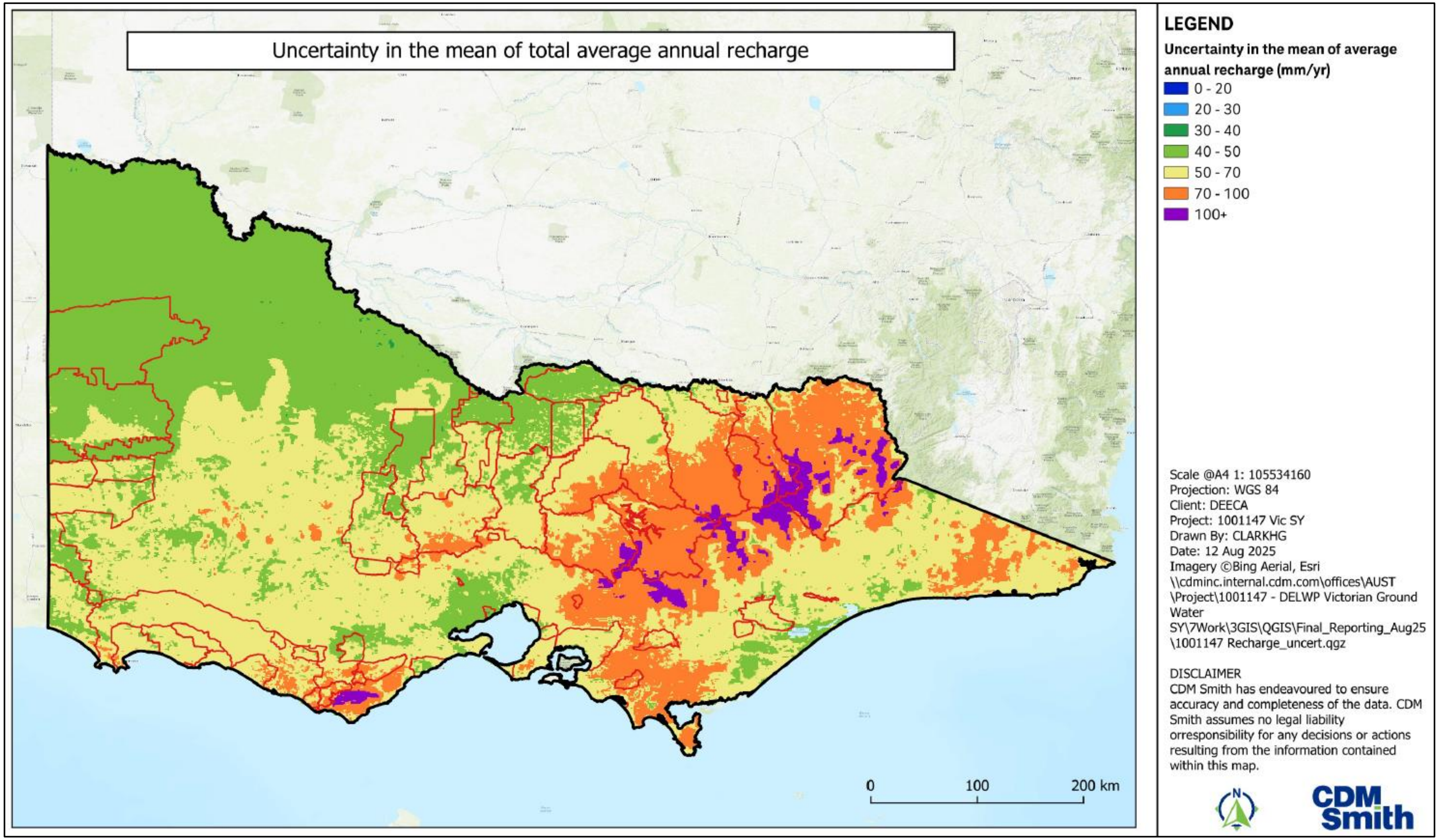
Report: *Statewide estimation of recharge using Soilflux*

Harc, 2023.



Appendix I

HydroSight (HydroMap) average annual recharge uncertainty



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Project: 1001147 Vic SY
Drawn By: CLARKHG
Date: 12 Aug 2025
Imagery ©Bing Aerial, Esri
\\cdminc.internal.cdm.com\offices\AUST
\Project\1001147 - DELWP Victorian Ground
Water
SY\7Work\3GIS\QGIS\Final_Reporting_Aug25
\1001147 Recharge_uncert.qgz

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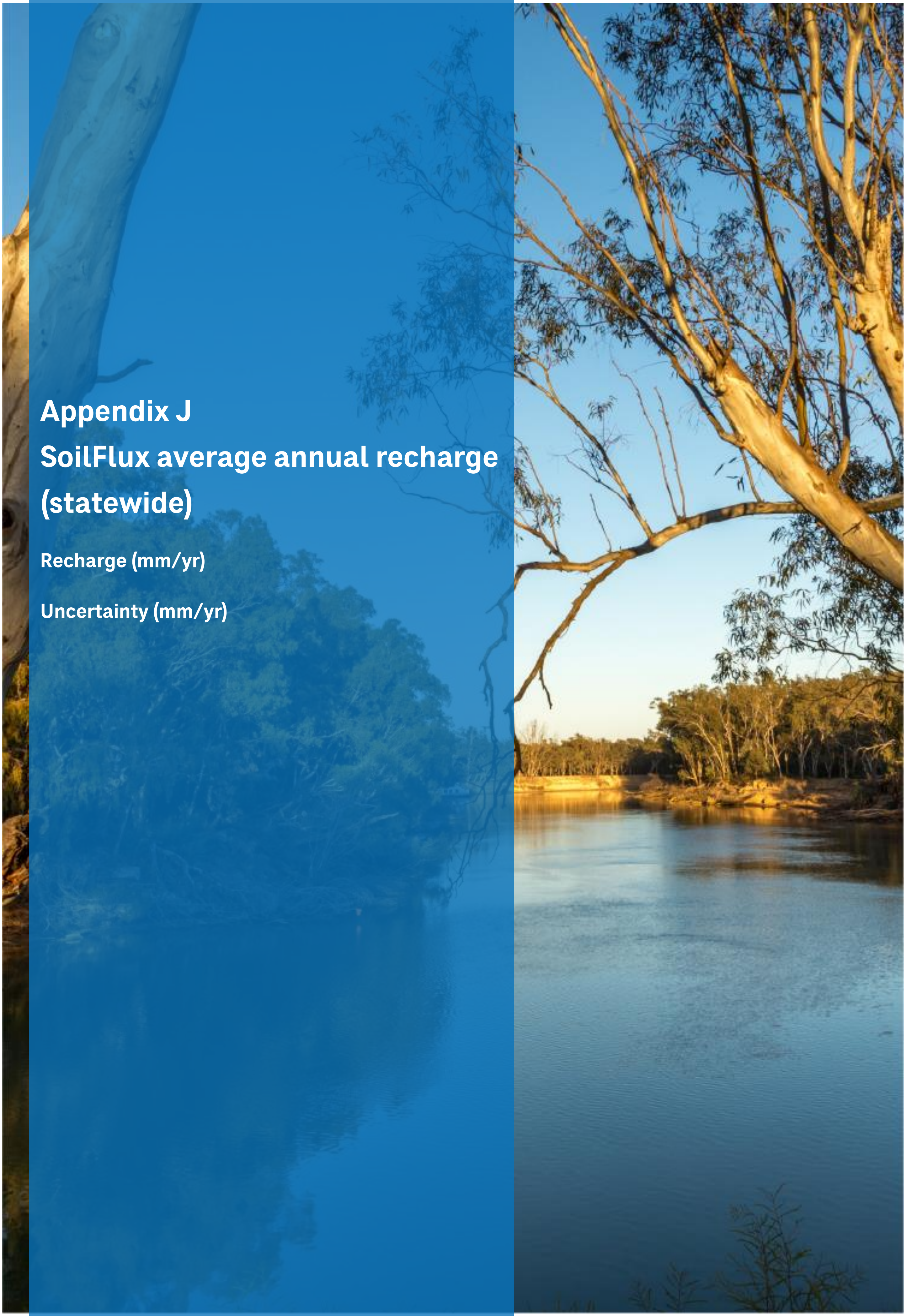
Figure I-1 Estimated variability in the mean of HydroSight gridded recharge (via HydroMap), based on 1950-1974 data.

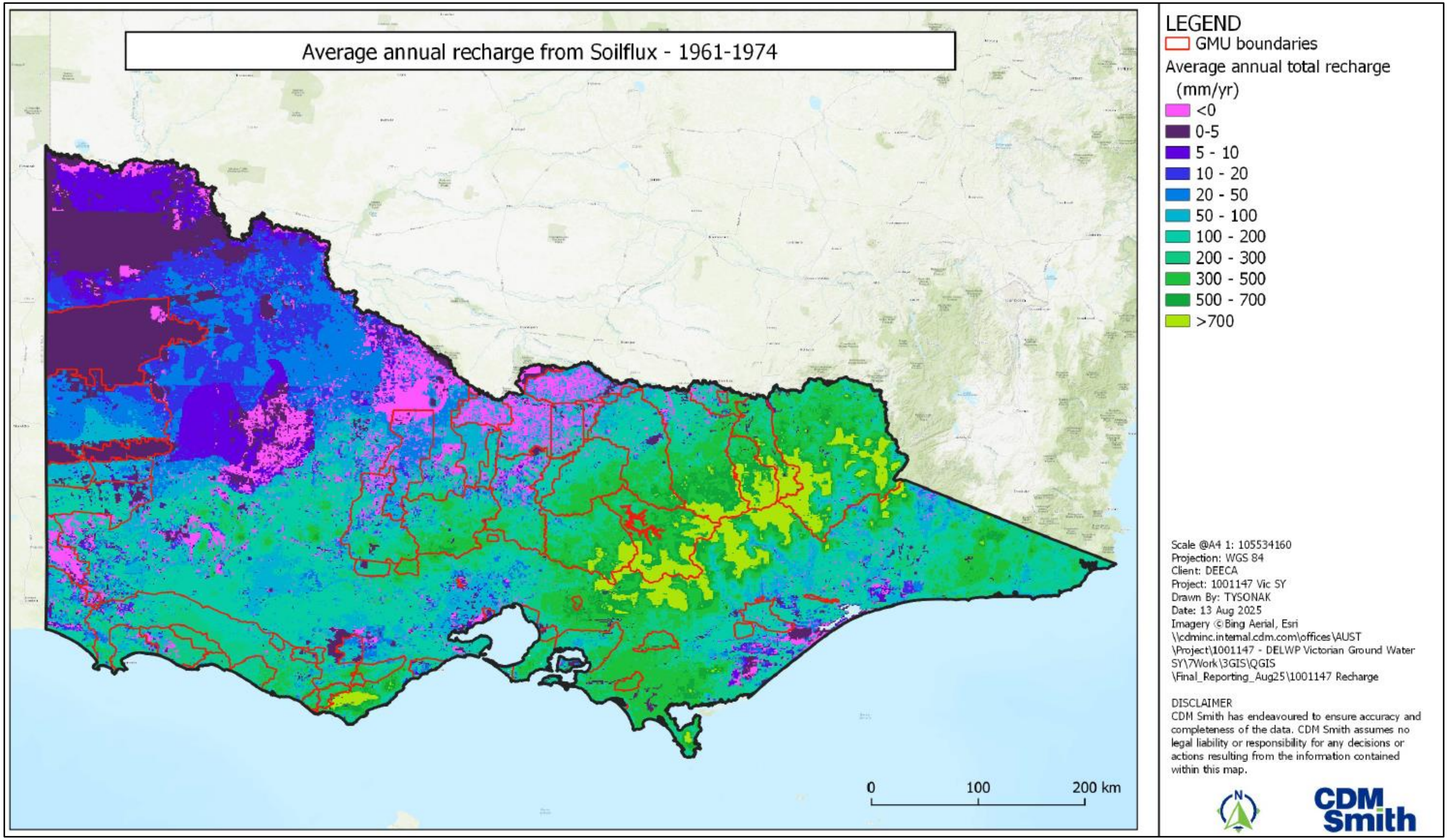
Appendix J

SoilFlux average annual recharge (statewide)

Recharge (mm/yr)

Uncertainty (mm/yr)





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Date: 13 Aug 2025
Imagery ©Bing Aerial, Esri
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SY\7Work\3GIS\QGIS
\Final_Reporting_Aug25\1001147 Recharge

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Figure J-1 Estimated average annual recharge for Victoria (SoilFlux result) – 1961-1974 (HARC 2023).

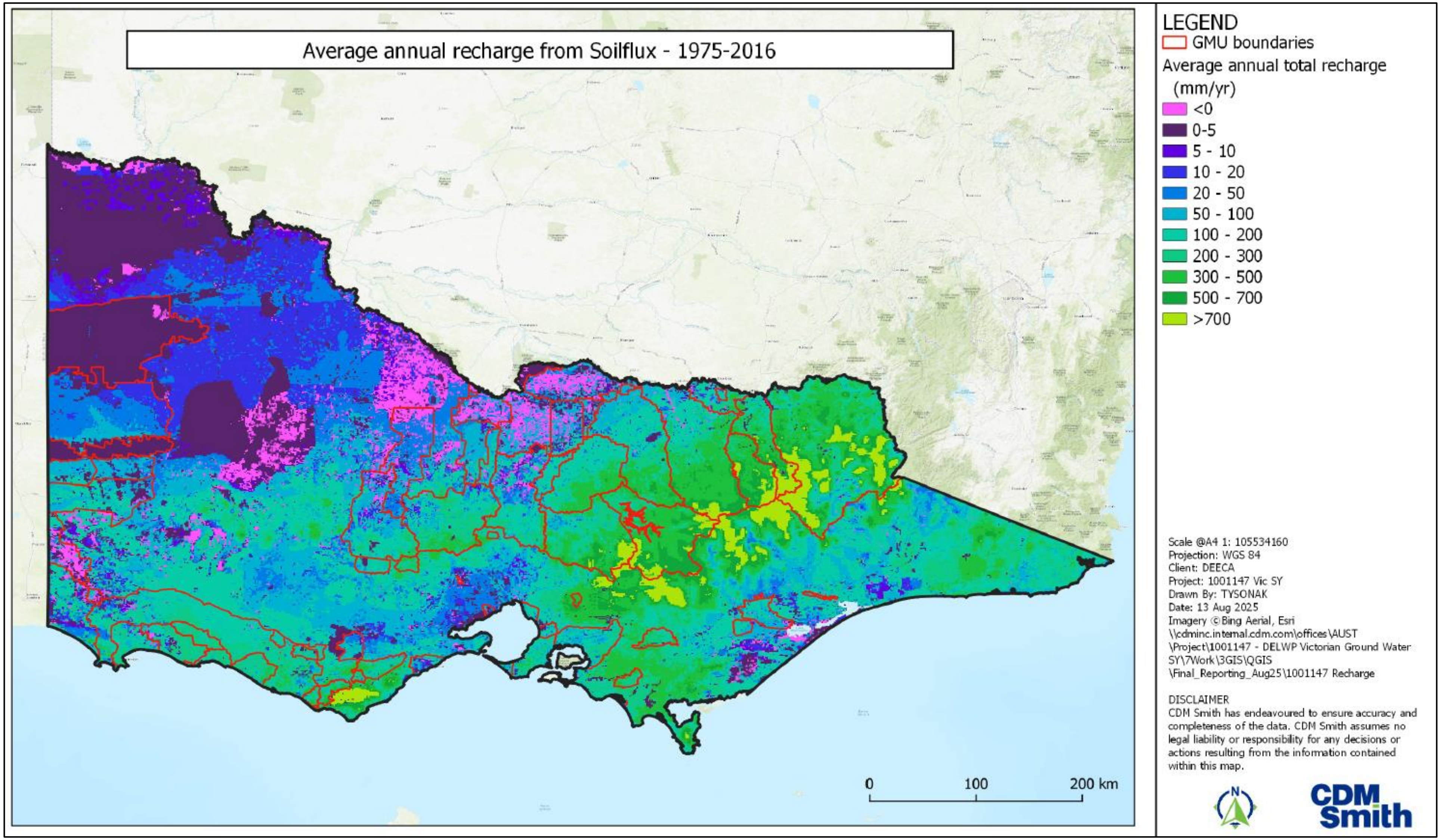


Figure J-2 Estimated average annual recharge for Victoria (SoilFlux result) – 1975-2016 (HARC 2023).

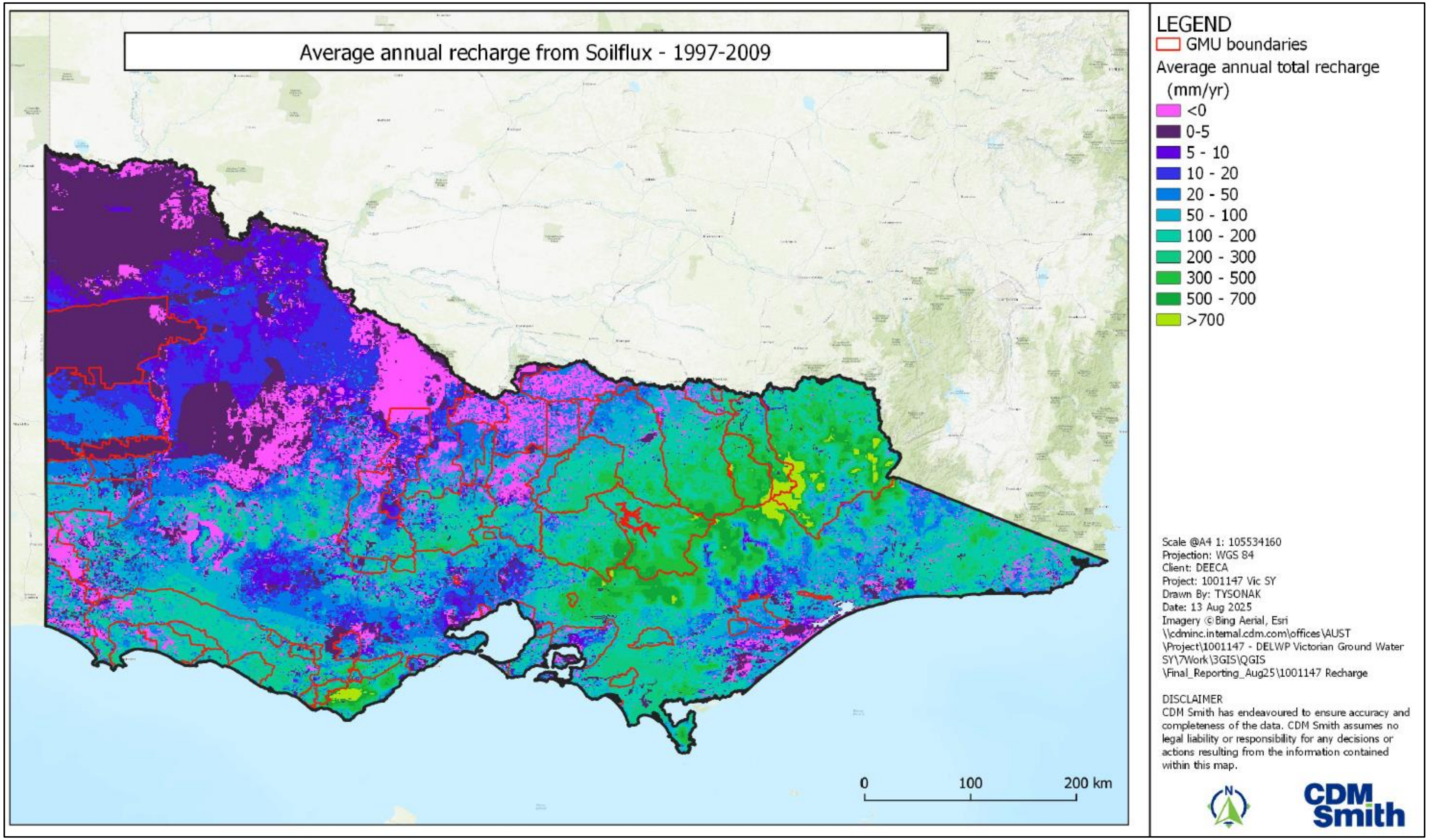


Figure J-3 Estimated average annual recharge for Victoria (SoilFlux result) – 1997-2009 (HARC 2023).

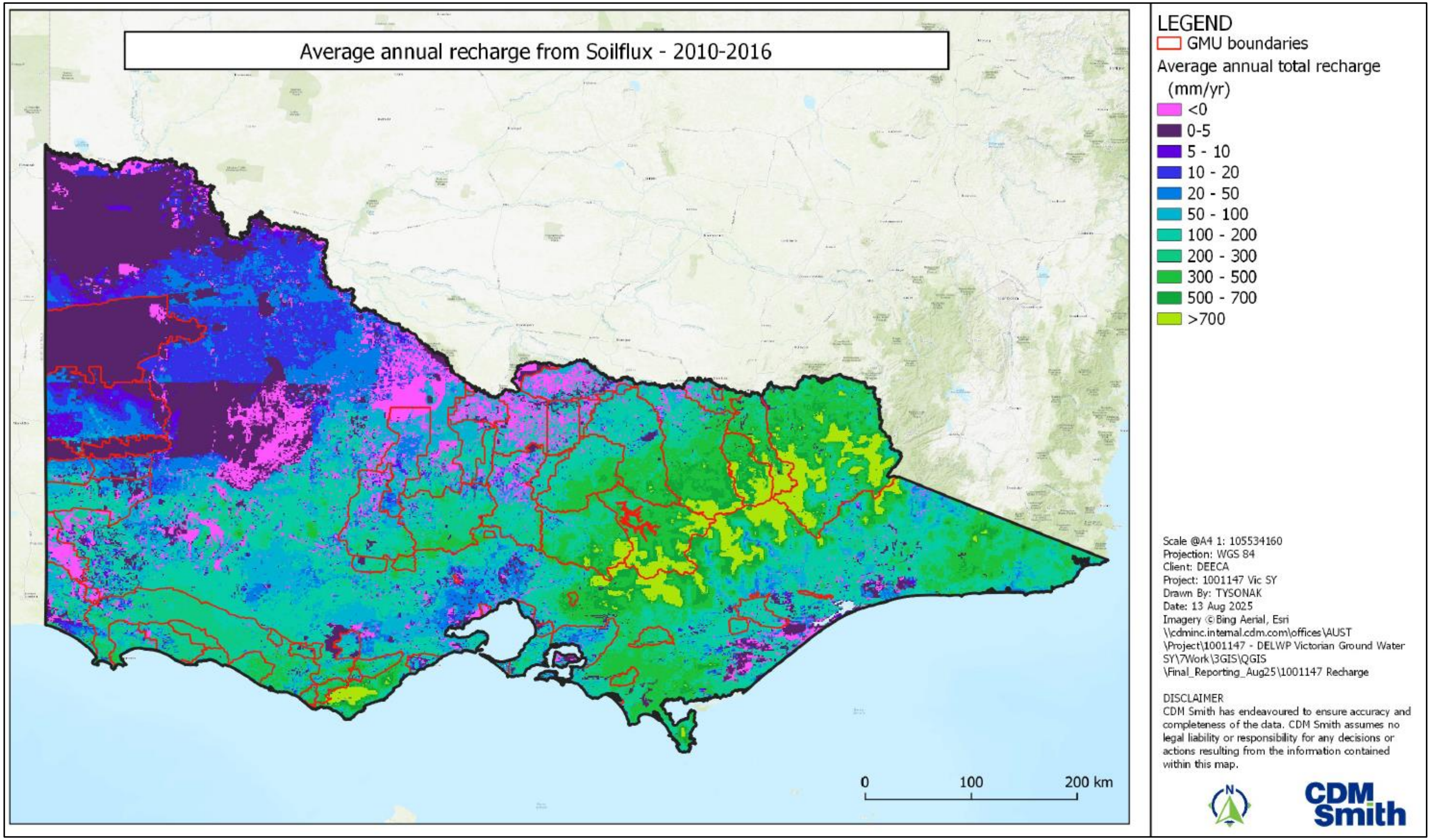


Figure J-4 Estimated average annual recharge for Victoria (SoilFlux result) – 2010 – 2016 (HARC 2023).

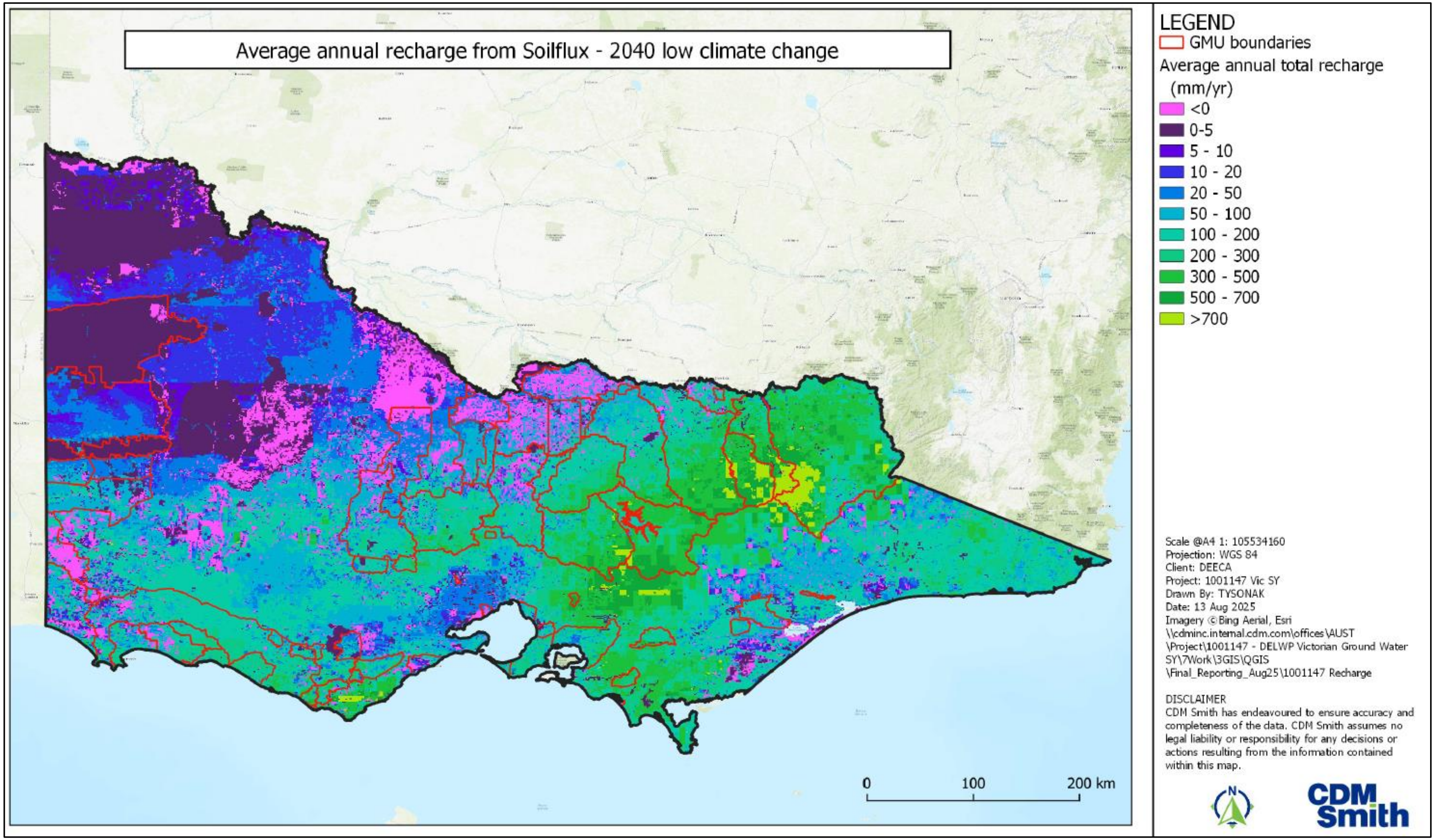
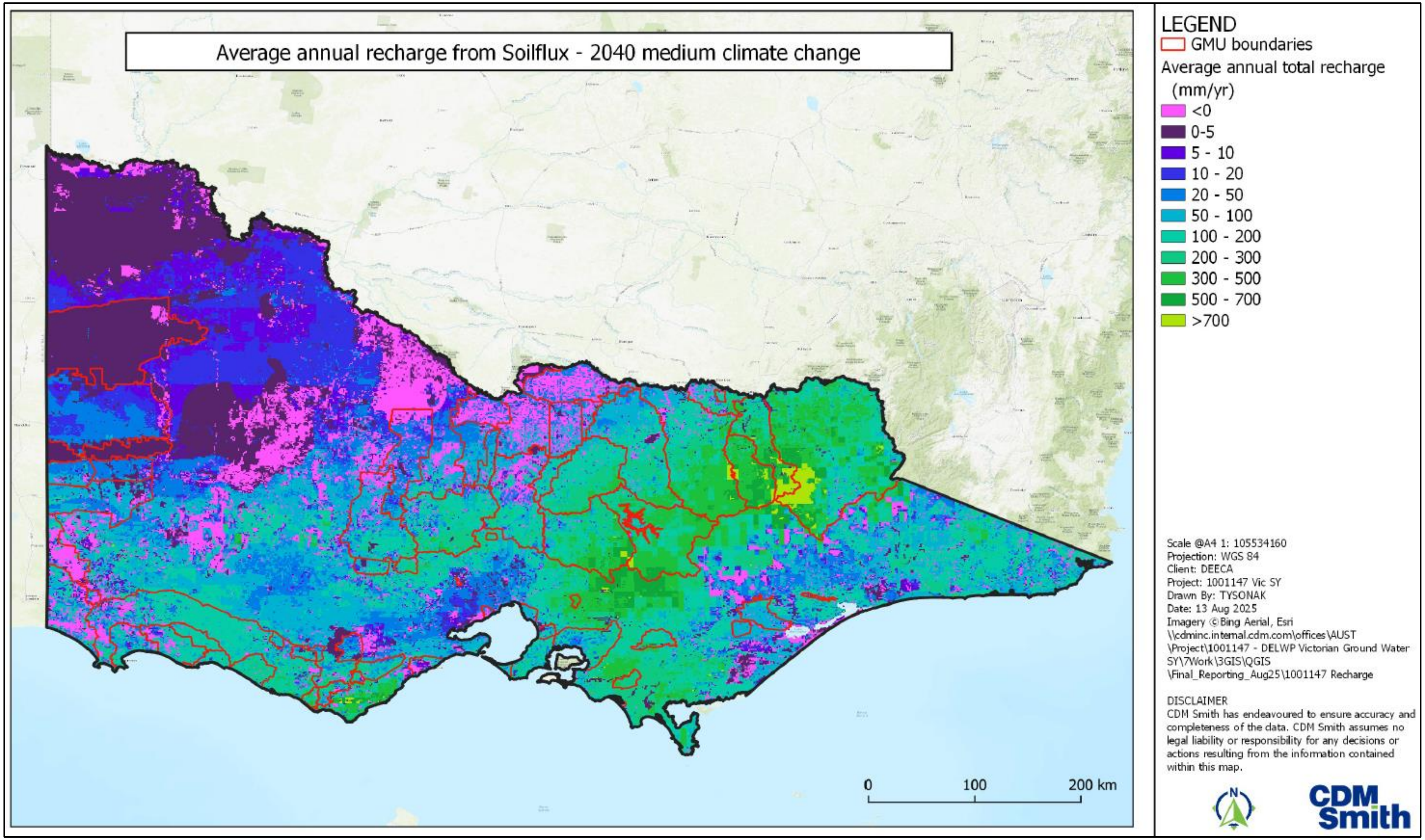


Figure J-5 Estimated average annual recharge for Victoria (SoilFlux result) – 2040 Low climate change (HARC 2023).



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Drawn By: TYSONAK
Date: 13 Aug 2025
Imagery © Bing Aerial, Esri
\\cdminc.internal.cdm.com\offices\AUST \Project\1001147 - DELWP Victorian Ground Water SY\7Work\3GIS\QGIS \Final_Reporting_Aug25\1001147 Recharge

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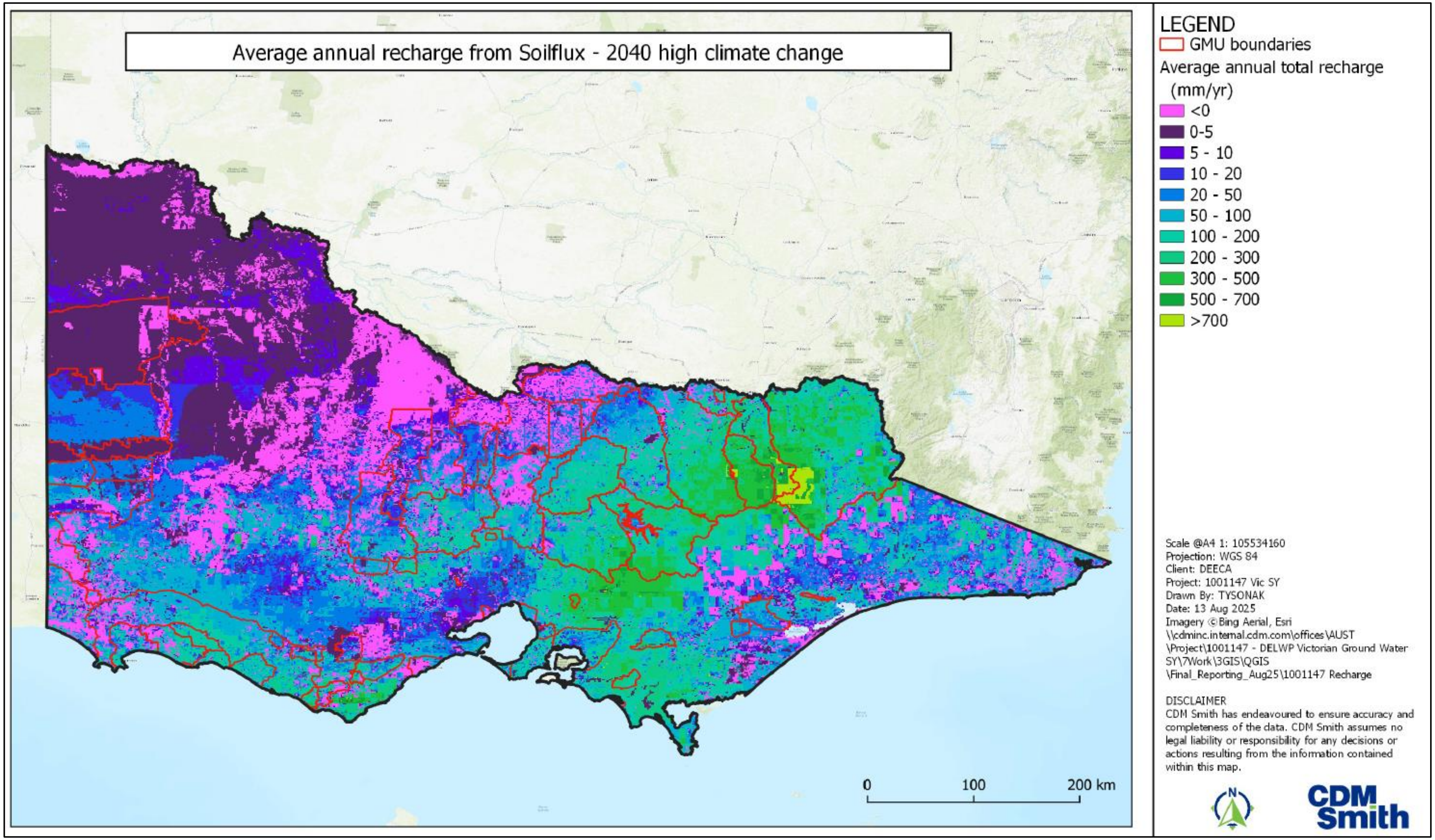
Figure J-6 Estimated average annual recharge for Victoria (SoilFlux result) – 2040 Medium climate change.



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Drawn By: TYSONAK
Date: 13 Aug 2025
Imagery ©Bing Aerial, Esri
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SY\7Work\3GIS\QGIS
\Final_Reporting_Aug25\1001147 Recharge

DISCLAIMER
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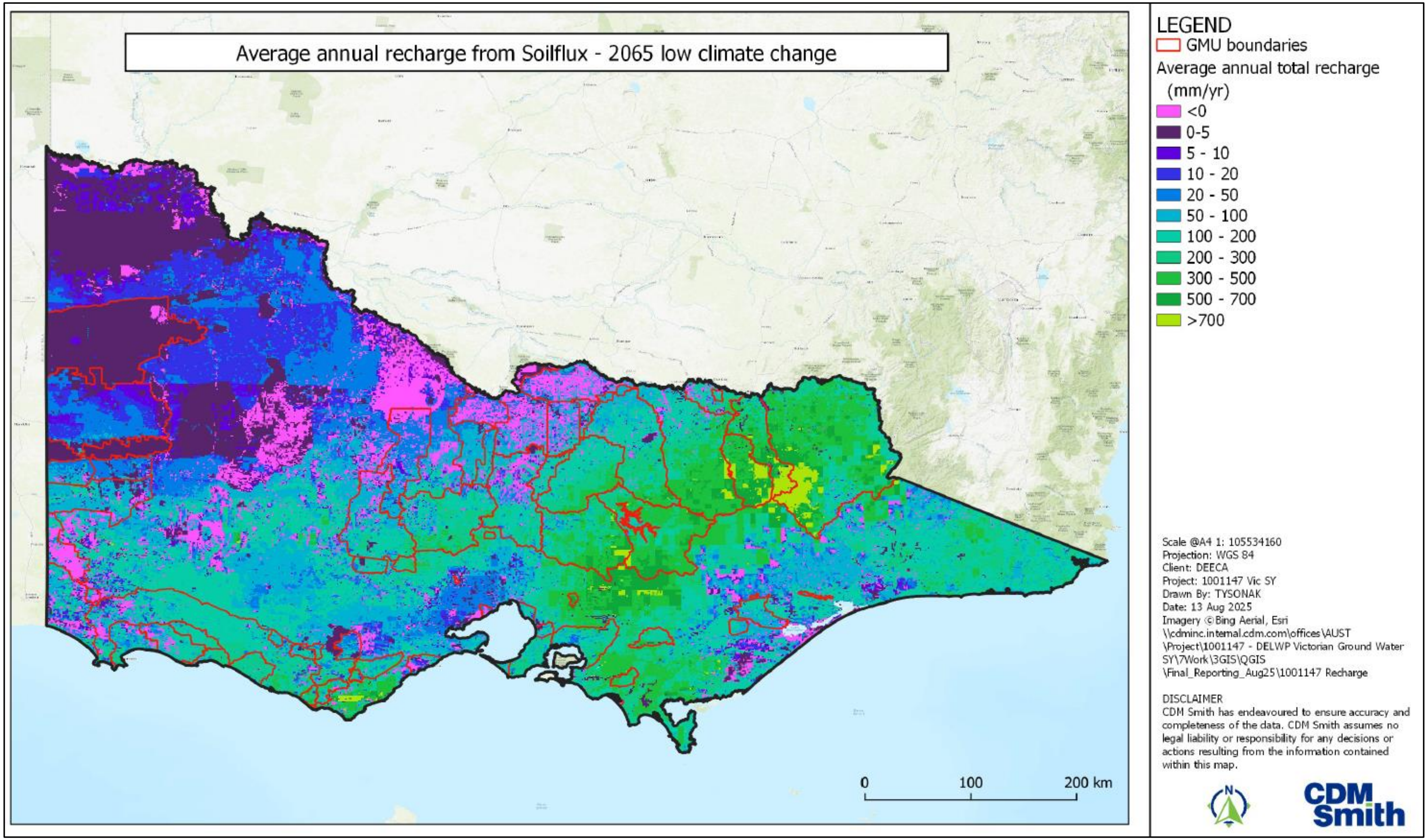
Figure J-7 Estimated average annual recharge for Victoria (SoilFlux result) – 2040 High climate change.



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Drawn By: TYSONAK
Date: 13 Aug 2025
Imagery ©Bing Aerial, Esri
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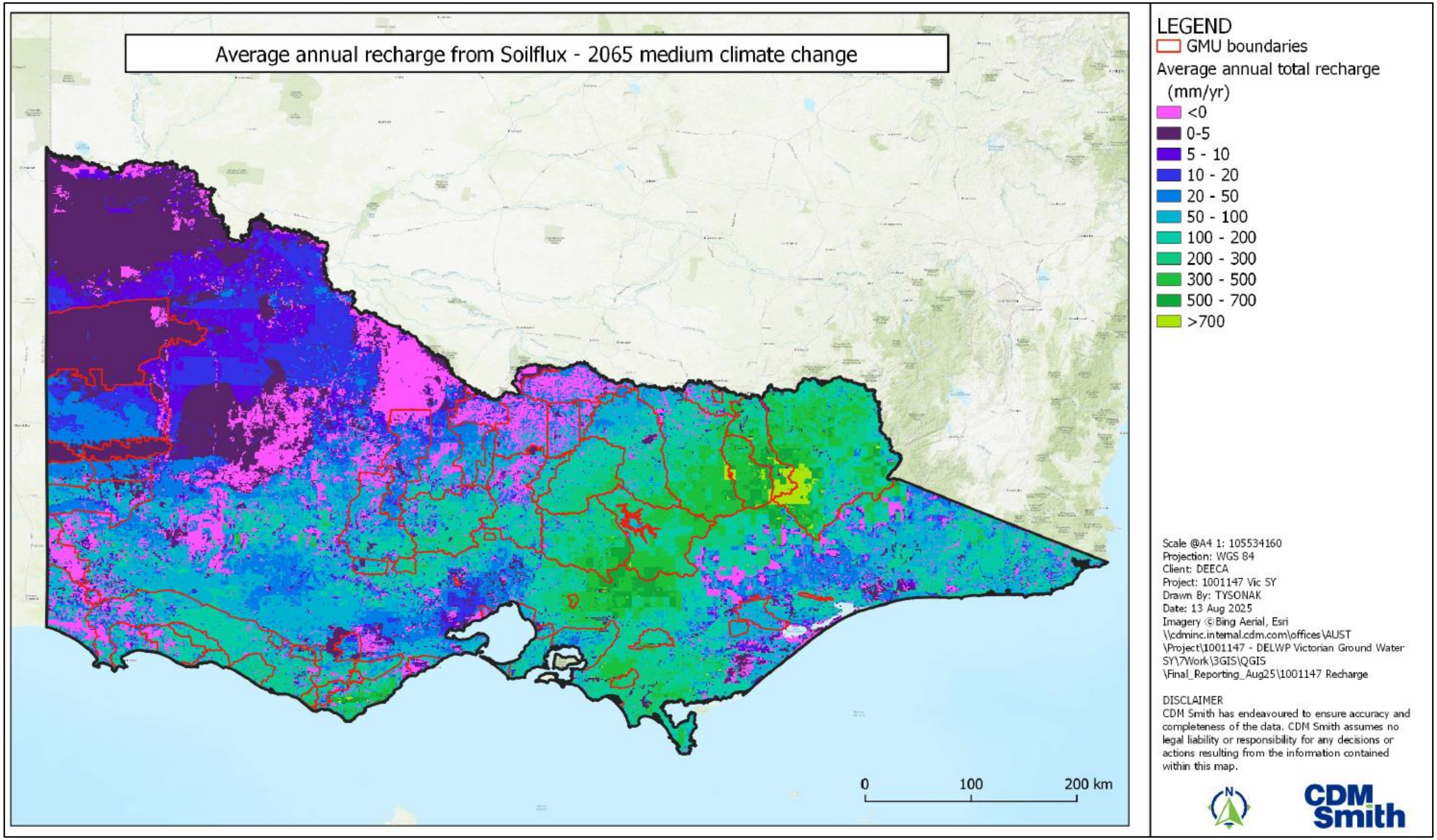
Figure J-8 Estimated average annual recharge for Victoria (SoilFlux result) – 2065 Low climate change.



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Drawn By: TYSONAK
Date: 13 Aug 2025
Imagery © Bing Aerial, Esri
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SY\7Work\3GIS\QGIS
\Final_Reporting_Aug25\1001147 Recharge

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Figure J-9 **Estimated average annual recharge for Victoria (SoilFlux result) – 2065 Medium climate change.**

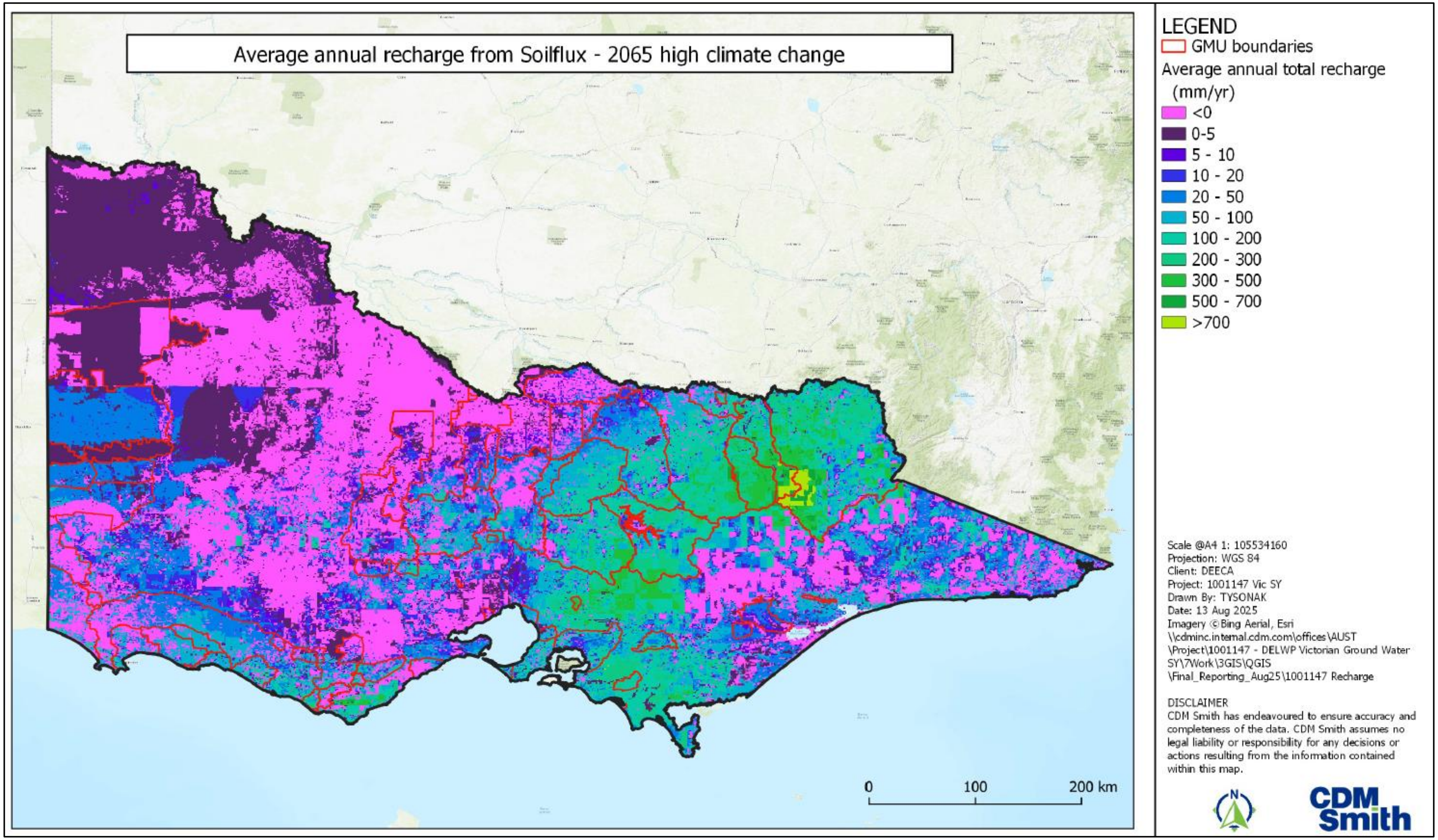
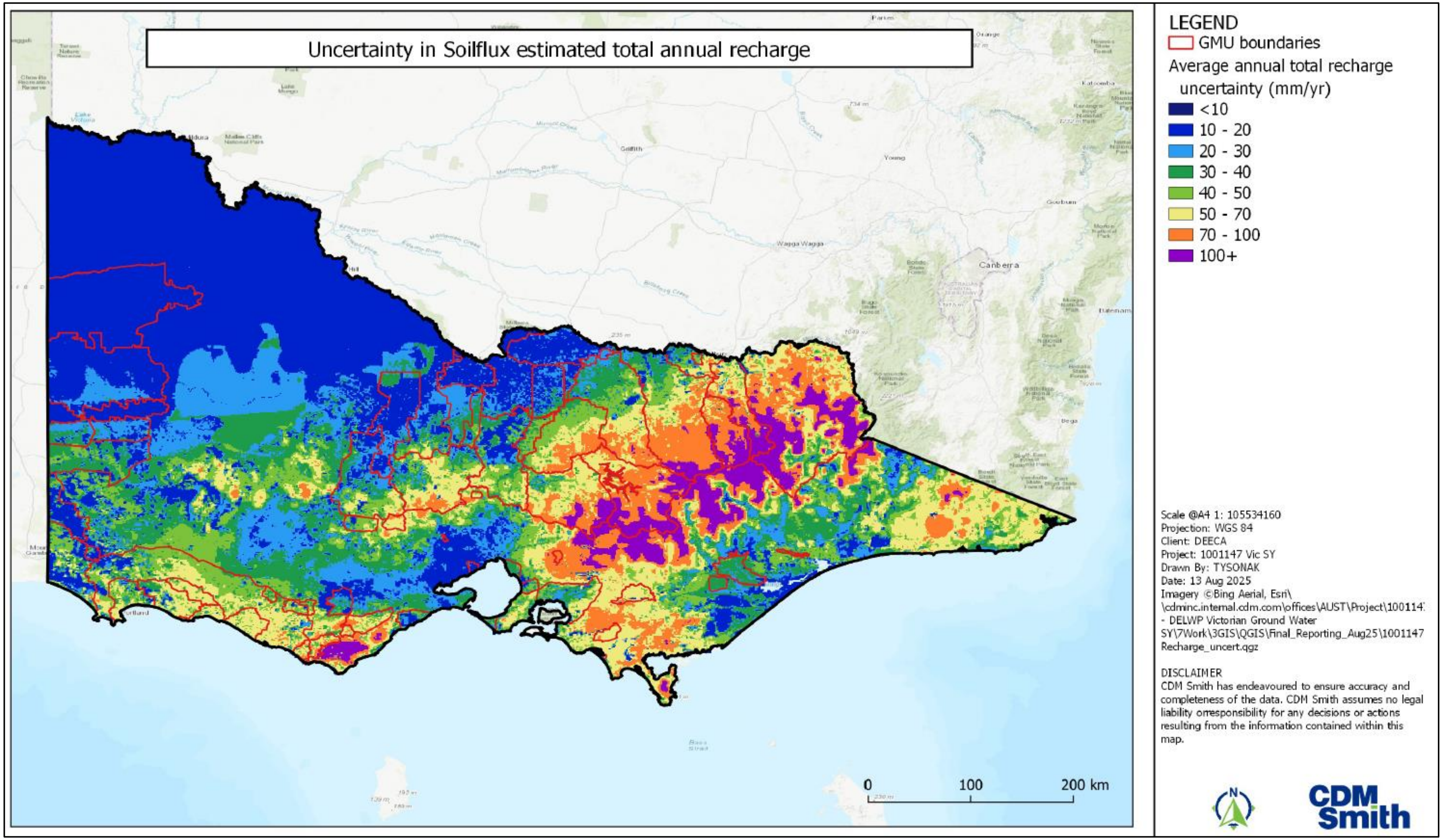


Figure J-10 Estimated average annual recharge for Victoria (SoilFlux result) – 2065 High climate change.



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Date: 13 Aug 2025
Imagery ©Bing Aerial, Esri\
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- DELWP Victorian Ground Water
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Recharge_uncert.qgz

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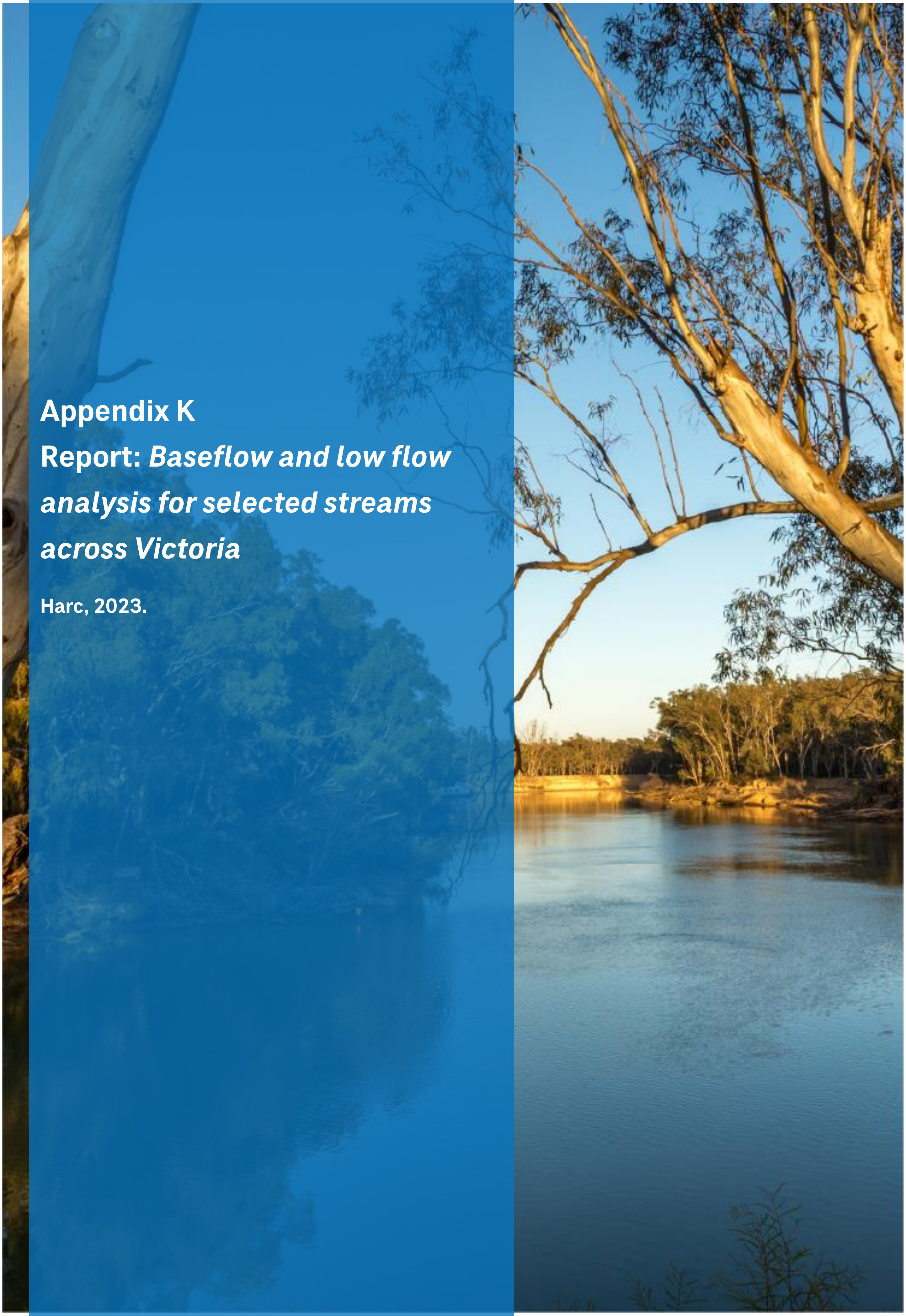
Figure J-11 Estimated uncertainty (as one standard deviation from the mean) of average annual recharge for Victoria (SoilFlux result) (HARC 2023).



Appendix K

Report: *Baseflow and low flow analysis for selected streams across Victoria*

Harc, 2023.

Appendix L

GMU conceptual models

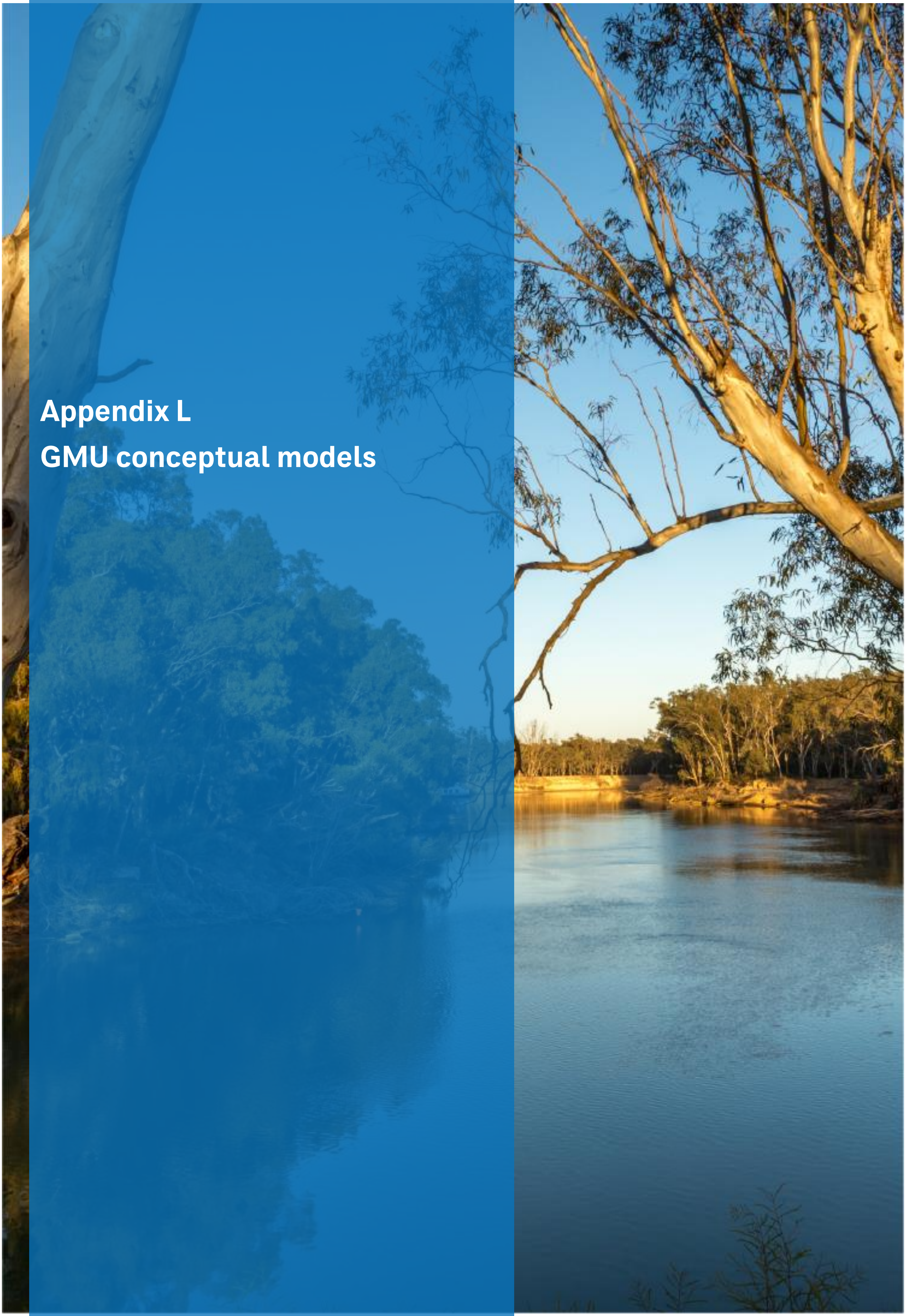
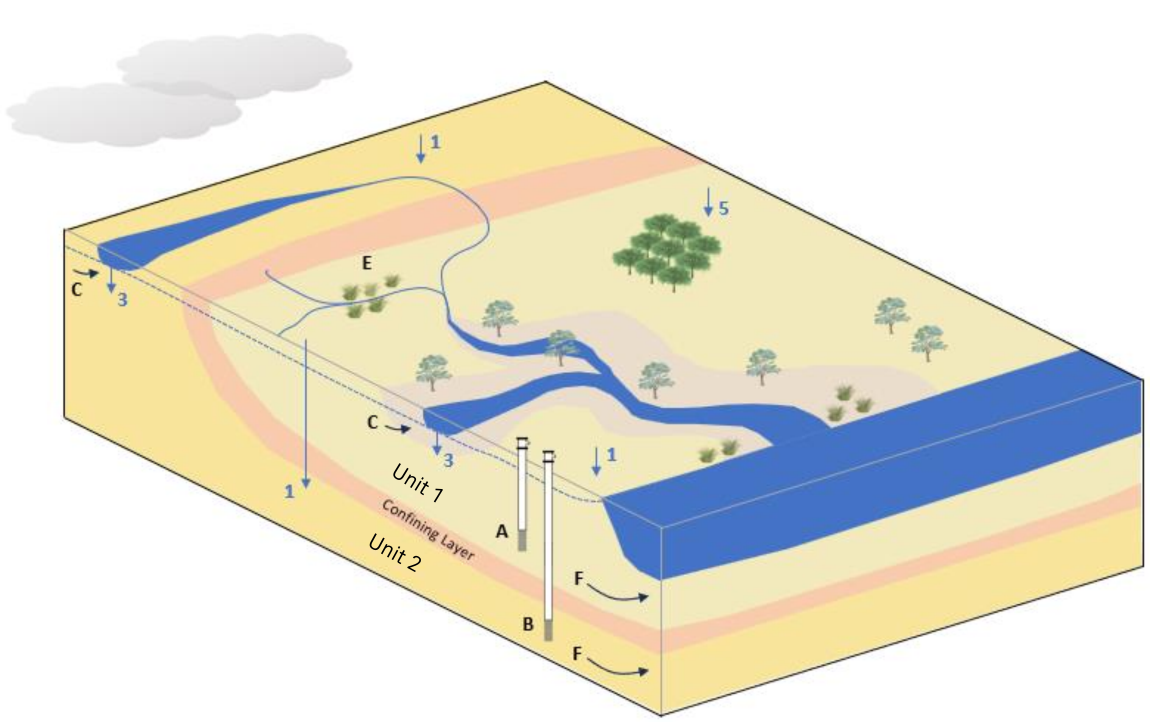


Table L-1 GMU conceptual model - Big and Little Desert Zones (West Wimmera)

Big Desert and Little Desert (West Wimmera GMA) ***Unconfined and Confined Sedimentary Plains***

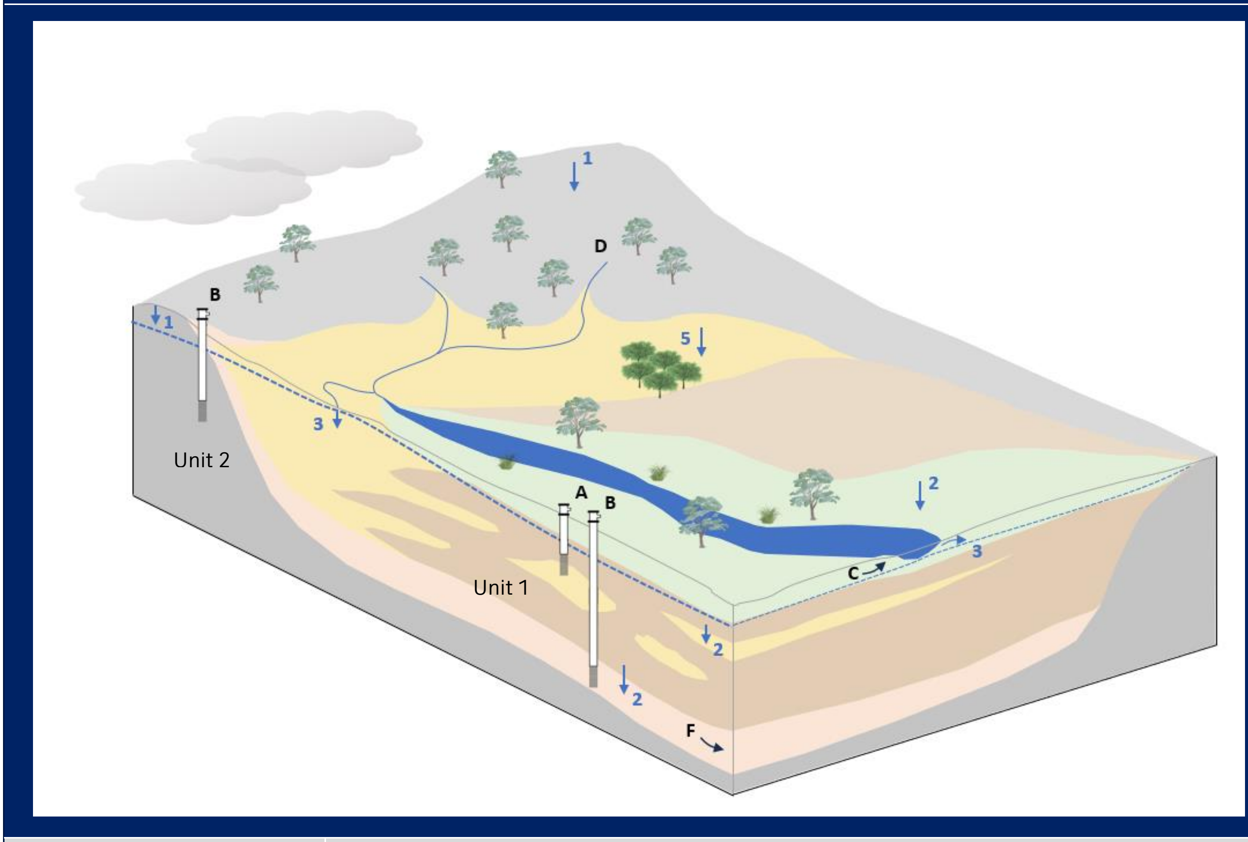


Unit description	Unit 1 is the Pliocene Sands Aquifer (Parilla Sands), Unit 2 is the Tertiary Limestone Aquifer	
Groundwater levels	Depth to groundwater ranges from <5 m to 130 m and averages 40 m within the GMU.	
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary aquifer) ranges from 6 m to 105 m and averages 55 m within the GMU.	
Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Sink holes and karstic features in the TLA can provide point recharge features.	Total estimated recharge (current period): Big Desert - 231,507 ML/yr Little Desert - 39,678 ML/yr
2 - Low Rainfall Recharge	The climate is semi-arid and modern vertical recharge via rainfall is low (a few mm per year).	
3 – River Recharge	Seasonal lakes, wetlands and swamps are important point sources of recharge to unconfined aquifers	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	Extraction from the Parilla Sands is limited to domestic and stock purposes due to low yields.	Average total extraction (current period): 0ML/yr Total current entitlement: 0 ML/yr
B - Pumping (from unit 2)	There are currently no licences issued in this the Big Desert GMA for the TLA	

C - Groundwater discharge to rivers	The Wimmera River is considered to have a high potential to receive groundwater discharge. The Wimmera River receives highly saline groundwater discharge from the Parilla Sands.	
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	Local groundwater discharge to low lying areas within the interdunal systems of the Parilla Sands can support wetland systems, although these are sometimes perched and therefore not part of the regional aquifer.	
F - Groundwater throughflow out	Note – this GMA does not have a coastal boundary	
References: GWMW (2011) West Wimmera Groundwater Management Strategy; GWMW (2019) West Wimmera Groundwater Management Area Local Management Plan		

Table L-2 GMU conceptual model – Broken GMA

Broken GMA ***Unconfined and Confined Sedimentary Valleys***



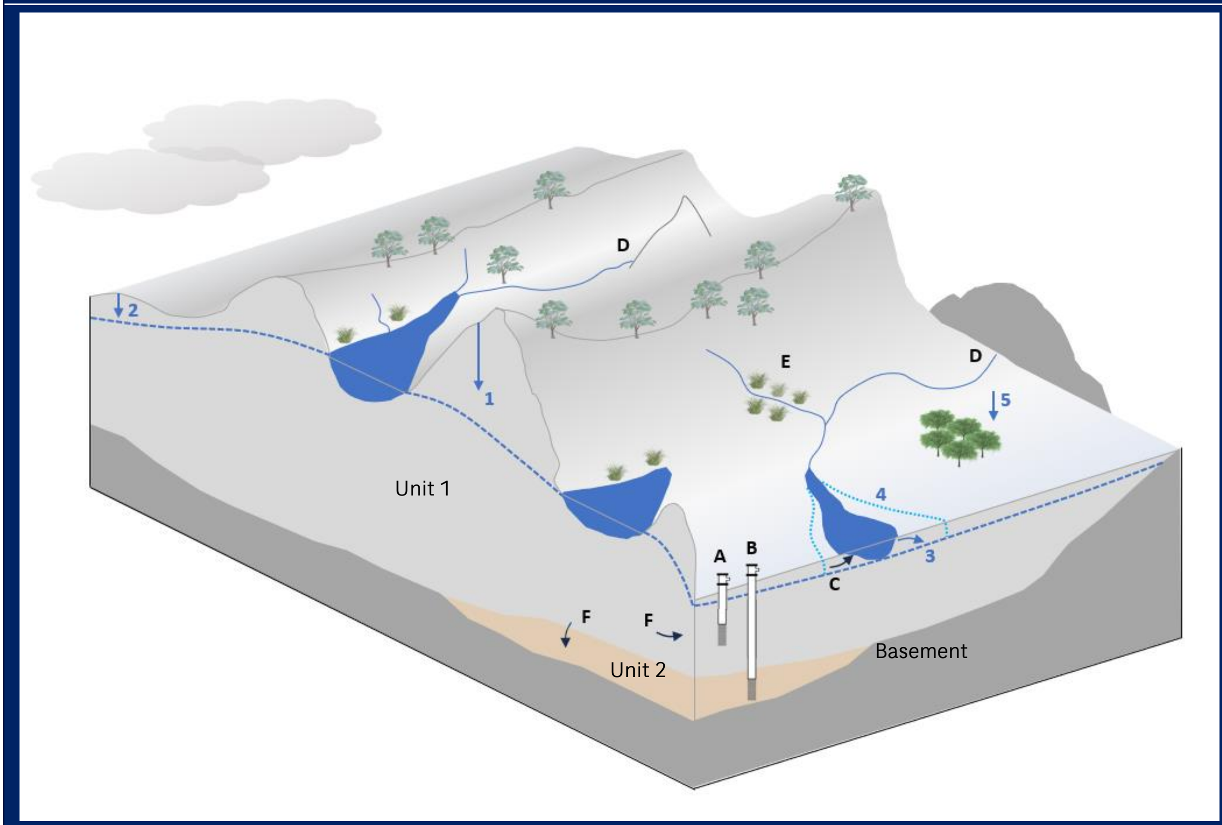
Unit description	Unit 1 is the alluvial sediments. Unit 2 is the fractured bedrock.
Groundwater levels	Depth to groundwater ranges from <5 m to 210 m and averages 20 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the quaternary alluvium aquifer) ranges from 0 m to 4 m and averages 15 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	High rainfall recharge to the bedrock aquifer in the highland areas.	Total estimated recharge (current period): 493,247 ML/yr
2 - Low Rainfall Recharge	The alluvial aquifer is recharged via rainfall over the sedimentary plain and runoff from the upland bedrock.	
3 – River Recharge	The Broken River and Broken Creek recharge the alluvial aquifer. Stream leakage to the bedrock aquifer only occurs during extended dry periods (and deeper watertables).	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	A small volume of groundwater is extracted by bores in the alluvial aquifer (both licensed and domestic and stock).	Average total extraction (current period): 654 ML/yr

B - Pumping (from unit 2)	A small volume of groundwater is extracted by bores in the bedrock aquifer, but it is still an important source of domestic water supply for residents without access to reticulated water.	Total current entitlement: 3,389 ML/yr
C - Groundwater discharge to rivers	Groundwater baseflow occurs to the Broken River and Broken Creek downstream of Benalla, in particular after prolonged rainfall. Groundwater in the fractured rock aquifer discharges to streams and springs in valley floors or breaks of slope where the water table is close to the surface. It is greatest in the highlands areas.	Baseflow index: 0.46 Mean annual baseflow: 167.3 ML/y/km^2 (Gauge: 404207 Holland Creek at Kelfeera)
D - Groundwater discharge to springs	Spring discharge occurs in the Broken GMA from the fractured rock aquifer.	
E - Groundwater discharge to wetlands	Wetlands are identified as groundwater dependent values in this GMU.	
F - Groundwater throughflow out	Regionally groundwater flows through the fractured rock aquifer from elevated areas upstream of the Lake Nillahcootie towards lower lying areas around Benalla.	
References: GMW (2016) Broken GMA Local Management Plan		

Table L-3 GMU conceptual model – Bungaree GMA

Bungaree GMA ***Unconfined Volcanics***

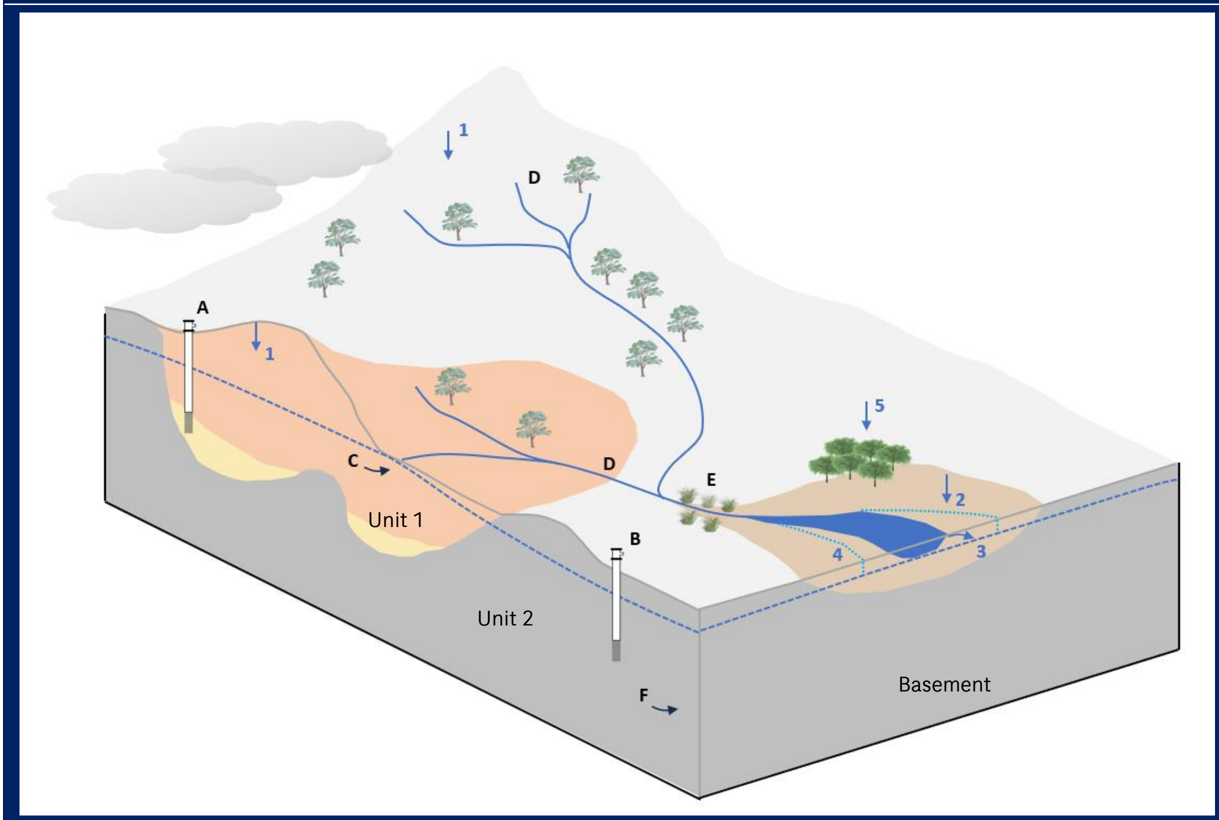


Unit description	Unit 1 is the Volcanic Aquifer (UTB), Unit 2 is the deep lead (UTAF)
Groundwater levels	Depth to groundwater ranges from <5 m to 170 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary basalt aquifer) ranges from 7 m to 155 m and averages 180 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	High rainfall recharge occurs in elevated northern part of catchment near the Great Dividing Range and around scoria cones.	Total estimated recharge (current period): 35,917 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	NA	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	90% of extraction licences are for irrigation and therefore some irrigation returns are likely.	
A - Pumping (from unit 1)	Newer Volcanics is the primary aquifer used for extraction in the GMA.	Average total extraction (current period): 2,037 ML/yr Total current entitlement: 4,234 ML/yr
B - Pumping (from unit 2)	NA	

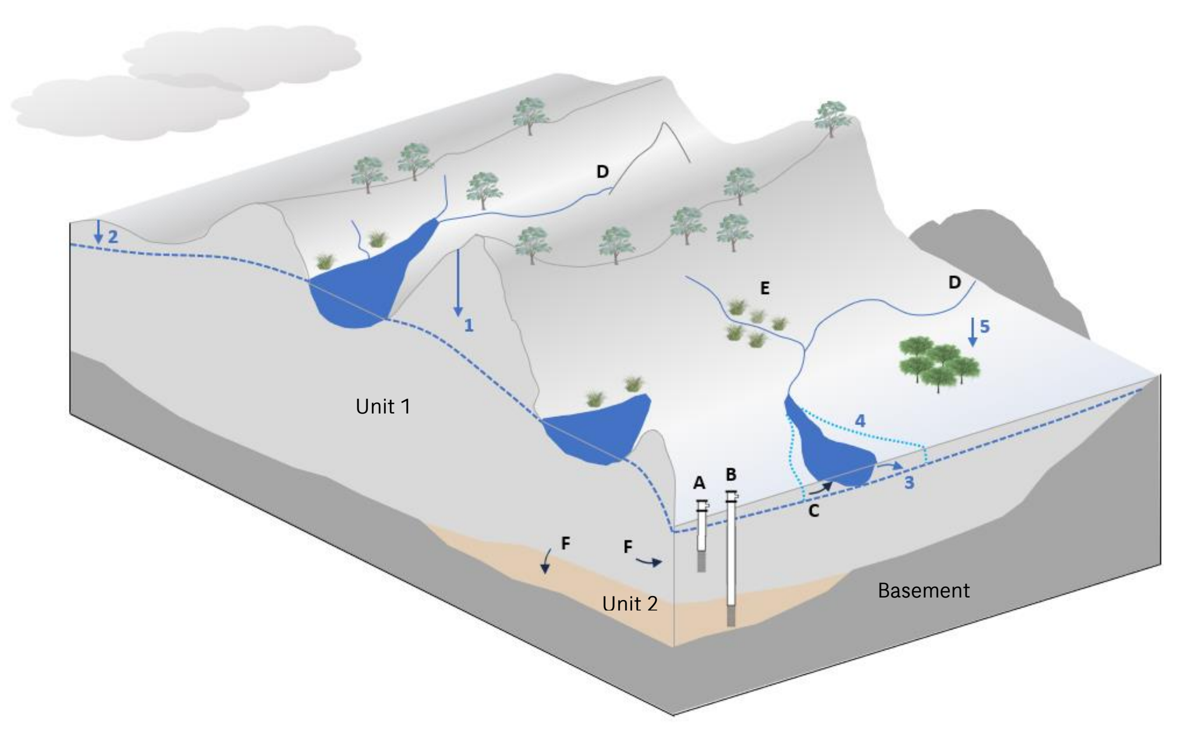
C - Groundwater discharge to rivers	Groundwater discharge to rivers is expected to be significant in this GMU.	Baseflow index: 0.61 Mean annual baseflow: 103.7 ML/y/km^2 (Gauge: 232236 West Moorabool River U/S Moorabool Reservoir) Baseflow index: 0.62 Mean annual baseflow: 82.6 ML/y/km^2 (Gauge: 232243 Whisky Creek At Whisky Creek Diversion Weir)
D - Groundwater discharge to springs	Spring discharge occurs as contact springs (hydrogeological boundaries), depression springs (topography intersects watertable) and structurally controlled springs.	
E - Groundwater discharge to wetlands	Springs are captured in dams across the catchment.	
F - Groundwater throughflow out	NA - negligible groundwater throughflow out of aquifer which acts as a 'bowl'.	
References: CDM Smith (2018) Long Term Water Resource Assessment – Groundwater, Phase 2; SRW (2016) Hopkins-Corangamite Groundwater Catchment Statement		

Table L-4 GMU conceptual model – Central Victorian Mineral Springs

GMU Detail – Central Victorian Mineral Springs		***Unconfined Volcanics***
		
Unit description	Unit 1 is the volcanics and the deep lead, Unit 2 is the basement aquifer.	
Groundwater levels	Depth to groundwater ranges from <5 m to 180 m and averages 20 m within the GMU.	
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the quaternary alluvium aquifer) ranges from 0 m to 10 m and averages 1 m within the GMU.	
Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Rainfall recharge is highest along the Great Dividing Range and around volcanic cones.	Total estimated recharge (current period): 348,214 ML/yr
2 - Low Rainfall Recharge	Lower rainfall recharge in lower lying areas where rainfall rates are lower.	
3 – River Recharge	River recharge is likely to occur in this GMU.	
4 - Episodic Flood Inundation	Flood events contribute to recharge in the GMA.	
5 - Irrigation Return	Returns of irrigation water are a source of recharge.	

A - Pumping (from unit 1)	The primary groundwater aquifer is the Newer Volcanic Basalt, which is of good quality and moderate yield (on the order of 1 ML/day). The Deep Lead is less commonly used because of its limited extent.	Average total extraction (current period): 1,369 ML/yr Total current entitlement: 4,092 ML/yr
B - Pumping (from unit 2)	Yields from the bedrock aquifer are typically low. The granite is a comparatively poor aquifer in the area with low yields and variable groundwater salinity, but it can provide useful domestic and stock supply.	
C - Groundwater discharge to rivers	Groundwater discharges as baseflow in the upper catchment or in low lying parts of the landscape. Thin alluvium in the valleys is likely to be well connected to waterways. Dams on the streams mean some of this water is captured and harvested.	Baseflow index: 0.25 Mean annual baseflow: 49.2 ML/y/km^2 (Gauge: 406213 Campaspe River at Redesdale)
D - Groundwater discharge to springs	Groundwater discharges as spring in the upper catchment or in low lying parts of the landscape. Mineral water discharges from the Ordovician bedrock. Springs in the catchment are often dammed for stock water supply and the carbonated mineral springs have been modified to supply tourists in a park setting.	
E - Groundwater discharge to wetlands	Groundwater fed wetlands are likely in this area.	
F - Groundwater throughflow out	Groundwater discharge as throughflow occurs to the Mid Loddon GMA and the Lower Campaspe Valley WSPA	
References: GMW (2013) Central Victorian Mineral Springs Groundwater Management Area Local Management Plan		

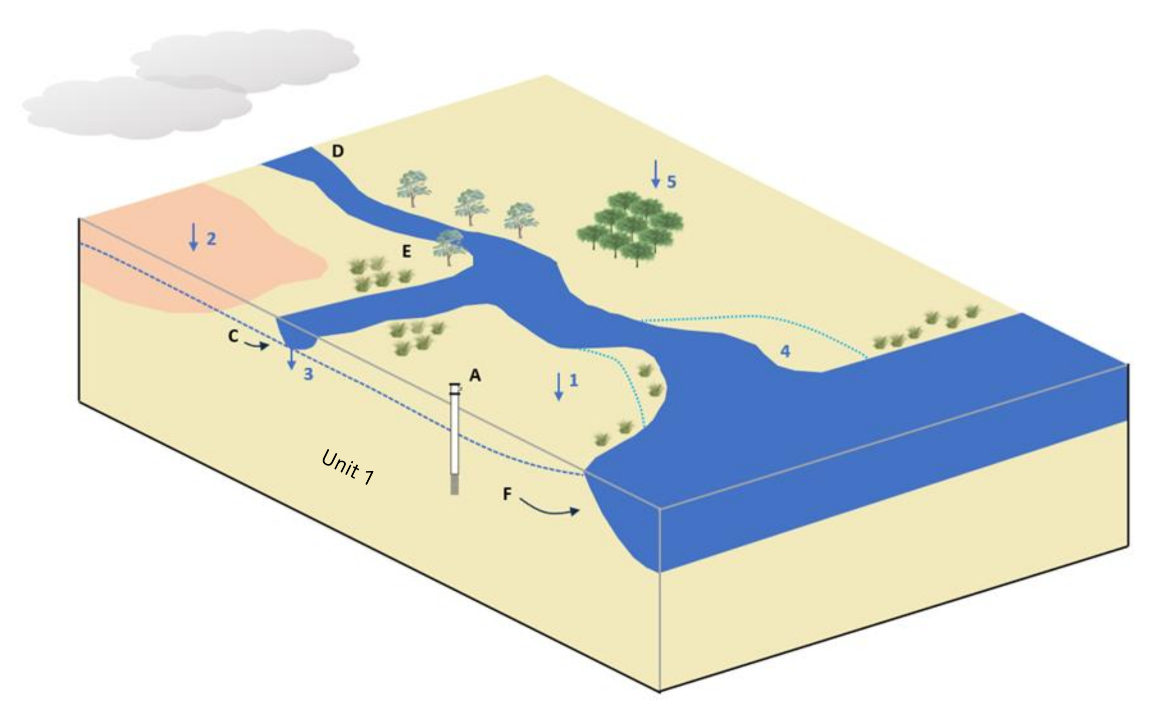
Table L-5 GMU conceptual model - Colongulac GMA

Colongulac GMA		***Unconfined Volcanics***
		
Unit description	Unit 1 is the volcanic aquifer (UTB), Unit 2 is the deep lead (UTAF)	
Groundwater levels	Depth to groundwater ranges from <5 m to 120 m and averages 10 m within the GMU.	
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary basalt aquifer) ranges from 0 m to 25 m and averages 10 m within the GMU.	
Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Rainfall recharge is highest around eruption centres.	Total estimated recharge (current period): 46,364 ML/yr
2 - Low Rainfall Recharge	Lower recharge occurs on weathered basalt plains.	
3 – River Recharge	NA	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	Pumping is mainly from the Newer Volcanics.	Average total extraction (current period): 484 ML/yr Total current entitlement: 1,718 ML/yr
B - Pumping (from unit 2)	NA	
C - Groundwater discharge to rivers	Groundwater discharge occurs along many drainage lines where the stream bed has incised to a depth below the watertable, such as at Bostock Creek in the lower portion of the GMA.	

D - Groundwater discharge to springs	Springs occur on the edge of basalt flow boundaries.	
E - Groundwater discharge to wetlands	Groundwater discharges in the form of spings can result in permanent wetlands and also lakes (e.g. Purrumbete, Gnotuk and Bullen Merri).	
F - Groundwater throughflow out	NA	
References: SKM (1998) Colongulac GMA PAV report; SRW (2016) Hopkins-Corangamite Groundwater Catchment Statement		

Table L-6 GMU conceptual model - Denison

Dension GMA	***Unconfined Sedimentary Plains***

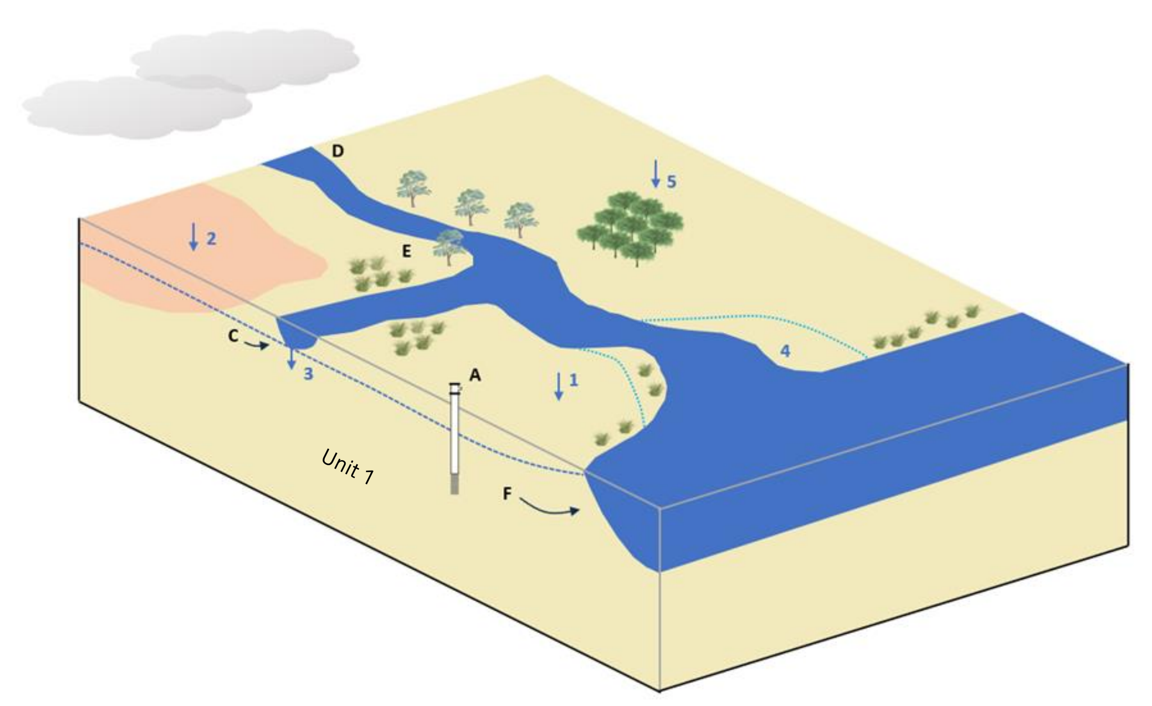


Unit description	Unit 1 is the shallow unconfined Quaternary Aquifer including the Haunted Hills, Pleistocene Prior Stream Deposits and Recent Alluvials
Groundwater levels	Depth to groundwater ranges from <5 m to 70 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary aquifer) ranges from 11 m to 146 m and averages 51 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Rainfall is a key recharge mechanism to the unconfined gravel aquifer.	Total estimated recharge (current period): 27,381 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	Rainbow Creek and the upper reaches of the Thomson River are thought to recharge the aquifer.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	The Denison GMU is in the Macalister Irrigation District. Irrigation returns are thought to be a key contributor to recharge in the GMA.	

A - Pumping (from unit 1)	Most groundwater licenced extraction in the GMA is used for irrigation purposes related to dairy production.	Average total extraction (current period): 5,580 ML/yr Total current entitlement: 9,734 ML/yr
B - Pumping (from unit 2)	NA	
C - Groundwater discharge to rivers	The Latrobe River and the lower reaches of the Thomson River are expected to receive groundwater as baseflow.	
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	Groundwater flows through the Killarney Gap, to the east of the region towards the Thomson River and via the southwest of the region around Snake Ridge towards the Latrobe River.	
References: SRW (2014) Catchment Statement for Central Gippsland and Moe Groundwater Catchments; Denison WSPA Consultative Committee (2002) Denison Water Supply Protection Area (Groundwater), Explanatory Paper to the Groundwater Management Plan; SKM (1998) PAV calculation for the Denison GMA		

Table L-7 GMU conceptual model – Deutgam GMA

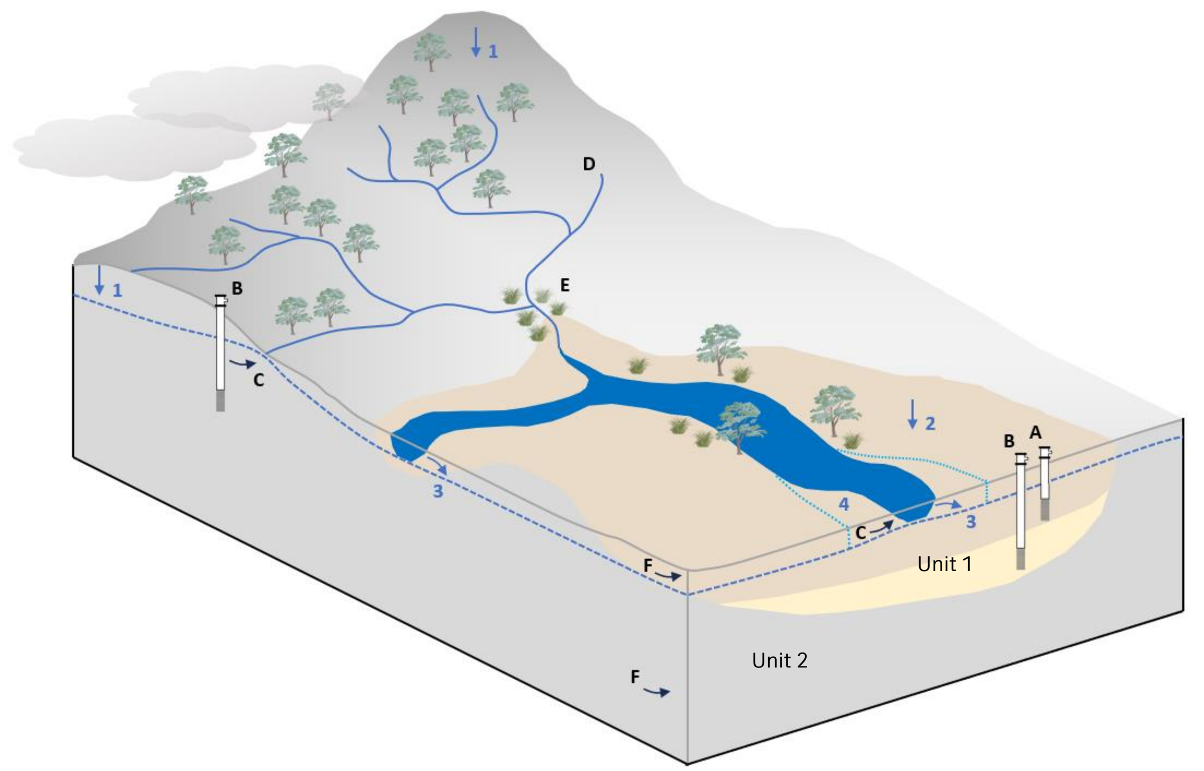
Deutgam GMA	***Unconfined Sedimentary Plains***
	
Unit description	Unit 1 is the shallow unconfined Quaternary Werribee Delta Aquifer
Groundwater levels	Depth to groundwater ranges from <5 m to 10 m and averages 2.5 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. quaternary alluvium aquifer) ranges from 5 m to 24 m and averages 15 m within the GMU.

Process	Description of Process	**Quantification of Process**
1 - High Rainfall Recharge	Rainfall recharge is thought to be a comparatively small source of aquifer recharge.	Total estimated recharge (current period): 14,130 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	Recharge to the aquifer occurs through the base of leaky and unlined irrigation diversion channels.	
4 - Episodic Flood Inundation	NA	Average total extraction (current period): 708 ML/yr Total current entitlement: 4,274 ML/yr
5 - Irrigation Return	Irrigation activities (mainly market gardens) provide a substantial source of recharge, with estimates of around 30% irrigation return for the area.	
A - Pumping (from unit 1)	Over 95% of groundwater is licensed for irrigation purposes, with a small volume licensed for industrial or commercial purposes.	Average total extraction (current period): 5,580 ML/yr Total current entitlement: 9,734 ML/yr

C - Groundwater discharge to rivers	Groundwater discharges to the lower Werribee River. There is the potential risk of sea water intrusion.	Baseflow index: 0.36 Mean annual baseflow: 40.5 ML/y/km^2 (Gauge: 231204 Werribee River at Werribee Diversion Weir)
(Gauge: 231204 Werribee River at Werribee Diversion Weir)		

Table L-8 GMU conceptual model – Eildon GMA

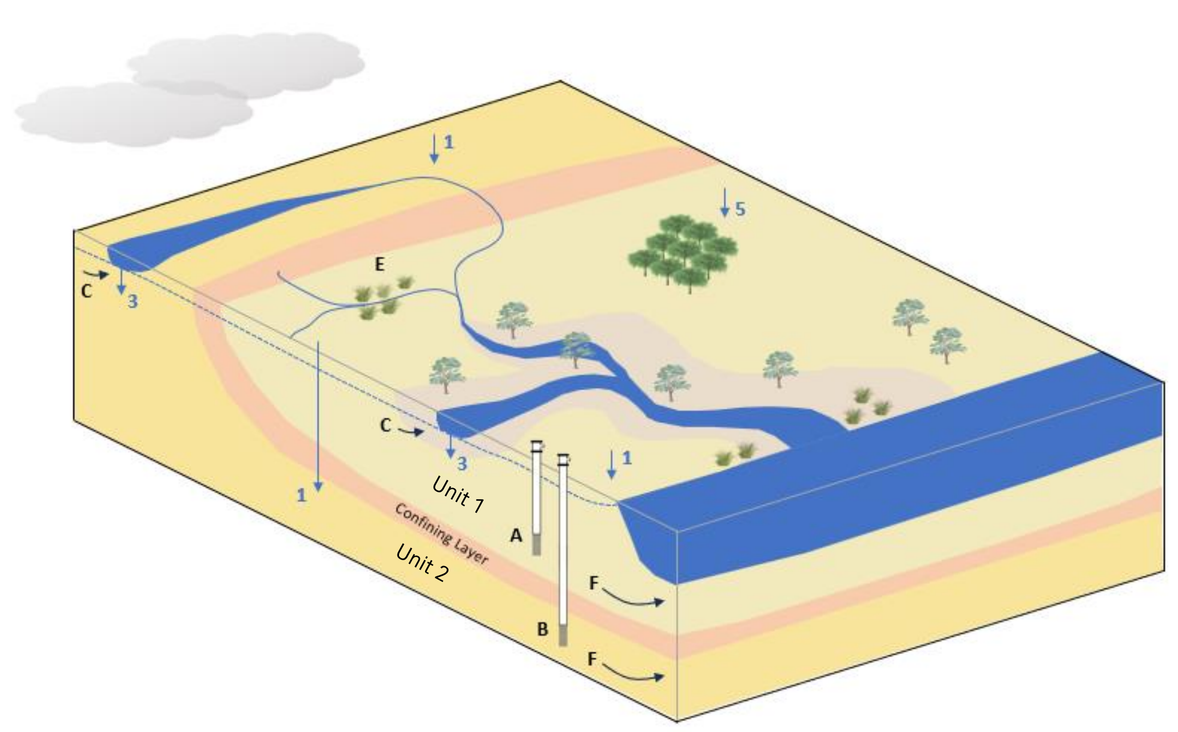
Eildon GMA ***Highland and Sedimentary Upland Valleys***



Unit description	Unit 1 is the Quaternary alluvial sediments, Unit 2 is the fractured bedrock	
Groundwater levels	Depth to groundwater ranges from <5 m to 270 m and averages 60 m within the GMU.	
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the quaternary alluvium) ranges from 0 m to 10 m and averages 5 m within the GMU.	
Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	The highest proportion of recharge in the Eildon GMA occurs in the southern highlands which receives the most rainfall.	Total estimated recharge (current period): 1,030,269 ML/yr
2 - Low Rainfall Recharge	Rainfall recharge is lower in the valleys	
3 – River Recharge	Aquifer recharge via river leakage occurs in the GMA and is the dominant process occurring at Fords Creek and the Delatite River. It was particularly evident during the millennium drought when groundwater levels declined.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	The Quaternary aquifer is limited by storage and yield and is generally only capable of supporting groundwater extraction for stock and domestic, or small scale irrigation.	Average total extraction (current period): 164 ML/yr Total current entitlement: 501 ML/yr
B - Pumping (from unit 2)	The bedrock aquifer is limited by low and variable yields but is an important source of domestic water supply in this GMU given a lack of reticulated water supply. It also supports industrial, commercial and agricultural industries.	

C - Groundwater discharge to rivers	Groundwater discharge to waterways is greater in the highlands where short flow paths cause water to discharge quickly at local topographic lows. Groundwater in the alluvial aquifer discharges into rivers and streams when the necessary conditions prevail (i.e. the watertable is elevated above the river level).	Baseflow Index: 0.58 Mean annual baseflow: 445.8 ML/y/km^2 (Gauge: 405219 Goulburn River at Dohertys)
D - Groundwater discharge to springs	Groundwater in the fractured rock aquifer discharges to streams and springs in valley floors, or breaks of slope where the water table is close to the surface.	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	NA	
References: GMW (2016) Eildon GMA Local Management Plan		

Table L-9 GMU conceptual model – Frankston GMA

Frankston GMA		**Unconfined and Confined Sedimentary Plains**
		
Unit description	Unit 1 is the shallow Brighton Group and Fyansford Formation, Unit 2 is the Older Volcanics and Werribee Formation	
Groundwater levels	Depth to groundwater ranges from <5 m to 30 m and averages <5 m within the GMU.	
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the lower tertiary basalt) ranges from 0 m to 35 m and averages 5 m within the GMU.	
Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	The main recharge areas are elevated to the north of the GMA in the Oakleigh, Dingley, Black Rock areas and to the south and south east of the coastal wetlands from Frankston to Cranbourne and where the Brighton Group outcrops east of the Frankston-Cranbourne Road.	Total estimated recharge (current period): 20,714 ML/yr
2 - Low Rainfall Recharge	Recharge to the Brighton Group via rainfall infiltration has been limited by urbanisation and by the overlying swamp deposits.	
3 – River Recharge	Groundwater-surface water interaction is somewhat limited by urbanisation, but where connected, the unconfined aquifers will be recharged by surface water and storm water when groundwater levels are lower than the creek /drain levels.	

4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	Local irrigation of numerous golf courses in the area results in some irrigation returns.	
A - Pumping (from unit 1)	Groundwater from the localised Quaternary Dune Sand aquifer along the coastline is a commonly used resource for domestic purposes. The Brighton Group is utilised for stock and domestic purposes.	Average total extraction (current period): 56 ML/yr Total current entitlement: 665 ML/yr
B - Pumping (from unit 2)	The lower units are utilised to a lesser degree (older volcanics, Werribee Fm and the basement).	
C - Groundwater discharge to rivers	Groundwater-surface water interaction is somewhat limited by urbanisation, but where connected, the unconfined aquifers will possibly discharge to surface water.	
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	In low elevation areas south of the Beaumaris Monocline, discharge from the Brighton Group occurs as upward leakage to the Edithvale and Chelsea wetlands.	
F - Groundwater throughflow out	Discharge occurs as throughflow to the coastline emerging along the beach zone. Groundwater discharge into Port Phillip Bay is the primary discharge mechanism	
References: SKM (1998) PAV Determination for Frankston GMA		

Table L-10 GMU conceptual model – Gellibrand GMA

<table>
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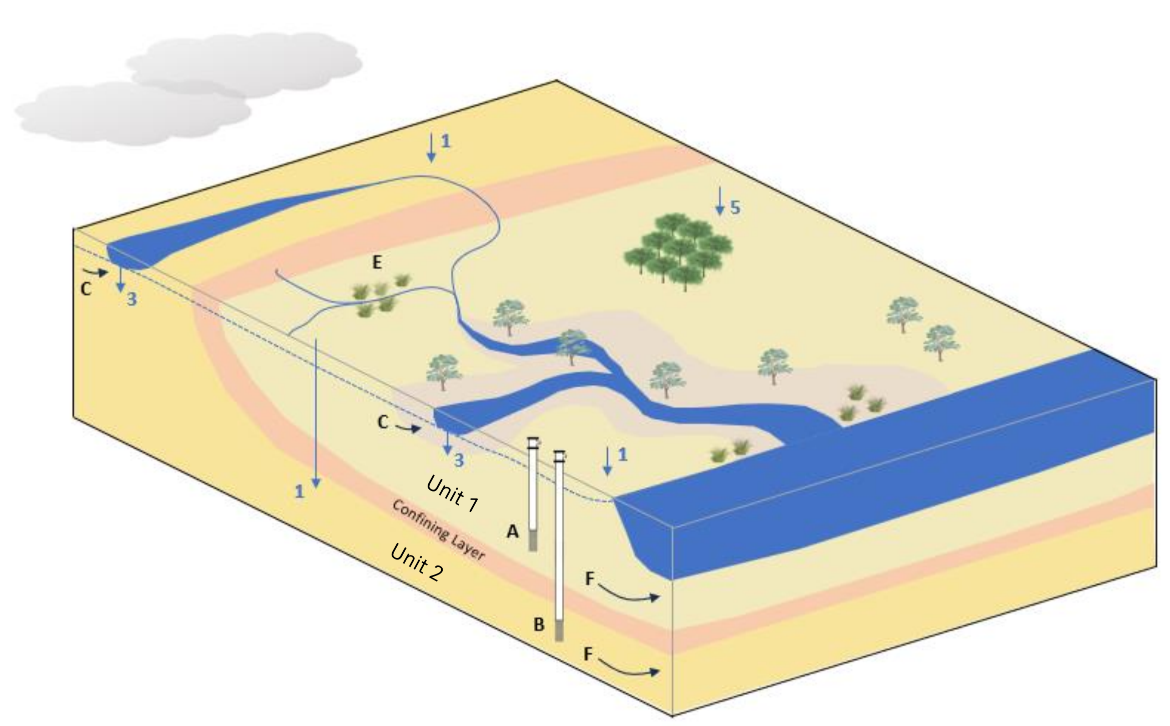
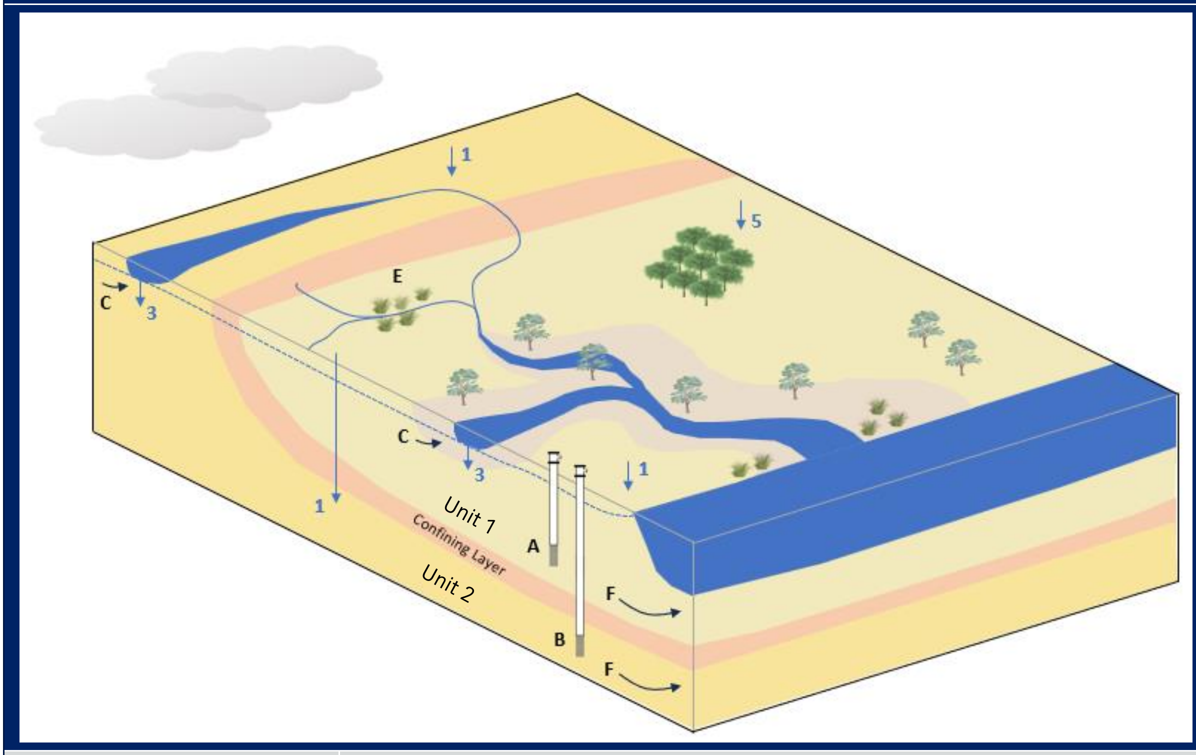
<tr><td colspan="3">
</td></tr>
<tr><td>Unit description</td><td colspan="2">Unit 1 is the Narrawaturk Marl, Clifton Formation and Gellibrand Marl, Unit 2 is the Lower Tertiary Aquifer Eastern View Formation equivalents (Pebble Point, Dilwyn and Mepunga Formations)</td></tr>
<tr><td>Groundwater levels</td><td colspan="2">Depth to groundwater ranges from <5 m to 120 m and averages 30 m within the GMU.</td></tr>
<tr><td>Watertable aquifer thickness</td><td colspan="2">Watertable aquifer thickness (i.e. the upper mid tertiary) ranges from 0 m to 225 m and averages 50 m within the GMU.</td></tr>
<tr><td>Process</td><td>Description of Process</td><td>Quantification of Process</td></tr>
<tr><td>1 - High Rainfall Recharge</td><td>The Barongarook High forms the major recharge zone for the LTA as this is where the unit outcrops.</td><td rowspan="3">Total estimated recharge (current period): 22,373 ML/yr</td></tr>
<tr><td>2 - Low Rainfall Recharge</td><td>Recharge is also likely to occur via leakage from the aquitards that overly the aquifer in confined areas.</td></tr>
<tr><td>3 – River Recharge</td><td>Modelled net fluxes for the major creeks in the area indicate that Porcupine Creek and Yahoo Creek are dominantly losing streams.</td></tr>
<tr><td>4 - Episodic Flood Inundation</td><td>NA</td><td rowspan="2"></td></tr>
<tr><td>5 - Irrigation Return</td><td>NA</td></tr>
</table>

A - Pumping (from unit 1)	NA	Average total extraction (current period): 0 ML/yr Total current entitlement: 0 ML/yr
B - Pumping (from unit 2)	There is no groundwater extraction occurring in the study area itself, however groundwater extraction from the adjacent Gerangamete GMA could potentially be influencing groundwater levels in this area.	
C - Groundwater discharge to rivers	The primary form of groundwater discharge is baseflow to the Gellibrand River, especially in the vicinity of the Gellibrand Township (and the Gellibrand Saddle). Modelled net fluxes for the major creeks in the area indicate that Gellibrand River and Ten Mile / Love Creek are gaining streams.	Baseflow index: 0.52 Mean annual baseflow: 381.9 ML/y/km^2 (Gauge: 235228 Gellibrand River at Gellibrand)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	The groundwater divide separating this part of the LTA aquifer from the Gerangamete GMA is not a physical divide and is based on groundwater recharge. Extraction from the neighbouring GMA can result in movement of the groundwater divide and flow out of the GMA.	
References: CDM Smith (2018) Long Term Water Resource Assessment – Groundwater, Phase 2		

Table L-11 GMU conceptual model – Gerangemete GMA

Gerangemete GMA	***Unconfined and Confined Sedimentary Plains***



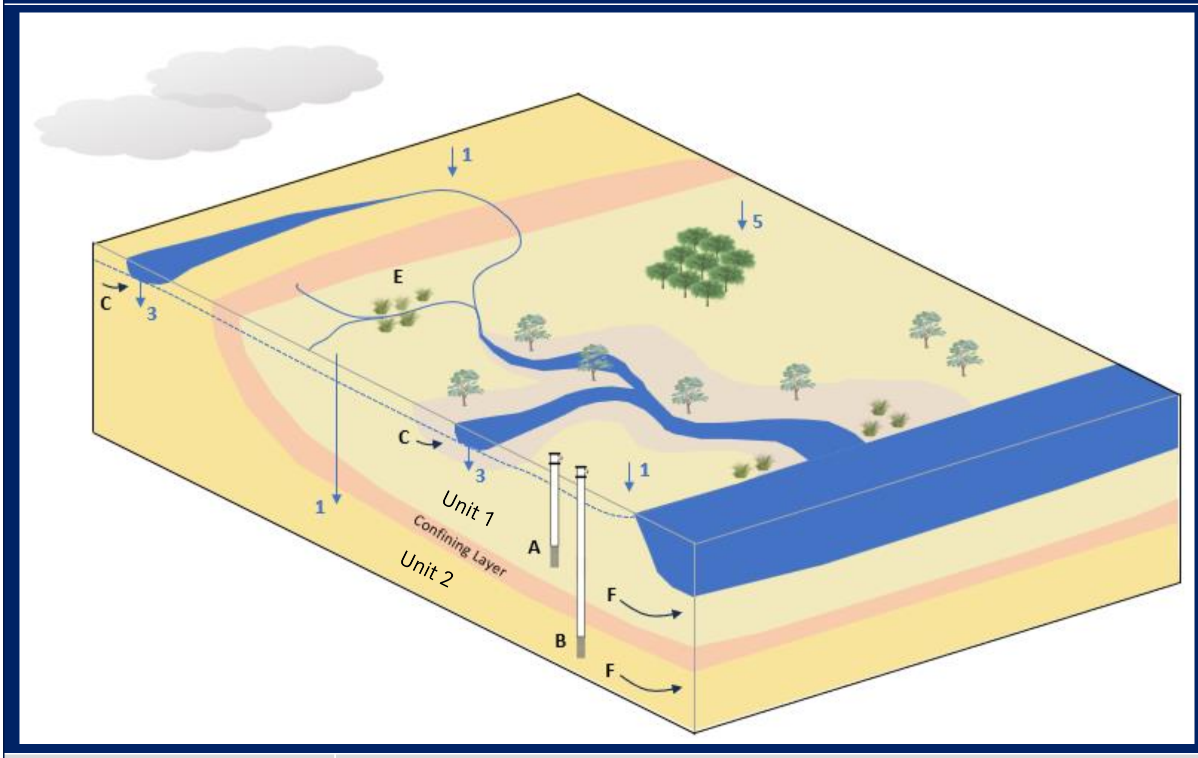
Unit description	Unit 1 is the Narrawaturk Marl, Clifton Formation and Gellibrand Marl, Unit 2 is the Lower Tertiary Aquifer Eastern View Formation equivalents (Pebble Point, Dilwyn and Mepunga Formations)
Groundwater levels	Depth to groundwater ranges from <5 m to 80 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the lower mid- tertiary aquitard) ranges from 0 m to 290 m and averages 100 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Recharge to the LTA occurs in the area of outcrop at the Barongarook High.	Total estimated recharge (current period): 69,788 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	Historically Boundary Creek was a gaining stream but declining waterlevels mean that parts of Boundary Creek now recharge the aquifer.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	NA	Average total extraction (current period): 0 ML/yr Total current entitlement: 11 ML/yr
B - Pumping (from unit 2)	Three licences are current and extraction for the water supply of Geelong from the Barwon Downs borefield has resulted in declining groundwater levels in the LTA.	

C - Groundwater discharge to rivers	Groundwater discharges to the Gellibrand River where the LTA outcrops. Historically there was discharge to Boundary Creek	Baseflow index: 0.36 Mean annual baseflow: 119.8 ML/y/km^2 (Gauge: 233224 Barwon River at Ricketts Marsh)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	Groundwater discharge occurs via vertical leakage to the overlying aquitard units.	
References: CDM Smith (2018) Long Term Water Resource Assessment – Groundwater		

Table L-12 GMU conceptual model – Glenelg WSPA

Glenelg WSPA	***Unconfined and Confined Sedimentary Plains***

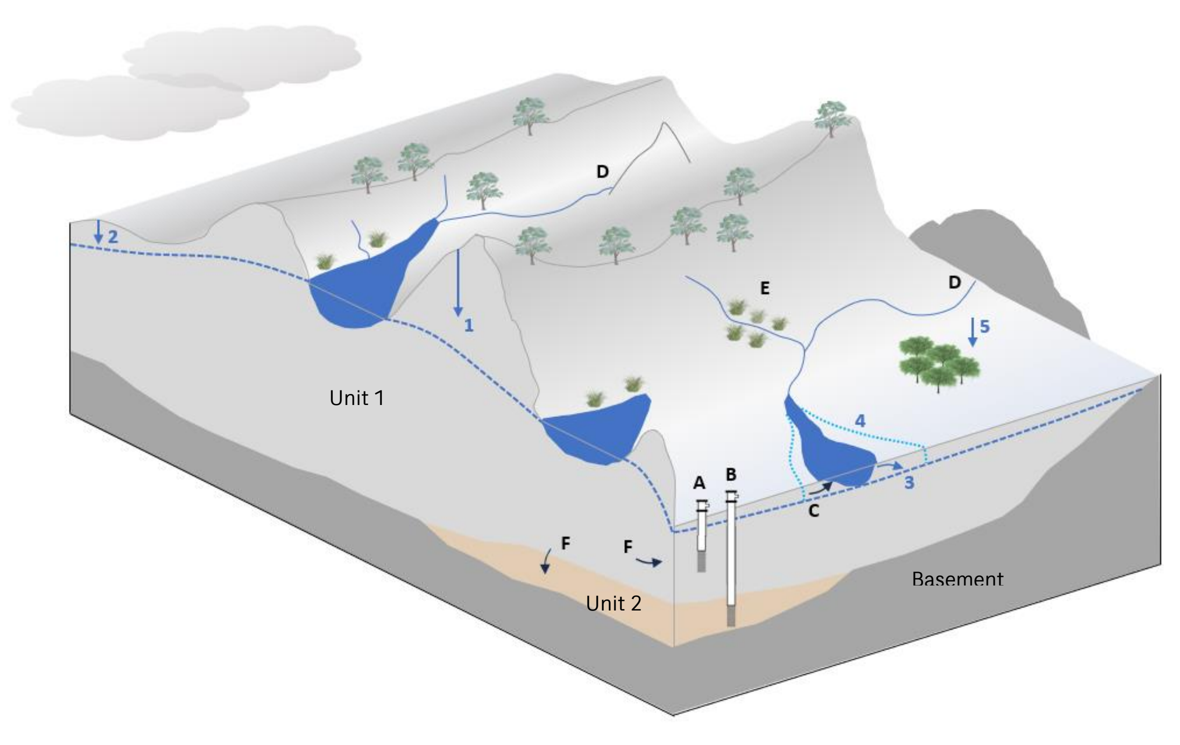


Unit description	Unit 1 is the Upper Mid Tertiary Aquifer (Limestone Aquifers) which also contains the Quaternary aquifer in drainage lines, Unit 2 is the Lower Mid Tertiary Aquifer (Clifton Formation) which is confined, and the Lower Tertiary Aquifer (predominantly comprising the Dilwyn Formation) which is partly confined
Groundwater levels	Depth to groundwater ranges from <5 m to 40 m and averages <5 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the lower tertiary aquifer) ranges from 130 m to 1,440 m and averages 880 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Rainfall recharge is the primary recharge mechanism where the aquifers outcrop. This is highest in areas of young outcropping basalt and eruption centres which act as recharge conduits for the underlying aquifers.	Total estimated recharge (current period): 228,208 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	There is a high degree of connection between the shallow aquifers and surface water features, with variable gaining and losing conditions. Recharge to the LTA can occur along rivers where the aquifer outcrops.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	Irrigation accessions form an additional form of recharge to the groundwater system	

A - Pumping (from unit 1)	Abstraction occurs from the Quaternary alluvium and upper aquifers for irrigation	Average total extraction (current period): 6,068 ML/yr Total current entitlement: 23,625 ML/yr
B - Pumping (from unit 2)	Groundwater is extracted from the LTA for irrigation in the north of the WSPA and around Dartmoor	
C - Groundwater discharge to rivers	Discharge from the shallow Quaternary aquifers generally occurs to the many natural surface water drainage systems and eventually to the coast. An upward gradient is present at Dartmoor and it is conceptualised that the Glenelg River receives baseflow from the Upper Mid-Tertiary Aquifer.	
D - Groundwater discharge to springs	Discharge occurs to springs from the shallow Quaternary aquifers.	
E - Groundwater discharge to wetlands	Discharge occurs to shallow depressions from the shallow Quaternary aquifers.	
F - Groundwater throughflow out	Groundwater throughflow to the ocean is a major source of groundwater discharge for the region.	
References: EcoMarkets (2010) Glenelg Hopkins CMA Groundwater Model		

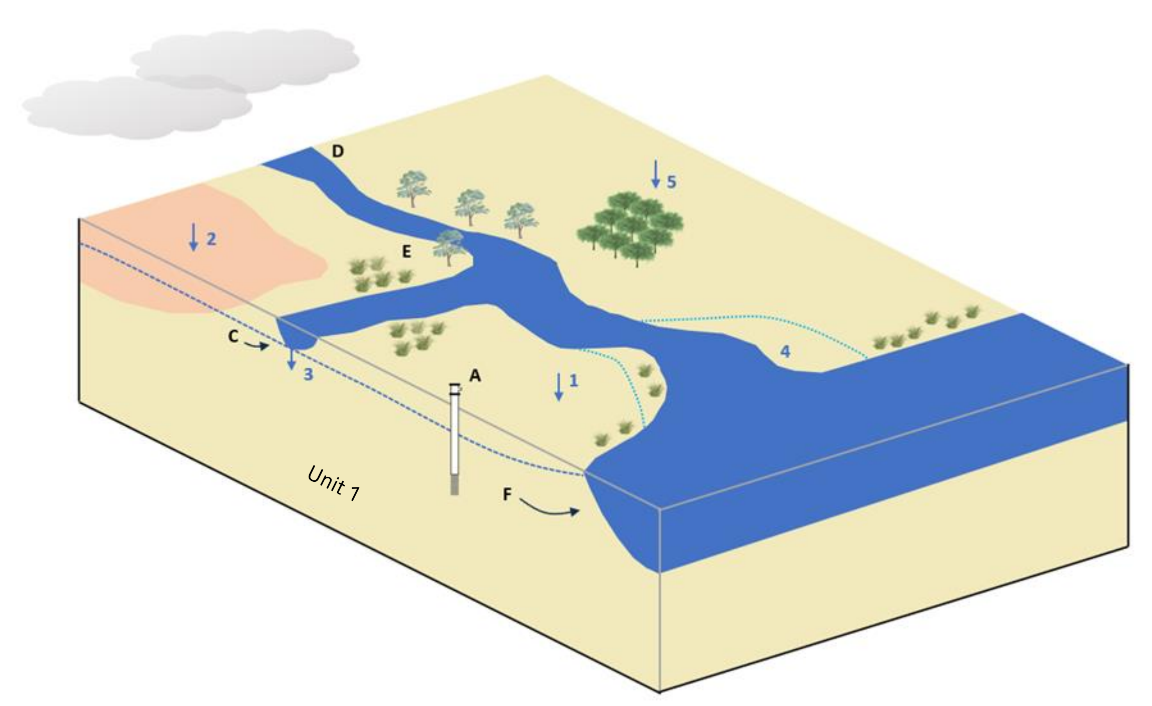
Table L-13 GMU conceptual model - Glenormiston

Glenormiston	***Unconfined Volcanics***
	
Unit description	Unit 1 is the volcanic aquifer (UTB), Unit 2 is the deep lead (UTAF)
Groundwater levels	Depth to groundwater ranges from <5 m to 130 m and averages <5 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary basalt aquifer) ranges from 0 m to 20 m and averages 5 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Higher rainfall recharge occurs around eruption centres.	Total estimated recharge (current period): 16,608 ML/yr
2 - Low Rainfall Recharge	Lower recharge occurs on weathered basalt plains.	
3 – River Recharge	NA	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	The primary groundwater resource is the Newer Volcanics aquifer.	Average total extraction (current period): 1,253 ML/yr Total current entitlement: 2,399 ML/yr
B - Pumping (from unit 2)	The Hanson Plains Sand aquifer is utilised to the north-west of Mount Noorat where the Newer Volcanics are thin, and where it outcrops to the west of the Terang-Mortlake Road.	

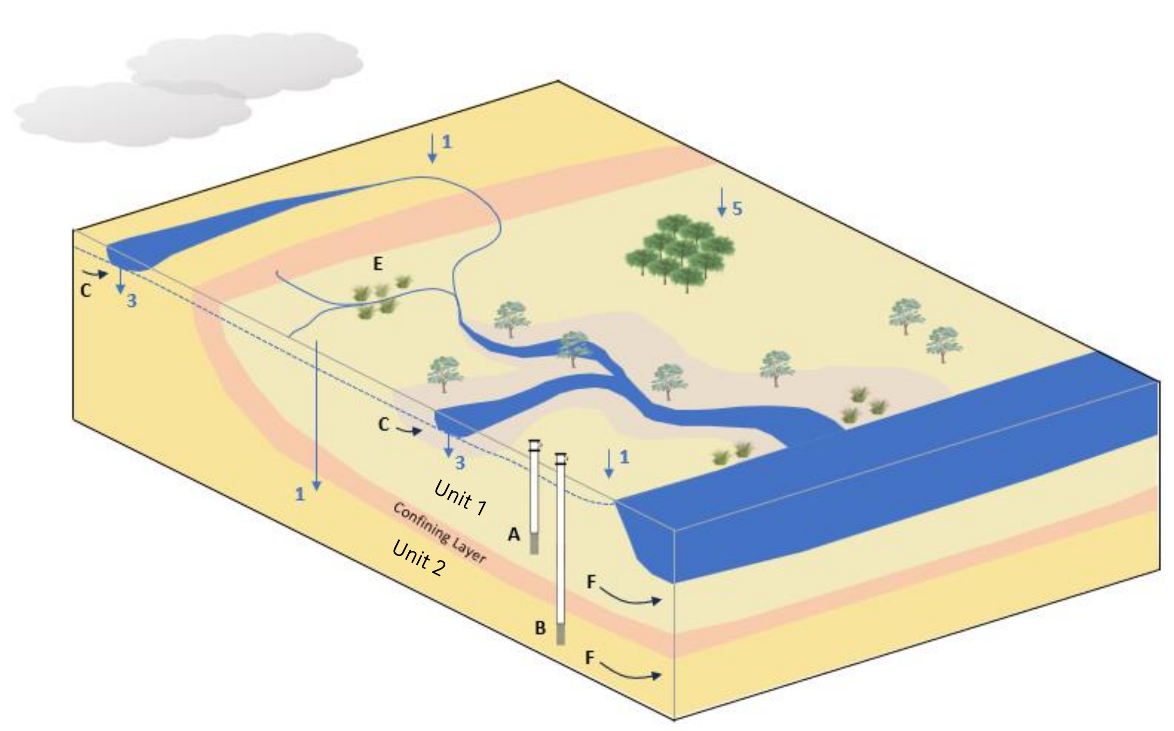
C - Groundwater discharge to rivers	Groundwater baseflow to drainage lines occurs in this GMU.	
D - Groundwater discharge to springs	Discharge from the volcanics occurs as spring discharge and regularly occurs on the edge of the flow boundaries.	
E - Groundwater discharge to wetlands	Some spring discharges result in permanent wetlands.	
F - Groundwater throughflow out	NA	
References: SKM (1998) Glenormiston PAV report; SRW (2016) Hopkins-Corangamite Groundwater Catchment Statement		

Table L-14 GMU conceptual model – Gymbowen Neuarpur and Southern Zones (West Wimmera)

<table>
<tr><th colspan="2">Gymbowen, Neuarpur and Southern Zones (West Wimmera GMA)</th><th>Unconfined Sedimentary Plains</th></tr>
<tr><td colspan="3">
</td></tr>
<tr><td>Unit description</td><td colspan="2">Unit 1 is shallow unconfined aquifers the Parilla Sands and Tertiary Limestone Aquifer</td></tr>
<tr><td>Groundwater levels</td><td colspan="2">Depth to groundwater ranges from <5 m to 130 m and averages 40 m within the GMU.</td></tr>
<tr><td>Watertable aquifer thickness</td><td colspan="2">Watertable aquifer thickness (i.e. the upper tertiary aquifer) ranges from 2 m to 90 m and averages 45 m within the GMU.</td></tr>
<tr><th>Process</th><th>Description of Process</th><th>Quantification of Process</th></tr>
<tr><td>1 - High Rainfall Recharge</td><td>A number of sink holes and karstic features exist in the area which generate localised point source recharge of the aquifer.</td><td rowspan="3">Total estimated recharge (current period):
Gymbowen - 61,230 ML/yr
Neuarpur - 54,856 ML/yr
Southern - 194,217 ML/yr</td></tr>
<tr><td>2 - Low Rainfall Recharge</td><td>Modern vertical recharge is assumed to be minimal across most of the area (i.e. on the order of a few millimetres per year).</td></tr>
<tr><td>3 – River Recharge</td><td>Seasonal lakes, wetlands and swamps are important point sources of recharge to unconfined aquifers.</td></tr>
<tr><td>4 - Episodic Flood Inundation</td><td>NA</td><td rowspan="2"></td></tr>
<tr><td>5 - Irrigation Return</td><td>In Neuarpur, irrigated agriculture is a key land use in the area and some returns to groundwater would be expected.</td></tr>
</table>

A - Pumping (from unit 1)	Groundwater from the Tertiary Limestone Aquifer is the source of urban water supply for the small town of Goroke and for irrigated agriculture. The Parilla Sands Aquifer is low yielding and its use is limited to domestic and stock purposes.	Average total extraction (current period): Gymbowen - 37 ML/yr Neuarpur - 25 ML/yr Southern - 561 ML/yr Total current entitlement: Gymbowen - 63 ML/yr Neuarpur - 200 ML/yr Southern - 2,687 ML/yr
B - Pumping (from unit 2)	NA	
C - Groundwater discharge to rivers	In the Southern Zone, Mosquito Creek may receive groundwater, as well as the upper reaches of the Glenelg River.	
D - Groundwater discharge to springs	In the Southern Zone in dry years, spring-fed pools in Mosquito Creek are critical refuges for threatened fish and other fauna because there is a lack of other connected surface water in the landscape.	
E - Groundwater discharge to wetlands	Groundwater discharge supports wetlands in this GMU (e.g. the Natimuk-Douglas chain of lakes). Local groundwater discharge to low lying areas within the interdunal systems of the PSA also supports wetland systems, although these are sometimes perched and therefore not part of the regional aquifer.	
F - Groundwater throughflow out	NA	
References: GWMW (2011) West Wimmera Groundwater Management Strategy; GWMW (2019) West Wimmera Groundwater Management Area Local Management Plan		

Table L-15 GMU conceptual model – Hawkesdale GMA

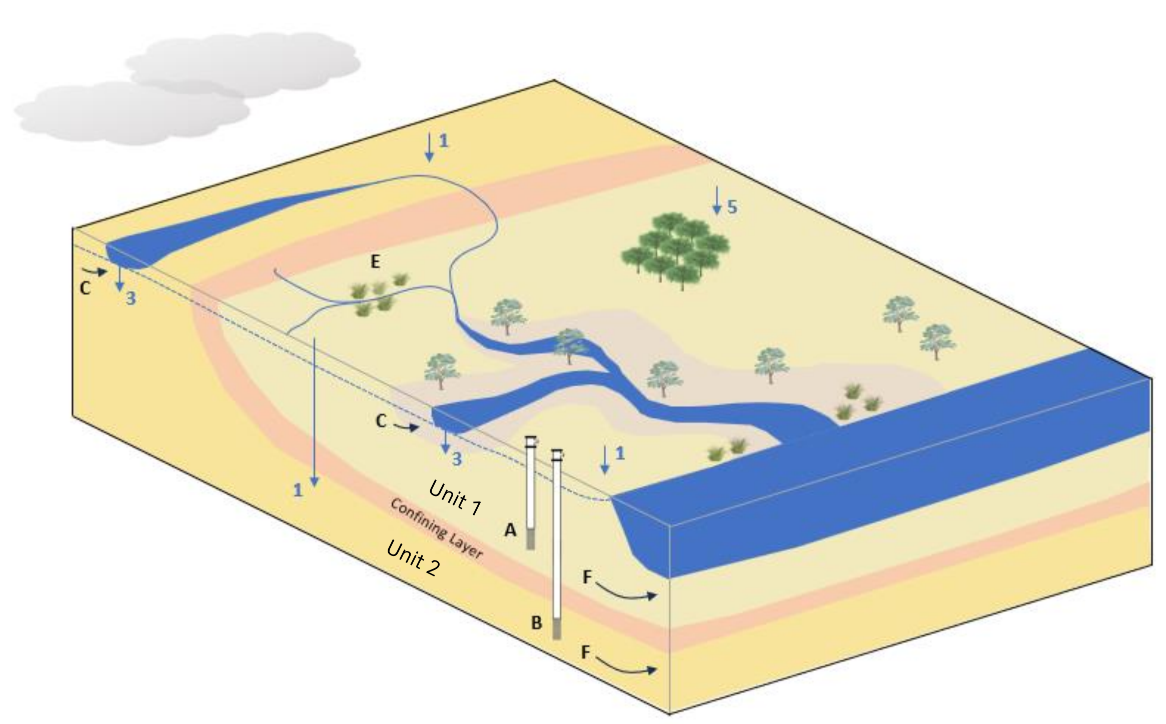
Hawkesdale GMA	***Unconfined and Confined Sedimentary Plains***
	
Unit description	Unit 1 is the Newer Volcanics and Port Campbell Limestone, Unit 2 is the Clifton Formation and Dilwyn Formation
Groundwater levels	Depth to groundwater ranges from <5 m to 10 m and averages <5 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper mid-tertiary aquifer) ranges from 70 m to 150 m and averages 100 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Rainfall infiltration directly to the outcropping units (Basalt and Limestone) is the primary recharge source. Eruption points such as Mount Eccles are areas of enhanced recharge in the GMA.	Total estimated recharge (current period): 289,345 ML/yr
2 - Low Rainfall Recharge	Areas of forested land result in lower rainfall recharge	
3 – River Recharge	NA	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	The Newer Volcanics Basalt and Port Campbell Limestone aquifers are the predominant aquifers utilized for stock/domestic purposes and for irrigation.	Average total extraction (current period): 4,790 ML/yr Total current entitlement: 11,192 ML/yr

B - Pumping (from unit 2)	Whilst the Clifton Formation and Dilwyn Formation are both present across the GMA, there is no recorded groundwater use from these aquifers	
C - Groundwater discharge to rivers	Baseflow to rivers is a predominant source of groundwater discharge in the GMA. Most of the rivers are likely to receive groundwater baseflow in this GMA.	
D - Groundwater discharge to springs	Discharge from the shallow Quaternary aquifers occurs via springs.	
E - Groundwater discharge to wetlands	Discharge from the shallow Quaternary aquifers occurs via evapotranspiration at shallow depressions and other areas where the watertable is shallow.	
F - Groundwater throughflow out	Groundwater throughflow discharge includes to the coast but also to other GMAs (Heywood and Yangery).	
References: SKM (2007) Preliminary Groundwater Resource Appraisal for the Hawkesdale Management Area; EcoMarkets (2010) Glenelg Hopkins CMA Groundwater Model		

Table L-16 GMU conceptual model – Heywood GMA

Heywood GMA	***Unconfined and Confined Sedimentary Plains***



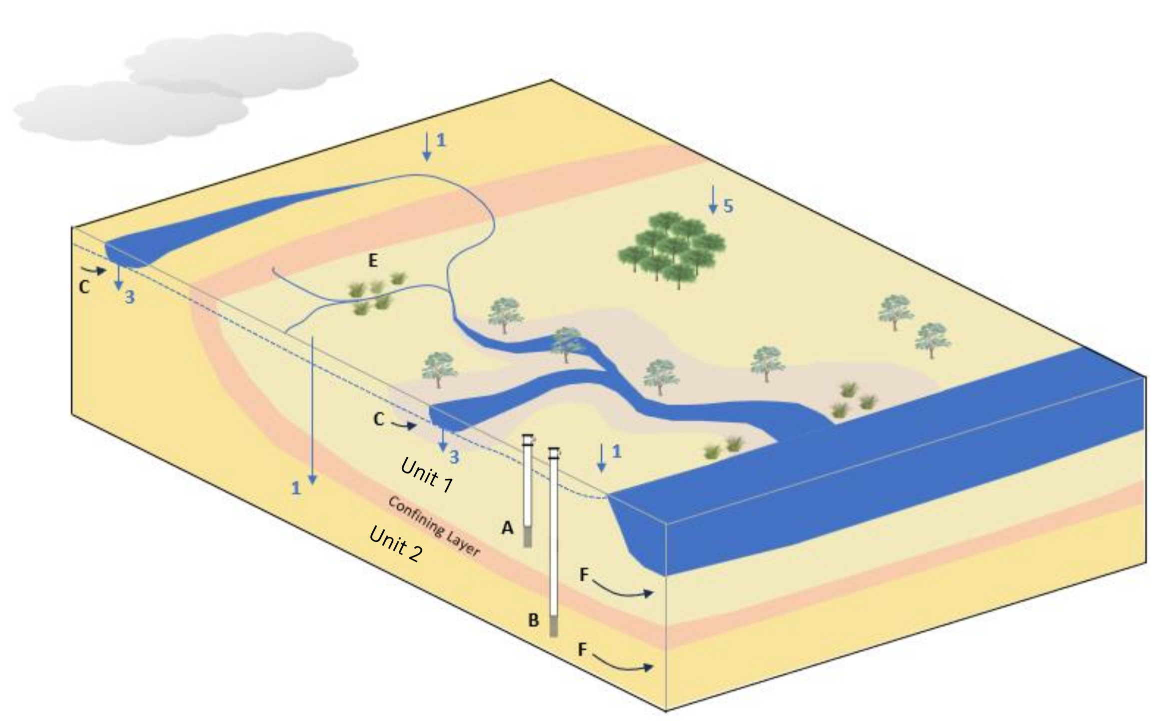
Unit description	Unit 1 is the Newer Volcanics and Port Campbell Limestone and the Quaternary alluvium, Unit 2 is the Clifton Formation and Dilwyn Formation
Groundwater levels	Depth to groundwater ranges from 0 m to 5 m and averages 2 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper mid-tertiary aquifer) ranges from 0 m to 450 m and averages 190 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Rainfall infiltration to the outcropping units (alluvium and volcanics) is the primary source of recharge, with recharge enhanced around eruption points.	Total estimated recharge (current period): 147,446 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	NA	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	Development of the aquifer is limited to a hand full of large extraction bores and numerous (estimated up to 1800) stock and domestic bores. All of the licensed extraction bores (eg for irrigation) are in the upper part of the Port Campbell Limestone aquifer either outcropping or underlying the Basalts.	Average total extraction (current period): 2,320 ML/yr Total current entitlement: 7,137 ML/yr

B - Pumping (from unit 2)	NA	
C - Groundwater discharge to rivers	Discharge from the shallow Quaternary aquifers generally occurs to the many natural surface water drainage systems and eventually to the coast.	Baseflow index: 0.56 Mean annual baseflow: 235.7 ML/y/km^2 (Gauge: 235224 Gellibrand River @ Burrupa)
D - Groundwater discharge to springs	Discharge from the shallow Quaternary aquifers occurs via springs.	
E - Groundwater discharge to wetlands	Discharge from the shallow Quaternary aquifers occurs via evapotranspiration at shallow depressions and other areas where the watertable is shallow.	
F - Groundwater throughflow out	Groundwater throughflow to the coast is a primary discharge mechanism.	
References: SKM (1998) PAV Determination for Heywood GMA; EcoMarkets (2010) Glenelg Hopkins CMA Groundwater Model		

Table L-17 GMU conceptual model – Jan Juc GMA

Jan Juc GMA ***Unconfined and Confined Sedimentary Plains***



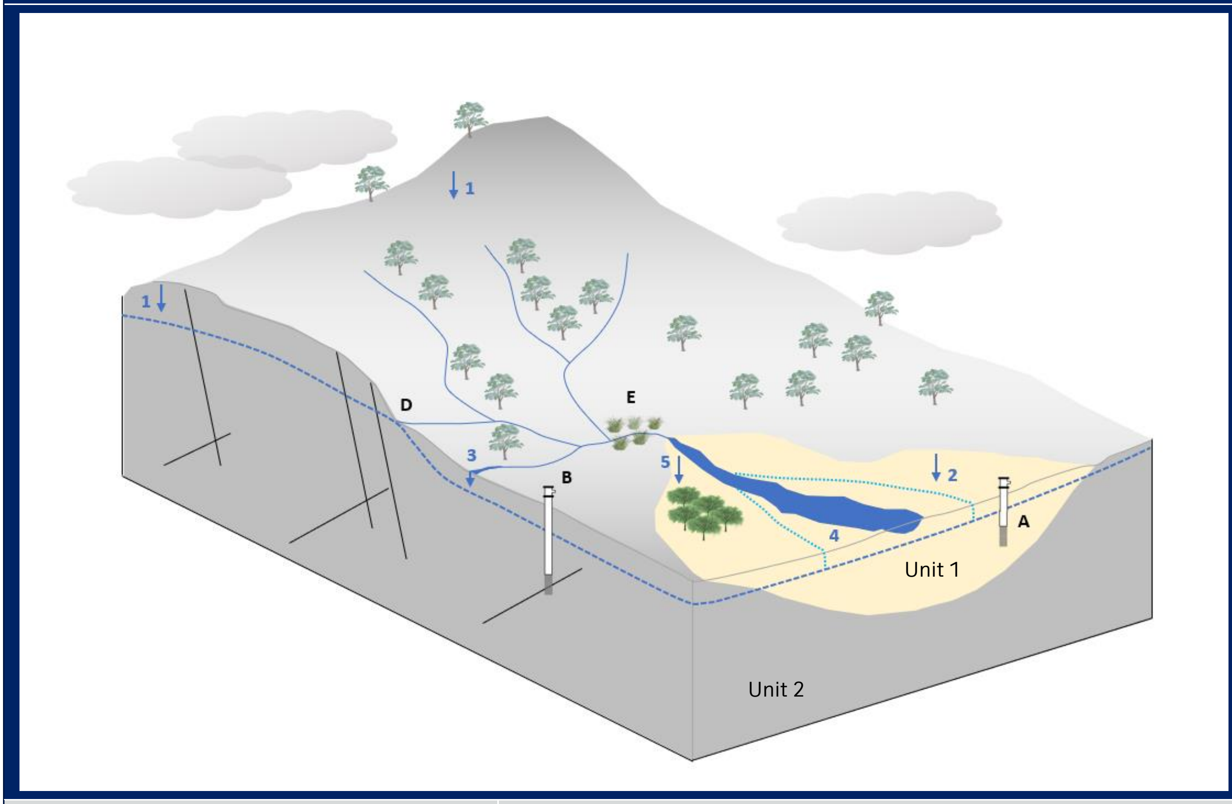
Unit description	Unit 1 is the Demons Bluff Formation and shallower units of the EVF and Quaternary alluvium, Unit 2 is the Lower Eastern View Formation
Groundwater levels	Depth to groundwater ranges from <5 m to 110 m and averages 20 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the lower tertiary aquifer) ranges from 5 m to 410 m and averages 200 m within the GMU.

Process	Description of Process	Quantification of Process
1 - High Rainfall Recharge	Primary recharge mechanism is rainfall infiltration over the outcrop area.	Total estimated recharge (current period): 17,144 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	For most of the GMA, the Lower Eastern View Formation (primary GMA unit) is disconnected from the surface water features and gw-sw interaction is restricted to shallow perched aquifers in the alluvium. Some losses may occur from streams but this is most likely lost to the shallow Quaternary Aquifers, not the EVF)	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	Limited extraction from shallower units within the EVF or shallow Quaternary aquifers.	Average total extraction (current period): 370 ML/yr

B - Pumping (from unit 2)	The Eastern View Formation is the primary aquifer used for groundwater extraction. The Lower Eastern View Formation (LEVF) is the target formation for the Anglesea Borefield (supplementary water supply for Geelong). Extraction for quarrying from the upper and lower EVF has also occurred.	Total current entitlement: 4,250 ML/yr
C - Groundwater discharge to rivers	Breakfast Creek may be supported by baseflow, however, in this area the LEVF is thin and there is the possibility that the baseflow contribution is mainly from the basement rocks (GHD, 2013). Painkalac Creek is the only perennial watercourse in the study area and the baseflow for this feature is from the basement rocks (GHD, 2008).	Baseflow index: 0.30 Mean annual baseflow: 115.0 ML/y/km^2 (Gauge: 235232 Painkalac Creek at Painkalac Creek Dam)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	Groundwater possible discharges from the alluvium to swamps in the GMU.	
F - Groundwater throughflow out	Groundwater throughflow to offshore areas of the aquifer is a primary groundwater discharge mechanism for the LEVF, as well as upwards leakage to overlying formations.	
References: CDM Smith (2018) Long Term Water Resource Assessment – Groundwater, Phase 2		

Table L-18 GMU conceptual model – Kiewa GMA

Kiewa GMA ***Sedimentary Upland Valleys***



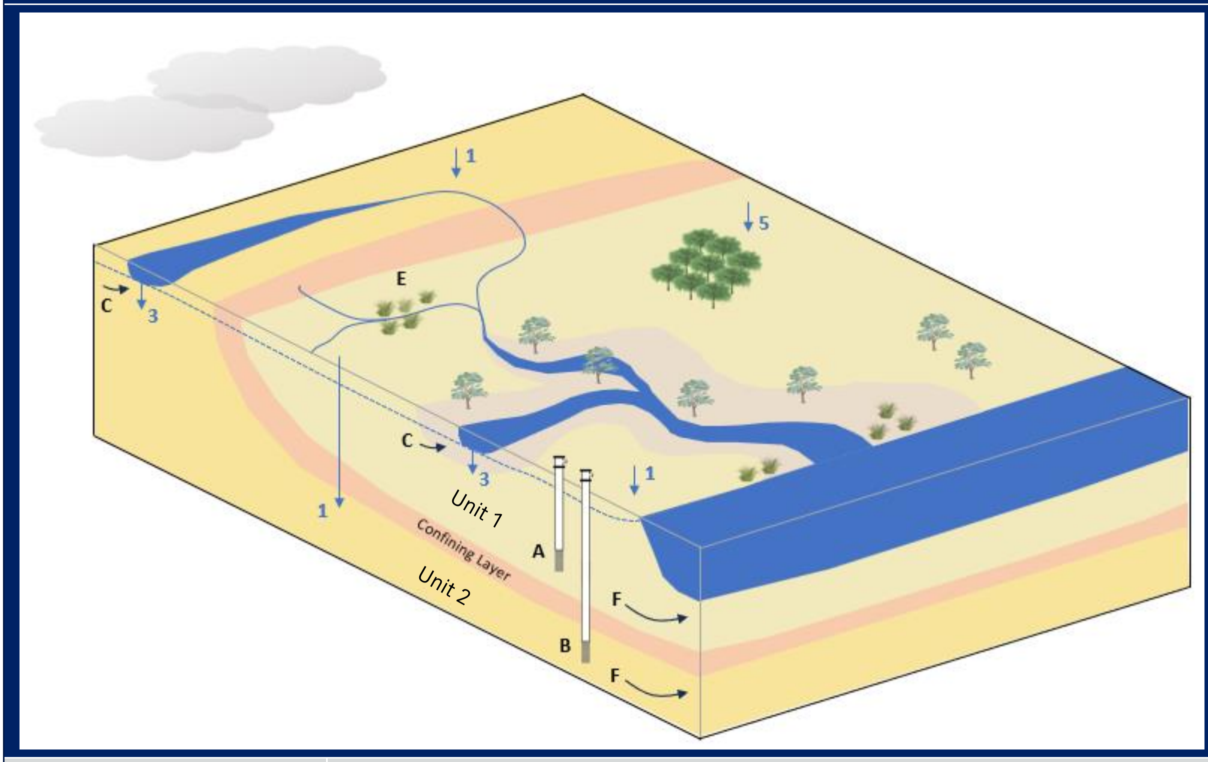
Unit description	Unit 1 is the alluvial sands and gravels and Unit 2 is the fractured bedrock aquifer
Groundwater levels	Depth to groundwater ranges from <5 m to 270 m and averages 50 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the quaternary aquifer) ranges from 0 m to 10 m and averages 5 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	The majority of recharge to the bedrock aquifers in the GMA originates from rainfall which is highest in the upland areas.	Total estimated recharge (current period): 1,074,282 ML/yr
2 - Low Rainfall Recharge	Rainfall recharge is lower in the valleys where rainfall is lower, although recharge also occurs in the valleys via runoff from thew surrounding upland bedrock.	
3 – River Recharge	Some river leakage to the aquifer is expected in this GMU.	
4 - Episodic Flood Inundation	Recharge occurs via Kiewa River flooding events.	
5 - Irrigation Return	NA	

A - Pumping (from unit 1)	The alluvial sands and gravels provide the major groundwater source, as they can store large quantities of good quality water and high yields (> 5-10L/s) can be obtained.	Average total extraction (current period): 666 ML/yr Total current entitlement: 2,864 ML/yr
B - Pumping (from unit 2)	The bedrock aquifer is a more limited groundwater source, with lower aquifer yields (typically less than 0.5 L/sec), however the aquifer does provide an important local groundwater resource for rural households, where it is the primary source of domestic water supply for residents without access to surface water, and it is also used to support industrial, commercial and the agricultural (irrigation) industry.	
C - Groundwater discharge to rivers	Baseflow from groundwater is a major component of river flow.	Baseflow index: 0.66 Mean annual baseflow: 847.0 ML/y/km^2 (Gauge: 402203 Kiewa River at Mongans Bridge) Baseflow index: 0.65 Mean annual baseflow: 221.1 ML/y/km^2 (Gauge: 402206 Running Creek at Running Creek)
D - Groundwater discharge to springs	Groundwater discharges as springs within the upland area, at breaks in slope or where faults and fissures in the rock appear at the surface	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	NA	
References: GMW (2014) Kiewa Groundwater Management Area Local Management Plan		

Table L-19 GMU conceptual model – Koo Wee Rup WSPA

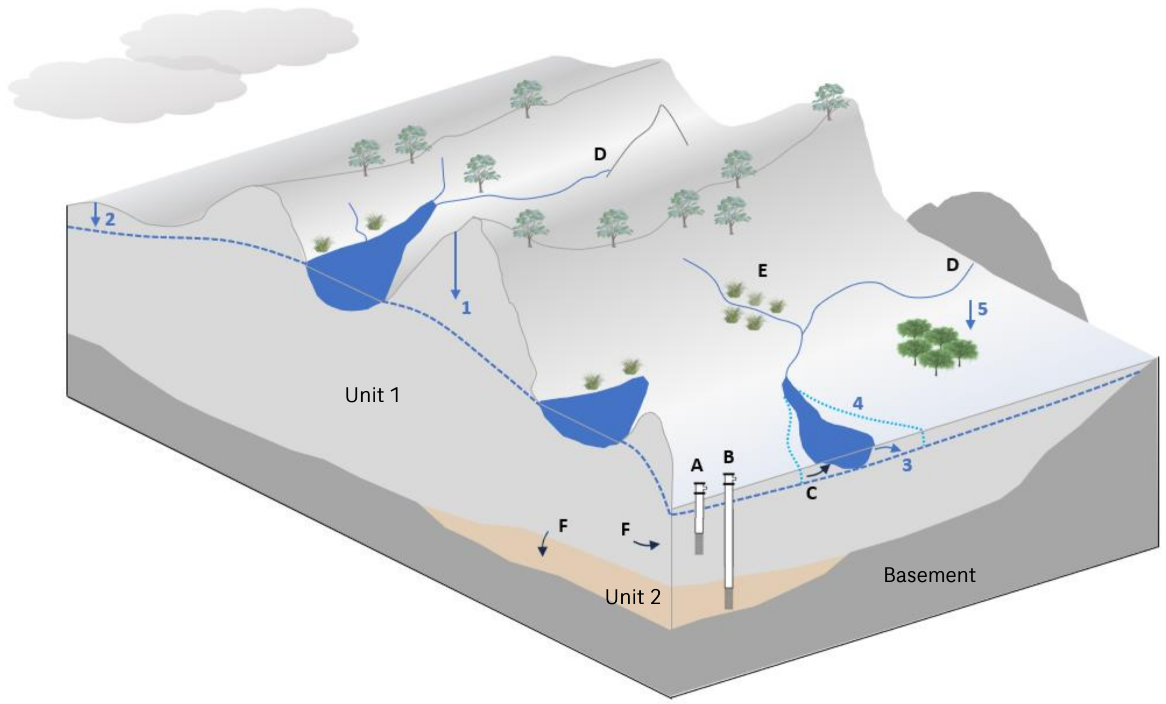
Koo Wee Rup WSPA		***Unconfined and Confined Sedimentary Plains***



Unit description	Unit 1 is the shallow Quaternary sediments, Unit 2 is the Westernport Formation and the Older Volcanics	
Groundwater levels	Depth to groundwater ranges from <5 m to 70 m and averages 10 m within the GMU.	
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the quaternary alluvium) ranges from 0 m to 60 m and averages 20 m within the GMU.	
Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	The Westernport aquifer system is considered to be confined to semi-confined. Groundwater recharge occurs vertically to the Tertiary aquifers through the overlying Quaternary sediments, as well as through areas where the Tertiary sediments outcrop along the edges of the Basin.	Total estimated recharge (current period): 281,829 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	Some hydraulic connection may exist between the lower reaches of the Bunyip and Lang Lang Rivers and the Quaternary (shallow, unconfined) aquifer.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	Irrigation is an important process in the region and returns from irrigation would be expected.	
A - Pumping (from unit 1)	Shallow Quaternary aquifer (unconfined) is generally used for stock and domestic supplies.	Average total extraction (current period): 3,483 ML/yr

B - Pumping (from unit 2)	Most extraction occurs from the Westernport Fm and is used for irrigation of market gardens and stock supplies. The Older Volcanics are also used for irrigation and stock. Childers Fm is not used except for town supply at Lang Lang.	Total current entitlement: 11,497 ML/yr
C - Groundwater discharge to rivers	There is little evidence of surface water/groundwater interaction; which is to be expected given that the area has been progressively drained over the last 120 years. However, it is possible that there is some hydraulic connection between the shallow Quaternary sediments and the lower reaches of the Lang Lang and Bunyip Rivers	Baseflow index: 0.57 Mean annual baseflow: 151.9 ML/y/km^2 (Gauge: 228213 Bunyip River @ Iona)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	Although significant groundwater-surface water interaction and groundwater-dependent ecosystems may have existed in the past, the swamp ecosystems have disappeared from the area.	
F - Groundwater throughflow out	Discharge is generally into Westernport Bay. There is the potential risk of sea water intrusion.	
References: CDM Smith (2018) Long Term Water Resource Assessment – Groundwater		

Table L-20 GMU conceptual model – Lancefield GMA

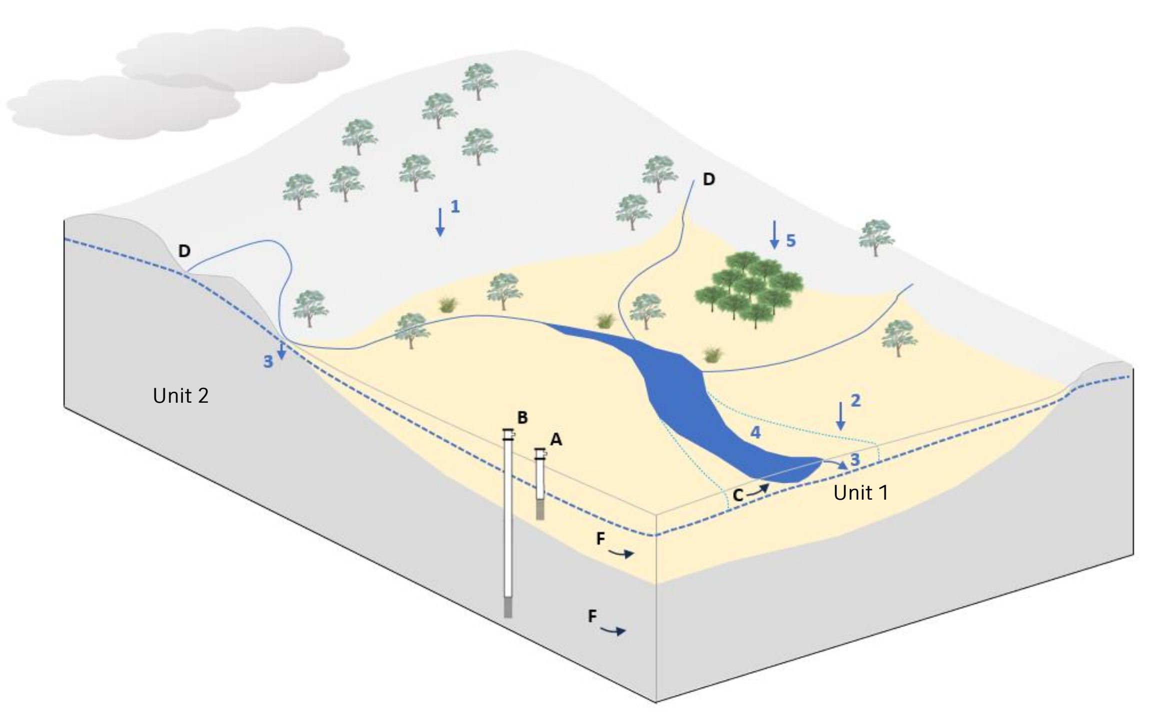
Lancefield GMA	***Unconfined Volcanics***
	
Unit description	Unit 1 is the volcanic aquifer (UTB), Unit 2 is the deep lead (UTAF)
Groundwater levels	Depth to groundwater ranges from <5 m to 90 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary basalt aquifer) ranges from 0 m to 115 m and averages 30 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Higher rainfall recharge occurs where the basaltic soils are thin.	Total estimated recharge (current period): 3,730 ML/yr
2 - Low Rainfall Recharge	Lower recharge occurs on weathered basalt plains.	
3 – River Recharge	Deep Creek, to the north of Lancefield, may provide a significant component of groundwater recharge during periods of high stream levels.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	Irrigation accessions are a small source of recharge compared with rainfall.	
A - Pumping (from unit 1)	The Newer Volcanic aquifer provides urban supply, irrigation and domestic and stock groundwater.	Average total extraction (current period): 206 ML/yr Total current entitlement: 968 ML/yr
B - Pumping (from unit 2)	NA	

C - Groundwater discharge to rivers	Deep Creek is primarily a gaining feature, with groundwater discharging in the form or baseflow.	
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	NA	
References: SKM (1998) Lancefield GMA PAV report; SRW (2013) West Port Phillip Bay Groundwater Catchment Statement		

Table L-21 GMU conceptual model - Leongatha

Leongatha GMA	***Unconfined Sedimentary Valleys***



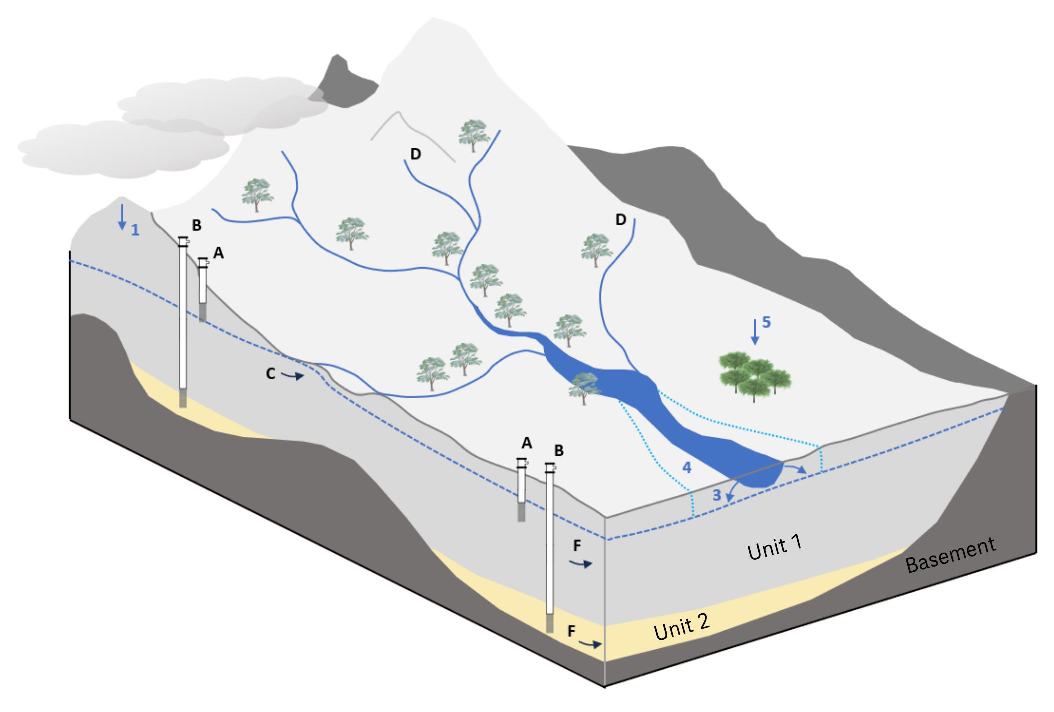
Unit description	Unit 1 is the Older Volcanics and Childers Formation.
Groundwater levels	Depth to groundwater ranges from <5 m to 80 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the lower tertiary aquifer) ranges from 0 m to 160 m and averages 35 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	The highest rainfall recharge occurs where there is the greatest exposure of basalt outcrop in the vicinity of and north of Leongatha.	Total estimated recharge (current period): 54,488 ML/yr
2 - Low Rainfall Recharge	The Childers Fm is directly recharged where it outcrops to the north of Leongatha and via infiltration from the overlying basalts.	
3 – River Recharge	NA	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	

A - Pumping (from unit 1)	The Older Volcanics and the Childers Formation are hydraulically connected and can be considered a single aquifer unit. Groundwater from this aquifer is used for irrigation, dairy wash downs and urban water supply.	Average total extraction (current period): 121 ML/yr Total current entitlement: 1,409 ML/yr
B - Pumping (from unit 2)	NA	
C - Groundwater discharge to rivers	Groundwater discharge is primarily to the surface water drainage system, eventually moving out of the basin via the Tarwin River, Powlett River and Pound Creek.	Baseflow index: 0.51 Mean annual baseflow: 191.5 ML/y/km^2 (Gauge: 227266 Tarwin River at Koonwarra)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	Groundwater flow in the aquifer system is towards the east central part of the GMA from the north, west, and south, as the graben structure is closed off to the south.	
References: SRW (2014) Tarwin Groundwater Catchment Statement; SKM(2006) Leongatha Water Supply groundwater feasibility study for town water supply		

Table L-22 GMU conceptual model - Loddon Highlands WSPA

Loddon Highlands WSPA	***Volcanic & Sedimentary Upland Valleys***

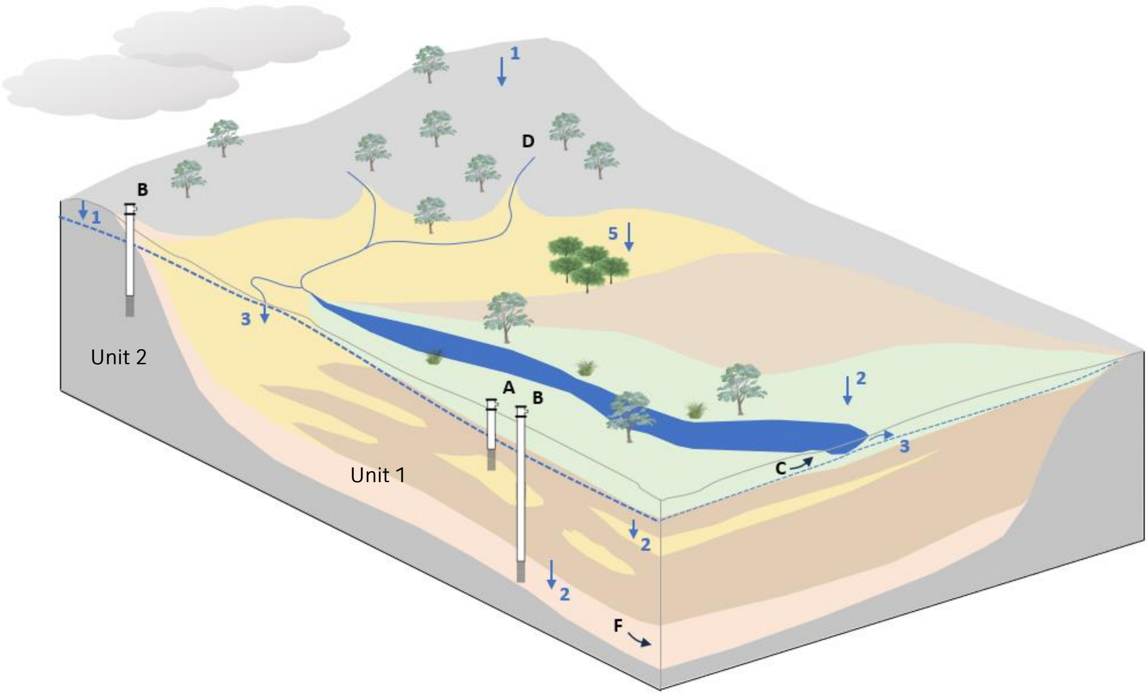


Unit description	Unit 1 is the volcanic aquifer (UTB), Unit 2 is the deep lead (UTAF)
Groundwater levels	Depth to groundwater ranges from <5 m to 230 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary basalt) ranges from 0 m to 70 m and averages 30 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	High rainfall recharge in the upper catchment and particularly around volcanic cones	Total estimated recharge (current period): 242,544 ML/yr
2 - Low Rainfall Recharge	Lower recharge in the lower catchment	
3 – River Recharge	Creeks are variably losing and gaining in the downstream reaches	
4 - Episodic Flood Inundation	Recharge occurs during flood events	
5 - Irrigation Return	Recharge occurs via percolation of irrigation water	
A - Pumping (from unit 1)	Newer Volcanic Basalt (UTB), mainly in the northern portion of the WSPA	Average total extraction (current period): 4,954 ML/yr Total current entitlement: 14,559 ML/yr
B - Pumping (from unit 2)	Deep lead sand and gravel deposits (UTAF), mainly in the northern portion of the WSPA	

C - Groundwater discharge to rivers	Groundwater discharges to creeks in the upper catchment	Baseflow index: 0.46 Mean annual baseflow: 39.4 ML/y/km^2 (Gauge: 407203 Loddon River at Laanecoorie) Baseflow index: 0.25 Mean annual baseflow: 49.2 ML/y/km^2 (Gauge: 407220 Bet Bet Creek at Norwood) Baseflow index: 0.43 Mean annual baseflow: 63.8 ML/y/km^2 (Gauge: 407222 Tullaroop Creek at Clunes) Baseflow index: 0.38 Mean annual baseflow: 74.8 ML/y/km^2 (Gauge: 407214 Creswick Creek at Clunes)
D - Groundwater discharge to springs	Springs commonly found at the base of volcanic cones, topographic lows and where basalt abuts bedrock.	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	Groundwater flows north to the Mid-Loddon GMA	
References: GMW (2012) Loddon Highlands WSPA Groundwater Management Plan		

Table L-23 GMU conceptual model - Lower Campaspe Valley WSPA

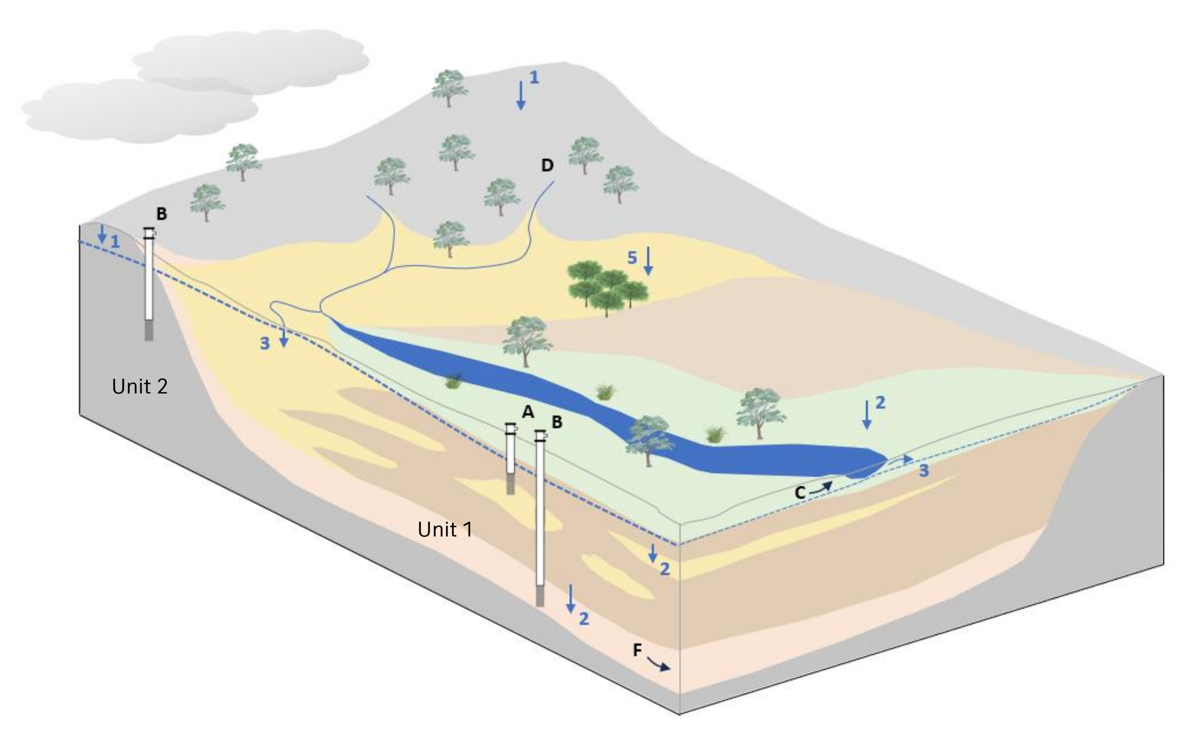
Lower Campaspe Valley WSPA	***Unconfined and Confined Sedimentary Valleys***
	
Unit description	Unit 1 includes the Shepparton Formation and Deep Lead (which includes the Calivil Formation and Renmark Group). Unit 2 is the fractured bedrock.
Groundwater levels	Depth to groundwater ranges from <5 m to 40 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary aquifer) ranges from 50 m to 130 m and averages 95 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	In the upland portions of the GMA (Barnadown and Elmore-Rochester zones) there is significant recharge from rainfall.	Total estimated recharge (current period): 122,745 ML/yr
2 - Low Rainfall Recharge	Rainfall recharge is lower in the lower valleys.	
3 – River Recharge	Upstream of the Campaspe weir the Campaspe River leaks to the groundwater. The Coonambidgal Fm is well connected to the river and leakage occur through this formation to the underlying aquifers.	
4 - Episodic Flood Inundation	NA	

5 - Irrigation Return	Recharge to groundwater from irrigation is important in the intensively developed areas (e.g. the Campaspe Irrigation District and the Rochester Irrigation Area). Irrigation accessions are also a significant source of recharge to the deep lead in the mid catchment (Elmore-Rochester zone).	
A - Pumping (from unit 1)	The Deep Lead is the primary aquifer systems developed in the Lower Campaspe Valley WSPA because it is high yielding and good quality.	Average total extraction (current period): 34,733 ML/yr Total current entitlement: 63,411 ML/yr
B - Pumping (from unit 2)	NA	
C - Groundwater discharge to rivers	Downstream of the Campaspe Weir, where groundwater levels are elevated as a result of land use (i.e. irrigation) groundwater discharges to the Campaspe River.	Baseflow index: 0.36 Mean annual baseflow: 40.7 ML/y/km^2 (Gauge: 406202 Campaspe River at Rochester D/S Waranga Western Ch Syphn) Baseflow index: 0.11 Mean annual baseflow: 41.4 ML/y/km^2 (Gauge: 406224 Mount Pleasant Creek at Runnymede)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	Groundwater flows northward through the aquifer, draining to the Murray Basin.	
References: GMW (2012) Lower Campaspe WSPA Groundwater Management Plan; CSIRO (2008) Southern Riverine Plains Groundwater Model Calibration Report		

Table L-24 GMU conceptual model - Lower Ovens GMA

Lower Ovens GMA	***Unconfined and Confined Sedimentary Valleys***

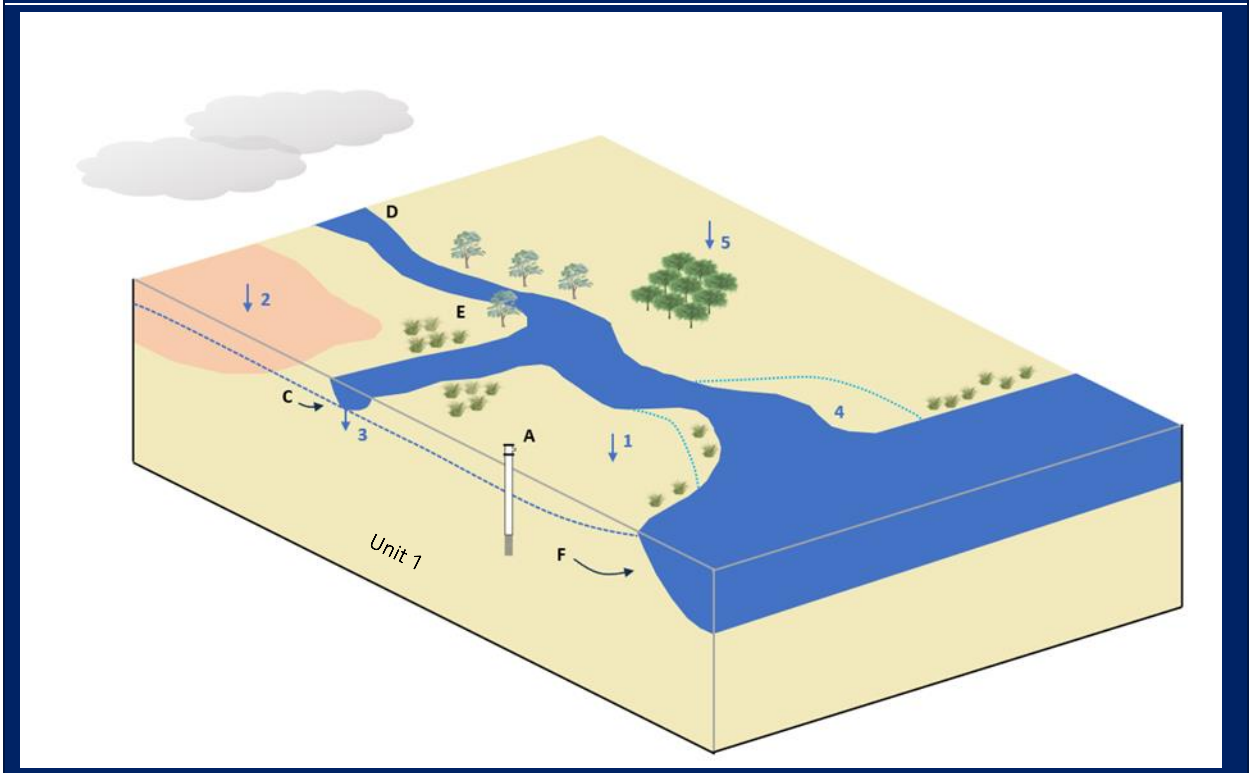


Unit description	Unit 1 includes the Shepparton Formation and deep leads such as the Calivil Formation. Unit 2 is the fractured bedrock.
Groundwater levels	Depth to groundwater ranges from <5 m to 330 m and averages 40 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary aquifer) ranges from 0 m to 70 m and averages 25 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	More recharge occurs to aquifers in the upper catchment and mid Ovens areas between Bright and Tarrawingee (due to higher rainfall), relative to the lower catchment.	Total estimated recharge (current period): 1,007,065 ML/yr
2 - Low Rainfall Recharge	Lower rainfall occurs in the north of the GMA (in the lower catchment) near Peechelba and the Murray River.	
3 – River Recharge	Where surface water is well connected to groundwater (i.e. the upper portions of the GMA) the groundwater can be recharged by the creeks.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	

A - Pumping (from unit 1)	The alluvial deposits are the primary source of groundwater for irrigation, urban and domestic and stock use in the catchment. Most of the groundwater use is associated with the Shepparton Formation and a smaller portion with the Calivil Formation.	Average total extraction (current period): 4,933 ML/yr Total current entitlement: 16,120 ML/yr
B - Pumping (from unit 2)	The bedrock aquifer provides a limited groundwater supply but is an important resource for licence holders away from the major water courses where this is the only source of water.	
C - Groundwater discharge to rivers	Groundwater discharge contributes to river flow in the alluvial filled valleys although in the lower catchment the aquifers are poorly connected to the river.	Baseflow index: 0.63 Mean annual baseflow: 203.8 ML/y/km^2 (Gauge: 403200 Ovens River at Wangaratta) Baseflow index: 0.59 Mean annual baseflow: 184.1 ML/y/km^2 (Gauge: 403241 Ovens River at Peechelba)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	Groundwater flow is generally northwards towards the Murray River where it enters the larger regional groundwater flow system of the Murray Basin	
References: GMW (2012) Lower Ovens GMA Local Management Plan		

Table L-25 GMU conceptual model – Merrimu GMA

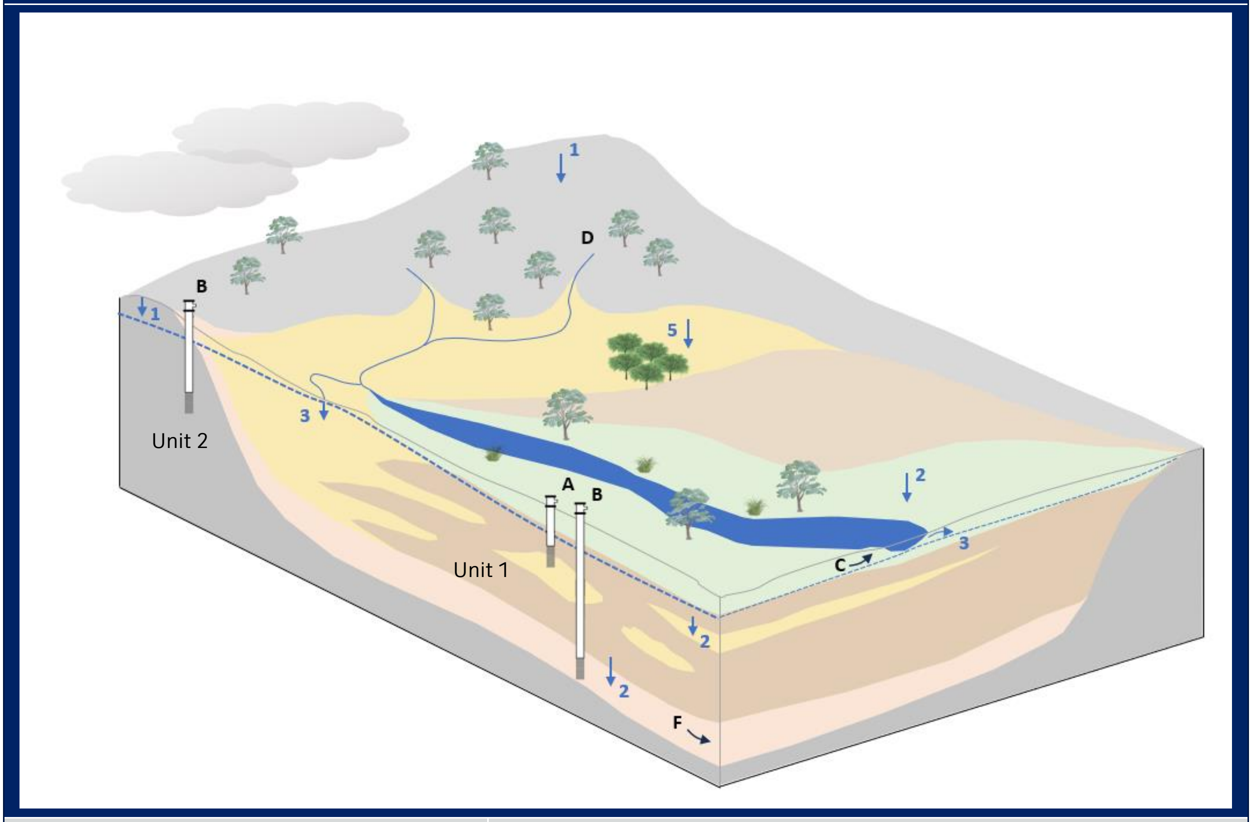
Merrimu GMA	Unconfined Sedimentary Plains
	
Unit description	Unit 1 is the shallow unconfined aquifer consisting of Quaternary age, alluvial and colluvial valley sediments
Groundwater levels	Depth to groundwater ranges from <5 m to 30 m and averages <5 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the quaternary alluvium) ranges from 3 m to 10 m and averages 5 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Recharge to the watertable aquifer is likely to be dominated by infiltration of rainfall directly on the low level alluvial sediments.	Total estimated recharge (current period): 1,135 ML/yr
2 - Low Rainfall Recharge	Some groundwater will be derived from rainfall via the elevated river terraces to the west and east, and also from the Bullengarook Flow volcanics to the east	
3 – River Recharge	NA	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	The GMA incorporates the Bacchus Marsh Irrigation district and fresher groundwater in the alluvial valleys may be the result of irrigation water returns.	
A - Pumping (from unit 1)	Nearly all of the groundwater licensed is used for irrigation purposes, with two bores licensed for commercial usage.	Average total extraction (current period): 74 ML/yr

B - Pumping (from unit 2)	NA	Total current entitlement: 203 ML/yr
C - Groundwater discharge to rivers	Discharge from the aquifer will occur principally via the Werribee and Lerderderg rivers.	Baseflow index: 0.36 Mean annual baseflow: 40.5 ML/y/km^2 (Gauge: 231204 Werribee River at Werribee Diversion Weir)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	NA	
References: SRW (2013) West Port Phillip Bay Groundwater Catchment Statement; SKM (1998) PAV determination for the Merrimu GMA		

Table L-26 GMU conceptual model - Mid Goulburn

Mid Goulburn GMA	***Unconfined and Confined Sedimentary Valleys***



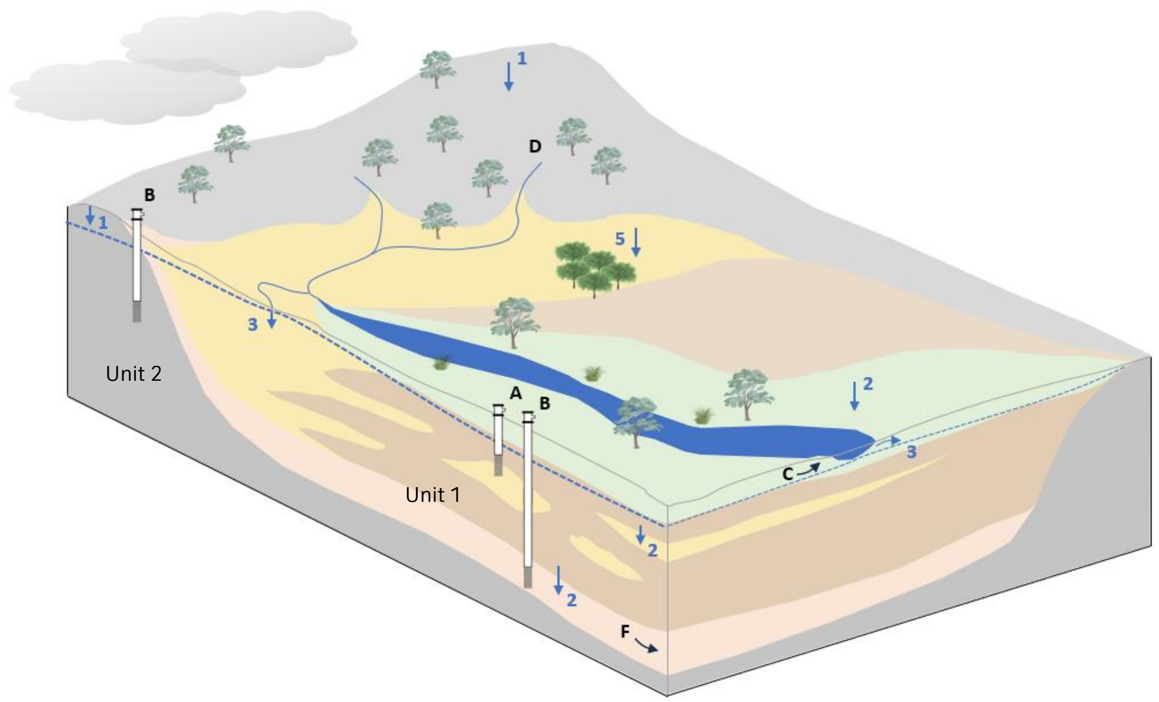
Unit description	Unit 1 includes the Coonambidgal Formation, Shepparton Formation and deep leads such as the Calivil Formation. Unit 2 is the fractured bedrock.
Groundwater levels	Depth to groundwater ranges from <5 m to 60 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary aquifer) ranges from 0 m to 60 m and averages 20 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	High rainfall recharge in the upper catchment (Nagambie zone).	Total estimated recharge (current period): 155,251 ML/yr
2 - Low Rainfall Recharge	Lower recharge in the lower catchment.	
3 – River Recharge	Very small contributions of recharge via leakage from the Goulburn River occurs.	
4 - Episodic Flood Inundation	Recharge occurs during flood events.	
5 - Irrigation Return	Recharge occurs via percolation of irrigation water.	
A - Pumping (from unit 1)	Coonambidgal Formation and Shepparton Formation, mainly in the northern portion of the GMA. Deep Lead sand and gravel deposits (UTAF), mainly in the northern portion of the GMA	Average total extraction (current period): 3,633 ML/yr Total current entitlement: 26,966 ML/yr

B - Pumping (from unit 2)		
C - Groundwater discharge to rivers	Groundwater discharges to the Goulburn River between Goulburn Weir and Murchison and in Hughes Creek.	Baseflow index: 0.54 Mean annual baseflow: 151.5 ML/y/km^2 (Gauge: 405200 Goulburn River at Murchison)
D - Groundwater discharge to springs	Discharge as springs may occur in low lying parts of the landscape.	
E - Groundwater discharge to wetlands	Groundwater discharge to wetlands likely occur in this GMU.	
F - Groundwater throughflow out	Groundwater flows north towards the Murray River via the Shepparton Irrigation Region GMA and the Katunga WSPA	
References: GMW (2015) Mid Goulburn GMA Local Management Plan.		

Table L-27 GMU conceptual model – Mid Loddon GMA

Mid Loddon GMA	***Unconfined and Confined Sedimentary Valleys***



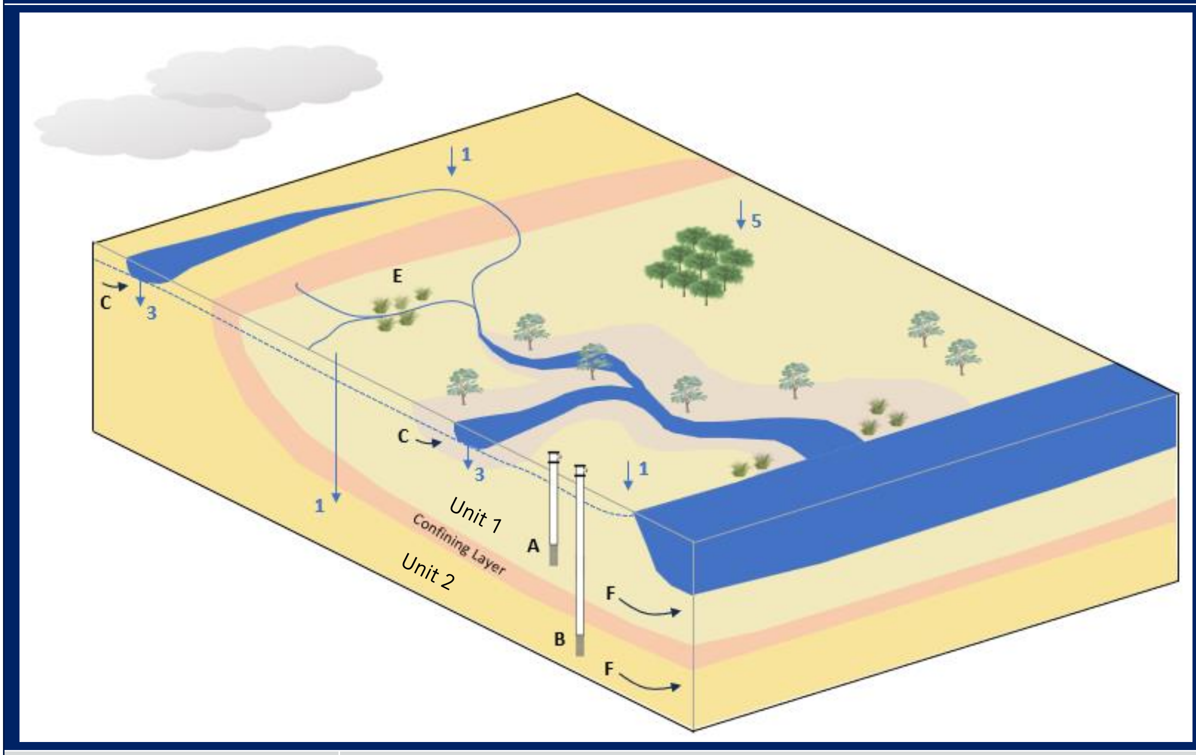
Unit description	Unit 1 includes the Newer Volcanics, Shepparton Formation and Calivil Formation. Unit 2 is the fractured bedrock.
Groundwater levels	Depth to groundwater ranges from <5 m to 110 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary aquifer) ranges from 0 m to 70 m and averages 30 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Rainfall recharge occurs where the deep lead outcrops in the south of the GMA.	Total estimated recharge (current period): 157,457 ML/yr
2 - Low Rainfall Recharge	There is connection between the Shepparton Formation and Deep Lead aquifers and rainfall recharge to the shallower aquifer leaks to the deep lead aquifer.	
3 – River Recharge	River leakage from the Loddon River and tributaries are considered a less important component of the water balance, however interaction increases where watercourses intersect basalts between Newbridge and Bridgewater. River leakage occurs for ~40km downstream of Bridgewater due to lowered groundwater levels. It also occurs between Appin South and the junction with the Murray River.	

4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	Irrigation return occurs in this GMU and has led to increased watertables.	
A - Pumping (from unit 1)	The major groundwater resource is the Deep Lead aquifers. The Shepparton Fm is used to a far more limited extent.	Average total extraction (current period): 17,771 ML/yr Total current entitlement: 28,238 ML/yr
B - Pumping (from unit 2)	NA	
C - Groundwater discharge to rivers	Groundwater discharges to the Loddon River at a low rate between Newstead and Bridgewater (i.e. in the upstream catchment). The Loddon is gaining or hydraulically neutral for the 81 km upstream of Appin South.	Baseflow index: 0.63 Mean annual baseflow: 27.9 ML/y/km^2 (Gauge: 407248 Tullaroop Creek at Tullarrop Res. (O'let Meas. Weir))
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	NA	
References: GMW (2009) Mid-Loddon GMA Local Management Rules; CSIRO 2008 Southern Riverine Plains Groundwater Model Calibration Report; CSIRO (2008). Water availability in the Loddon-Avoca		

Table L-28 GMU conceptual model – Moe GMA

Moe GMA	***Unconfined and Confined Sedimentary Plains***

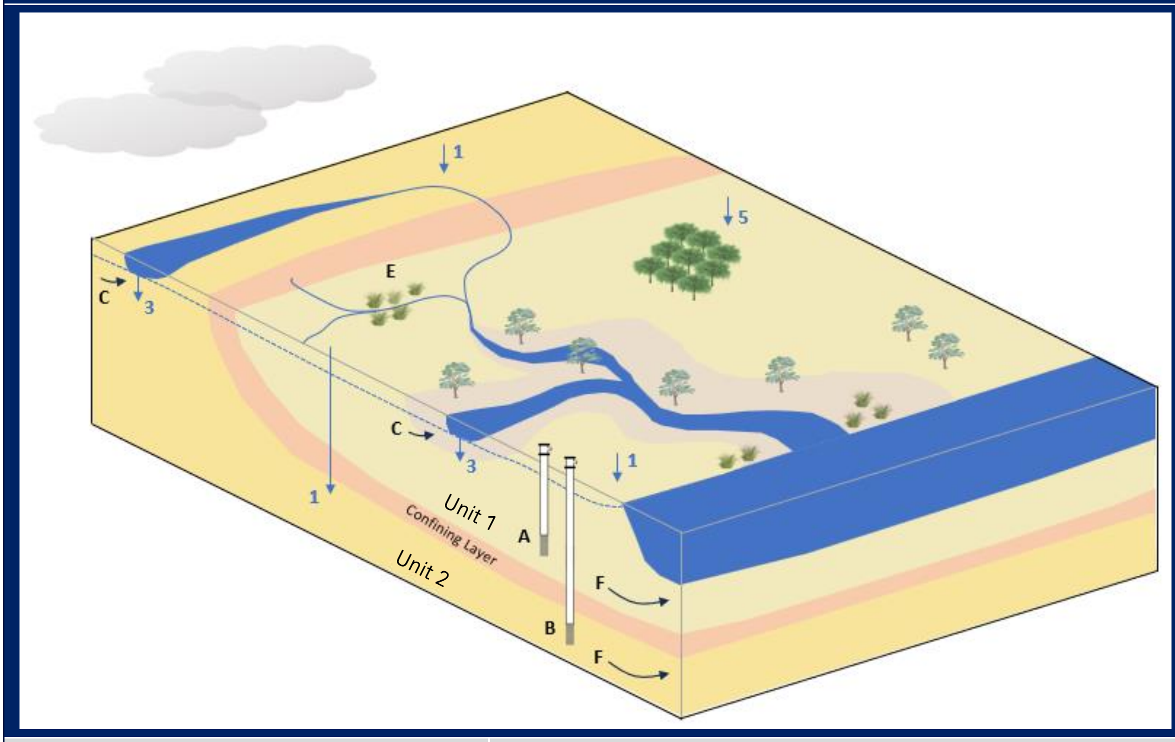


Unit description	Unit 1 is the Quaternary sediments (Haunted Hills), Unit 2 is the Thorpdale Volcanics and Yarragon Formation	
Groundwater levels	Depth to groundwater ranges from <5 m to 80 m and averages 20 m within the GMU.	
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the quaternary alluvium) ranges from 0 m to 8 m and averages 5 m within the GMU.	
Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Groundwater recharge occurs in upland areas of the Basin margins where the major aquifers outcrop or sub-crop.	Total estimated recharge (current period): 101,647 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	Recharge occurs to the major aquifers (Thorpdale Volcanics and the Yarragon Formation) where streams flow over the outcrop areas.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	Over 70% of extracted groundwater is used for irrigation in the GMA and hence irrigation returns are likely.	
A - Pumping (from unit 1)	The Quaternary alluvium is of limited extent and thickness and does not form a significant groundwater resource.	Average total extraction (current period): 782 ML/yr

B - Pumping (from unit 2)	The major productive aquifers are the Thorpdale Volcanics and the Yarragon Formation	Total current entitlement: 2973 ML/yr
C - Groundwater discharge to rivers	Discharge to streams is the primary discharge mechanism from the basement formation (i.e. the streams are gaining in the headwaters of the catchment where the basement geology outcrops). The Latrobe and Tanjil Rivers receive groundwater discharge via the overlying confining units.	Baseflow index: 0.74 Mean annual baseflow: 320.4 ML/y/km^2 (Gauge: 226204 Latrobe River @ Willow Grove)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	The Moe Basin has been described as a closed groundwater catchment, meaning there is no significant sub-surface discharge via its lateral boundaries	
References:		

Table L-29 GMU conceptual model – Moorabbin GMA

Moorabbin GMA	***Unconfined and Confined Sedimentary Plains***



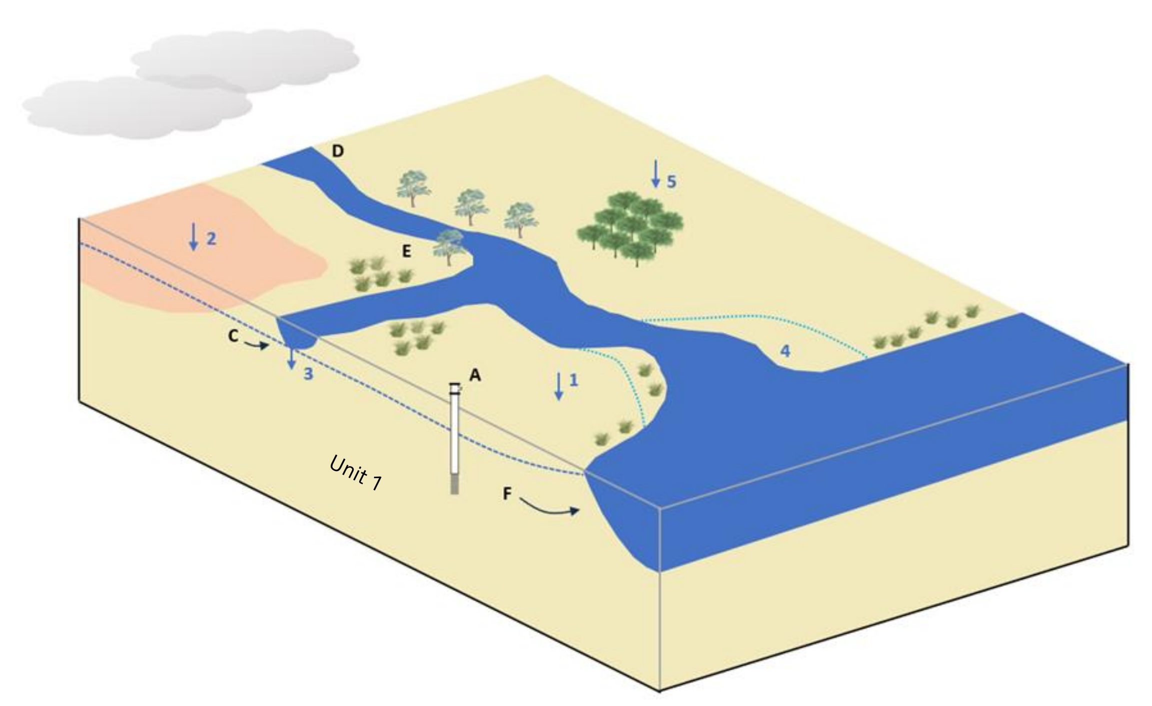
Unit description	Unit 1 is the Brighton Formation and Fyansford Formation, Unit 2 is the Older Volcanics and the Werribee Formation
Groundwater levels	Depth to groundwater ranges from <5 m to 20 m and averages <5 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary aquifer) ranges from 10 m to 35 m and averages 20 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	The main source of recharge to the Brighton Group and Fyansford Fm is from rainfall infiltrating the Brighton Group.	Total estimated recharge (current period): 20,659 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	No significant streams or rivers cross the Moorabbin area and urbanisation means that drains are generally engineered and not connected to groundwater.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	Irrigation of numerous golf courses in the GMA results in irrigation returns to the outcropping aquifer.	

A - Pumping (from unit 1)	The Brighton Group-Fyansford Fm are hydraulically connected and considered together to be the primary groundwater resource in the GMA. The Quaternary alluvium aquifers are used to a lesser degree.	Average total extraction (current period): 91 ML/yr Total current entitlement: 257 ML/yr
B - Pumping (from unit 2)	Other units where the groundwater is utilised to a lesser degree include the underlying Tertiary aquifers and the Palaeozoic basement sediments which, locally provide moderately high yields.	
C - Groundwater discharge to rivers	No significant streams or rivers cross the Moorabbin area and urbanisation means that drains are generally engineered and not connected to groundwater.	
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	Discharge is primarily via throughflow and coastal discharge.	
References: SKM (1998) PAV Determination for Moorabbin GMA.		

Table L-30 GMU conceptual model – Nepean GMA

Nepean GMA | ***Unconfined Sedimentary Plains***



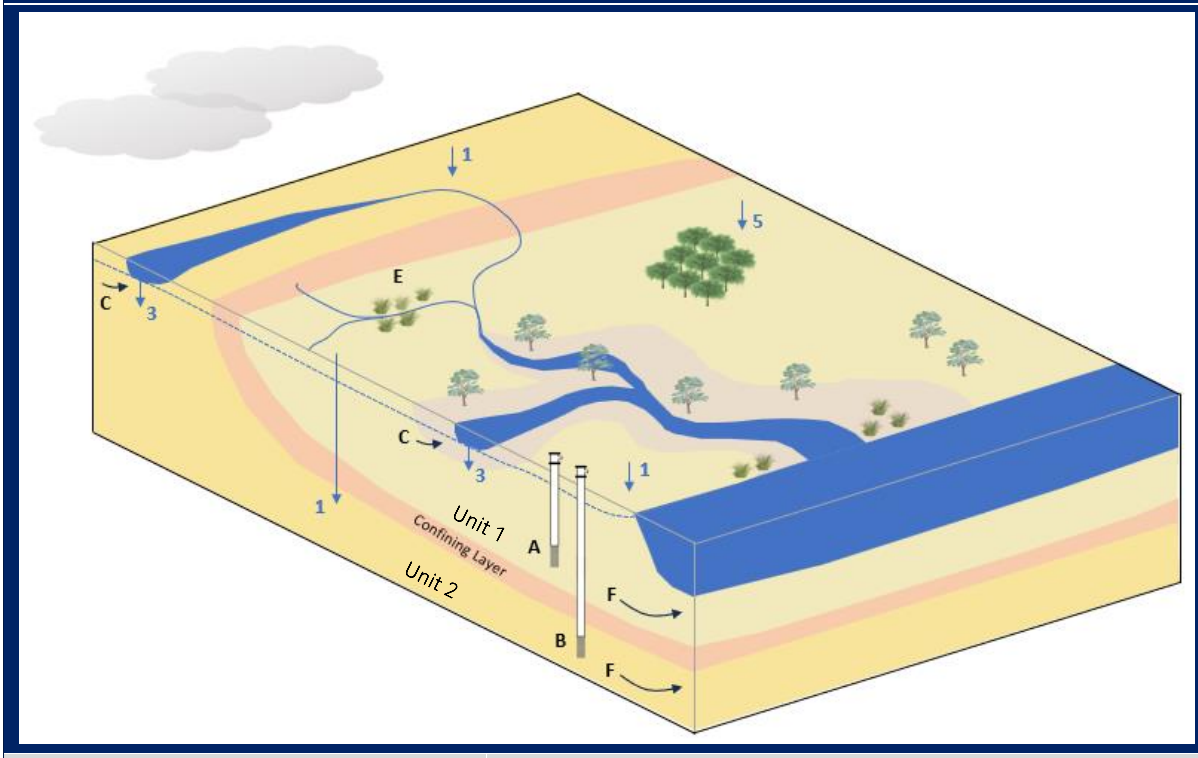
Unit description	Unit 1 is the shallow unconfined aquifer consisting of shallow sands of the Bridgewater, Wannaeue Formations, the Brighton Group Sands, and basalts of the Older Volcanics
Groundwater levels	Depth to groundwater ranges from <5 m to 90 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the lower tertiary aquifer) ranges from 1 m to 320 m and averages 205 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Recharge to the watertable aquifer occurs principally via infiltration of precipitation. The area referred to as "The Cups" in the eastern section of the GMA is a sequence of undulating sand dunes with up to 20 metres relief and permits a substantial amount of the precipitation to recharge the shallow aquifer.	Total estimated recharge (current period): 18,933 ML/yr
2 - Low Rainfall Recharge	In urban areas of the peninsula, roads and drainage will interfere with infiltration, however, the volume reduction is likely to be offset by similar increases in recharge due to the widespread use of seepage areas across the peninsula for disposal of run-off.	
3 – River Recharge	NA	
4 - Episodic Flood Inundation	NA	

5 - Irrigation Return	The Cups is the main irrigation area in the GMA. Water extracted from the aquifer likely returns as irrigation accessions from watering of gardens.	
A - Pumping (from unit 1)	Extraction is from the shallow unconfined aquifer, mainly for irrigation purposes.	Average total extraction (current period): 2,103 ML/yr Total current entitlement: 4,306 ML/yr
B - Pumping (from unit 2)	It is considered unlikely that there is development of any deeper aquifers due to poor water quality.	
C - Groundwater discharge to rivers	NA	
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	Groundwater flows to Bass Strait and Port Phillip Bay on either side of the peninsula.	
References: CDM Smith (2018) Long Term Water Resource Assessment – Groundwater; SRW (2014) East Port Phillip Bay Groundwater Catchment Statement		

Table L-31 GMU conceptual model – Newlingrook GMA

Newlingrook GMA	***Unconfined and Confined Sedimentary Plains***



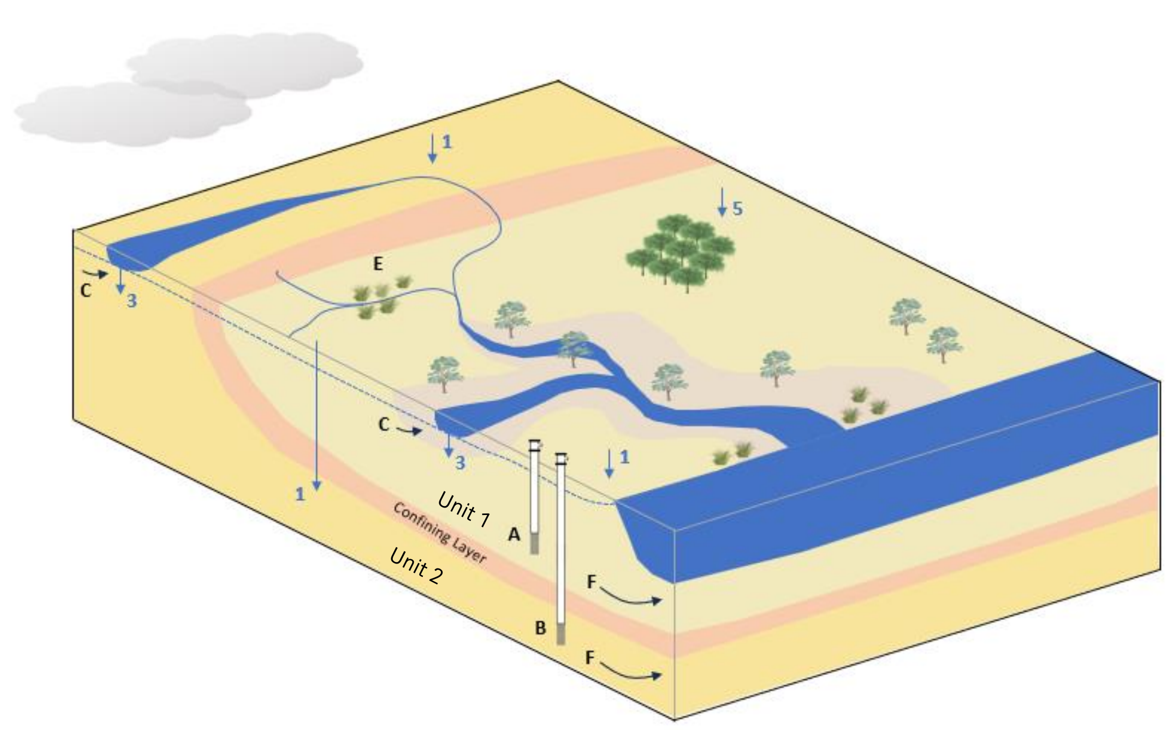
Unit description	Unit 1 is the shallow unconfined Eastern View Formation and Quaternary sediments, Unit 2 is the Eastern View Formation
Groundwater levels	Depth to groundwater ranges from <5 m to 120 m and averages 30 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the quaternary alluvium aquifer) ranges from 0 m to 15 m and averages 5 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	The groundwater is recharged via rainfall infiltration in the areas where the aquifers outcrop. Rainfall is highest in the Otway Ranges where the basement outcrops.	Total estimated recharge (current period): 127,813 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	Recharge to the aquifer from streams occurs during high flow events, however is likely to be small and short lived.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	NA	Average total extraction (current period): 29 ML/yr Total current entitlement: 1,922 ML/yr
B - Pumping (from unit 2)	Town water supply bores at Carlisle River extract from the lower LTA. Town water supply, irrigation and dairy are the licenced extraction uses in the GMA but licence volume is small.	

C - Groundwater discharge to rivers	The Gellibrand River is a major discharge feature for the LTA in the Newlingrook GMA.	Baseflow index: 0.56 Mean annual baseflow: 235.7 ML/y/km^2 (Gauge: 235224 Gellibrand River @ Burrupa)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	Throughflow and discharge to the ocean is a primary discharge mechanism	
References: SRW (2016) Hopkins Corangamite Groundwater Catchment statement		

Table L-32 GMU conceptual model - Northern Zone (West Wimmera)

Northern Zone (West Wimmera GMA)	***Unconfined and Confined Sedimentary Plain***

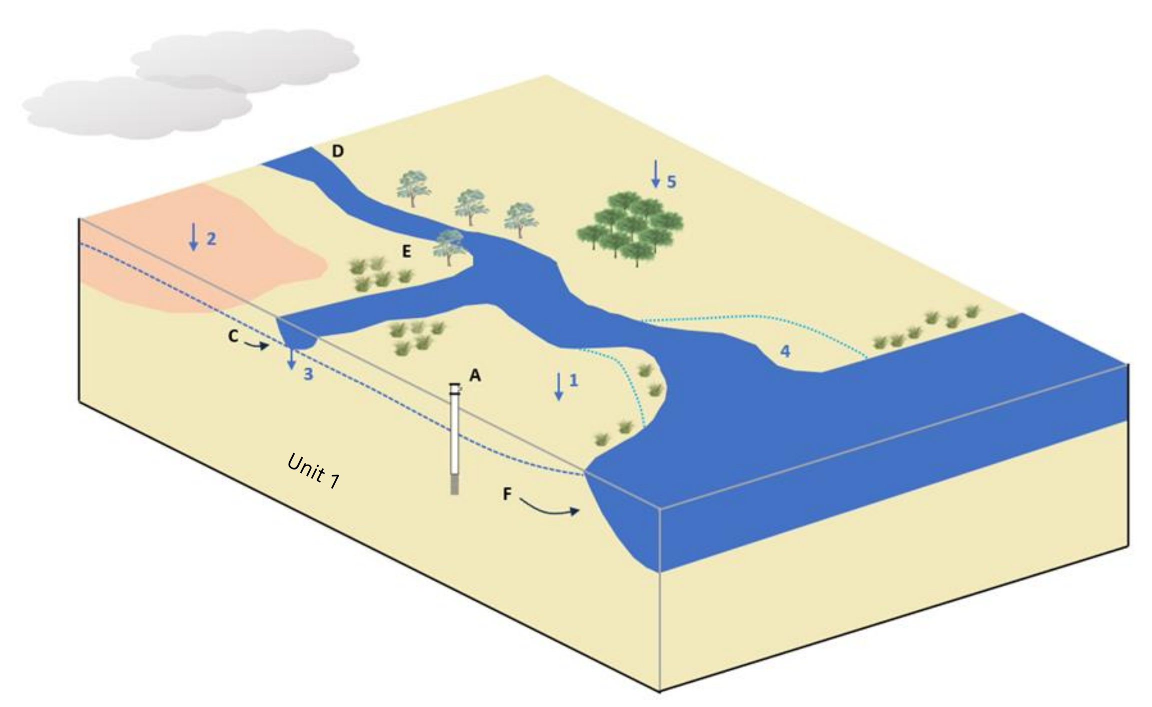


Unit description	Unit 1 is the shallow unconfined Eastern View Formation and Quaternary sediments, Unit 2 is the Eastern View Formation
Groundwater levels	Depth to groundwater ranges from <5 m to 120 m and averages 30 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the Quaternary Aquifer) ranges from 3 m to 30 m and averages 15 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Sink holes and karstic features in the TLA can provide point recharge features	Total estimated recharge (current period): 210,170 ML/yr
2 - Low Rainfall Recharge	The climate is semi arid and modern vertical recharge via rainfall is low (a few mm per year)	
3 – River Recharge	Lakes, wetlands and swamps are important point sources of recharge to unconfined sedimentary aquifers	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	Extraction from the Parilla Sands is limited to domestic and stock purposes due to the low yields	Average total extraction (current period): 1,369 ML/yr Total current entitlement: 4,068 ML/yr
B - Pumping (from unit 2)	All licences in the GMA are issued from the Tertiary Limestone Aquifer.	

C - Groundwater discharge to rivers	The Tertiary Limestone Aquifer is the primary source for groundwater extraction due to the relatively high bore yields and the low salinity groundwater located at shallow depths. It is generally used for domestic and stock, irrigation and urban supply (for Nhill and Kaniva).	
D - Groundwater discharge to springs	The Wimmera River is considered to have a high potential to receive groundwater discharge.	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	Local groundwater discharge to low lying areas within the interdunal systems of the Parilla Sands can support wetland systems, although these are sometimes perched and therefore not part of the regional aquifer.	
References: GWMW (2011) West Wimmera Groundwater Management Strategy; GWMW (2019) West Wimmera Groundwater Management Area Local Management Plan		

Table L-33 GMU conceptual model – Nullawarre WSPA

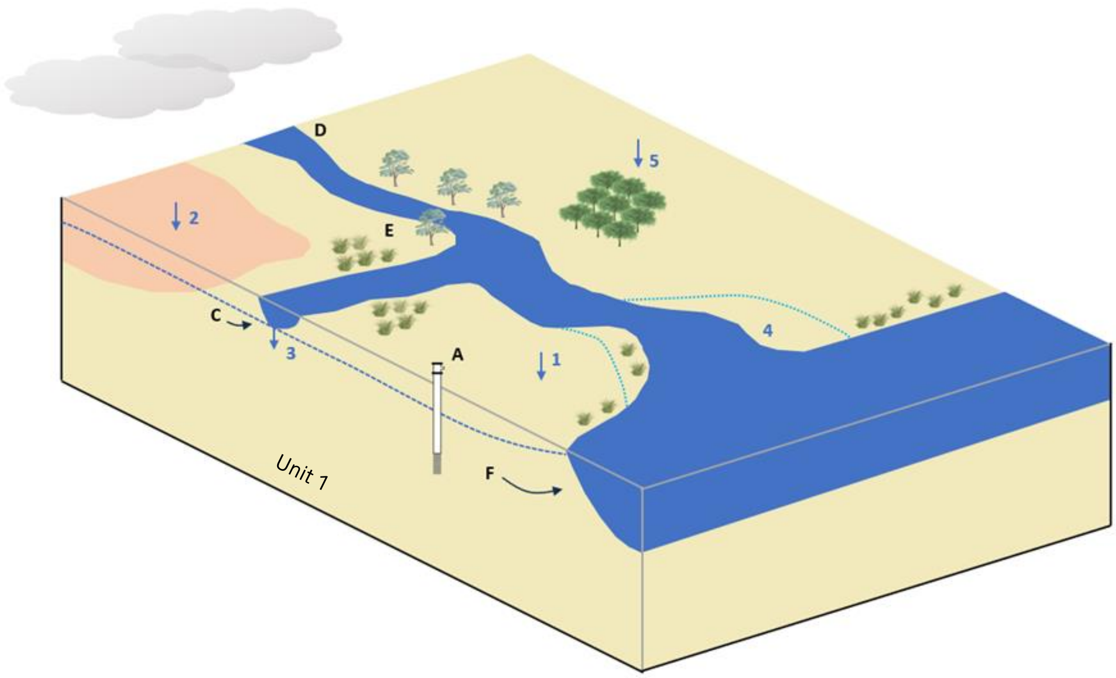
Nullawarre WSPA	***Unconfined Sedimentary Plains***
	
Unit description	Unit 1 is the shallow unconfined aquifer including the Port Campbell Limestone and Newer Volcanic basalts
Groundwater levels	Depth to groundwater ranges from <5 m to 50 m and averages 20 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper mid tertiary aquifer) ranges from 65 m to 140 m and averages 100 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Recharge to the Port Campbell Limestone occurs via direct infiltration of precipitation into the outcropping limestone, with sink holes and swallow holes often providing preferred pathways. Where the Newer Volcanics outcrop to the north there is expected to be higher recharge rates around volcanic eruption points and where the stony rise basalt deposits occur.	Total estimated recharge (current period): 135,928 ML/yr
2 - Low Rainfall Recharge	Infiltration rates are expected to be lower north of Brucknell Creek, because of weathered clay profiles of the basalt plains.	
3 – River Recharge	NA	
4 - Episodic Flood Inundation	NA	

5 - Irrigation Return	Additional recharge by infiltration of deep drainage from irrigation water is likely to occur in areas where irrigation activity is most concentrated.	
A - Pumping (from unit 1)	The limestone aquifer has been extensively developed for irrigation, stock watering and domestic water supply.	Average total extraction (current period): 11,103 ML/yr Total current entitlement: 20,194 ML/yr
B - Pumping (from unit 2)	NA	
C - Groundwater discharge to rivers	Brucknell Creek is expected to receive a significant volume of groundwater as baseflow and baseflow is also likely to occur in the lower reaches of the Hopkins River.	
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	Groundwater discharge may occur at topographically low areas.	
F - Groundwater throughflow out	Groundwater flows to the coast and discharge to the ocean through the coastal cliffs.	
References: SKM (1998) PAV determination for Nullaware; CDM Smith (2018) Long Term Water Resource Assessment – Groundwater; EcoMarkets (2010) Glenelg Hopkins CMA Groundwater Model		

Table L-34 GMU conceptual model – Shepparton Irrigation GMA

Shepparton Irrigation GMA ***Unconfined Sedimentary Plains***



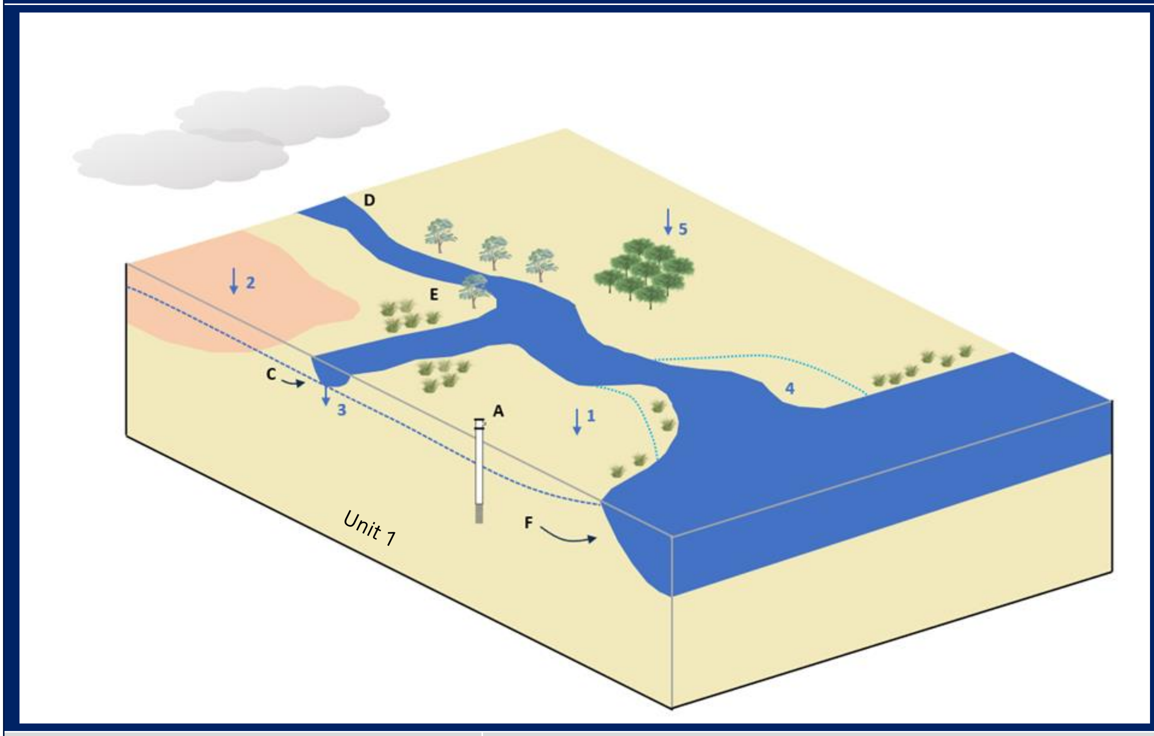
Unit description	Unit 1 is the Shepparton Formation
Groundwater levels	Depth to groundwater ranges from <5 m to 30 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary aquifer) ranges from 10 m to 88 m and averages 59 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Rainfall infiltration is a source of recharge to the shallow unconfined aquifer	Total estimated recharge (current period): 522,676 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	NA	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	Roughly 60% of the SIR GMA is irrigated and this results in significant deep drainage to the aquifer.	

A - Pumping (from unit 1)	Significant pumping from the shallow aquifer (Shepparton Fm) occurs across the GMA. The major use of shallow groundwater is for irrigation, however it is also used for commercial and stock and domestic purposes, and is extracted for salinity management.	Average total extraction (current period): 55,314 ML/yr Total current entitlement: 266,555 ML/yr
B - Pumping (from unit 2)	NA	
C - Groundwater discharge to rivers	In some locations shallow groundwater discharges to the river systems (Murray, Goulburn, and Campaspe Rivers and the Broken River and Creek), however this is a very small component of river flow, compared to the releases from regulated storages, which support these rivers. Shallow groundwater may also support riparian vegetation along some of these rivers, where water tables are high, particularly after river flooding.	Baseflow index: 0.53 Mean annual baseflow: 67.5 ML/y/km^2 (Gauge: 405232 GOULBURN RIVER at Mccoys BRIDGE)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	Shallow, saline watertables pose a threat to local wetlands and aquatic and terrestrial ecosystems in the GMA.	
F - Groundwater throughflow out	NA	
References: GMW (2015) Shepparton Irrigation Region Groundwater Management Area Local Management Plan		

Table L-35 GMU conceptual model - South West Limestone GMA

South West Limestone GMA ***Unconfined Sedimentary Plains***



Unit description	Unit 1 is the shallow unconfined and semi confined Gambier Limestone, Port Campbell Limestone and Portland Limestone
Groundwater levels	Depth to groundwater ranges from <5 m to 160 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper mid-tertiary aquifer) ranges from 0 m to 210 m and averages 110 m within the GMU.

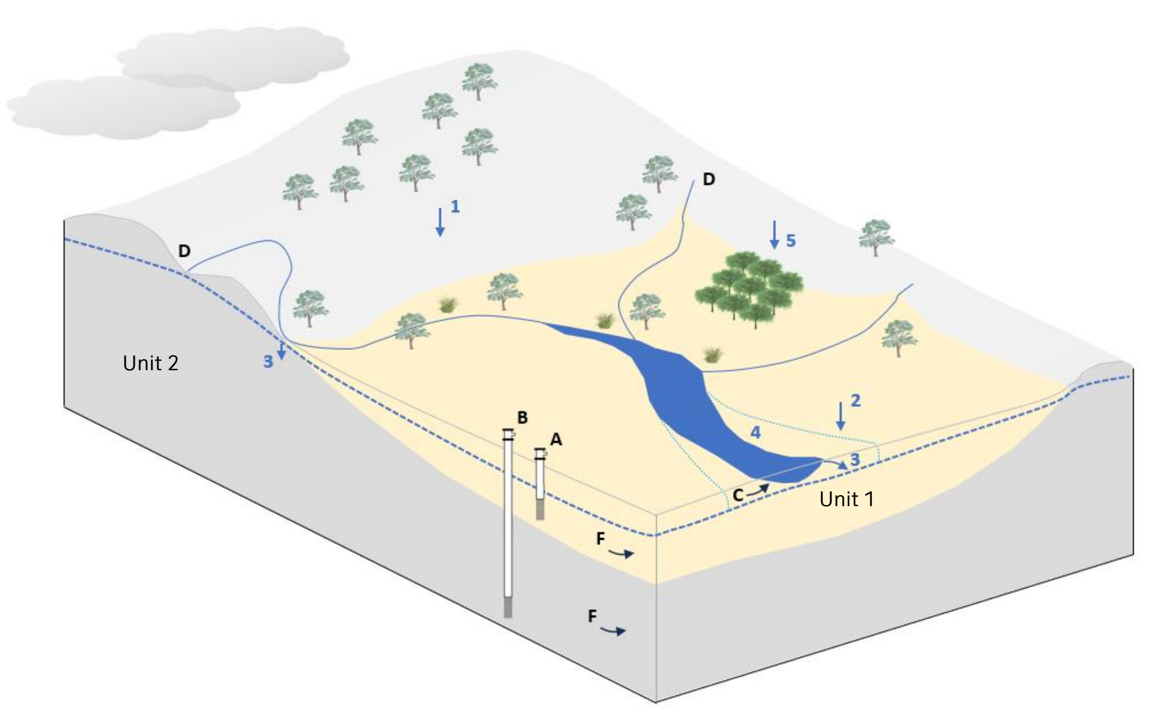
Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Recharge to the aquifer is via direct rainfall infiltration (where the aquifer is at the surface) or via indirect rainfall infiltration where it is overlain by shallow aquifers.	Total estimated recharge (current period): 1,681,837 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	Recharge to the aquifer from surface water feature may occur when groundwater levels decline below the creek/wetland as there is a high degree of connection between groundwater and surface water.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	Additional recharge by infiltration of deep drainage from irrigation water is likely to occur in areas where irrigation activity is most concentrated.	

A - Pumping (from unit 1)	The limestone aquifer has been extensively developed for irrigation, stock watering and domestic water supply. The area of most extensive use is along the coast between Port Fairy and Port Campbell.	Average total extraction (current period): 30,801 ML/yr Total current entitlement: 83,330 ML/yr
B - Pumping (from unit 2)	NA	

C - Groundwater discharge to rivers	In general, the lower reaches of all the identified rivers in the GMA are likely to receive baseflow contributions, as well as the upper reaches of the Crawford and Curdies Rivers. In particular, the lower reaches of the Moyne and Eumeralla Rivers are likely to receive significant contributions of groundwater.	Baseflow index: 0.44 Mean annual baseflow: 27.5 ML/y/km^2 (Gauge: 236209 Hopkins River at Hopkins Falls) Baseflow index: 0.41 Mean annual baseflow: 109.7 ML/y/km^2 (Gauge: 237202 Fitzroy River at Heywood) Baseflow index: 0.70 Mean annual baseflow: 73.4 ML/y/km^2 (Gauge: 237205 Darlot Creek at Homerton Bridge) Baseflow index: 0.37 Mean annual baseflow: 57.7 ML/y/km^2 (Gauge: 236205 Merri River at Woodford) Baseflow index: 0.69 Mean annual baseflow: 118.2 ML/y/km^2 (Gauge: 238233 Moleside Creek at Kentbruck) Baseflow index: 0.29 Mean annual baseflow: 74.7 ML/y/km^2 (Gauge: 238230 Stokes River at Teakettle) Baseflow index: 0.46 Mean annual baseflow: 34.6 ML/y/km^2 (Gauge: 238206 Glenelg River at Dartmoor) Baseflow index: 0.40 Mean annual baseflow: 19.7 ML/y/km^2 (Gauge: 236210 Hopkins River at Framlingham) Baseflow index: 0.46 Mean annual baseflow: 25.0 ML/y/km^2 (Gauge: 236216 Mount Emu Creek at Taroon (Ayrford Road Bridge)) Baseflow index: 0.44 Mean annual baseflow: 116.1 ML/y/km^2 (Gauge: 236212 Brucknell Creek at Cudgee)

		Baseflow index: 0.49 Mean annual baseflow: 54.6 ML/y/km^2 (Gauge: 237206 Eumeralla River at Codrington) Baseflow index: 0.33 Mean annual baseflow: 68.7 ML/y/km^2 (Gauge: 237200 Moyne River at Toolong) Baseflow index: 0.75 Mean annual baseflow: 50.6 ML/y/km^2 (Gauge: 237209 Darlot Creek at Myamyn) Baseflow index: 0.40 Mean annual baseflow: 84.8 ML/y/km^2 (Gauge: 237207 Surry River at Heathmere) Baseflow index: 0.34 Mean annual baseflow: 106.3 ML/y/km^2 (Gauge: 235203 Curdies River at Curdie) Baseflow index: 0.29 Mean annual baseflow: 131.3 ML/y/km^2 (Gauge: 235237 Scotts Creek at Curdie (Digneys Bridge)) Baseflow index: 0.31 Mean annual baseflow: 142.1 ML/y/km^2 (Gauge: 235223 Scotts Creek at Scotts Creek)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	The Glenelg Estuary and Long Swamp are likely to receive groundwater discharge and are significant wetlands in the area.	
F - Groundwater throughflow out	Groundwater discharge is via throughflow to the coast.	
References: SRW (2015) South West Limestone Local Management Plan; EcoMarkets (2010) Glenelg Hopkins CMA Groundwater Model		

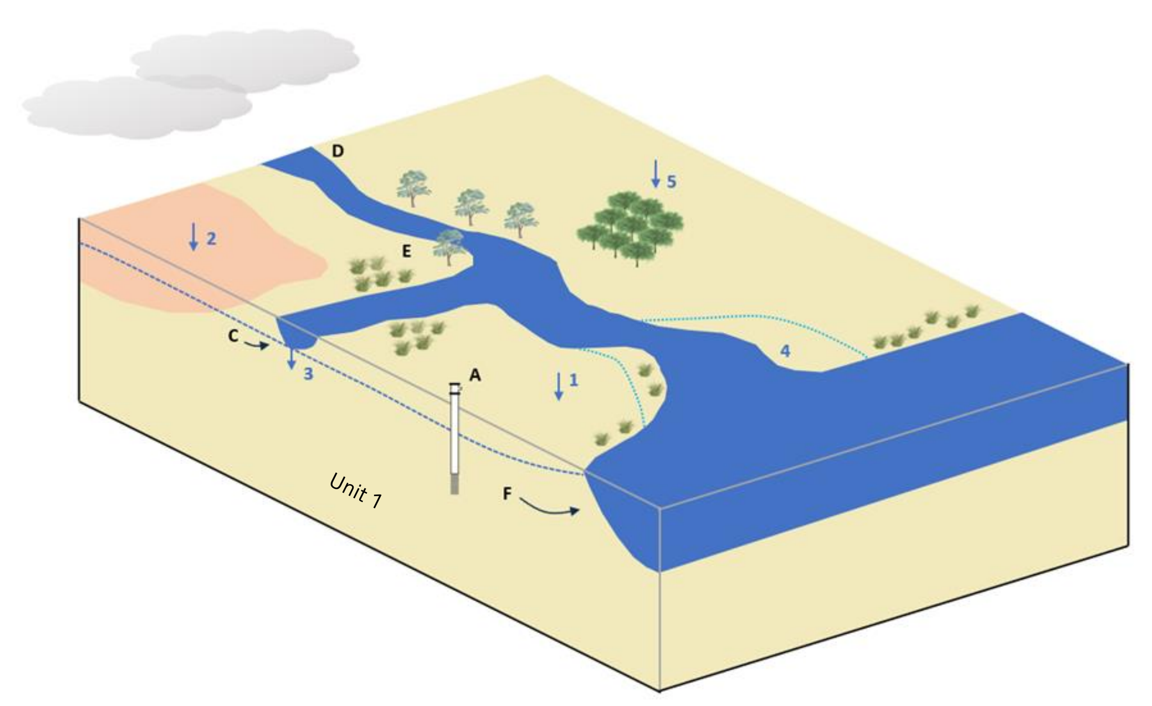
Table L-36 GMU conceptual model – Strathbogie GMA

Strathbogie GMA	***Unconfined Sedimentary Valleys***
	
Unit description	Unit 1 is the alluvial aquifer and Unit 2 is the bedrock
Groundwater levels	Depth to groundwater ranges from <5 m to 170 m and averages 20 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary aquifer) ranges from 0 m to 60 m and averages 10 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	High rainfall recharge occurs in the uplands part of the GMU.	Total estimated recharge (current period): 422,297 ML/yr
2 - Low Rainfall Recharge	Rainfall recharge is lower on the alluvial plain.	
3 – River Recharge	It is likely that some recharge to the aquifers occurs from river leakage.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	The alluvial aquifer is dominated by low permeability clays and silts with limited sand deposits and it is developed mainly for stock and domestic use.	Average total extraction (current period): 412 ML/yr Total current entitlement: 1,109 ML/yr
B - Pumping (from unit 2)	The bedrock aquifer comprises both volcanic (including granitic) and sedimentary rock types. The aquifer is typically used for stock and domestic supply, although there are also a number of licensed bores.	

C - Groundwater discharge to rivers	Groundwater discharges into local stream systems. Where discharge occurs it is typically in valley bottoms where the water table is close to the surface, or at a break of slope, or where faults and fissures in the rock appear at the surface.	Baseflow index: 0.50 Mean annual baseflow: 129.9 ML/y/km^2 (Gauge: 405228 Hughes Creek at Tarcombe Road)
D - Groundwater discharge to springs	Groundwater discharges as springs on the Strathbogie uplands. Where discharge occurs it is typically in valley bottoms where the water table is close to the surface, or at a break of slope, or where faults and fissures in the rock appear at the surface.	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	NA	
References: GMW (2013) Strathbogie GMA Local Management Plan		

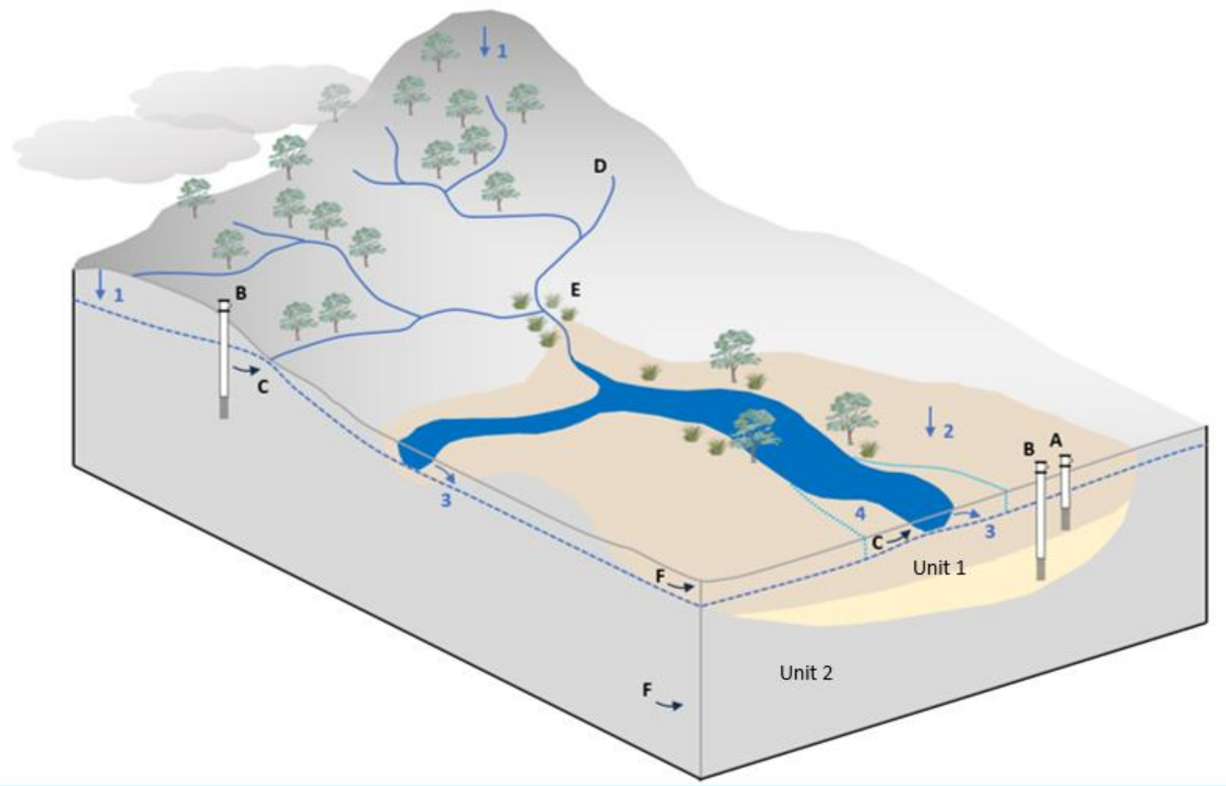
Table L-37 GMU conceptual model – Tarwin GMA

Tarwin GMA	***Unconfined Sedimentary Plains***
	
Unit description	Unit 1 is the shallow unconfined aquifer of the aeolian dune deposit of Quaternary age
Groundwater levels	Depth to groundwater ranges from <5 m to 50 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary aquifer) ranges from 2 m to 50 m and averages 25 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	The more elevated dunal areas contribute the most rainfall recharge to the aquifer.	Total estimated recharge (current period): 7,993 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	There are no rivers in this GMA.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	The reliance on groundwater for supplementing rainwater, particularly for domestic and garden use has resulted in a high density of bores in the Venus Bay area. There is a much lower density of bores outside of this area.	Average total extraction (current period): 11 ML/yr Total current entitlement: 49 ML/yr
B - Pumping (from unit 2)	NA	
C - Groundwater discharge to rivers	There are no rivers in this GMA.	

D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	Groundwater throughflow to the ocean and inlet is the primary discharge mechanism.	
References: SRW (2013) Tarwin Groundwater Catchment Statement; SKM (1998) PAV for the Tarwin GMA		

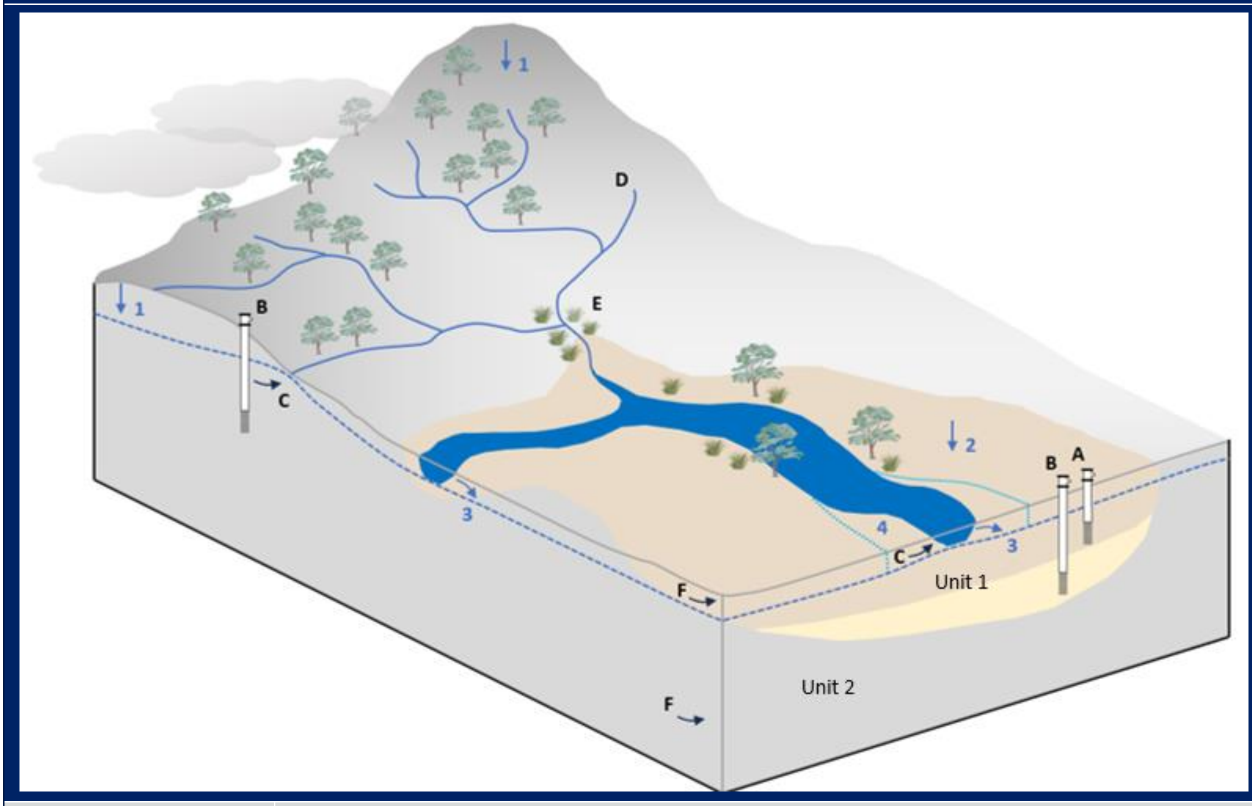
Table L-38 GMU conceptual model - Upper Goulburn GMA

Upper Goulburn GMA *Valleys*		***Highland and Sedimentary Upland***
		
Unit description	Unit 1 is the Quaternary alluvial sediments, Unit 2 is the fractured bedrock	
Groundwater levels	Depth to groundwater ranges from <5 m to 250 m and averages 40 m within the GMU.	
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the quaternary alluvium aquifer) ranges from 0 m to 19 m and averages 7 m within the GMU.	
Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Rainfall recharge is highest in the uplands.	Total estimated recharge (current period): 839,437 ML/yr
2 - Low Rainfall Recharge	Rainfall is lower in the valleys.	
3 – River Recharge	River recharge is likely to occur in this GMU.	
4 - Episodic Flood Inundation	The alluvial aquifer is recharged from the Goulburn River, mainly during flooding events and as run off from the upland bedrock.	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	Some extraction from Quaternary aquifer where yields are sufficient.	Average total extraction (current period): 715 ML/yr Total current entitlement: 4,938 ML/yr
B - Pumping (from unit 2)	Bedrock aquifer yields are variable but the aquifer still provides an important local groundwater resource for upland towns (e.g. Kinglake) where it is the primary source of domestic supply, irrigation and bottled water.	

C - Groundwater discharge to rivers	Groundwater flow in the alluvial sands and gravels along the Goulburn River will generally discharge into the river, except during times of flood. Groundwater discharge to streams in the headwaters is temporal (with streams ceasing to flow seasonally).	Baseflow index: 0.62 Mean annual baseflow: 178.7 ML/y/km^2 (Gauge: 405231 King Parrot Creek at Flowerdale)
D - Groundwater discharge to springs	Groundwater discharge to surface in the lower parts of the Yea and King Parrot catchments (e.g. Flowerdale on the King Parrot Creek) illustrated by spring activity and pressure levels in artesian bores.	
E - Groundwater discharge to wetlands	A number of nationally significant peat wetlands occur in the Upper Goulburn area.	
F - Groundwater throughflow out	NA	
References: GMW (2013) Upper Goulburn GMA Local Management Plan		

Table L-39 GMU conceptual model - Upper Murray GMA

Upper Murray GMA	***Highland and Sedimentary Upland Valleys***



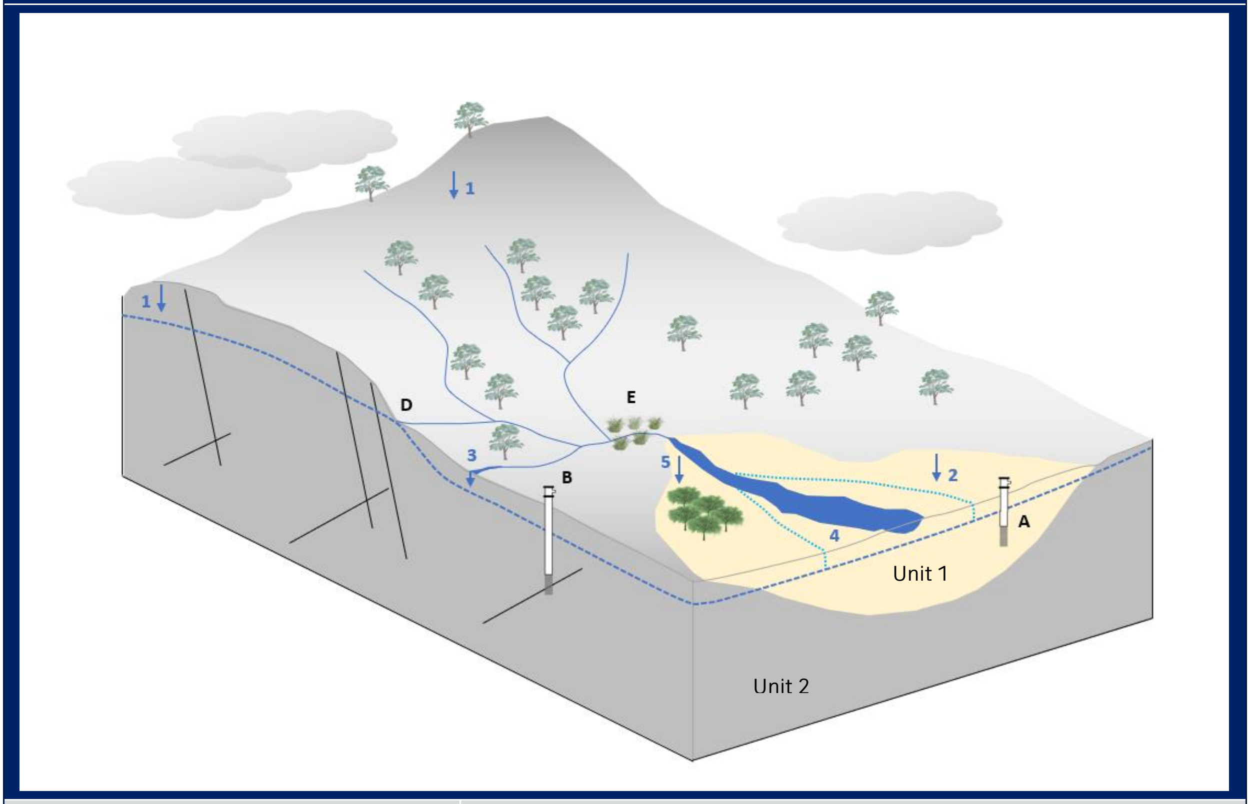
Unit description	Unit 1 is the Quaternary alluvial sediments, Unit 2 is the fractured bedrock
Groundwater levels	Depth to groundwater ranges from <5 m to 280 m and averages 60 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the quaternary alluvium aquifer) ranges from 0 m to 20 m and averages 5 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	The majority of recharge to the bedrock aquifers in the GMA originates from rainfall, although a significant portion of rainfall is runoff and does not infiltrate. Annual average recharge in the Hume and Indi management zones is approximately double that estimated in the Hume zone.	Total estimated recharge (current period): 4,465,528 ML/yr
2 - Low Rainfall Recharge	Less rainfall recharge in the Indi management zone area.	
3 – River Recharge	River recharge is likely to occur in this GMU.	
4 - Episodic Flood Inundation	The alluvial aquifer is recharged from the Upper Murray River, mainly during flooding events and as run off from the upland bedrock.	
5 - Irrigation Return	NA	

A - Pumping (from unit 1)	Bore yields above 5-10 L/sec can be obtained from the alluvial aquifer.	Average total extraction (current period): 510 ML/yr Total current entitlement: 3,185 ML/yr
B - Pumping (from unit 2)	Bore yields from the bedrock aquifers are generally low (typically less than 0.5 L/sec) however the aquifer provides an important local groundwater resource for rural households and it is also used to support industrial, commercial and the agricultural (irrigation) industry	
C - Groundwater discharge to rivers	Hydrographs from observation bores situated throughout the Upper Murray Valley shows the Upper Murray River and its tributaries are fed by groundwater. Groundwater discharge (baseflow) is a major component of total river flow within the Upper Murray GMA.	Baseflow index: 0.64 Mean annual baseflow: 270.7 ML/y/km^2 (Gauge: 401203 Mitta Mitta River at Hinnomunjie) Baseflow index: 0.66 Mean annual baseflow: 624.2 ML/y/km^2 (Gauge: 401216 Big River at Jokers Creek) Baseflow index: 0.70 Mean annual baseflow: 624.2 ML/y/km^2 (Gauge: 401210 Snowy Creek at Below Granite Flat) Baseflow index: 0.71 Mean annual baseflow: 1048.4 ML/y/km^2 (Gauge: 401231 Snowy Creek at D/S Lightning Ck) Baseflow index: 0.60 Mean annual baseflow: 50.8 ML/y/km^2 (Gauge: 401202 Mitta Mitta River at Mitta Mitta)
D - Groundwater discharge to springs	Groundwater discharges to springs in the valley bottoms where the watertable is close to the surface, at breaks of slope and where faults and fissures in the rock appear at the surface.	
E - Groundwater discharge to wetlands	Wetlands occur on the valley floor associated with waterways.	
F - Groundwater throughflow out	NA	
References: GMW (2014) Upper Murray GMA Local Management Plan		

Table L-40 GMU conceptual model – Upper Ovens GMA

Upper Ovens GMA	***Sedimentary Upland Valleys***



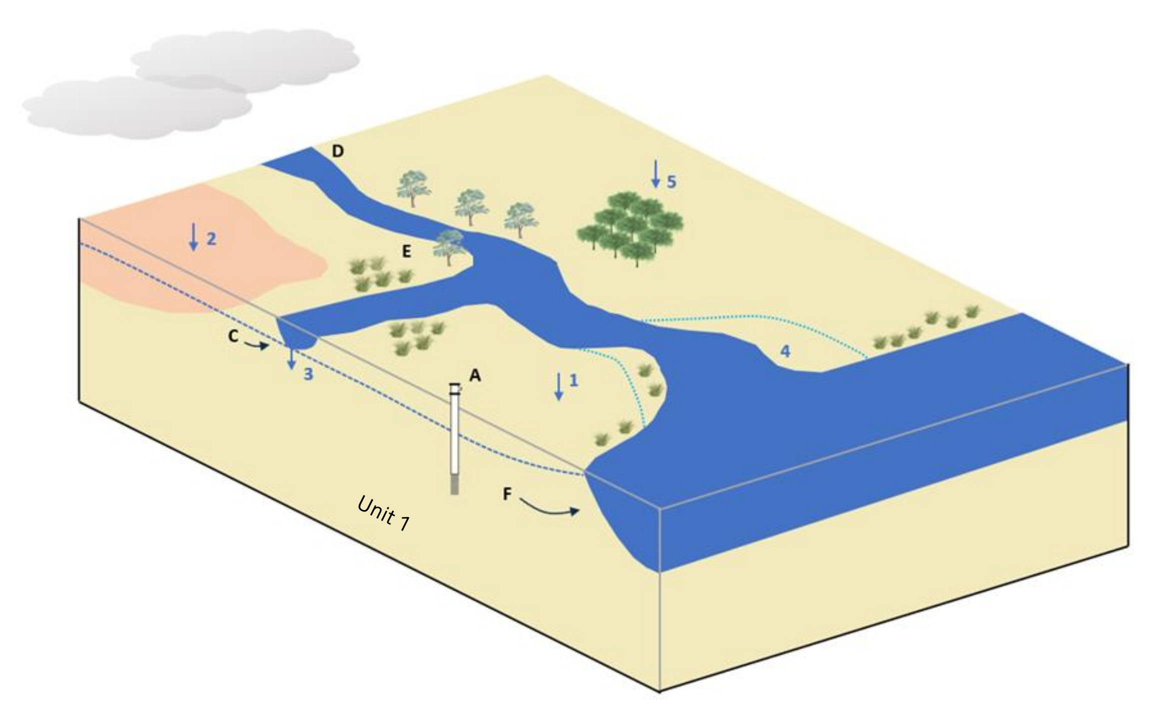
Unit description	Unit 1 is the alluvial sands and gravels and Unit 2 is the fractured bedrock aquifer
Groundwater levels	Depth to groundwater ranges from <5 m to 330 m and averages 70 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the quaternary alluvium aquifer) ranges from 0 m to 9 m and averages 2 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Rainfall recharge is a major contributor to the aquifers.	Total estimated recharge (current period): 796,286 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	River losses to groundwater are expected to occur in some places and under certain conditions, however it should be noted that data in the Myrtleford area between 1980 and 2009 indicated that the watertable never dropped below the level of the stream at this location (thus preventing losing river conditions).	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	There is significant irrigation development along the river flats bordering the ovens river and returns to the aquifer would be expected.	

A - Pumping (from unit 1)	The unconsolidated alluvial aquifer is the primary unit for groundwater extraction.	Average total extraction (current period): 978 ML/yr Total current entitlement: 3,498 ML/yr
B - Pumping (from unit 2)	The fractured rock aquifer is far less utilised, with groundwater mainly used for domestic and stock purposes.	
C - Groundwater discharge to rivers	Significant groundwater discharge to surfacewater occurs in this GMU.	Baseflow index: 0.67 Mean annual baseflow: 589.4 ML/y/km^2 (Gauge: 403244 Ovens River at Harrietville)
D - Groundwater discharge to springs	Discharge from the bedrock aquifer to the surface occurs as springs associated with faults.	
E - Groundwater discharge to wetlands	Groundwater discharging as baseflow or springs can support GDEs including wetlands in this GMU.	
F - Groundwater throughflow out	NA	
References: GMW (2011) Upper Ovens River Water Supply Protection Area Water Management Plan		

Table L-41 GMU conceptual model - Wa De Lock GMA

Wa De Lock GMA	***Unconfined Sedimentary Plains***



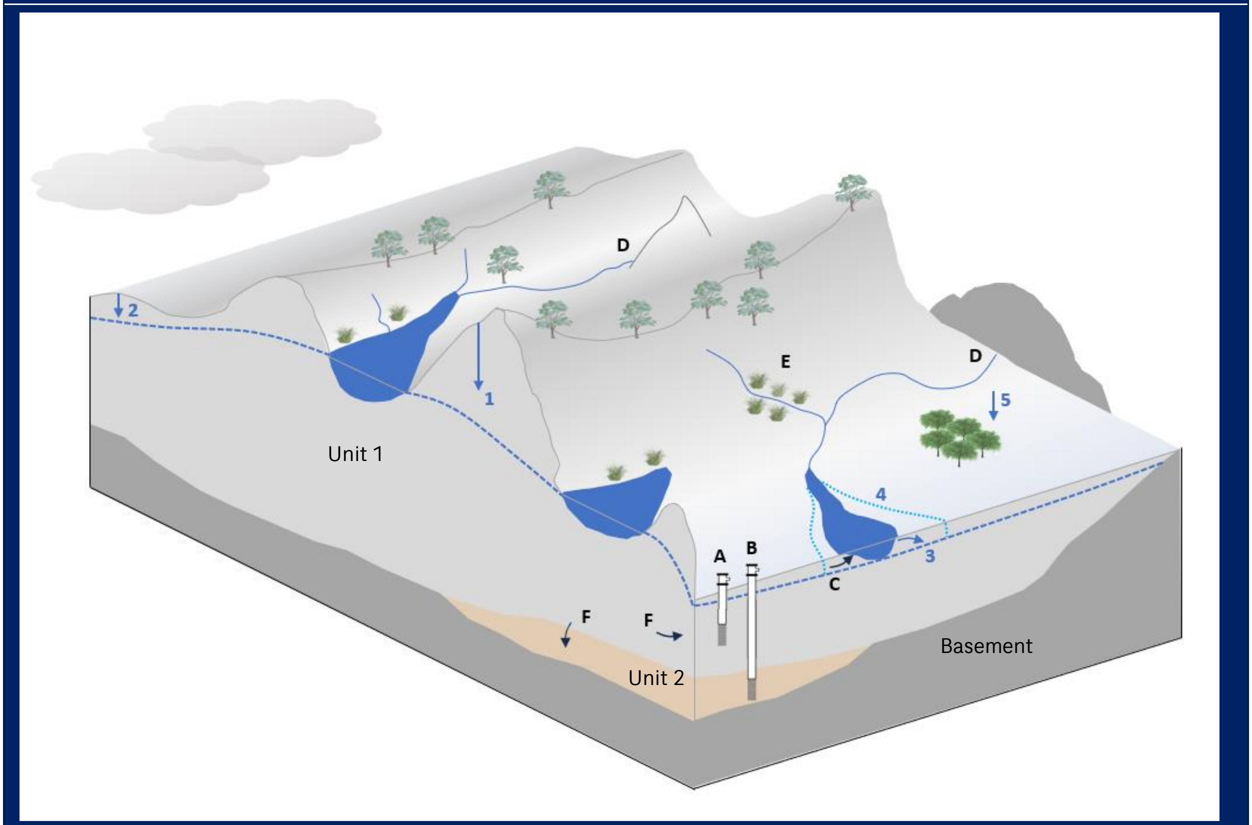
Unit description	Unit 1 is the shallow unconfined aquifers in the Haunted Hills, Pleistocene Prior Stream Deposits and Recent Alluvials
Groundwater levels	Depth to groundwater ranges from <5 m to 80 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary aquifer) ranges from 1 m to 55 m and averages 25 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Recharge to the aquifer occurs via infiltration of rainfall	Total estimated recharge (current period): 98,711 ML/yr
2 - Low Rainfall Recharge	NA	
3 – River Recharge	Surface water leakage to groundwater is expected to occur from the Freestone Creek which is connected with the shallow alluvial aquifer. Recommendations to consider the two water sources as one during low river flows have been made based on the connectivity.	
4 - Episodic Flood Inundation	Groundwater recharge is thought to be minimal from the Macalister and Avon Rivers apart from during short lived periods of high river levels.	
5 - Irrigation Return	Recharge to the aquifer is believed to occur by infiltration of irrigation accessions.	

A - Pumping (from unit 1)	Groundwater from the prior stream deposits and the Recent alluvium, provides the resource for irrigation and urban supply (Briagalong and Boisdale).	Average total extraction (current period): 6,818 ML/yr Total current entitlement: 22,401 ML/yr
B - Pumping (from unit 2)	NA	
C - Groundwater discharge to rivers	Groundwater discharge to surfacewater is expected to occur to the Freestone Creek which is connected with the shallow alluvial aquifer. Recommendations to consider the two water sources as one during low river flows have been made based on the connectivity. Groundwater discharge to the Macalister and Avon Rivers is expected to occur over most of their length in the GMA.	Baseflow index: 0.22 Mean annual baseflow: 115.0 ML/y/km^2 (Gauge: 225218 Freestone Creek at Briagalong) Baseflow index: 0.28 Mean annual baseflow: 104.1 ML/y/km^2 (Gauge: 225201 Avon River at Stratford) Baseflow index: 0.58 Mean annual baseflow: 63.7 ML/y/km^2 (Gauge: 225247 Macalister River at Riverslea) Baseflow index: 0.44 Mean annual baseflow: 62.4 ML/y/km^2 (Gauge: 225234 Avon River at Clydebank (Chinn's Bridge))
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	NA	
References: SRW (2014) Catchment Statement for Central Gippsland and Moe Groundwater Catchments; SKM (1998) PAV for the Wa De Lock GMA		

Table L-42 GMU conceptual model - Wandin Yallock GMA

Wandin Yallock GMA ***Unconfined Volcanics***



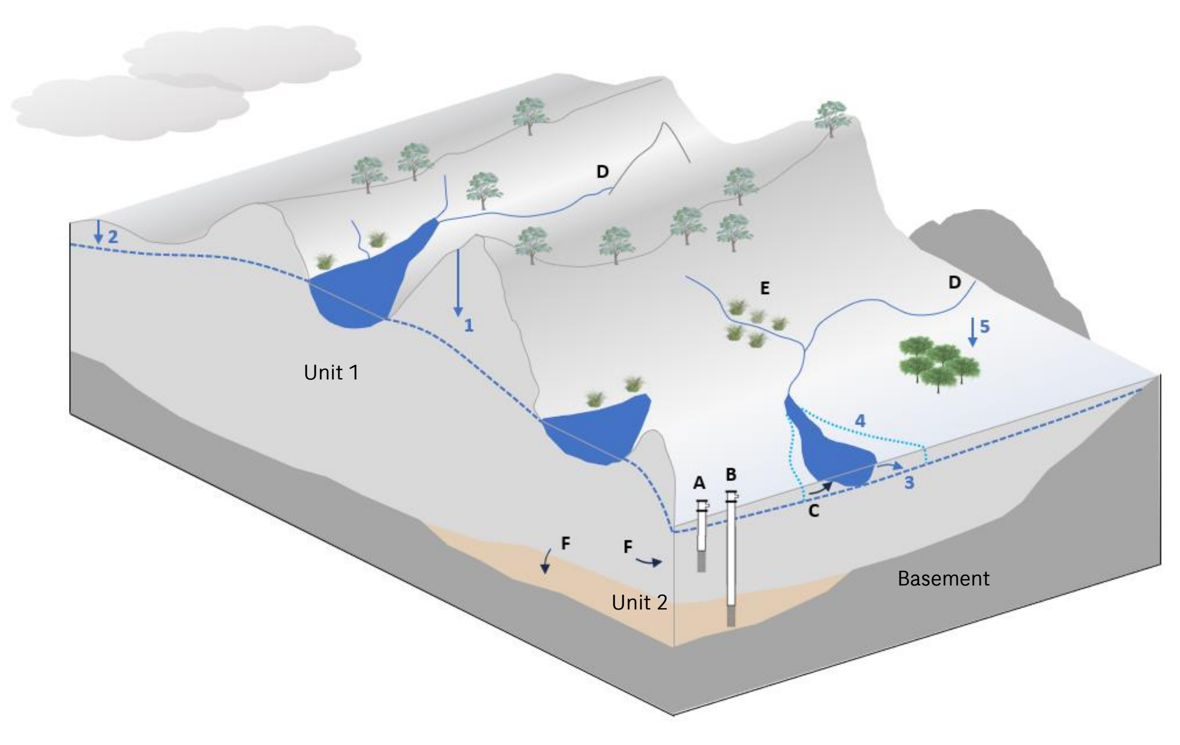
Unit description	Unit 1 is the volcanic aquifer (UTB), Unit 2 is the deep lead (UTAF)
Groundwater levels	Depth to groundwater ranges from <5 m to 70 m and averages 30 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary basalt aquifer) ranges from 0 m to 2 m and averages 0.5 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Higher rainfall recharge occurs around eruption centres.	Total estimated recharge (current period): 20,800 ML/yr
2 - Low Rainfall Recharge	Lower rainfall recharge occurs on weathered basalt plains.	
3 – River Recharge	Rivers act as sources of groundwater recharge during high streamflow periods.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	Groundwater sourced from the Older Volcanic aquifer is used for both the irrigation of crops and for stock and domestic uses.	Average total extraction (current period): 553 ML/yr Total current entitlement: 2,606 ML/yr
B - Pumping (from unit 2)	NA	

C - Groundwater discharge to rivers	Groundwater discharges to streams in the base of the valleys where the streams are located adjacent to the boundary of the aquifer (e.g. Wandin Yallock and Stony Creeks).	
D - Groundwater discharge to springs	Groundwater discharges as contact springs where basalt abuts outcropping basement.	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	NA	
References: SKM (1998) Wandin Yallock GMA PAV report; SRW (2104) East Port Phillip Bay Groundwater Catchment Statement		

Table L-43 GMU conceptual model – Warrion WSPA

Warrion WSPA	***Unconfined Volcanics***

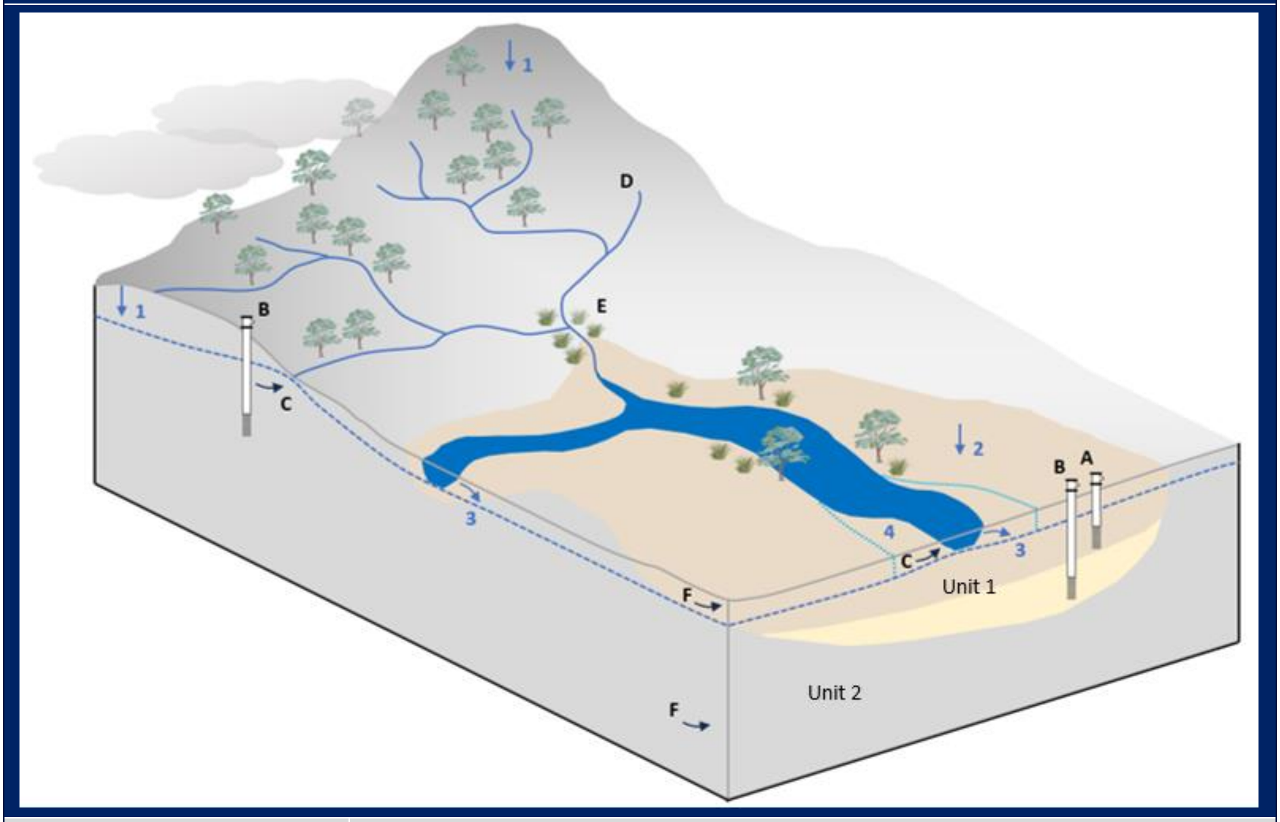


Unit description	Unit 1 is the volcanic aquifer (UTB), Unit 2 is the deep lead (UTAF)
Groundwater levels	Depth to groundwater ranges from <5 m to 120 m and averages 10 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary basalt aquifer) ranges from 0 m to 178 m and averages 41 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	High recharge occurs around volcanic cones and stony rises.	Total estimated recharge (current period): 53,240 ML/yr
2 - Low Rainfall Recharge	Lower recharge occurs across basalt plains.	
3 – River Recharge	NA	
4 - Episodic Flood Inundation	Some lakes act as recharge areas (e.g. Lake Colac).	
5 - Irrigation Return	Groundwater extraction is mainly for irrigation and some returns would be expected.	
A - Pumping (from unit 1)	Newer Volcanics is the primary aquifer used for extraction. The dominant water use is associated with dairy farming.	Average total extraction (current period): 2,847 ML/yr Total current entitlement: 10,742 ML/yr
B - Pumping (from unit 2)	Minor development of the underlying Hanson Plains Sands, which is limited in extent and more saline than the volcanics.	

C - Groundwater discharge to rivers	NA	Baseflow index: 0.50 Mean annual baseflow: 129.9 ML/y/km^2 (Gauge: 405228 Hughes Creek at Tarcombe Road)
D - Groundwater discharge to springs	Spring discharge occurs at break of slope, stony rises and at contact points of basalt flows.	
E - Groundwater discharge to wetlands	Wetlands and lakes intersect groundwater in low lying areas. Lake Corangamite is a discharge lake.	
F - Groundwater throughflow out	NA	
References: SRW (2010) Groundwater Management Plan Warrion Water Supply Protection Area, CDM Smith (2018) Long Term Water Resource Assessment – Groundwater, Phase 2.		

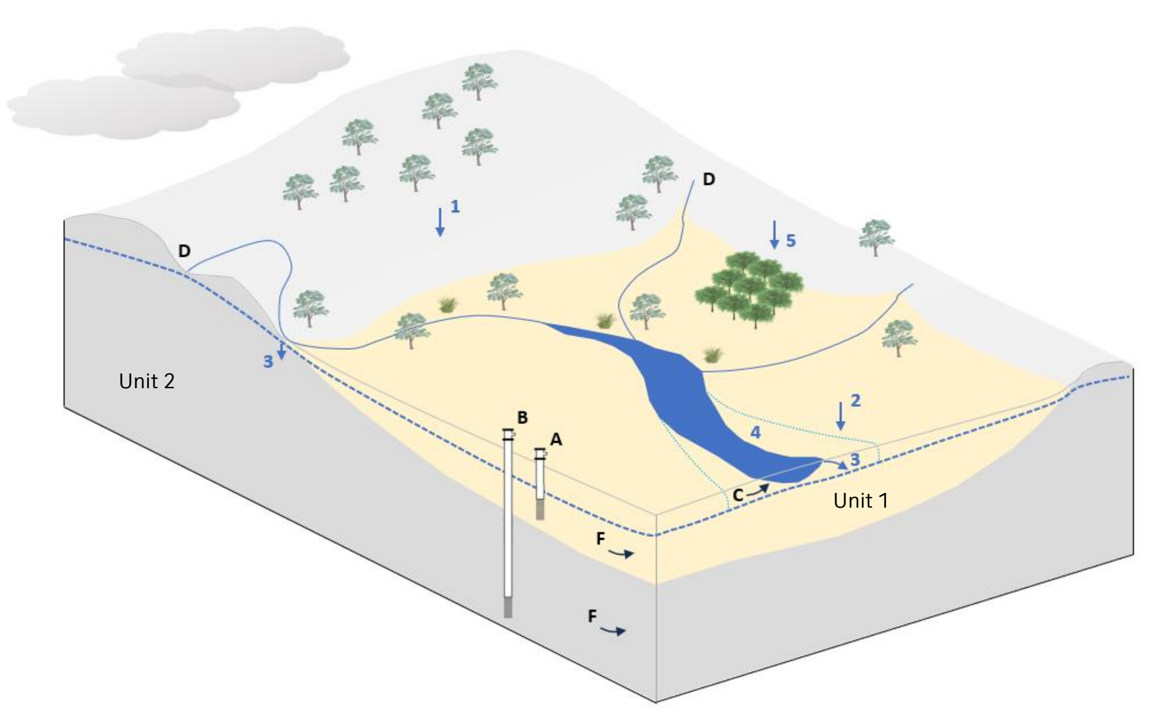
Table L-44 GMU conceptual model – West Goulburn GMA

West Goulburn GMA		***Highland and Sedimentary Upland Valleys***
		
Unit description	Unit 1 is the Quaternary alluvial sediments, the Shepparton Formation, the Newer Volcanics and the Deep Lead, Unit 2 is the fractured bedrock	
Groundwater levels	Depth to groundwater ranges from <5 m to 190 m and averages 10 m within the GMU.	
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the upper tertiary/quaternary aquifer) ranges from 0 m to 30 m and averages 5 m within the GMU.	
Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Rainfall recharge occurs in the areas of bedrock outcrop in the south and the zone of greatest recharge is around Puckapunyal.	Total estimated recharge (current period): 488,593 ML/yr
2 - Low Rainfall Recharge	In the north, recharge occurs through rainfall infiltrating the Shepparton Formation then leaking to underlying aquifers.	
3 – River Recharge	NA	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	NA	
A - Pumping (from unit 1)	The Deep Lead is high yield relative to the more variable Shepparton Formation. The basalt is not considered a significant resource.	Average total extraction (current period): 3,509 ML/yr.

B - Pumping (from unit 2)	Bore yields in the fractured bedrock are variable but this is the main aquifer used in the south of the GMA.	Total current entitlement: 95,132 ML/yr
C - Groundwater discharge to rivers	Groundwater discharge to waterways occurs in this GMU.	Baseflow index: 0.38 Mean annual baseflow: 90.4 ML/y/km^2 (Gauge: 405212 Sunday Creek at Tallarook)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	Groundwater discharge to wetlands occurs in this GMU.	
F - Groundwater throughflow out	The greatest output from the GMU is throughflow to the Murray Valley Deep Lead system.	
References: GMW (2017) West Goulburn GMA Local Management Plan,		

Table L-45 GMU conceptual model – Wy Yung GMA

Wy Yung GMA	***Unconfined Sedimentary Valleys***

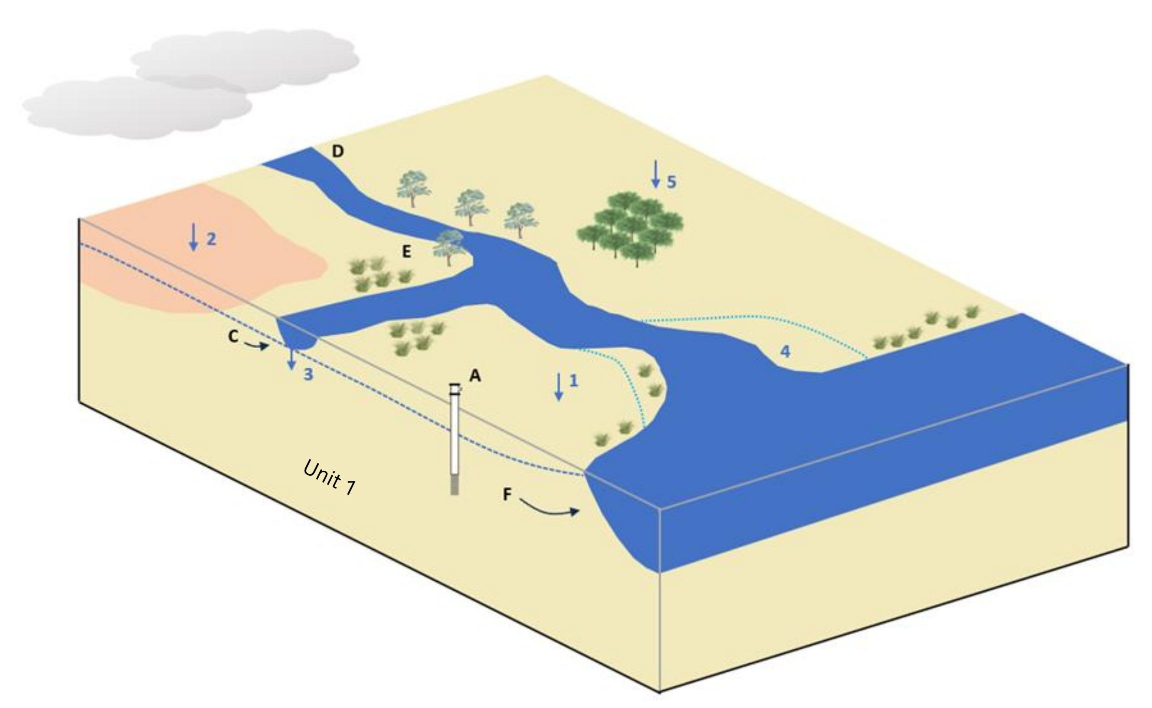


Unit description	Unit 1 is the Quaternary Mitchell River Gravels and Unit 2 is the Gippsland Basin units.
Groundwater levels	Depth to groundwater ranges from <5 m to 20 m and averages <5 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the quaternary alluvium aquifer) ranges from 0 m to 50 m and averages 20 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	NA	Total estimated recharge (current period): 7,854 ML/yr
2 - Low Rainfall Recharge	Diffuse recharge to the aquifer occurs via rainfall across the GMU extent.	
3 – River Recharge	There is a high degree of connection between the river and the aquifer - the river is a key recharge feature. Recharge from the river to the aquifer is most common in the upper reaches of the aquifer and everywhere along the reach during high flows when river levels are elevated.	
4 - Episodic Flood Inundation	The river plays an important role in recharging the aquifer during floods, which can periodically replenish the aquifer to its maximum level, given its limited storage.	

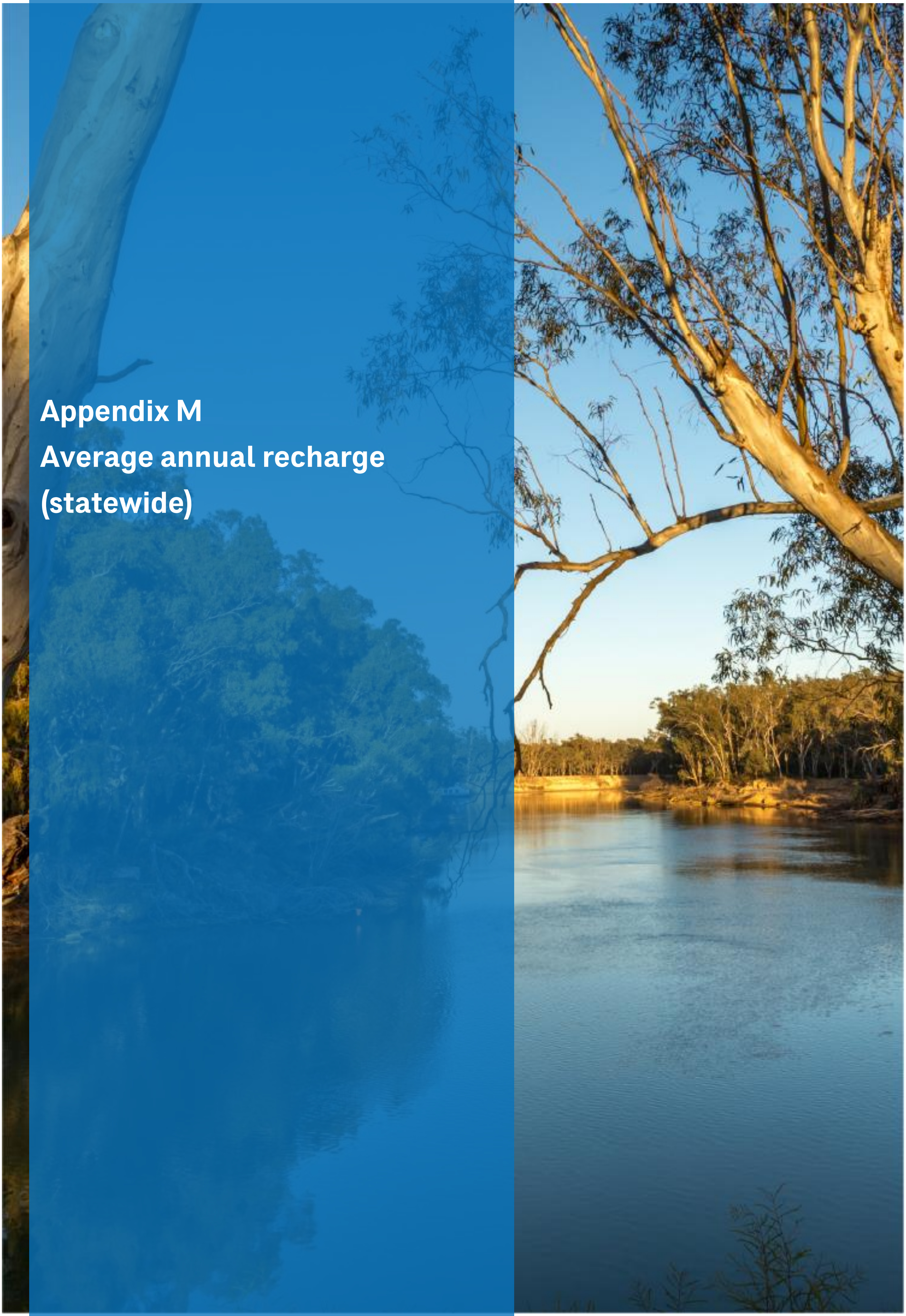
5 - Irrigation Return	Diffuse recharge to the aquifer occurs via irrigation accessions however, the magnitude of irrigation recharge has been influenced by the efficiency of irrigation practices in the last 30-40 years, leading to a reduction in irrigation recharge over time.	
A - Pumping (from unit 1)	Groundwater from the alluvial aquifer is primarily used as a back-up water supply for irrigation and will generally be used when restrictions are placed on surface water diversions.	Average total extraction (current period): 680 ML/yr Total current entitlement: 5,748 ML/yr
B - Pumping (from unit 2)	NA	
C - Groundwater discharge to rivers	There is a high degree of connection between the river and the aquifer. Overall, (in net terms) the predominant direction and magnitude of flux is from the aquifer to the river, and this discharge supports low flows in the river.	
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	NA	
F - Groundwater throughflow out	NA	
References: CDM Smith (2018) Long Term Water Resource Assessment		

Table L-46 GMU conceptual model – Yangery WSPA

Yangery WSPA	***Unconfined Sedimentary Plains***
	
Unit description	Unit 1 is the shallow unconfined aquifer including Quaternary sediments, Newer Volcanic basalt, Hanson Plain Sands and the Port Campbell Limestone
Groundwater levels	Depth to groundwater ranges from <5 m to 10 m and averages <5 m within the GMU.
Watertable aquifer thickness	Watertable aquifer thickness (i.e. the xxx aquifer) ranges from 1 m to 145 m and averages 40 m within the GMU.

Process	**Description of Process**	**Quantification of Process**
1 - High Rainfall Recharge	Recharge occurs via rainfall infiltration, which is enhanced in areas of thin soil cover, such as the volcanic vents, the stony rise basalts and the dune sands and limestones. Karst features in the outcropping Port Campbell Limestone also provide major conduits for watertable aquifer recharge.	Total estimated recharge (current period): 48,948 ML/yr
2 - Low Rainfall Recharge	The volcanics often have deeply weathered profiles, particularly the older sheet flows and the infiltration rate is somewhat suppressed in these areas.	
3 – River Recharge	Groundwater and surface water interaction is likely to occur in the area as the aquifer is shallow and unconfined.	
4 - Episodic Flood Inundation	NA	
5 - Irrigation Return	Irrigation is a key use of groundwater in the area and some returns of irrigation accessions is likely a source of recharge.	

A - Pumping (from unit 1)	Groundwater bores extract from the shallow unconfined aquifer (Newer Volcanic Basalts and Port Campbell Limestone).	Average total extraction (current period): 3,425 ML/yr Total current entitlement: 12,123 ML/yr
B - Pumping (from unit 2)	NA	
C - Groundwater discharge to rivers	Groundwater discharge to drainage lines is likely and baseflow assessments indicate relatively large baseflow in the Moyne River, Merri River and Hopkins River.	Baseflow index: 0.56 Mean annual baseflow: 235.7 $ML/y/km^2$ (Gauge: 235224 Gellibrand River @ Burrupa)
D - Groundwater discharge to springs	NA	
E - Groundwater discharge to wetlands	Groundwater discharge to swamps and marshes is likely. Key surface water features in the area include Tower Hill Lakes and Kelly Swamp.	
F - Groundwater throughflow out	Groundwater flows out of the GMA to the ocean	
References: EcoMarkets (2010) Glenelg Hopkins CMA Groundwater Model; Yangery GSPA Consultative Committee (2001) Yangery Groundwater Supply Protection Area Explanatory Paper to the Groundwater Management Plan; SKM (1998) PAV Determination for Yangery		



Appendix M

Average annual recharge (statewide)

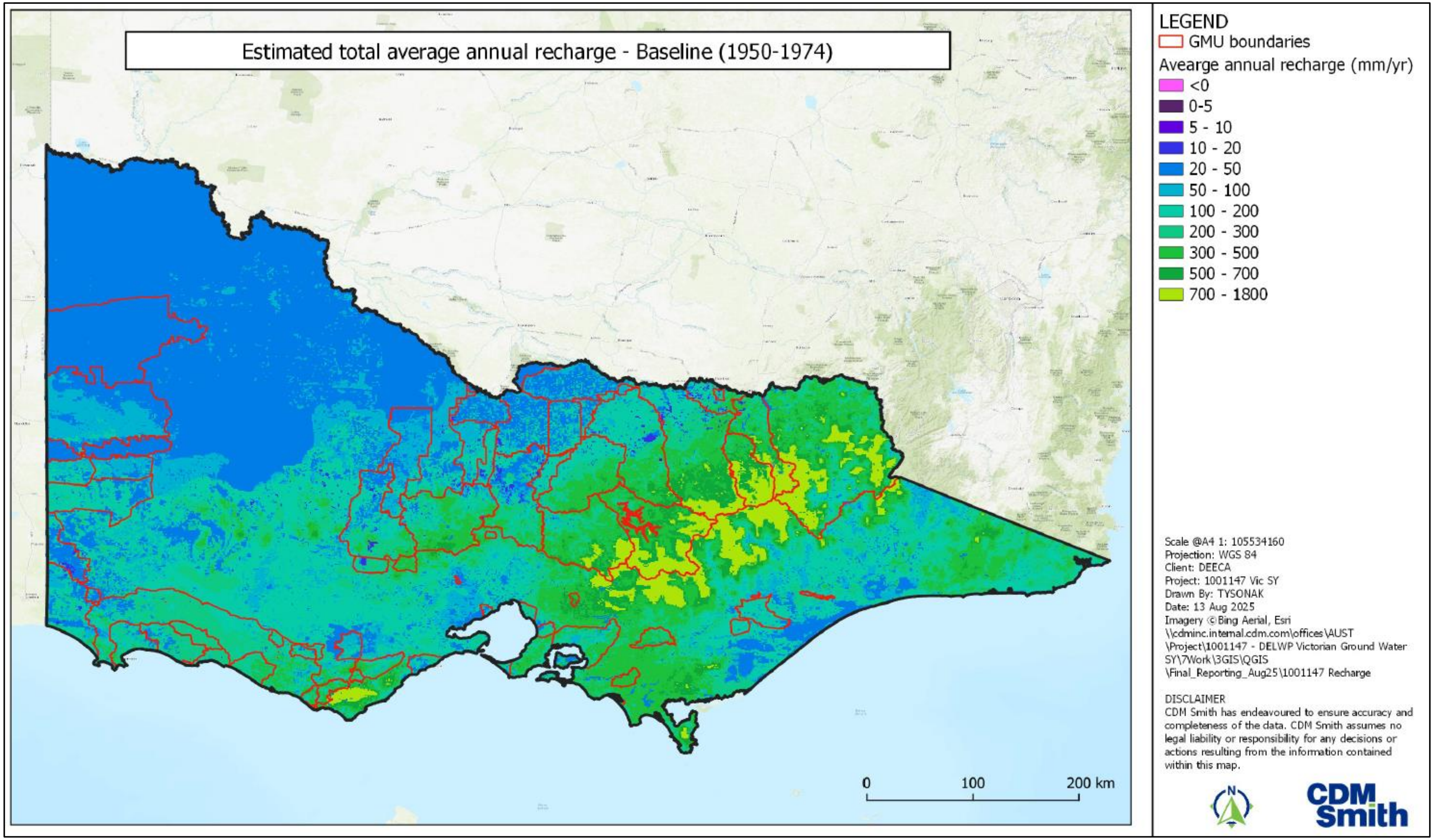


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Figure M-1 **Estimated average annual recharge for Victoria (HydroSight and SoilFlux merged result) - Baseline 1950-1974.**

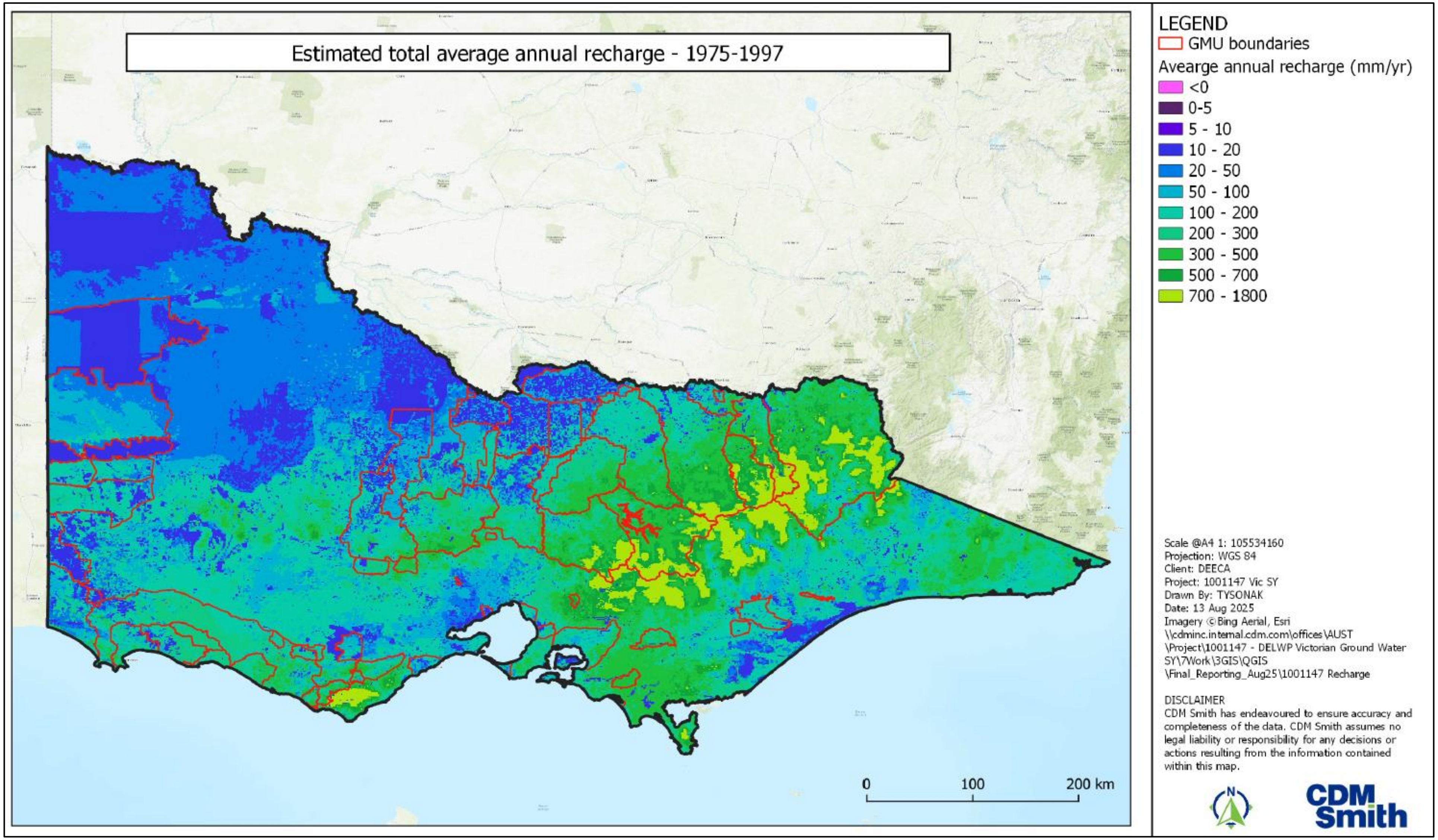

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Figure M-2 Estimated average annual recharge for Victoria (HydroSight and SoilFlux merged result) – 1975-1997.

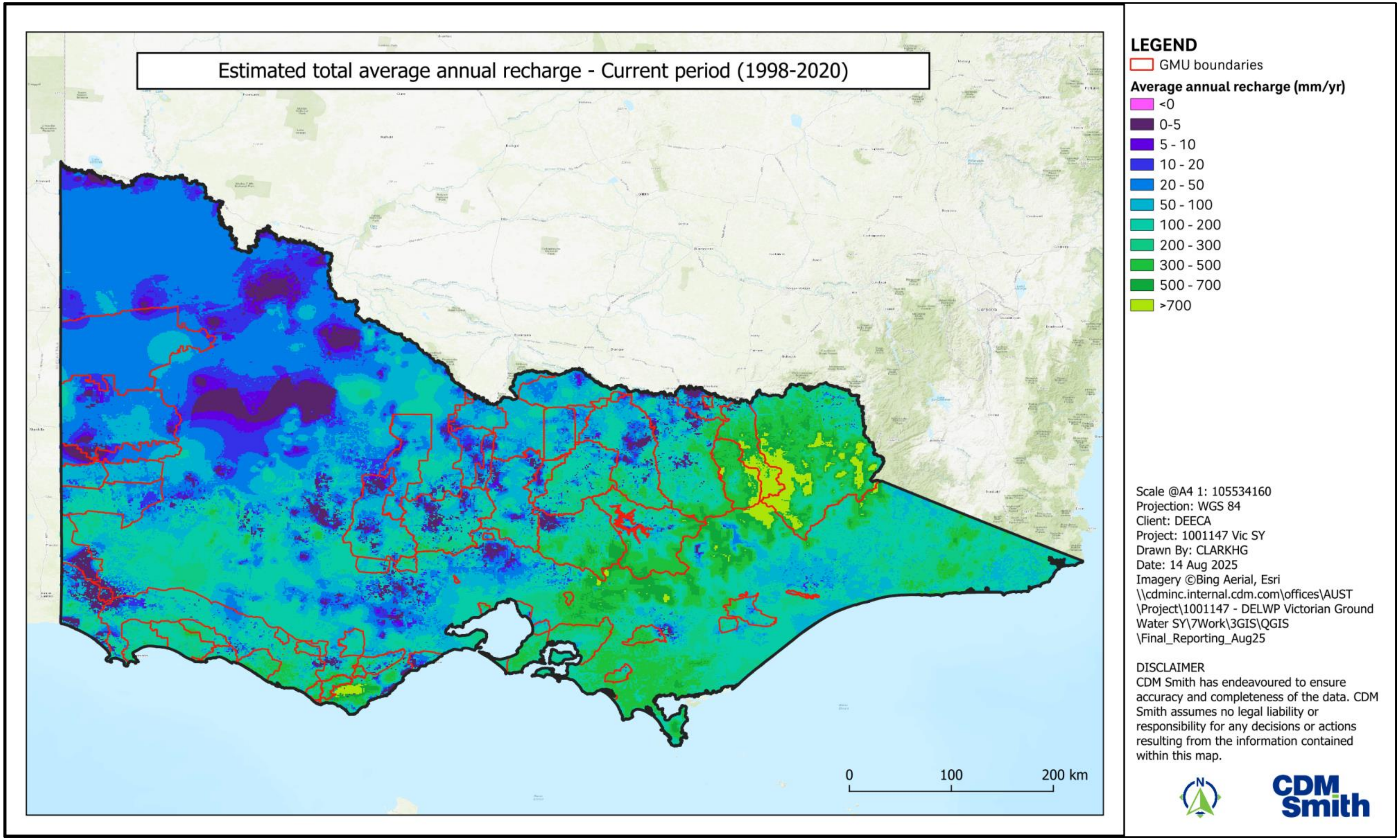

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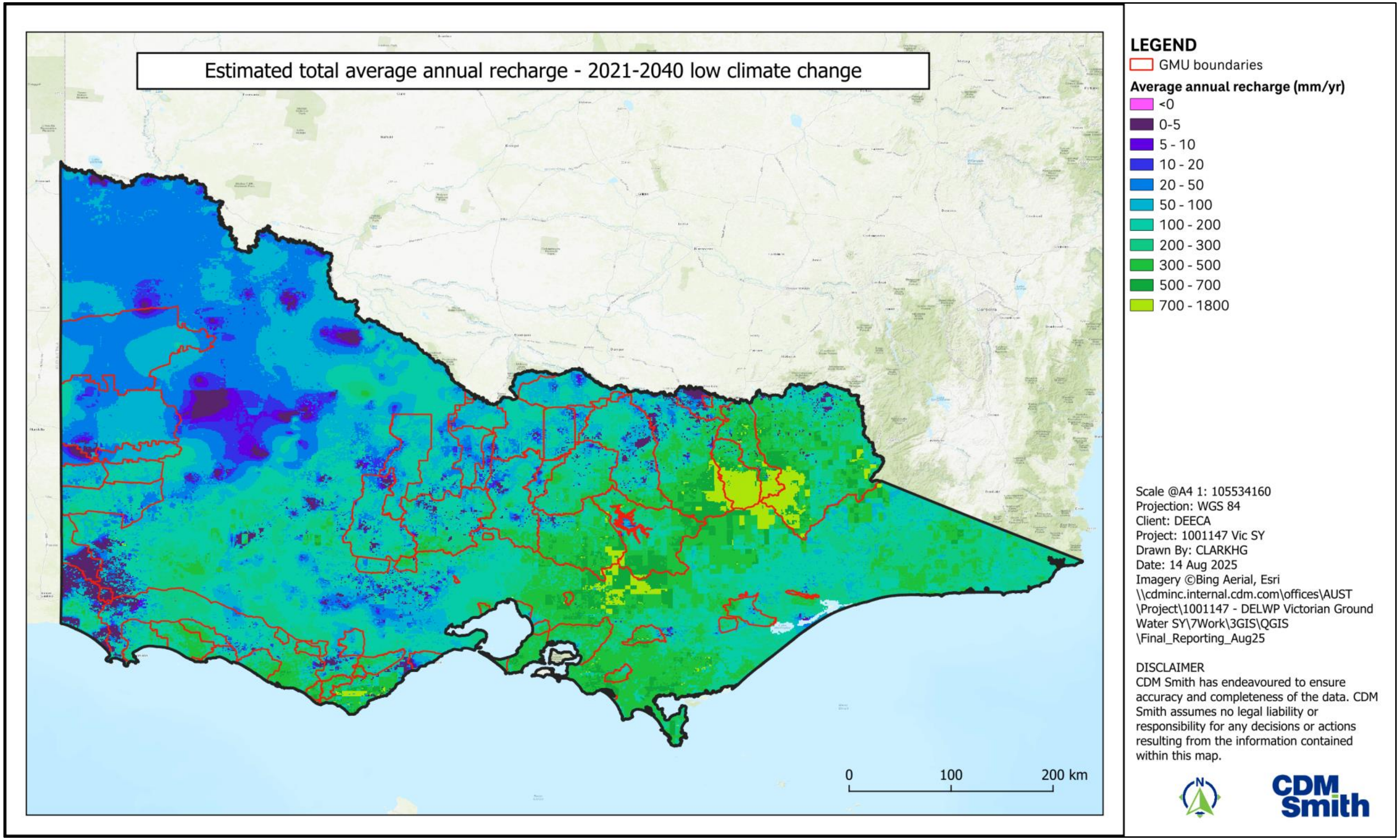
Figure M-3 Estimated average annual recharge for Victoria (HydroSight analysis)– 1998-2020.



Estimated total average annual recharge - 2021-2040 low climate change

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Figure M-4 Estimated average annual recharge for Victoria (HydroSight analysis) 2021-2040 Low Climate Change.

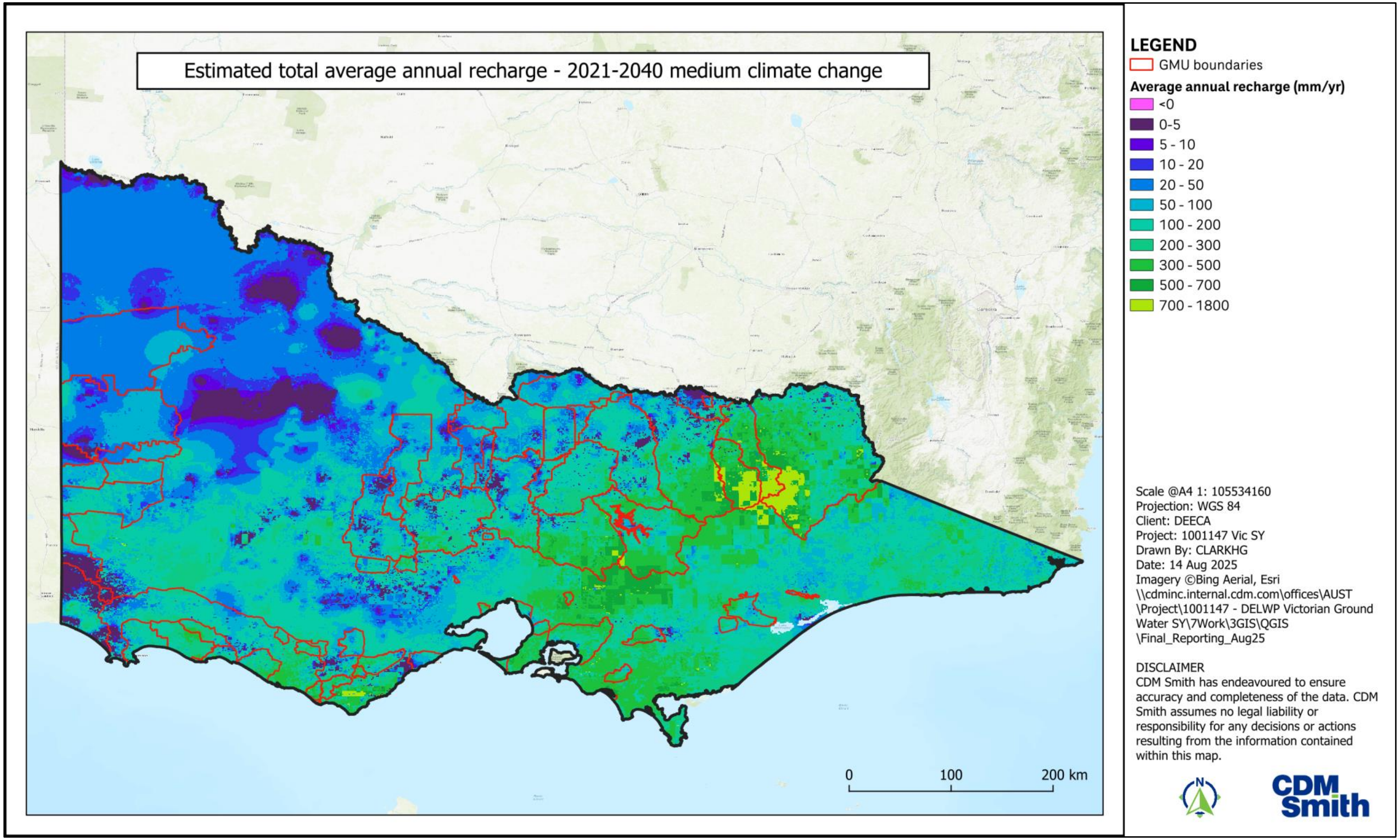

Figure M-5 Estimated average annual recharge for Victoria (HydroSight analysis) - 2021-2040 Medium Climate Change.

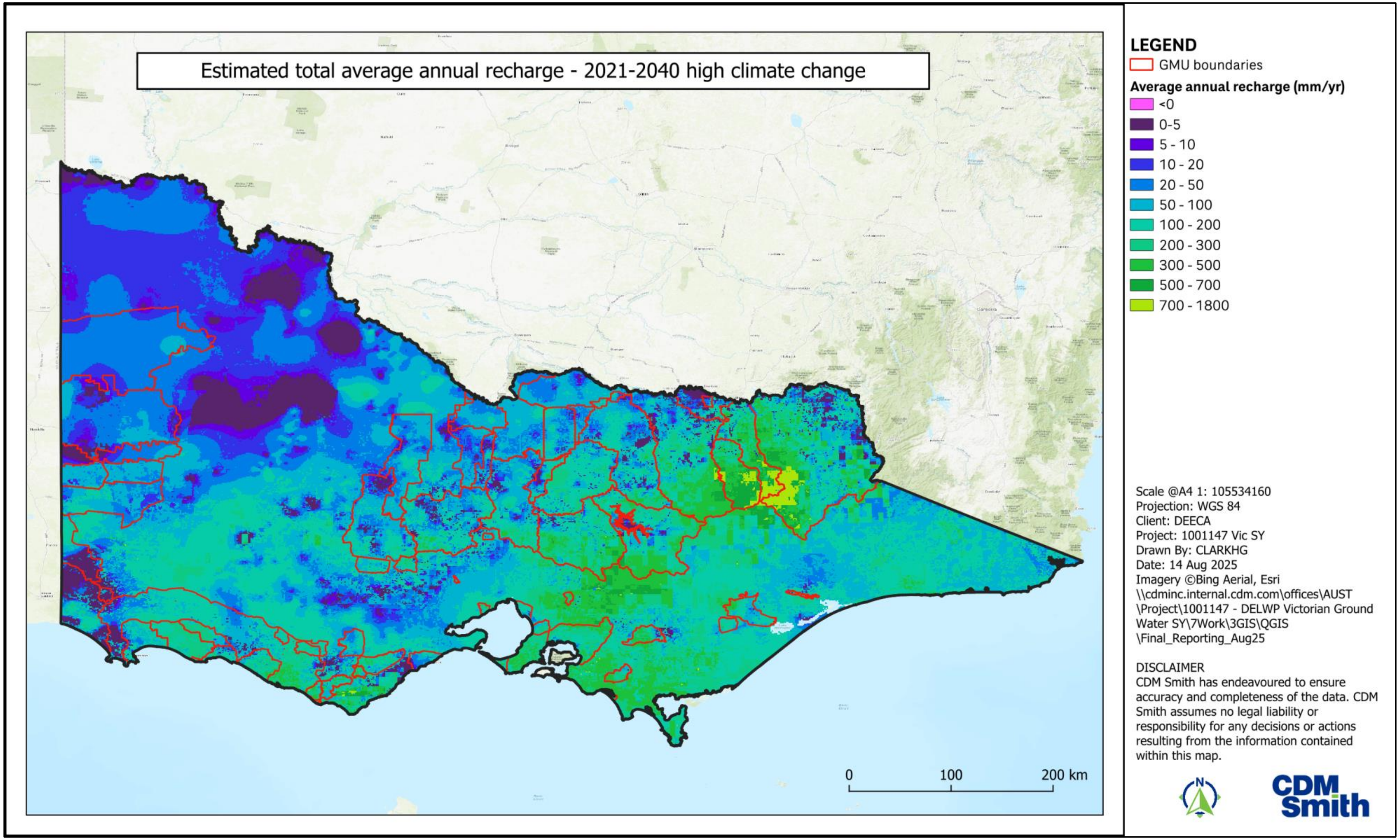

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Figure M-6 Estimated average annual recharge for Victoria (HydroSight analysis) - 2021-2040 High Climate Change.

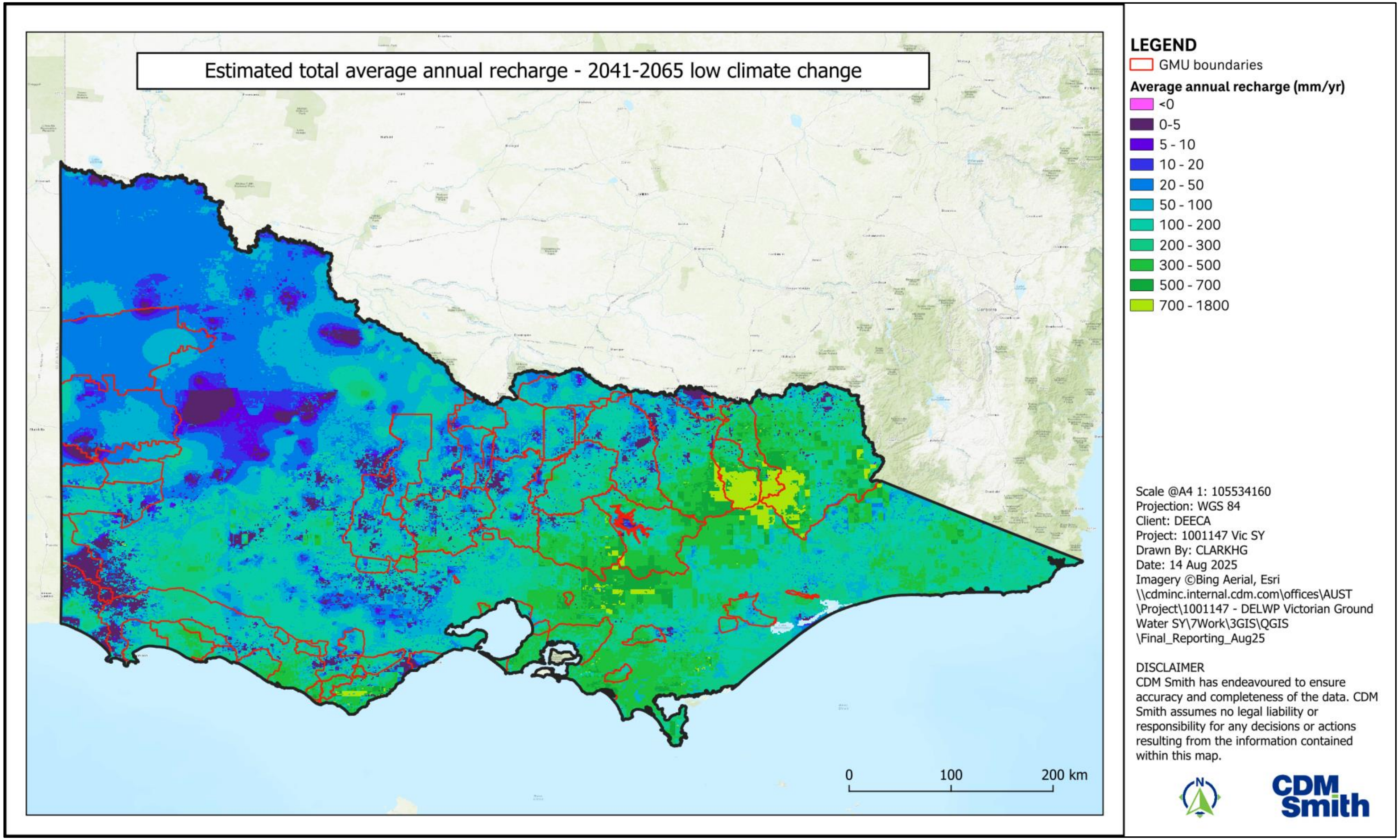

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Figure M-7 Estimated average annual recharge for Victoria (HydroSight analysis) - 2041-2065 Low Climate Change.

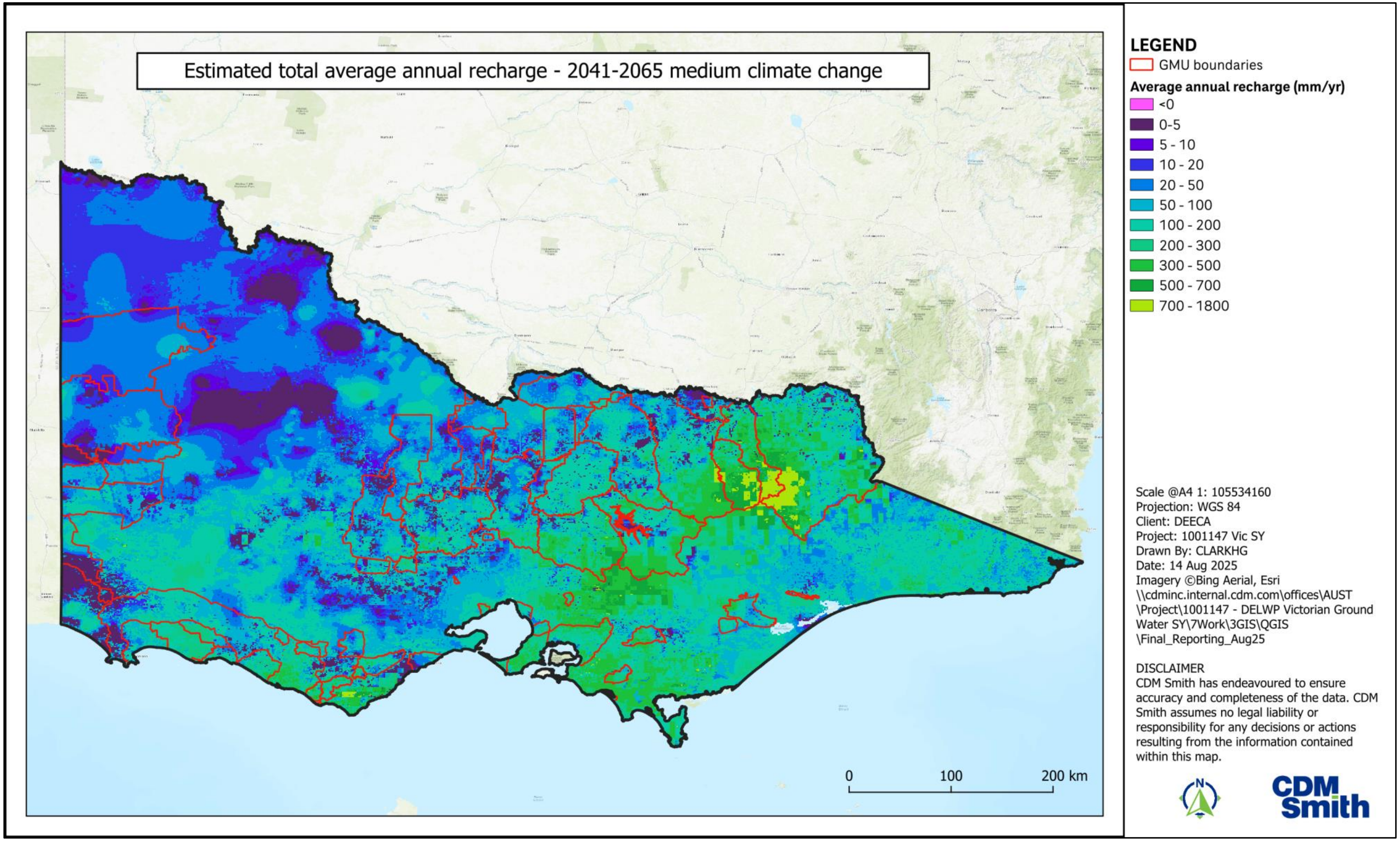

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Figure M-8 Estimated average annual recharge for Victoria (HydroSight analysis) - 2041-2065 Medium Climate Change.

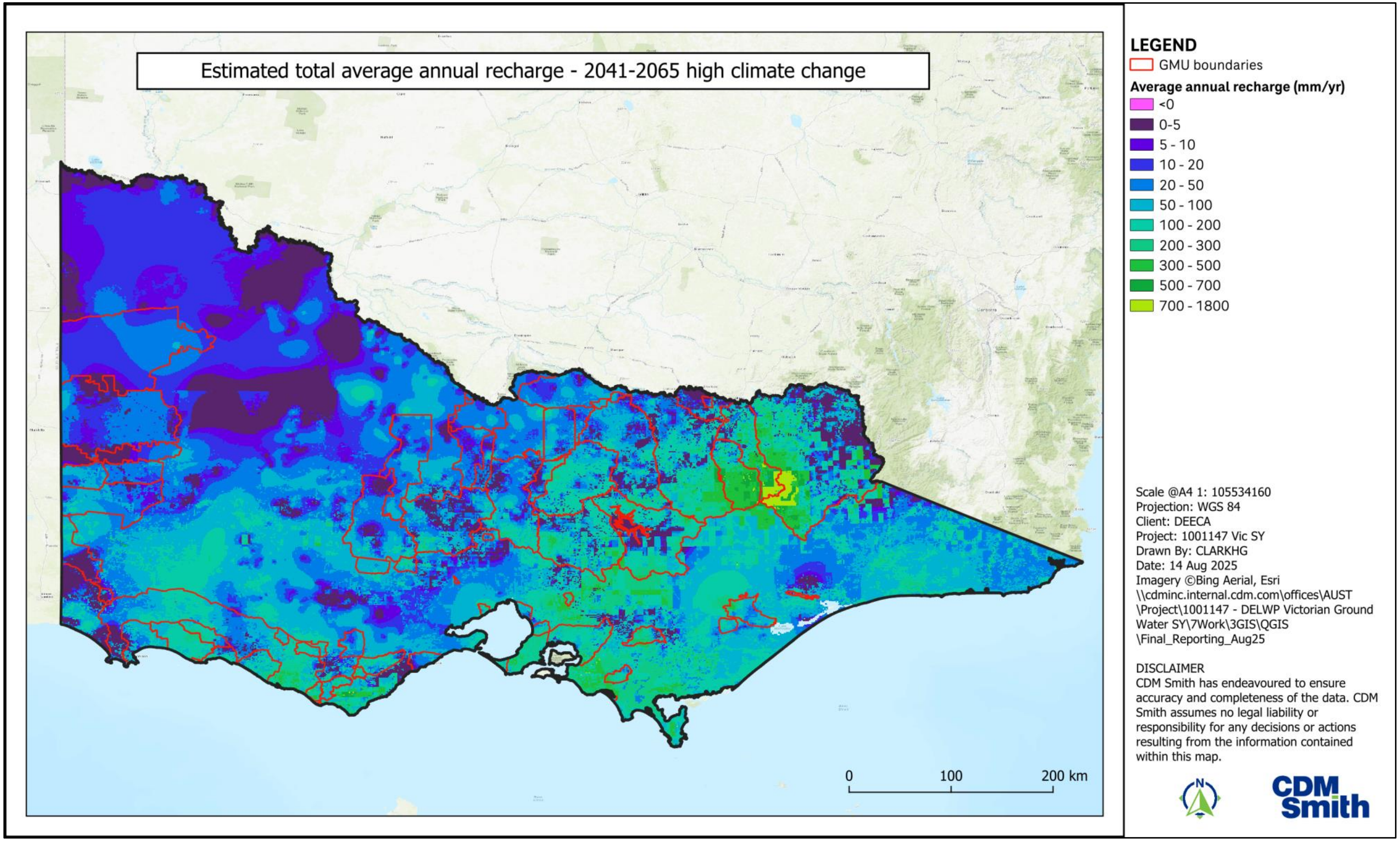
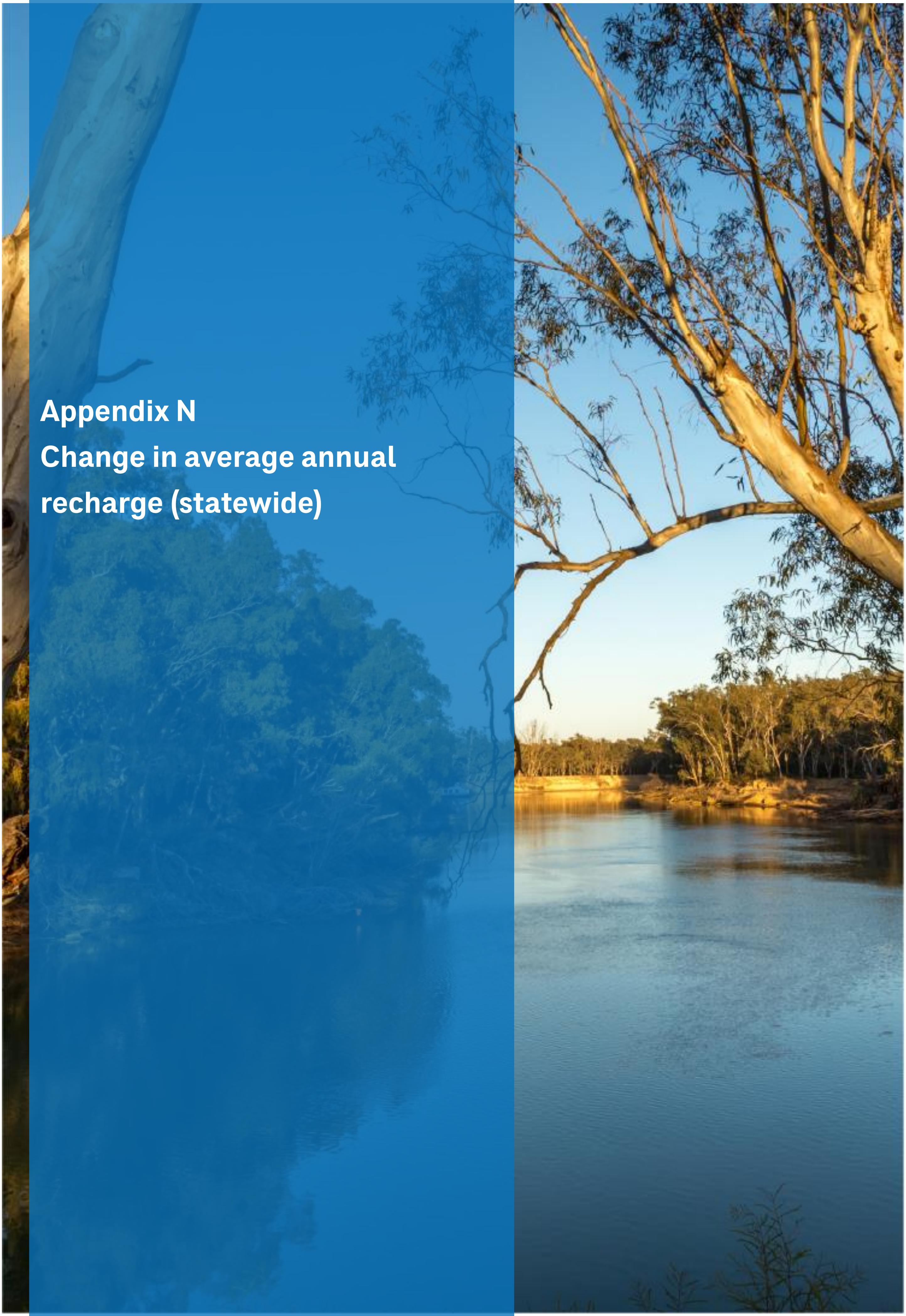


Figure M-9 Estimated uncertainty of annual recharge (HydroSight analysis) -2041-2065 High Climate Change.



Appendix N

Change in average annual recharge (statewide)

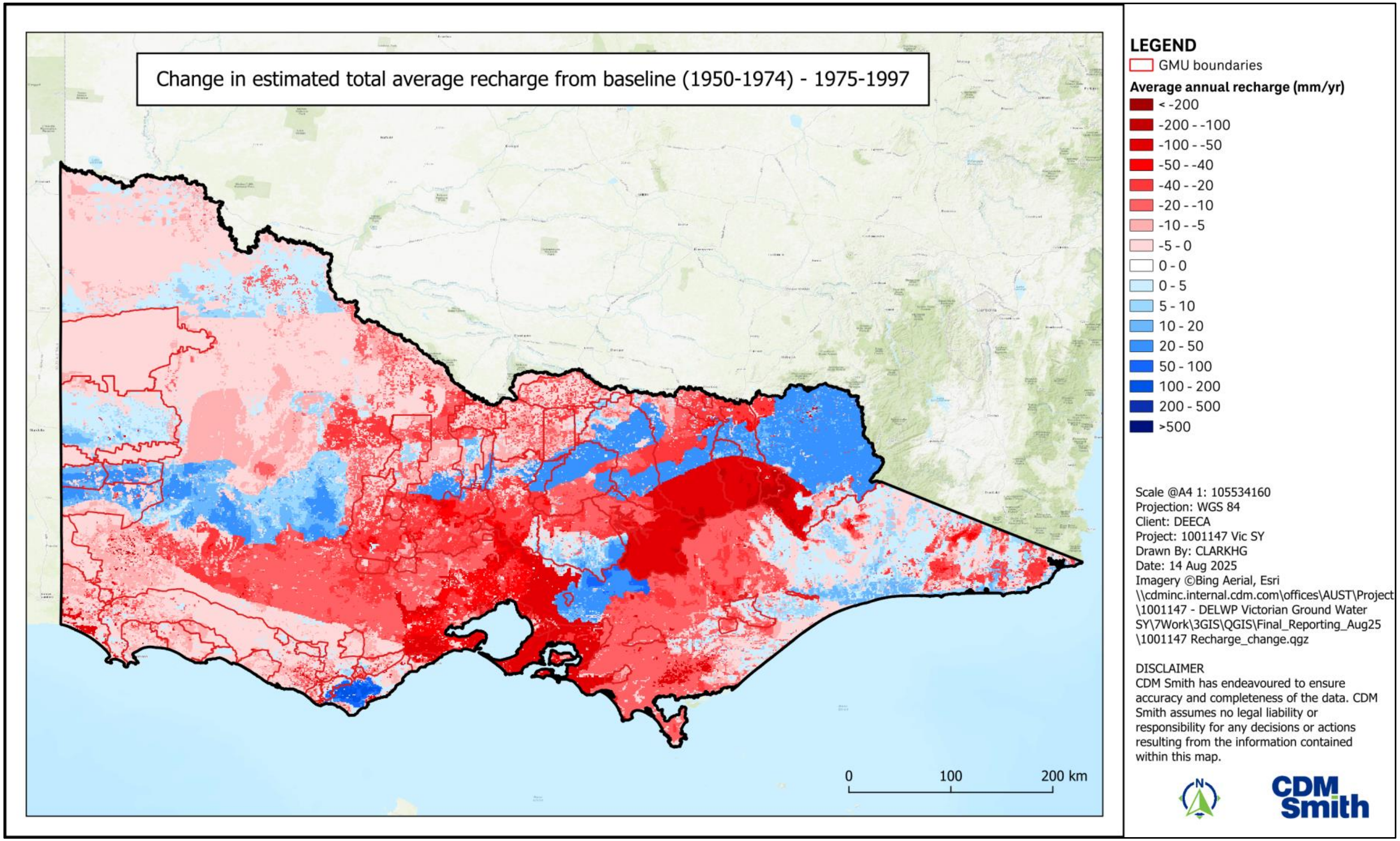


Figure N-1 Change in estimated average annual recharge for Victoria (HydroSight and SoilFlux merged result)– Baseline (1950-1974) to 1975-1997.

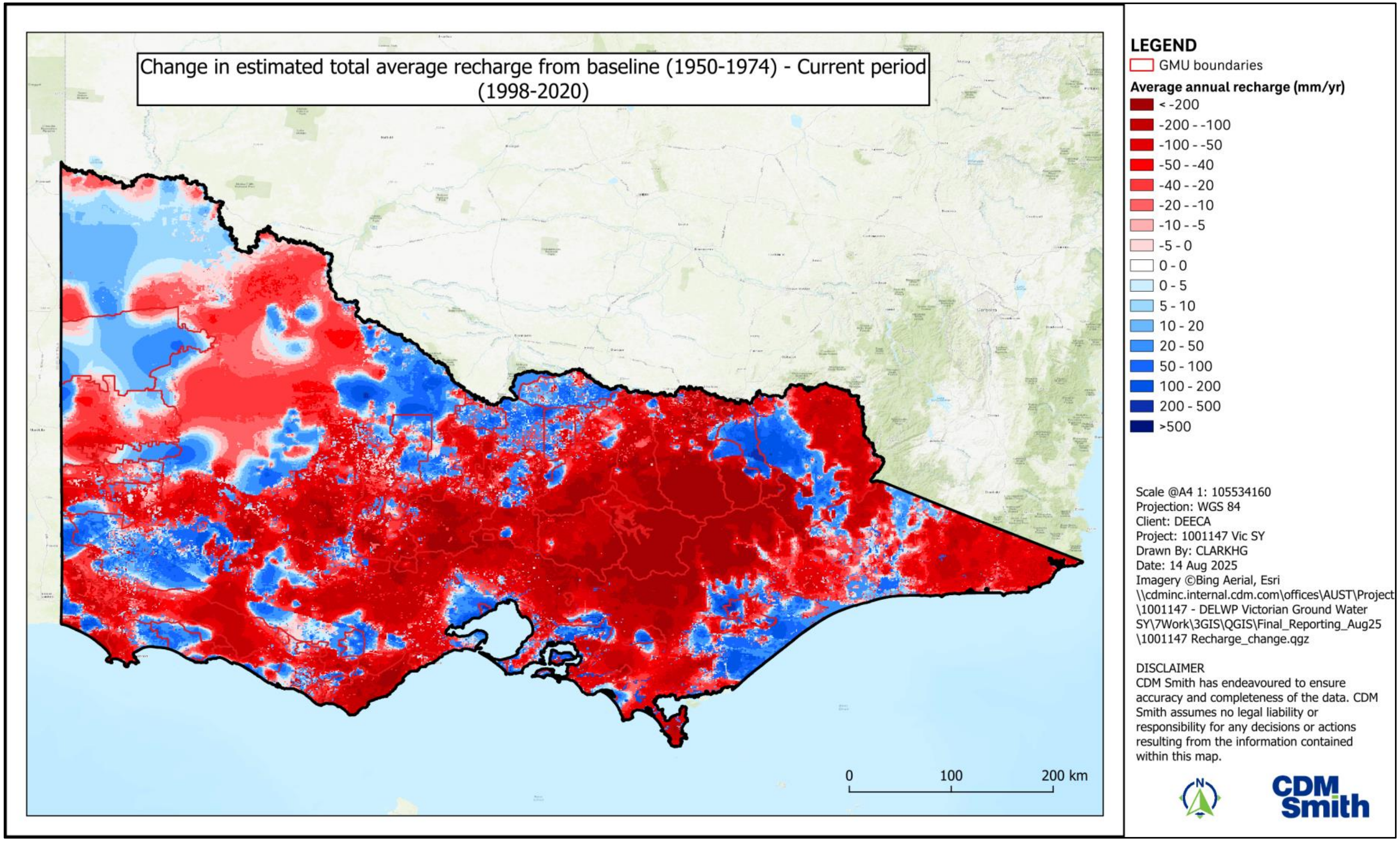


Figure N-2 Change in estimated average annual recharge for Victoria – Baseline (1950-1974) to 1998-2020.

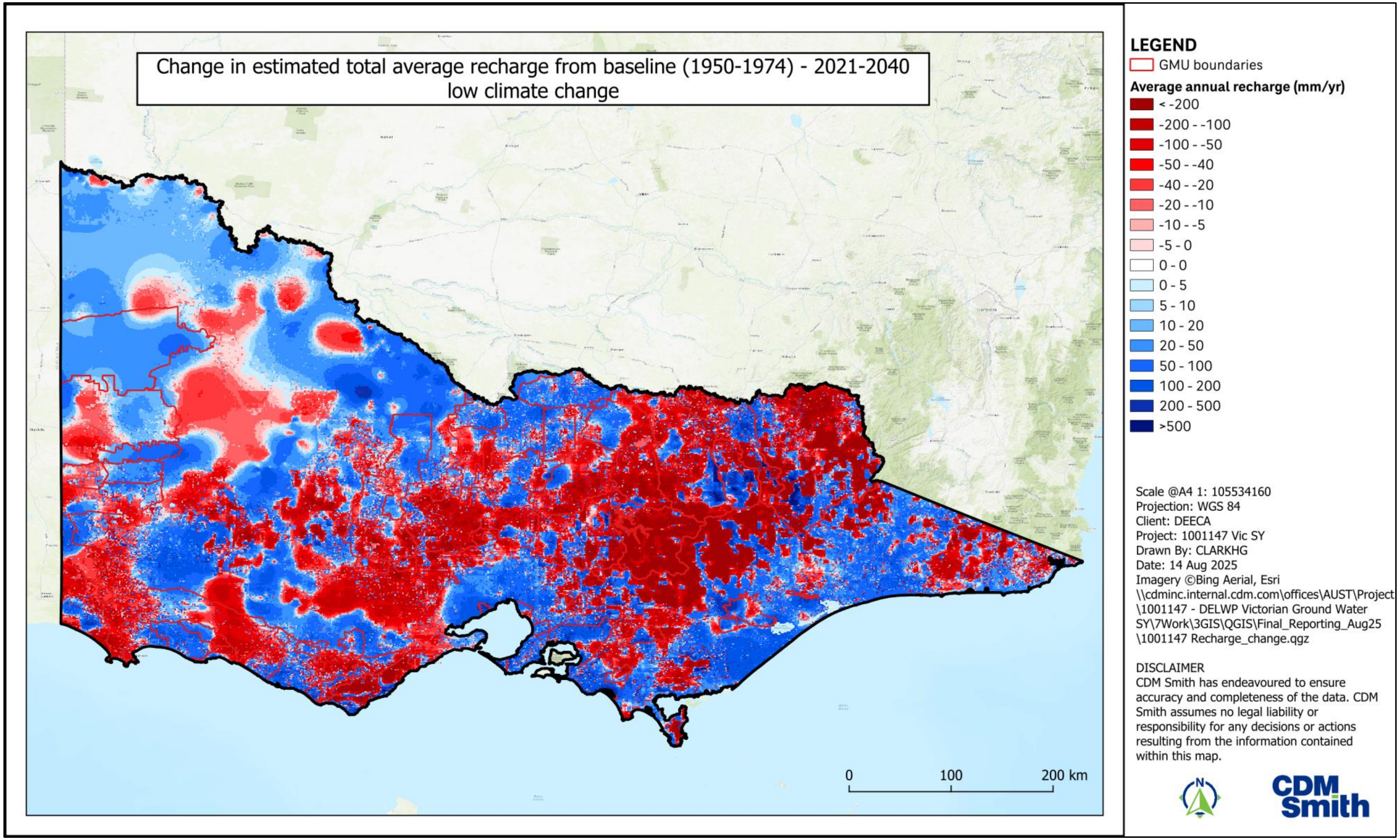


Figure N-3 Change in estimated average annual recharge for Victoria – Baseline (1950-1974) to 2021-2040 Low Climate Change.

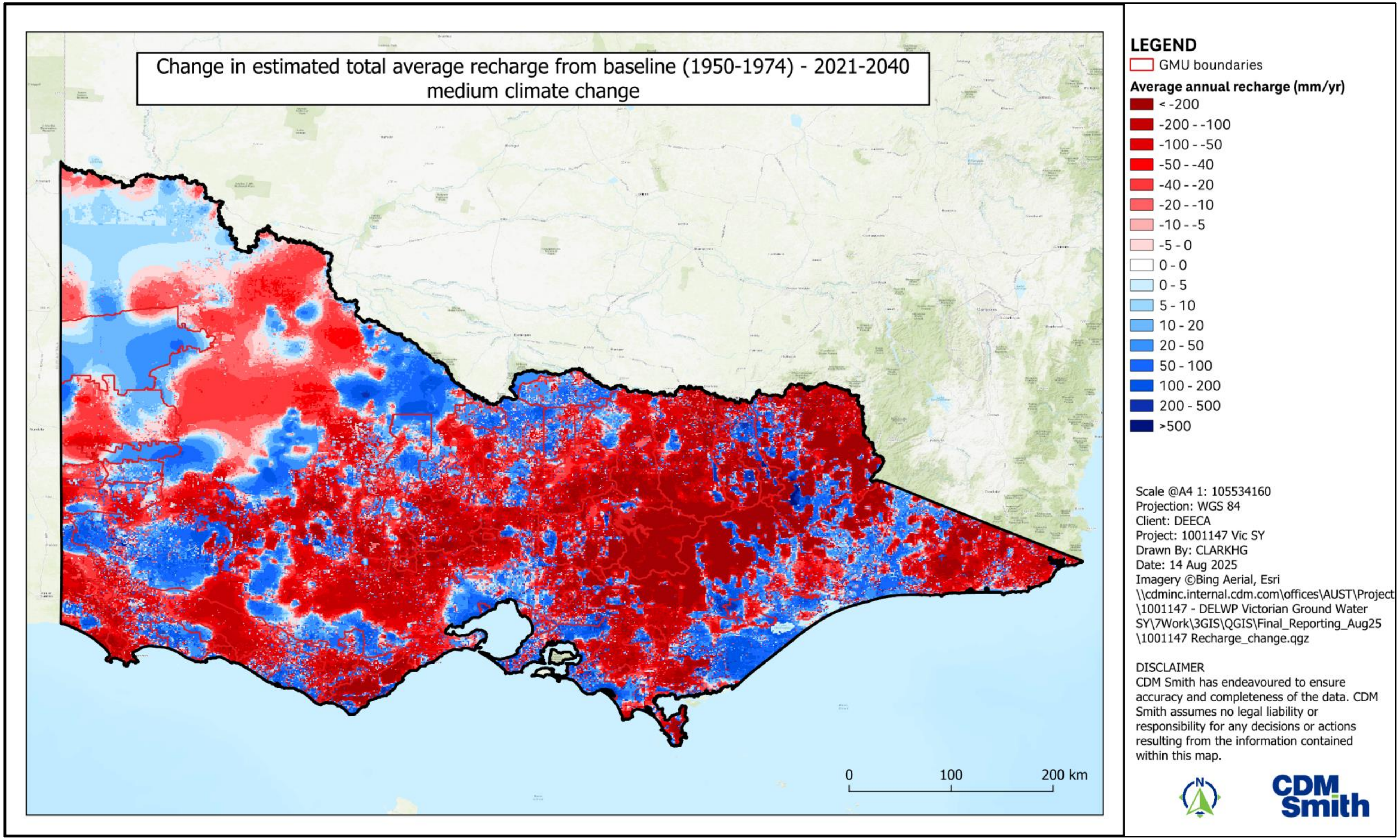


Figure N-4 Change in estimated average annual recharge for Victoria – Baseline (1950-1974) to 2021-2040 Medium Climate Change.

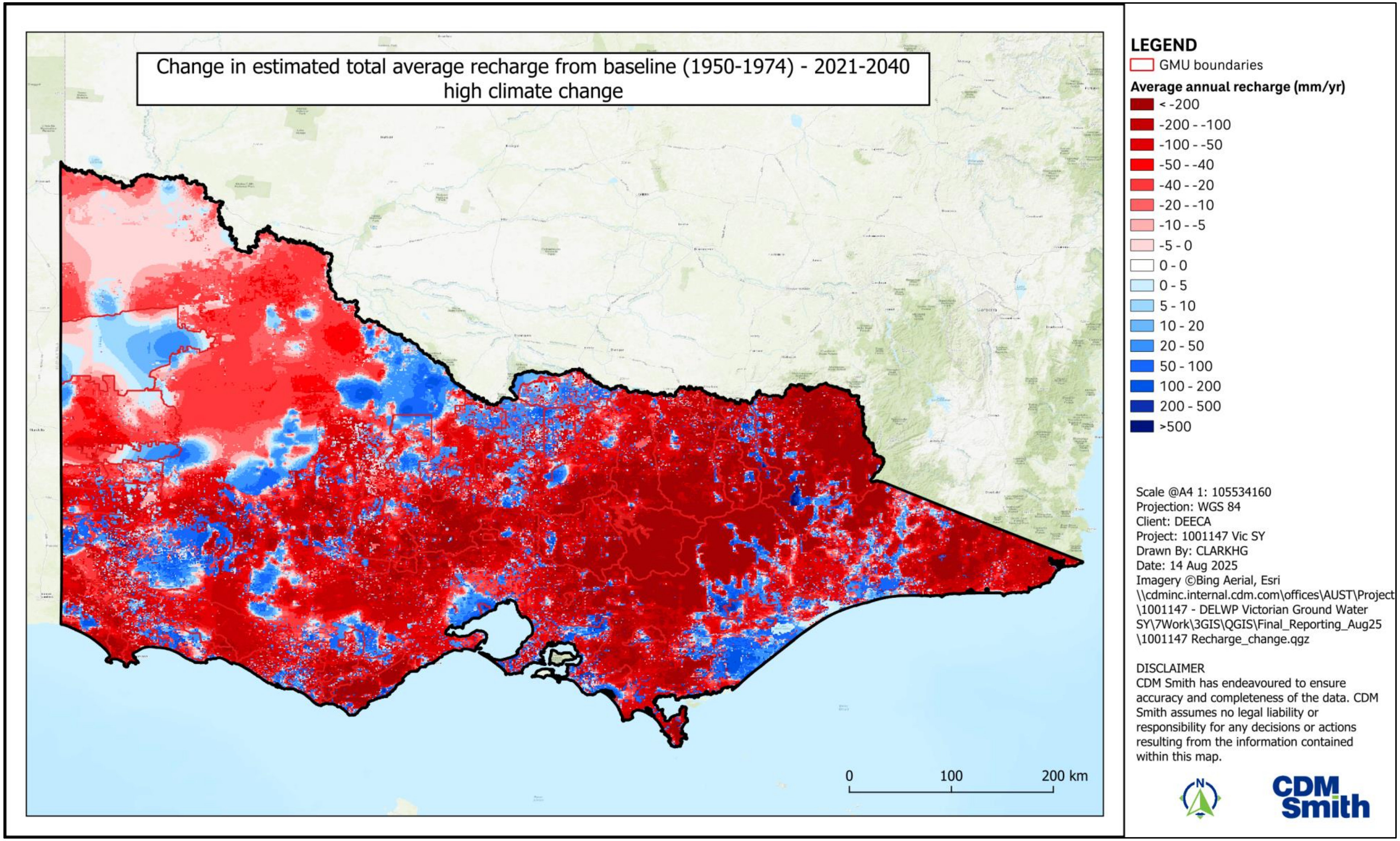


Figure N-5 **Change in estimated average annual recharge for Victoria – Baseline (1950-1974) to 2021-2040 High Climate Change.**

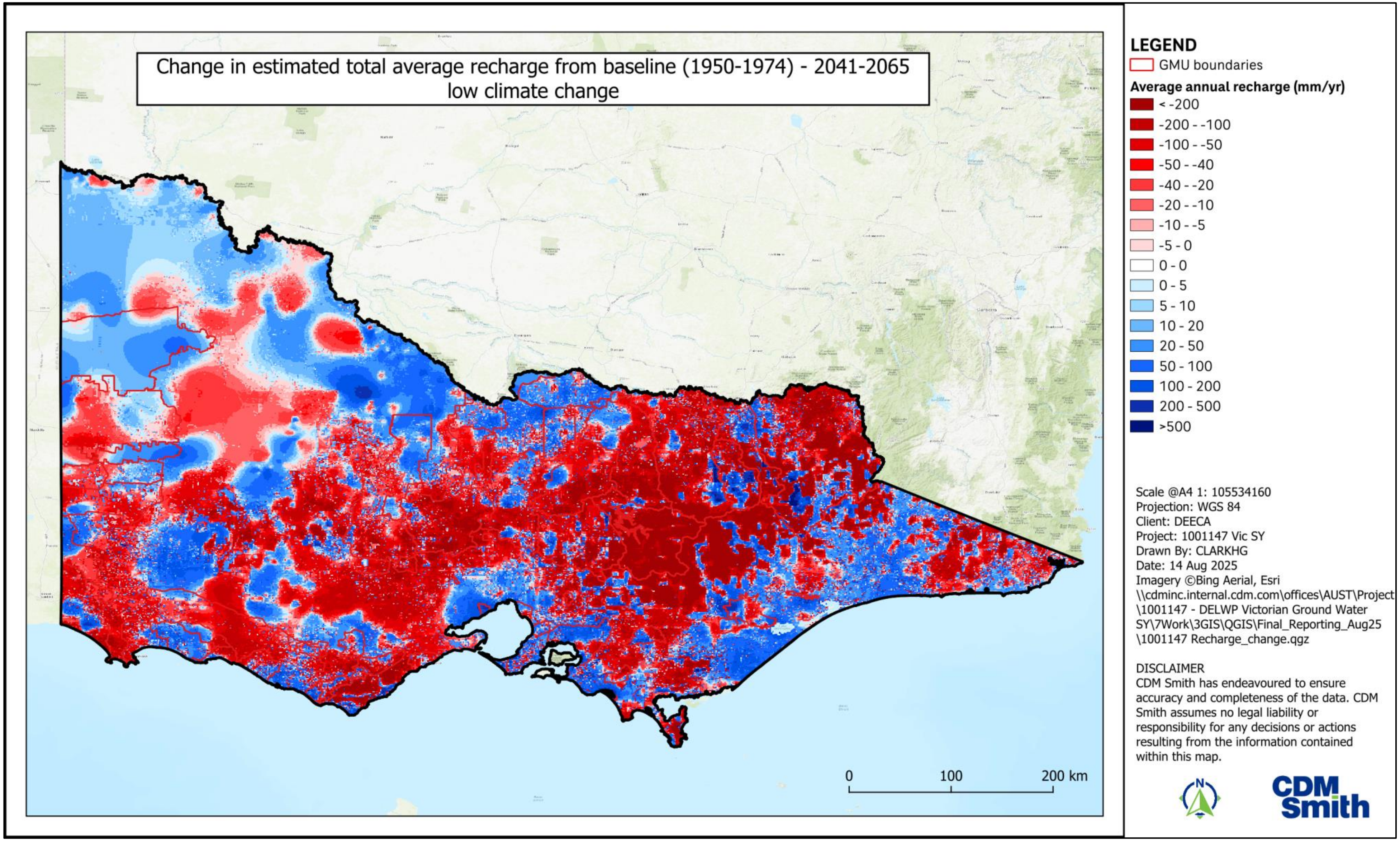


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Figure N-6 Change in estimated average annual recharge for Victoria – Baseline (1950-1974) to 2041-2065 Low Climate Change.

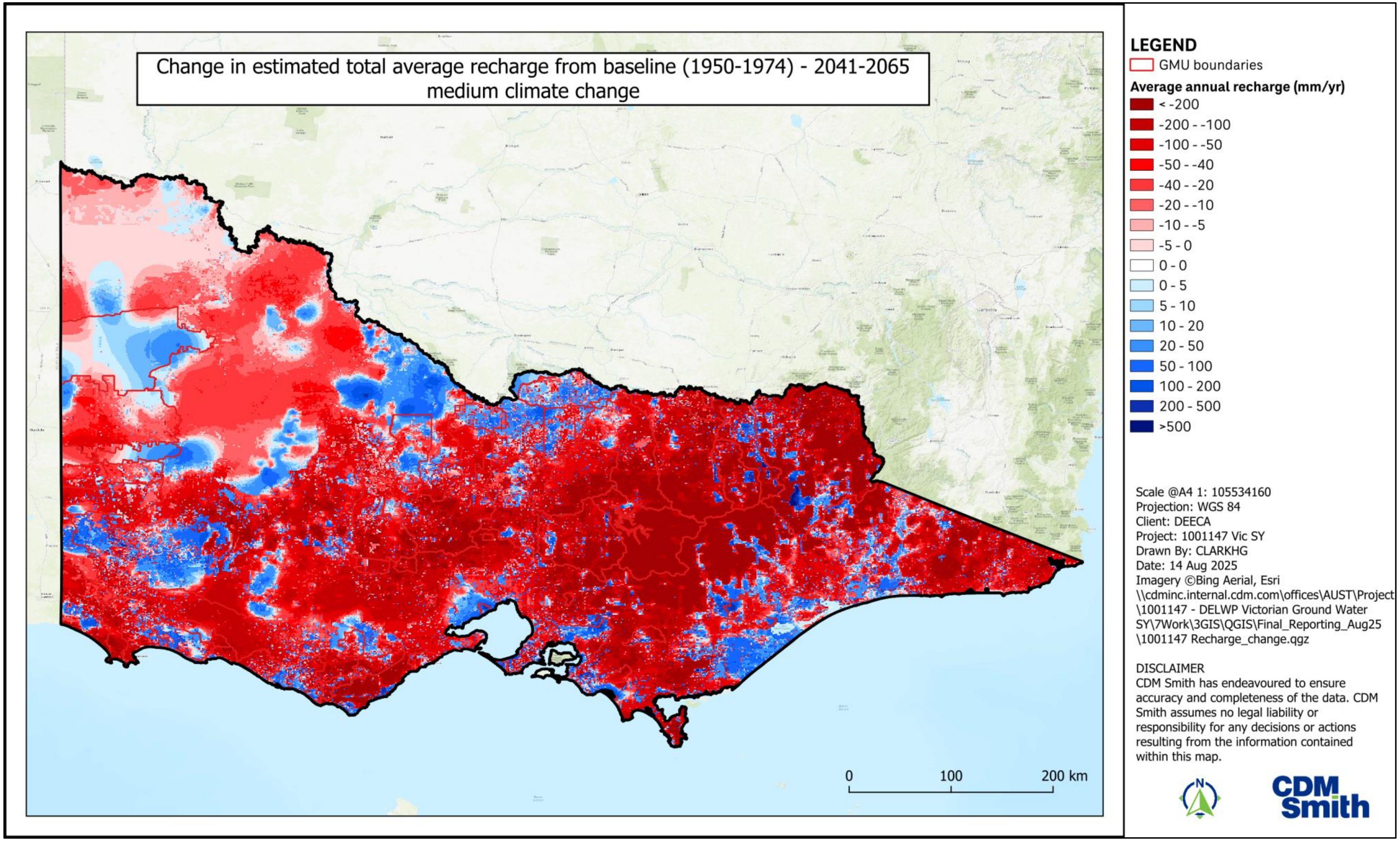

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Figure N-7 Change in estimated average annual recharge for Victoria – Baseline (1950-1974) to 2041-2065 Medium Climate Change.

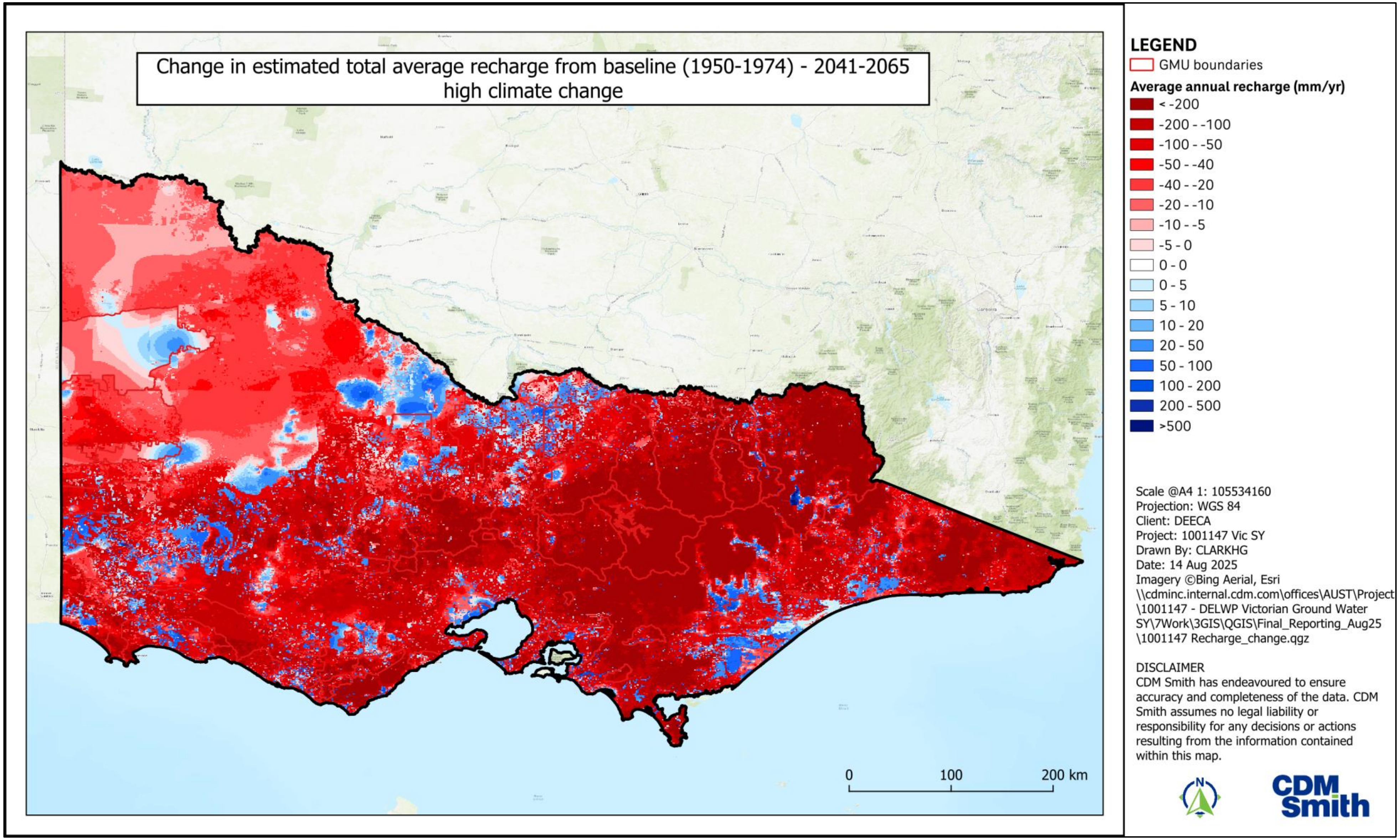
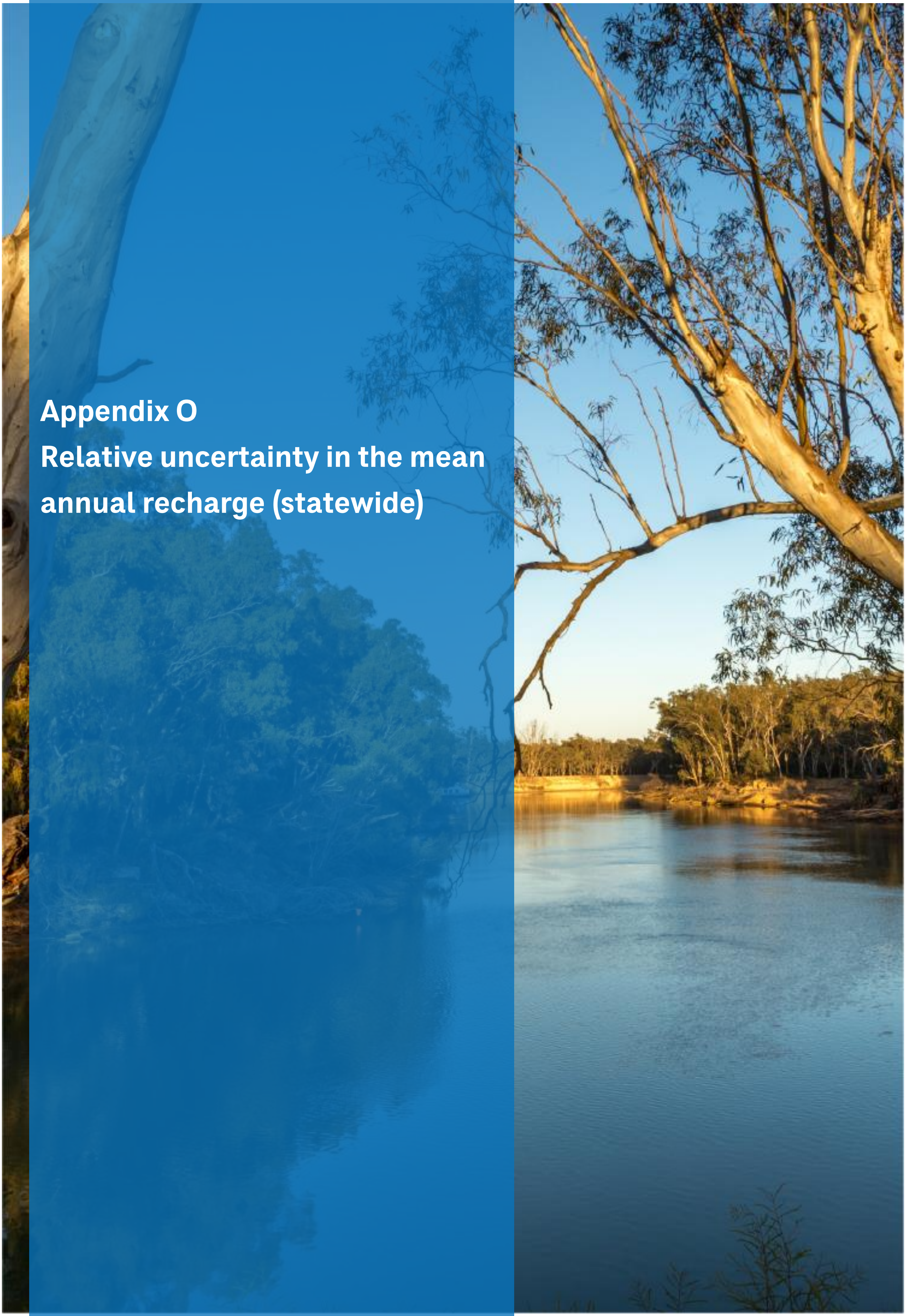


Figure N-8 Change in estimated average annual recharge for Victoria – Baseline (1950-1974) to 2041-2065 High Climate Change.



Appendix O

Relative uncertainty in the mean annual recharge (statewide)

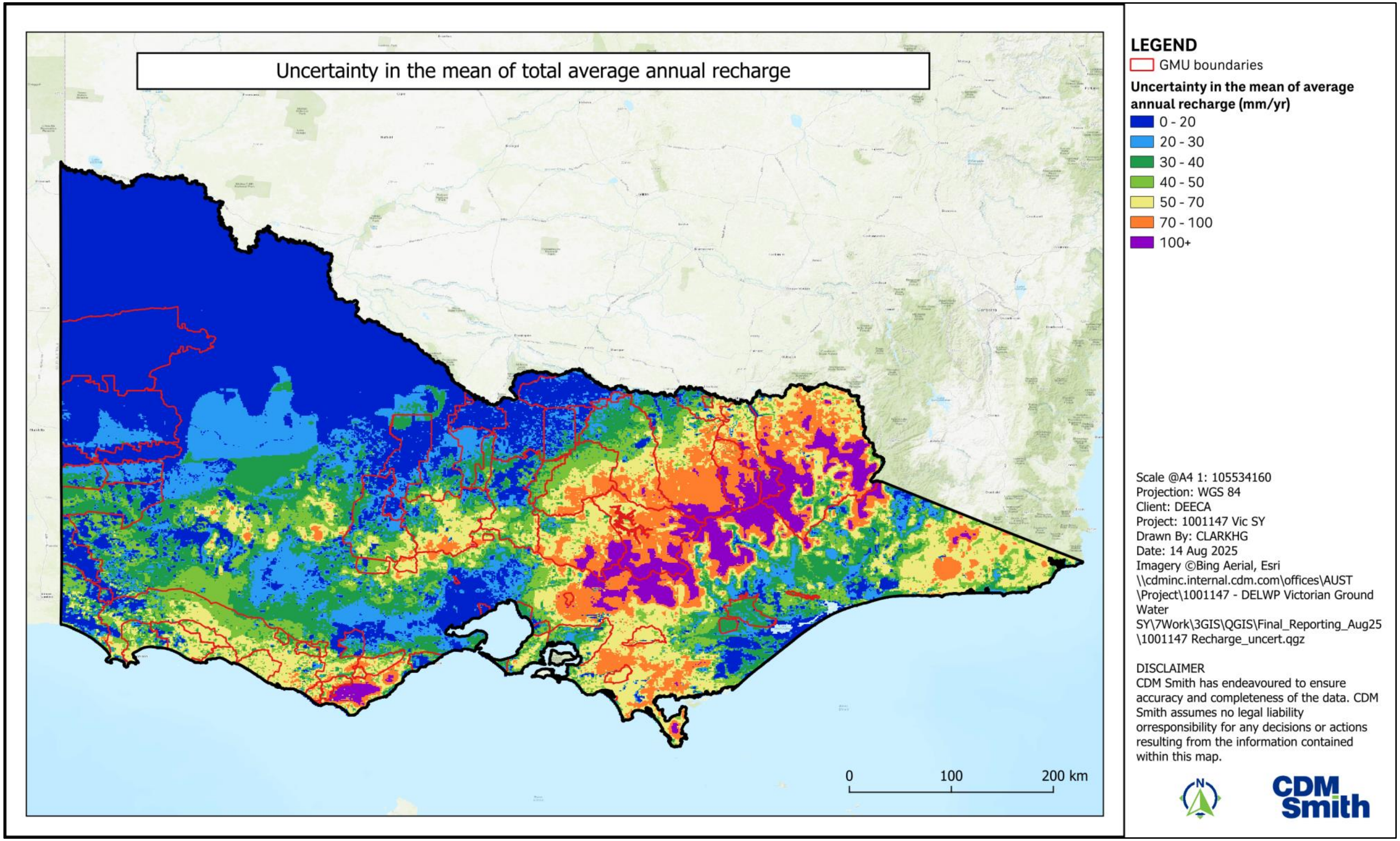


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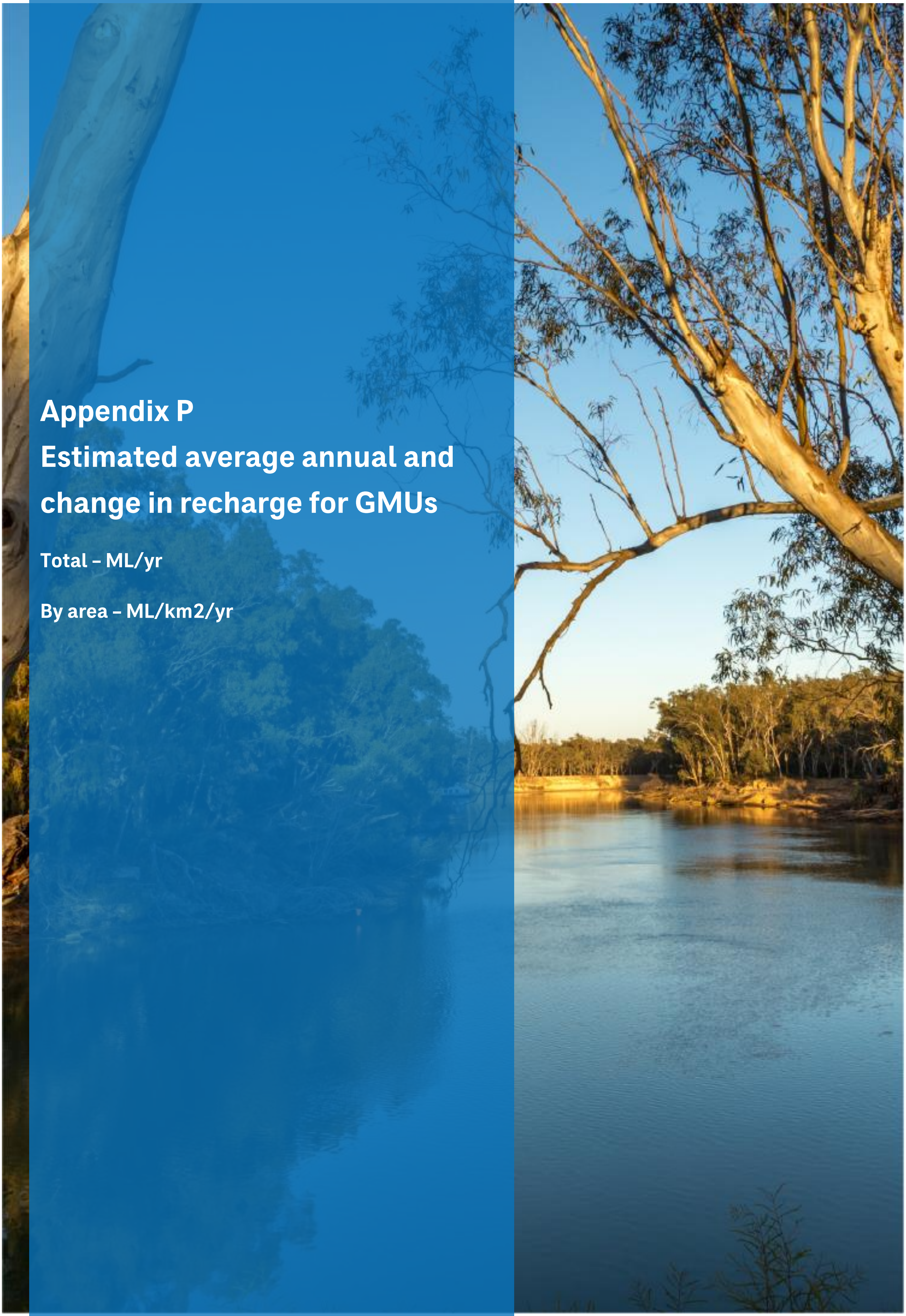
Figure O-1 Uncertainty in the mean of in estimated annual recharge (HydroSight and SoilFlux merged result) (mm/yr).



Appendix P

Estimated average annual and change in recharge for GMUs

Total – ML/yr

By area – ML/km2/yr

Table P-1 Estimated average annual recharge (ML/yr) and change in recharge from baseline (1950-1974) for GMUs by modelled scenarios - LCC – low climate change, MCC – medium climate change, HCC – high climate change

GMU	Average annual recharge ML/yr (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
		Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ
Barnawartha GMA	13,117	11,975	-9%	7,577	-42%	5,293	-60%	3,286	-75%	2,627	-80%	4,513	-66%	2,493	-81%	1,531	-88%
Big Desert Zone (West Wimmera)	147,570	127,724	-13%	231,507	57%	323,129	119%	252,786	71%	186,059	26%	265,997	80%	187,975	27%	123,592	-16%
Broken GMA	983,807	996,690	1%	493,247	-50%	703,416	-29%	570,026	-42%	429,821	-56%	596,934	-39%	441,006	-55%	266,006	-73%
Bungaree GMA	70,879	68,244	-4%	35,917	-49%	52,939	-25%	42,271	-40%	34,329	-52%	44,602	-37%	31,693	-55%	21,333	-70%
Cardigan GMA	66,782	60,756	-9%	39,812	-40%	49,786	-25%	39,612	-41%	35,065	-47%	41,729	-38%	28,823	-57%	25,643	-62%
Central Victorian Mineral Springs GMA	860,088	774,713	-10%	348,214	-60%	545,085	-37%	500,628	-42%	322,049	-63%	434,152	-50%	347,416	-60%	163,097	-81%
Colongulac GMA	50,973	50,402	-1%	46,364	-9%	60,485	19%	55,125	8%	46,640	-8%	50,833	0%	42,195	-17%	34,162	-33%
Denison GMA	26,033	24,044	-8%	27,381	5%	36,695	41%	30,613	18%	25,641	-2%	30,782	18%	23,467	-10%	17,404	-33%
Deutgam WSPA	4,881	2,393	-51%	14,130	190%	19,010	289%	15,008	208%	12,575	158%	17,302	255%	12,487	156%	9,213	89%
Eildon GMA	2,335,086	2,101,056	-10%	1,030,269	-56%	1,399,185	-40%	1,138,010	-51%	808,620	-65%	1,197,767	-49%	894,252	-62%	444,733	-81%
Frankston GMA	28,026	21,997	-22%	20,714	-26%	38,433	37%	30,815	10%	25,738	-8%	34,041	21%	25,224	-10%	19,437	-31%
Gellibrand GMA	22,663	20,621	-9%	22,373	-1%	25,385	12%	22,883	1%	19,145	-16%	20,897	-8%	16,831	-26%	14,190	-37%
Gerangamete GMA	121,567	117,978	-3%	69,788	-43%	106,979	-12%	92,273	-24%	76,196	-37%	80,450	-34%	62,126	-49%	48,785	-60%
Glenelg WSPA	288,686	255,235	-12%	228,208	-21%	227,732	-21%	165,383	-43%	137,664	-52%	217,839	-25%	140,620	-51%	109,153	-62%
Glenormiston GMA	18,049	17,845	-1%	16,608	-8%	19,853	10%	18,431	2%	15,337	-15%	16,111	-11%	13,734	-24%	10,509	-42%
Gymbowen Zone (West Wimmera)	68,184	80,663	18%	61,230	-10%	103,363	52%	83,170	22%	56,452	-17%	80,131	18%	53,095	-22%	29,536	-57%
Hawkesdale GMA	278,928	272,066	-2%	289,345	4%	357,193	28%	313,337	12%	265,876	-5%	323,359	16%	267,687	-4%	196,030	-30%
Heywood GMA	141,443	137,033	-3%	147,446	4%	142,329	1%	118,458	-16%	88,870	-37%	116,761	-17%	91,784	-35%	55,724	-61%
Jan Juc GMA	36,797	27,116	-26%	17,144	-53%	25,412	-31%	22,516	-39%	18,559	-50%	20,571	-44%	17,101	-54%	11,251	-69%
Kiewa GMA	1,074,210	1,012,756	-6%	1,074,282	0%	971,914	-10%	927,995	-14%	748,275	-30%	886,001	-18%	807,641	-25%	545,386	-49%
Koo Wee Rup WSPA	270,202	212,995	-21%	281,829	4%	371,688	38%	313,180	16%	260,704	-4%	340,892	26%	266,653	-1%	171,384	-37%
Lancefield GMA	13,362	12,770	-4%	3,730	-72%	12,941	-3%	6,497	-51%	5,027	-62%	10,345	-23%	4,145	-69%	2,576	-81%

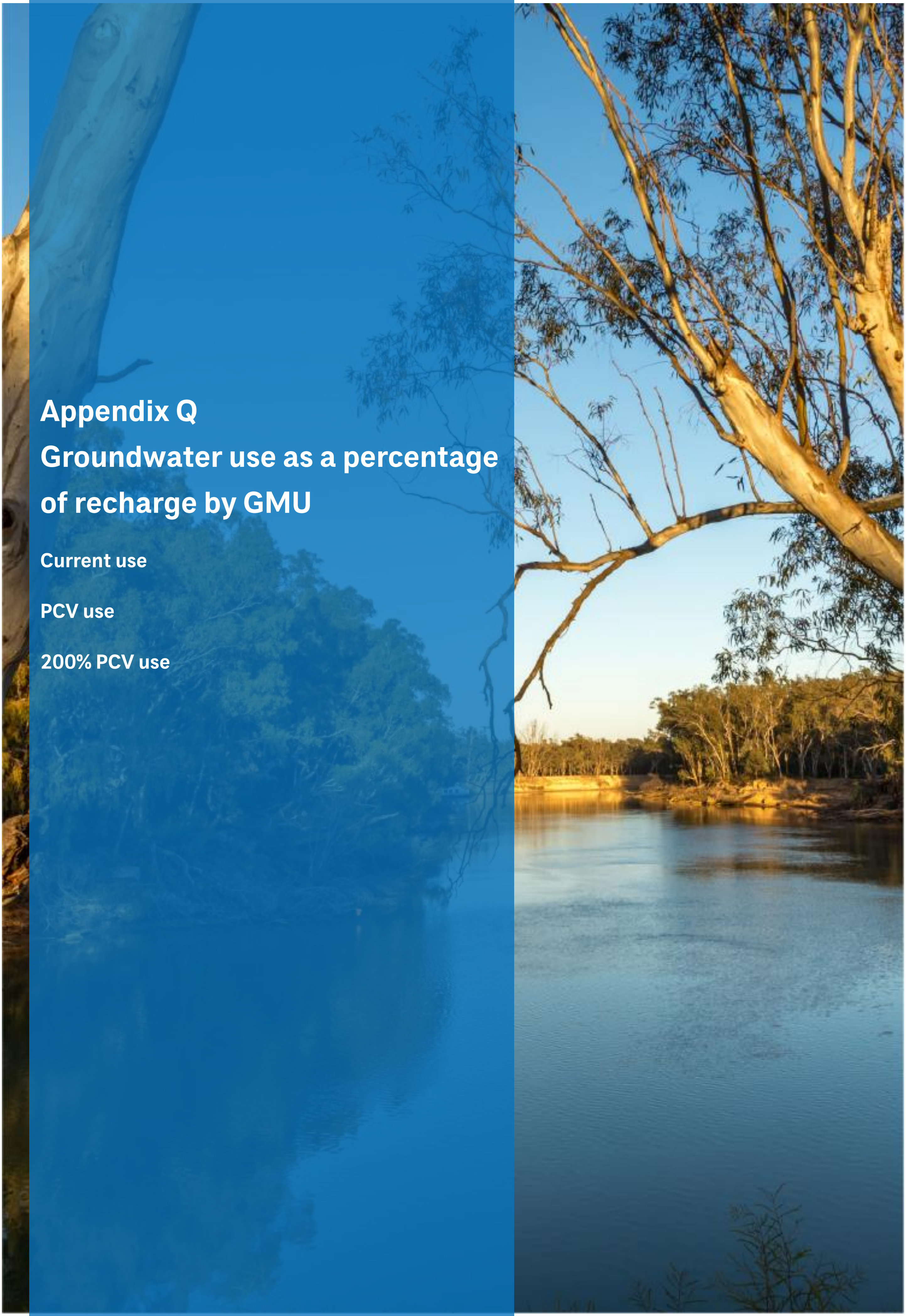
GMU	Average annual recharge ML/yr (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
		Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ
Leongatha GMA	74,869	70,580	-6%	54,488	-27%	68,855	-8%	57,719	-23%	48,692	-35%	63,411	-15%	49,284	-34%	35,324	-53%
Little Desert Zone (West Wimmera)	27,568	24,930	-10%	39,678	44%	71,968	161%	54,181	97%	33,411	21%	54,304	97%	32,611	18%	14,647	-47%
Loddon Highlands WSPA	460,604	405,548	-12%	242,544	-47%	362,889	-21%	266,106	-42%	219,950	-52%	287,874	-38%	192,807	-58%	126,759	-72%
Lower Campaspe Valley WSPA	154,258	134,972	-13%	122,745	-20%	189,395	23%	140,575	-9%	106,868	-31%	154,084	0%	102,146	-34%	64,277	-58%
Lower Ovens GMA	2,202,365	2,034,418	-8%	1,007,065	-54%	1,887,312	-14%	1,439,170	-35%	1,137,391	-48%	1,618,798	-26%	1,151,890	-48%	727,880	-67%
Merrimu GMA	722	468	-35%	1,135	57%	1,304	81%	1,070	48%	842	17%	1,085	50%	778	8%	515	-29%
Mid Goulburn GMA	175,256	175,093	0%	155,251	-11%	206,577	18%	165,022	-6%	139,113	-21%	177,711	1%	133,042	-24%	94,630	-46%
Mid Loddon GMA	143,028	122,246	-15%	157,457	10%	229,877	61%	182,789	28%	139,876	-2%	197,065	38%	139,071	-3%	88,120	-38%
Moe GMA	112,833	107,624	-5%	101,647	-10%	124,131	10%	100,576	-11%	83,478	-26%	108,414	-4%	81,874	-27%	58,540	-48%
Moorabbin GMA	26,314	19,803	-25%	20,659	-21%	31,630	20%	23,879	-9%	17,800	-32%	27,545	5%	18,253	-31%	10,138	-61%
Nepean GMA	15,906	11,541	-27%	18,933	19%	26,511	67%	22,356	41%	18,638	17%	23,133	45%	18,037	13%	13,630	-14%
Neuarpur Zone (West Wimmera)	81,570	93,888	15%	54,856	-33%	72,652	-11%	66,797	-18%	50,587	-38%	62,604	-23%	50,613	-38%	37,628	-54%
Newlingrook GMA	139,012	140,891	1%	127,813	-8%	144,637	4%	117,244	-16%	85,387	-39%	137,557	-1%	100,232	-28%	68,101	-51%
Northern Zone (West Wimmera)	300,896	309,695	3%	210,170	-30%	317,246	5%	250,337	-17%	171,000	-43%	260,084	-14%	182,227	-39%	109,937	-63%
Nullawarre WSPA	142,688	140,127	-2%	135,928	-5%	147,707	4%	123,145	-14%	96,882	-32%	129,992	-9%	98,517	-31%	69,730	-51%
Shepparton Irrigation GMA	391,905	330,426	-16%	522,676	33%	675,048	72%	534,398	36%	416,412	6%	602,093	54%	431,701	10%	278,478	-29%
South West Limestone GMA	2,087,566	2,008,239	-4%	1,681,837	-19%	1,966,807	-6%	1,642,639	-21%	1,370,922	-34%	1,731,501	-17%	1,329,449	-36%	1,002,914	-52%
Southern Zone (West Wimmera)	256,956	272,262	6%	194,217	-24%	256,172	0%	220,615	-14%	150,205	-42%	206,071	-20%	152,164	-41%	94,962	-63%
Strathbogie GMA	801,688	812,416	1%	422,297	-47%	617,846	-23%	506,828	-37%	433,695	-46%	506,595	-37%	386,682	-52%	286,869	-64%
Tarwin GMA	5,951	5,169	-13%	7,993	34%	10,967	84%	9,247	55%	7,791	31%	9,794	65%	7,785	31%	5,720	-4%
Upper Goulburn GMA	1,446,883	1,434,084	-1%	839,437	-42%	1,283,802	-11%	1,073,408	-26%	761,830	-47%	1,094,390	-24%	816,833	-44%	407,104	-72%
Upper Murray GMA	5,004,179	5,087,294	2%	4,465,528	-11%	3,871,603	-23%	3,538,239	-29%	2,504,564	-50%	3,728,559	-25%	2,941,890	-41%	1,782,612	-64%
Upper Ovens WSPA	1,127,890	1,023,762	-9%	796,286	-29%	1,165,352	3%	959,639	-15%	773,579	-31%	1,061,951	-6%	828,422	-27%	565,014	-50%

GMU	Average annual recharge ML/yr (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
		Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ
Wa De Lock GMA	84,926	81,004	-5%	98,711	16%	132,901	56%	111,008	31%	92,536	9%	112,337	32%	87,659	3%	65,699	-23%
Wandin Yallock GMA	28,978	30,449	5%	20,800	-28%	24,466	-16%	19,807	-32%	16,928	-42%	21,701	-25%	16,102	-44%	12,465	-57%
Warrion WSPA	35,381	33,689	-5%	53,240	50%	52,790	49%	44,710	26%	34,374	-3%	38,985	10%	27,894	-21%	19,896	-44%
West Goulburn GMA	628,881	561,482	-11%	488,593	-22%	710,927	13%	557,195	-11%	445,482	-29%	588,296	-6%	421,343	-33%	283,610	-55%
Wy Yung GMA	8,072	7,614	-6%	7,854	-3%	13,185	63%	10,148	26%	7,332	-9%	11,380	41%	7,903	-2%	4,204	-48%
Yangery WSPA	63,060	62,509	-1%	48,948	-22%	53,942	-14%	45,812	-27%	37,301	-41%	48,674	-23%	38,435	-39%	28,453	-55%

Table P-2 Estimated average annual recharge (by area ML/km^2/yr) and change in recharge from baseline (1950-1974) for GMUs by modelled scenarios - LCC – low climate change, MCC – medium climate change, HCC – high climate change.

GMU	Average annual recharge ML/km^2/yr (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
		Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ
Barnawartha GMA	190	173	-9%	110	-42%	77	-60%	48	-75%	38	-80%	65	-66%	36	-81%	22	-88%
Big Desert Zone (West Wimmera)	22	19	-13%	35	57%	49	119%	38	71%	28	26%	40	80%	28	27%	19	-16%
Broken GMA	225	228	1%	113	-50%	161	-29%	130	-42%	98	-56%	136	-39%	101	-55%	61	-73%
Bungaree GMA	343	331	-4%	174	-49%	256	-25%	205	-40%	166	-52%	216	-37%	154	-55%	103	-70%
Cardigan GMA	196	178	-9%	117	-40%	146	-25%	116	-41%	103	-47%	122	-38%	85	-57%	75	-62%
Central Victorian Mineral Springs GMA	260	234	-10%	105	-60%	164	-37%	151	-42%	97	-63%	131	-50%	105	-60%	49	-81%
Colongulac GMA	179	177	-1%	163	-9%	213	19%	194	8%	164	-8%	179	0%	148	-17%	120	-33%
Denison GMA	152	140	-8%	160	5%	214	41%	178	18%	149	-2%	179	18%	137	-10%	101	-33%
Deutgam WSPA	75	37	-51%	217	190%	292	289%	231	208%	193	158%	266	255%	192	156%	142	89%
Eildon GMA	614	553	-10%	271	-56%	368	-40%	299	-51%	213	-65%	315	-49%	235	-62%	117	-81%
Frankston GMA	197	154	-22%	145	-26%	270	37%	216	10%	181	-8%	239	21%	177	-10%	136	-31%
Gellibrand GMA	273	248	-9%	269	-1%	305	12%	275	1%	230	-16%	251	-8%	202	-26%	171	-37%
Gerangamete GMA	251	244	-3%	144	-43%	221	-12%	191	-24%	157	-37%	166	-34%	128	-49%	101	-60%
Glenelg WSPA	96	85	-12%	76	-21%	76	-21%	55	-43%	46	-52%	72	-25%	47	-51%	36	-62%
Glenormiston GMA	171	169	-1%	157	-8%	188	10%	175	2%	145	-15%	153	-11%	130	-24%	100	-42%
Gymbowen Zone (West Wimmera)	73	87	18%	66	-10%	111	52%	89	22%	61	-17%	86	18%	57	-22%	32	-57%
Hawkesdale GMA	197	192	-2%	205	4%	253	28%	222	12%	188	-5%	229	16%	189	-4%	139	-30%
Heywood GMA	174	168	-3%	181	4%	175	1%	146	-16%	109	-37%	143	-17%	113	-35%	68	-61%
Jan Juc GMA	127	94	-26%	59	-53%	88	-31%	78	-39%	64	-50%	71	-44%	59	-54%	39	-69%
Kiewa GMA	570	538	-6%	570	0%	516	-10%	493	-14%	397	-30%	470	-18%	429	-25%	290	-49%
Koo Wee Rup WSPA	243	191	-21%	253	4%	334	38%	281	16%	234	-4%	306	26%	239	-1%	154	-37%
Lancefield GMA	292	279	-4%	82	-72%	283	-3%	142	-51%	110	-62%	226	-23%	91	-69%	56	-81%
Leongatha GMA	372	350	-6%	270	-27%	342	-8%	287	-23%	242	-35%	315	-15%	245	-34%	175	-53%
Little Desert Zone (West Wimmera)	21	19	-10%	31	44%	56	161%	42	97%	26	21%	42	97%	25	18%	11	-47%
Loddon Highlands WSPA	160	141	-12%	84	-47%	126	-21%	92	-42%	76	-52%	100	-38%	67	-58%	44	-72%
Lower Campaspe Valley WSPA	72	63	-13%	57	-20%	88	23%	65	-9%	50	-31%	72	0%	47	-34%	30	-58%
Lower Ovens GMA	396	366	-8%	181	-54%	339	-14%	259	-35%	205	-48%	291	-26%	207	-48%	131	-67%
Merrimu GMA	51	33	-35%	80	57%	92	81%	75	48%	59	17%	77	50%	55	8%	36	-29%

GMU	Average annual recharge ML/km^2/yr (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
		Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ	Vol.	% Δ
Mid Goulburn GMA	104	103	0%	92	-11%	122	18%	98	-6%	82	-21%	105	1%	79	-24%	56	-46%
Mid Loddon GMA	62	53	-15%	68	10%	99	61%	79	28%	60	-2%	85	38%	60	-3%	38	-38%
Moe GMA	315	301	-5%	284	-10%	347	10%	281	-11%	233	-26%	303	-4%	229	-27%	163	-48%
Moorabbin GMA	193	145	-25%	151	-21%	232	20%	175	-9%	130	-32%	202	5%	134	-31%	74	-61%
Nepean GMA	154	111	-27%	183	19%	256	67%	216	41%	180	17%	223	45%	174	13%	132	-14%
Neuarpur Zone (West Wimmera)	104	119	15%	70	-33%	92	-11%	85	-18%	64	-38%	80	-23%	64	-38%	48	-54%
Newlingrook GMA	311	315	1%	286	-8%	323	4%	262	-16%	191	-39%	307	-1%	224	-28%	152	-51%
Northern Zone (West Wimmera)	56	58	3%	39	-30%	59	5%	47	-17%	32	-43%	48	-14%	34	-39%	20	-63%
Nullawarre WSPA	251	247	-2%	239	-5%	260	4%	217	-14%	170	-32%	229	-9%	173	-31%	123	-51%
Shepparton Irrigation GMA	58	49	-16%	78	33%	100	72%	79	36%	62	6%	89	54%	64	10%	41	-29%
South West Limestone GMA	184	177	-4%	149	-19%	174	-6%	145	-21%	121	-34%	153	-17%	117	-36%	89	-52%
Southern Zone (West Wimmera)	114	121	6%	86	-24%	114	0%	98	-14%	67	-42%	91	-20%	68	-41%	42	-63%
Strathbogie GMA	277	280	1%	146	-47%	213	-23%	175	-37%	150	-46%	175	-37%	133	-52%	99	-64%
Tarwin GMA	201	174	-13%	269	34%	370	84%	312	55%	263	31%	330	65%	262	31%	193	-4%
Upper Goulburn GMA	422	418	-1%	245	-42%	374	-11%	313	-26%	222	-47%	319	-24%	238	-44%	119	-72%
Upper Murray GMA	497	506	2%	444	-11%	385	-23%	352	-29%	249	-50%	371	-25%	292	-41%	177	-64%
Upper Ovens WSPA	685	621	-9%	483	-29%	707	3%	583	-15%	470	-31%	645	-6%	503	-27%	343	-50%
Wa De Lock GMA	135	129	-5%	157	16%	211	56%	176	31%	147	9%	178	32%	139	3%	104	-23%
Wandin Yallock GMA	496	521	5%	356	-28%	419	-16%	339	-32%	290	-42%	372	-25%	276	-44%	213	-57%
Warrion WSPA	90	85	-5%	135	50%	134	49%	113	26%	87	-3%	99	10%	71	-21%	50	-44%
West Goulburn GMA	118	106	-11%	92	-22%	134	13%	105	-11%	84	-29%	111	-6%	79	-33%	53	-55%
Wy Yung GMA	147	139	-6%	143	-3%	240	63%	185	26%	134	-9%	207	41%	144	-2%	77	-48%
Yangery WSPA	215	213	-1%	167	-22%	184	-14%	156	-27%	127	-41%	166	-23%	131	-39%	97	-55%



Appendix Q

Groundwater use as a percentage of recharge by GMU

Current use

PCV use

200% PCV use

Table Q-1 Licenced groundwater use as a percentage of average annual recharge by GMU for future scenarios with current use– no CC- no climate change/ current climate, LCC – low climate change, MCC – medium climate change, HCC – high climate change.

GMU	Groundwater use as a percentage of average annual recharge - Current pumping (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
	% Rech.	% Rech.	% Δ	% Rech.	% Rech.	% Rech.	% Rech.	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ
Barnawartha GMA	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%	0.1%	0.2%	0.2%	0.3%	0.2%	0.2%	0.1%	0.3%	0.2%	0.5%	0.4%
Big Desert Zone (West Wimmera)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Broken GMA	0.1%	0.1%	0.0%	0.1%	0.1%	0.1%	0.0%	0.1%	0.0%	0.2%	0.1%	0.1%	0.0%	0.1%	0.1%	0.2%	0.2%
Bungaree GMA	2.9%	3.0%	0.1%	5.7%	2.8%	3.8%	1.0%	4.8%	1.9%	5.9%	3.1%	4.6%	1.7%	6.4%	3.6%	9.5%	6.7%
Cardigan GMA	0.8%	0.9%	0.1%	1.3%	0.5%	1.1%	0.3%	1.4%	0.6%	1.5%	0.7%	1.3%	0.5%	1.9%	1.1%	2.1%	1.3%
Central Victorian Mineral Springs GMA	0.2%	0.2%	0.0%	0.4%	0.2%	0.3%	0.1%	0.3%	0.1%	0.4%	0.3%	0.3%	0.2%	0.4%	0.2%	0.8%	0.7%
Colongulac GMA	0.9%	1.0%	0.0%	1.0%	0.1%	0.8%	-0.1%	0.9%	-0.1%	1.0%	0.1%	1.0%	0.0%	1.1%	0.2%	1.4%	0.5%
Denison GMA	21.4%	23.2%	1.8%	20.4%	-1.1%	15.2%	-6.2%	18.2%	-3.2%	21.8%	0.3%	18.1%	-3.3%	23.8%	2.3%	32.1%	10.6%
Deutgam WSPA	14.5%	29.6%	15.1%	5.0%	-9.5%	3.7%	-10.8%	4.7%	-9.8%	5.6%	-8.9%	4.1%	-10.4%	5.7%	-8.8%	7.7%	-6.8%
Eildon GMA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Frankston GMA	0.2%	0.3%	0.1%	0.3%	0.1%	0.1%	-0.1%	0.2%	0.0%	0.2%	0.0%	0.2%	0.0%	0.2%	0.0%	0.3%	0.1%
Gellibrand GMA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Gerangamete GMA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Glenelg WSPA	2.1%	2.4%	0.3%	2.7%	0.6%	2.7%	0.6%	3.7%	1.6%	4.4%	2.3%	2.8%	0.7%	4.3%	2.2%	5.6%	3.5%
Glenormiston GMA	6.9%	7.0%	0.1%	7.5%	0.6%	6.3%	-0.6%	6.8%	-0.1%	8.2%	1.2%	7.8%	0.8%	9.1%	2.2%	11.9%	5.0%
Gymbowen Zone (West Wimmera)	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%
Hawkesdale GMA	1.7%	1.8%	0.0%	1.7%	-0.1%	1.3%	-0.4%	1.5%	-0.2%	1.8%	0.1%	1.5%	-0.2%	1.8%	0.1%	2.4%	0.7%
Heywood GMA	1.6%	1.7%	0.1%	1.6%	-0.1%	1.6%	0.0%	2.0%	0.3%	2.6%	1.0%	2.0%	0.3%	2.5%	0.9%	4.2%	2.5%
Jan Juc GMA	1.0%	1.4%	0.4%	2.2%	1.2%	1.5%	0.5%	1.6%	0.6%	2.0%	1.0%	1.8%	0.8%	2.2%	1.2%	3.3%	2.3%
Kiewa GMA	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.1%
Koo Wee Rup WSPA	1.3%	1.6%	0.3%	1.2%	-0.1%	0.9%	-0.4%	1.1%	-0.2%	1.3%	0.0%	1.0%	-0.3%	1.3%	0.0%	2.0%	0.7%
Lancefield GMA	1.5%	1.6%	0.1%	5.5%	4.0%	1.6%	0.1%	3.2%	1.6%	4.1%	2.6%	2.0%	0.4%	5.0%	3.4%	8.0%	6.5%
Leongatha GMA	0.2%	0.2%	0.0%	0.2%	0.1%	0.2%	0.0%	0.2%	0.0%	0.2%	0.1%	0.2%	0.0%	0.2%	0.1%	0.3%	0.2%

GMU	Groundwater use as a percentage of average annual recharge - Current pumping (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
	% Rech.	% Rech.	% Δ	% Rech.	% Rech.	% Rech.	% Rech.	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ
Little Desert Zone (West Wimmera)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Loddon Highlands WSPA	1.1%	1.2%	0.1%	2.0%	1.0%	1.4%	0.3%	1.9%	0.8%	2.3%	1.2%	1.7%	0.6%	2.6%	1.5%	3.9%	2.8%
Lower Campaspe Valley WSPA	22.5%	25.7%	3.2%	28.3%	5.8%	18.3%	-4.2%	24.7%	2.2%	32.5%	10.0%	22.5%	0.0%	34.0%	11.5%	54.0%	31.5%
Lower Ovens GMA	0.2%	0.2%	0.0%	0.5%	0.3%	0.3%	0.0%	0.3%	0.1%	0.4%	0.2%	0.3%	0.1%	0.4%	0.2%	0.7%	0.5%
Merrimu GMA	10.3%	15.8%	5.6%	6.5%	-3.7%	5.7%	-4.6%	6.9%	-3.3%	8.8%	-1.5%	6.8%	-3.4%	9.5%	-0.7%	14.4%	4.1%
Mid Goulburn GMA	2.1%	2.1%	0.0%	2.3%	0.3%	1.8%	-0.3%	2.2%	0.1%	2.6%	0.5%	2.0%	0.0%	2.7%	0.7%	3.8%	1.8%
Mid Loddon GMA	12.4%	14.5%	2.1%	11.3%	-1.1%	7.7%	-4.7%	9.7%	-2.7%	12.7%	0.3%	9.0%	-3.4%	12.8%	0.4%	20.2%	7.7%
Moe GMA	0.7%	0.7%	0.0%	0.8%	0.1%	0.6%	-0.1%	0.8%	0.1%	0.9%	0.2%	0.7%	0.0%	1.0%	0.3%	1.3%	0.6%
Moorabbin GMA	0.3%	0.5%	0.1%	0.4%	0.1%	0.3%	-0.1%	0.4%	0.0%	0.5%	0.2%	0.3%	0.0%	0.5%	0.2%	0.9%	0.6%
Nepean GMA	13.2%	18.2%	5.0%	11.1%	-2.1%	7.9%	-5.3%	9.4%	-3.8%	11.3%	-1.9%	9.1%	-4.1%	11.7%	-1.6%	15.4%	2.2%
Neuarpur Zone (West Wimmera)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
Newlingrook GMA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Northern Zone (West Wimmera)	0.5%	0.4%	0.0%	0.7%	0.2%	0.4%	0.0%	0.5%	0.1%	0.8%	0.3%	0.5%	0.1%	0.8%	0.3%	1.2%	0.8%
Nullawarre WSPA	7.8%	7.9%	0.1%	8.2%	0.4%	7.5%	-0.3%	9.0%	1.2%	11.5%	3.7%	8.5%	0.8%	11.3%	3.5%	15.9%	8.1%
Shepparton Irrigation GMA	14.1%	16.7%	2.6%	10.6%	-3.5%	8.2%	-5.9%	10.4%	-3.8%	13.3%	-0.8%	9.2%	-4.9%	12.8%	-1.3%	19.9%	5.7%
South West Limestone GMA	1.5%	1.5%	0.1%	1.8%	0.4%	1.6%	0.1%	1.9%	0.4%	2.2%	0.8%	1.8%	0.3%	2.3%	0.8%	3.1%	1.6%
Southern Zone (West Wimmera)	0.2%	0.2%	0.0%	0.3%	0.1%	0.2%	0.0%	0.3%	0.0%	0.4%	0.2%	0.3%	0.1%	0.4%	0.2%	0.6%	0.4%
Strathbogie GMA	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.1%	0.1%	0.1%
Tarwin GMA	0.2%	0.2%	0.0%	0.1%	0.0%	0.1%	-0.1%	0.1%	-0.1%	0.1%	0.0%	0.1%	-0.1%	0.1%	0.0%	0.2%	0.0%
Upper Goulburn GMA	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.2%	0.1%
Upper Murray GMA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Upper Ovens WSPA	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.2%	0.1%
Wa De Lock GMA	8.0%	8.4%	0.4%	6.9%	-1.1%	5.1%	-2.9%	6.1%	-1.9%	7.4%	-0.7%	6.1%	-2.0%	7.8%	-0.3%	10.4%	2.3%
Wandin Yallock GMA	1.9%	1.8%	-0.1%	2.7%	0.7%	2.3%	0.4%	2.8%	0.9%	3.3%	1.4%	2.5%	0.6%	3.4%	1.5%	4.4%	2.5%
Warrion WSPA	8.0%	8.5%	0.4%	5.3%	-2.7%	5.4%	-2.7%	6.4%	-1.7%	8.3%	0.2%	7.3%	-0.7%	10.2%	2.2%	14.3%	6.3%

GMU	Groundwater use as a percentage of average annual recharge - Current pumping (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
	% Rech.	% Rech.	% Δ	% Rech.	% Rech.	% Rech.	% Rech.	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ
West Goulburn GMA	0.6%	0.6%	0.1%	0.7%	0.2%	0.5%	-0.1%	0.6%	0.1%	0.8%	0.2%	0.6%	0.0%	0.8%	0.3%	1.2%	0.7%
Wy Yung GMA	8.4%	8.9%	0.5%	8.7%	0.2%	5.2%	-3.3%	6.7%	-1.7%	9.3%	0.8%	6.0%	-2.5%	8.6%	0.2%	16.2%	7.8%
Yangery WSPA	5.4%	5.5%	0.0%	7.0%	1.6%	6.4%	0.9%	7.5%	2.0%	9.2%	3.8%	7.0%	1.6%	8.9%	3.5%	12.0%	6.6%

Table Q-2 **Licenced groundwater use as a percentage of average annual recharge by GMU for future scenarios with PCV use–** no CC- no climate change/ current climate, LCC – low climate change, MCC – medium climate change, HCC – high climate change.

GMU	Groundwater use as a percentage of average annual recharge - PCV pumping rate (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
	% Rech.	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ
Barnawartha GMA	2.9%	3.1%	0.3%	4.9%	2.1%	7.1%	4.2%	11.4%	8.6%	14.3%	11.4%	8.3%	5.5%	15.0%	12.2%	24.5%	21.6%
Big Desert Zone (West Wimmera)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Broken GMA	0.3%	0.3%	0.0%	0.7%	0.3%	0.5%	0.1%	0.6%	0.3%	0.8%	0.4%	0.6%	0.2%	0.8%	0.4%	1.3%	0.9%
Bungaree GMA	6.0%	6.2%	0.2%	11.8%	5.8%	8.0%	2.0%	10.0%	4.0%	12.3%	6.4%	9.5%	3.5%	13.4%	7.4%	19.8%	13.9%
Cardigan GMA	4.1%	4.5%	0.4%	6.9%	2.8%	5.5%	1.4%	6.9%	2.8%	7.8%	3.7%	6.6%	2.5%	9.5%	5.4%	10.7%	6.6%
Central Victorian Mineral Springs GMA	0.5%	0.5%	0.1%	1.2%	0.7%	0.8%	0.3%	0.8%	0.3%	1.3%	0.8%	0.9%	0.5%	1.2%	0.7%	2.5%	2.0%
Colongulac GMA	3.4%	3.4%	0.0%	3.7%	0.3%	2.8%	-0.5%	3.1%	-0.3%	3.7%	0.3%	3.4%	0.0%	4.1%	0.7%	5.0%	1.7%
Denison GMA	37.4%	40.5%	3.1%	35.6%	-1.8%	26.5%	-10.9%	31.8%	-5.6%	38.0%	0.6%	31.6%	-5.8%	41.5%	4.1%	55.9%	18.5%
Deutgam WSPA	87.6%	178.6%	91.0%	30.2%	-57.3%	22.5%	-65.1%	28.5%	-59.1%	34.0%	-53.6%	24.7%	-62.9%	34.2%	-53.3%	46.4%	-41.2%
Eildon GMA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%
Frankston GMA	2.4%	3.0%	0.7%	3.2%	0.8%	1.7%	-0.6%	2.2%	-0.2%	2.6%	0.2%	2.0%	-0.4%	2.6%	0.3%	3.4%	1.0%
Gellibrand GMA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Gerangamete GMA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Glenelg WSPA	8.2%	9.3%	1.1%	10.4%	2.2%	10.4%	2.2%	14.3%	6.1%	17.2%	9.0%	10.8%	2.7%	16.8%	8.6%	21.6%	13.5%
Glenormiston GMA	13.3%	13.4%	0.2%	14.4%	1.2%	12.1%	-1.2%	13.0%	-0.3%	15.6%	2.4%	14.9%	1.6%	17.5%	4.2%	22.8%	9.5%
Gymbowen Zone (West Wimmera)	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.2%	0.1%
Hawkesdale GMA	4.0%	4.1%	0.1%	3.9%	-0.1%	3.1%	-0.9%	3.6%	-0.4%	4.2%	0.2%	3.5%	-0.6%	4.2%	0.2%	5.7%	1.7%
Heywood GMA	5.0%	5.2%	0.2%	4.8%	-0.2%	5.0%	0.0%	6.0%	1.0%	8.0%	3.0%	6.1%	1.1%	7.8%	2.7%	12.8%	7.8%
Jan Juc GMA	11.5%	15.7%	4.1%	24.8%	13.2%	16.7%	5.2%	18.9%	7.3%	22.9%	11.4%	20.7%	9.1%	24.9%	13.3%	37.8%	26.2%
Kiewa GMA	0.3%	0.3%	0.0%	0.3%	0.0%	0.3%	0.0%	0.3%	0.0%	0.4%	0.1%	0.3%	0.1%	0.4%	0.1%	0.5%	0.3%
Koo Wee Rup WSPA	4.3%	5.4%	1.1%	4.1%	-0.2%	3.1%	-1.2%	3.7%	-0.6%	4.4%	0.2%	3.4%	-0.9%	4.3%	0.1%	6.7%	2.5%
Lancefield GMA	7.2%	7.6%	0.3%	26.0%	18.7%	7.5%	0.2%	14.9%	7.7%	19.3%	12.0%	9.4%	2.1%	23.4%	16.1%	37.6%	30.3%
Leongatha GMA	1.9%	2.0%	0.1%	2.6%	0.7%	2.0%	0.2%	2.4%	0.6%	2.9%	1.0%	2.2%	0.3%	2.9%	1.0%	4.0%	2.1%

GMU	Groundwater use as a percentage of average annual recharge - PCV pumping rate (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
	% Rech.	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ
Little Desert Zone (West Wimmera)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Loddon Highlands WSPA	3.2%	3.6%	0.4%	6.0%	2.8%	4.0%	0.9%	5.5%	2.3%	6.6%	3.5%	5.1%	1.9%	7.6%	4.4%	11.5%	8.3%
Lower Campaspe Valley WSPA	41.1%	47.0%	5.9%	51.7%	10.6%	33.5%	-7.6%	45.1%	4.0%	59.3%	18.2%	41.2%	0.0%	62.1%	21.0%	98.7%	57.5%
Lower Ovens GMA	0.7%	0.8%	0.1%	1.6%	0.9%	0.9%	0.1%	1.1%	0.4%	1.4%	0.7%	1.0%	0.3%	1.4%	0.7%	2.2%	1.5%
Merrimu GMA	28.2%	43.4%	15.2%	17.9%	-10.3%	15.6%	-12.6%	19.0%	-9.2%	24.1%	-4.0%	18.7%	-9.4%	26.1%	-2.1%	39.5%	11.3%
Mid Goulburn GMA	15.4%	15.4%	0.0%	17.4%	2.0%	13.1%	-2.3%	16.3%	1.0%	19.4%	4.0%	15.2%	-0.2%	20.3%	4.9%	28.5%	13.1%
Mid Loddon GMA	19.7%	23.1%	3.4%	17.9%	-1.8%	12.3%	-7.5%	15.4%	-4.3%	20.2%	0.4%	14.3%	-5.4%	20.3%	0.6%	32.0%	12.3%
Moe GMA	2.6%	2.8%	0.1%	2.9%	0.3%	2.4%	-0.2%	3.0%	0.3%	3.6%	0.9%	2.7%	0.1%	3.6%	1.0%	5.1%	2.4%
Moorabbin GMA	1.0%	1.3%	0.3%	1.2%	0.3%	0.8%	-0.2%	1.1%	0.1%	1.4%	0.5%	0.9%	0.0%	1.4%	0.4%	2.5%	1.6%
Nepean GMA	27.1%	37.3%	10.2%	22.7%	-4.3%	16.2%	-10.8%	19.3%	-7.8%	23.1%	-4.0%	18.6%	-8.5%	23.9%	-3.2%	31.6%	4.5%
Neuarpur Zone (West Wimmera)	0.2%	0.2%	0.0%	0.4%	0.1%	0.3%	0.0%	0.3%	0.1%	0.4%	0.2%	0.3%	0.1%	0.4%	0.1%	0.5%	0.3%
Newlingrook GMA	1.4%	1.4%	0.0%	1.5%	0.1%	1.3%	-0.1%	1.6%	0.3%	2.3%	0.9%	1.4%	0.0%	1.9%	0.5%	2.8%	1.4%
Northern Zone (West Wimmera)	1.4%	1.3%	0.0%	1.9%	0.6%	1.3%	-0.1%	1.6%	0.3%	2.4%	1.0%	1.6%	0.2%	2.2%	0.9%	3.7%	2.3%
Nullawarre WSPA	14.2%	14.4%	0.3%	14.9%	0.7%	13.7%	-0.5%	16.4%	2.2%	20.8%	6.7%	15.5%	1.4%	20.5%	6.3%	29.0%	14.8%
Shepparton Irrigation GMA	68.0%	80.7%	12.7%	51.0%	-17.0%	39.5%	-28.5%	49.9%	-18.1%	64.0%	-4.0%	44.3%	-23.7%	61.7%	-6.3%	95.7%	27.7%
South West Limestone GMA	4.0%	4.1%	0.2%	5.0%	1.0%	4.2%	0.2%	5.1%	1.1%	6.1%	2.1%	4.8%	0.8%	6.3%	2.3%	8.3%	4.3%
Southern Zone (West Wimmera)	1.0%	1.0%	-0.1%	1.4%	0.3%	1.0%	0.0%	1.2%	0.2%	1.8%	0.7%	1.3%	0.3%	1.8%	0.7%	2.8%	1.8%
Strathbogie GMA	0.1%	0.1%	0.0%	0.3%	0.1%	0.2%	0.0%	0.2%	0.1%	0.3%	0.1%	0.2%	0.1%	0.3%	0.1%	0.4%	0.2%
Tarwin GMA	0.8%	0.9%	0.1%	0.6%	-0.2%	0.4%	-0.4%	0.5%	-0.3%	0.6%	-0.2%	0.5%	-0.3%	0.6%	-0.2%	0.9%	0.0%
Upper Goulburn GMA	0.3%	0.3%	0.0%	0.6%	0.2%	0.4%	0.0%	0.5%	0.1%	0.6%	0.3%	0.5%	0.1%	0.6%	0.3%	1.2%	0.9%
Upper Murray GMA	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.1%	0.1%	0.0%	0.1%	0.0%	0.2%	0.1%
Upper Ovens WSPA	0.3%	0.3%	0.0%	0.4%	0.1%	0.3%	0.0%	0.4%	0.1%	0.5%	0.1%	0.3%	0.0%	0.4%	0.1%	0.6%	0.3%

GMU	Groundwater use as a percentage of average annual recharge - PCV pumping rate (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
	% Rech.	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ
Wa De Lock GMA	26.4%	27.7%	1.3%	22.7%	-3.7%	16.9%	-9.5%	20.2%	-6.2%	24.2%	-2.2%	19.9%	-6.4%	25.6%	-0.8%	34.1%	7.7%
Wandin Yallock GMA	9.0%	8.6%	-0.4%	12.5%	3.5%	10.7%	1.7%	13.2%	4.2%	15.4%	6.4%	12.0%	3.0%	16.2%	7.2%	20.9%	11.9%
Warrion WSPA	30.4%	31.9%	1.5%	20.2%	-10.2%	20.3%	-10.0%	24.0%	-6.3%	31.3%	0.9%	27.6%	-2.8%	38.5%	8.1%	54.0%	23.6%
West Goulburn GMA	15.1%	16.9%	1.8%	19.5%	4.3%	13.4%	-1.7%	17.1%	1.9%	21.4%	6.2%	16.2%	1.0%	22.6%	7.5%	33.5%	18.4%
Wy Yung GMA	71.2%	75.5%	4.3%	73.2%	2.0%	43.6%	-27.6%	56.6%	-14.6%	78.4%	7.2%	50.5%	-20.7%	72.7%	1.5%	136.7%	65.5%
Yangery WSPA	19.2%	19.4%	0.2%	24.8%	5.5%	22.5%	3.2%	26.5%	7.2%	32.5%	13.3%	24.9%	5.7%	31.5%	12.3%	42.6%	23.4%

Table Q-3 **Licenced groundwater use as a percentage of average annual recharge by GMU for future scenarios with <u>200% PCV use</u>–** no CC- no climate change/ current climate, LCC – low climate change, MCC – medium climate change, HCC – high climate change.

GMU	Groundwater use as a percentage of average annual recharge - 200% PCV pumping rate (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
	% Rech.	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ
Barnawartha GMA	5.7%	6.3%	0.5%	9.9%	4.2%	14.2%	8.5%	22.8%	17.1%	28.6%	22.8%	16.6%	10.9%	30.1%	24.4%	49.0%	43.3%
Big Desert Zone (West Wimmera)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Broken GMA	0.7%	0.7%	0.0%	1.4%	0.7%	1.0%	0.3%	1.2%	0.5%	1.6%	0.9%	1.1%	0.4%	1.5%	0.8%	2.5%	1.9%
Bungaree GMA	11.9%	12.4%	0.5%	23.6%	11.6%	16.0%	4.0%	20.0%	8.1%	24.7%	12.7%	19.0%	7.0%	26.7%	14.8%	39.7%	27.7%
Cardigan GMA	8.2%	9.0%	0.8%	13.8%	5.6%	11.0%	2.8%	13.8%	5.6%	15.6%	7.4%	13.1%	4.9%	19.0%	10.8%	21.4%	13.2%
Central Victorian Mineral Springs GMA	1.0%	1.1%	0.1%	2.4%	1.4%	1.5%	0.5%	1.6%	0.7%	2.5%	1.6%	1.9%	0.9%	2.4%	1.4%	5.0%	4.1%
Colongulac GMA	6.7%	6.8%	0.1%	7.4%	0.7%	5.7%	-1.1%	6.2%	-0.5%	7.4%	0.6%	6.8%	0.0%	8.1%	1.4%	10.1%	3.3%
Denison GMA	74.8%	81.0%	6.2%	71%	-3.7%	53.1%	-21.7%	64%	-11.2%	76%	1.1%	63%	-11.5%	83%	8.2%	112%	37%
Deutgam WSPA	175%	357%	182%	61%	-115%	45%	-130%	57%	-118%	68%	-107%	49%	-126%	69%	-107%	93%	-82%
Eildon GMA	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%	0.1%	0.1%	0.0%	0.1%	0.1%	0.2%	0.2%
Frankston GMA	4.7%	6.0%	1.3%	6.4%	1.7%	3.5%	-1.3%	4.3%	-0.4%	5.2%	0.4%	3.9%	-0.8%	5.3%	0.5%	6.8%	2.1%
Gellibrand GMA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Gerangamete GMA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Glenelg WSPA	16.4%	18.5%	2.1%	20.7%	4.3%	20.7%	4.4%	28.6%	12.2%	34.3%	18.0%	21.7%	5.3%	33.6%	17.2%	43.3%	26.9%
Glenormiston GMA	26.6%	26.9%	0.3%	28.9%	2.3%	24.2%	-2.4%	26.0%	-0.6%	31.3%	4.7%	29.8%	3.2%	34.9%	8.4%	45.7%	19.1%
Gymbowen Zone (West Wimmera)	0.2%	0.2%	0.0%	0.2%	0.0%	0.1%	-0.1%	0.2%	0.0%	0.2%	0.0%	0.2%	0.0%	0.2%	0.1%	0.4%	0.2%
Hawkesdale GMA	8.0%	8.2%	0.2%	7.7%	-0.3%	6.3%	-1.8%	7.1%	-0.9%	8.4%	0.4%	6.9%	-1.1%	8.4%	0.3%	11.4%	3.4%
Heywood GMA	10.1%	10.4%	0.3%	9.7%	-0.4%	10.0%	-0.1%	12.0%	2.0%	16.1%	6.0%	12.2%	2.1%	15.6%	5.5%	25.6%	15.5%
Jan Juc GMA	23.1%	31.3%	8.2%	49.6%	26.5%	33.4%	10.3%	37.8%	14.7%	45.8%	22.7%	41.3%	18.2%	49.7%	26.6%	75.5%	52.4%
Kiewa GMA	0.5%	0.6%	0.0%	0.5%	0.0%	0.6%	0.1%	0.6%	0.1%	0.8%	0.2%	0.6%	0.1%	0.7%	0.2%	1.1%	0.5%
Koo Wee Rup WSPA	8.5%	10.8%	2.3%	8.2%	-0.4%	6.2%	-2.3%	7.3%	-1.2%	8.8%	0.3%	6.7%	-1.8%	8.6%	0.1%	13.4%	4.9%
Lancefield GMA	14.5%	15.2%	0.7%	51.9%	37.4%	15.0%	0.5%	29.8%	15.3%	38.5%	24.0%	18.7%	4.2%	46.7%	32.2%	75.2%	60.7%
Leongatha GMA	3.8%	4.0%	0.2%	5.2%	1.4%	4.1%	0.3%	4.9%	1.1%	5.8%	2.0%	4.4%	0.7%	5.7%	2.0%	8.0%	4.2%

GMU	Groundwater use as a percentage of average annual recharge - 200% PCV pumping rate (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
	% Rech.	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ
Little Desert Zone (West Wimmera)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Loddon Highlands WSPA	6.3%	7.2%	0.9%	12.0%	5.7%	8.0%	1.7%	10.9%	4.6%	13.2%	6.9%	10.1%	3.8%	15.1%	8.8%	23.0%	16.6%
Lower Campaspe Valley WSPA	82.2%	94.0%	11.7%	103.3%	21.1%	67.0%	-15.3%	90.2%	8.0%	118.7%	36.5%	82.3%	0.1%	124.2%	41.9%	197.3%	115.1%
Lower Ovens GMA	1.5%	1.6%	0.1%	3.2%	1.7%	1.7%	0.2%	2.2%	0.8%	2.8%	1.4%	2.0%	0.5%	2.8%	1.3%	4.4%	3.0%
Merrimu GMA	56.3%	86.8%	30.5%	35.8%	-21%	31.2%	-25.2%	38.0%	-18.4%	48.3%	-8.1%	37.5%	-18.9%	52.2%	-4.1%	78.9%	22.6%
Mid Goulburn GMA	30.8%	30.8%	0.0%	34.7%	4.0%	26.1%	-4.7%	32.7%	1.9%	38.8%	8.0%	30.3%	-0.4%	40.5%	9.8%	57.0%	26.2%
Mid Loddon GMA	39.5%	46.2%	6.7%	35.9%	-3.6%	24.6%	-14.9%	30.9%	-8.6%	40.4%	0.9%	28.7%	-10.8%	40.6%	1.1%	64.1%	24.6%
Moe GMA	5.3%	5.5%	0.3%	5.9%	0.6%	4.8%	-0.5%	5.9%	0.6%	7.1%	1.9%	5.5%	0.2%	7.3%	2.0%	10.2%	4.9%
Moorabbin GMA	2.0%	2.6%	0.6%	2.5%	0.5%	1.6%	-0.3%	2.2%	0.2%	2.9%	0.9%	1.9%	-0.1%	2.8%	0.9%	5.1%	3.1%
Nepean GMA	54.1%	74.6%	20.5%	45.5%	-8.7%	32.5%	-21.7%	38.5%	-15.6%	46.2%	-7.9%	37.2%	-16.9%	47.7%	-6.4%	63.2%	9.0%
Neuarpur Zone (West Wimmera)	0.5%	0.4%	-0.1%	0.7%	0.2%	0.6%	0.1%	0.6%	0.1%	0.8%	0.3%	0.6%	0.1%	0.8%	0.3%	1.1%	0.6%
Newlingrook GMA	2.8%	2.7%	0.0%	3.0%	0.2%	2.7%	-0.1%	3.3%	0.5%	4.5%	1.7%	2.8%	0.0%	3.8%	1.1%	5.6%	2.9%
Northern Zone (West Wimmera)	2.7%	2.6%	-0.1%	3.9%	1.2%	2.6%	-0.1%	3.3%	0.5%	4.8%	2.1%	3.1%	0.4%	4.5%	1.8%	7.4%	4.7%
Nullawarre WSPA	28.3%	28.8%	0.5%	29.7%	1.4%	27.3%	-1.0%	32.8%	4.5%	41.7%	13.4%	31.1%	2.8%	41.0%	12.7%	57.9%	29.6%
Shepparton Irrigation GMA	136.0%	161.3%	25.3%	102.0%	-34%	79.0%	-57.1%	99.8%	-36.3%	128.0%	-8.0%	88.5%	-47.5%	123.5%	-12.5%	191.4%	55.4%
South West Limestone GMA	8.0%	8.3%	0.3%	9.9%	1.9%	8.5%	0.5%	10.1%	2.2%	12.2%	4.2%	9.6%	1.6%	12.5%	4.6%	16.6%	8.6%
Southern Zone (West Wimmera)	2.1%	2.0%	-0.1%	2.8%	0.7%	2.1%	0.0%	2.4%	0.3%	3.6%	1.5%	2.6%	0.5%	3.5%	1.4%	5.7%	3.6%
Strathbogie GMA	0.3%	0.3%	0.0%	0.5%	0.2%	0.4%	0.1%	0.4%	0.2%	0.5%	0.2%	0.4%	0.2%	0.6%	0.3%	0.8%	0.5%
Tarwin GMA	1.6%	1.9%	0.2%	1.2%	-0.4%	0.9%	-0.8%	1.1%	-0.6%	1.3%	-0.4%	1.0%	-0.6%	1.3%	-0.4%	1.7%	0.1%
Upper Goulburn GMA	0.7%	0.7%	0.0%	1.2%	0.5%	0.8%	0.1%	0.9%	0.2%	1.3%	0.6%	0.9%	0.2%	1.2%	0.5%	2.4%	1.7%
Upper Murray GMA	0.1%	0.1%	0.0%	0.1%	0.0%	0.2%	0.0%	0.2%	0.1%	0.3%	0.1%	0.2%	0.0%	0.2%	0.1%	0.4%	0.2%
Upper Ovens WSPA	0.6%	0.7%	0.1%	0.9%	0.3%	0.6%	0.0%	0.7%	0.1%	0.9%	0.3%	0.7%	0.0%	0.8%	0.2%	1.2%	0.6%
Wa De Lock GMA	52.8%	55.3%	2.6%	45.4%	-7.4%	33.7%	-19.0%	40.4%	-12.4%	48.4%	-4.3%	39.9%	-12.9%	51.1%	-1.6%	68.2%	15.4%
Wandin Yallock GMA	18.0%	17.1%	-0.9%	25.1%	7.1%	21.3%	3.3%	26.3%	8.3%	30.8%	12.8%	24.0%	6.0%	32.4%	14.4%	41.8%	23.8%
Warrion WSPA	60.7%	63.8%	3.0%	40.4%	-20%	40.7%	-20.0%	48.1%	-12.7%	62.5%	1.8%	55.1%	-5.6%	77.0%	16.3%	108.0%	47.3%
West Goulburn GMA	30.3%	33.9%	3.6%	38.9%	8.7%	26.8%	-3.5%	34.1%	3.9%	42.7%	12.5%	32.3%	2.1%	45.2%	14.9%	67.1%	36.8%
Wy Yung GMA	142.4%	151.0%	8.6%	146.4%	4.0%	87.2%	-55.2%	113.3%	-29.1%	156.8%	14.4%	101.0%	-41.4%	145.5%	3.0%	273.5%	131.0%

GMU	Groundwater use as a percentage of average annual recharge - 200% PCV pumping rate (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
	% Rech.	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ	% Rech.	% Δ
Yangery WSPA	38.4%	38.8%	0.3%	49.5%	11.1%	44.9%	6.5%	52.9%	14.5%	65.0%	26.6%	49.8%	11.4%	63.1%	24.6%	85.2%	46.8%

Appendix R
Recharge as a proportion of rainfall by GMU

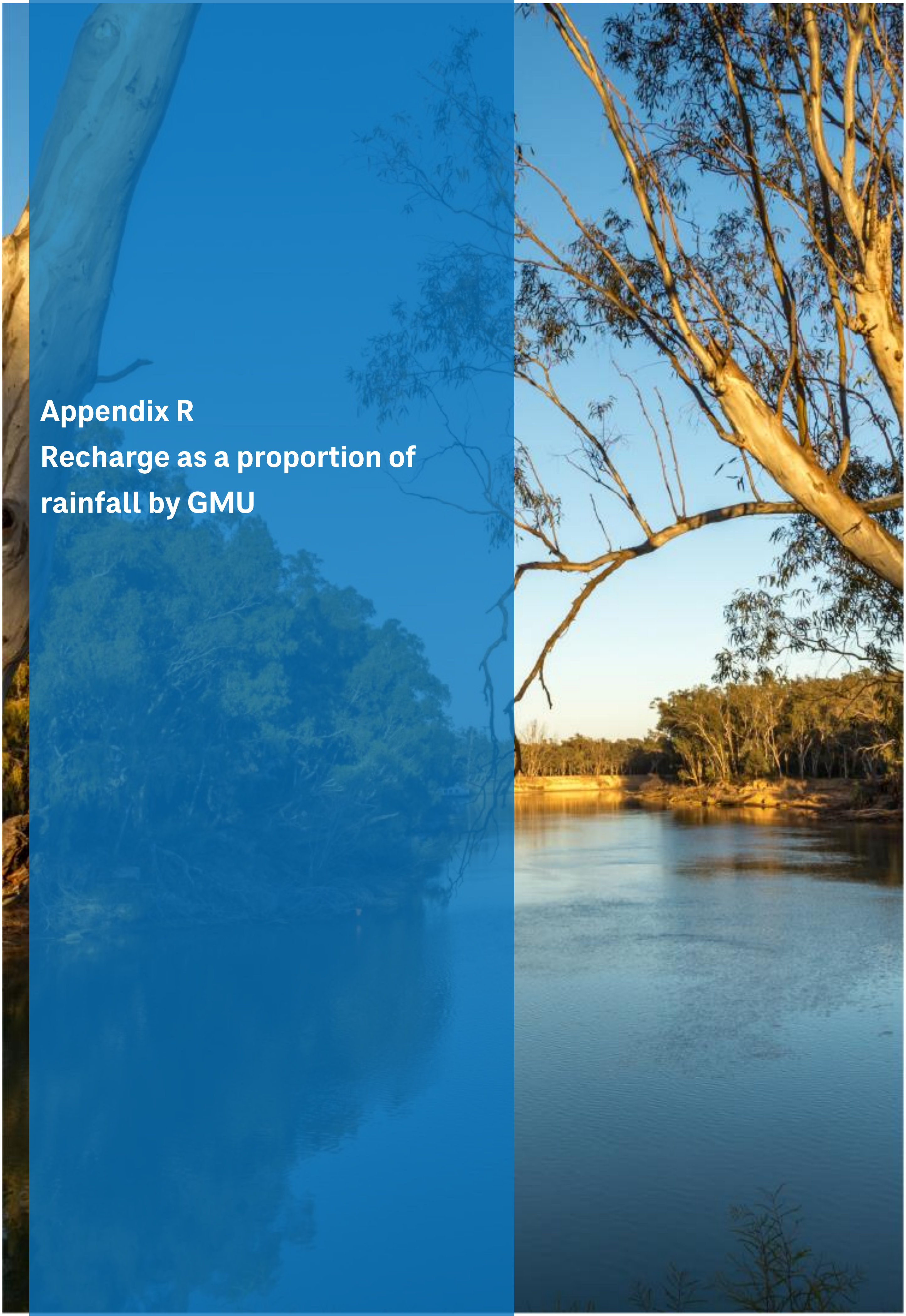
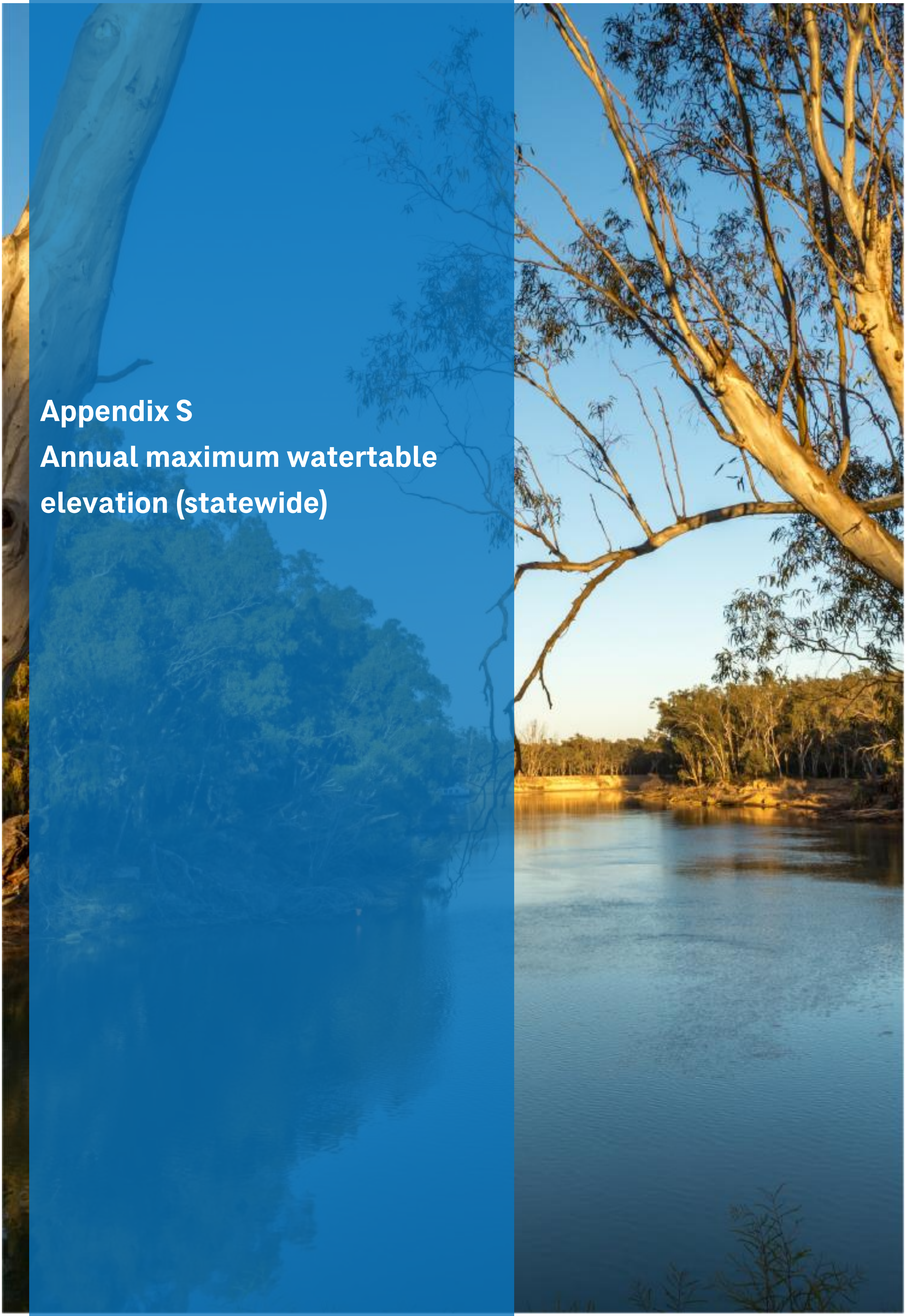


Table R-1 Estimated average annual recharge as a percentage of rainfall and change in percentage from baseline (1950-1974) for GMUs by modelled scenarios - LCC – low climate change, MCC – medium climate change, HCC – high climate change.

GMU	Average annual recharge as a percentage of rainfall (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
	% rain	% rain	% Δ	% rain	% Δ	% rain	% Δ	% rain	% Δ	% rain	% Δ	% rain	% Δ	% rain	% Δ	% rain	% Δ
Barnawartha GMA	28%	26%	-6%	17%	-37%	11%	-60%	7%	-74%	6%	-77%	9%	-67%	6%	-80%	4%	-86%
Big Desert Zone (West Wimmera)	6%	6%	-8%	11%	80%	14%	125%	11%	90%	9%	54%	11%	82%	9%	43%	7%	11%
Broken GMA	29%	32%	10%	18%	-39%	22%	-26%	19%	-35%	16%	-47%	18%	-37%	15%	-49%	10%	-64%
Bungaree GMA	37%	37%	0%	22%	-41%	28%	-24%	24%	-36%	21%	-44%	24%	-35%	18%	-50%	14%	-61%
Cardigan GMA	26%	26%	0%	19%	-29%	21%	-20%	18%	-33%	17%	-36%	18%	-32%	13%	-50%	14%	-48%
Central Victorian Mineral Springs GMA	34%	33%	-5%	16%	-52%	22%	-34%	22%	-37%	15%	-55%	18%	-48%	16%	-55%	8%	-75%
Colongulac GMA	22%	23%	2%	23%	5%	27%	20%	25%	14%	23%	3%	23%	3%	20%	-9%	18%	-17%
Denison GMA	24%	23%	-4%	29%	22%	33%	41%	29%	23%	26%	11%	29%	20%	23%	-2%	19%	-19%
Deutgam WSPA	13%	7%	-45%	49%	274%	57%	334%	47%	260%	42%	221%	52%	301%	40%	208%	33%	156%
Eildon GMA	49%	48%	-1%	27%	-45%	31%	-37%	26%	-46%	20%	-58%	27%	-45%	21%	-56%	12%	-75%
Frankston GMA	25%	21%	-15%	21%	-15%	36%	46%	30%	23%	27%	9%	32%	29%	25%	3%	22%	-11%
Gellibrand GMA	26%	24%	-8%	30%	17%	29%	11%	27%	4%	24%	-6%	24%	-7%	20%	-20%	20%	-24%
Gerangamete GMA	30%	30%	-2%	21%	-30%	26%	-12%	24%	-22%	21%	-30%	20%	-33%	17%	-45%	15%	-51%
Glenelg WSPA	13%	12%	-6%	11%	-14%	10%	-18%	8%	-37%	7%	-45%	10%	-20%	7%	-43%	6%	-52%
Glenormiston GMA	22%	23%	3%	24%	8%	25%	11%	24%	8%	21%	-4%	21%	-7%	19%	-16%	16%	-28%
Gymbowen Zone (West Wimmera)	14%	18%	26%	16%	9%	23%	59%	19%	34%	14%	-1%	18%	24%	13%	-11%	8%	-43%
Hawkesdale GMA	25%	26%	3%	30%	18%	33%	30%	31%	20%	28%	8%	31%	22%	28%	9%	23%	-11%
Heywood GMA	21%	22%	4%	25%	19%	22%	4%	19%	-8%	15%	-27%	19%	-11%	16%	-24%	11%	-50%
Jan Juc GMA	18%	14%	-22%	10%	-44%	13%	-29%	12%	-35%	10%	-42%	11%	-41%	9%	-48%	7%	-61%
Kiewa GMA	47%	47%	0%	56%	20%	43%	-8%	44%	-6%	37%	-20%	39%	-16%	39%	-17%	29%	-38%
Koo Wee Rup WSPA	27%	22%	-16%	31%	18%	38%	44%	34%	28%	30%	13%	35%	32%	30%	11%	21%	-21%
Lancefield GMA	32%	34%	6%	11%	-66%	33%	5%	18%	-45%	15%	-53%	27%	-16%	12%	-64%	8%	-74%
Leongatha GMA	36%	36%	-2%	30%	-18%	34%	-7%	30%	-17%	27%	-26%	32%	-13%	26%	-27%	21%	-43%
Little Desert Zone (West Wimmera)	4%	4%	-1%	8%	75%	12%	181%	10%	122%	6%	51%	9%	114%	6%	39%	3%	-28%
Loddon Highlands WSPA	25%	23%	-6%	16%	-37%	21%	-17%	16%	-36%	14%	-42%	16%	-35%	12%	-52%	9%	-64%

GMU	Average annual recharge as a percentage of rainfall (with % change from baseline (1950-1974))																
	Baseline 1950-1974	1975-1997		Current 1998-2020		2021-40 LCC		2021-2040 MCC		2021-40 HCC		2041-2065 LCC		2041-65 MCC		2041-65 HCC	
	% rain	% rain	% Δ	% rain	% Δ	% rain	% Δ	% rain	% Δ	% rain	% Δ	% rain	% Δ	% rain	% Δ	% rain	% Δ
Lower Campaspe Valley WSPA	15%	14%	-3%	14%	-4%	19%	32%	15%	3%	13%	-13%	15%	6%	11%	-23%	8%	-43%
Lower Ovens GMA	38%	38%	0%	21%	-46%	34%	-11%	28%	-28%	23%	-39%	29%	-24%	23%	-41%	16%	-58%
Merrimu GMA	11%	8%	-31%	21%	87%	21%	91%	18%	65%	15%	38%	18%	58%	14%	23%	10%	-8%
Mid Goulburn GMA	18%	20%	11%	20%	9%	23%	26%	19%	7%	18%	0%	19%	8%	16%	-12%	13%	-26%
Mid Loddon GMA	13%	12%	-7%	16%	28%	22%	71%	18%	43%	16%	21%	19%	44%	14%	10%	11%	-17%
Moe GMA	30%	31%	3%	33%	8%	35%	14%	30%	-2%	26%	-13%	31%	2%	25%	-17%	20%	-34%
Moorabbin GMA	25%	22%	-11%	26%	4%	35%	38%	28%	10%	22%	-13%	30%	21%	22%	-14%	14%	-46%
Nepean GMA	21%	25%	19%	43%	103%	57%	170%	50%	137%	44%	112%	49%	135%	41%	95%	35%	65%
Neuarpur Zone (West Wimmera)	19%	24%	27%	15%	-19%	18%	-4%	17%	-7%	15%	-22%	16%	-16%	14%	-26%	12%	-37%
Newlingrook GMA	27%	29%	7%	27%	-1%	29%	8%	25%	-9%	19%	-29%	28%	4%	22%	-20%	17%	-38%
Northern Zone (West Wimmera)	13%	14%	13%	11%	-17%	14%	13%	12%	-6%	9%	-29%	12%	-7%	9%	-29%	6%	-50%
Nullawarre WSPA	29%	31%	6%	32%	9%	32%	8%	27%	-5%	23%	-21%	29%	-2%	23%	-20%	18%	-37%
Shepparton Irrigation GMA	11%	11%	-2%	19%	64%	22%	91%	18%	61%	16%	39%	19%	67%	15%	33%	11%	0%
South West Limestone GMA	23%	23%	2%	21%	-10%	22%	-3%	19%	-15%	17%	-25%	20%	-12%	17%	-27%	14%	-39%
Southern Zone (West Wimmera)	20%	22%	11%	18%	-11%	20%	2%	18%	-7%	14%	-32%	17%	-17%	13%	-33%	10%	-52%
Strathbogie GMA	36%	39%	7%	23%	-37%	28%	-22%	25%	-32%	23%	-36%	23%	-36%	19%	-47%	17%	-54%
Tarwin GMA	24%	34%	41%	58%	142%	69%	189%	62%	159%	55%	131%	63%	164%	54%	127%	44%	83%
Upper Goulburn GMA	40%	42%	6%	29%	-29%	36%	-9%	32%	-20%	25%	-38%	32%	-21%	25%	-37%	15%	-64%
Upper Murray GMA	45%	50%	10%	47%	3%	36%	-20%	35%	-22%	27%	-41%	34%	-24%	29%	-35%	20%	-56%
Upper Ovens WSPA	49%	46%	-6%	40%	-17%	51%	3%	44%	-9%	38%	-23%	46%	-6%	39%	-21%	30%	-40%
Wa De Lock GMA	20%	21%	1%	28%	37%	32%	58%	28%	39%	25%	25%	28%	37%	23%	14%	20%	-3%
Wandin Yallock GMA	43%	48%	13%	36%	-16%	38%	-12%	32%	-25%	30%	-31%	34%	-22%	27%	-38%	24%	-45%
Warrion WSPA	14%	13%	-8%	24%	71%	20%	42%	18%	25%	15%	3%	15%	6%	11%	-19%	9%	-34%
West Goulburn GMA	20%	19%	-2%	18%	-7%	23%	19%	19%	-1%	17%	-13%	19%	-1%	15%	-23%	12%	-39%
Wy Yung GMA	19%	21%	8%	23%	20%	34%	76%	28%	44%	21%	10%	30%	55%	22%	17%	13%	-31%
Yangery WSPA	27%	31%	13%	26%	-4%	26%	-6%	23%	-16%	20%	-27%	24%	-12%	20%	-26%	17%	-39%

Appendix S
Annual maximum watertable elevation (statewide)



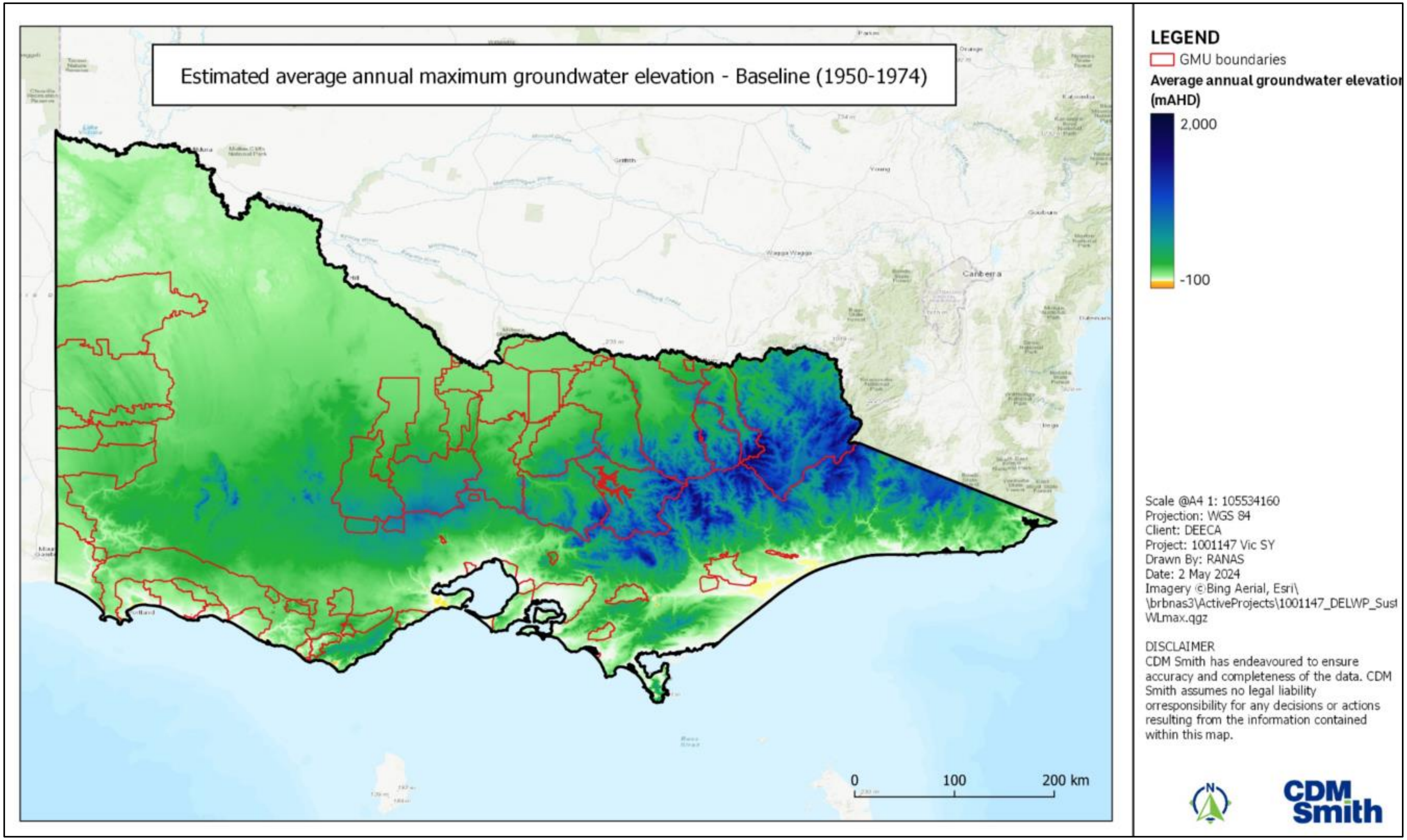
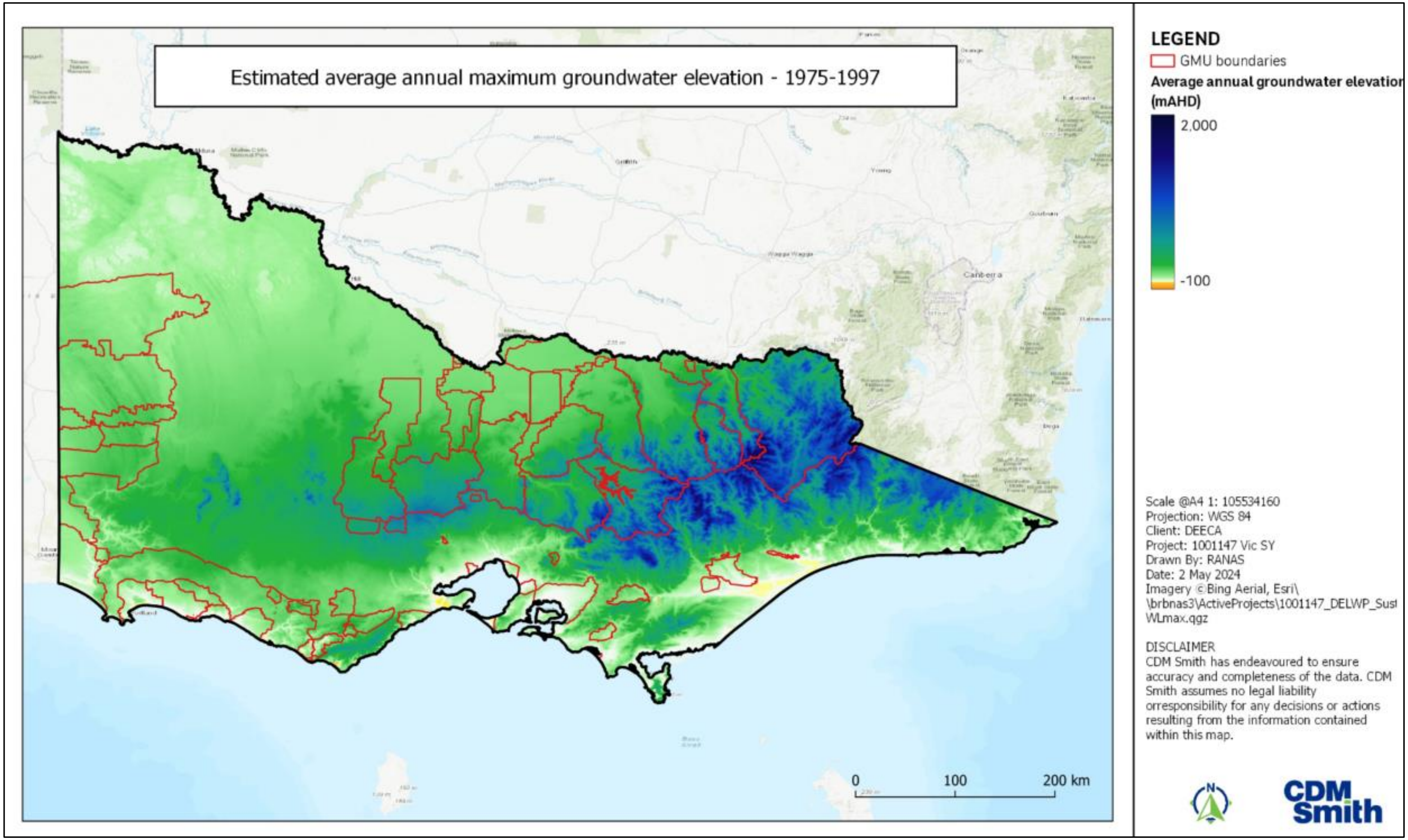


Figure S-1 Estimated average annual maximum watertable elevation (mAHD) – Baseline (1950-1974).



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Projection: WGS 84
Client: DEECA
Project: 1001147 Vic SY
Drawn By: RANAS
Date: 2 May 2024
Imagery ©Bing Aerial, Esri\
\brbnas3\ActiveProjects\1001147_DELWP_Sust
WLmax.qgz

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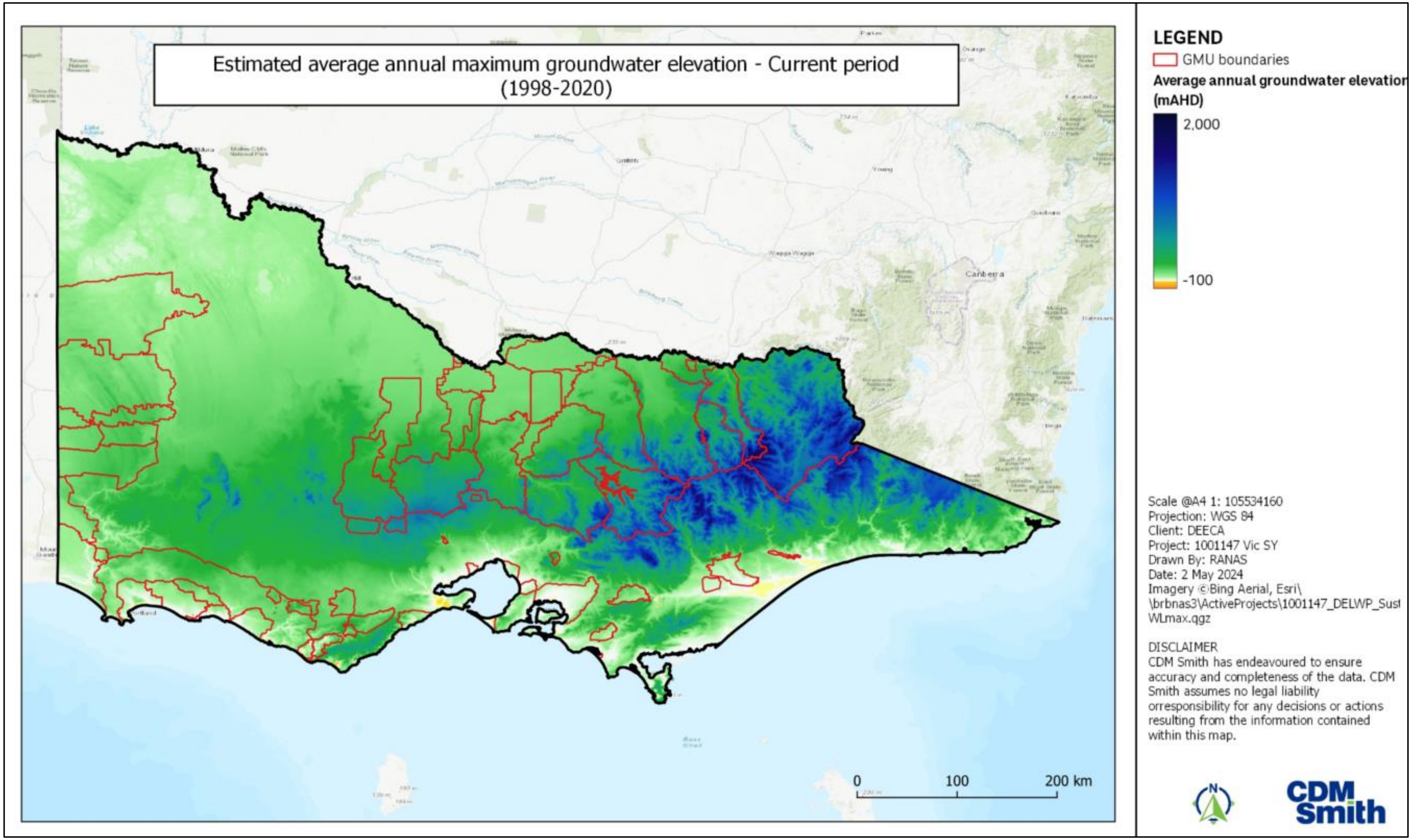
Figure S-2 **Estimated annual maximum watertable elevation (mAHD) – 1975-1997.**



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Projection: WGS 84
Client: DEECA
Project: 1001147 Vic SY
Drawn By: RANAS
Date: 2 May 2024
Imagery ©Bing Aerial, Esri\
\brbnas3\ActiveProjects\1001147_DELWP_Sus
WLmax.qgz

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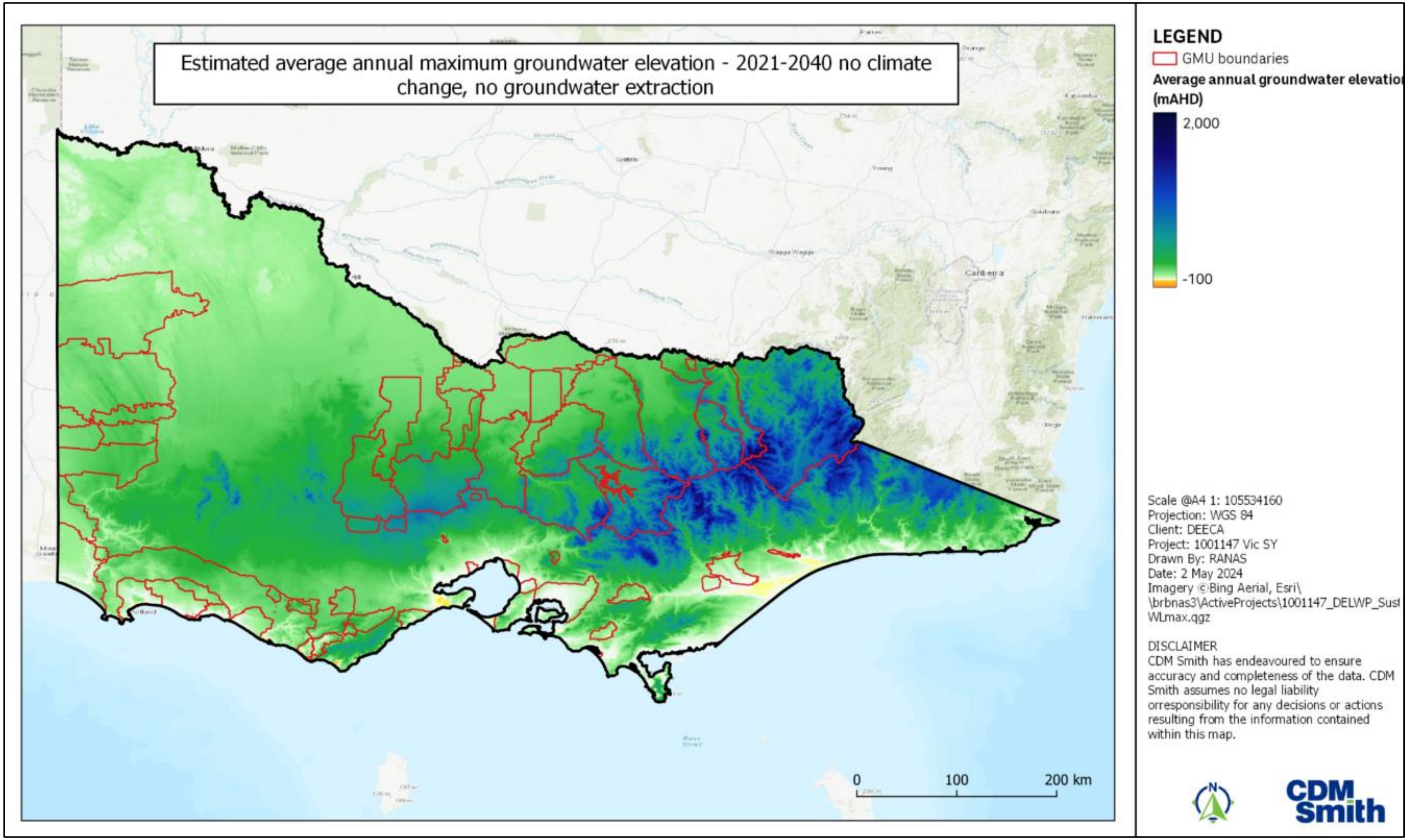
Figure S-3 Estimated annual maximum watertable elevation (mAHD) – Current period (1998-2020).



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Projection: WGS 84
Client: DEECA
Project: 1001147 Vic SY
Drawn By: RANAS
Date: 2 May 2024
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Figure S-4 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 No climate change and no groundwater extraction.

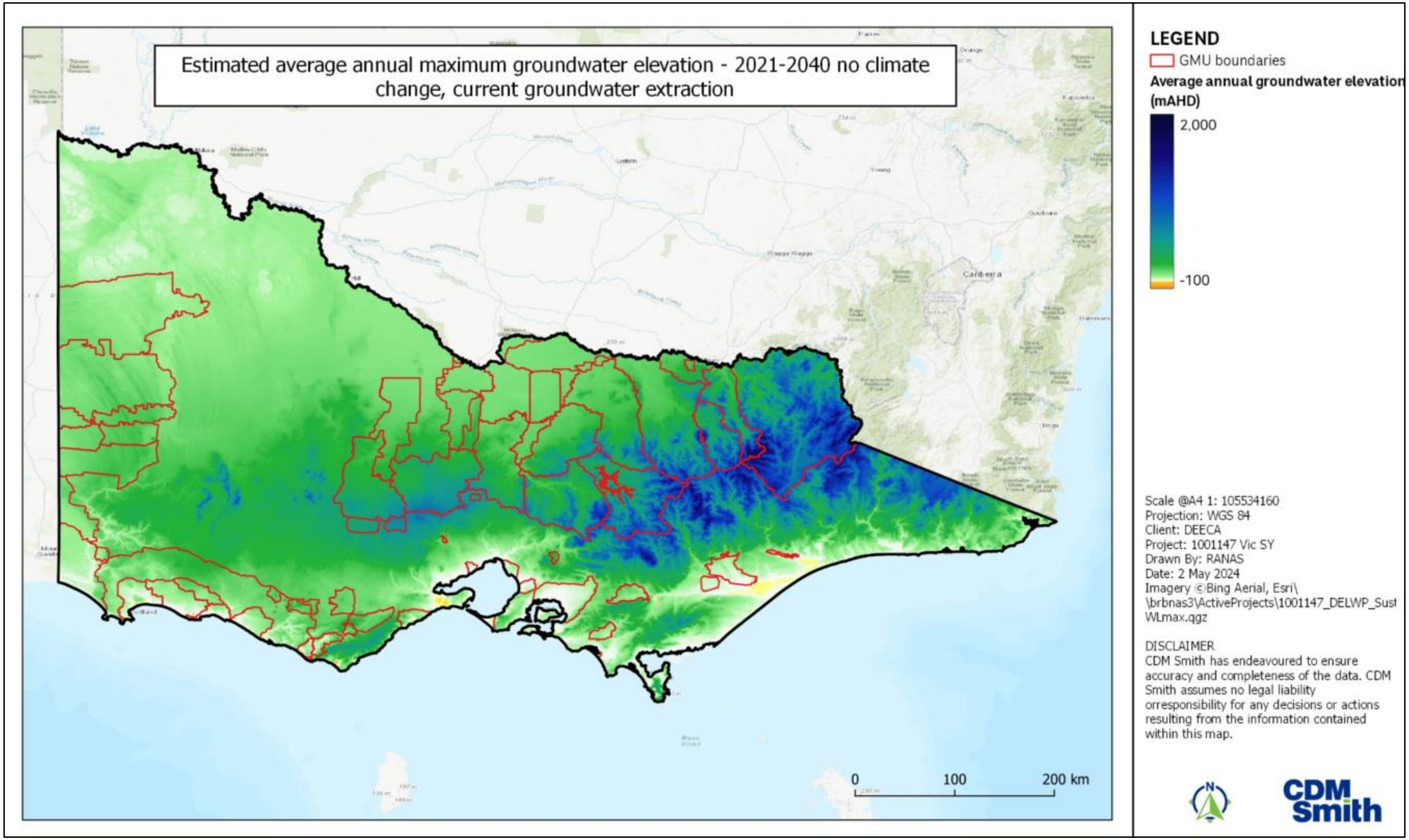


Figure S-5 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 No climate change and current groundwater extraction.

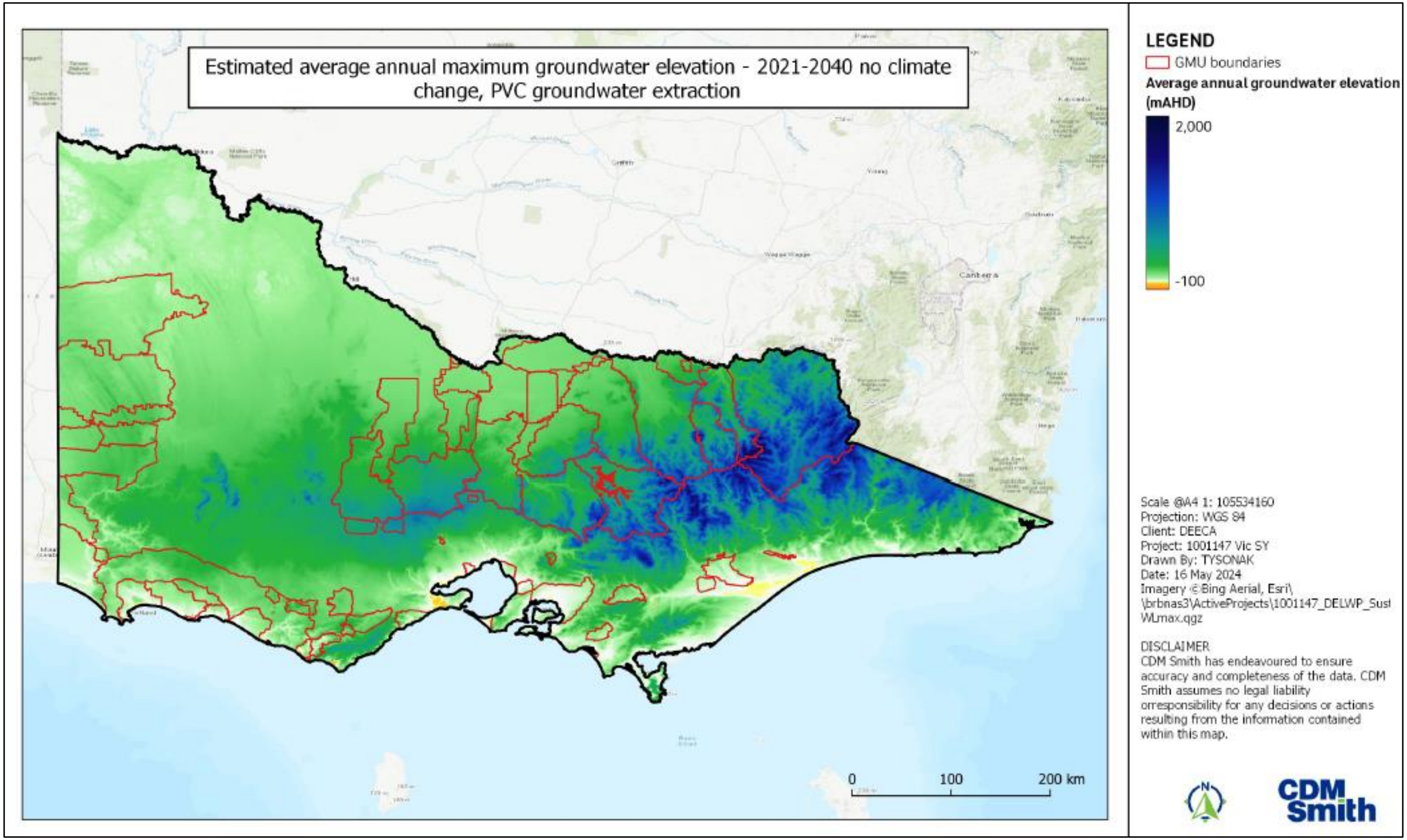
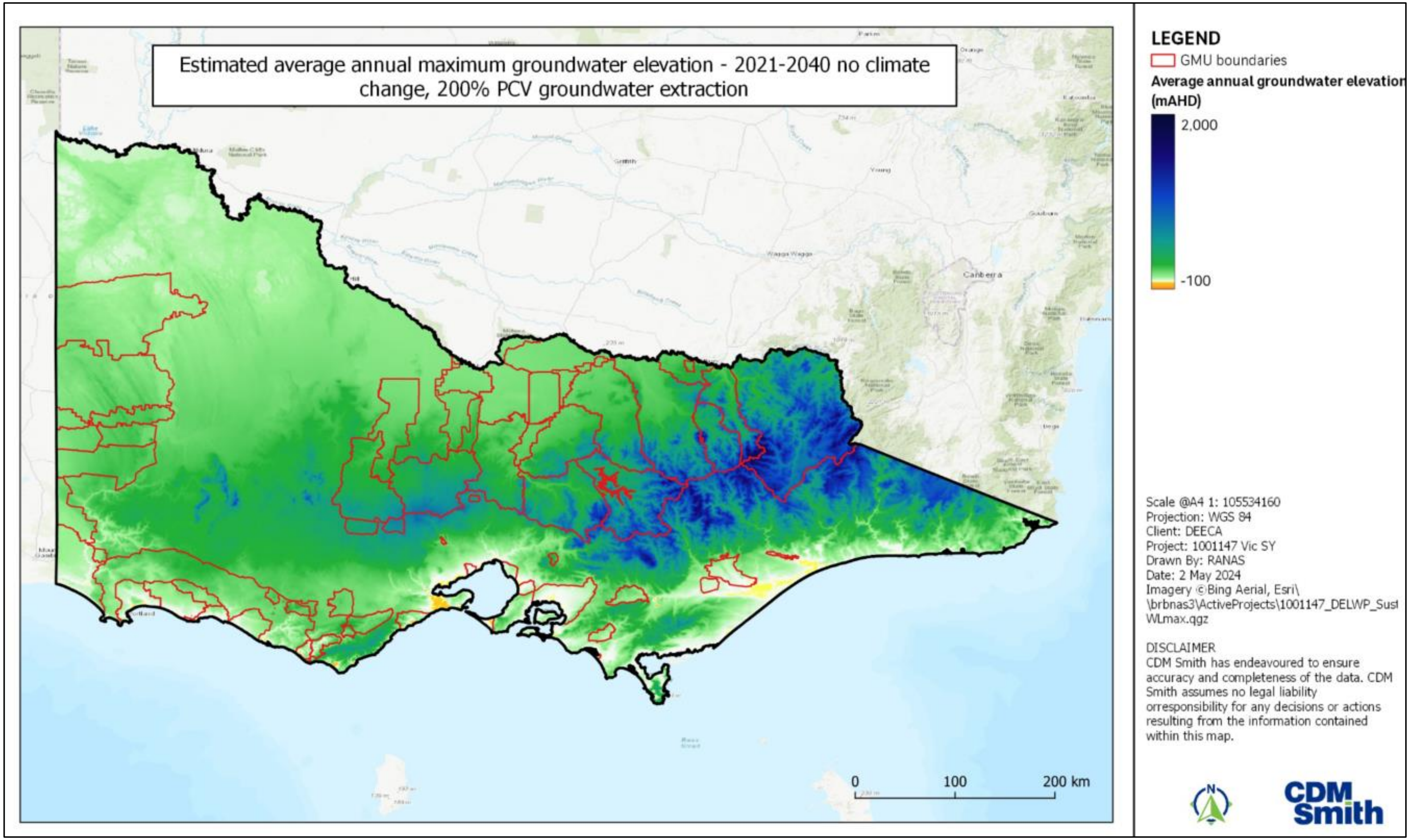


Figure S-6 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 No climate change and PCV rate extraction.


Estimated average annual maximum groundwater elevation - 2021-2040 no climate change, 200% PCV groundwater extraction

Scale @A4 1: 105534160
Projection: WGS 84
Client: DEECA
Project: 1001147 Vic SY
Drawn By: RANAS
Date: 2 May 2024
Imagery ©Bing Aerial, Esri\
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Figure S-7 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 No climate change and 200% of PCV rate extraction.

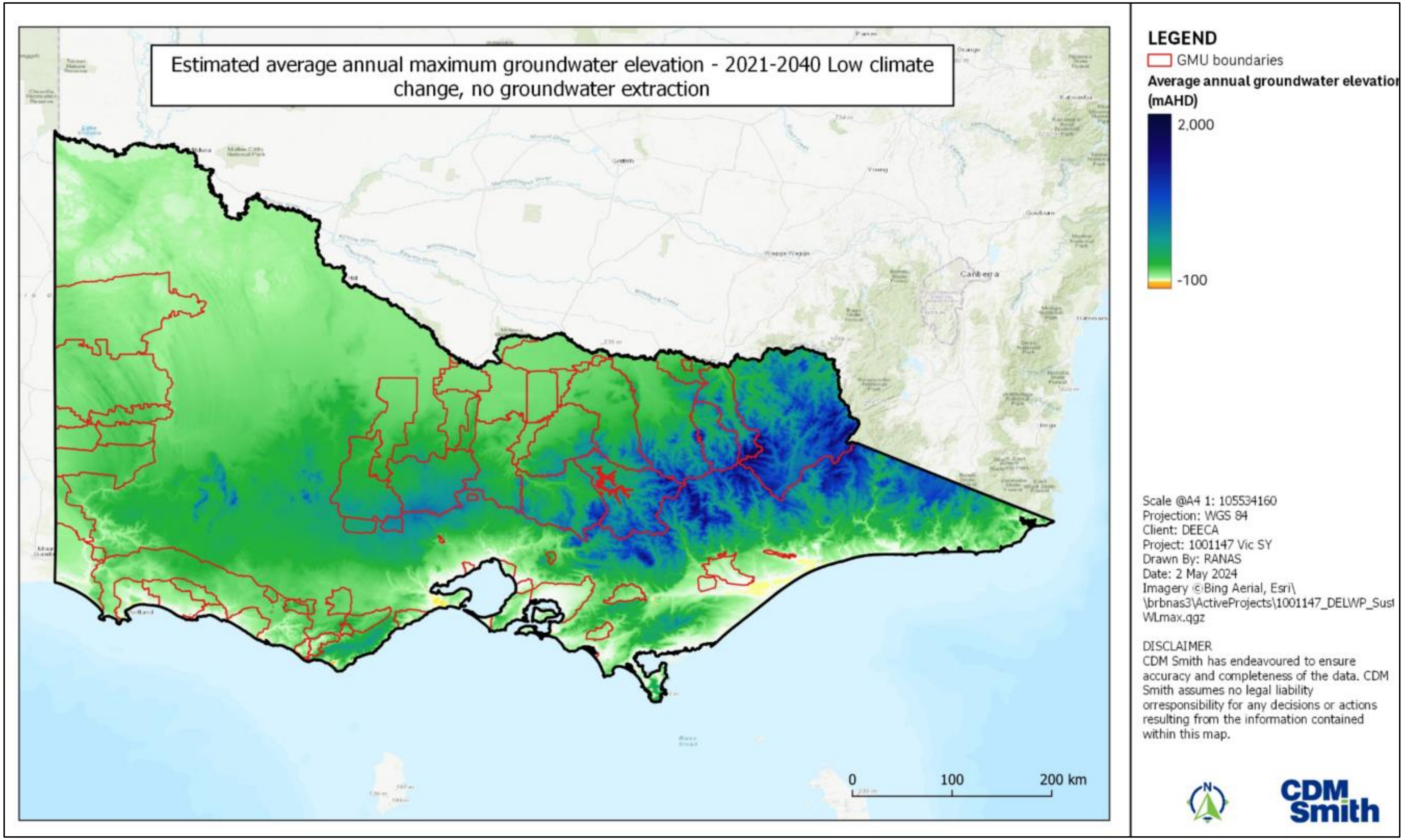


Figure S-8 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 Low climate change and no groundwater extraction.

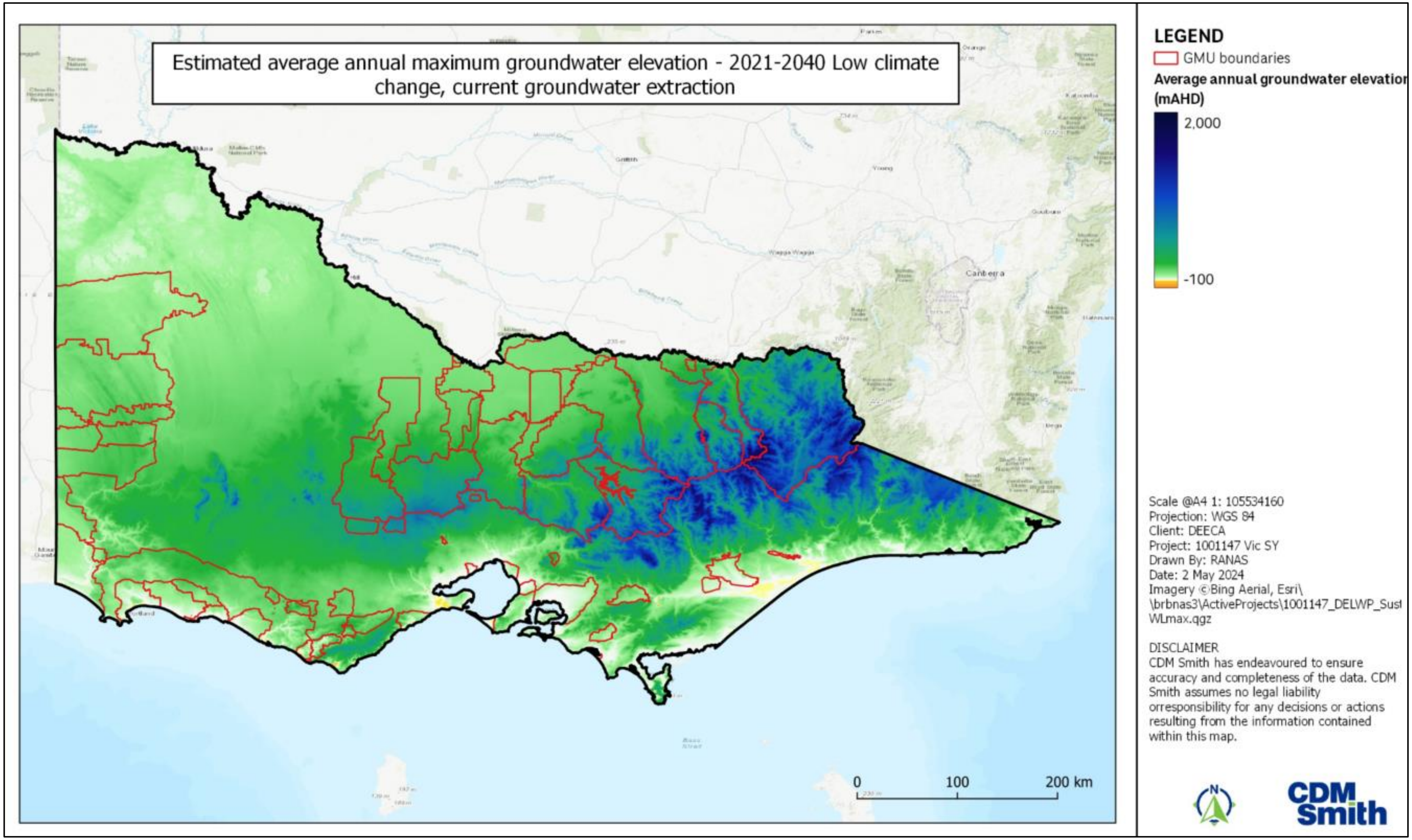


Figure S-9 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 Low climate change and current groundwater extraction.

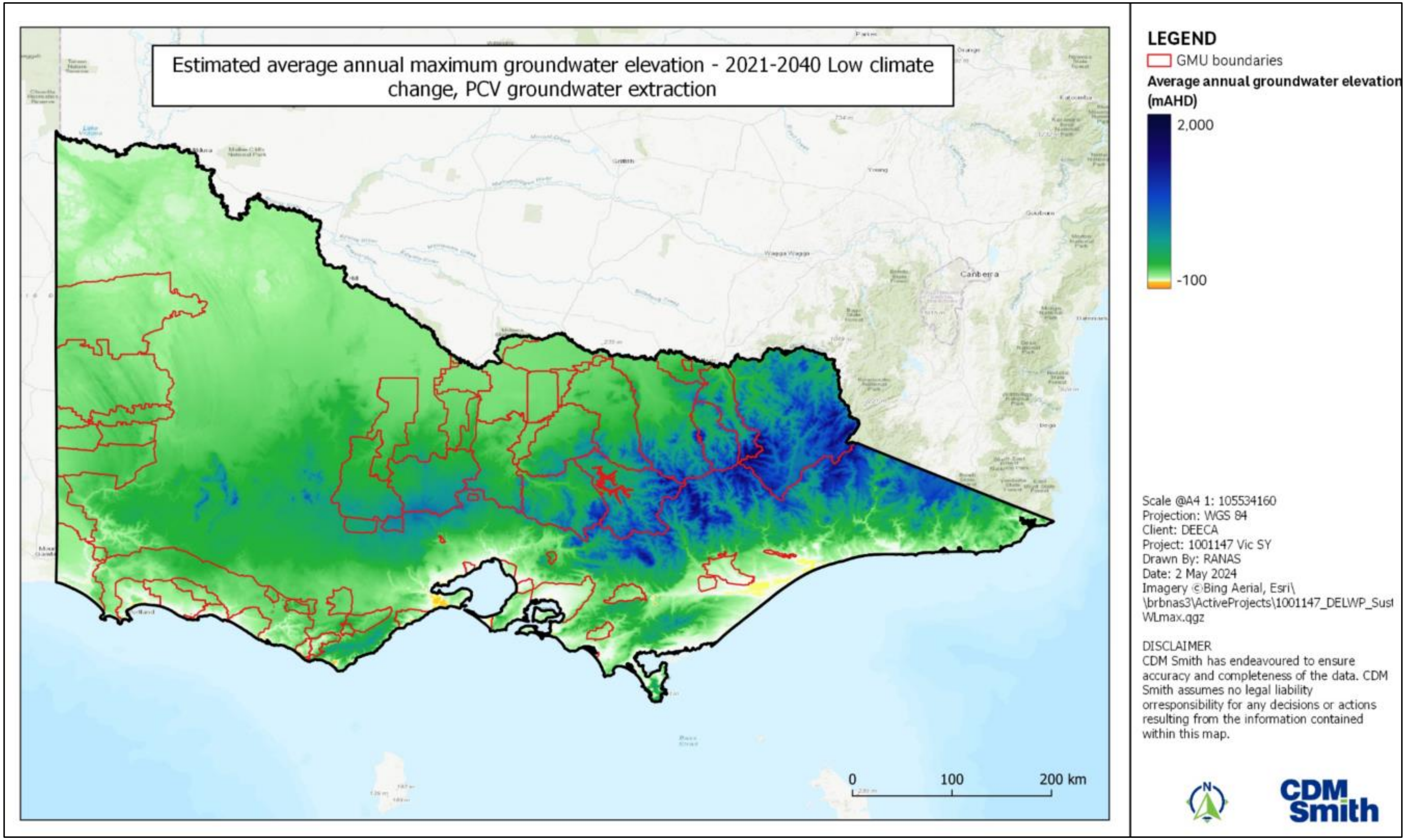


Figure S-10 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 Low climate change and PCV rate extraction.

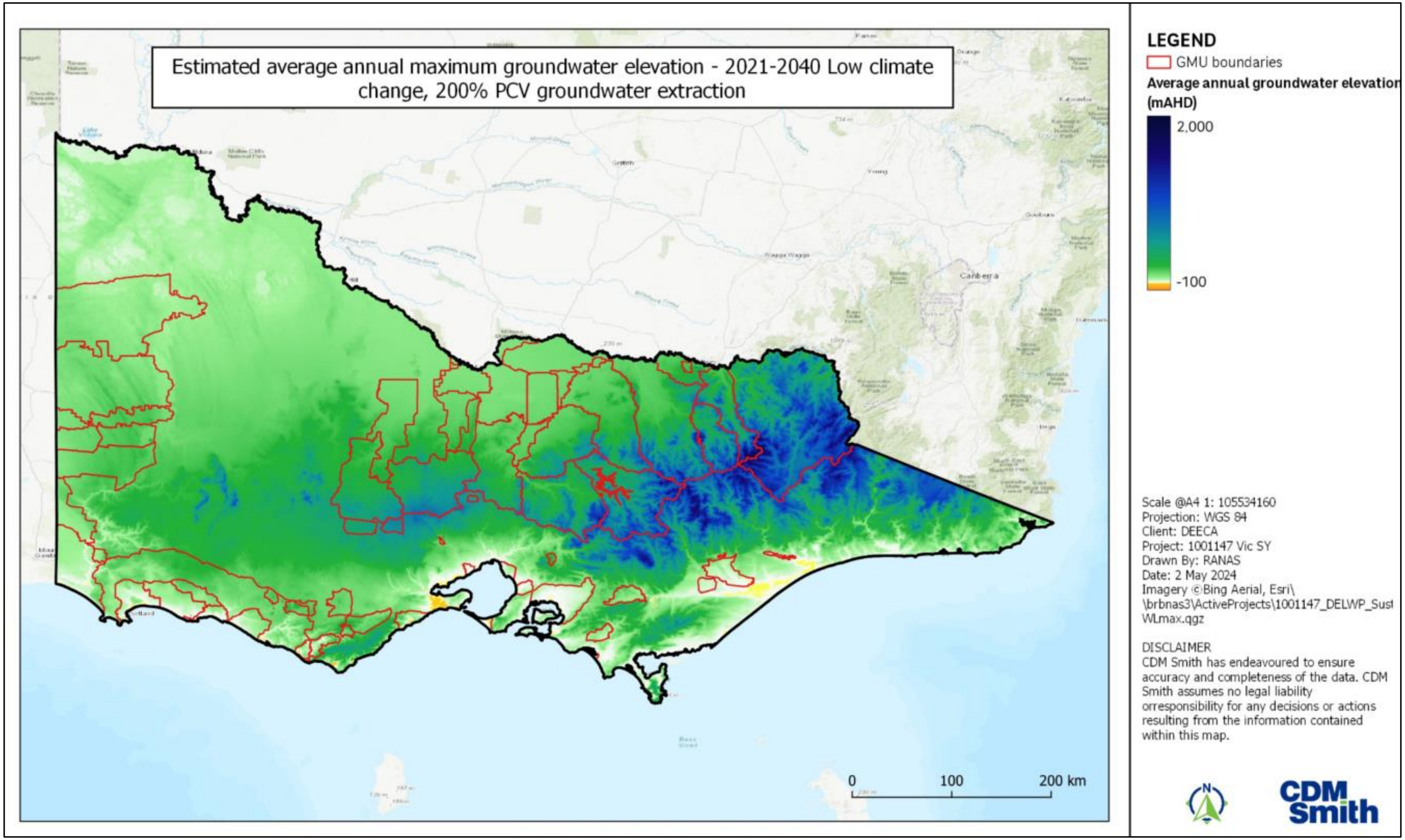
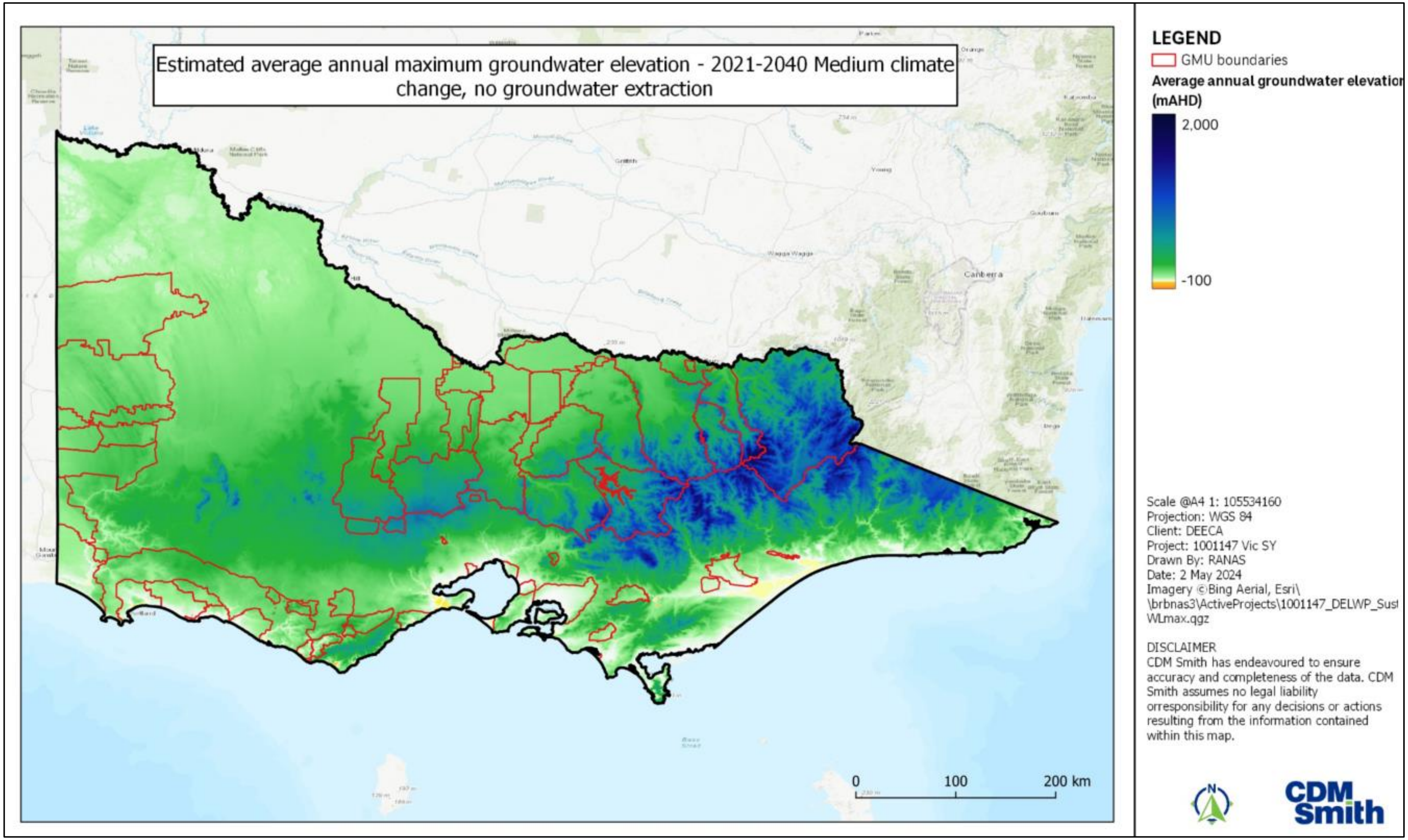


Figure S-11 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 Low climate change and 200% of PCV rate extraction.



Scale @A4 1: 105534160
Projection: WGS 84
Client: DEECA
Project: 1001147 Vic SY
Drawn By: RANAS
Date: 2 May 2024
Imagery ©Bing Aerial, Esri\
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Figure S-12 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 Medium climate change and no groundwater extraction.

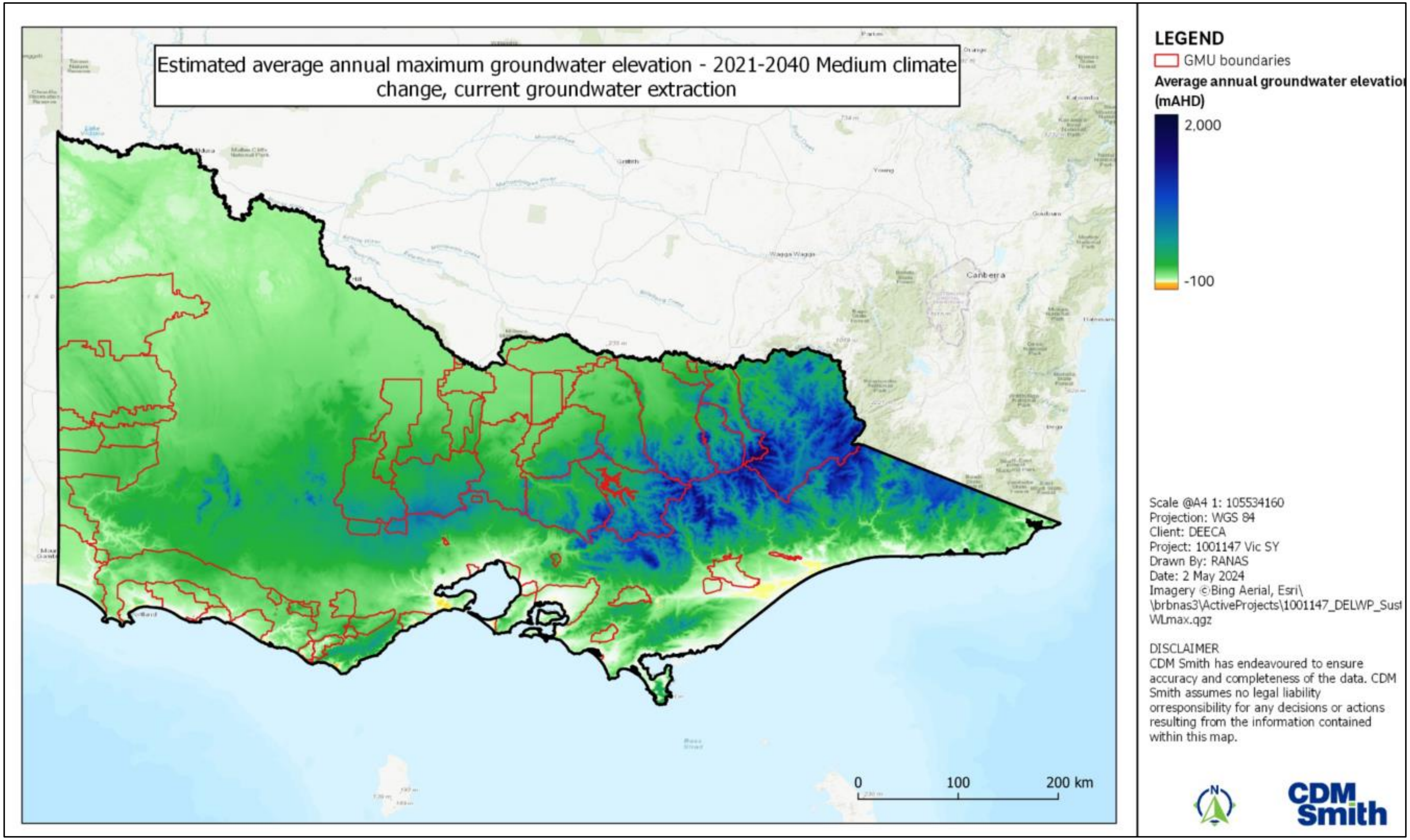

Figure S-13 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 Medium climate change and current groundwater extraction.

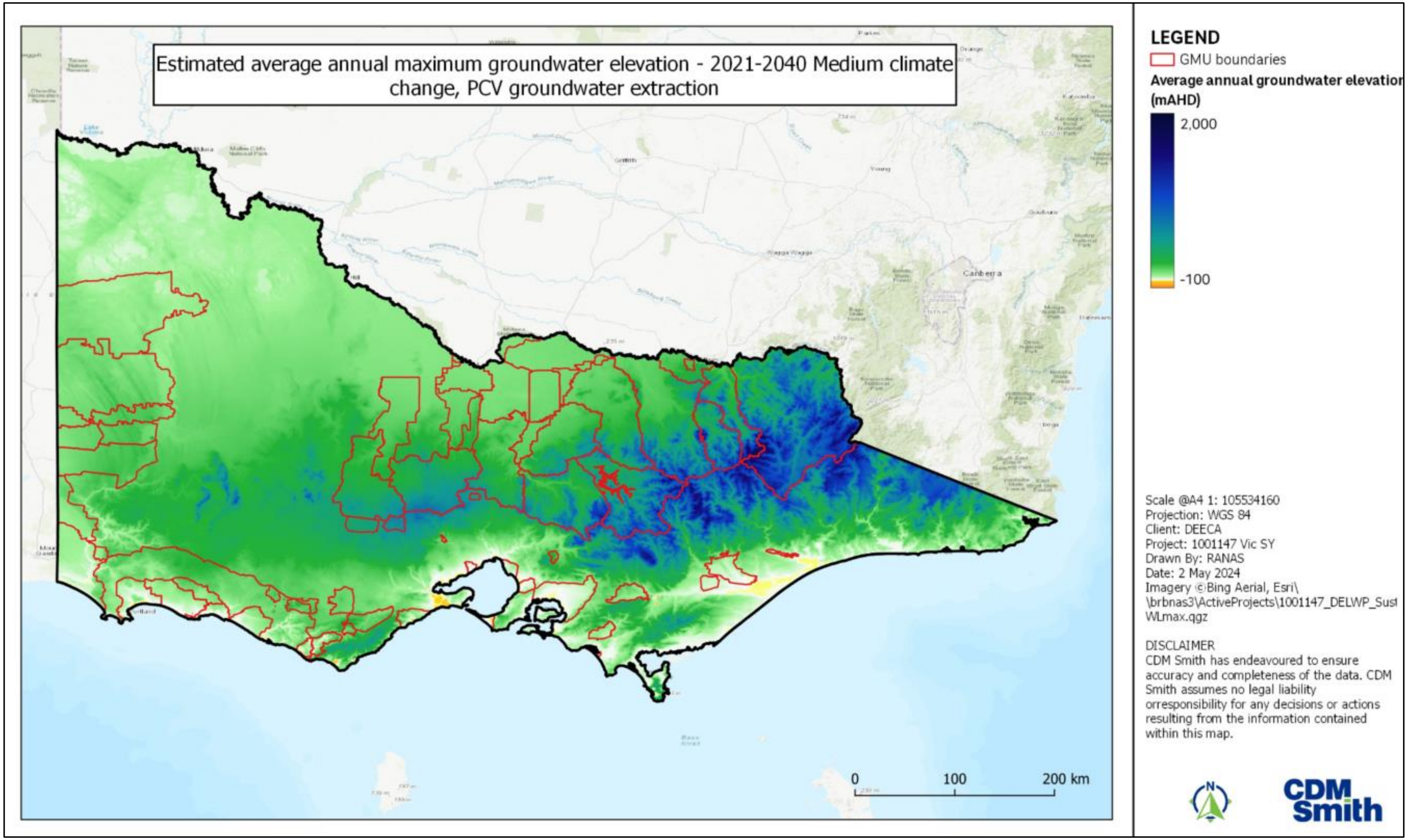

Figure S-14 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 Medium climate change and PCV rate extraction.

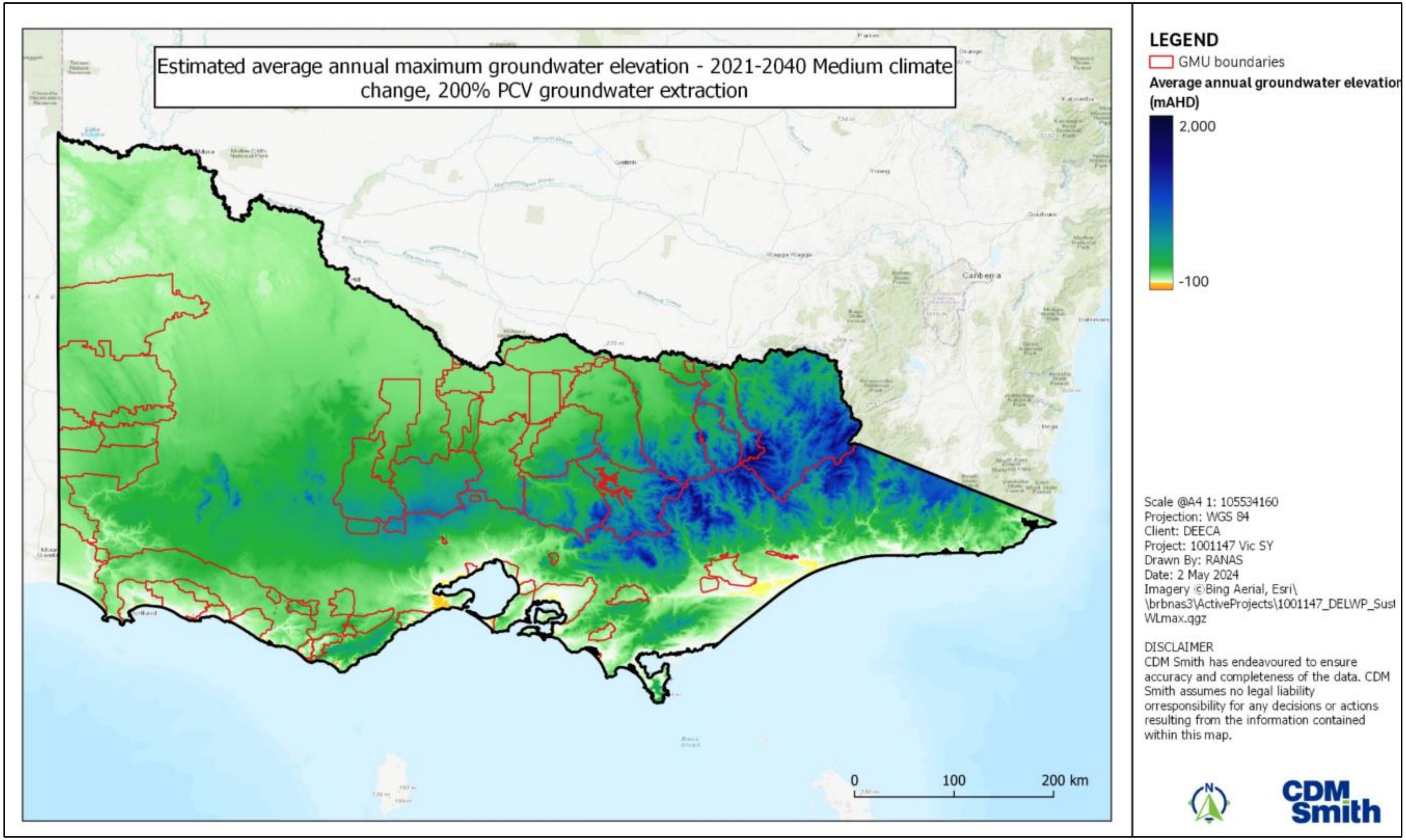

Figure S-15 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 Medium climate change and 200% of PCV rate extraction.

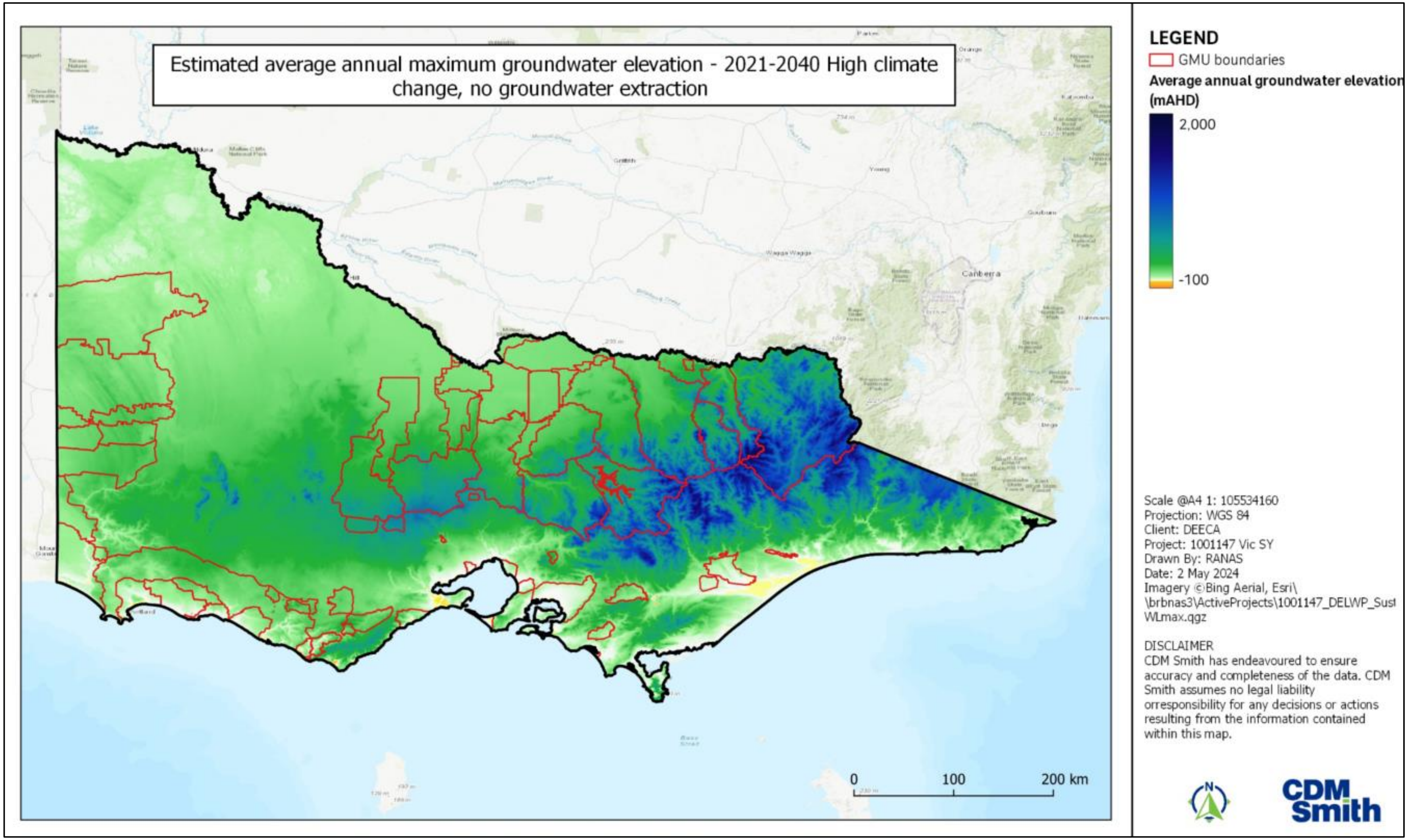

Figure S-16 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 High climate change and no groundwater extraction.

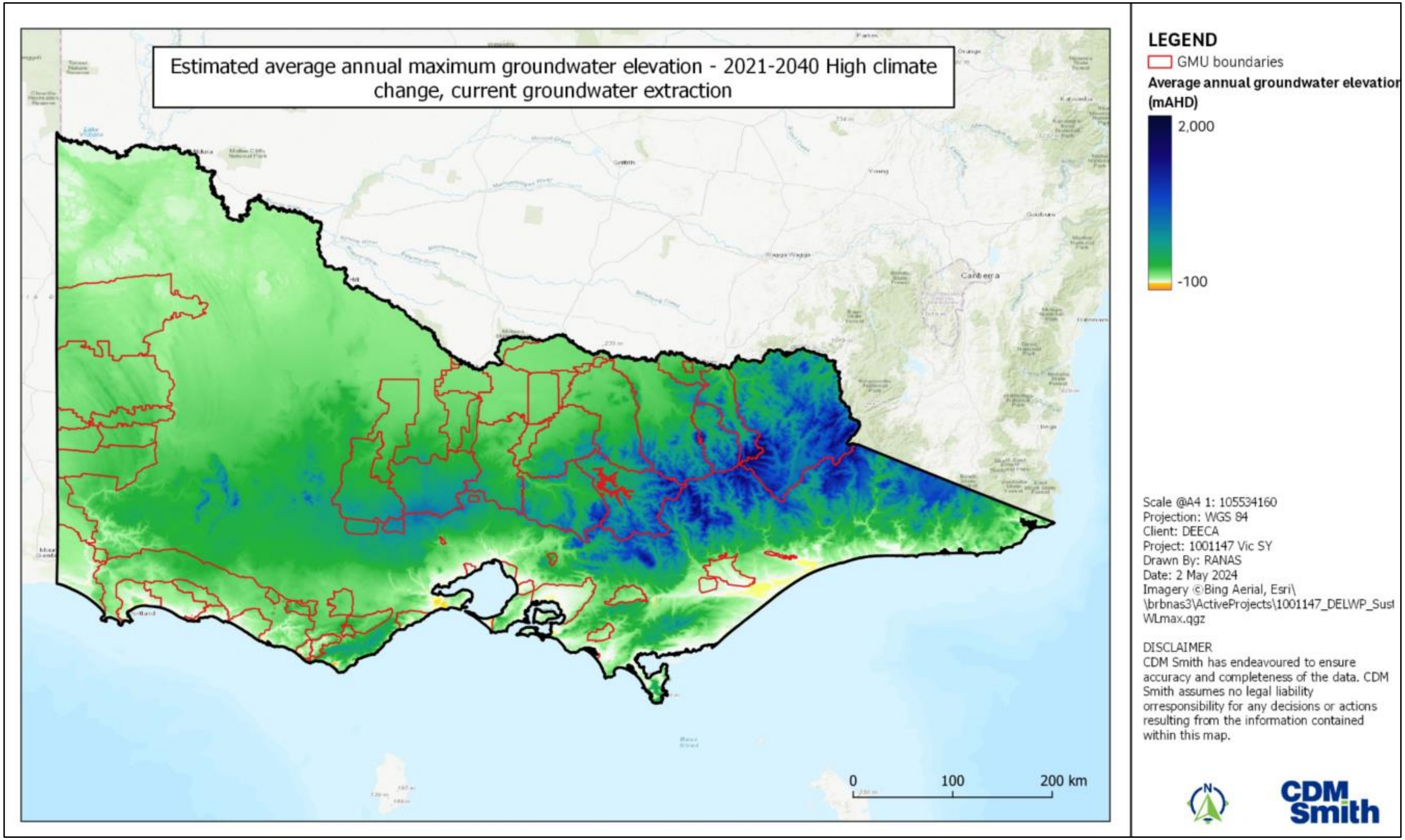

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Figure S-17 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 High climate change and current groundwater extraction.

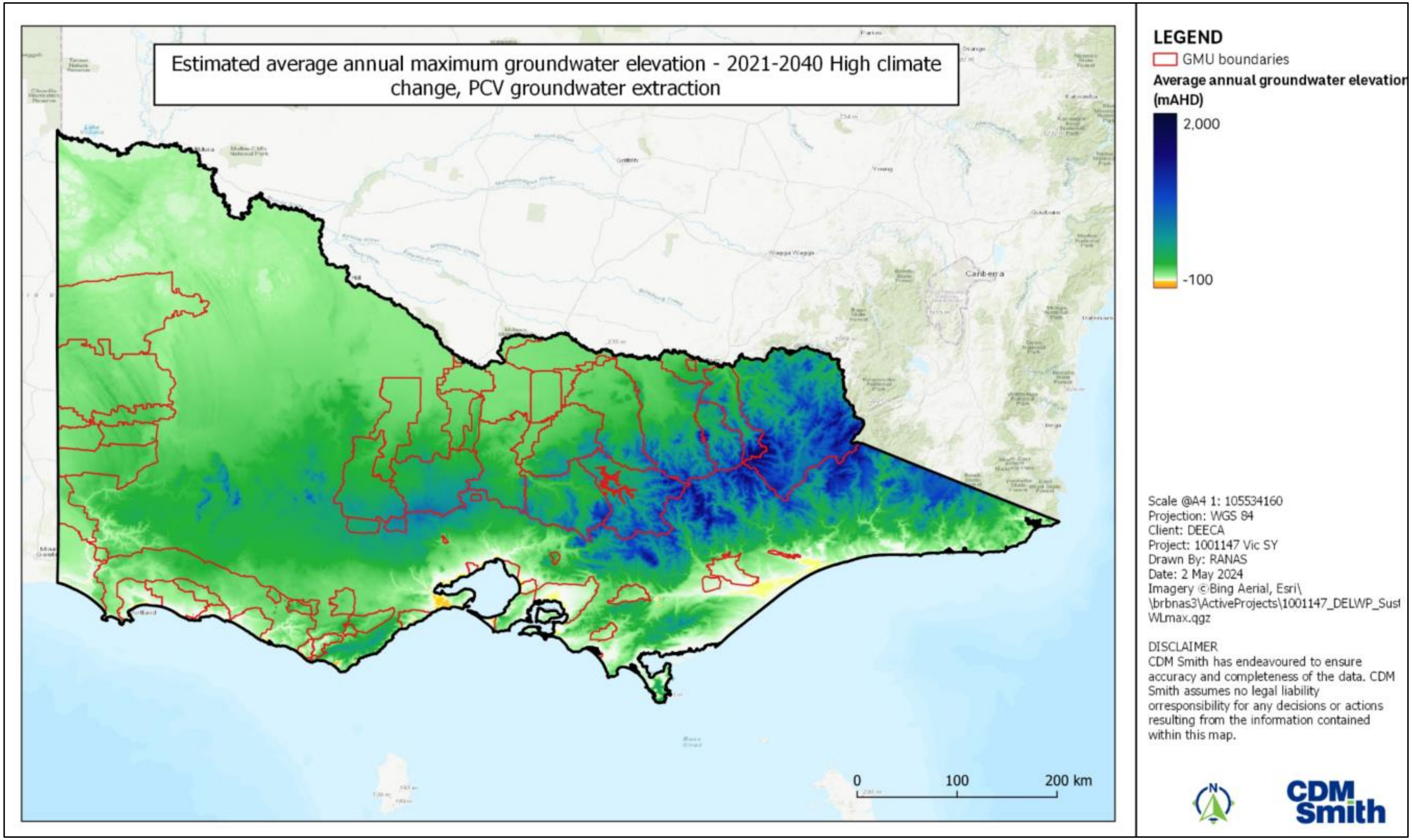
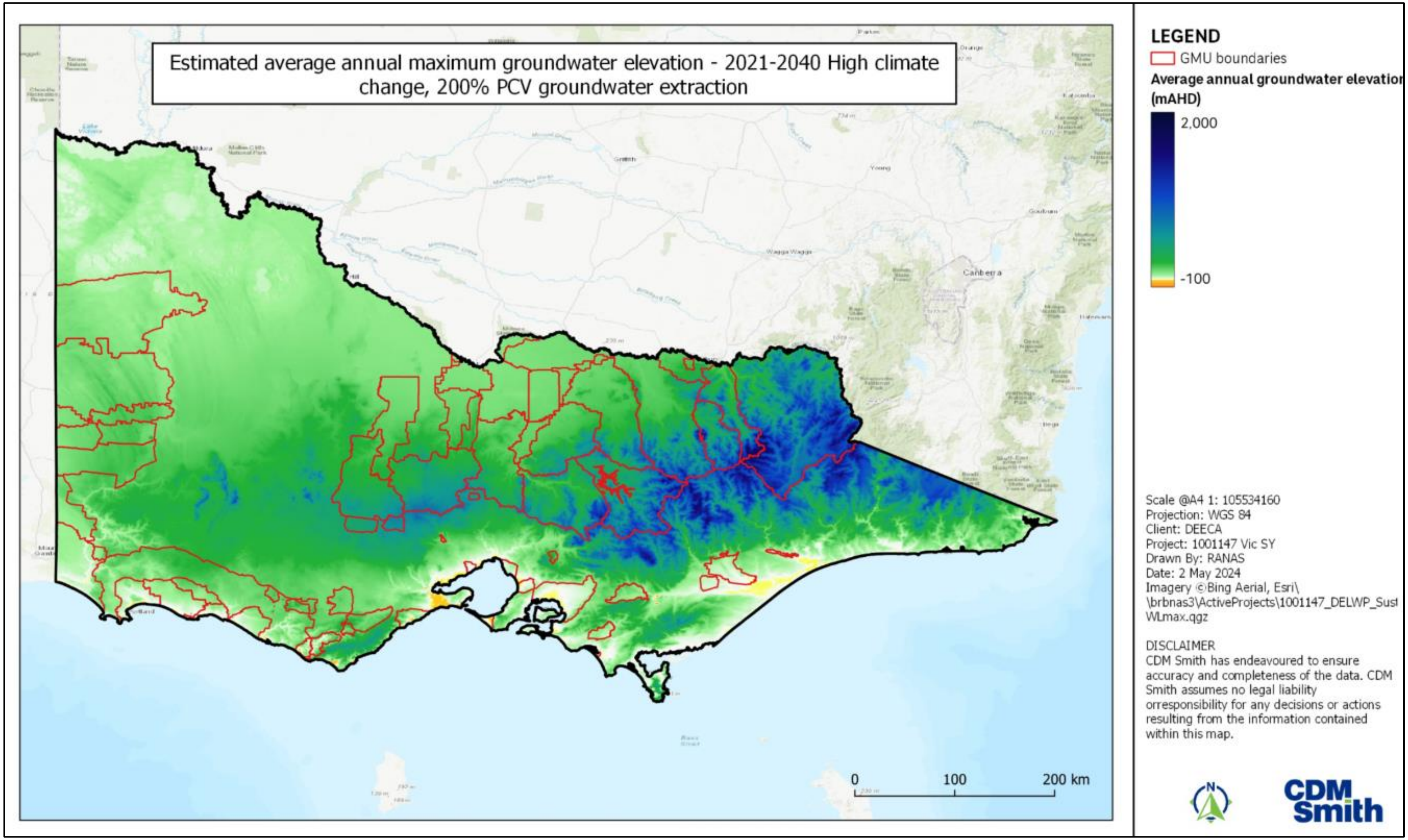


Figure S-18 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 High climate change and PCV rate extraction.



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Drawn By: RANAS
Date: 2 May 2024
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Figure S-19 Estimated annual maximum watertable elevation (mAHD) – 2021-2040 High climate change and 200% of PCV rate extraction.

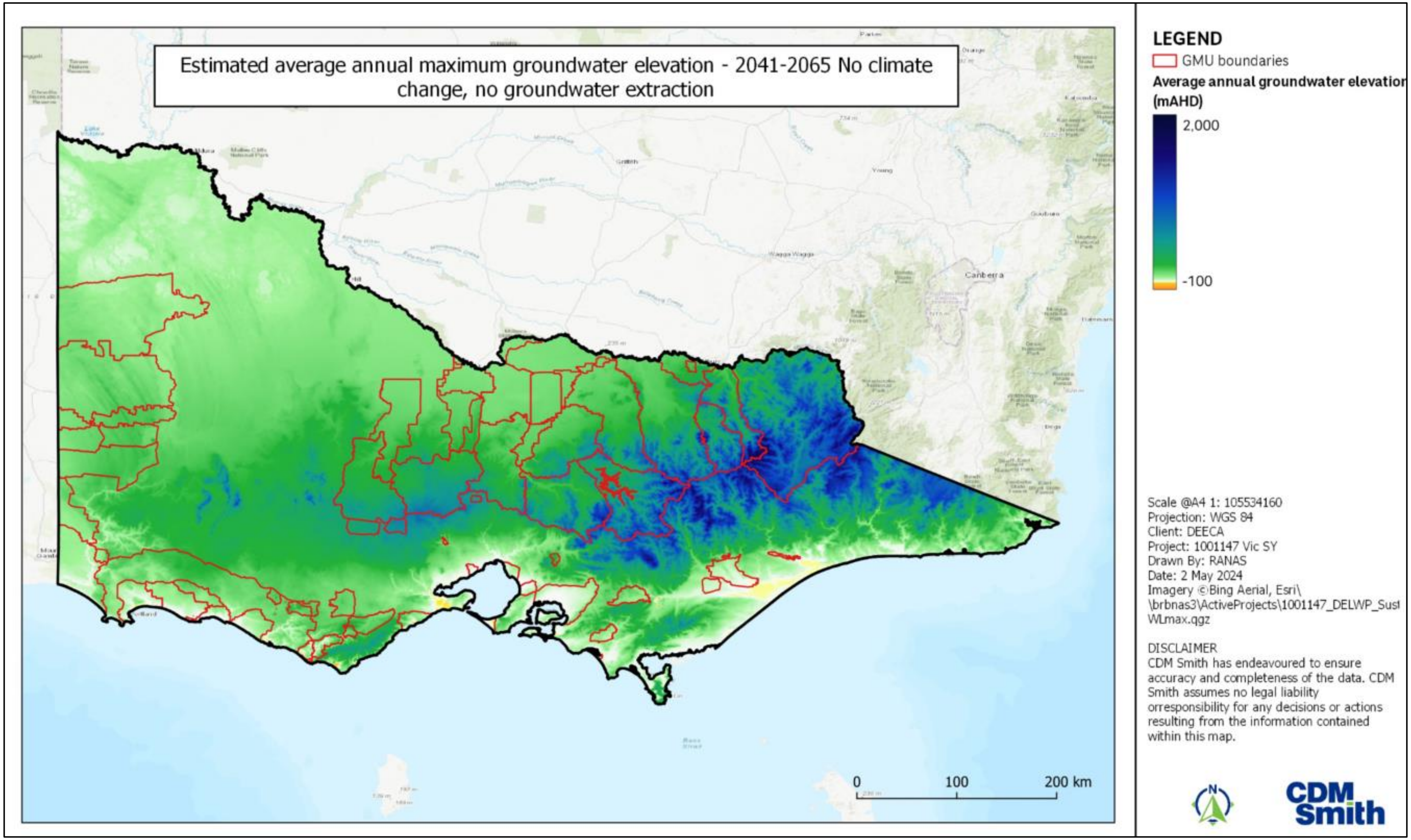


Figure S-20 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 No climate change and no groundwater extraction.

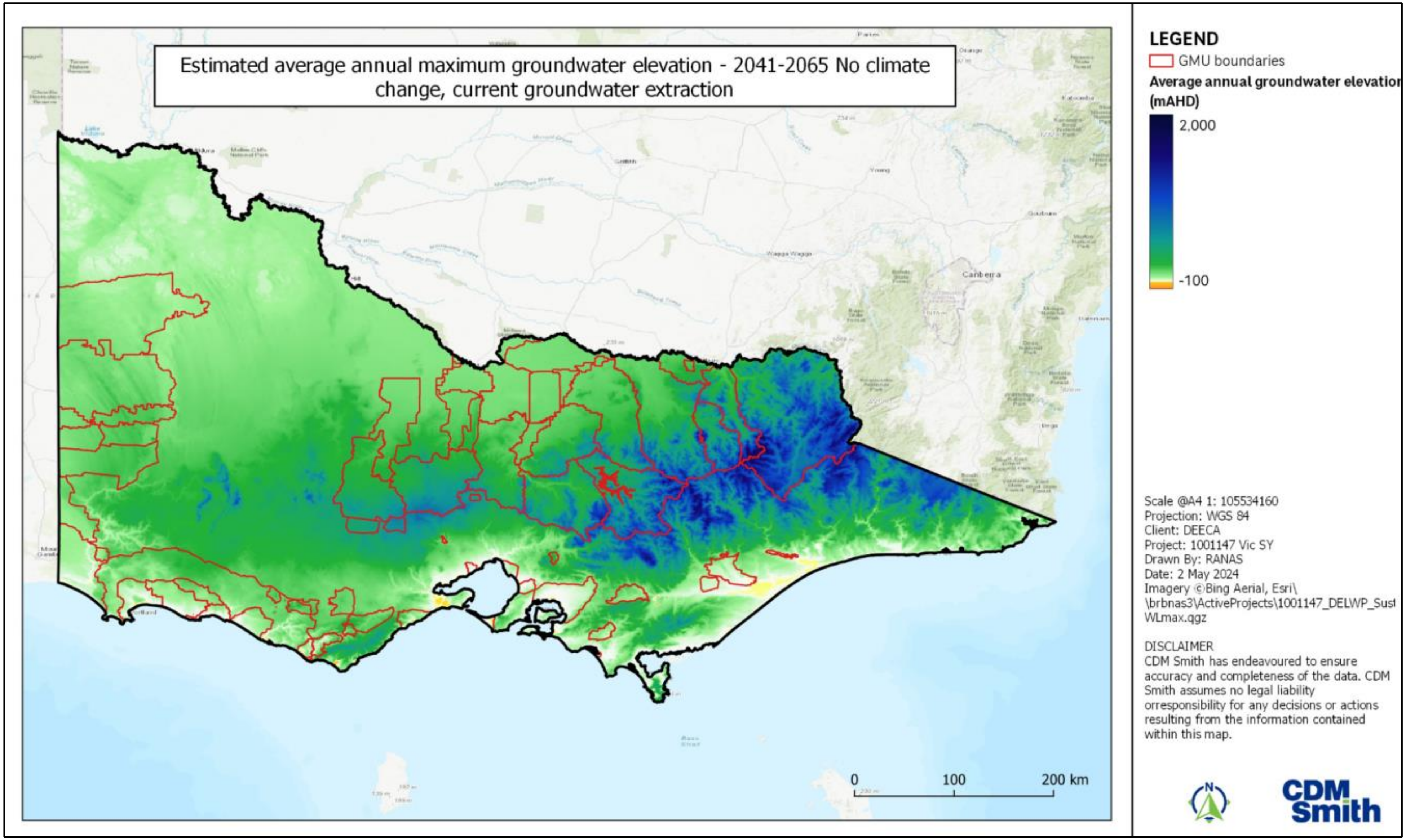
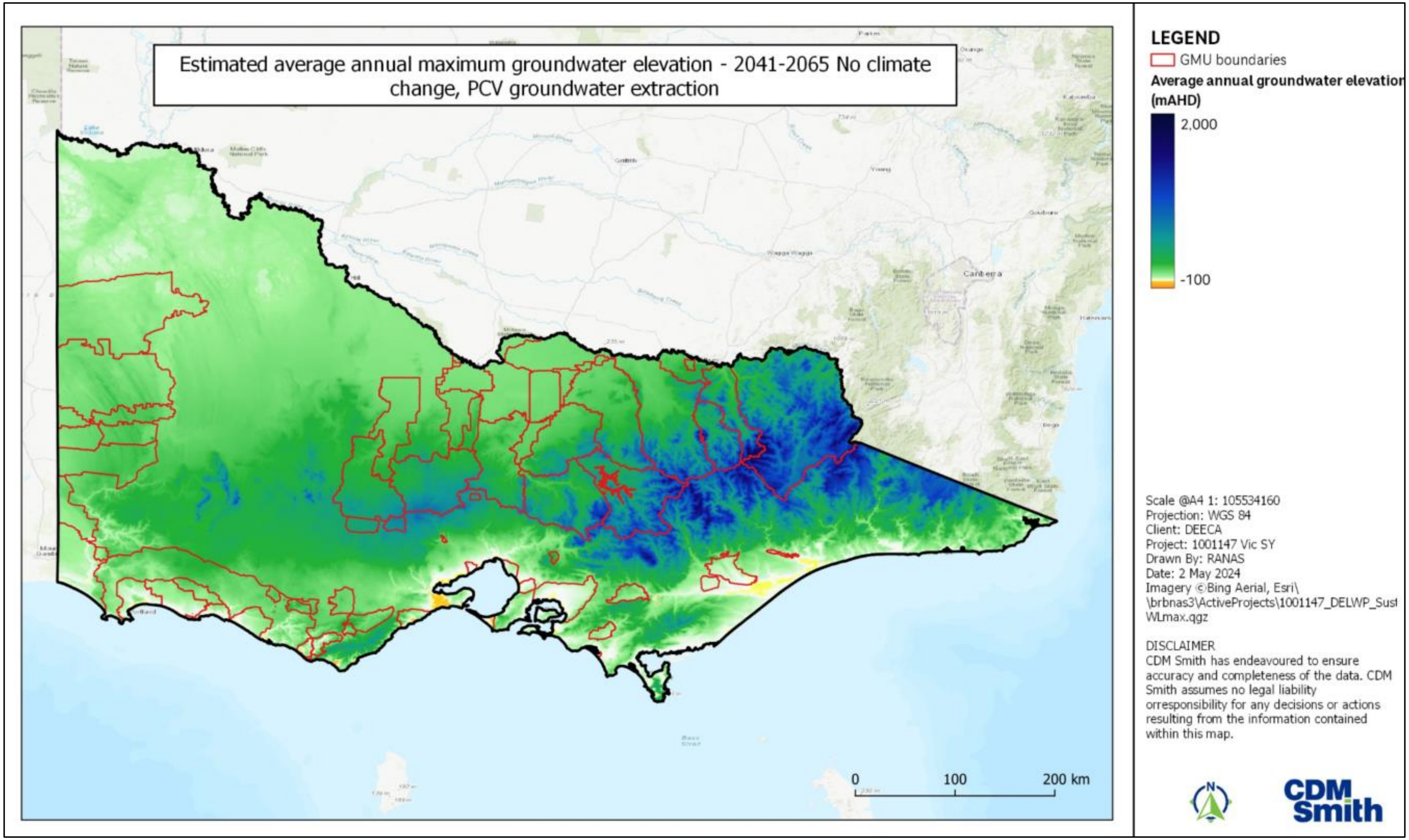


Figure S-21 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 No climate change and current groundwater extraction.



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Project: 1001147 Vic SY
Drawn By: RANAS
Date: 2 May 2024
Imagery ©Bing Aerial, Esri\
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WLmax.qgz

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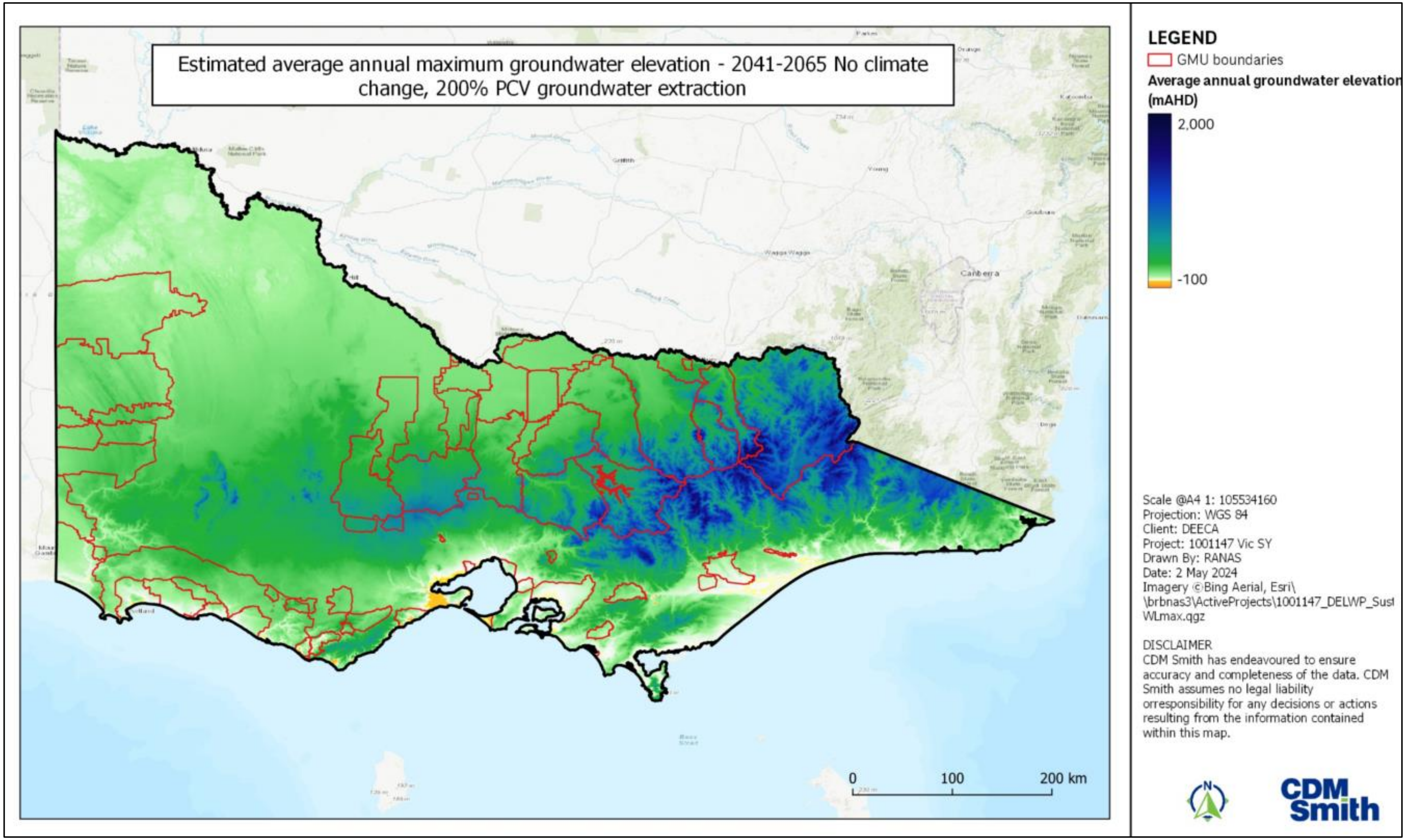
Figure S-22 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 No climate change and PCV rate extraction.



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Project: 1001147 Vic SY
Drawn By: RANAS
Date: 2 May 2024
Imagery ©Bing Aerial, Esri\
\brbnas3\ActiveProjects\1001147_DELWP_Sust
WLmax.qgz

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Figure S-23 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 No climate change and 200% of PCV rate extraction.

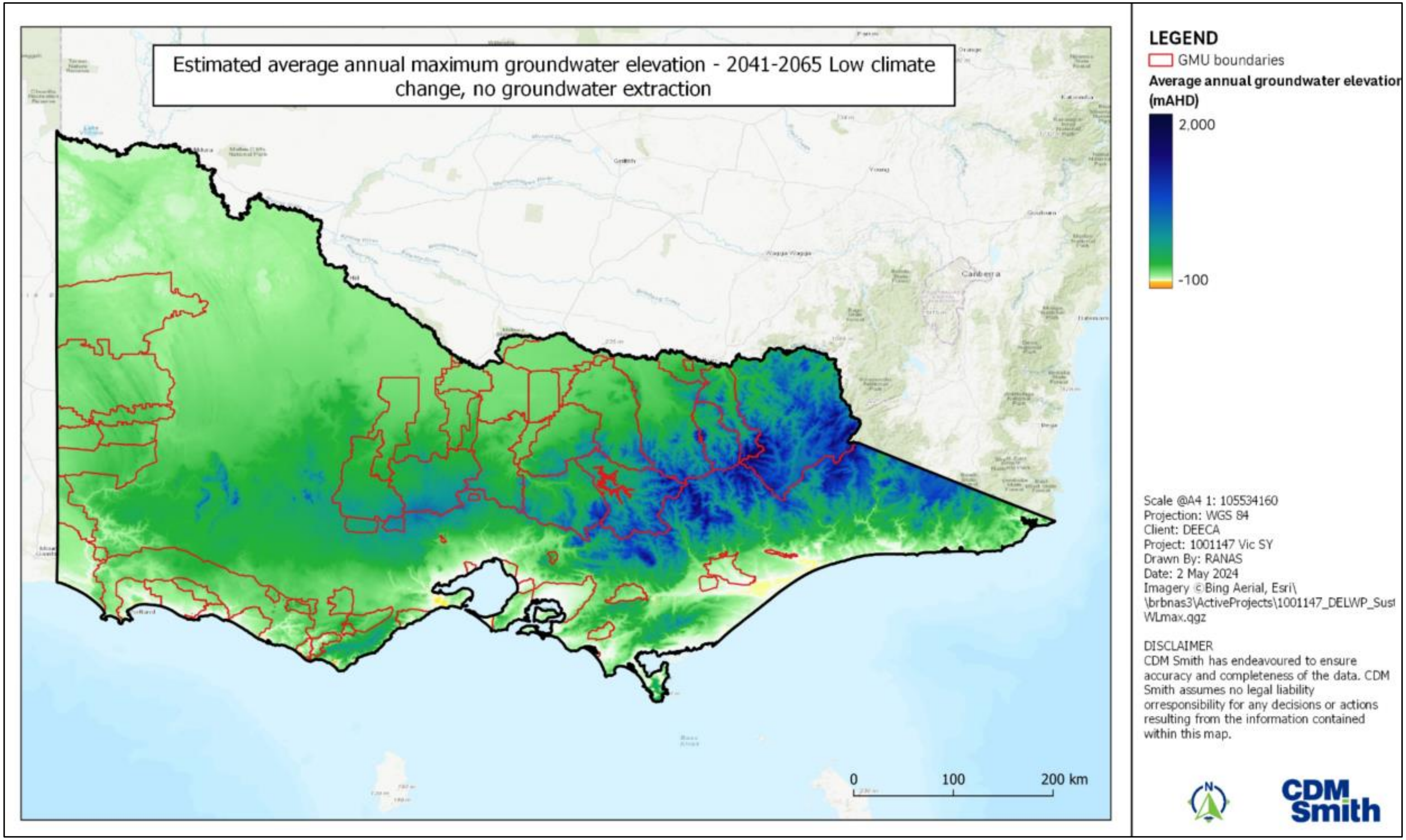


Figure S-24 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 Low climate change and no groundwater extraction.

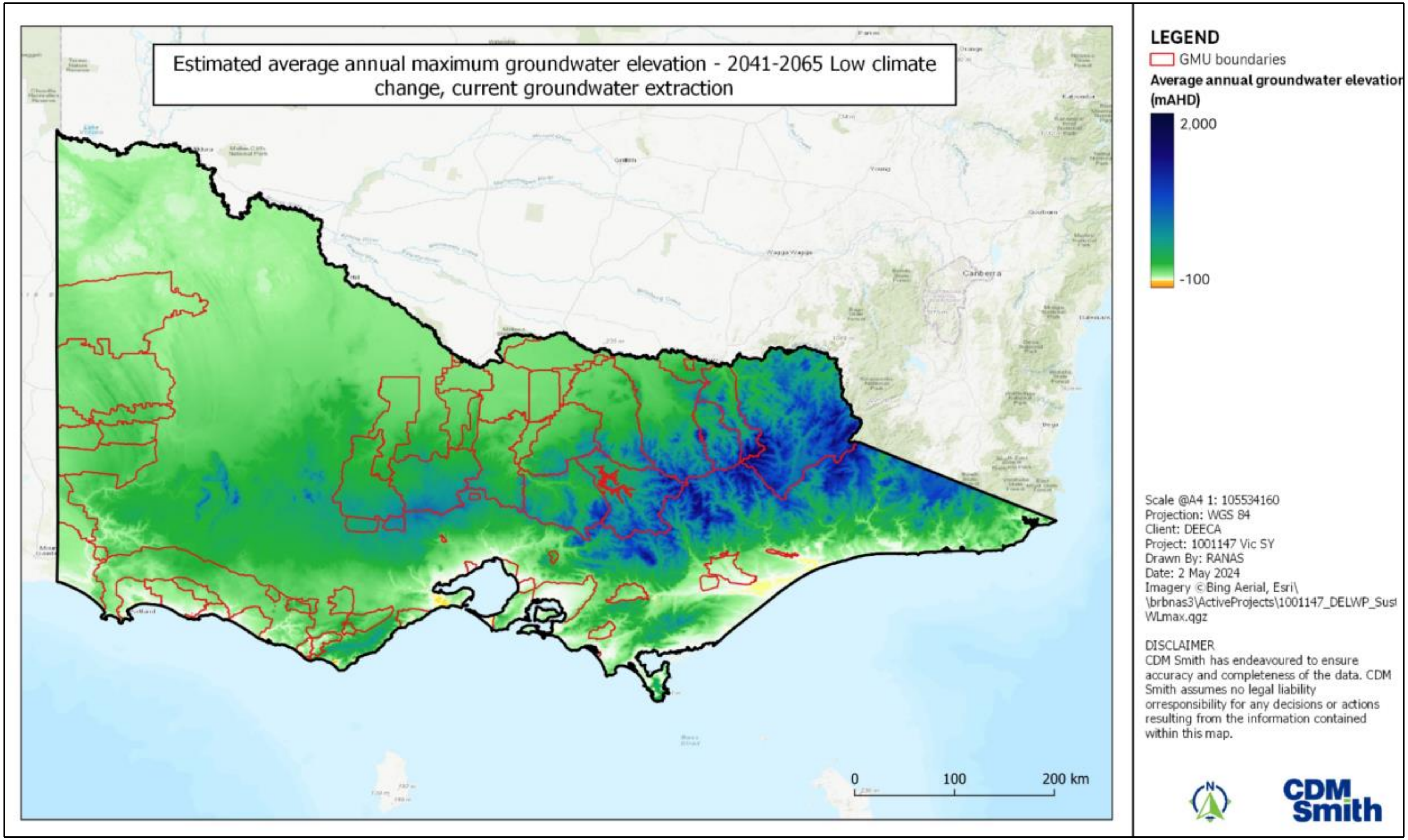
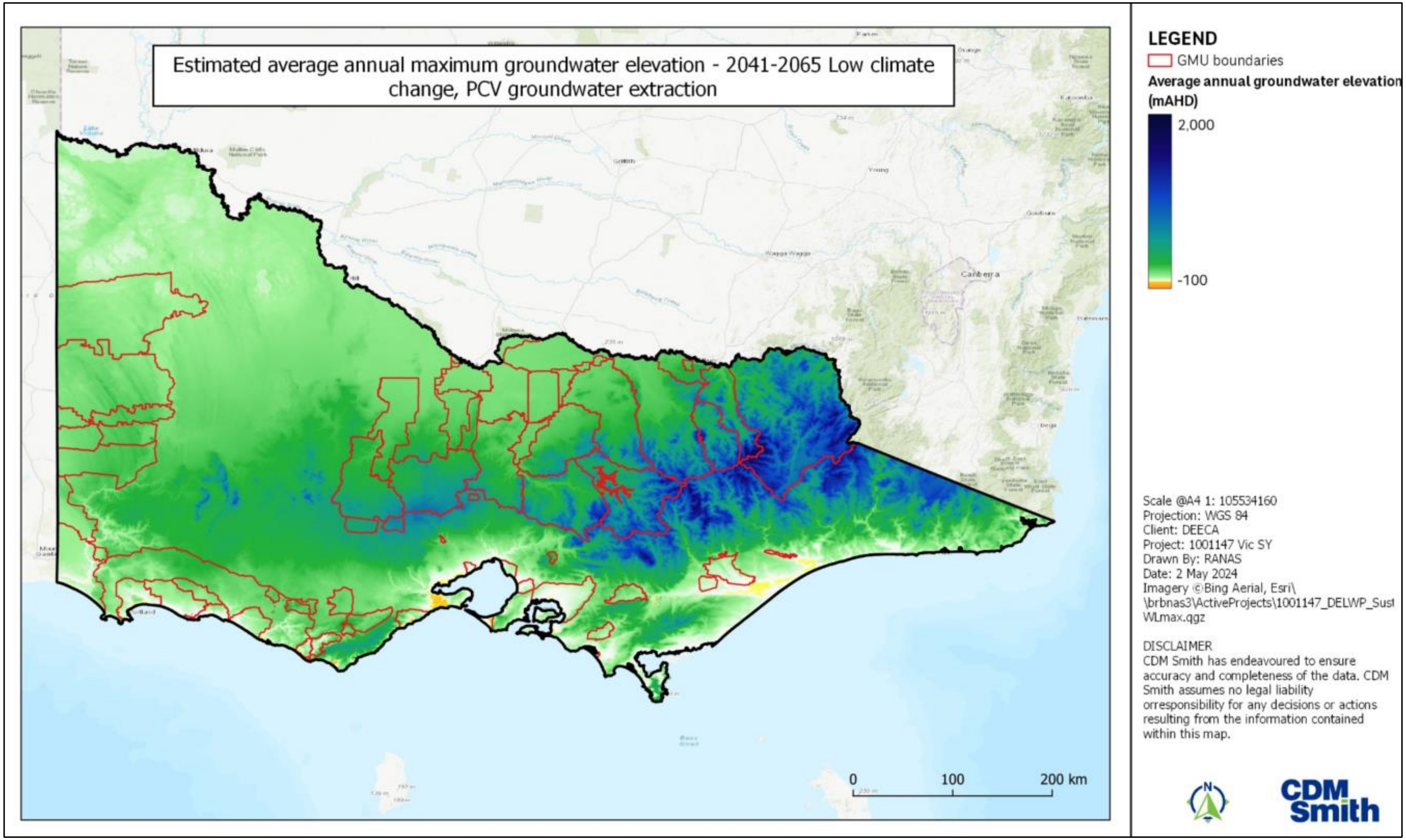


Figure S-25 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 Low climate change and current groundwater extraction.



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Projection: WGS 84
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Project: 1001147 Vic SY
Drawn By: RANAS
Date: 2 May 2024
Imagery ©Bing Aerial, Esri\
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WLmax.qgz

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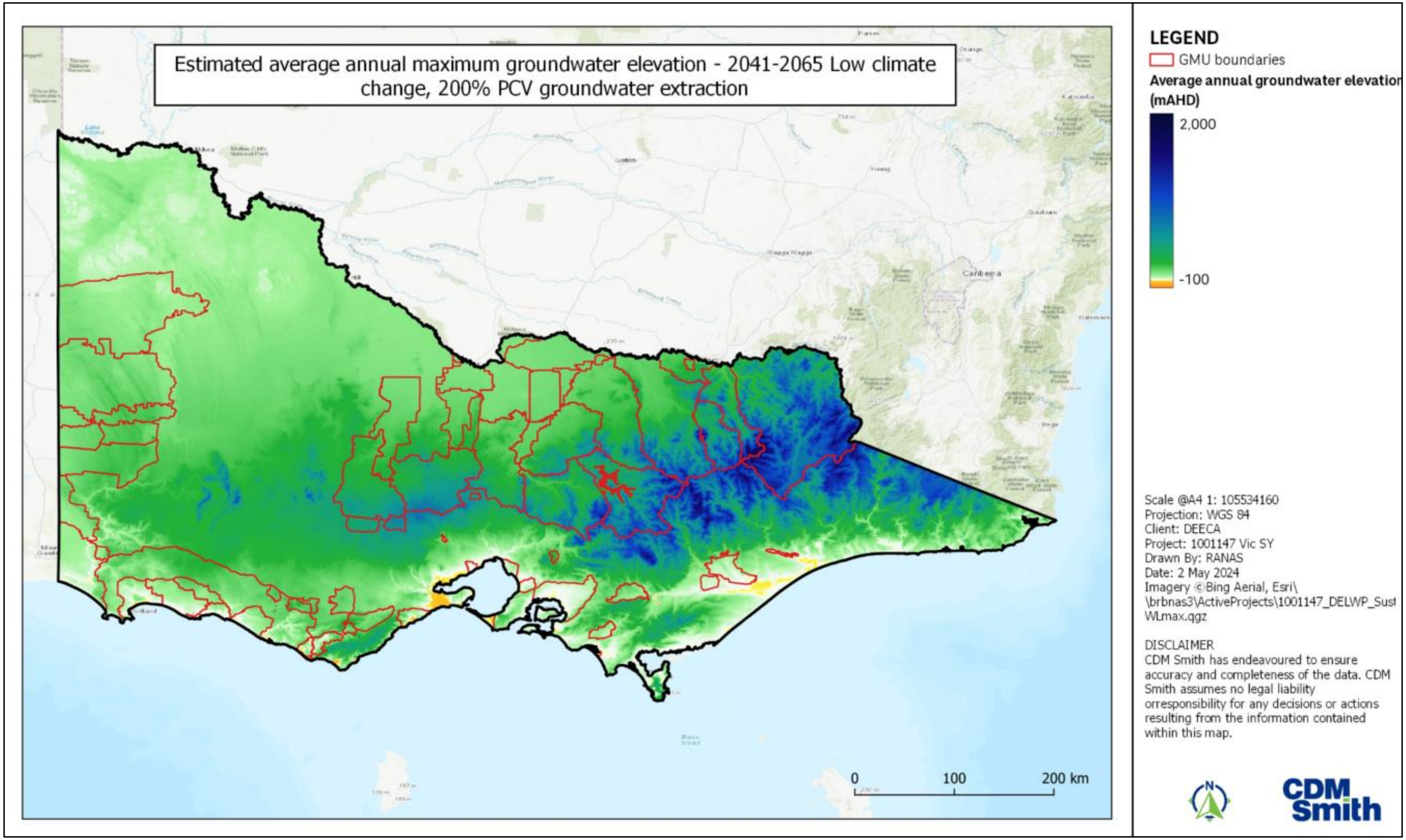
Figure S-26 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 Low climate change and PCV rate extraction.



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Project: 1001147 Vic SY
Drawn By: RANAS
Date: 2 May 2024
Imagery ©Bing Aerial, Esri\
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WLmax.qgz

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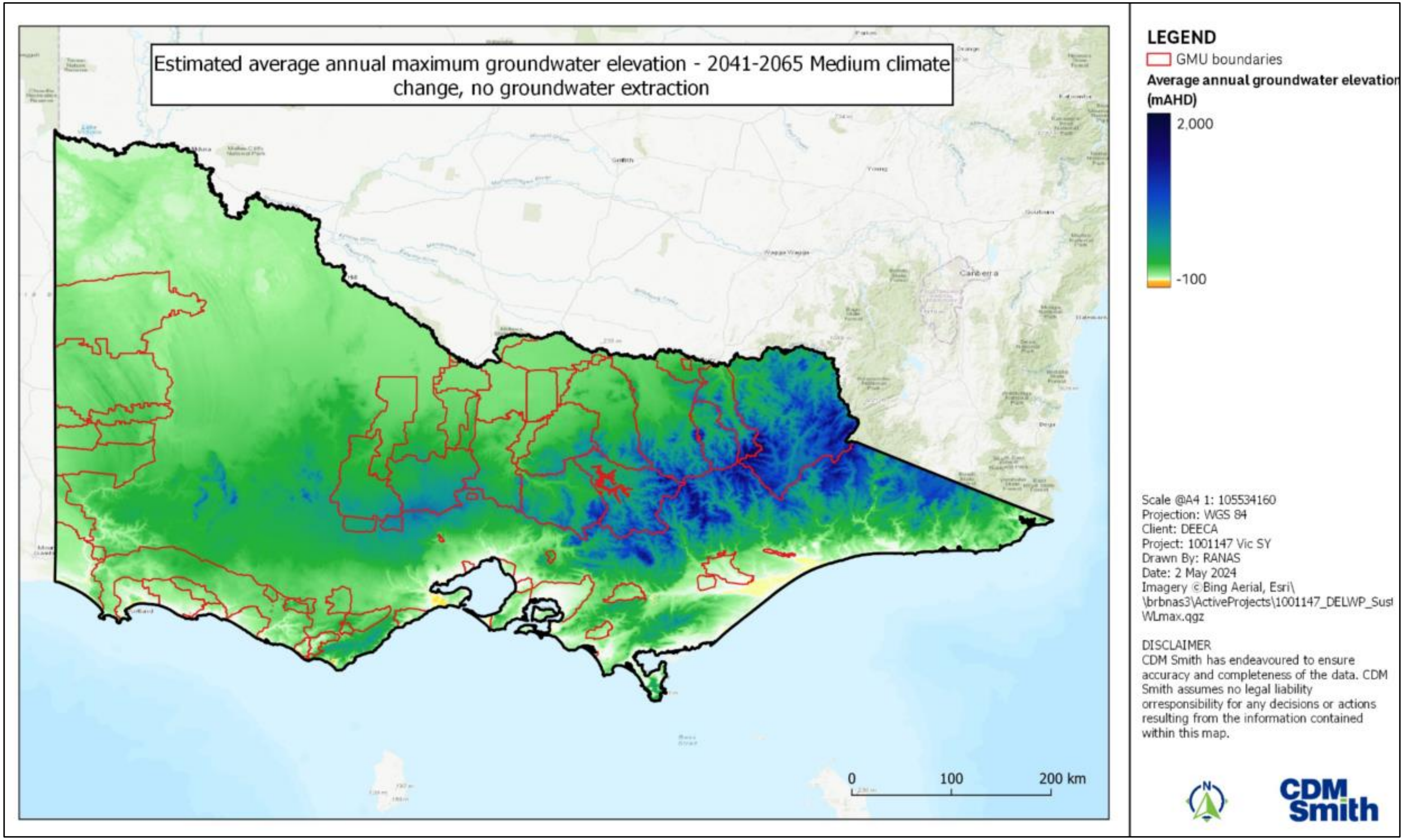
Figure S-27 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 Low climate change and 200% of PCV rate extraction.



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Project: 1001147 Vic SY
Drawn By: RANAS
Date: 2 May 2024
Imagery ©Bing Aerial, Esri\
\brbnas3\ActiveProjects\1001147_DELWP_Sus
WLmax.qgz

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Figure S-28 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 Medium climate change and no groundwater extraction.

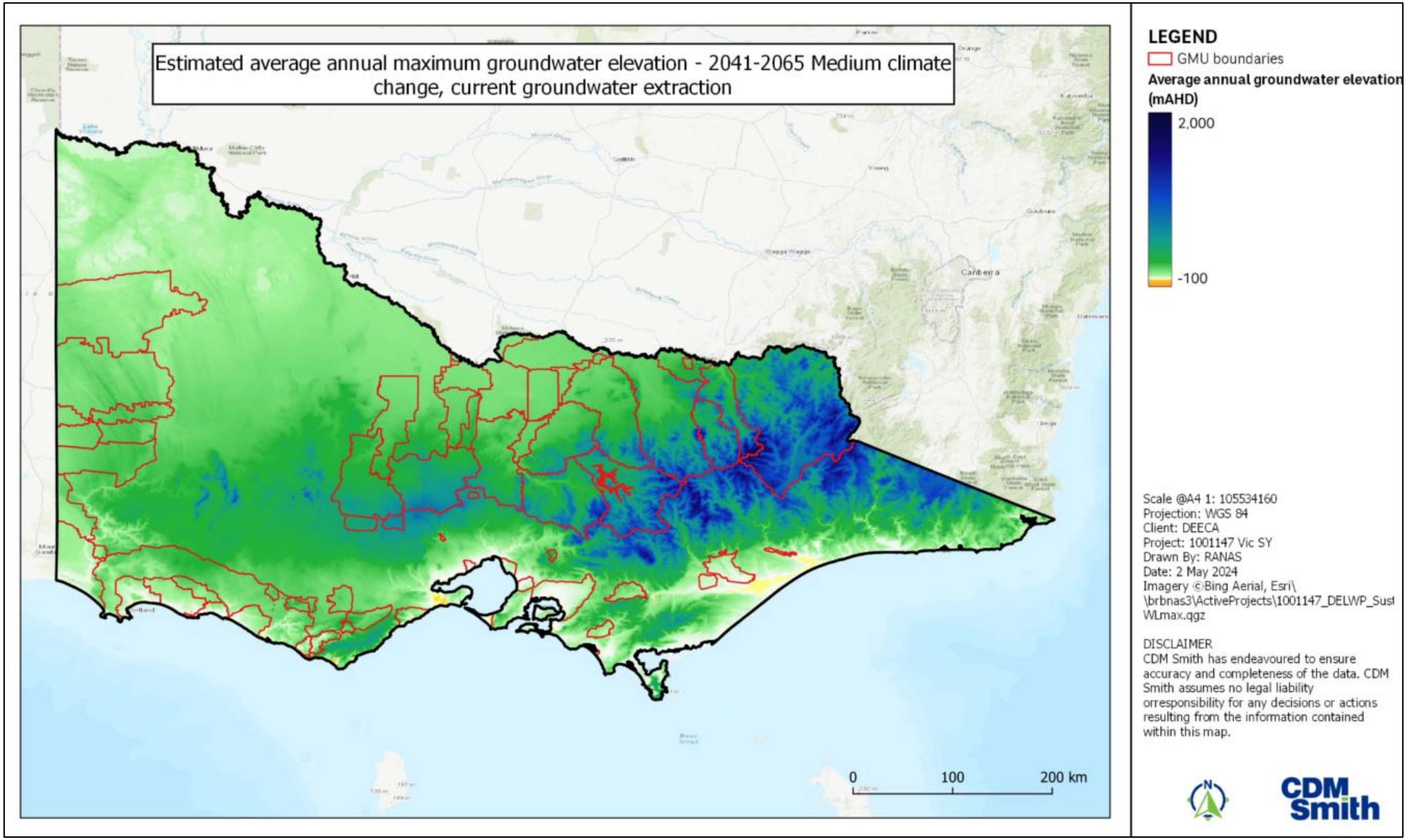

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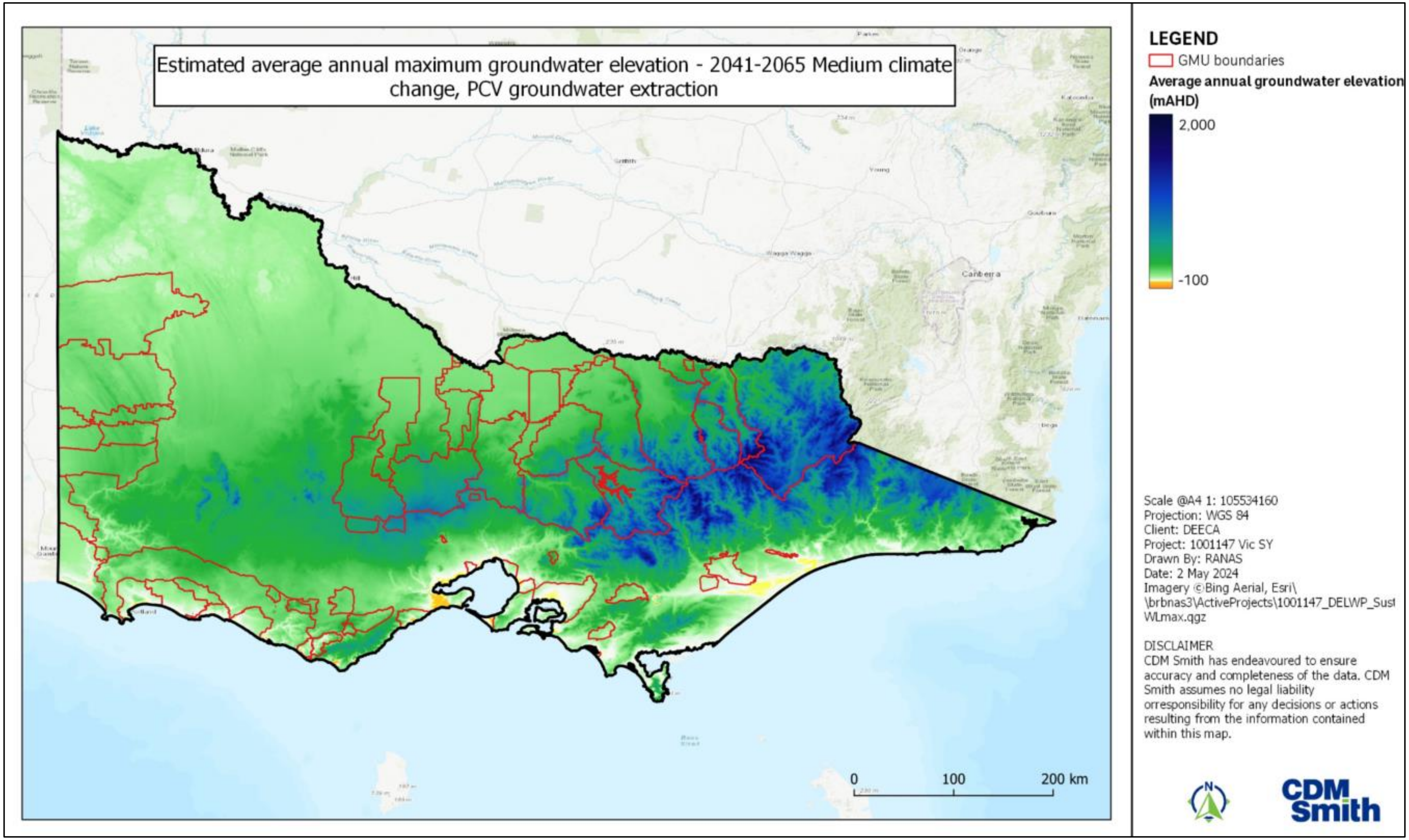
Figure S-29 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 Medium climate change and current groundwater extraction.



Estimated average annual maximum groundwater elevation - 2041-2065 Medium climate change, PCV groundwater extraction

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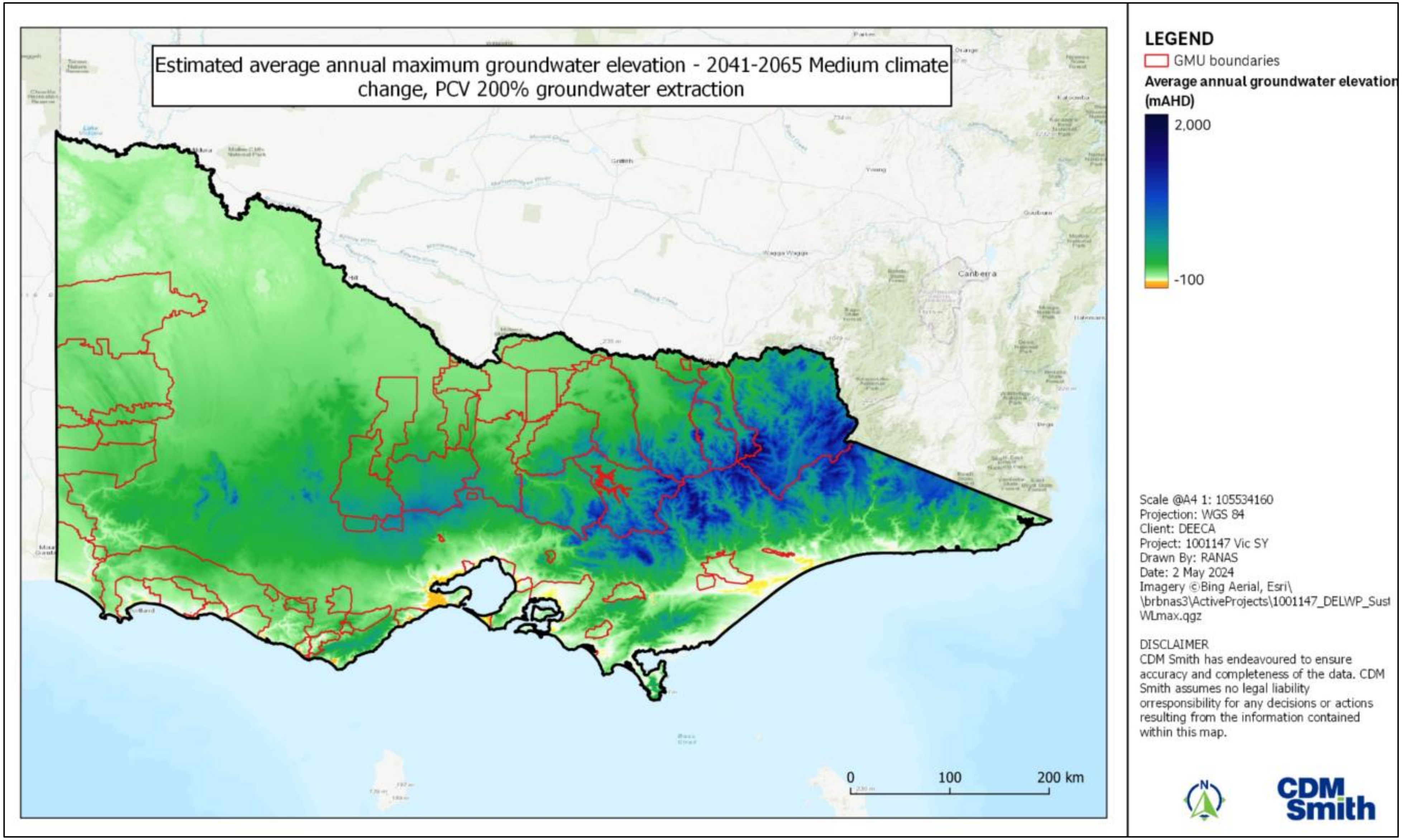
Figure S-30 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 Medium climate change and PCV rate extraction.



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Drawn By: RANAS
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Figure S-31 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 Medium climate change and 200% of PCV rate extraction.

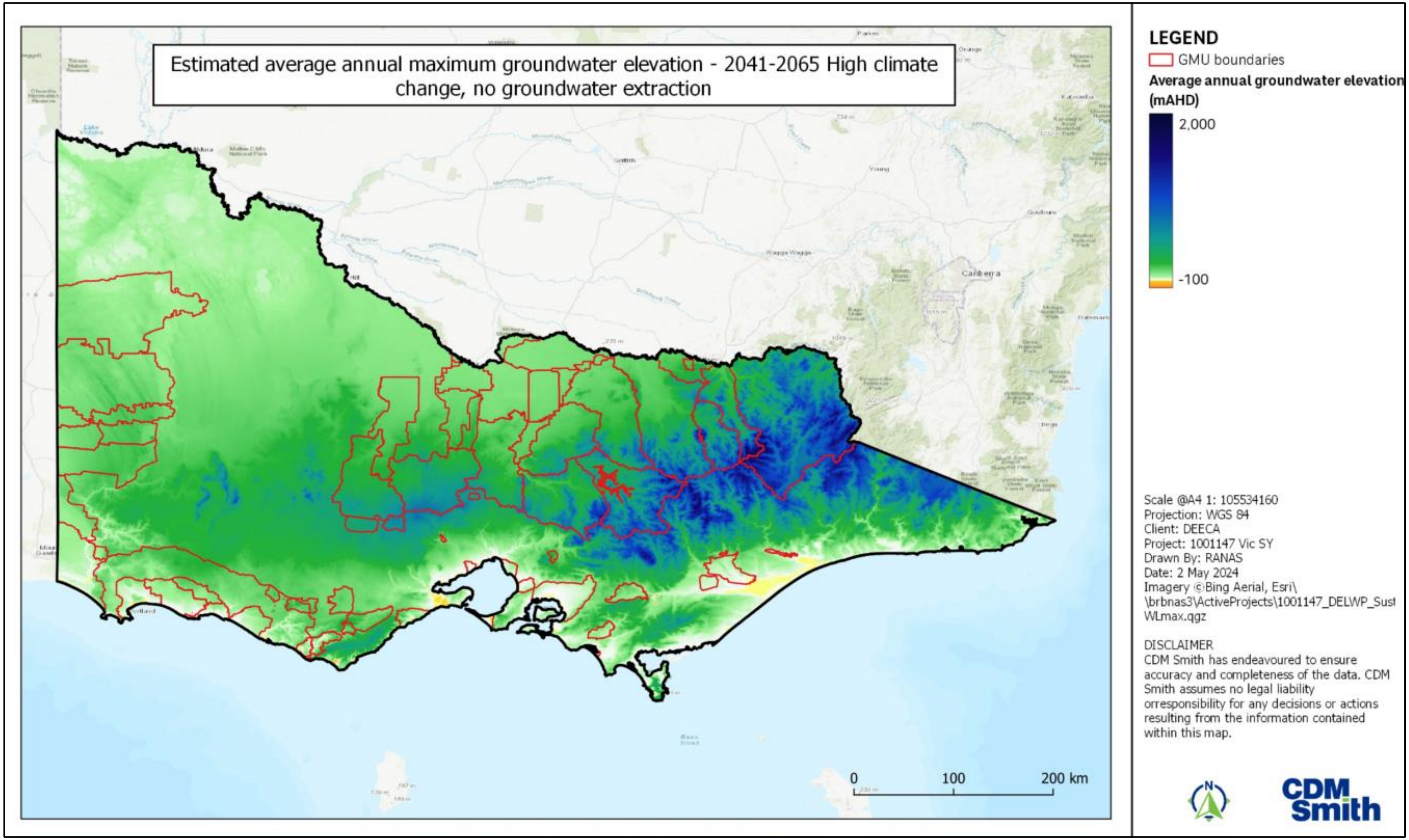
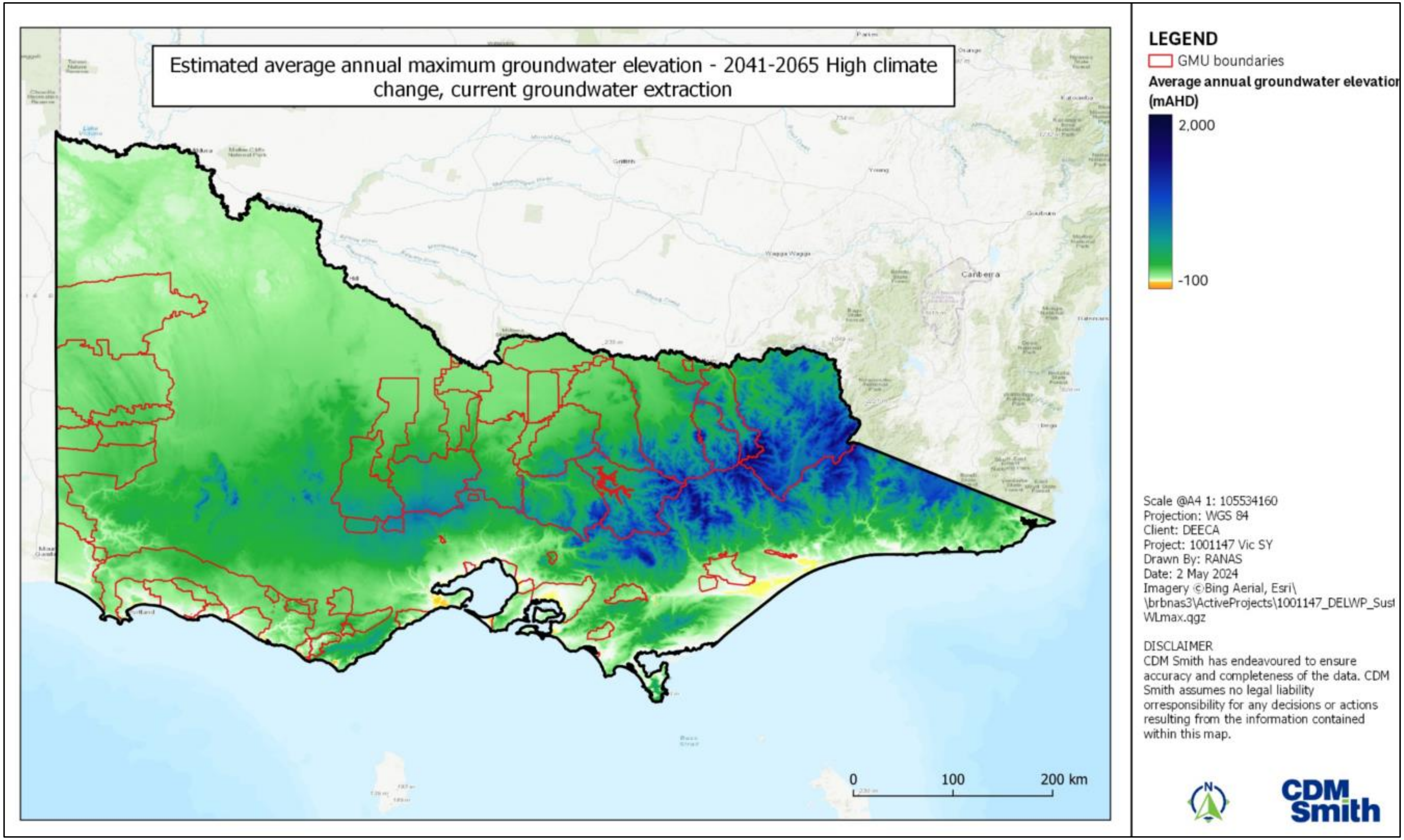


Figure S-32 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 High climate change and no groundwater extraction.



Estimated average annual maximum groundwater elevation - 2041-2065 High climate change, current groundwater extraction

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Client: DEECA
Project: 1001147 Vic SY
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Figure S-33 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 High climate change and current groundwater extraction.

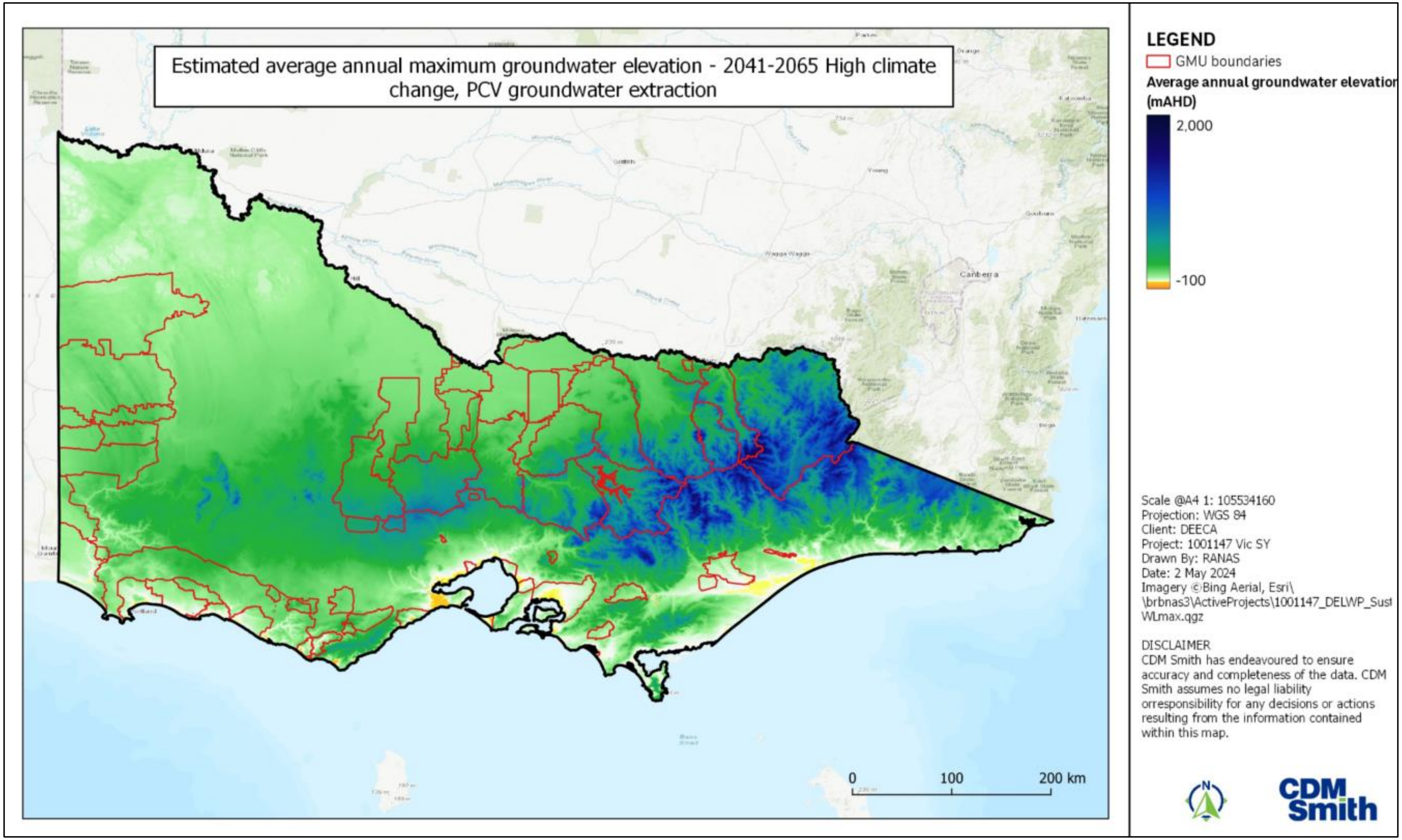
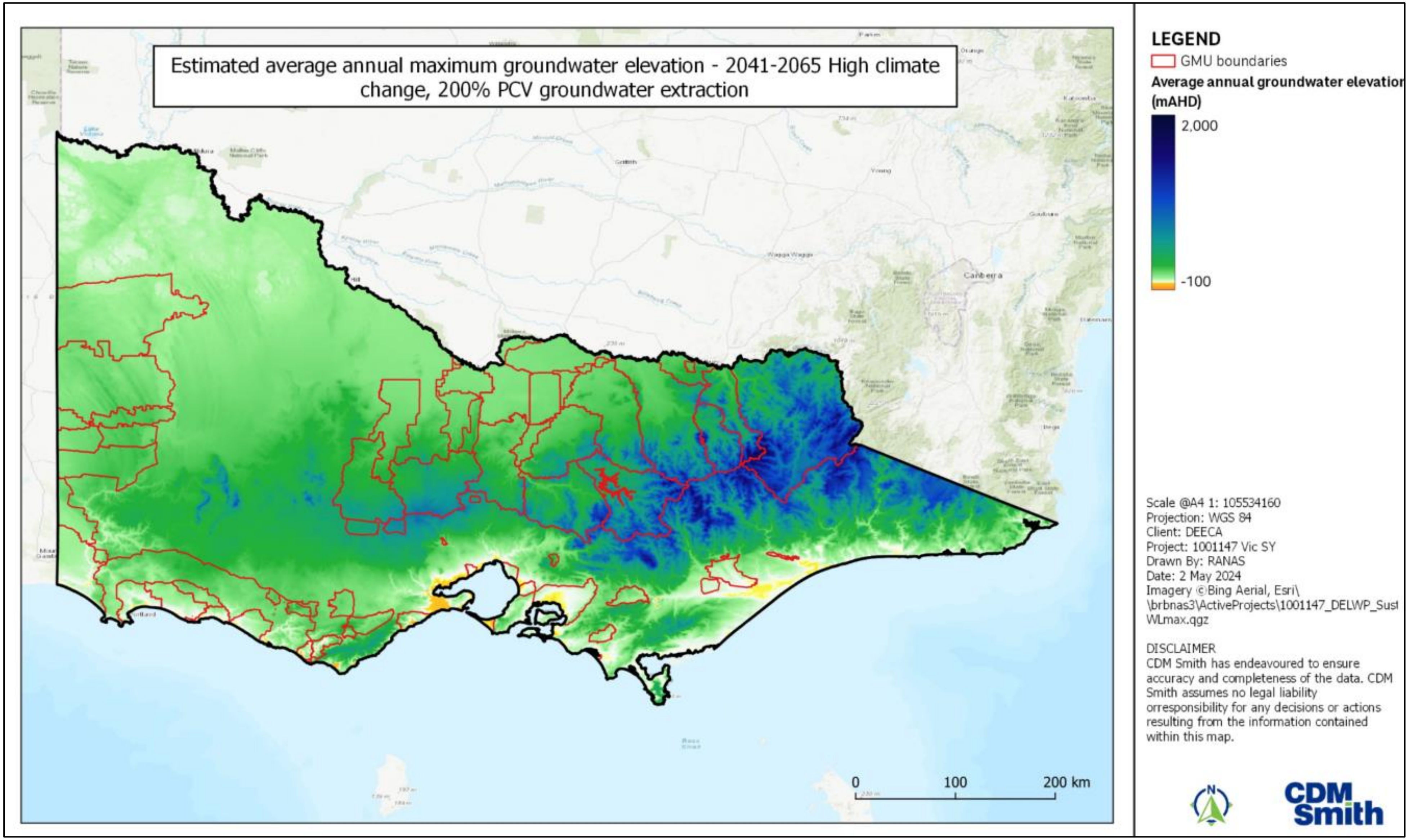


Figure S-34 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 High climate change and PCV rate extraction.



Scale @A4 1: 105534160
Projection: WGS 84
Client: DEECA
Project: 1001147 Vic SY
Drawn By: RANAS
Date: 2 May 2024
Imagery ©Bing Aerial, Esri\
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Figure S-35 Estimated annual maximum watertable elevation (mAHD) – 2041-2065 High climate change and 200% of PCV rate extraction

Technical Assessments of Statewide Groundwater Sustainable Yields for Victoria

Statewide estimation of recharge using Soilflux

Version 1

5 December 2023

Document status

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1. Introduction

1.1 Sustainable Yields project and objective

The Sustainable Yields project is led by the Groundwater Assessment and Modelling Team of the Department of Energy, Environment and Climate Action (DEECA) (formerly in the Department of Environment, Land, Water and Planning, DELWP). The overall objective of the Sustainable Yields project is to determine sustainable yield volumes for Groundwater Management Units (GMUs) and selected unincorporated areas across Victoria. The sustainable yield assessments must be technically rigorous; be reported within the bounds of uncertainty; be reported according to the level of risk they present to the environment and existing users; and consider future groundwater conditions associated with a changing climate. The outcomes of the Sustainable Yields project will inform a future review of Permissible Consumptive Volumes (PCV), albeit it is outside the scope of the Sustainable Yields project to make recommendations around any potential changes to PCVs.

The Sustainable Yields project objective is to develop sustainable yield volumes for GMUs and selected unincorporated areas, including assessment of the following components:

- Volume of water available for groundwater entitlement and use (annual and where required, seasonal)
- Acceptable resource condition (based largely on the assessment approach of DEECA)
- Assessment of potential risk of impacts from overuse of the resource on other users and the environment
- Uncertainty around the sustainable yield estimates and
- Comparison with current PCV, entitlement and average use.

1.2 Technical assessments supporting the Sustainable Yields project

CDM Smith were engaged by DELWP and then DEECA to deliver technical assessments for the Sustainable Yields project.

HARC were engaged as a sub-consultant on the CDM Smith team to analyse results of modelling undertaken with the SoilFlux model, to provide a gridded dataset of modelled recharge across Victoria, under historical climate under several future climate scenarios. A gridded data set of uncertainty in recharge estimates from SoilFlux is also provided, which provided information for merging these recharge estimates with estimates made from other analyses undertaken as part of the Technical Assessment project. The recharge model used in this study was SoilFlux, as described in Section 2.1.

The study approach involved extracting recharge data for the baseline period from 1975 to 2016, and estimating the anticipated change in recharge using projected changes in mean annual rainfall for six future climate projections. The six future climate rainfall projections were derived for the low, medium, and high projected changes for 2040 and 2065, from the *Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria* (DELWP 2020). Sections 3 and 4 of this report provide detailed information on the data extraction and the methodology used to estimate the projected change in recharge for future scenarios.

2. The SoilFlux model

SoilFlux is a one-dimensional model which uses the Richards Equation (Richards 1931) to estimate water movement through the soil profile. In Sinclair Knight Merz (2008) state-wide estimates of water use for key land use types were developed, by applying SoilFlux independently at 1km² grid cells over all of Victoria.

The SoilFlux model represents the water balance in a catchment using the following assumptions:

- Rainfall is the only water input at the land surface (i.e. irrigation and river recharge are ignored)
- Water input to a vegetation root zone may also occur from shallow underlying water tables
- Water inputs are partitioned into output fluxes (evapotranspiration, surface runoff and drainage below a root zone) using the SoilFlux model to estimate water movement in the vertical soil/geology profile
- Drainage below a vegetation root zone enters the shallow groundwater system that is hydraulically connected to the stream or river network (the drainage output flux) and
- In some areas there may also be losses from the near-surface water systems (both groundwater and surface water) to underlying deep and confined groundwater systems and this water volume is then lost from the sub-catchment.

The model is run on a daily time-step, with the key outputs being evapotranspiration, groundwater recharge and surface runoff. Further details on the model development and assumptions can be found in Sinclair Knight Merz (2008). The processes simulated in the SoilFlux water balance are shown in Figure 2-1.

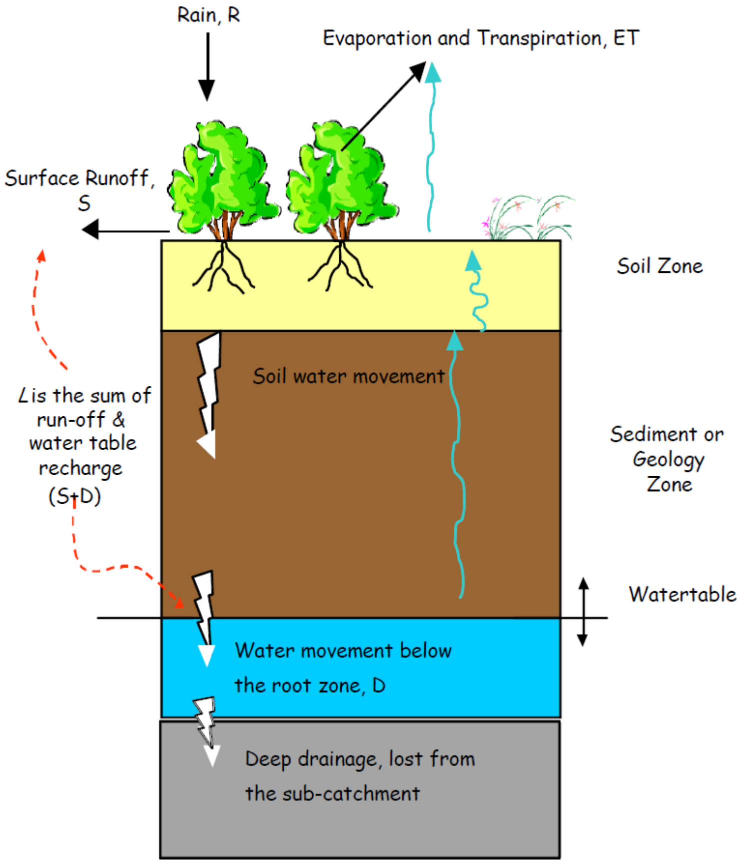

Figure 2-1: Processes simulated by the SoilFlux model in this project

The water balance for the simulated profile is therefore as shown in Equation 2-1.

$$ET = R - D - S$$

- Equation 2-1

Where

- ET = Evapotranspiration
- D = net recharge to the water table below the root zone
- S = surface runoff

The D and S terms are commonly expressed in combined terms as “losses” (L).

HARC (2016, 2017) re-ran SoilFlux on a 1 km grid across Victoria, for the period between 1950 and 2016, which included the full duration of the Millennium drought (1997-2009). Results were therefore available for the entire period between 1950 and 2016.

The SoilFlux model was configured to use 24 representative rainfall gauges across Victoria. The gauges were then classified within different rainfall zones, broadly consistent with the Bureau of Meteorology rainfall district boundaries. Each rainfall zone had 100mm rainfall bands defined based on the mean annual rainfall over 1961 – 1990 Bureau of Meteorology climatology period. The input rainfall within each model cell was then defined by scaling the data series of the representative gauge such as the mean annual rainfall for 1961-1990 matched either the upper or lower limit value for the rainfall band. HARC (2016, 2017) extended the rainfall input such as to cover the simulated period of 1950 to 2016.

SoilFlux was run using ten land use types, shown in Table 2-1. They were selected based on importance on hydrologic impacts as a result of land use changes.

Table 2-1: Land uses adopted for SoilFlux modelling

Land use ID for SoilFlux	Land use name
1	Annual Pasture
2	Perennial Pasture
3	Native Grassland
4	Native Forest
5	Native Woodland
6	Annual Cropping
7	Lucerne
8	Perennial Horticulture
22	Hardwood Forestry Plantations
24	Softwood Forestry Plantations

As part of HARC (2016,2017) updates to SoilFlux runs, the model was run using four depths to water table classes assigned to each 1km² cell (0 to 5m, 5 to 10m, 10 to 20 m and greater than 20m).

3. SoilFlux data extraction

As explained in section 2, HARC (2016, 2017) created a data cube with a set of SoilFlux model outputs generated by model runs undertaken with different ranges of depth to the water table and land use types. In this study we were interested in mean annual recharge values corresponding to the depth to water table values from the Department of Environment Land Water and Planning (2013) updated water table information and the Victorian Land Use Information System (VLUIS) data from 2014/2015 for each 1km² grid cell.

The DWELP (2013) updated water table information was then classified into the four classes used in the SoilFlux runs (section 2), as shown in Figure 3-1. Similarly, the VLUIS (2015) land use data was reclassified within the classes presented in Table 2-1, as shown in Figure 3-2.

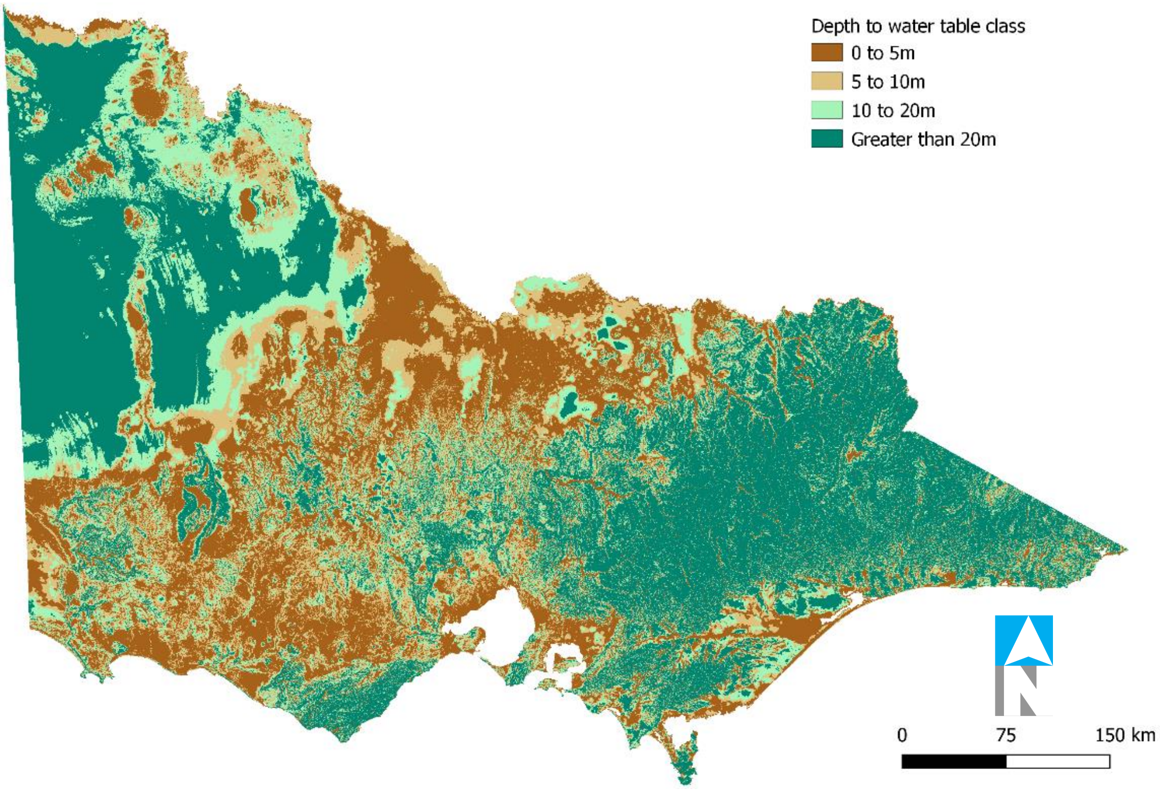

Figure 3-1: Reclassified DELWP (2013) depth to water table layer

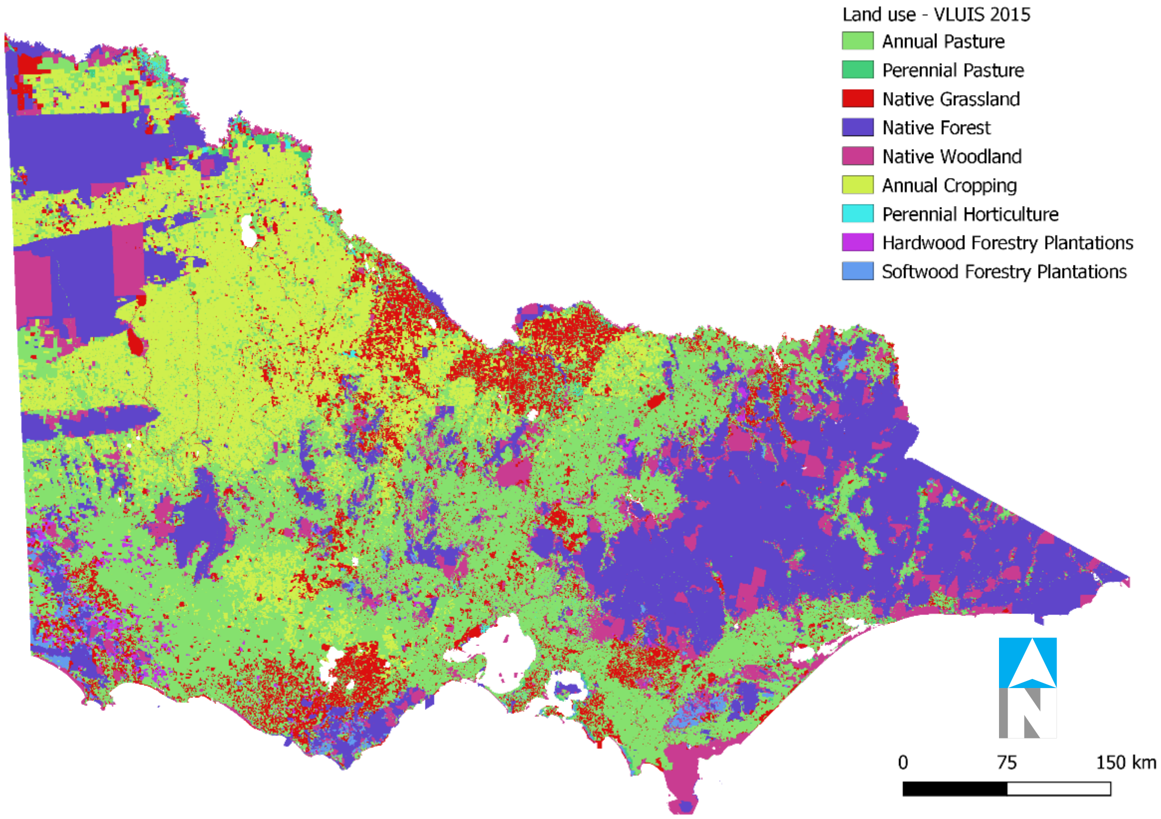

Figure 3-2: Reclassified VLUIS (2015) land use information

Using a series of scripts written in C#, the mean annual recharge was then extracted for the historical climate baseline period of 1975 to 2016 (Figure 3-3); and for additional 5 periods of time (1961 to 1974, 1975 to 1996, 1997 to 2009, and 2010 to 2016) (see Figure 3-4).

It is important to notice that the warmup period of the model was taken to be from 1/1/1950 to 1/1/1961, so the output data extraction started from 1961 onwards. Upon extraction, the rasters were post-processed such as areas in Victoria where gaps with no data were identified and replaced by the average recharge values of the surrounding grid cells.

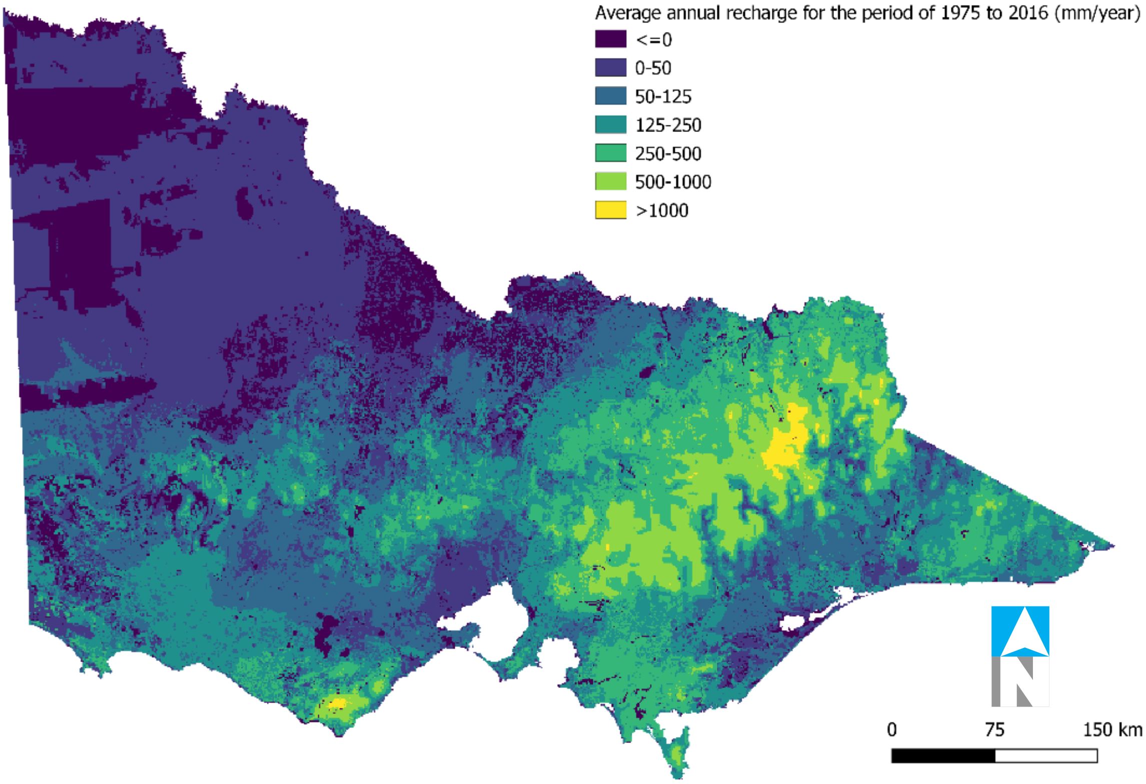

Figure 3-3: SoilFlux mean annual recharge extracted for the historical climate baseline period of 1975 to 2016

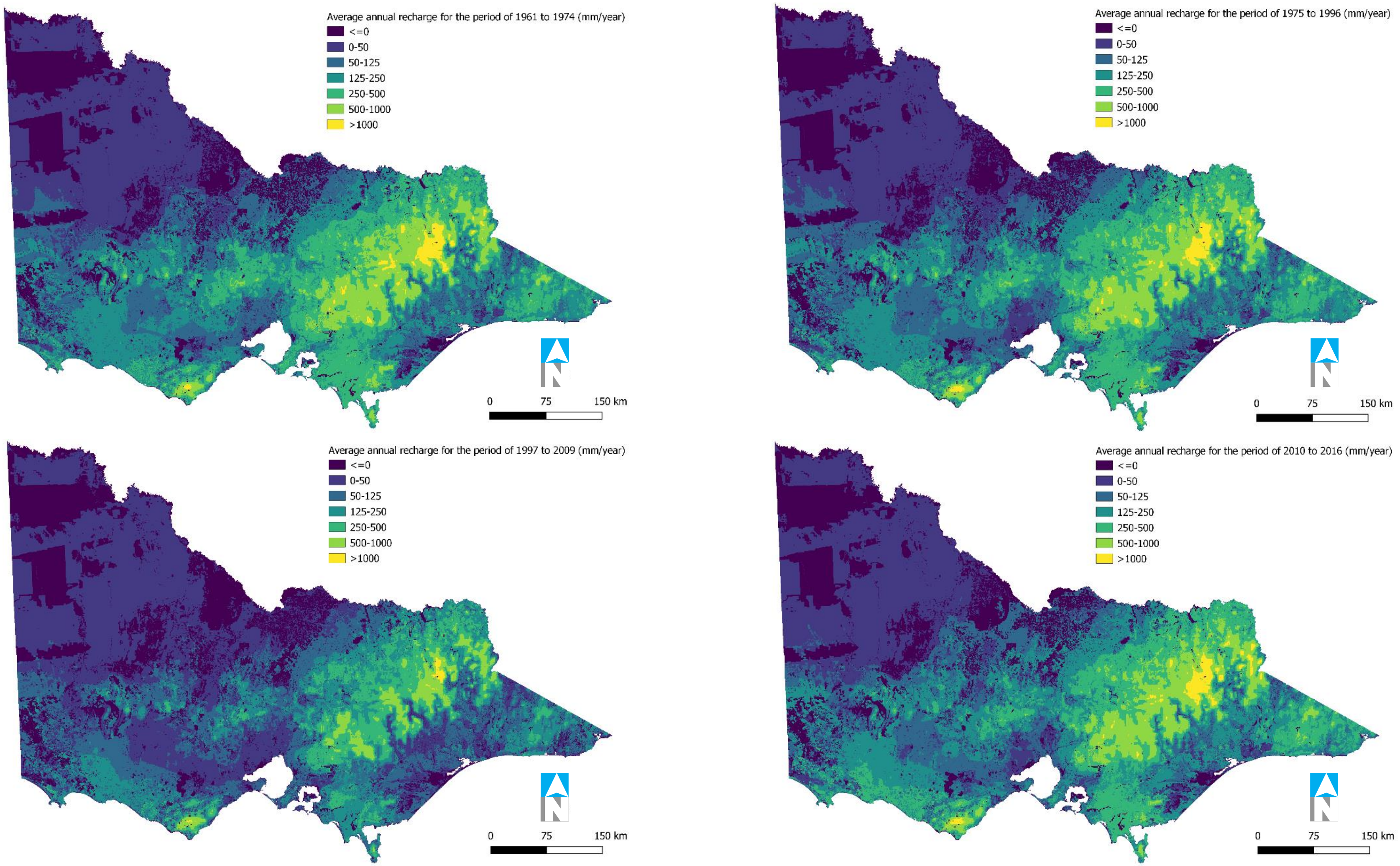

Figure 3-4: SoilFlux mean annual recharge extracted the periods of 1961 to 1974 (upper left), 1975 to 1996 (upper right), 1997 to 2009 (lower left), and 2012 to 2016 (lower right)

4. Estimate of recharge for future scenarios

4.1 Projection method

This step of the analysis consisted of estimating recharge for future scenarios under climate change conditions. The scenarios adopted for analysis consisted of projected rainfall changes using the Climate Change Guidelines low, medium, and high factors for 2040 and 2065.

In addition to that, estimates of recharge were calculated under same projected rainfall changes but with increased depth to water table values. For those estimates, SoilFlux recharge data was also extracted for a modified version of the DEWLP (2013) depth to water table layer, where all the classes were lowered by one unit, such as the overall depth to water table increased throughout the state by approximately 5 metres from the 2013 estimates.

The methodology consisted in using the 4 sets of mean annual rainfall and recharge data extracted in section 3 to calculate the recharge relative to the projected mean annual rainfall value for the scenario of interest by interpolating its values from the available data. This calculation was performed per each individual 1 km² grid cell within the state of Victoria, for the 12 scenarios of interest, with the use of an R script tailored for this task. The preparation of the projected mean annual rainfall used in the interpolation is described in section 4.2. Figure 4-1 shows the example of the interpolation undertaken at an individual grid cell.

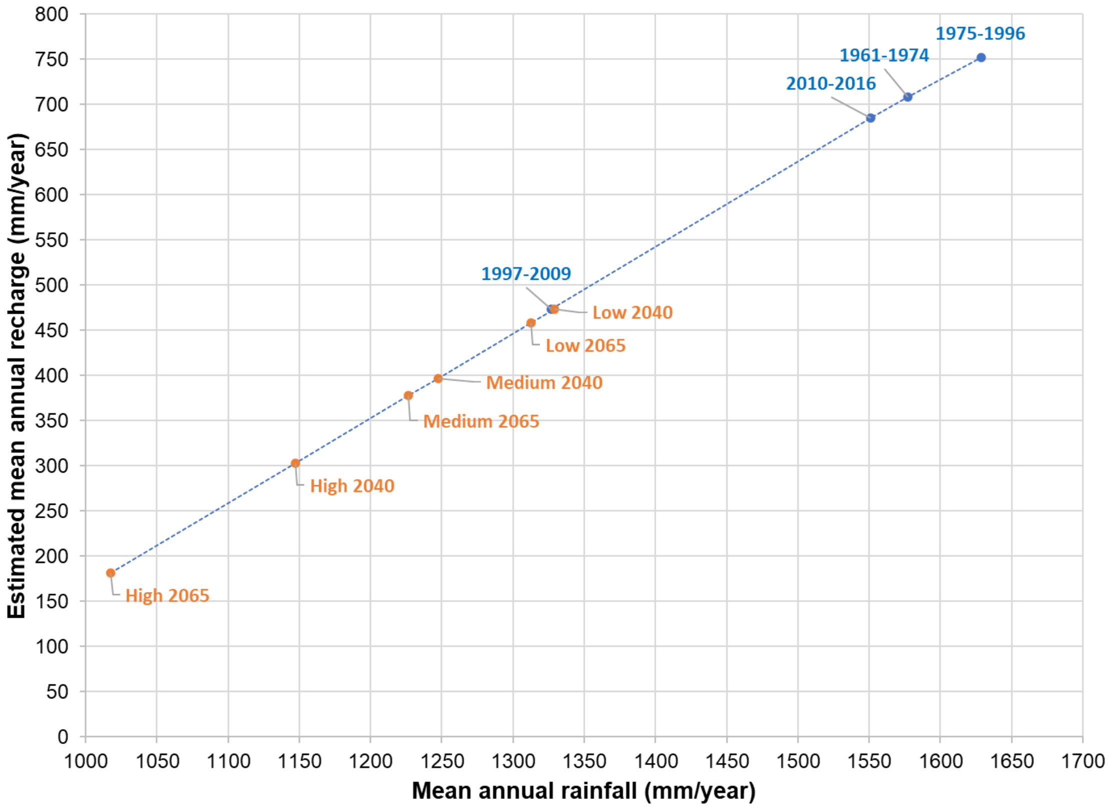

Figure 4-1 : Example of interpolation undertaken for estimating recharge at an individual grid cell

4.2 Climate change adjustment factors for mean annual rainfall

The projections in the *Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria* (DELWP 2020) are expressed relative to the post 1975 climate reference period. In this project, the annual climate change factors were adopted for the RCP8.5 scenario, provided by the guidelines for each major basin in Victoria. The guidelines regard the RCP8.5 as a high emissions scenario that is suitably precautionary for water supply planning purposes in Victoria. The climate change projection factors adopted for this study are shown in Table 4-1.

Table 4-1: Annual climate change factors for rainfall, RCP8.5 (DEWLP, 2020)

Basin	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Avoca	4.8%	-3.8%	-15.5%	6.9%	-3.4%	-20.6%
Barwon	2.0%	-3.0%	-11.5%	1.2%	-5.2%	-19.6%
Broken	6.0%	-3.7%	-14.2%	6.8%	-3.5%	-18.3%
Bunyip	2.9%	-3.9%	-10.9%	2.1%	-5.0%	-16.1%
Campaspe	2.4%	-2.2%	-15.2%	2.6%	-6.1%	-23.2%
East Gippsland	6.8%	-1.0%	-10.8%	7.9%	-1.2%	-15.0%
Glenelg	1.2%	-5.0%	-12.7%	1.4%	-8.4%	-21.7%
Goulburn	3.9%	-2.5%	-13.6%	2.4%	-4.0%	-20.7%
Hopkins	2.1%	-4.4%	-11.6%	1.0%	-5.7%	-20.9%
Kiewa	5.5%	-2.5%	-9.5%	4.0%	-2.1%	-16.0%
Lake Corangamite	2.0%	-3.9%	-11.6%	-0.2%	-5.3%	-19.1%
Latrobe	3.3%	-4.0%	-11.4%	2.2%	-4.5%	-16.7%
Loddon	2.5%	-2.8%	-14.3%	3.2%	-5.6%	-22.9%
Lower Murray	7.3%	-3.8%	-15.0%	9.1%	-2.3%	-19.1%
Mallee	4.7%	-5.3%	-17.8%	6.9%	-6.5%	-23.6%
Maribyrnong	2.7%	-2.4%	-12.0%	2.6%	-5.5%	-21.6%
Millicent	1.2%	-5.5%	-15.0%	1.1%	-8.5%	-22.9%
Mitchell	4.3%	-2.3%	-9.7%	2.3%	-4.8%	-18.5%
Moorabool	2.0%	-3.4%	-11.6%	1.5%	-5.9%	-21.4%
Otway Coast	2.1%	-3.6%	-11.7%	0.5%	-5.8%	-19.0%
Ovens	5.3%	-3.4%	-9.5%	3.8%	-3.7%	-17.5%
Portland Coast	2.6%	-4.6%	-10.9%	-0.2%	-8.4%	-19.0%
Snowy	7.6%	-1.4%	-10.4%	8.5%	-4.5%	-14.9%
South Gippsland	2.6%	-4.5%	-11.7%	2.2%	-4.4%	-15.9%
Tambo	5.9%	-2.6%	-10.8%	7.1%	-4.5%	-16.6%
Thomson	4.1%	-2.0%	-10.6%	2.3%	-4.1%	-19.9%
Upper Murray	7.5%	-0.7%	-8.5%	8.2%	-2.6%	-14.4%
Werribee	2.2%	-2.7%	-11.7%	2.4%	-6.2%	-21.4%
Wimmera	2.0%	-3.7%	-13.3%	3.9%	-5.9%	-22.3%
Yarra	3.7%	-2.7%	-10.5%	2.4%	-4.3%	-20.6%

Mean annual rainfall for the period of 1975 to 2016 was calculated from the CSIRO’s Australian Water Availability Program (AWAP) data (Raupach et al. 2012), and the climate change factors were applied to the data, generating 6 different gridded rainfall layers for the state of Victoria.

5. Uncertainty Estimates

5.1 Overall method for uncertainty estimation

Estimates of uncertainty in mean annual recharge estimates from SoilFlux were produced, as an input to the Bayesian fusion process that provides an overall estimate of the spatial variation in recharge across Victoria. The Bayesian fusion process applied more weight to data sources that had lower uncertainty in recharge estimates and less weight to data sources that had higher uncertainty in recharge estimates.

Estimates were used provide a 1 km resolution grid of the uncertainty in mean annual recharge across Victoria. The previous SoilFlux runs (HARC 2017; Sinclair Knight Merz 2010) consider input only from natural precipitation and they did not represent irrigation inputs. As a result, the recharge estimates in irrigation areas represented in SoilFlux would be much lower than would have been the case had irrigation been included. A final adjustment was applied to represent much higher values of uncertainty in irrigation areas, where the SoilFlux model runs would not accurately represent recharge estimates (see Section 5.2).

It is difficult to obtain objective data on the uncertainty in recharge estimates from SoilFlux, across such a wide area as the state of Victoria. For this project, analysis of the uncertainty in recharge estimates from SoilFlux was related to the uncertainty in mean annual runoff, estimated at a catchment scale from SoilFlux compared to catchment-level estimates of mean annual flow from an independent data source. Uncertainty in modelled mean annual runoff was used as a proxy for uncertainty in mean annual recharge because the runoff and recharge components in SoilFlux close the water balance, after evapotranspiration is removed from rainfall. Mean annual runoff represents an integrated metric, at a catchment scale, of the difference between mean annual rainfall and mean annual evapotranspiration. The scatter, or uncertainty, in the mean annual catchment runoff value compared to SoilFlux estimates of mean annual and runoff and recharge (for a consistent climate period) provides an independent estimate of the uncertainty in the SoilFlux estimates of mean annual recharge, at a catchment level.

Once a relationship was developed between for the uncertainty in mean annual recharge at a catchment scale, the same relative uncertainty in mean annual recharge was assumed to apply for each 1 km^2 grid square (outside of irrigation areas), across Victoria.

To assess the degree of uncertainty in the recharge estimates from SoilFlux, a comparison between the SoilFlux mean annual recharge and runoff estimates obtained from the Victorian Winterfill Period Sustainable Diversion Limits (SDL) project from 1961 to 2000 was also undertaken for each SDL catchment. The 1961-2000 period was chosen for comparison between the SoilFlux mean annual flow and recharge estimates and the SDL estimates of mean annual flow, because the SDL project was undertaken in 2001-03 and provided estimates of mean annual flow that were estimated using streamflow data collected up to the year 2000. Use of SoilFlux estimates for 1961-2000 would therefore be reasonably consistent with the mean annual flow estimates in the SDL spatial data set.

The scatter plot of the mean annual recharge and runoff estimated by SoilFlux against the SDL mean annual flow estimates for the period between 1961 and 2000 is shown in Figure 5-1. As shown in the figure, mean annual runoff is well correlated with the SoilFlux estimates of mean annual recharge and runoff. Mean annual runoff, estimated from streamflow gauging data, is slightly higher than the SoilFlux model values because SoilFlux includes a deep recharge component that would remain in the groundwater. The focus of this investigation was on the uncertainty or scatter in the mean annual runoff and recharge estimates. Uncertainty in mean annual flow is heteroscedastic, in that there is a trend toward increasing uncertainty in mean annual flow estimates for increasing mean annual recharge and runoff estimates in SoilFlux. A Box Cox transformation of the data was also undertaken with lambda value of 0.4, shown in Figure 5-2. The Box-Cox transformation made the transformed data set homoscedastic, producing consistent scatter in transformed estimates of mean annual flow and mean annual recharge plus runoff. As shown in Figure 5-2, a regression relationship and ±1 standard deviation confidence limits were fitted to the mean annual flow, as a function of mean annual recharge plus runoff. The one standard deviation confidence limits were back-transformed by inverting the Box-Cox transformation to estimate the one standard deviation uncertainty bands in mean annual runoff.

A spatial raster layer (1 km resolution) of the estimated standard error (one standard deviation) in the SoilFlux recharge estimates was generated for the same period of data (Figure 5-3). By analysing the map shown in Figure 5-3, it is noted that uncertainty in recharge is larger (in absolute terms) in areas of the state with larger rainfall, runoff and recharge estimates. In areas with 0 mm/year of estimated mean annual runoff (eg. Wimmera and Mallee), the standard error range is about 12 mm/year. In the highest runoff areas of the state, the uncertainty is about 180 mm/year (current climate mean annual recharge is >1600 mm/year).

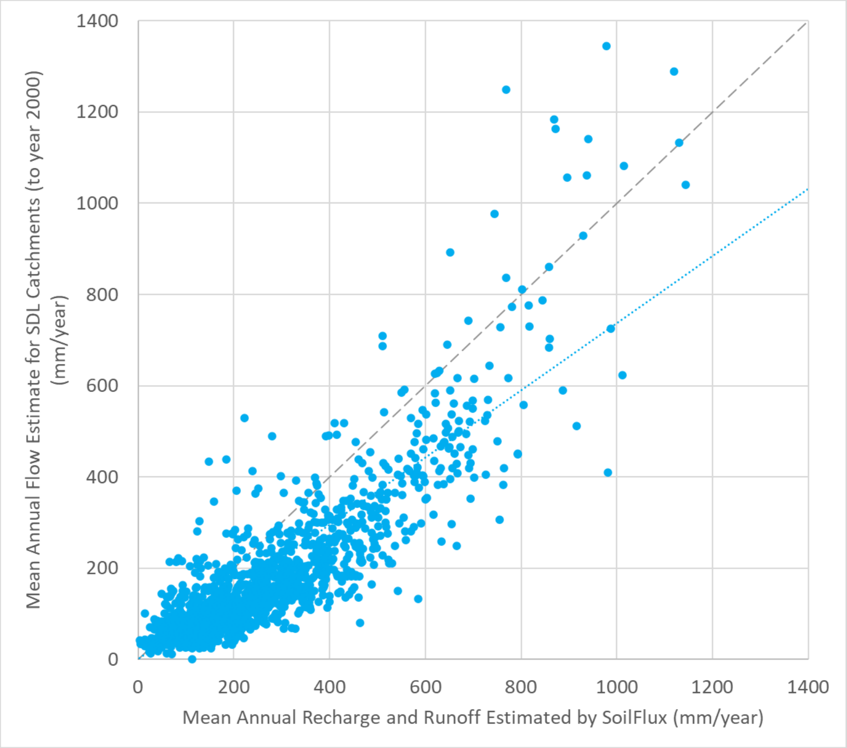

Figure 5-1: Comparison between SoilFlux mean annual recharge plus runoff and SDL mean annual flow estimates

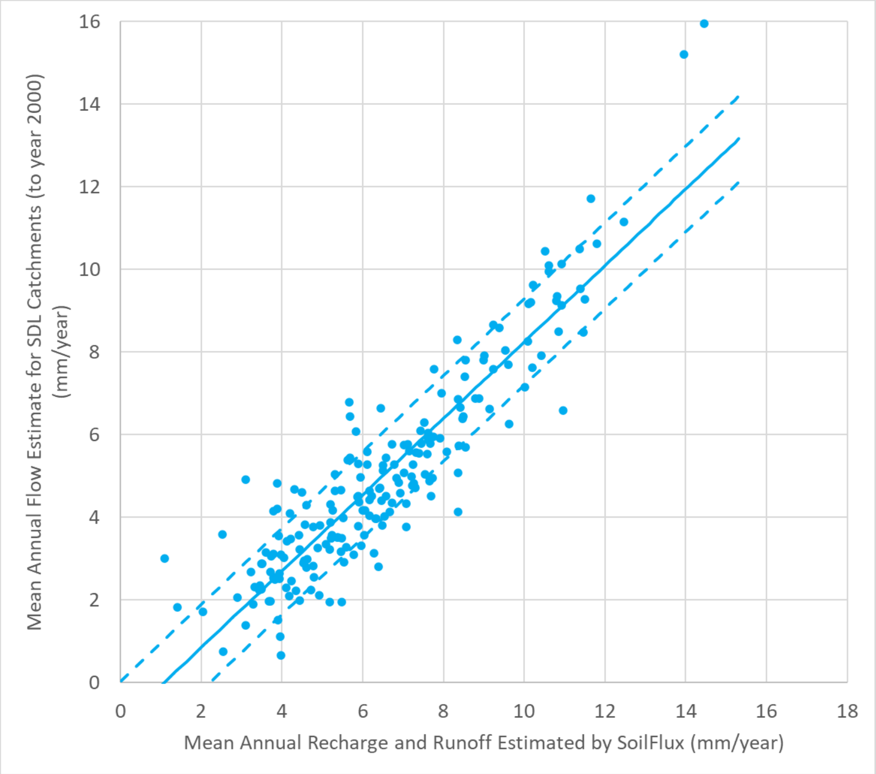

Figure 5-2: Box Cox transformed data - SoilFlux mean annual recharge plus runoff versus SDL mean annual flow estimates (lambda = 0.4 for transformation of values on both axes)

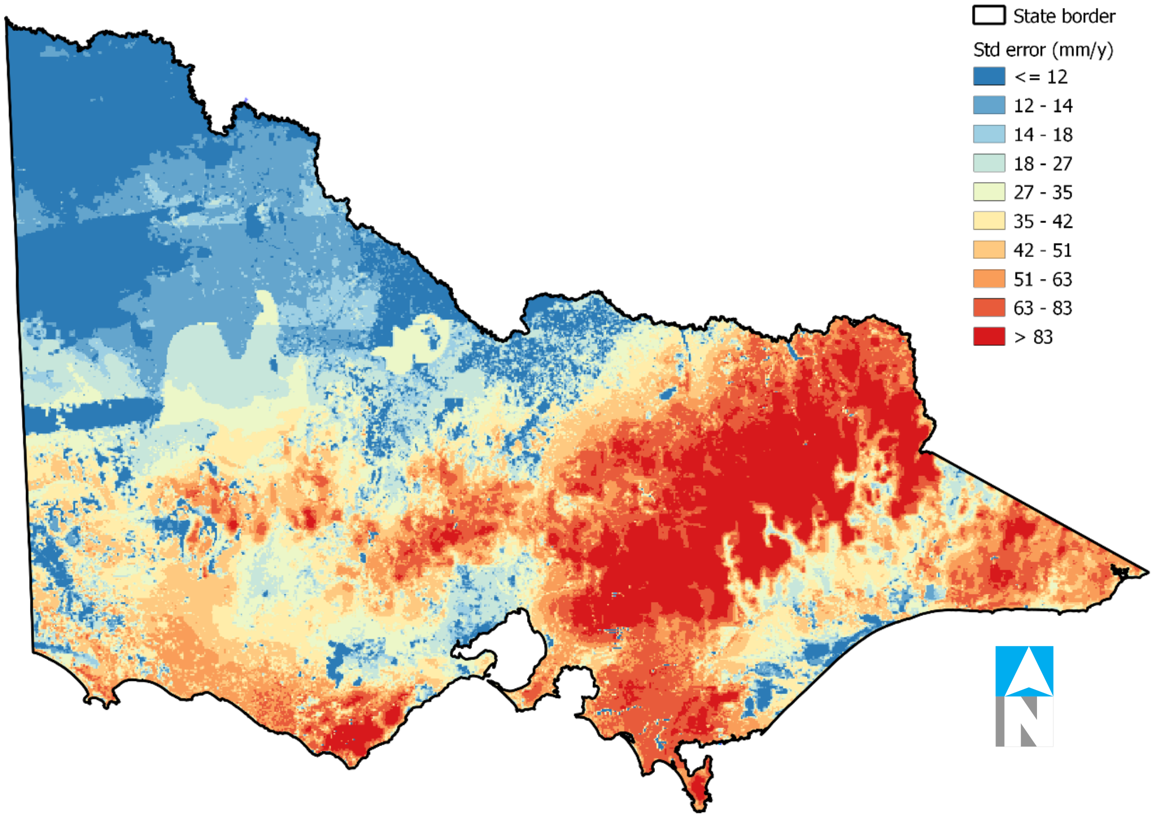

Figure 5-3: Standard error of SoilFlux mean annual recharge plus runoff versus SDL mean annual flow estimates

5.2 Representation of standard error in irrigation areas

The previous SoilFlux runs (HARC 2017; Sinclair Knight Merz 2010) consider input only from natural precipitation and they did not represent irrigation inputs. As a result, the recharge estimates in irrigation areas represented in SoilFlux would be much lower than would have been the case had irrigation been included. The uncertainty of mean annual recharge estimates in irrigation areas from SoilFlux was therefore much larger than in other areas of the state where rainfall is the dominant water input.

Irrigation districts were identified using spatial data from Data.vic. For any grid cell that intersected with, or was within 2 km of the edge of an irrigation district, the uncertainty estimate for mean annual recharge was set to 999 mm/year. The uncertainty estimate in and near irrigation districts was therefore more than 5 times the uncertainty estimate in the grid cell that had the highest estimate for the rest of the state (~180 mm/year).

Figure 5-4shows a map of the overall standard error estimate in mean annual recharge across Victoria. For areas where SoilFlux modelling was valid, the standard error ranges between 11.4 and almost 180 mm/year. For irrigation districts and surrounding areas, the standard error (for the purposes of the Bayesian fusion process) was set to 999 mm/year.

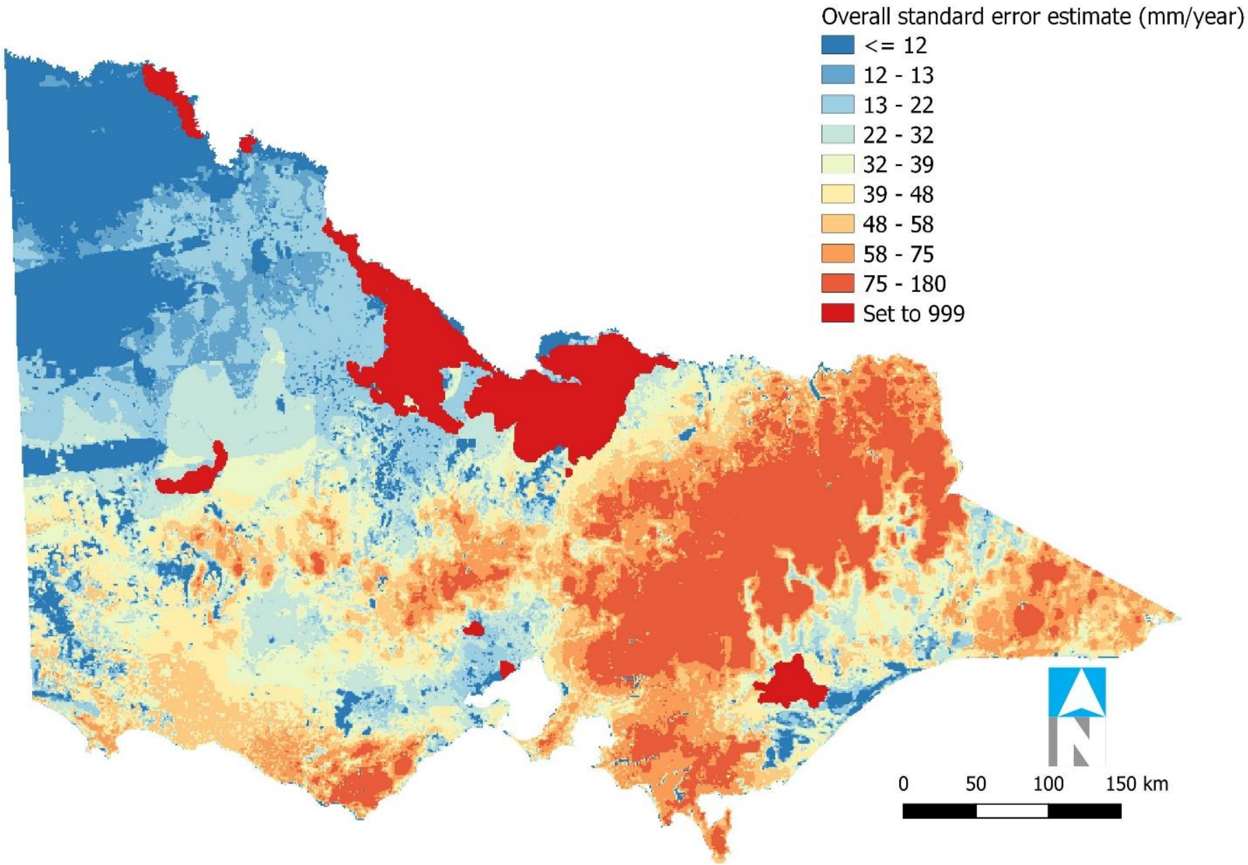

Figure 5-4 Standard error of SoilFlux mean annual recharge adopted for Victoria, with uncertainty in irrigation influenced areas set to a nominal high value of 999

6. Conclusion

This report describes the methodology used to assess the spatial variation in recharge across groundwater management units (GMUs) and the potential impact on recharge under projected climate change. SoilFlux was used to model recharge, and data was extracted from 1975 to 2016 for the baseline period, with estimates made for the anticipated change in recharge using the Climate Change Guidelines' low, medium, and high factors for projected changes in mean annual rainfall to 2040 and 2065.

The report also includes scatter plots of the mean annual recharge and runoff estimated by SoilFlux against the Victorian SDL project's mean annual flow estimates for each SDL catchment, revealing significant similarity between the two, although SoilFlux was generally larger. A raster layer of the estimated standard error in the recharge estimates indicated larger uncertainty in recharge in areas with larger rainfall, runoff, and recharge estimates. A standard deviation of the recharge values was calculated for each grid cell and each climate change scenario output, and the recharge standard deviation maps show higher variation in recharge in the east of the state where higher runoff values are found.

It is noted that SoilFlux has several limitations, including uncalibrated outputs and hard-coded assumptions that cannot be adapted easily. SoilFlux also assumes that the water table level is constant for the entire model run period, and while it allows for water to move between the unsaturated and saturated zones, its previous runs made relatively generic assumptions regarding the management of plantations. More effort could be placed on the calibration of SoilFlux against observed data, such as runoff from gauged catchments and satellite estimates of evapotranspiration and soil moisture, to improve its accuracy.

All SoilFlux runs were undertaken assuming that the only water input is from natural rainfall. SoilFlux does not provide accurate estimates of runoff or recharge for irrigation areas, as it ignores the additional water input from irrigation. Additional SoilFlux runs could be undertaken for irrigated land use types, to provide estimates of recharge in irrigation areas. For the purposes of this project, the uncertainty estimates in mean annual recharge in and near irrigation districts were set to an arbitrarily large value, to represent the lack of confidence in the SoilFlux estimates for these parts of the state.

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Technical Assessments of Statewide Groundwater Sustainable Yields for Victoria

Baseflow and low flow analysis for selected streams across Victoria

Version 1

5 December 2023

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1. Introduction

1.1 Sustainable Yields project and objective

The Sustainable Yields project is led by the Groundwater Assessment and Modelling Team of the Department of Energy, Environment and Climate Action (DEECA) (formerly in the Department of Environment, Land, Water and Planning, DELWP). The overall objective of the Sustainable Yields project is to determine sustainable yield volumes for Groundwater Management Units (GMUs) and selected unincorporated areas across Victoria. The sustainable yield assessments must be technically rigorous; be reported within the bounds of uncertainty; be reported according to the level of risk they present to the environment and existing users; and consider future groundwater conditions associated with a changing climate. The outcomes of the Sustainable Yields project will inform a future review of Permissible Consumptive Volumes (PCV), albeit it is outside the scope of the Sustainable Yields project to make recommendations around any potential changes to PCVs.

The Sustainable Yields project objective is to develop sustainable yield volumes for GMUs and selected unincorporated areas, including assessment of the following components:

- Volume of water available for groundwater entitlement and use (annual and where required, seasonal)
- Acceptable resource condition (based largely on the assessment approach of DEECA)
- Assessment of potential risk of impacts from overuse of the resource on other users and the environment
- Uncertainty around the sustainable yield estimates and
- Comparison with current PCV, entitlement and average use.

1.2 Technical assessments supporting the Sustainable Yields project

CDM Smith were engaged by DELWP and then DEECA to deliver technical assessments for the Sustainable Yields project.

HARC were engaged as a sub-consultant on the CDM Smith team to analyse the baseflow and low flow statistics from streamflow data, using historical gauging data and with projections of climate change, from a targeted selection of gauges across Victoria where there is known or likely to be stronger connections between groundwater levels, recharge and streamflow.

2. Methods

This section describes the steps undertaken to perform the baseflow analysis of relevant streamflow sites across Victoria for the available gauged data, and for the 2040 and 2065 climate change projections of the streamflow series. Changes in ground water levels are likely to be reflected as changes in streamflow in streams around Victoria, particularly during periods of low flow. Baseflow index (BFI), mean annual baseflow volume and the flow exceeded on 90% of days (or Q90) were assessed, as indicators of aspects of streamflow that could change, in response to changes in groundwater levels.

2.1 Streamflow data collation and quality control

To perform the baseflow analysis, streamflow data was collated and analysed for a group of gauges selected based on the following criteria:

1. Streamflow gauges within Victoria where there is known to be, or likely to be, a stronger connection between in-stream baseflows and levels in unconfined groundwater aquifers;
2. Streamflow gauges with data available from the period post-1975 hydroclimatic baseline; and
3. Streamflow gauges with continuous data, with acceptable quality code flags, for a large proportion of the post-1975 period.

The final selection consisted of a group of 67 streamflow gauges, with 15 of them located in regulated rivers. Their location is shown in Figure 2-1. The gauges names, start and end dates can be found in Table 2-1.

Once the streamflow gauges were selected, quality control steps were undertaken for each of the data series, as follows:

1. Data filtering, where any record with quality code indicative of unreliable data (quality code numbers of 150 and greater) was set to missing data;
2. Visual inspection of the data series, where periods of time with suspicious behaviour (such as successive flat periods in low flows) were set as missing.

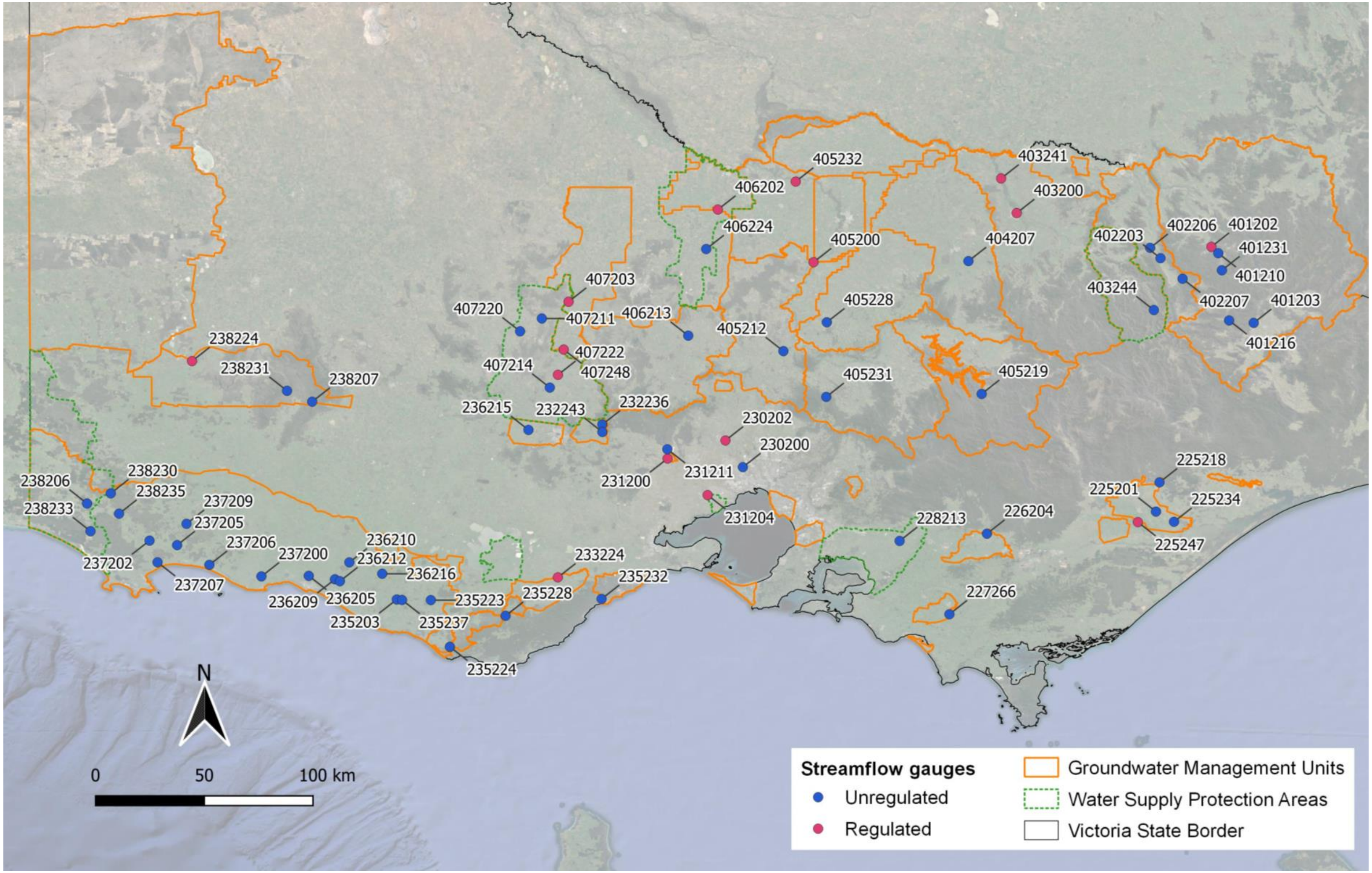

Figure 2-1 Locations of selected streamflow gauges, Groundwater Management Units and Water Supply Protection Areas

Table 2-1 Selected streamflow gauges

Gauge	Name	Groundwater Management Unit	River Classification	Commenced	Ceased	Start of adopted analysis period	End of adopted analysis period
225201	Avon River @ Stratford	Wa De Lock	unregulated	1/11/1976	NA	12/11/1976	9/02/2022
225218	Freestone Creek @ Briagalong	Wa De Lock	unregulated	12/04/1967	NA	13/04/1967	9/02/2022
225234	Avon River @ Clydebank (Chinn's Bridge)	Wa De Lock	unregulated	5/05/1977	NA	10/07/2004	9/01/2022
225247	Macalister River @ Riverslea	Wa De Lock	regulated	16/12/1996	NA	12/01/2001	9/02/2022
226204	Latrobe River @ Willow Grove	Moe	unregulated	23/10/1924	NA	1/07/1930	9/02/2022
227266	Tarwin River @ Koonwarra	Leongatha	unregulated	22/09/2008	NA	1/10/2008	15/01/2013
228213	Bunyip River @ Iona	Koo-Wee-Rup	unregulated	12/06/1962	13/07/2004	4/11/1971	12/07/2004
230200	Maribyrnong River @ Keilor	Maribyrnong Basin	unregulated	20/05/1907	NA	14/01/1967	9/02/2022
230202	Jackson Creek @ Sunbury	Maribyrnong Basin	regulated	1/02/1908	NA	1/05/1962	9/02/2022
231200	Werribee River @ Bacchus Marsh	Werribee Basin	regulated	1887/04/01	NA	24/06/1978	9/02/2022
231204	Werribee River @ Werribee Diversion Weir	Deutgam	regulated	1/02/1911	NA	2/07/1946	9/02/2022
231211	Lerderderg River @ U/S Goodman Creek Junction	Werribee Basin	unregulated	31/05/1956	NA	26/08/1978	9/02/2022
232236	West Moorabool River U/S Moorabool Reservoir	Bungaree	unregulated	9/05/2001	NA	10/05/2001	9/02/2022
232243	Whisky Creek At Whisky Creek Diversion Weir	Bungaree	unregulated	22/11/2011	NA	4/06/2012	1/10/2021
233224	Barwon River @ Ricketts Marsh	Gerangamete	regulated	27/07/1971	NA	28/07/1971	9/02/2022
235203	Curdies River @ Curdie	South West Limestone	unregulated	5/10/1955	NA	24/01/1975	9/02/2022
235223	Scotts Creek @ Scotts Creek	South West Limestone	unregulated	28/03/1968	24/06/1987	12/12/1973	23/06/1987
235224	Gellibrand River @ Burrupa	Newlingrook	unregulated	20/03/1969	NA	21/03/1969	9/02/2022
235228	Gellibrand River @ Gellibrand	Gellibrand	unregulated	13/03/1970	7/05/2009	6/09/1974	24/05/1989
235232	Painkalac Creek @ Painkalac Creek Dam	Janjuc	unregulated	26/03/1974	NA	27/03/1974	9/02/2022
235237	Scotts Creek @ Curdie (Digneys Bridge)	South West Limestone	unregulated	27/04/1982	NA	6/05/1982	17/01/2022
236205	Merri River @ Woodford	South West Limestone	unregulated	1/08/1948	NA	17/06/1965	9/02/2022
236209	Hopkins River @ Hopkins Falls	South West Limestone	unregulated	23/05/1955	NA	24/05/1955	9/02/2022
236210	Hopkins River @ Framlingham	South West Limestone	unregulated	10/06/1955	NA	16/07/1974	9/02/2022
236212	Brucknell Creek @ Cudgee	South West Limestone	unregulated	4/06/1965	NA	24/01/1975	9/02/2022

Gauge	Name	Groundwater Management Unit	River Classification	Commenced	Ceased	Start of adopted analysis period	End of adopted analysis period
236215	Burrumbeet Creek @ Lake Burrumbeet	Cardigan	unregulated	3/12/1975	NA	16/06/1977	9/02/2022
236216	Mount Emu Creek @ Taroon (Ayrford Road Bridge)	South West Limestone	unregulated	10/10/1977	NA	11/10/1977	9/02/2022
237200	Moyne River @ Toolong	South West Limestone	unregulated	2/06/1948	NA	21/11/1973	9/02/2022
237202	Fitzroy River @ Heywood	South West Limestone	unregulated	29/07/1948	NA	11/10/1968	9/02/2022
237205	Darlot Creek @ Homerton Bridge	South West Limestone	unregulated	10/01/1963	NA	7/11/1969	9/02/2022
237206	Eumeralla River @ Codrington	South West Limestone	unregulated	27/02/1964	NA	20/11/1973	9/02/2022
237207	Surry River @ Heathmere	South West Limestone	unregulated	20/04/1970	NA	25/09/1975	9/02/2022
237209	Darlot Creek @ Myamyn	South West Limestone	unregulated	15/10/1987	9/11/2010	16/10/1987	8/11/2010
238206	Glenelg River @ Dartmoor	South West Limestone	unregulated	1/06/1948	NA	20/11/1973	9/02/2022
238207	Wannon River @ Jimmy Creek	Upper Glenelg	unregulated	26/01/1950	NA	27/01/1950	4/01/2022
238224	Glenelg R @ Fulham Bridge (Bottom Ec Probe)	Upper Glenelg	regulated	6/03/1964	NA	9/01/1976	9/02/2022
238230	Stokes River @ Teakettle	South West Limestone	unregulated	27/06/1966	NA	19/11/1974	9/01/2022
238231	Glenelg River @ Big Cord	Upper Glenelg	unregulated	23/04/1968	NA	18/05/1979	9/02/2022
238233	Moleside Creek @ Kentbruck	South West Limestone	unregulated	12/08/1969	30/01/1986	19/12/1973	30/08/1985
238235	Crawford River @ Lower Crawford	South West Limestone	unregulated	25/05/1970	NA	26/05/1970	22/01/2022
401202	Mitta Mitta River @ Mitta Mitta	Upper Murray	regulated	25/11/1917	NA	19/10/1977	30/12/1981
401203	Mitta Mitta River @ Hinnomunjie	Upper Murray	unregulated	17/06/1925	NA	17/04/1931	9/02/2022
401210	Snowy Creek @ Below Granite Flat	Upper Murray	unregulated	10/10/1932	NA	25/03/1953	9/02/2022
401216	Big River @ Jokers Creek	Upper Murray	unregulated	29/08/1934	NA	30/08/1934	9/02/2022
401231	Snowy Creek @ D/S Lightning Ck	Upper Murray	unregulated	21/04/1993	NA	21/04/1993	9/02/2022
402203	Kiewa River @ Mongans Bridge	Kiewa	unregulated	29/04/1955	NA	1/05/1955	4/03/2021
402206	Running Creek @ Running Creek	Kiewa	unregulated	14/04/1966	NA	25/07/1975	4/03/2021
402207	Mountain Creek @ Coopers	Kiewa	unregulated	7/04/1966	25/10/1982	28/12/1972	24/10/1982
403200	Ovens River @ Wangaratta	Lower Ovens	regulated	1885/06/28	NA	29/06/1885	2/03/2021
403241	Ovens River @ Peechelba	Lower Ovens	regulated	8/03/1979	NA	2/07/1993	31/03/2021
403244	Ovens River @ Harrietville	Upper Ovens	unregulated	4/02/1987	NA	6/02/1987	22/03/2021

Gauge	Name	Groundwater Management Unit	River Classification	Commenced	Ceased	Start of adopted analysis period	End of adopted analysis period
404207	Holland Creek @ Kelfeera	Broken	unregulated	9/05/1960	NA	11/05/1960	30/03/2021
405200	Goulburn River @ Murchison	Mid Goulburn	regulated	1881/06/14	NA	16/06/1881	5/05/2018
405212	Sunday Creek @ Tallarook	West Goulburn	unregulated	21/11/1945	NA	5/02/1961	6/08/2020
405219	Goulburn River @ Dohertys	Eildon	unregulated	26/08/1954	NA	14/12/1967	26/08/2020
405228	Hughes Creek @ Tarcombe Road	Strathbogie	unregulated	16/09/1958	NA	16/05/1975	4/08/2020
405231	King Parrot Creek @ Flowerdale	Upper Goulburn	unregulated	25/06/1951	NA	1/01/1975	27/07/2020
405232	Goulburn River @ Mccoys Bridge	Shepparton	regulated	24/08/1965	NA	6/11/1976	3/08/2020
406202	Campaspe River @ Rochester D/S Waranga Western Ch Syphn	Lower Campaspe Valley	regulated	1885/01/01	NA	15/08/1965	1/02/2021
406213	Campaspe River @ Redesdale	Central Victorian Mineral Springs	unregulated	1/11/1953	NA	13/08/1975	30/12/2020
406224	Mount Pleasant Creek @ Runnymede	Lower Campaspe Valley	unregulated	21/06/1974	NA	12/08/1975	27/09/2020
407203	Loddon River @ Laanecoorie	Loddon Highlands	regulated	1891/07/04	NA	3/06/1966	27/01/2021
407211	Bet Bet Creek @ Bet Bet	Loddon Highlands	unregulated	23/09/1943	NA	28/09/1990	1/12/2020
407214	Creswick Creek @ Clunes	Loddon Highlands	unregulated	10/08/1943	NA	1/05/1966	10/02/2021
407220	Bet Bet Creek @ Norwood	Loddon Highlands	unregulated	4/03/1954	NA	7/02/1973	11/02/2021
407222	Tullaroop Creek @ Clunes	Loddon Highlands	regulated	12/08/1955	NA	4/02/1973	10/02/2021
407248	Tullaroop Creek @ Tullarrop Res. (O'let Meas. Weir)	Mid Loddon	regulated	11/05/1960	NA	20/08/1983	28/01/2021

2.2 Preparation of climate change adjusted data for 2040 and 2065

The impact of climate change on streamflow was derived in accordance with the *Guidelines for assessing the impact of climate change on water availability in Victoria* (DELWP 2020).

2.2.1 Correction to post-1975 hydroclimatic baseline

The streamflow gauges with data records pre-1975 were adjusted to derive climate representative of the post 1975 reference climate period. These adjustments make historical droughts more reflective of how they might behave, if they were to occur under current post-1975 levels of greenhouse gas concentrations in the atmosphere.

The Guidelines (DEWLP 2020) allow for this transformation to be done using seasonal decile scaling, which picks up on changes in flows at different times of year over recent decades under historical climate change. A four seasons decile scaling transformation was undertaken in this project.

2.2.2 Climate change projections for 2040 and 2065

The projections in the *Guidelines for assessing the impact of climate change on water availability in Victoria* (DELWP 2020) are expressed relative to the post 1975 climate reference period, which is approximately centred on the year 1995. Current and future climate change conditions are expressed as a range, which allows for uncertainty in the climate change projections. This range represents the uncertainty in the projections for a given emissions scenario, when using climate models from different research organisations around the world.

The streamflow gauges data series were projected for 2040 and 2065, under low, medium, and high climate change scenarios. In this project, the annual climate change factors were adopted for the RCP8.5 scenario, provided by the guidelines for each major basin in Victoria. The DELWP (2020) guidelines regard the RCP8.5 as a high emissions scenario that is suitably precautionary for water supply planning purposes in Victoria.

Table 2-2: Annual climate change factors for streamflow, RCP8.5 (DEWLP, 2020)

Basin	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Barwon	16.1%	-6.1%	-33.1%	-0.8%	-21.6%	-47.6%
Broken	18.6%	-9.7%	-35.9%	8.1%	-16.8%	-50.0%
Bunyip	10.6%	-13.7%	-33.0%	1.5%	-19.1%	-47.0%
Campaspe	10.5%	-12.3%	-37.1%	1.0%	-20.7%	-57.0%
Glenelg	7.6%	-13.6%	-37.3%	-3.4%	-31.4%	-60.8%
Goulburn	9.9%	-9.5%	-29.1%	1.3%	-13.7%	-41.9%
Hopkins	14.9%	-13.0%	-35.7%	-5.2%	-28.5%	-59.8%
Kiewa	11.2%	-9.1%	-22.4%	1.5%	-12.1%	-39.4%
Latrobe	8.7%	-10.7%	-31.3%	0.1%	-16.3%	-41.5%
Loddon	12.4%	-7.4%	-36.6%	6.9%	-17.6%	-57.6%
Maribyrnong	15.0%	-13.2%	-33.1%	5.1%	-20.0%	-55.4%
Moorabool	13.5%	-8.0%	-30.4%	-5.5%	-17.3%	-45.6%
Otway Coast	6.6%	-7.2%	-25.3%	-4.7%	-15.8%	-41.9%
Ovens	11.7%	-10.8%	-23.3%	1.2%	-15.7%	-43.9%
Portland Coast	15.5%	-10.8%	-36.0%	-2.7%	-30.4%	-54.8%
South Gippsland	8.8%	-11.9%	-33.7%	1.6%	-16.9%	-44.8%
Thomson	10.3%	-9.1%	-27.6%	2.0%	-13.9%	-41.9%
Upper Murray	17.2%	-8.4%	-23.3%	13.5%	-16.6%	-39.4%
Werribee	11.8%	-7.7%	-28.9%	7.5%	-18.1%	-45.5%

2.3 Baseflow separation and statistical analysis

In streams that are likely to be connected to an unconfined aquifer, baseflow and low flows recorded in the stream are likely to be an indicator of groundwater levels, which, in turn, are an indicator for recharge.

The gauged flow records were analysed to identify indicators of baseflow and low flow. For each gauge, the key statistics that were extracted were:

- Mean flow (ML/y)
- Mean runoff, or mean annual flow per unit catchment area, (mm/y)
- Mean baseflow (ML/y)
- Mean baseflow per unit catchment area (mm/y)
- Baseflow index, or the mean baseflow divided by mean flow
- Flow exceeded on 90 percent of days in the record (ML/d)

For unregulated streams, the baseflow volume and baseflow index are likely to be reasonable indicators of baseflow. However, in regulated systems, the gauged flows are influenced by releases from upstream storages. Even though baseflow volumes and baseflow index can be calculated at regulated sites, these statistics are likely to be influenced by regulated releases, rather than an indication of the true baseflow response of the catchment at this location.

The daily baseflow signal was calculated, from the daily gauged flow, by applying the (Lyne and Hollick, 1979) digital filter. Digital filters are a common means of separating out baseflow from a gauged flow record. (Nathan and McMahon, 1990) found that applying the Lyne and Hollick (1979) digital filter, with three passes and a filter parameter value of 0.925, provided a reliable, fast and objective method for separating baseflow from gauged flow at streamflow gauges across south eastern Australia. (Ladson et al., 2013) also found that the Lyne and Hollick (1979) digital filter worked well for baseflow separation at 178 unregulated gauge sites across the Murray Darling Basin.

For the current analysis, the Lyne and Hollick (1990) digital filter was applied with three passes and a filter parameter of 0.925. This produced a daily time series of baseflow at each gauge site. The daily time series of total flow and baseflow was used to calculate annual and monthly mean statistics for gauged total flow, baseflow and baseflow index.

3. Results

3.1 Baseflow volume and index

Table 3-1 presents the key statistics of the baseflow separation results obtained for the gauged data series for each of the selected streamflow data. The baseflow index presented in Table 3-1 accounts for the weighted average of the ratio of total baseflow over total flow calculated for each segment of minimum of 30 consecutive days of non-missing data.

Given that the Climate Change Guidelines only provide mean annual projected changes in streamflow, the BFI values are unchanged in the projected data. As means of comparison, the mean annual flow per unit catchment area, and the mean annual baseflow per unit catchment area (ML/y/km^2) values are presented for gauged data and the climate change adjusted data in Table 3-2 and Table 3-3.

Table 3-1 Baseflow separation metrics for the gauged streamflow data series

Gauge	Name	Baseflow Index	Mean annual flow (ML/y)	Mean annual baseflow (ML/y)	Mean annual flow per unit catchment area (ML/y/km²)	Mean annual baseflow per unit catchment area (ML/y/km²)
225201	Avon River @ Stratford	0.28	154646.9	43210.3	104.1	29.1
225218	Freestone Creek @ Briagalong	0.22	35528.4	6941.3	115.0	22.5
225234	Avon River @ Clydebank (Chinn's Bridge)	0.44	98817.6	35236.8	62.4	22.2
225247	Macalister River @ Riverslea	0.58	135999.6	66483.5	63.7	31.2
226204	Latrobe River @ Willow Grove	0.74	185833.8	137954.3	320.4	237.9
227266	Tarwin River @ Koonwarra	0.51	121459.7	63625.6	191.5	100.3
228213	Bunyip River @ Iona	0.57	105869.3	60780.7	151.9	87.2
230200	Maribyrnong River @ Keilor	0.37	80322.4	29445.1	61.6	22.6
230202	Jackson Creek @ Sunbury	0.32	22419.0	7141.0	66.5	21.2
231200	Werribee River @ Bacchus Marsh	0.35	17184.4	5868.1	47.3	16.2
231204	Werribee River @ Werribee Diversion Weir	0.36	57733.4	17959.9	40.5	12.6
231211	Lerderderg River @ U/S Goodman Creek Junction	0.42	16537.2	5867.4	70.7	25.1
232236	West Moorabool River U/S Moorabool Reservoir	0.61	951.2	582.9	103.7	63.6
232243	Whisky Creek At Whisky Creek Diversion Weir	0.62	580.8	337.2	82.6	47.9
233224	Barwon River @ Ricketts Marsh	0.36	71049.0	25367.1	119.8	42.8
235203	Curdies River @ Curdie	0.34	83966.2	28709.3	106.3	36.3
235223	Scotts Creek @ Scotts Creek	0.31	8386.8	2560.3	142.1	43.4
235224	Gellibrand River @ Burrupa	0.56	246516.7	138961.3	235.7	132.9
235228	Gellibrand River @ Gellibrand	0.52	37808.2	19721.3	381.9	199.2
235232	Painkalac Creek @ Painkalac Creek Dam	0.30	4139.3	1161.1	115.0	32.3
235237	Scotts Creek @ Curdie (Digneys Bridge)	0.29	47396.6	13490.5	131.3	37.4
236205	Merri River @ Woodford	0.37	51884.8	19428.8	57.7	21.6
236209	Hopkins River @ Hopkins Falls	0.44	229735.3	101413.3	27.5	12.1
236210	Hopkins River @ Framlingham	0.40	101773.2	40926.2	19.7	7.9
236212	Brucknell Creek @ Cudgee	0.44	25887.1	11466.1	116.1	51.4

Gauge	Name	Baseflow Index	Mean annual flow (ML/y)	Mean annual baseflow (ML/y)	Mean annual flow per unit catchment area (ML/y/km²)	Mean annual baseflow per unit catchment area (ML/y/km²)
236215	Burrumbeet Creek @ Lake Burrumbeet	0.44	10010.5	4225.3	60.3	25.5
236216	Mount Emu Creek @ Taroon (Ayrford Road Bridge)	0.46	71983.2	31916.0	25.0	11.1
237200	Moyne River @ Toolong	0.33	39184.8	13055.6	68.7	22.9
237202	Fitzroy River @ Heywood	0.41	25680.7	10580.0	109.7	45.2
237205	Darlot Creek @ Homerton Bridge	0.70	55803.6	38971.7	73.4	51.3
237206	Eumeralla River @ Codrington	0.49	27393.3	13286.3	54.6	26.5
237207	Surry River @ Heathmere	0.40	26275.5	10585.1	84.8	34.1
237209	Darlot Creek @ Myamyn	0.75	30372.2	21783.3	50.6	36.3
238206	Glenelg River @ Dartmoor	0.46	411707.1	190067.9	34.6	16.0
238207	Wannon River @ Jimmy Creek	0.50	9816.3	4997.0	245.4	124.9
238224	Glenelg R @ Fulham Bridge (Bottom Ec Probe)	0.45	40620.9	17736.4	20.2	8.8
238230	Stokes River @ Teakettle	0.29	13523.0	3911.6	74.7	21.6
238231	Glenelg River @ Big Cord	0.56	8101.8	4542.2	142.1	79.7
238233	Moleside Creek @ Kentbruck	0.69	8984.1	6155.4	118.2	81.0
238235	Crawford River @ Lower Crawford	0.39	41383.7	15574.3	68.3	25.7
401202	Mitta Mitta River @ Mitta Mitta	0.60	192188.7	115401.0	50.8	30.5
401203	Mitta Mitta River @ Hinnomunjie	0.64	414939.9	266966.8	270.7	174.1
401210	Snowy Creek @ Below Granite Flat	0.70	188181.6	131156.0	462.4	322.3
401216	Big River @ Jokers Creek	0.66	222198.2	146860.7	624.2	412.5
401231	Snowy Creek @ D/S Lightning Ck	0.71	110086.9	77951.3	1048.4	742.4
402203	Kiewa River @ Mongans Bridge	0.66	467525.1	307328.8	847.0	556.8
402206	Running Creek @ Running Creek	0.65	27858.0	18157.3	221.1	144.1
402207	Mountain Creek @ Coopers	0.69	28051.9	19433.5	596.8	413.5
403200	Ovens River @ Wangaratta	0.63	1047319.9	657630.7	203.8	128.0
403241	Ovens River @ Peechelba	0.59	1148511.2	662794.0	184.1	106.2
403244	Ovens River @ Harrietville	0.67	70730.7	46948.0	589.4	391.2

Gauge	Name	Baseflow Index	Mean annual flow (ML/y)	Mean annual baseflow (ML/y)	Mean annual flow per unit catchment area (ML/y/km²)	Mean annual baseflow per unit catchment area (ML/y/km²)
404207	Holland Creek @ Kelfeera	0.46	75444.5	35068.3	167.3	77.8
405200	Goulburn River @ Murchison	0.54	1631487.5	902247.6	151.5	83.8
405212	Sunday Creek @ Tallarook	0.28	30463.9	8680.4	90.4	25.8
405219	Goulburn River @ Dohertys	0.58	309393.6	179639.6	445.8	258.8
405228	Hughes Creek @ Tarcombe Road	0.50	61205.8	30309.2	129.9	64.4
405231	King Parrot Creek @ Flowerdale	0.62	32339.5	19915.5	178.7	110.0
405232	GOULBURN RIVER @ Mccoys BRIDGE	0.53	1134071.7	596084.7	67.5	35.5
406202	Campaspe River @ Rochester D/S Waranga Western Ch Syphn	0.36	138383.0	50254.7	40.7	14.8
406213	Campaspe River @ Redesdale	0.36	60494.4	20541.1	96.2	32.7
406224	Mount Pleasant Creek @ Runnymede	0.11	10274.1	1012.9	41.4	4.1
407203	Loddon River @ Laanecoorie	0.46	164491.2	74141.7	39.4	17.7
407211	Bet Bet Creek @ Bet Bet	0.19	14301.3	2264.9	22.5	3.6
407214	Creswick Creek @ Clunes	0.38	23032.8	12695.6	74.8	41.2
407220	Bet Bet Creek @ Norwood	0.25	17057.6	3628.0	49.2	10.5
407222	Tullaroop Creek @ Clunes	0.43	40315.3	16685.4	63.8	26.4
407248	Tullaroop Creek @ Tullarrop Res. (O'let Meas. Weir)	0.63	20352.9	12207.4	27.9	16.7

Table 3-2 Mean annual flow per unit catchment area (ML/y/km²)

Gauge	Name	Gauged data	Climate change adjusted projections					
			2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
225201	Avon River @ Stratford	104.1	119.7	94.7	75.4	98.7	74.5	41.9
225218	Freestone Creek @ Briagalong	115.0	112.1	92.4	73.6	103.7	87.5	59.0
225234	Avon River @ Clydebank (Chinn's Bridge)	62.4	68.8	56.7	45.2	63.6	53.7	36.3
225247	Macalister River @ Riverslea	63.7	70.3	57.9	46.1	65.0	54.9	37.0
226204	Latrobe River @ Willow Grove	320.4	279.2	229.4	176.5	257.1	215.0	150.3
227266	Tarwin River @ Koonwarra	191.5	208.3	168.7	127.0	194.6	159.1	105.7
228213	Bunyip River @ Iona	151.9	166.3	129.8	100.7	152.6	121.6	79.7
230200	Maribyrnong River @ Keilor	61.6	58.2	43.9	34.9	53.2	40.5	22.6
230202	Jackson Creek @ Sunbury	66.5	70.9	53.5	41.3	64.8	49.3	27.5
231200	Werribee River @ Bacchus Marsh	47.3	52.9	43.7	33.7	50.9	38.8	25.8
231204	Werribee River @ Werribee Diversion Weir	40.5	47.7	39.4	30.4	45.9	35.0	23.3
231211	Lerderderg River @ U/S Goodman Creek Junction	70.7	79.0	65.2	50.3	76.0	57.9	38.5
232236	West Moorabool River U/S Moorabool Reservoir	103.7	117.8	95.5	72.2	109.5	85.8	56.4
232243	Whisky Creek At Whisky Creek Diversion Weir	82.6	93.7	76.0	57.5	87.1	68.3	44.9
233224	Barwon River @ Ricketts Marsh	119.8	130.6	105.6	75.2	111.6	88.2	58.9
235203	Curdies River @ Curdie	106.3	113.3	98.6	79.4	101.3	89.5	61.8
235223	Scotts Creek @ Scotts Creek	142.2	151.5	131.9	106.2	135.5	119.7	82.6
235224	Gellibrand River @ Burrupa	235.7	240.7	209.6	168.7	215.2	190.2	131.2
235228	Gellibrand River @ Gellibrand	381.9	407.1	354.4	285.3	364.0	321.6	221.9
235232	Painkalac Creek @ Painkalac Creek Dam	115.0	122.6	106.7	85.9	109.6	96.8	66.8
235237	Scotts Creek @ Curdie (Digneys Bridge)	131.3	140.0	121.8	98.1	125.1	110.6	76.3
236205	Merri River @ Woodford	57.7	65.7	49.7	36.8	54.2	40.9	23.0
236209	Hopkins River @ Hopkins Falls	27.5	27.7	21.0	15.5	22.8	17.2	9.7
236210	Hopkins River @ Framlingham	19.7	22.7	17.2	12.7	18.7	14.1	7.9
236212	Brucknell Creek @ Cudgee	116.1	133.4	101.0	74.6	110.1	83.0	46.7
236215	Burrumbeet Creek @ Lake Burrumbeet	60.3	69.3	52.5	38.8	57.2	43.1	24.2

Gauge	Name	Gauged data	Climate change adjusted projections					
			2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
236216	Mount Emu Creek @ Taroon (Ayrford Road Bridge)	25.0	28.8	21.8	16.1	23.7	17.9	10.1
237200	Moyne River @ Toolong	68.8	79.4	61.3	44.0	66.9	47.9	31.1
237202	Fitzroy River @ Heywood	109.8	117.2	90.5	64.9	98.7	70.6	45.9
237205	Darlot Creek @ Homerton Bridge	73.4	81.6	63.0	45.2	68.7	49.1	31.9
237206	Eumeralla River @ Codrington	54.6	63.0	48.7	34.9	53.1	38.0	24.7
237207	Surry River @ Heathmere	84.8	97.9	75.6	54.3	82.5	59.0	38.3
237209	Darlot Creek @ Myamyn	50.6	58.5	45.2	32.4	49.3	35.2	22.9
238206	Glenelg River @ Dartmoor	34.6	37.2	29.9	21.7	33.4	23.7	13.6
238207	Wannon River @ Jimmy Creek	245.4	196.2	157.5	114.3	176.1	125.1	71.5
238224	Glenelg R @ Fulham Bridge (Bottom Ec Probe)	20.2	21.8	17.5	12.7	19.5	13.9	7.9
238230	Stokes River @ Teakettle	74.7	80.4	64.6	46.8	72.2	51.3	29.3
238231	Glenelg River @ Big Cord	142.1	152.9	122.8	89.1	137.3	97.5	55.7
238233	Moleside Creek @ Kentbruck	118.2	127.2	102.1	74.1	114.2	81.1	46.3
238235	Crawford River @ Lower Crawford	68.3	23.4	18.8	13.6	21.0	14.9	8.5
401202	Mitta Mitta River @ Mitta Mitta	50.8	59.5	46.5	38.9	57.6	42.3	30.8
401203	Mitta Mitta River @ Hinnomunjie	270.7	287.0	224.3	187.8	278.0	204.3	148.4
401210	Snowy Creek @ Below Granite Flat	462.4	507.3	396.5	332.0	491.2	361.0	262.3
401216	Big River @ Jokers Creek	624.2	670.2	523.8	438.6	649.1	476.9	346.6
401231	Snowy Creek @ D/S Lightning Ck	1048.5	1228.8	960.4	804.2	1190.0	874.4	635.4
402203	Kiewa River @ Mongans Bridge	847.0	886.5	724.7	618.7	809.2	700.8	483.1
402206	Running Creek @ Running Creek	221.1	245.9	201.0	171.6	224.4	194.3	134.0
402207	Mountain Creek @ Coopers	596.9	19.0	15.6	13.3	17.4	15.1	10.4
403200	Ovens River @ Wangaratta	203.8	198.4	158.5	136.3	179.8	149.8	99.7
403241	Ovens River @ Peechelba	184.1	205.6	164.2	141.2	186.3	155.2	103.3
403244	Ovens River @ Harrietville	589.4	658.4	525.8	452.1	596.5	496.9	330.7
404207	Holland Creek @ Kelfeera	167.3	181.1	137.9	97.9	165.0	127.0	76.3
405200	Goulburn River @ Murchison	151.5	32.4	26.7	20.9	29.9	25.4	17.1

Gauge	Name	Gauged data	Climate change adjusted projections					
			2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
405212	Sunday Creek @ Tallarook	90.4	93.2	76.8	60.1	85.9	73.2	49.3
405219	Goulburn River @ Dohertys	445.8	459.0	378.0	296.1	423.1	360.4	242.7
405228	Hughes Creek @ Tarcombe Road	130.0	142.8	117.6	92.1	131.6	112.2	75.5
405231	King Parrot Creek @ Flowerdale	178.7	196.4	161.7	126.7	181.0	154.2	103.8
405232	GOULBURN RIVER @ Mccoys BRIDGE	67.5	74.2	61.1	47.8	68.4	58.2	39.2
406202	Campaspe River @ Rochester D/S Waranga Western Ch Syphn	40.7	37.5	29.7	21.3	34.3	26.9	14.6
406213	Campaspe River @ Redesdale	96.2	106.3	84.4	60.5	97.1	76.3	41.4
406224	Mount Pleasant Creek @ Runnymede	41.4	45.8	36.3	26.1	41.8	32.9	17.8
407203	Loddon River @ Laanecoorie	39.4	40.2	33.1	22.7	38.2	29.4	15.2
407211	Bet Bet Creek @ Bet Bet	22.5	11.3	9.3	6.4	10.7	8.3	4.3
407214	Creswick Creek @ Clunes	74.8	108.8	89.7	61.4	103.5	79.8	41.1
407220	Bet Bet Creek @ Norwood	49.2	55.3	45.5	31.2	52.6	40.5	20.8
407222	Tullaroop Creek @ Clunes	63.8	71.7	59.1	40.4	68.2	52.6	27.1
407248	Tullaroop Creek @ Tullarrop Res. (O'let Meas. Weir)	27.9	31.3	25.8	17.7	29.8	23.0	11.8

Table 3-3 Mean annual baseflow per unit catchment area (ML/y/km²)

Gauge	Name	Gauged data	Climate change adjusted projections					
			2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
225201	Avon River @ Stratford	29.1	33.4	26.4	21.1	27.6	20.8	11.7
225218	Freestone Creek @ Briagalong	22.5	21.5	17.8	14.1	19.9	16.8	11.3
225234	Avon River @ Clydebank (Chinn's Bridge)	22.2	24.5	20.2	16.1	22.7	19.2	12.9
225247	Macalister River @ Riverslea	31.2	34.4	28.3	22.6	31.8	26.8	18.1
226204	Latrobe River @ Willow Grove	237.9	205.3	168.7	129.8	189.1	158.1	110.5
227266	Tarwin River @ Koonwarra	100.3	109.1	88.4	66.5	101.9	83.4	55.4
228213	Bunyip River @ Iona	87.2	95.7	74.7	58.0	87.8	70.0	45.9
230200	Maribyrnong River @ Keilor	21.2	22.4	16.9	13.0	20.5	15.6	8.7
230202	Jackson Creek @ Sunbury	16.2	18.1	14.9	11.5	17.4	13.2	8.8
231200	Werribee River @ Bacchus Marsh	12.6	9.6	7.9	6.1	9.2	7.0	4.7
231204	Werribee River @ Werribee Diversion Weir	25.1	28.0	23.1	17.8	27.0	20.5	13.7
231211	Lerderderg River @ U/S Goodman Creek Junction	63.6	72.2	58.5	44.2	67.1	52.6	34.6
232236	West Moorabool River U/S Moorabool Reservoir	47.9	54.4	44.1	33.4	50.6	39.6	26.1
232243	Whisky Creek At Whisky Creek Diversion Weir	42.8	45.8	37.0	26.4	39.1	30.9	20.7
233224	Barwon River @ Ricketts Marsh	36.3	38.7	33.7	27.1	34.6	30.6	21.1
235203	Curdies River @ Curdie	43.4	46.3	40.3	32.4	41.4	36.5	25.2
235223	Scotts Creek @ Scotts Creek	132.9	134.8	117.4	94.5	120.5	106.5	73.5
235224	Gellibrand River @ Burrupa	199.2	212.4	184.9	148.8	189.8	167.7	115.7
235228	Gellibrand River @ Gellibrand	32.3	34.4	29.9	24.1	30.7	27.2	18.7
235232	Painkalac Creek @ Painkalac Creek Dam	37.4	39.8	34.7	27.9	35.6	31.5	21.7
235237	Scotts Creek @ Curdie (Digneys Bridge)	21.6	24.5	18.5	13.7	20.2	15.2	8.6
236205	Merri River @ Woodford	12.1	12.0	9.1	6.7	9.9	7.5	4.2
236209	Hopkins River @ Hopkins Falls	7.9	9.1	6.9	5.1	7.5	5.7	3.2
236210	Hopkins River @ Framlingham	51.4	59.1	44.7	33.1	48.7	36.8	20.7
236212	Brucknell Creek @ Cudgee	25.5	29.2	22.1	16.4	24.1	18.2	10.2
236215	Burrumbeet Creek @ Lake Burrumbeet	11.1	12.7	9.7	7.1	10.5	7.9	4.5

Gauge	Name	Gauged data	Climate change adjusted projections					
			2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
236216	Mount Emu Creek @ Taroon (Ayrford Road Bridge)	22.9	26.5	20.4	14.7	22.3	15.9	10.4
237200	Moyne River @ Toolong	45.2	46.7	36.1	25.9	39.4	28.2	18.3
237202	Fitzroy River @ Heywood	51.3	56.7	43.8	31.4	47.7	34.1	22.2
237205	Darlot Creek @ Homerton Bridge	26.5	30.6	23.6	16.9	25.8	18.4	12.0
237206	Eumeralla River @ Codrington	34.1	39.4	30.5	21.9	33.2	23.8	15.4
237207	Surry River @ Heathmere	36.3	41.9	32.4	23.2	35.3	25.3	16.4
237209	Darlot Creek @ Myamyn	16	17.2	13.8	10.0	15.4	10.9	6.3
238206	Glenelg River @ Dartmoor	124.9	93.8	75.3	54.7	84.2	59.8	34.2
238207	Wannon River @ Jimmy Creek	8.8	9.5	7.6	5.5	8.5	6.1	3.5
238224	Glenelg R @ Fulham Bridge (Bottom Ec Probe)	21.6	23.3	18.7	13.6	20.9	14.8	8.5
238230	Stokes River @ Teakettle	79.7	85.7	68.9	50.0	77.0	54.7	31.2
238231	Glenelg River @ Big Cord	81	87.1	70.0	50.8	78.2	55.6	31.7
238233	Moleside Creek @ Kentbruck	21.2	22.4	16.9	13.0	20.5	15.6	8.7
238235	Crawford River @ Lower Crawford	25.7	10.1	8.1	5.9	9.0	6.4	3.7
401202	Mitta Mitta River @ Mitta Mitta	30.5	35.7	27.9	23.4	34.6	25.4	18.5
401203	Mitta Mitta River @ Hinnomunjie	174.1	186.9	146.1	122.3	181.0	133.0	96.6
401210	Snowy Creek @ Below Granite Flat	322.3	354.2	276.8	231.8	343.0	252.0	183.1
401216	Big River @ Jokers Creek	412.5	448.4	350.5	293.5	434.2	319.1	231.9
401231	Snowy Creek @ D/S Lightning Ck	742.4	870.1	680.0	569.4	842.6	619.2	449.9
402203	Kiewa River @ Mongans Bridge	556.8	586.6	479.5	409.4	535.5	463.7	319.7
402206	Running Creek @ Running Creek	144.1	160.2	131.0	111.8	146.3	126.7	87.3
402207	Mountain Creek @ Coopers	413.5	14.4	11.8	10.1	13.2	11.4	7.9
403200	Ovens River @ Wangaratta	128	122.2	97.6	83.9	110.7	92.2	61.4
403241	Ovens River @ Peechelba	106.2	118.7	94.8	81.5	107.5	89.6	59.6
403244	Ovens River @ Harrietville	391.2	437.0	349.0	300.1	395.9	329.8	219.5
404207	Holland Creek @ Kelfeera	77.8	80.1	61.0	43.3	73.0	56.2	33.8
405200	Goulburn River @ Murchison	83.8	15.2	12.5	9.8	14.0	11.9	8.0

Gauge	Name	Gauged data	Climate change adjusted projections					
			2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
405212	Sunday Creek @ Tallarook	25.8	25.3	20.9	16.3	23.4	19.9	13.4
405219	Goulburn River @ Dohertys	258.8	262.5	216.2	169.4	242.0	206.2	138.8
405228	Hughes Creek @ Tarcombe Road	64.4	70.7	58.2	45.6	65.2	55.5	37.4
405231	King Parrot Creek @ Flowerdale	110	120.9	99.6	78.0	111.5	95.0	63.9
405232	GOULBURN RIVER @ Mccoys BRIDGE	35.5	39.0	32.1	25.1	35.9	30.6	20.6
406202	Campaspe River @ Rochester D/S Waranga Western Ch Syphn	14.8	12.6	10.0	7.2	11.5	9.0	4.9
406213	Campaspe River @ Redesdale	32.7	36.1	28.6	20.5	33.0	25.9	14.0
406224	Mount Pleasant Creek @ Runnymede	4.1	4.5	3.6	2.6	4.1	3.2	1.8
407203	Loddon River @ Laanecoorie	17.7	17.7	14.5	10.0	16.8	12.9	6.7
407211	Bet Bet Creek @ Bet Bet	3.6	1.8	1.5	1.0	1.7	1.3	0.7
407214	Creswick Creek @ Clunes	41.2	39.9	32.9	22.5	38.0	29.3	15.1
407220	Bet Bet Creek @ Norwood	10.5	11.8	9.7	6.6	11.2	8.6	4.4
407222	Tullaroop Creek @ Clunes	26.4	29.7	24.4	16.7	28.2	21.8	11.2
407248	Tullaroop Creek @ Tullarrop Res. (O'let Meas. Weir)	16.7	18.8	15.5	10.6	17.9	13.8	7.1

3.2 90th percentile low flow

The flow exceeded on 90 percent of the days was adopted to analyse the baseflow component of streamflow gauges located in regulated streams. The values obtained for each scenario for the regulated streamflow gauges are presented in Table 3-4.

Table 3-4 Flow exceeded on 90 percent of days in the record (ML/d)

Gauge	Name	Gauged data	Climate change adjusted projections					
			2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
225247	Macalister River @ Riverslea	50.1	55.3	45.6	36.3	51.1	43.1	29.1
230202	Jackson Creek @ Sunbury	1.9	2.1	1.6	1.2	1.9	1.5	0.8
231200	Werribee River @ Bacchus Marsh	2.4	2.6	2.2	1.7	2.5	1.9	1.3
231204	Werribee River @ Werribee Diversion Weir	15.5	0.0	0.0	0.0	0.0	0.0	0.0
233224	Barwon River @ Ricketts Marsh	5.4	5.3	4.3	3.0	4.5	3.5	2.4
238224	Glenelg R @ Fulham Bridge (Bottom Ec Probe)	6.8	7.4	5.9	4.3	6.6	4.7	2.7
401202	Mitta Mitta River @ Mitta Mitta	137.3	160.9	125.8	105.3	155.9	114.5	83.2
403200	Ovens River @ Wangaratta	237.6	233.0	186.1	160.0	211.1	175.9	117.0
403241	Ovens River @ Peechelba	227.9	254.6	203.3	174.8	230.7	192.2	127.9
405200	Goulburn River @ Murchison	188.3	248.7	204.8	160.5	229.3	195.3	131.5
405232	Goulburn River @ Mccoys Bridge	400.2	439.8	362.2	283.7	405.4	345.4	232.5
406202	Campaspe River @ Rochester D/S Waranga Western Ch Syphn	6.3	6.9	5.5	3.9	6.3	5.0	2.7
407203	Loddon River @ Laanecoorie	18.7	19.7	16.2	11.1	18.7	14.4	7.4
407222	Tullaroop Creek @ Clunes	3.1	3.5	2.9	2.0	3.3	2.5	1.3
407248	Tullaroop Creek @ Tullarrop Res. (O'let Meas. Weir)	4.6	5.2	4.3	2.9	4.9	3.8	2.0

4. Discussion

The baseflow index values obtained for the selected unregulated streamflow gauges ranged from 0.11 (406224 - Mount Pleasant Creek @ Runnymede) to 0.75 (237209 - Darlot Creek @ Myamyn). The number of unregulated streamflow gauges per baseflow index range is presented in Figure 4-1.

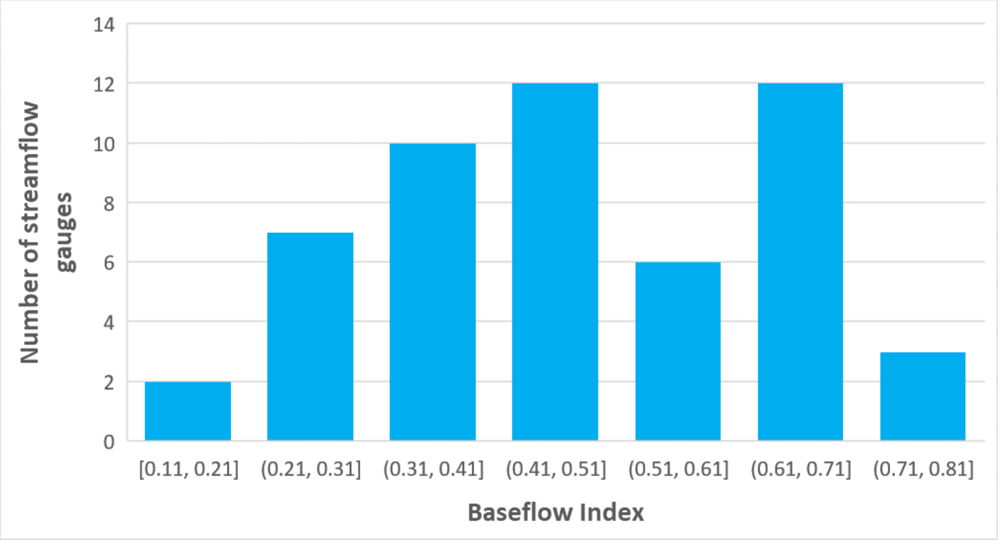

Figure 4-1 Number of unregulated streamflow gauges per baseflow index range

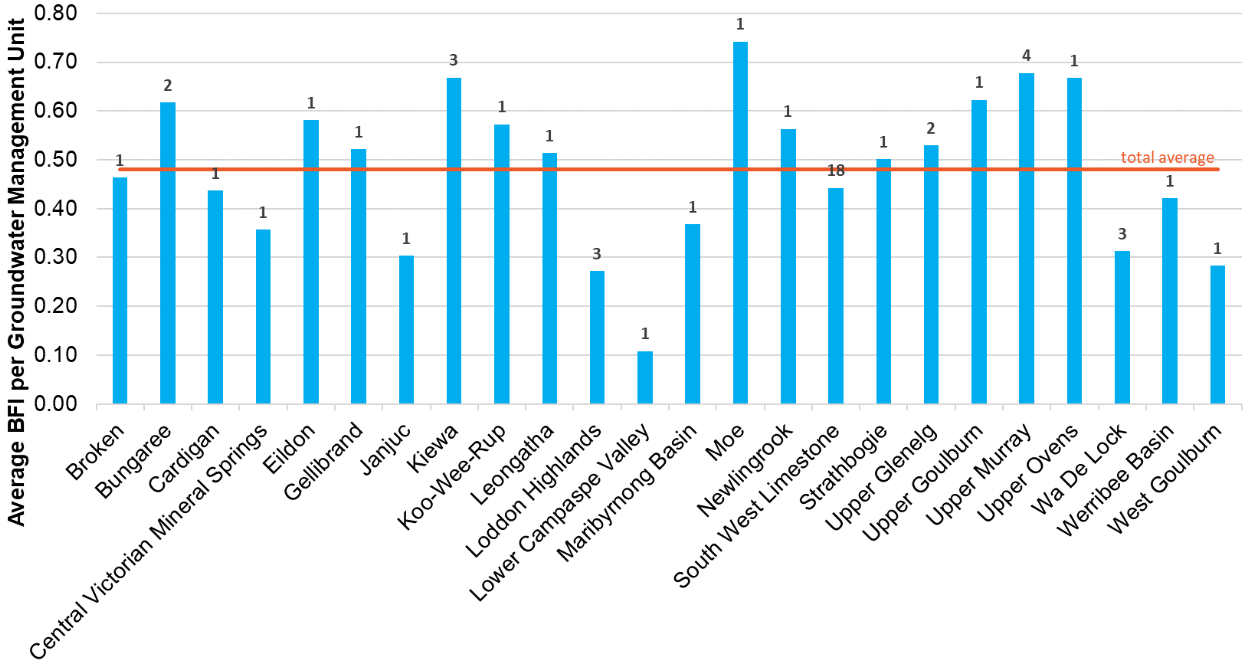

Figure 4-2 Average baseflow index per groundwater management unit. The number of gauges analysed in each GMU is present on the top of each respective column in the chart

As expected, given that the climate change projected data implied in the scaling of both the baseflow and quick flow components by the same factor, the baseflow index produced for the climate change projected data series was the same as in the historical gauged data series. When comparing volumes of flow and baseflow in the historical gauged data with the climate change scenarios, it is noticeable that the 2040 low climate change scenario is usually wettest and the 2065 high climate change scenario is the driest. An example of the mean annual flow and baseflow changes per unit of catchment area of each climate scenario for gauge 235224 is shown in Figure 4-4.

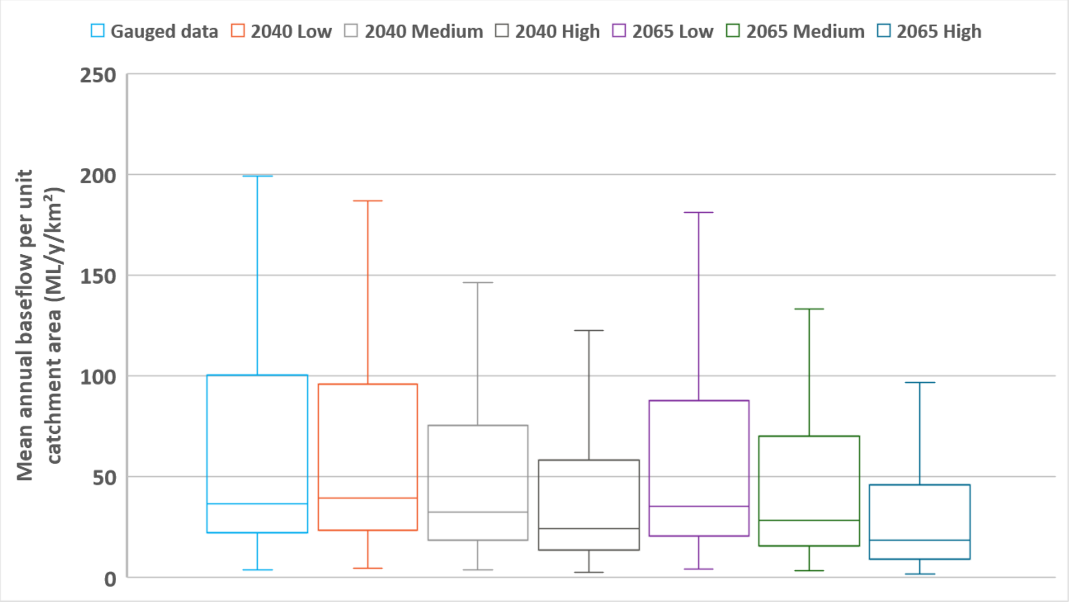

Figure 4-3 Summary of the mean annual baseflow per unit catchment area values for each analysed scenario

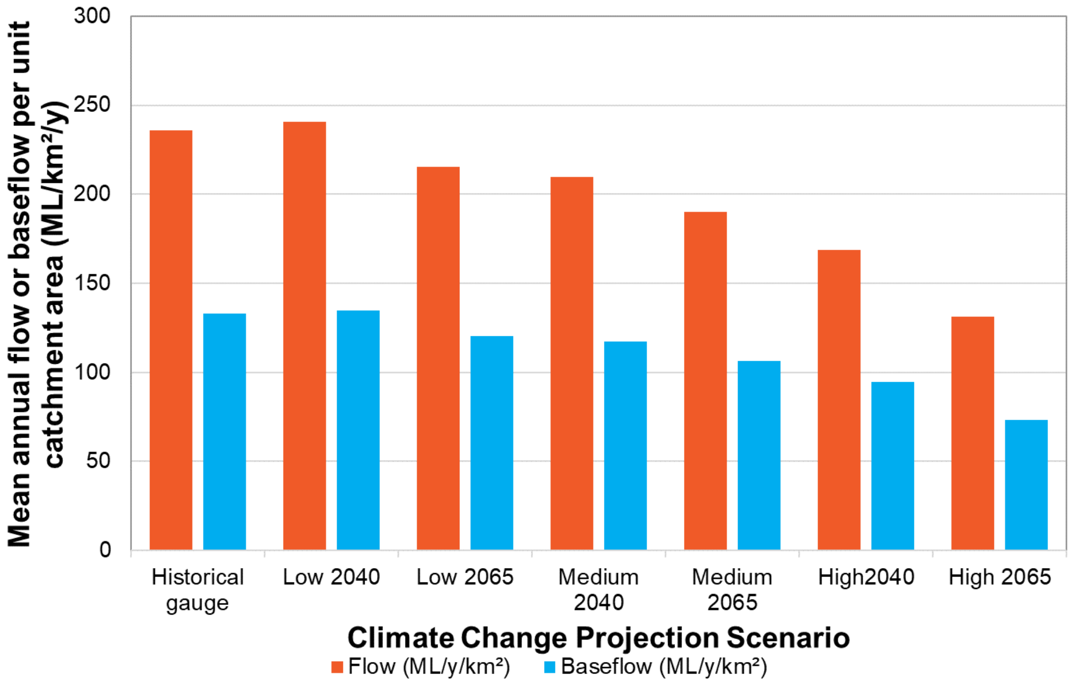

Figure 4-4 Mean annual flow and baseflow per unit of catchment area for gauge 235224

Given that the *Guidelines for assessing the impact of climate change on water availability in Victoria* (DELWP 2020) only provide mean annual projected changes in streamflow, the 90th percentile flow will have the same percentage change as the projected percentage change in the mean annual flow. This can be seen in Figure 4-6, where an example 90% probability of exceedance of each climate scenario of regulated gauge 405200 is shown. The same behaviour can be observed in the summary of the 90th percentile low flow values for each analysed scenario presented in Figure 4-5.

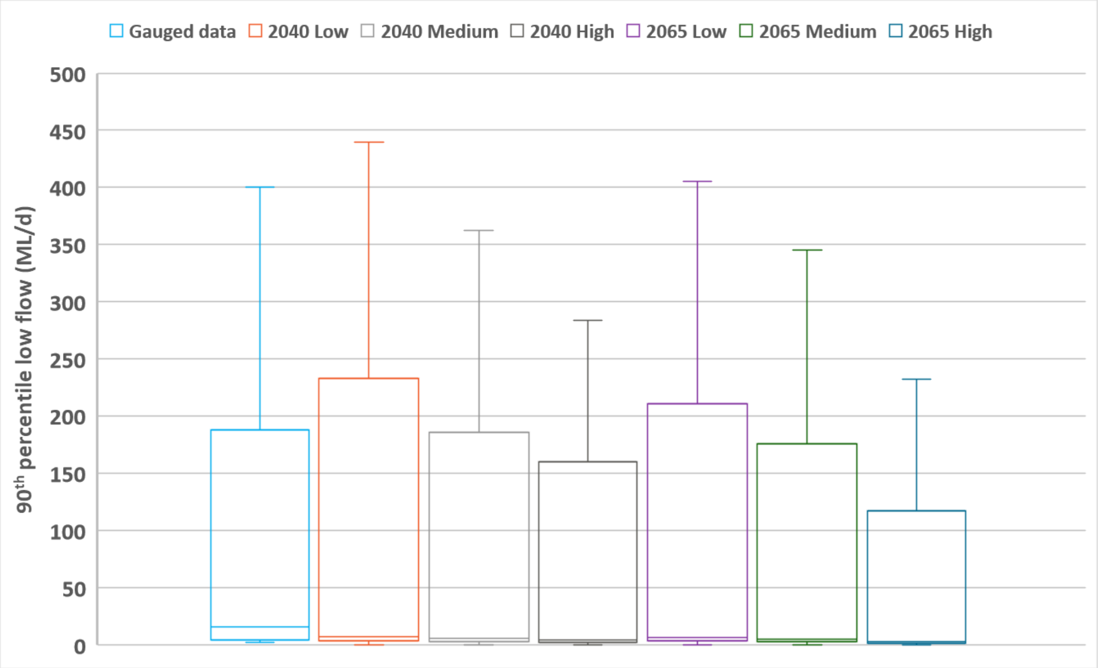

Figure 4-5 Summary of the 90th percentile low flow values for each analysed scenario

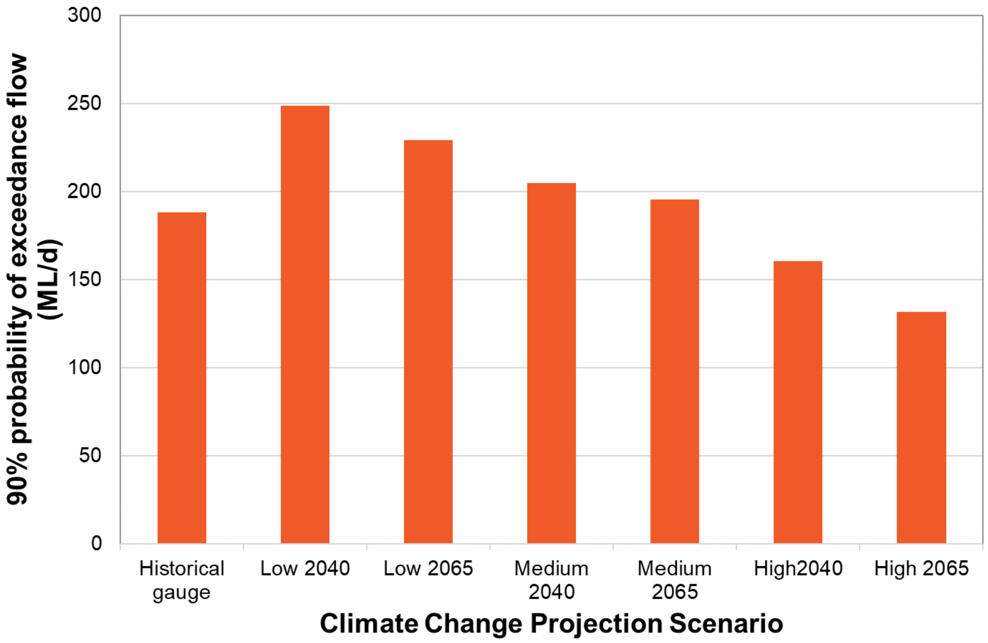

Figure 4-6 Q90 values of gauge 405200

It is important to notice that the BFI and 90th percentile flow statistics may be influenced by the years of flow data that are available to calculate them at each of the gauge sites. A gauge site that happened to have data recorded across a period with more drier years may record different statistics to a gauge that had data recorded with more wetter years, or a mix of dry and wet periods. It is also important to remember that when interpreting the climate change scenario results, all global climate model projections (high, medium and low) are considered equally plausible.

5. Conclusions and recommendations

This report presents the baseflow analysis for 67 streamflow gauges across Victoria streams where there is known to be, or likely to be, a stronger connection between in-stream baseflows and levels in unconfined groundwater aquifers. The baseflow index was calculated for unregulated streams by applying the Lynne and Hollick digital filter, to separate the estimated baseflow component from the total flow. The 90th percentile flow was calculated for the 15 gauges located in regulated streams, where it was assumed that the environmental flows would be released to compensate for groundwater interactions. The *Guidelines for assessing the impact of climate change on water availability in Victoria* (Department of Environment Land Water and Planning, 2020) were applied to calculate estimated BFI and 90th percentile flows with projected climate change. The process was applied in a consistent manner, across all streamflow gauges in Victoria.

The climate change projections adopted the projected changes in mean annual flow, for the six scenarios, to derive projections of changes in mean annual baseflow, baseflow index and 90th percentile low flow at each gauge. This allowed the sensitivity of changes in low flows to be related to climate change projections. As a result of the method that was applied for each site, the percentage change projected for the mean annual baseflow and the 90th percentile low flow will be the same as the percentage change in the mean annual flow for the given climate change projection scenario. Also, the baseflow index for the climate change projections, using this method, will be the same for all scenarios as the base case hydroclimatic period. A more sophisticated method, using rainfall runoff models calibrated to gauged flows, may be able to provide more nuanced and accurate projections of the changes in baseflow volumes, 90th percentile low flows and baseflow index under climate change, as the rainfall runoff model could incorporate projected changes in rainfall and PET. However, such an approach would require considerably more effort, as it would require rainfall runoff models to be calibrated to gauged flows at each site.

6. References

Department of Environment Land Water and Planning (2020) *Guidelines for assessing the impact of climate change on water availability in Victoria*, Melbourne.

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Lyne V and Hollick M (1979) ‘Stochastic time-variable rainfall-runoff modelling’, in *Institute of Engineers Australia National Conference*, Institute of Engineers Australia Barton, Australia.

Nathan RJ and McMahon TA (1990) ‘Evaluation of automated techniques for base flow and recession analyses’, *Water Resources Research*, 26(7):1465–1473.