27. Glenelg WSPA

27.1 Conceptualisation

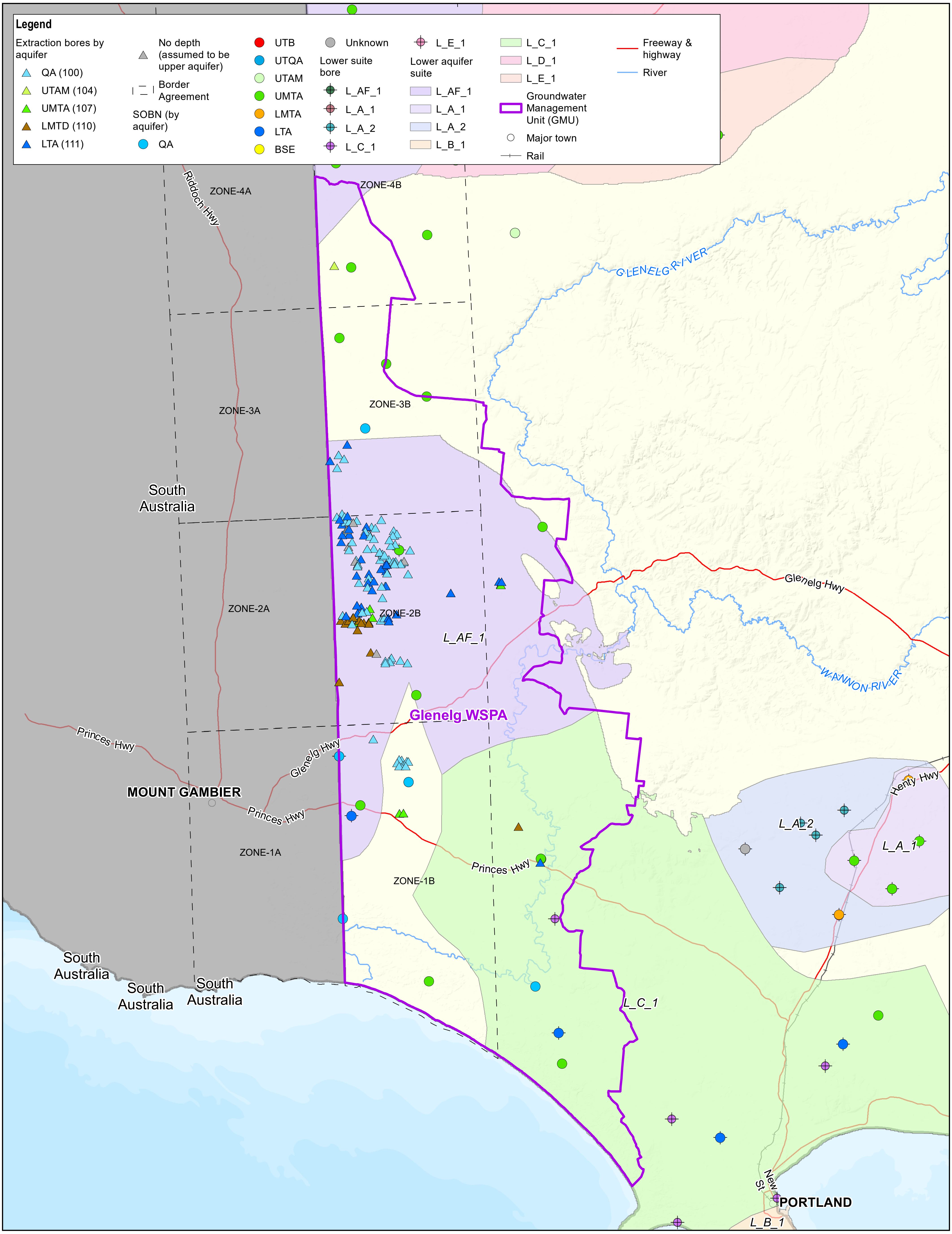
The hydrogeological conceptualisation elements relevant to this study are summarised in Table 160 and a map of the GMU is presented in Figure 439. It is noted that a significant volume of information was collated to inform the hydrogeological conceptual understanding of the GMU. The information that is directly relevant to the modelling are in bold or colour coded within Table 160.

Table 160 Glenelg WSPA – Tabulated conceptualisation

GMU summary								
Glenelg WSPA was situated in southwest Victoria, covering an area of approximately 3,008 km^2; in 2022 was abolished. The WSPA is bordered in the south by the Discovery Bay coastline, the west by the South Australian (SA) border and the east by a line extending from Cape Bridgewater to the south-western corner of West Wimmera GMA. The townships of Lake Mundi, Dartmoor and Nelson occur within Glenelg WSPA. Glenelg WSPA falls within the Border Designated Area. Areas located within this zone fall under the joint management arrangements of the SA/Victorian Border Zone Agreement. Glenelg WSPA pertains to all formation below the surface, but was intended to primarily manage groundwater resource of the Bridgewater Formation (Quaternary Aquifer, QA) and the Port Campbell Limestone (Upper-Mid Tertiary Aquifer, UMTA). The PCV (33,262 ML/year) therefore relates to both unconfined and confined aquifers. Princess Margaret Caves and Glenelg River items of environmental vale within the GMA. Within the WSPA, groundwater is primarily extracted for irrigation as well as domestic and stock use. Groundwater is also licensed for use in dairies for cooling and wash-down, and for urban water supply. Glenelg WSPA has a high urban use compared to other Victorian GMUs. The usage for Glenelg WSPA now sits within the South West Limestone GMA and the Border Zones.								
Hydrostratigraphy summary								
Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Use volumes ML (2019/20)	Entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Bridgewater Formation (QA)	U_D_8 (92%)	92%	5	Irrigation, domestic, stock, dairy	3,238 (221)	9,025 (831)	Medium
	Newer Volcanics (UTB)	U_A_2 (1%)	1%	0	Unknown	0		Low
	Hanson Plain Sand (UTAM)	U_E_1 (6%)	6%	0	Irrigation	0	90	Low
Middle	Port Campbell Limestone (UMTA)	M_AE_1 (11%), M_AF_1 (40%), M_AG_1 (6%), M_C_1 (11%), M_C_2 (1%)	69%	10	Urban, irrigation	331	753	Medium
	Gellibrand Marl (UMTD)	-	-	0	NA	0	0	Low
Lower	Clifton Formation (LMTA)	-	-	0	NA	0	0	Low
	Narrawaturk Marl (LMTD)	-	-	0	Irrigation, domestic	531	866	Low
	Dilwyn Formation (LTA)	L_AF_1 (40%), L_C_1 (32%)	72%	5	Urban, irrigation, stock	1,411	4,780	Medium
Basement	Cretaceous and Permian Sediments (CPS)	-	-	0	Unknown	0	0	Low
	Basement rocks (BSE)	B_B_8 (4%)	4%	0	Irrigation	257	579	Low

Note that volumes listed above are based on the DEECA provided licenced bore dataset with associated VAF layers. Bores have been assigned to a VAF layer based on bore depth where available. In some instances, bore depth is not available or it has been assessed that usage is likely incorrectly assigned and has been reallocated where possible; the reassigned volumes are indicated within the brackets. Note that volumes listed above do not include 221 ML of unassigned use due to unknown depths.		
Characteristic and importance	**Description**	**Degree of understanding**
Aquifer extent, geometry and flow (UMTA, highlighted blue in table above)		
Aquifer thickness within GMU (range, based on VAF)	Max: 294 m, Average: 96 m	High
As per Aquifer extent	Regional, extensive	High
Likelihood of inter-aquifer flow	Medium	Medium (SKM, 2010)
Likelihood of groundwater – surface water interaction	High	Medium (SKM, 2010)
Representative Suite	**U_D_8**	**Medium. 52% of GMU extraction occurs within this Suite which relates to the most relevant GMU aquifer**
Current hydrological condition		
Representative Suite trend	Decreasing	
Groundwater quality (average salinity based on WMIS and CDM Smith spatial segment(s) with highest coverage)	1,202 mg/L (WMIS) 0 – 1,200 mg/L (CDM Smith, 2022)	Moderate – WMIS data quite variable Based on WMIS and CDM Smith (2022)
Groundwater yield	0.5 – 5 L/s (based on referenced data; should be much higher based on GHD experience)	Low – yields appear low Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1974-2021**	
Spatial clustering of licensed bores in relation to Suites	**Yes, clustering of Lower Aquifer bores in L_AF_1 and Upper Aquifer bores in U_D_8**	**Based on DEECA density mapping and licenced bore data.**
Groundwater use		
Licensed groundwater use	**7,383 ML**	**High (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	2,413 ML	High (Based on historical VWA data, year 2020/21)
Maximum historic groundwater use	**19,952 ML**	**High (Based on historical VWA data, year 2004/05)**
Entitlement (Groundwater allocation)	**16,092 ML**	**High (Based on licenced volumes in 2020/21)**
Significant drivers of groundwater level variability (primary)	Pumping for irrigation & dairy	Moderate
Secondary drivers of groundwater level variability	Pumping for town water supply	Moderate

Groundwater use profile	Seasonal (~Oct-Apr irrigation season)	Low
External Influence	**Border zone extraction (zones 1A and 2A)**	
Groundwater values and risks		
Existing Environmental Values to be protected, relevant to this GMU	Potable water supply Licensed non-potable supply (irrigation, commercial, industrial) Unlicensed non-potable supply (domestic and stock)	
Risks to groundwater values	Direct risks: – Drawdown which may affect access to groundwater by existing users	
Indicators used to assess impacts to groundwater	– Measured drawdown using pre-determined metrics measured from a pre-determined level for the purpose of this modelling	



Paper Size ISO A3

0 3 6 9 12

Kilometers

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 VICGRID94

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DEECA
Sustainable yield review - confined aquifers

Glenelg WSPA: Lower Aquifers
Site location and key features

Project No. 12564066
Revision No. 0
Date 16/01/2024

Figure 439

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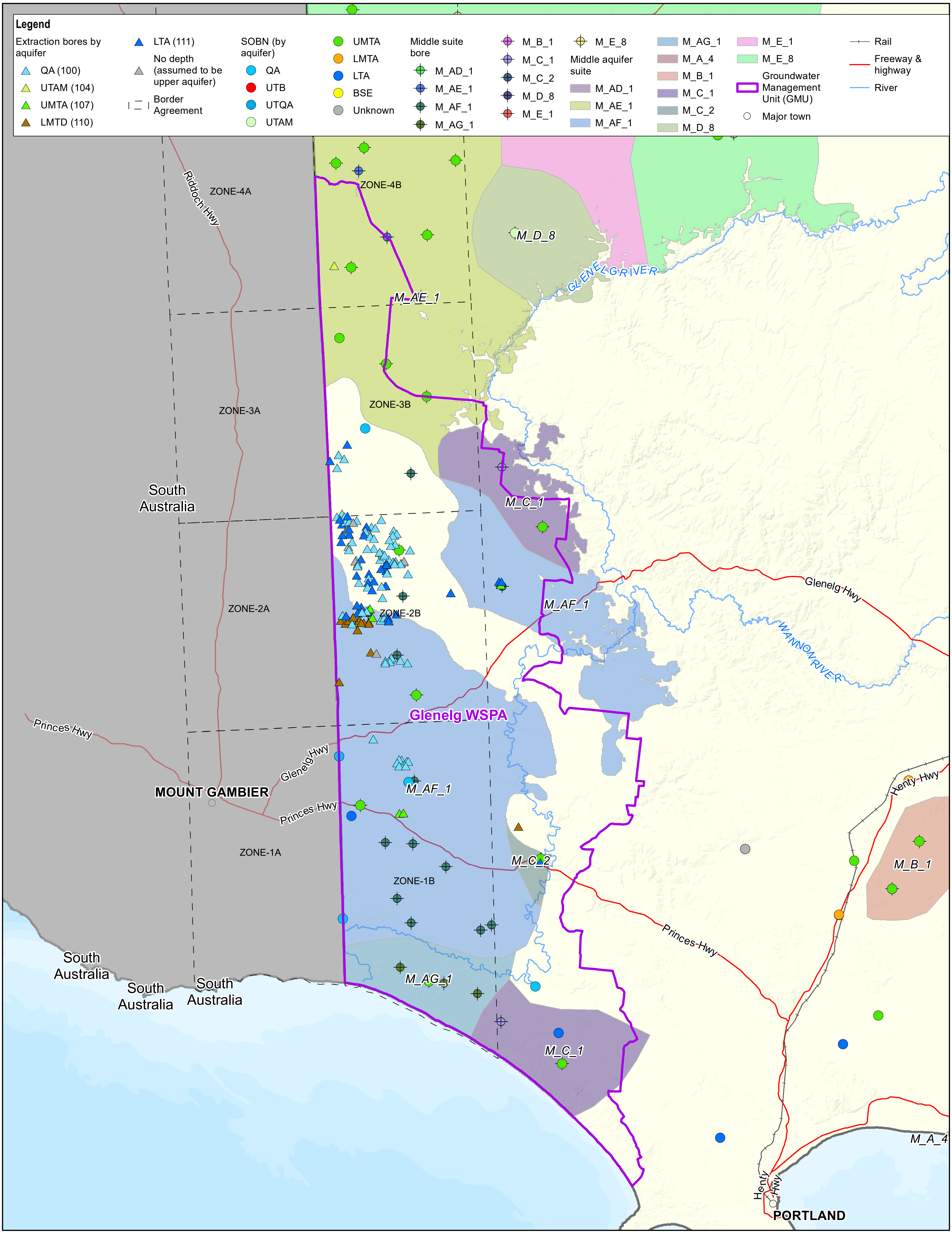
Print date: 16 Jan 2024 - 12:37

Data source: DELWP, VicMap, 2022; DELWP, GMUs, 2022; DELWP, SOBN, 2022; GHD, aquifer suites, 2018; DELWP, extraction bores, 2022; DWLBC, border agreements, 1998 Created by: cperyer



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Kilometers

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 VICGRID94

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DEECA
Sustainable yield review - confined aquifers

Glenelg WSPA: Middle Aquifers
Site location and key features

Project No. 12564066
Revision No. 0
Date 16/01/2024

Figure 439

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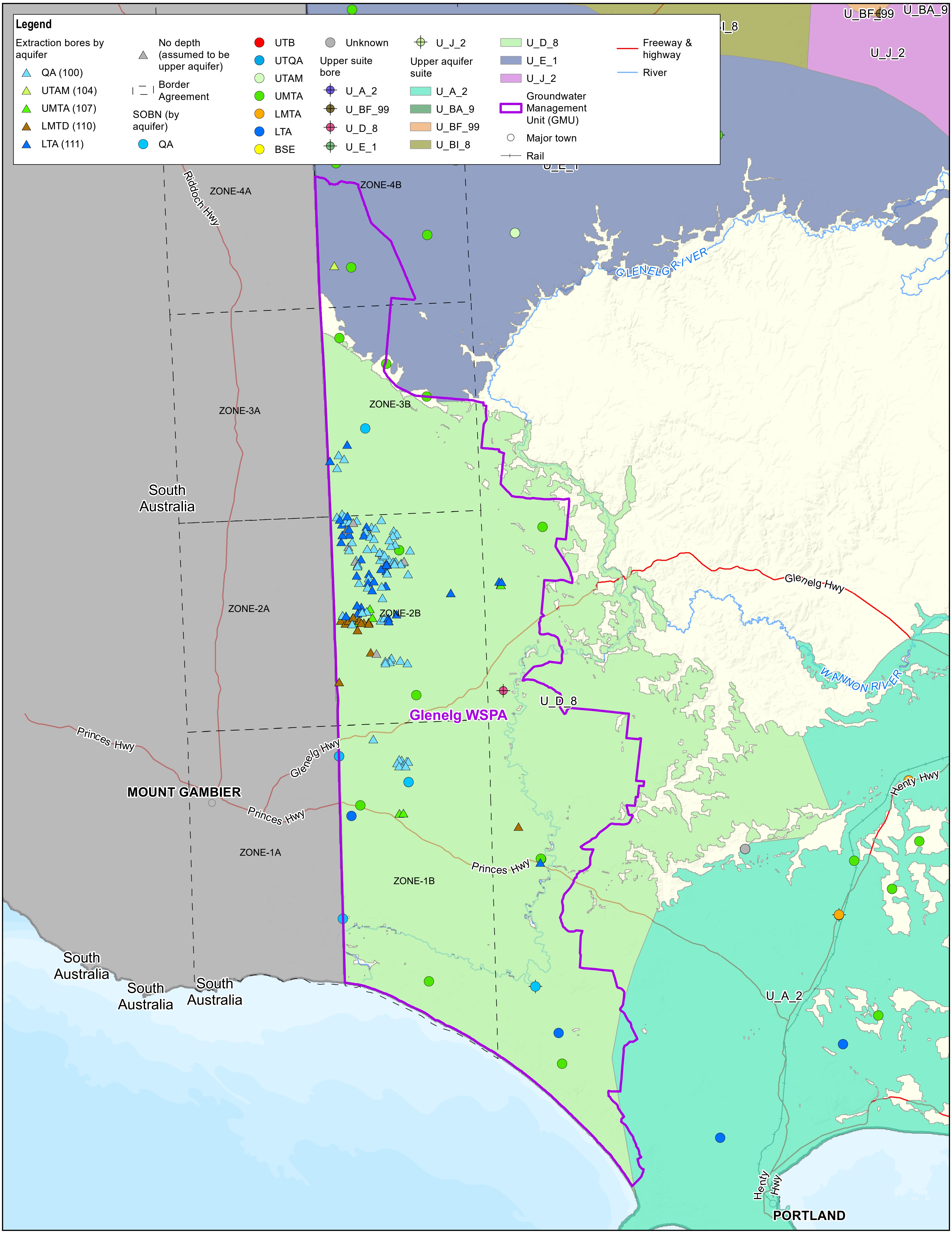
Print date: 16 Jan 2024 - 12:36

Data source: DELWP, VicMap, 2022; DELWP, GMUs, 2022; DELWP, SOBN, 2022; GHD, aquifer suites, 2018; DELWP, extraction bores, 2022; DWLBC, border agreements, 1998 Created by: cperyer



Paper Size ISO A3

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Kilometers

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 VICGRID94

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DEECA
Sustainable yield review - confined aquifers

Glenelg WSPA: Upper Aquifers
Site location and key features

Project No. **12564066**
Revision No. **0**
Date **16/01/2024**

Figure 439

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Print date: 16 Jan 2024 - 12:35

Data source: DELWP, VicMap, 2022; DELWP, GMUs, 2022; DELWP, SOBN, 2022; GHD, aquifer suites, 2018; DELWP, extraction bores, 2022; DWLBC, border agreements, 1998 Created by: cperyer

27.2 Technical analysis

27.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the relevant Suites for Glenelg WSPA as shown in Figure 440. Generally, the Suite hydrographs show seasonal fluctuations and hence recovered water levels. Suites M_C_2 and M_C_1 show large fluctuations prior to 1985, rather than the smaller seasonal fluctuations exhibited in other suits. Most Suites have a decreasing trend, except for Suite B_B_8.

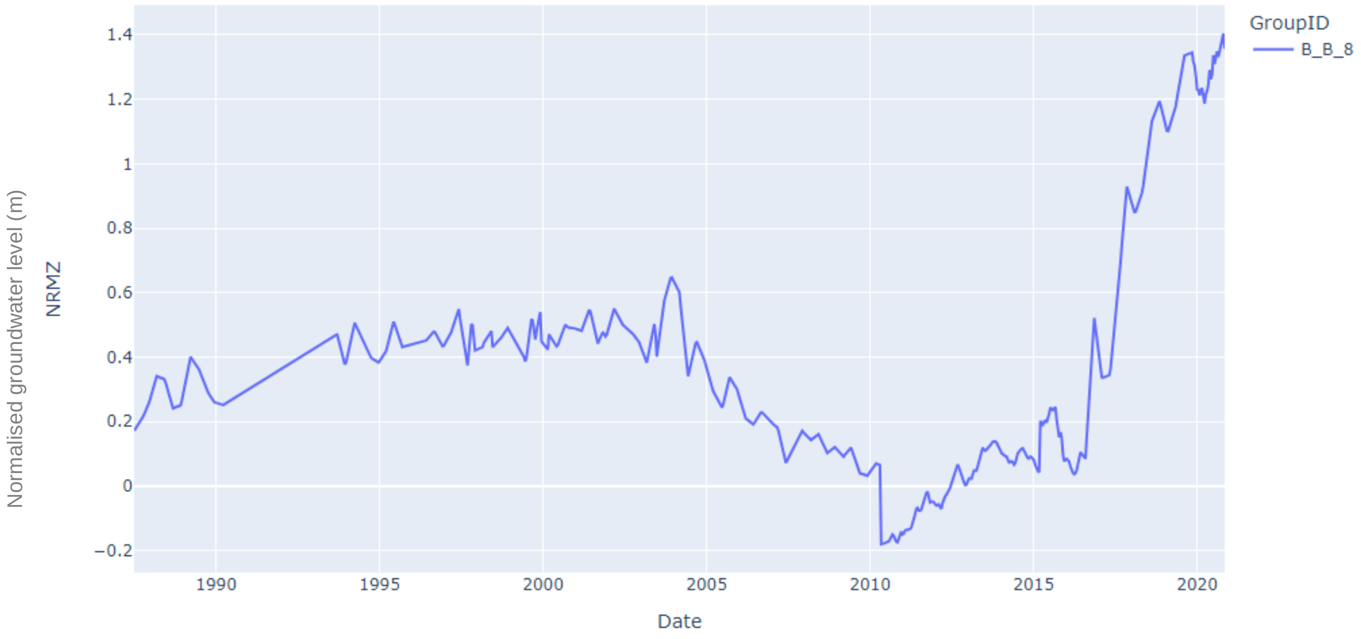


Figure 440 Glenelg WSPA Suite Hydrographs for all basement aquifers

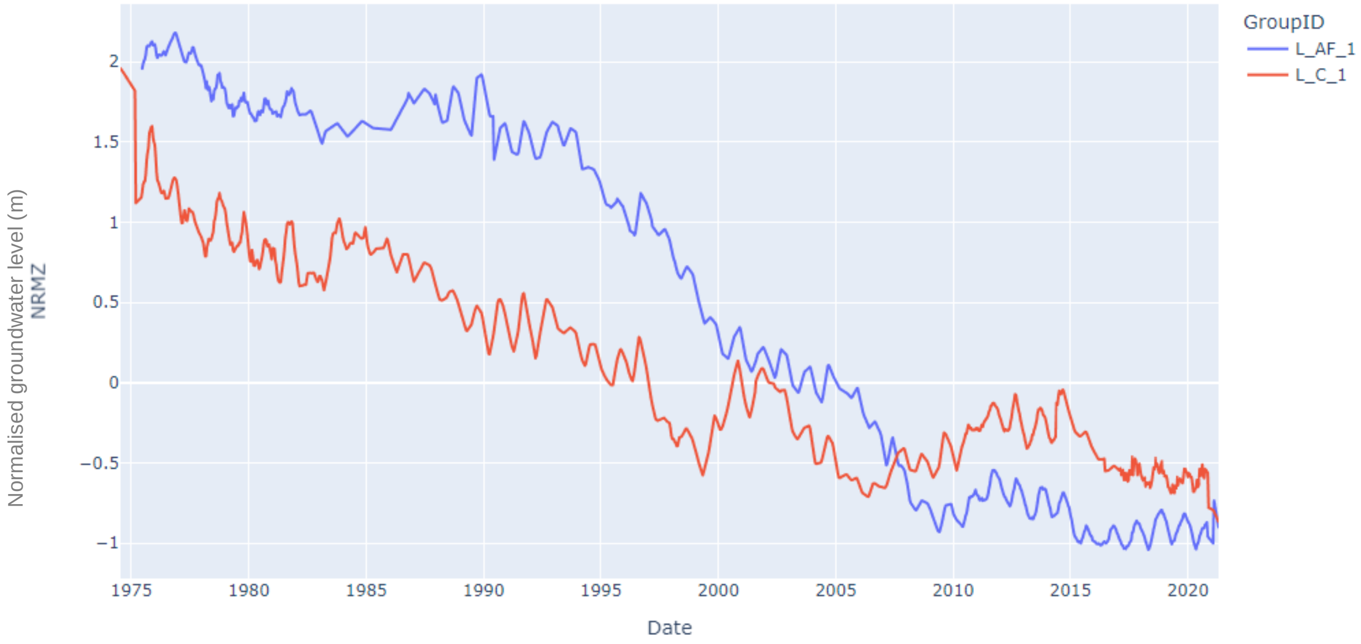


Figure 441 Glenelg WSPA Suite Hydrographs for all lower aquifers

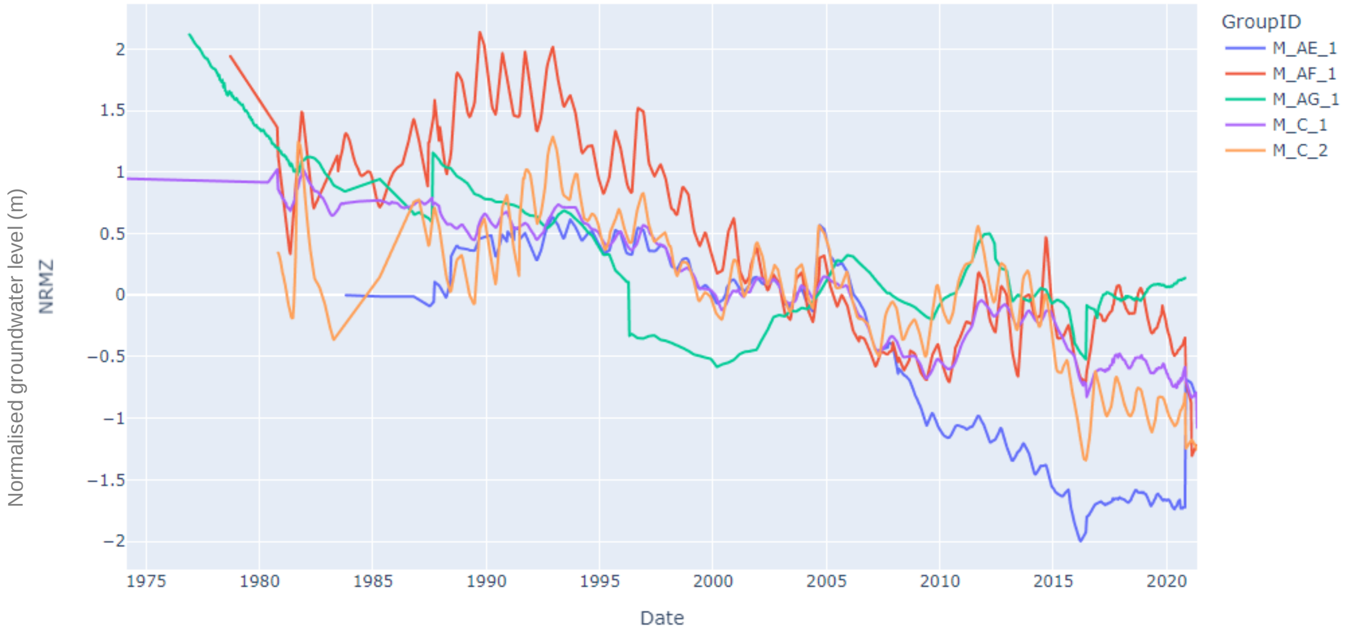


Figure 442 ***Glenelg WSPA Suite Hydrographs for all middle aquifers***

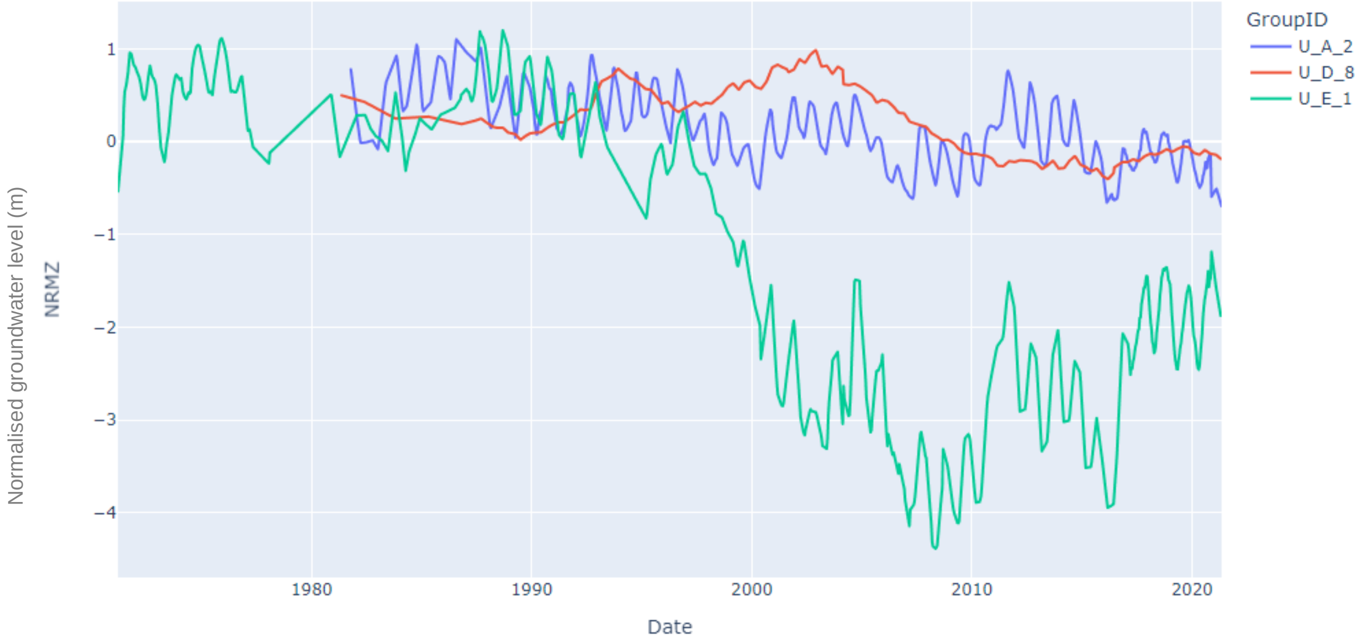


Figure 443 ***Glenelg WSPA Suite Hydrographs for all upper aquifers***

The representative Suites analysed for this GMU were Suites U_D_8, M_AF_1 and L_AF_1. The Representative Suites were selected based on the methodology outlined in section 2.6.4 which identified Suite U_D_8 as the most representative followed by L_AF_1 and M_AF_1. The process is summarised as follows:

- The greatest volume of extraction occurs within the Upper Aquifer
- The Upper Aquifer pertains to the QA which is one of the two intended aquifers for this GMU but is an unconfined aquifer
- The Lower Aquifer pertains to the LTA which has the second highest extraction and is a confined aquifer
- Suite U_D_8 covers 92% of the GMU, L_AF_1 covers 40% of the GMU and M_AF _1 covers 40% of the GMU

– Suite U_D_8 has one active SOBN bores within the Suite area, while Suite L_AF_1 has three and Suite M_AF_1 has one
– One Suite bore in Suite L_AF_1 is close to extraction points and four in Suite M_AF_1 are close to extraction points (however neither are close to extraction points related to their relevant aquifer)

The annual recovered Suite hydrographs for the representative Suites for Glenelg WSPA, Suites U_D_8, M_AF_1 and L_AF_1, are shown in Figure 444.

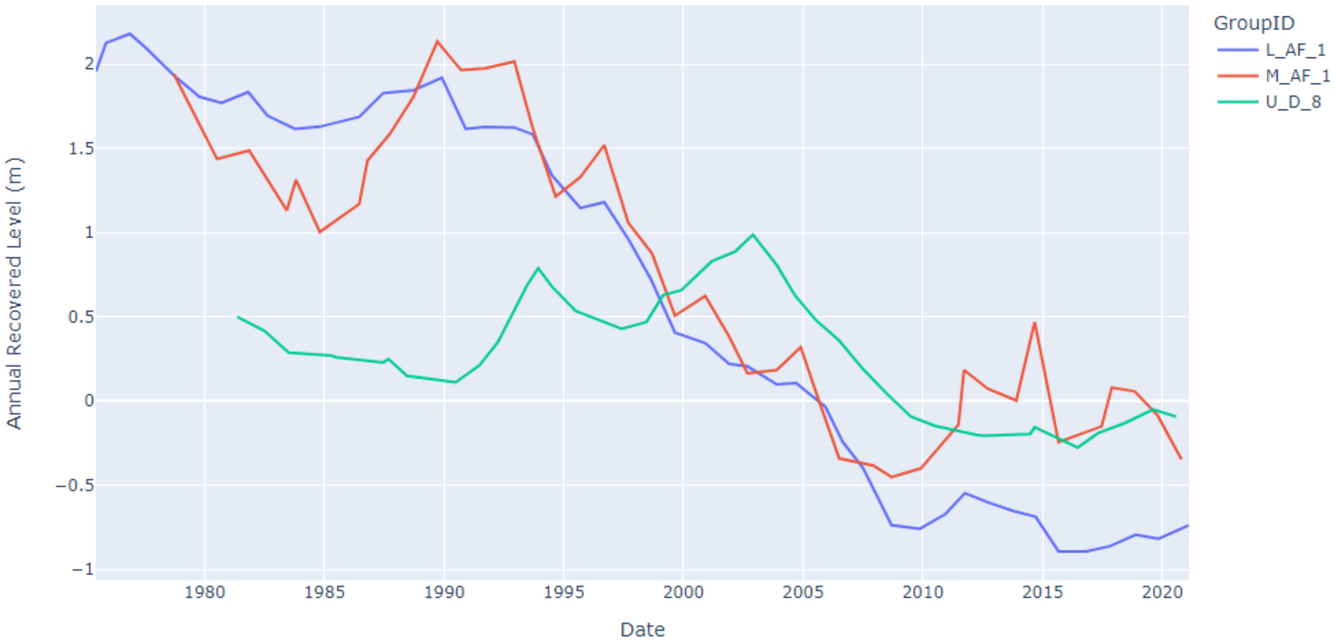


Figure 444 Glenelg WSPA Annual Recovered Level Suite Hydrographs for representative Suites

27.2.2 Pre-development level

To estimate the pre-development level conditions, GHD reviewed the Suite hydrographs of annual recovered levels and assumed that the early time series data was the best representation of conditions prior to major development within Glenelg WSPA for the three representative Suites.

The pre-development annual recovered level was taken to be the first two readings of the time series data for Suite U_D_8, which occur in the years 1980/1981 and 1981/1982 and equates to 0.50 m. The pre-development annual recovered level was taken to be the average of the first 18 readings of the time series data for Suite L_AF_2, over the years 1974/1975 to 1991/1992 and equates to 1.83 m. The pre-development annual recovered level was taken to be the maximum level before major development in the time series data for Suite M_AF_2, this occurs in the year 1992/1993 and equates to 2.00 m.

27.2.3 Externalities

As identified through the conceptualisation, Glenelg WSPA may be influenced by extraction occurring in the Border Zones in South Australia (zones 1A to 2A). To test the influence of this extraction, data obtained for border zones 1A to 2A for the Tertiary Limestone Aquifer and incorporated into the model.

Figure 150 shows the Glenelg WSPA annual groundwater extraction volumes, the border zones 1A to 2A combined extraction volumes and the combined volumes from Glenelg WSPA and the border zone. Note that where extraction does not occur in both Glenelg WSPA and the border zones, that year of data cannot be incorporated into the model without hindcasting. It is noted that the Glenelg WSPA extraction only makes up around 15% of the combined extraction.

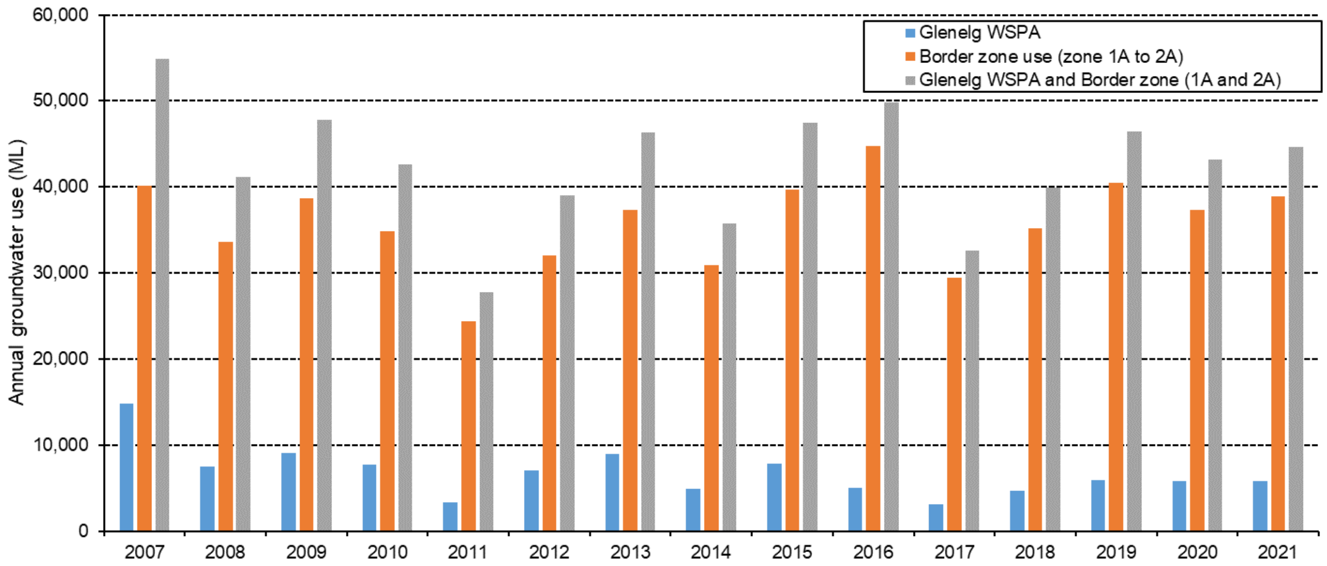


Figure 445 ***Glenelg WSPA and border zones 1A to 2A groundwater use***

27.2.4 Hindcasting

Groundwater use data for Glenelg WSPA is available from 2004/2005 to 2020/2021. The hindcasting methodologies outlined in section 3.3.4.5 were applied to Glenelg WSPA. A summary of the hindcasting results is shown in the following sections.

27.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, four different correlations were developed as described below in Figure 446:

- Annual rainfall vs annual groundwater extraction at Glenelg WSPA
- Two yearly average annual rainfall vs annual groundwater extraction at Glenelg WSPA
- Annual summer period rainfall vs annual groundwater extraction at Glenelg WSPA
- Annual irrigation period rainfall vs annual groundwater extraction at Glenelg WSPA

Applying the method using annual irrigation extraction at Glenelg WSPA as shown in Figure 447:

- Annual rainfall vs annual irrigation groundwater extraction at Glenelg WSPA
- Two yearly average annual rainfall vs annual irrigation groundwater extraction at Glenelg WSPA
- Annual summer period rainfall vs annual irrigation groundwater extraction at Glenelg WSPA
- Annual irrigation period rainfall vs annual irrigation groundwater extraction at Glenelg WSPA

Applying the method again using the combined Glenelg WSPA and border zone (1A and 2A) extraction as shown in Figure 448:

- Annual rainfall vs annual groundwater extraction at Glenelg WSPA and border zone (1A and 2A)
- Two yearly average annual rainfall vs annual groundwater extraction at Glenelg WSPA and border zone (1A and 2A)
- Annual summer period rainfall vs annual groundwater extraction at Glenelg WSPA and border zone (1A and 2A)
- Annual irrigation period rainfall vs annual groundwater extraction at Glenelg WSPA and border zone (1A and 2A)

As shown in Figure 446, the goodness-of-fit represented by the R^2 is greatest for annual summer rainfall with annual irrigation groundwater use. The correlation decreased when groundwater extraction for the whole GMU was used. Given the result of the correlations for hindcast method H2 and hindcast method H3 in the sections below, annual irrigation extraction with annual rainfall has been adopted for hindcast method H1 when not considering externalities (keeping the type of rainfall consistent across all three methods).

When externalities are included, that is border zone extraction, the correlation using the annual rainfall has the greatest R^2, thus this correlation has been adopted when applying hindcast method H1 when considering externalities.

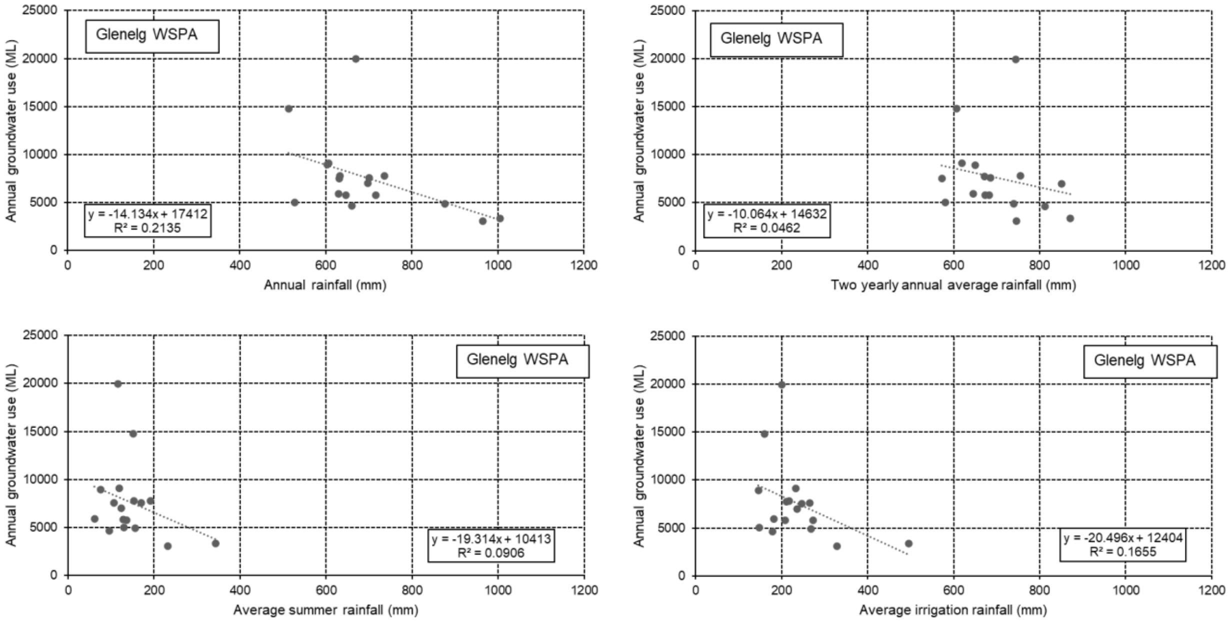


Figure 446 Glenelg WSPA: Hindcast method 1 correlations (Glenelg WSPA annual extraction)

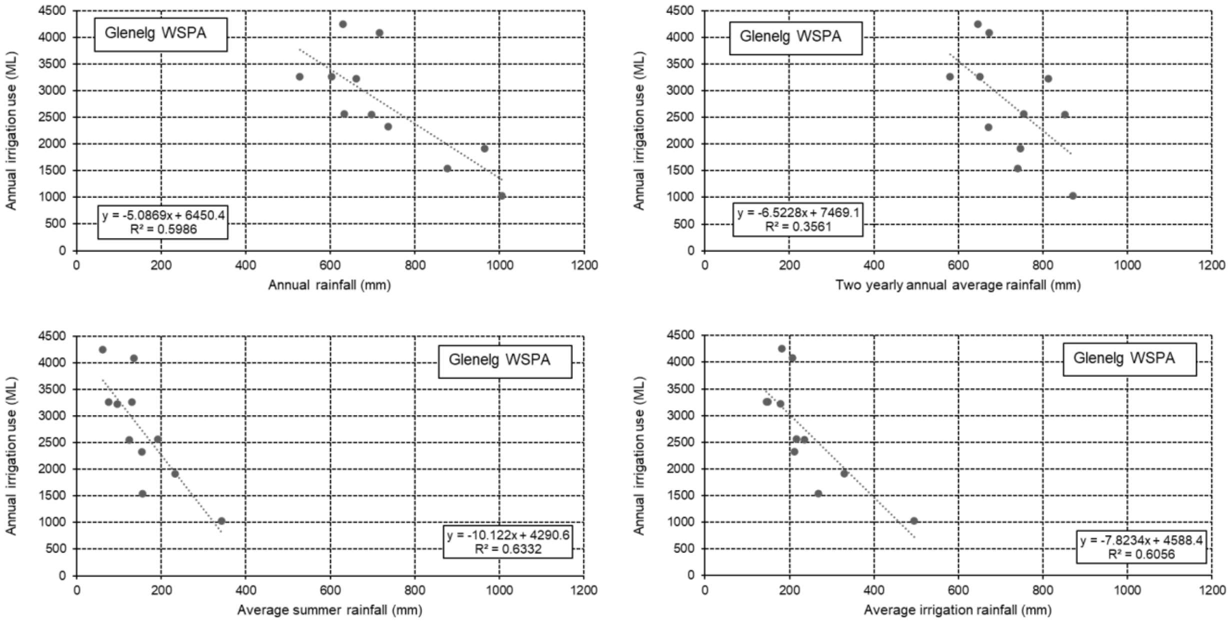


Figure 447 Glenelg WSPA: Hindcast method 1 correlations (Glenelg WSPA annual irrigation extraction)

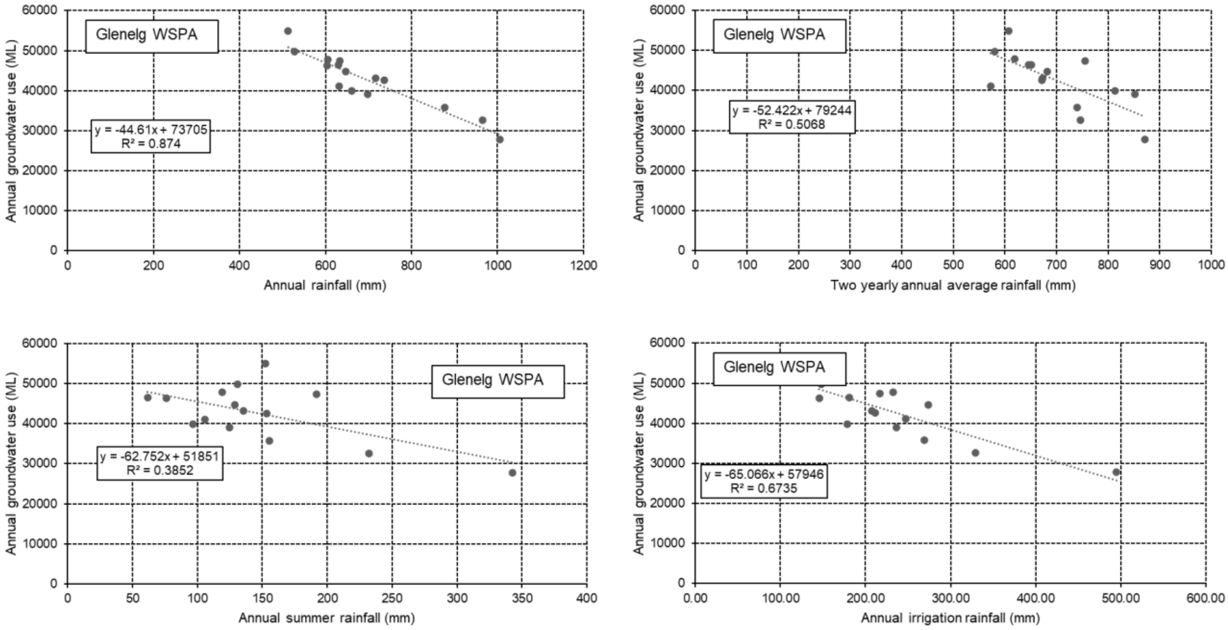


Figure 448 Glenelg WSPA: Hindcast method 1 correlations (Glenelg WSPA and border zone (1A and 2A) annual extraction)

27.2.4.2 Hindcasting Method 2 (H2)

Similar to method H1, four correlations were developed using method H2 as described below and shown in Figure 449:

- Glenelg WSPA use per Glenelg WSPA bore vs annual rainfall
- Glenelg WSPA use per Glenelg WSPA bore vs two yearly average annual rainfall
- Glenelg WSPA use per Glenelg WSPA bore vs annual summer period rainfall
- Glenelg WSPA use per Glenelg WSPA bore vs annual irrigation period rainfall

Another four were developed to take into consideration externalities (border zone extraction) as described below and shown in Figure 450:

- Glenelg WSPA and border zone (1A and 2A) use per Glenelg WSPA bore vs annual rainfall
- Glenelg WSPA and border zone (1A and 2A) use per Glenelg WSPA bore vs two yearly average annual rainfall
- Glenelg WSPA and border zone (1A and 2A) use per Glenelg WSPA bore vs annual summer period rainfall
- Glenelg WSPA and border zone (1A and 2A) use per Glenelg WSPA bore vs annual irrigation period rainfall

As shown in Figure 449, the goodness-of-fit represented by the R^2 is greatest for annual rainfall with annual groundwater use. The correlation decreased significantly when rainfall was reduced to summer rainfall only, and averaged over two years. Thus, the annual rainfall with annual groundwater use was modelled for hindcast method H2 when considering only Glenelg WSPA extraction. As shown in Figure 450, the R^2 improved across all correlations when border zone extraction was included. Similar to hindcast method H1, the highest R^2 was for when annual rainfall was used in the correlation. Thus this correlation has been adopted when applying hindcast method H2 when considering externalities.

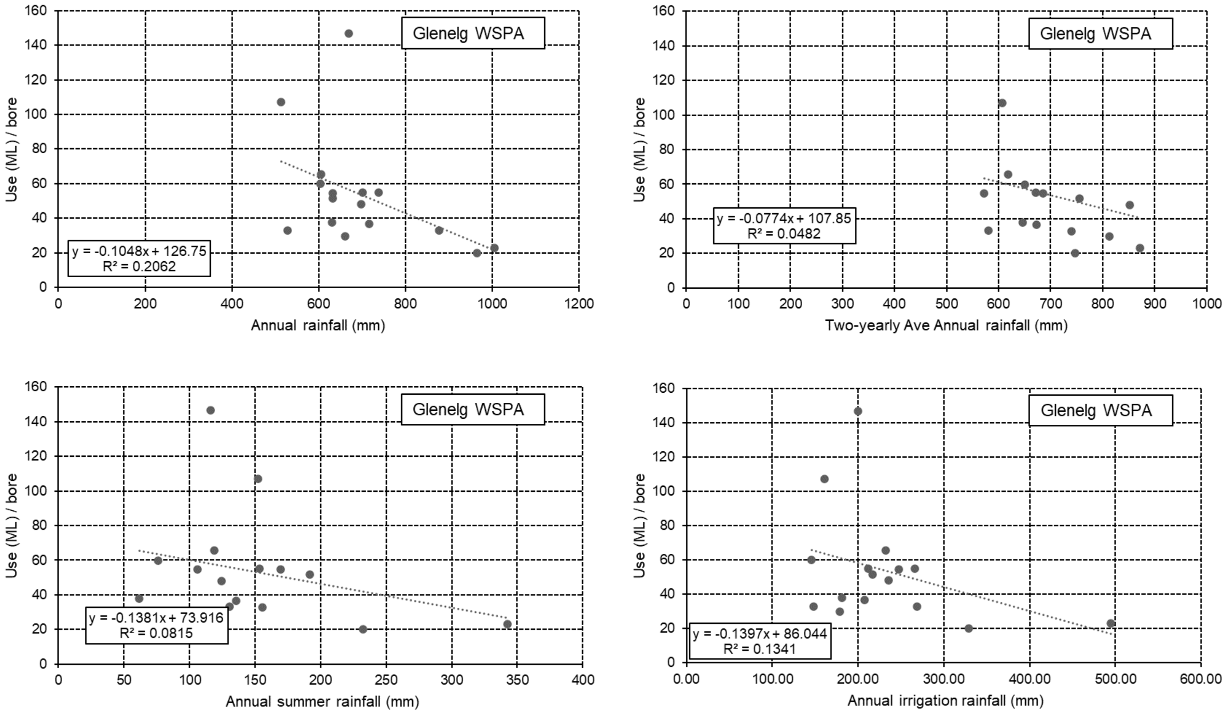


Figure 449 Glenelg WSPA: Hindcast method 2 correlations (Glenelg WSPA only extraction)

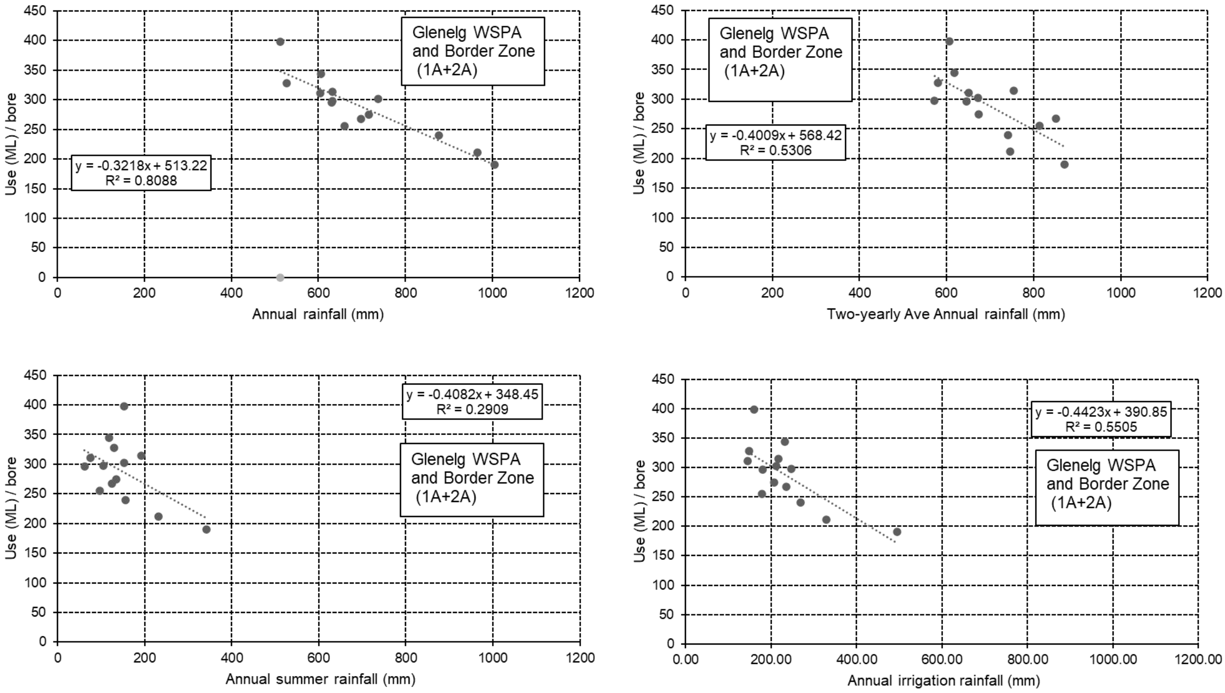


Figure 450 Glenelg WSPA: Hindcast method 2 correlations (Glenelg WSPA and border zone extraction)

27.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 451:

- Percentage of entitlement vs annual rainfall
- Percentage of entitlement vs two yearly average annual rainfall
- Percentage of entitlement vs annual summer period rainfall
- Percentage of entitlement vs annual irrigation period rainfall

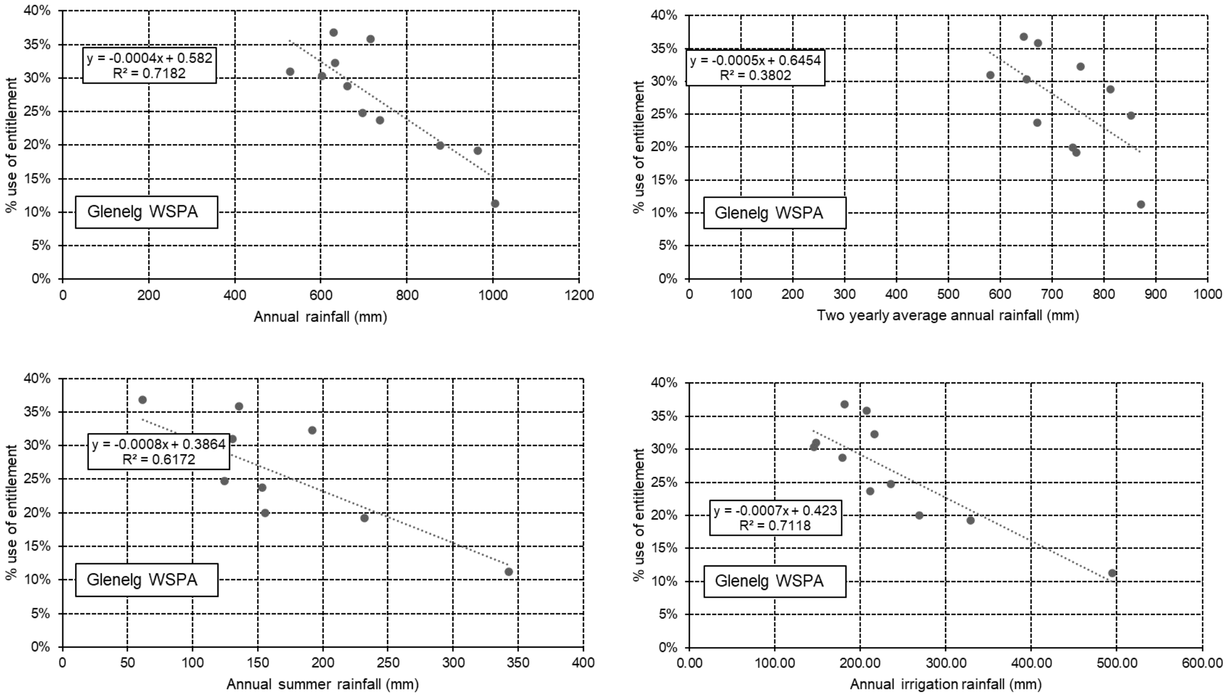


Figure 451 Glenelg WSPA: Hindcast method 3 correlations

As shown in Figure 451 and similar to method H2, the best goodness-of-fit result was shown to be the correlation of the annual rainfall with annual groundwater extraction. Thus, this is the correlation modelled for hindcast method H3.

27.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 452 and Figure 453 for the hindcasting based on Glenelg WSPA groundwater use. Figure 452 shows a comparison of the three hindcasting methods against the recorded use only over the recorded use date and Figure 453 shows the hindcasted data back to 1991/1992.

As shown in Figure 453, groundwater use using method 3 does not decrease historically as there is no factor to account for the changing number of bores extracting over time. This results in a higher groundwater extraction estimate than the other two methods. The hindcasting results show that the smallest average variation of recorded use to estimated use occurs for method 2; thus, this hindcasting method is expected to provide a more probable estimated groundwater use than the other two methods for Glenelg WSPA.

A comparison of the two input datasets (hindcasting methods H1 and H2) is shown in Figure 454 and Figure 455 for the hindcasting based on the combined Glenelg WSPA and border zone (1A and 2A) groundwater use. Figure 454 shows a comparison of the two hindcasting methods against the recorded use only over the recorded use date and Figure 455 shows the hindcasted data back to 1991/1992.

As shown in Figure 455, groundwater use using method 1 does not decrease historically as there is no factor to account for the changing number of bores extracting over time. This results in a higher groundwater extraction estimate than the other two methods. The hindcasting results show that the smallest average variation of recorded use to estimated use occurs for method 2; thus, this hindcasting method is expected to provide a more probable estimated groundwater use for the combined Glenelg WSPA and border zone (1A and 2A) extraction.

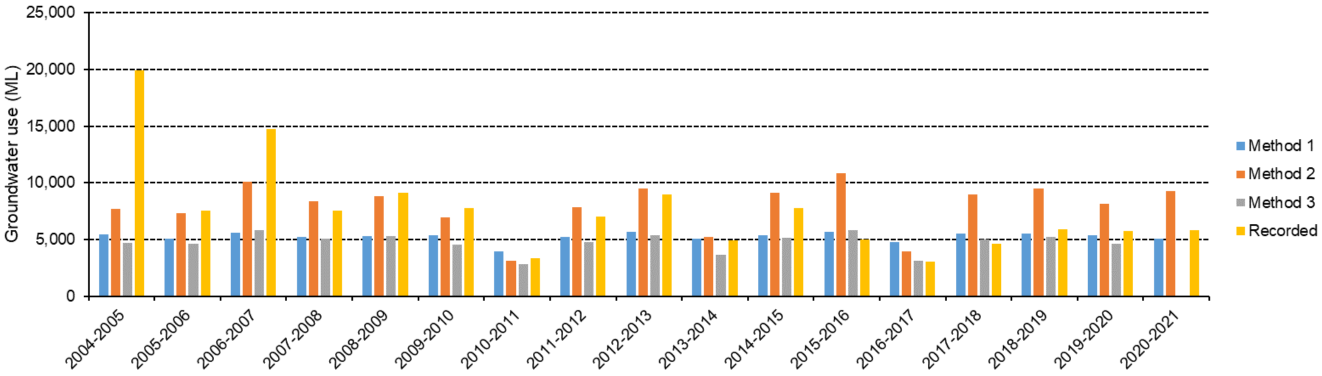


Figure 452 ***Glenelg WSPA: Comparison of hindcasting over recorded use period***

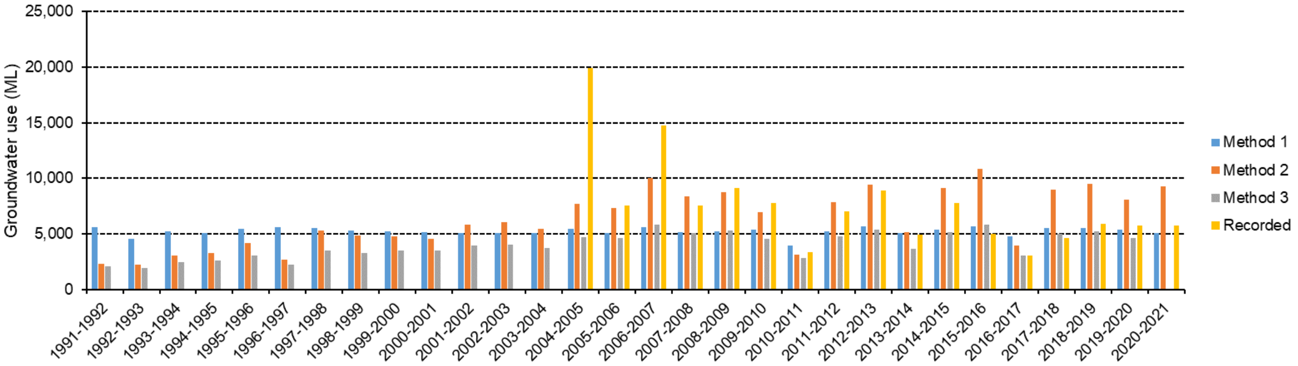


Figure 453 ***Glenelg WSPA: Comparison of hindcasting***

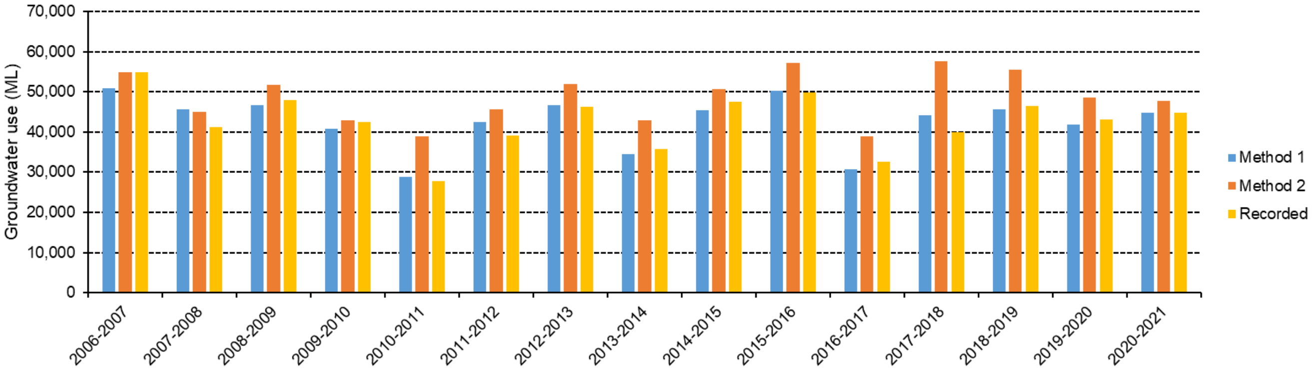


Figure 454 ***Glenelg WSPA: Comparison of hindcasting over recorded use period with border zone extraction***

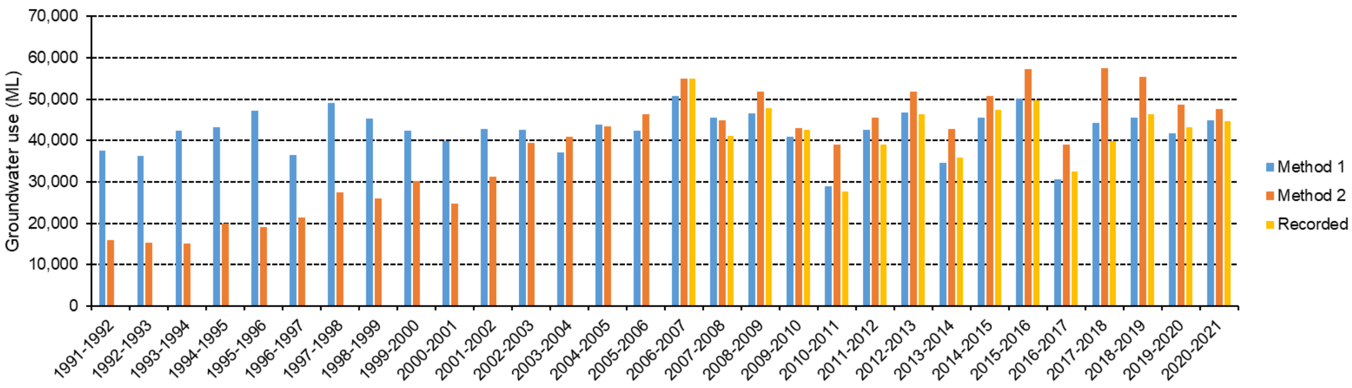


Figure 455 ***Glenelg WSPA: Comparison of hindcasting with border zone extraction***

27.3 Modelling

27.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 161 summarises these combinations of model inputs run for Glenelg WSPA. Model runs highlighted blue were run with annual extraction and grey were run using two yearly average annual extraction.

Table 161 Glenelg WSPA: summary of model inputs

Model input	Model runs																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Annual recovered levels for representative Suites (U_D_8, M_AF_1, L_AF_1)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Glenelg WSPA only	✓																		
Two yearly average annual extraction – Glenelg WSPA only		✓																	
Annual extraction – Glenelg WSPA and Externalities			✓																
Two yearly average annual extraction – Glenelg WSPA and Externalities				✓															
H1 annual extraction – Glenelg WSPA only					✓														
H1 annual extraction – Glenelg WSPA and Externalities						✓													
H2 annual extraction – Glenelg WSPA only							✓												
H2 annual extraction – Glenelg WSPA and Externalities								✓											
H3 annual extraction – Glenelg WSPA only									✓										
H1 two yearly average annual extraction – Glenelg WSPA only										✓									
H1 two yearly average annual extraction – Glenelg WSPA and Externalities											✓								

Model input	Model runs																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
H2 two yearly average annual extraction – Glenelg WSPA only												✓							
H2 two yearly average annual extraction – Glenelg WSPA and Externalities													✓						
S1 annual extraction – Glenelg WSPA only														✓					
S2 annual extraction – Glenelg WSPA only															✓				
S3 annual extraction – Glenelg WSPA only																✓			
S1 annual extraction and H1 annual extraction – Glenelg WSPA only																	✓		
S2 annual extraction and H2 annual extraction – Glenelg WSPA only																		✓	
S3 annual extraction and H3 annual extraction – Glenelg WSPA only																			✓

27.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 161 is presented in Table 162 for the selection of potential representative Suites for Glenelg WSPA. The column heading for U_D_8 is highlighted blue to indicate that this Suite was selected as the most likely representative Suite based on the process outlined in section 27.2.1. The statistics summarised include four key statistical measures pf the average 95 PPU thickness (95PPU TH), percentage of observed levels within 95 PPU (%Obs in 95 PPU), R^2 and root mean square error (RMSE) as well as the number of annual recovered level observation points (No obs data points) and the range of observed annual recovered levels.

Suite L_AF_1

A review of the results and statistical summary for Suite L_AF_1 shows that model run 8 (highlighted green) had the best results when considering the four statistical measures and the length of the observation record of the 19 different model input combinations. Model 8 has the highest R^2 and equal lowest RMSE of the model runs including the full annual recovered level dataset. The graphical model output for this model run is shown in Figure 456. Based on these results, modelling was progressed on the basis of adopting model 8 for Suite L_AF_1.

Suite M_AF_1

A review of the results and statistical summary for Suite M_AF_1 shows that model run 8 (highlighted green) had the best results when considering the four statistical measures and the length of the observation record of the 19 different model input combinations. Model 8 has the highest R^2 as well as the lowest RMSE and 95PPU thickness of the model runs that included the full annual recovered level dataset. The graphical model output for this model run is shown in Figure 457. Based on these results, modelling was progressed on the basis of adopting model 8 for Suite M_AF_1.

Suite U_D_8

A review of the results and statistical summary for Suite U_D_8 shows that model run 1 (highlighted green) had the best results (when considering the 95PPU thickness and then the three other statistical measures) of the 19 different model input combinations. However, this model did not cover the period of pre-development. Considering the need to include a longer historic record and this period in the calibration model, the hindcasted datasets were looked at further. This identified model run 6 as the best hindcasted model, with the highest R^2 as well as the lowest RMSE and 95PPU thickness of the model runs that included the full annual recovered level dataset The graphical model output for model run 6 is shown in Figure 458. Based on these results, modelling was progressed on the basis of adopting model 6 for Suite U_D_8.

Modelling was progressed on the basis of adopting model run 8 for both Suite L_AF_1 and M_AF_1, and model run 6 for Suite U_D_8.

Table 162 Glenelg WSPA: summary of model outputs

Suite	Statistic	Model run																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
L_AF_1	95PPU TH	0.62	0.67	0.36	0.49	1.24	1.09	3	0.72	2.82	1.2	1.11	1.2	0.73	0.32	0.37	0.24	0.93	NA	NA
	%Obs in 95 PPU	100	100	92.86	92.86	93.1	89.66	100	89.66	100	93.1	96.21	93.1	89.66	100	100	100	92.86	0	0
	R^2	78.3	73.9	69.9	41.4	96.1	97.0	24.0	97.1	33.2	95.6	96.9	93.7	96.6	74.6	42.4	74.5	97.3	97.1	97.1
	RMSE	0.11	0.12	0.07	0.1	0.16	0.14	0.71	0.14	0.66	0.17	0.14	0.2	0.15	0.06	0.09	0.06	0.13	0.14	0.14
	No obs data points	16	16	14	14	29	29	29	29	29	29	29	29	29	10	10	10	28	28	28
	Range of observed levels	0.9	0.9	0.5	0.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.3	0.3	0.3	2.5	2.5	2.5
M_AF_1	95PPU TH	0.94	0.9	18.7	NA	1.35	1.28	1.74	0.91	1.49	1.6	1.19	1.37	0.93	0.72	0.77	0.77	0.85	1.22	1.5
	%Obs in 95 PPU	93.75	93.75	14.29	0	96.55	86.55	100	96.55	96.55	96.55	96.55	93.1	93.1	70	90	90	92.86	10.71	53.57
	R^2	30.3	33.1	2.8	28.2	83.8	86.9	75.8	90.8	76.9	78.7	86.7	81.0	89.0	9.2	4.9	5.8	92.0	89.2	-34.3
	RMSE	0.2	0.2	0.25	0.21	0.27	0.24	0.33	0.2	0.32	0.31	0.24	0.29	0.22	0.18	0.19	0.19	0.19	0.22	0.76
	No obs data points	16	16	14	14	29	29	29	29	29	29	29	29	29	10	10	10	28	28	28
	Range of observed levels	0.9	0.9	0.9	0.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.7	0.7	0.7	2.5	2.5	2.5
U_D_8	95PPU TH	0.21	0.21	0.46	0.36	1.1	0.77	1.1	0.88	0.97	1.48	2.05	1.24	0.93	0.38	0.27	0.27	0.89	33.01	33.01
	%Obs in 95 PPU	100	93.75	100	100	89.66	93.1	82.76	96.55	86.21	75.86	96.55	79.31	89.66	80	100	100	96.43	96.43	96.43
	R^2	97.8	97.7	49.1	64.6	77.7	88.2	63.8	79.4	71.8	29.8	39.7	53.0	74.8	-2.9	-2.8	-4.0	81.7	85.0	85.0
	RMSE	0.03	0.03	0.08	0.07	0.19	0.14	0.25	0.19	0.22	0.35	0.49	0.28	0.21	0.07	0.07	0.07	0.18	0.16	0.16
	No obs data points	16	16	14	14	29	29	29	29	29	29	29	29	29	10	10	10	28	28	28
	Range of observed levels	0.8	0.8	0.5	0.5	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	0.2	0.2	0.2	1.3	1.3	1.3

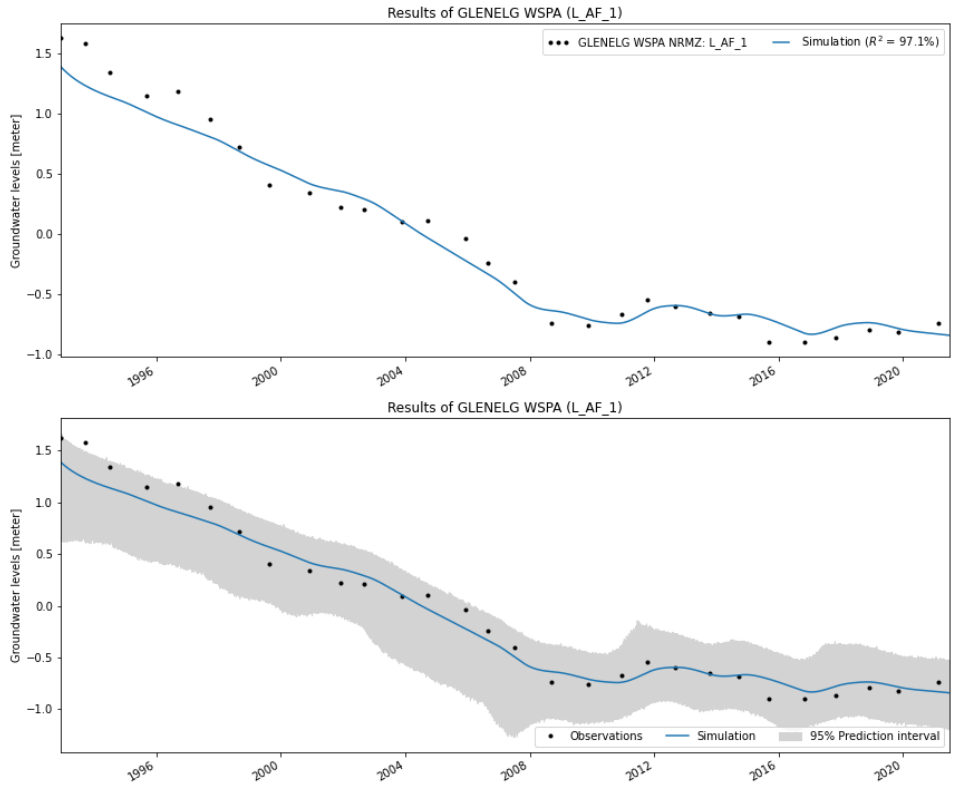


Figure 456 ***Glenelg WSPA Suite L_AF_1: model run 8 (Glenelg WSPA and border zone annual extraction with hindcast method H2) output hydrographs***

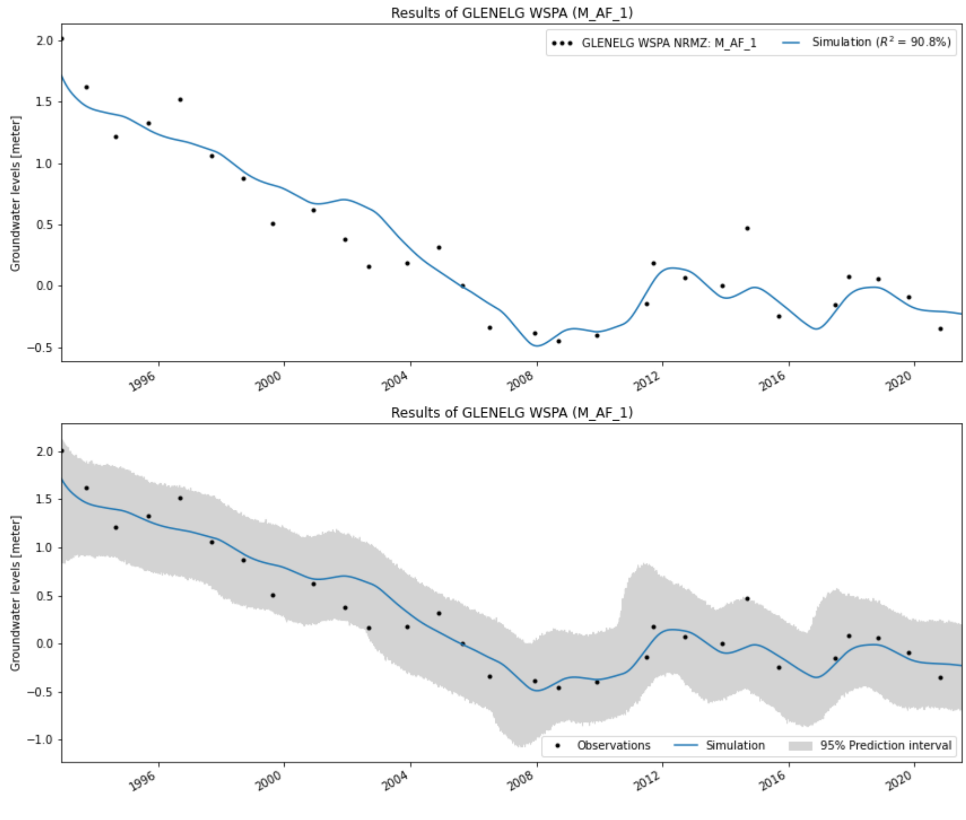


Figure 457 ***Glenelg WSPA Suite M_AF_1: model run 8 (Glenelg WSPA and border zone annual extraction with hindcast method H2) output hydrographs***

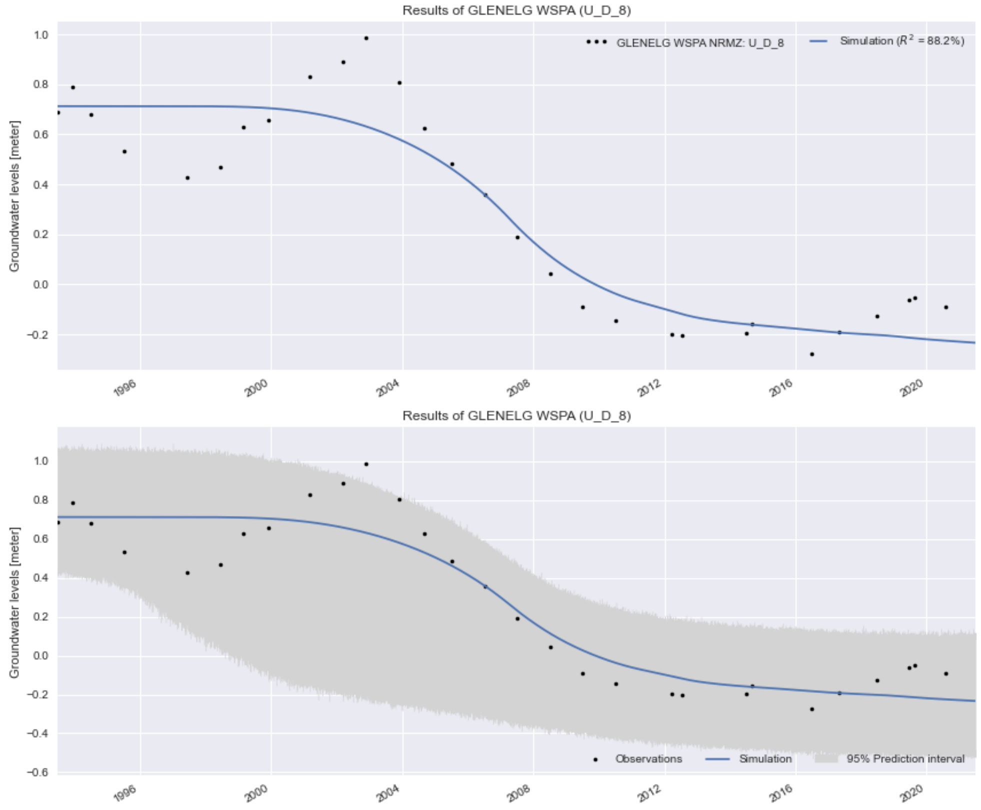


Figure 458 Glenelg WSPA Suite U_D_8: model run 6 (Glenelg WSPA and border zone annual extraction with hindcast method H1) output hydrographs

27.4 Predictive modelling

27.4.1 Model inputs

The preferred model to run the predictive modelling for Glenelg WSPA was model run 8 for Suites L_AF_1 and M_AF_1, and model run 6 for Suite U_D_8. The key inputs for the model were the annual recovered levels and the annual extraction in Glenelg WSPA and the border zone (within hindcast method H1 or H2 applied). To conduct the forecasting for the 19 scenarios discussed in section 3.5.3, a few factors were required in the calculations; these factors are summarised in Table 163.

Table 163 Glenelg WSPA: forecast scenario inputs

Input item	PCV	Licenced entitlement (based on 2020/21)	Existing use (based on 2020/2021)	Average use over recorded period (from VWA)	Maximum use over recorded period (from VWA, year 2004/05)
Combined Glenelg WSPA and border zone (1A and 2A) values (ML/year)	90,074	89,511	44,687	42,620	54,930

27.4.2 Predictive model uncertainty

The model output files of the predicted models can be found in the data package provided as part of Appendix E.

MCMC predictions were undertaken on each of the forecasted scenarios for each of the two Suites. An example of one of the outputs is presented in Figure 459 for scenario 3. As shown in Figure 459, the uncertainty of the model prediction increases as the model predicts further into the future. Comparing with the graphical output for the same scenario, a small number of the MCMC realisations sometimes fall outside the 95% prediction interval bands as shown in Figure 460.

Uncertainty is also accounted for by using 19 forecast scenarios to develop a groundwater use to drawdown relationship (analogous to a Monte Carlo type simulation) where a range of possible outcomes are generated. It is noted however, that the forecast scenarios were not randomly generated, but rather based upon a series of estimated use behaviours.

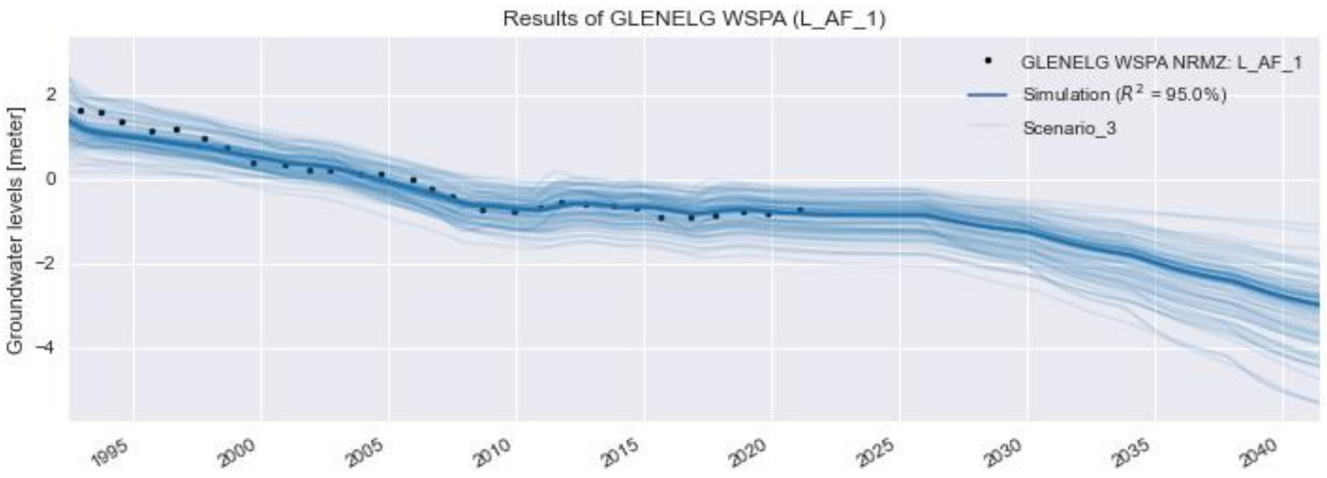


Figure 459 Glenelg WSPA: Suite L_AF_1 MCMC analysis for Forecast Scenario 3

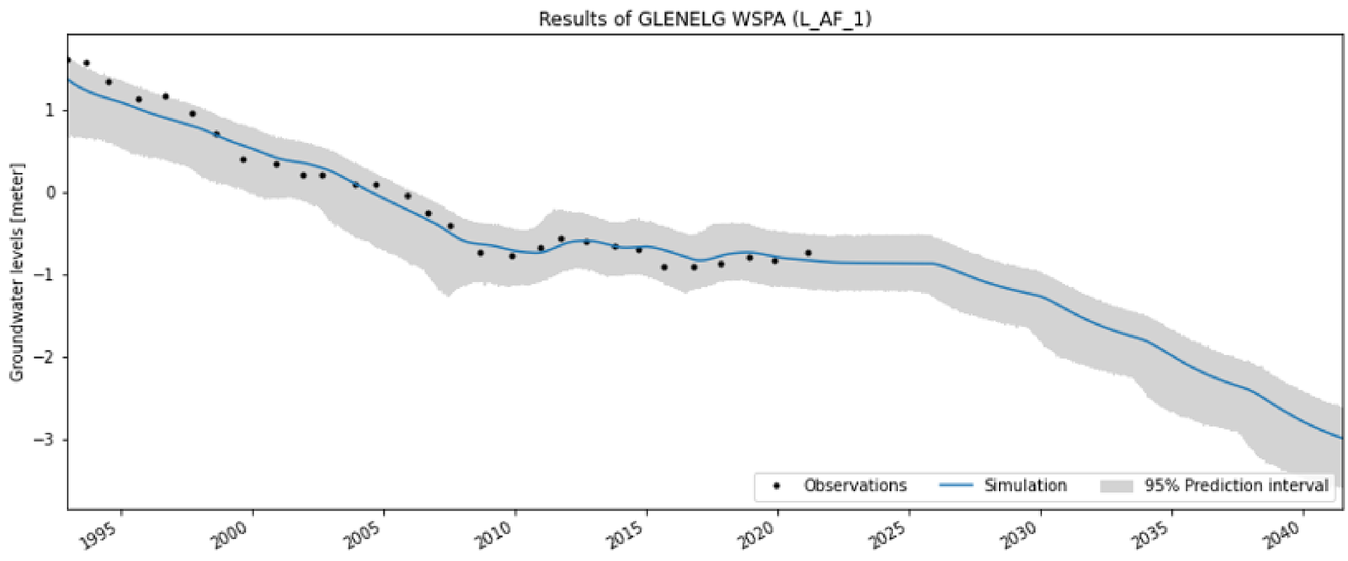


Figure 460 Glenelg WSPA: Suite L_AF_1 Forecast Scenario 3 with 95% prediction bands

27.4.3 Extraction vs drawdown

To calculate the drawdown based on the annual recovered levels simulated by the model, the pre-development conditions (pre commencement of extraction) need to be estimated. For Glenelg WSPA, Suite water level data is available prior to the estimated commencement of extraction.

Using the pre-development levels defined in section 27.2.2, the modelled water levels were converted into drawdowns (from this baseline pre-development level) for each of the 19 scenarios. This predevelopment condition is shown in Figure 461 for Suite L_AF_1 hydrograph of annual recovered levels. In Figure 461:

- Actual annual groundwater use for Glenelg WSPA and border zones (1A and 2A) is represented by the blue column graph between 2004/2005 and 2020/2021
- Hindcasted groundwater use is represented by the orange columns between 1995/1993 and 2004/2005
- Forecasted use is represented by the grey columns after 2021/2022
- The annual recovered water level behaviour based on recorded data is represented by the red line graph
- The pre-development annual recovered levels are taken to be the average of the first 18 readings which equate to 1.83 m
- The modelled forecasted annual recovered levels are represented by the purple line in Figure 461
- The calibration annual recovered levels are represented by the black line in Figure 461

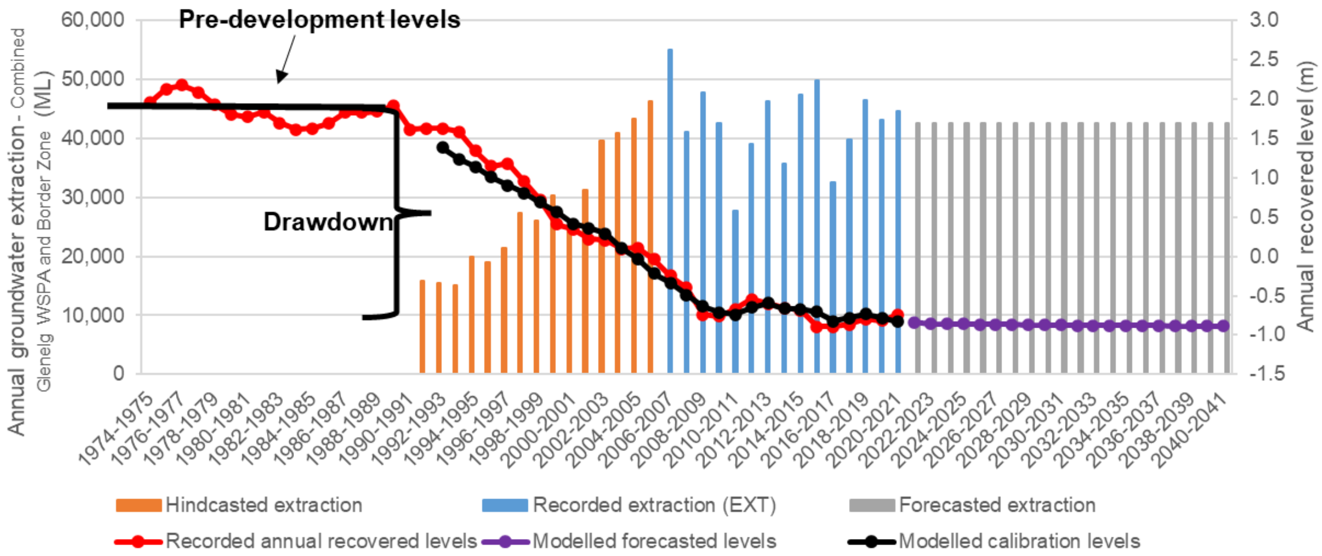


Figure 461 Estimating pre-pumping water levels (example from Suite L_AF_1)

For all three Suites, the volumes needed to be converted from a combined volume of Glenelg WSPA and border zone to just a volume that represents Glenelg WSPA for the use-drawdown relationships. On average, Glenelg WSPA extraction makes up 15% of the combined volume based on the recorded datasets. As such 15% of the combined volume has been used in the use-drawdown relationships for the three Suites.

For Suite L_AF_1, the calculated drawdowns and volumes for each of the scenarios were plotted in individual graphs for each scenario, all scenarios together in the one graph (Figure 462) and a graph of the scenarios for specific time periods (Figure 463) to develop the volume to drawdown relationship. For each scenario, a linear regression was applied and the coefficient of determination (R^2) was calculated. A comparison of each of these graphs shows slight variations in the coefficient of determination and slope of the line of best fit. The same process was applied for Suite M_AF_1 and again, there were slight variations between the graphs. When applied to U_D_8, there were larger variations between the graphs. Given this, the drawdown-use plot of all scenarios was adopted to capture these variations.

The use-drawdown for all the 19 forecast scenario drawdowns and volumes (both the recorded and forecasted volumes) over each year modelled is shown in Figure 462 for Suite L_AF_1, Figure 464 for Suite M_AF_1 and Figure 465 for U_D_8. Note the abscissa range of the chart has been clipped and does not show forecast drawdowns for the higher use scenarios (more improbable). Reviewing these figures, the following is noted:

– There should be zero drawdown under zero use and therefore a line of best fit should pass through the origin (0,0) or close to it
– Average use is around 6,000 ML. Figure 462 indicates that at use of around 6,000 ML the model forecast drawdown tends to occur around the predicted line of best fit, for Figure 464 this usage tends to plot forecast drawdown around the predicted line of best fit and for Figure 465, use at around 6,000 ML tends to plot forecast drawdown below to the predicted line of best fit
– For the same annual use, different drawdowns can be obtained as Pastas predicts a water level for each year. For example, Figure 461 shows a scenario where groundwater use remains constant at around 42,600 ML/year (Glenelg WSPA and border zone combined use, which is around 6,400 ML/year for only Glenelg WSPA) over the next 20 years
– The correlation for groundwater use and drawdown for Suite L_AF_1 is excellent, for Suite M_AF_1 is excellent and for Suite U_D_8 is poor, as shown in Figure 462, Figure 464 and Figure 465 respectively
– The various forecast scenarios generally result in data plotting reasonably close together in a linear trend. The 19 forecast scenarios applied to populate the chart is analogous to a Monte Carlo type simulation where a range of possible outcomes are generated. It is noted however, that the forecast scenarios were not randomly generated, but rather based upon a series of estimated use behaviours.

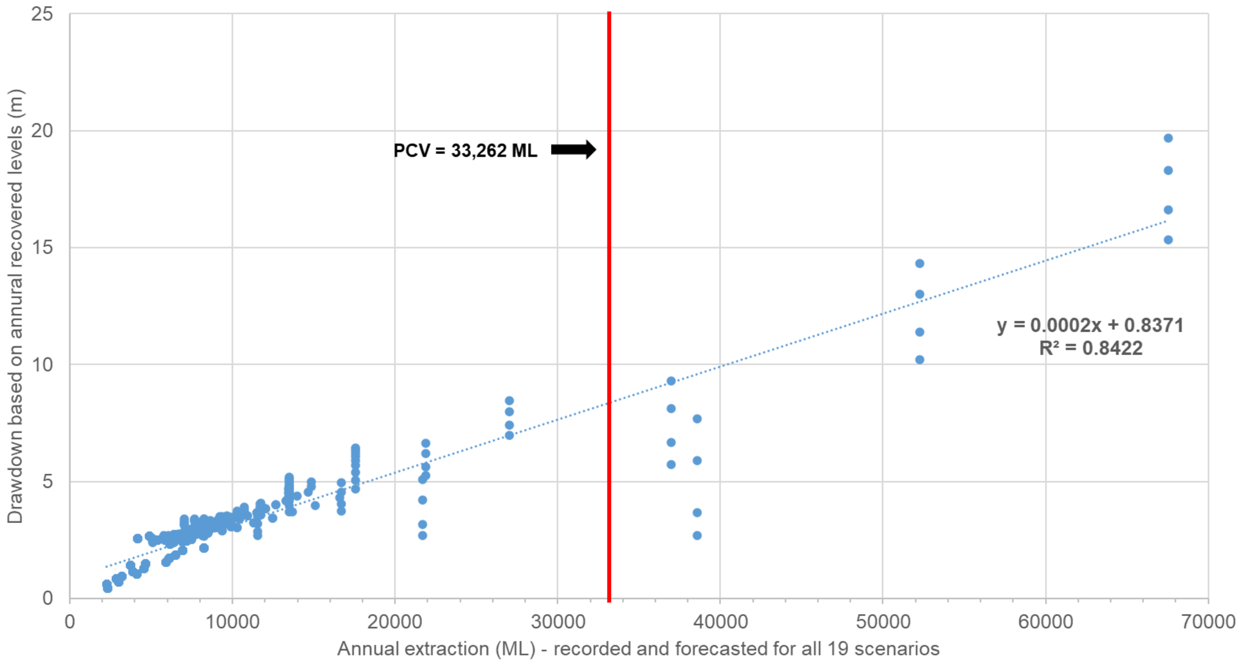


Figure 462 *Glenelg WSPA Suite L_AF_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <70,000 ML) for all data between 1993 to 2041 and all forecasted scenarios*

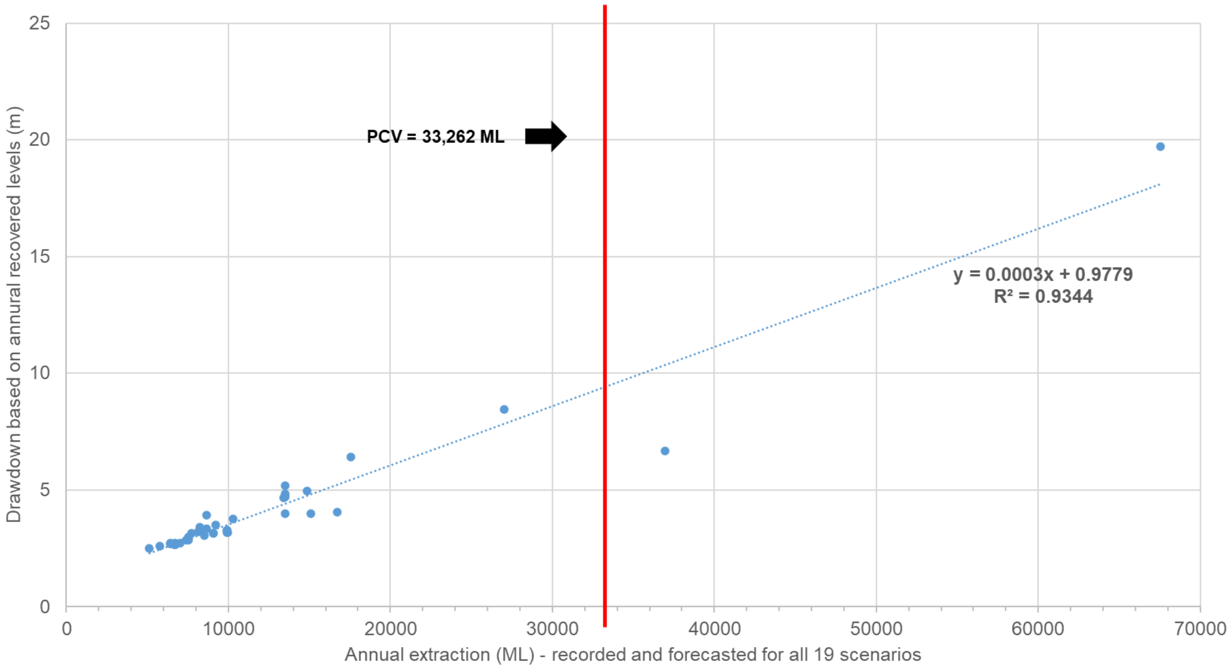


Figure 463 *Glenelg WSPA Suite L_AF_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <70,000 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

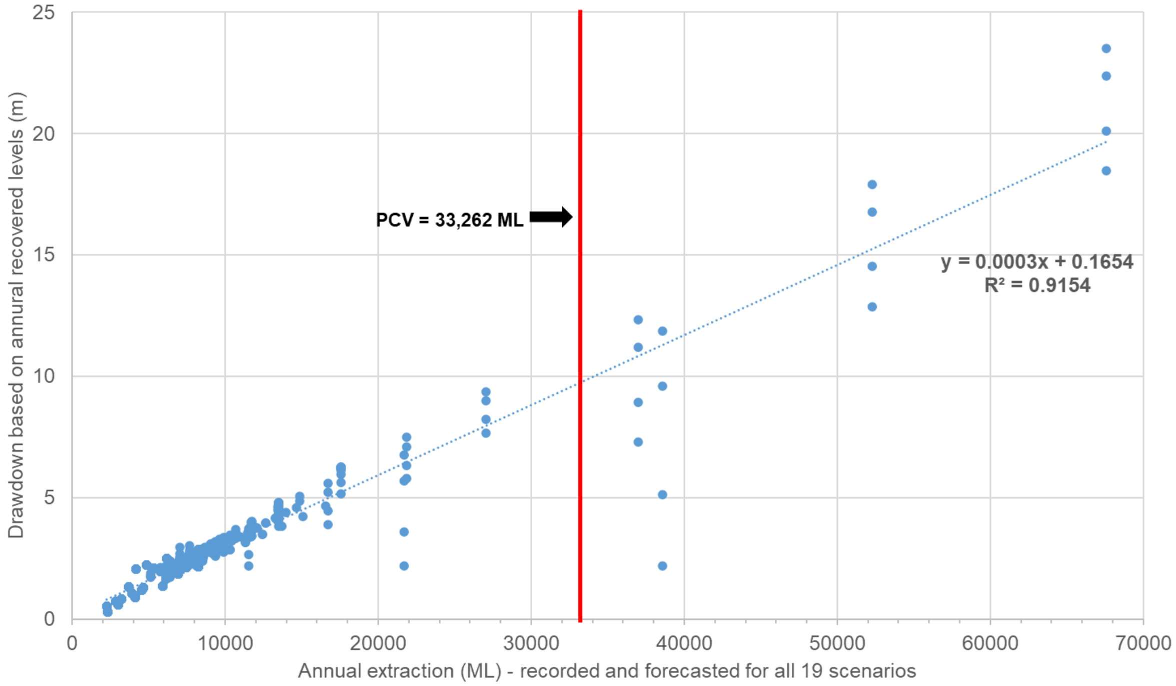


Figure 464 *Glenelg WSPA Suite M_AF_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <70,000 ML) for all data between 1993 to 2041 and all forecasted scenarios*

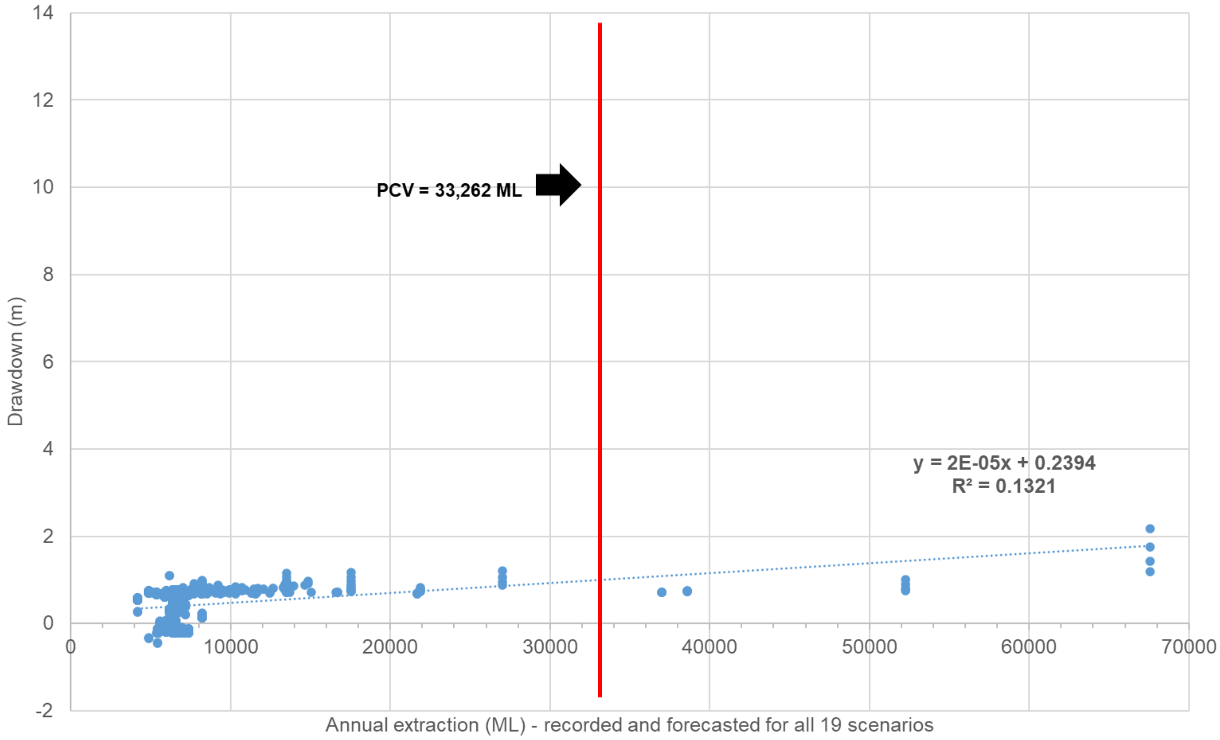


Figure 465 *Glenelg WSPA Suite U_D_8: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <70,000 ML) for all data between 1993 to 2041 and all forecasted scenarios*

27.5 Sustainability metrics

27.5.1 Application of metrics

Using the use - drawdown relationships developed through the previous step of forecasting aquifer response under a range of use scenarios, groundwater drawdown can be used to compare against groundwater resource sustainability metrics.

The application of these metrics and the relationship developed between drawdown based on the Suite annual recovered levels and extraction volume for the whole GMU, which is shown in Table 164 for Glenelg WSPA Suite L_AF_1, Table 165 for Glenelg WSPA Suite M_AF_1 and Table 166 for Glenelg WSPA Suite U_D_8 (noting Glenelg WSPA has a current PCV of 33,262 ML/year). As part of the modelling, a 95% prediction interval band was applied to the modelling results. The relationship between drawdown and extraction volumes can also be interrogated at the lower and upper bands of the 95% prediction interval as shown in Table 164 and Figure 466 for Suite L_AF_1, Table 165 and Figure 467 for Suite M_AF_1, and Table 166 and Figure 468 for Suite U_D_8.

As previously discussed, for the three Suites, the predicted model adopted was based on the combined extraction from Glenelg WSPA and border zone extraction). This was brought back to a Glenelg WSPA only extraction for plotting the drawdown with extraction by taking 15% of the combined extraction (15% is the average portion of Glenelg WSPA to the combined extraction based on recorded data). Table 164 shows the volume for Glenelg WSPA to a given drawdown for Suite L_AF_1; the same table has been replicated for the combined use as shown in Table 167 (its noted that this is the actual usage used in the predictive model). Table 165 shows the volume for Glenelg WSPA to a given drawdown for Suite M_AF_1; the same table has been replicated for the combined use as shown in Table 168 (its noted that this is the actual usage used in the predictive model). Table 166 shows the volume for Glenelg WSPA to a given drawdown for Suite U_D_8; the same table has been replicated for the combined use as shown in Table 169 (its noted that this is the actual usage used in the predictive model).

Figure 469 shows graphically and spatially by Suite, the drawdowns associated with extraction rates for the whole GMU. In comparing the three Glenelg WSPA Suites, Suite U_D_8 has a lower drawdown for a given use when compared to Suite L_AF_1 and M_AF_1.

A comparison of volumes at drawdown intervals provided by DEECA is shown in Table 170 for Suites L_AF_1, M_AF_1 and U_D_8. It's noted that Suite U_D_8 represents the upper aquifer in Glenelg WSPA which is conceptualised as being unconfined, as such, the Suite is assessed against the unconfined metrics provided by DEECA. Based on this, a 5 m of drawdown is predicted to occur at a groundwater extraction volume of 20,800 ML (which could range from 14,100 to 21,500 ML) for Suite L_AF_1, a volume of 16,100 ML (which could range from 11,900 to 16,900 ML) for Suite M_AF_1 and a 1 m of drawdown is predicted to occur at a groundwater extraction volume of 38,000 ML (which could range from 9,800 to 60,000 ML) for Suite U_D_8. A 10 m of drawdown is predicted to occur at a groundwater extraction volume of 45,800 ML (which could range from 30,700 to 46,500 ML) for Suite L_AF_1, a volume of 32,800 ML (which could range from 24,400 to 33,500 ML) for Suite M_AF_1 and a 2 m of drawdown is predicted to occur at a groundwater extraction volume of 88,000 ML (which could range from 43,100 to 110,000 ML) for Suite U_D_8.

Suite U_D_8 covers the larger portion of the GMU and 52% of extraction from the GMU occurs from this Suite, however, Suite U_D_8 shows less significant drawdowns for higher volumes extracted compared to Suite L_AF_1 and Suite M_AF_1. Since Suite U_D_8 monitors the Bridgewater Formation, an unconfined aquifer, it is likely that it is being recharged by rainfall processes.

Table 164 Relationship of Suite drawdown to GMU extraction for Glenelg WSPA Suite L_AF_1

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_AF_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
100,000	20.8 (20.7 - 30.8)
90,000	18.8 (18.7 - 27.8)
80,000	16.8 (16.7 - 24.8)
70,000	14.8 (14.7 - 21.8)
60,000	12.8 (12.7 - 18.8)
50,000	10.8 (10.7 - 15.8)
40,000	8.8 (8.7 - 12.8)
30,000	6.8 (6.7 - 9.8)
20,000	4.8 (4.7 - 6.8)
10,000	2.8 (2.7 - 3.8)
0	0.8 (0.7 - 0.8)

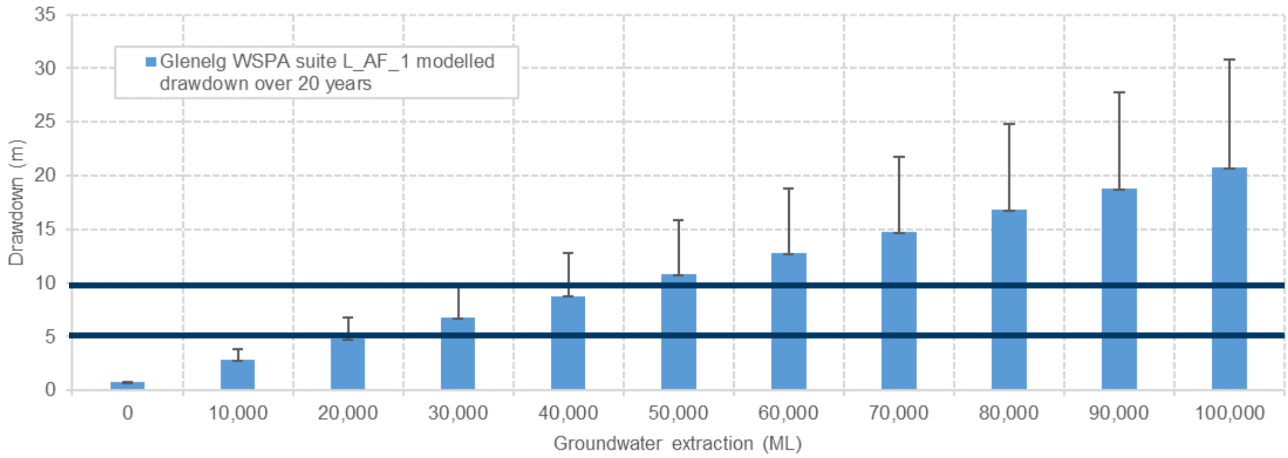


Figure 466 Glenelg WSPA Suite L_AF_1: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 165 Relationship of Suite drawdown to GMU extraction for Glenelg WSPA Suite M_AF_1

Volume (ML/year) for whole of GMU	Based on model prediction of Suite M_AF_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
100,000	30.2 (29.9 - 40.2)
90,000	27.2 (26.9 - 36.2)
80,000	24.2 (23.9 - 32.2)
70,000	21.2 (20.9 - 28.2)
60,000	18.2 (17.9 - 24.2)
50,000	15.2 (14.9 - 20.2)
40,000	12.2 (11.9 - 16.2)
30,000	9.2 (8.9 - 12.2)
20,000	6.2 (5.9 - 8.2)
10,000	3.2 (2.9 - 4.2)
0	0.2 (-0.1 - 0.2)

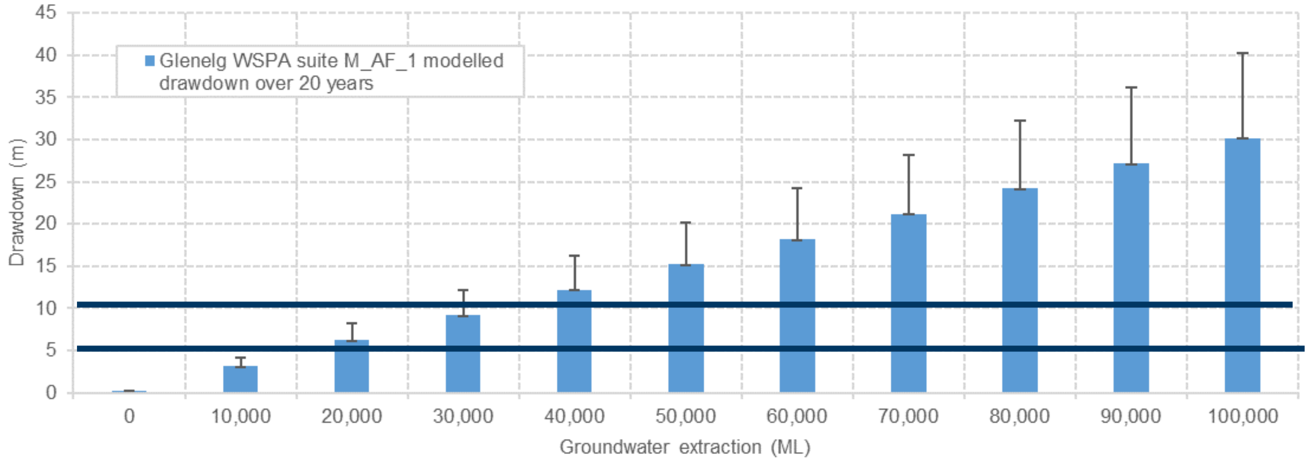


Figure 467 Glenelg WSPA Suite M_AF_1: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 166 Relationship of Suite drawdown to GMU extraction for Glenelg WSPA Suite U_D_8

Volume (ML/year) for whole of GMU	Based on model prediction of Suite U_D_8 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
90,000	2 (2.5 - 7.6)
85,000	1.9 (2.4 - 7.2)
80,000	1.8 (2.2 - 6.8)
75,000	1.7 (2.1 - 6.4)
70,000	1.6 (1.9 - 6)
65,000	1.5 (1.8 - 5.6)
60,000	1.4 (1.6 - 5.2)
55,000	1.3 (1.5 - 4.8)
50,000	1.2 (1.3 - 4.4)
45,000	1.1 (1.2 - 4)

Volume (ML/year) for whole of GMU	Based on model prediction of Suite U_D_8 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
40,000	1 (1 - 3.6)
35,000	0.9 (0.9 - 3.2)
30,000	0.8 (0.7 - 2.8)
25,000	0.7 (0.6 - 2.4)
20,000	0.6 (0.4 - 2)
15,000	0.5 (0.3 - 1.6)
10,000	0.4 (0.1 - 1.2)
5,000	0.3 (0 - 0.8)
0	0.2 (-0.2 - 0.4)

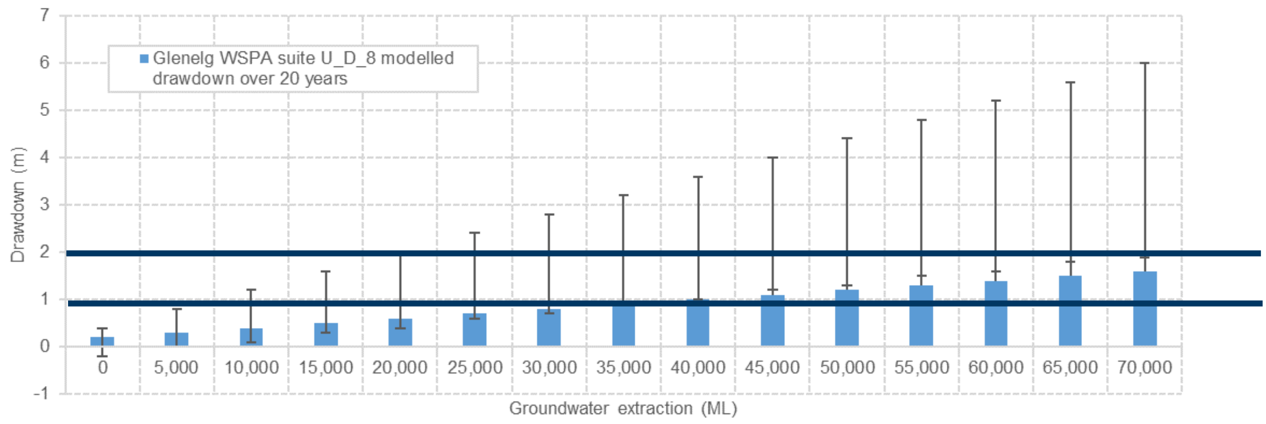


Figure 468 Glenelg WSPA Suite U_D_8: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 167 Relationship of Suite drawdown to Glenelg WSPA and border zone extraction for Glenelg WSPA Suite L_AF_1

Volume (ML/year) for combined Glenelg WSPA and border zone (1A and 2A) extraction	Based on model prediction of Suite L_AF_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
260,000	10.9 (10.7 - 13.7)
240,000	10.1 (9.9 - 12.7)
220,000	9.3 (9.1 - 11.7)
200,000	8.5 (8.3 - 10.7)
180,000	7.7 (7.5 - 9.7)
160,000	6.9 (6.7 - 8.7)
140,000	6.1 (5.9 - 7.7)
120,000	5.3 (5.1 - 6.7)
100,000	4.5 (4.3 - 5.7)
80,000	3.7 (3.5 - 4.7)
60,000	2.9 (2.7 - 3.7)
40,000	2.1 (1.9 - 2.7)
20,000	1.3 (1.1 - 1.7)
0	0.5 (0.3 - 0.7)

Table 168 Relationship of Suite drawdown to Glenelg WSPA and border zone extraction for Glenelg WSPA Suite M_AF_1

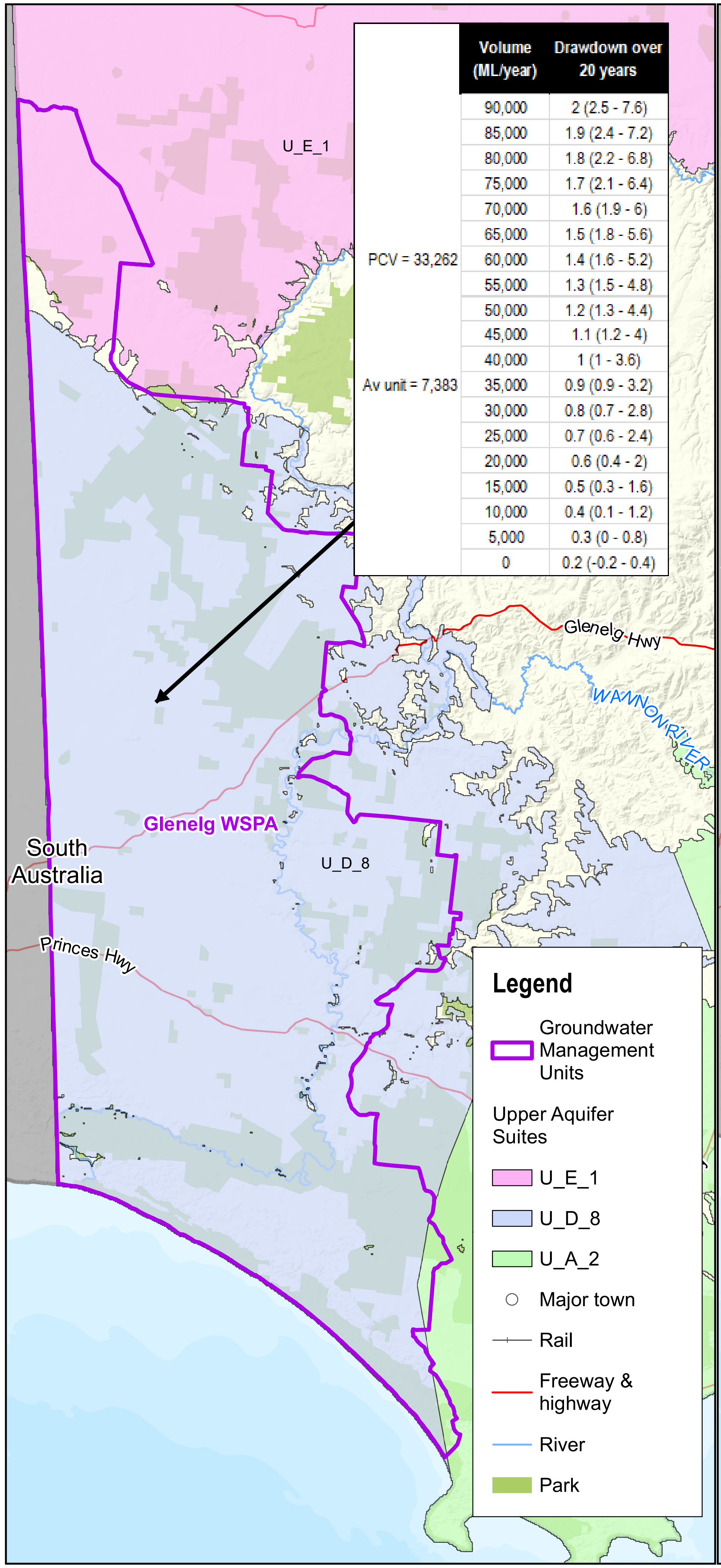
Volume (ML/year) for combined Glenelg WSPA and border zone (1A and 2A) extraction	Based on model prediction of Suite M_AF_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
260,000	13 (10.1 - 13.3)
240,000	12 (9.3 - 12.3)
220,000	11 (8.5 - 11.3)
200,000	10 (7.7 - 10.3)
180,000	9 (6.9 - 9.3)
160,000	8 (6.1 - 8.3)
140,000	7 (5.3 - 7.3)
120,000	6 (4.5 - 6.3)
100,000	5 (3.7 - 5.3)
80,000	4 (2.9 - 4.3)
60,000	3 (2.1 - 3.3)
40,000	2 (1.3 - 2.3)
20,000	1 (0.5 - 1.3)
0	0 (-0.3 - 0.3)

Table 169 Relationship of Suite drawdown to Glenelg WSPA and border zone extraction for Glenelg WSPA Suite U_D_8

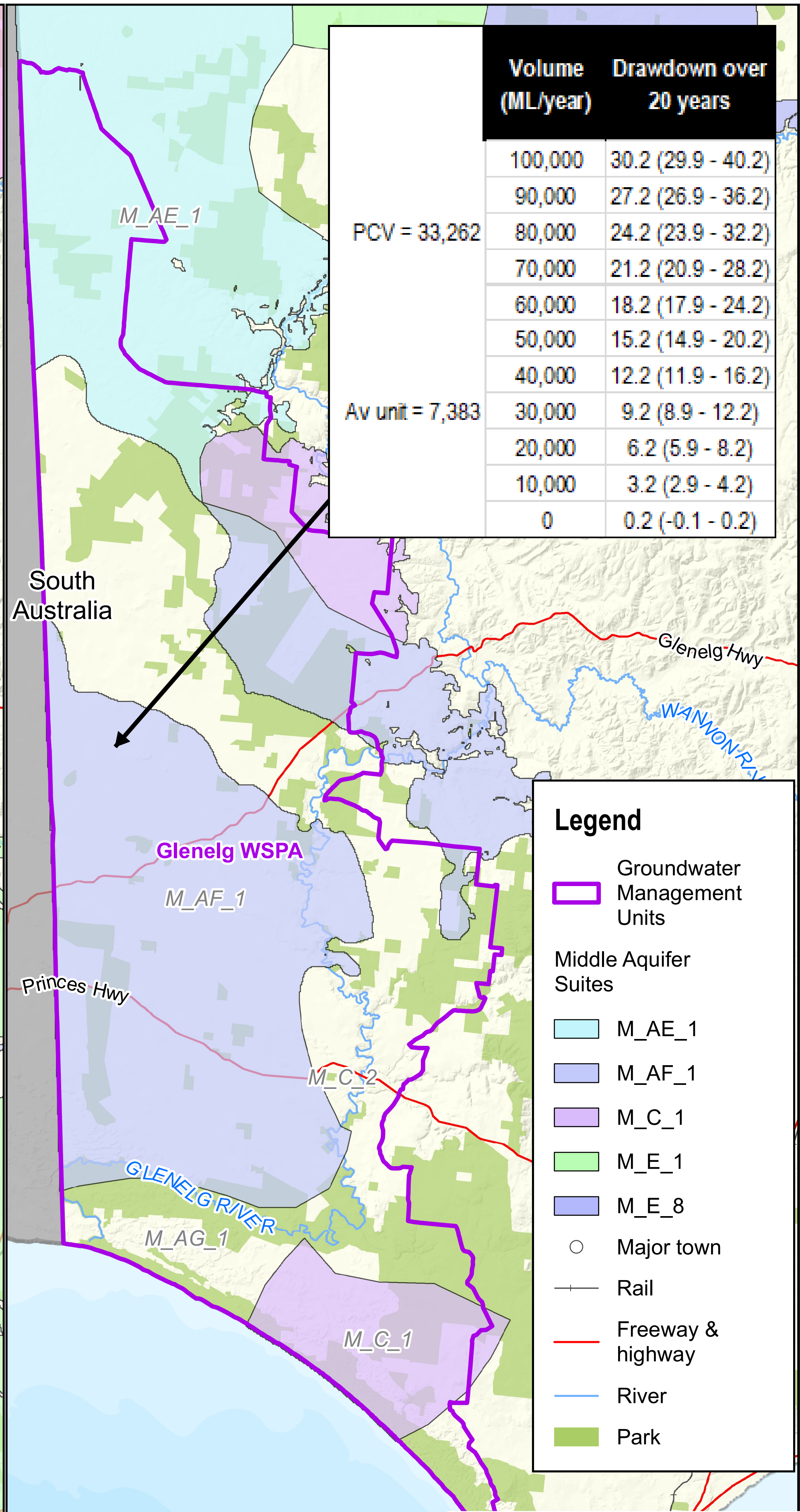
Volume (ML/year) for combined Glenelg WSPA and border zone (1A and 2A) extraction	Based on model prediction of Suite U_D_8 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
260,000	2.3 (2.1 - 3)
240,000	2.1 (1.9 - 2.8)
220,000	2 (1.7 - 2.6)
200,000	1.8 (1.5 - 2.4)
180,000	1.6 (1.3 - 2.2)
160,000	1.4 (1.1 - 2)
140,000	1.2 (0.9 - 1.8)
120,000	1.1 (0.7 - 1.6)
100,000	0.9 (0.5 - 1.4)
80,000	0.7 (0.3 - 1.2)
60,000	0.5 (0.1 - 1)
40,000	0.3 (-0.1 - 0.8)
20,000	0.2 (-0.3 - 0.6)
0	0 (-0.5 - 0.4)

Table 170 Predicted volumes for drawdown metrics

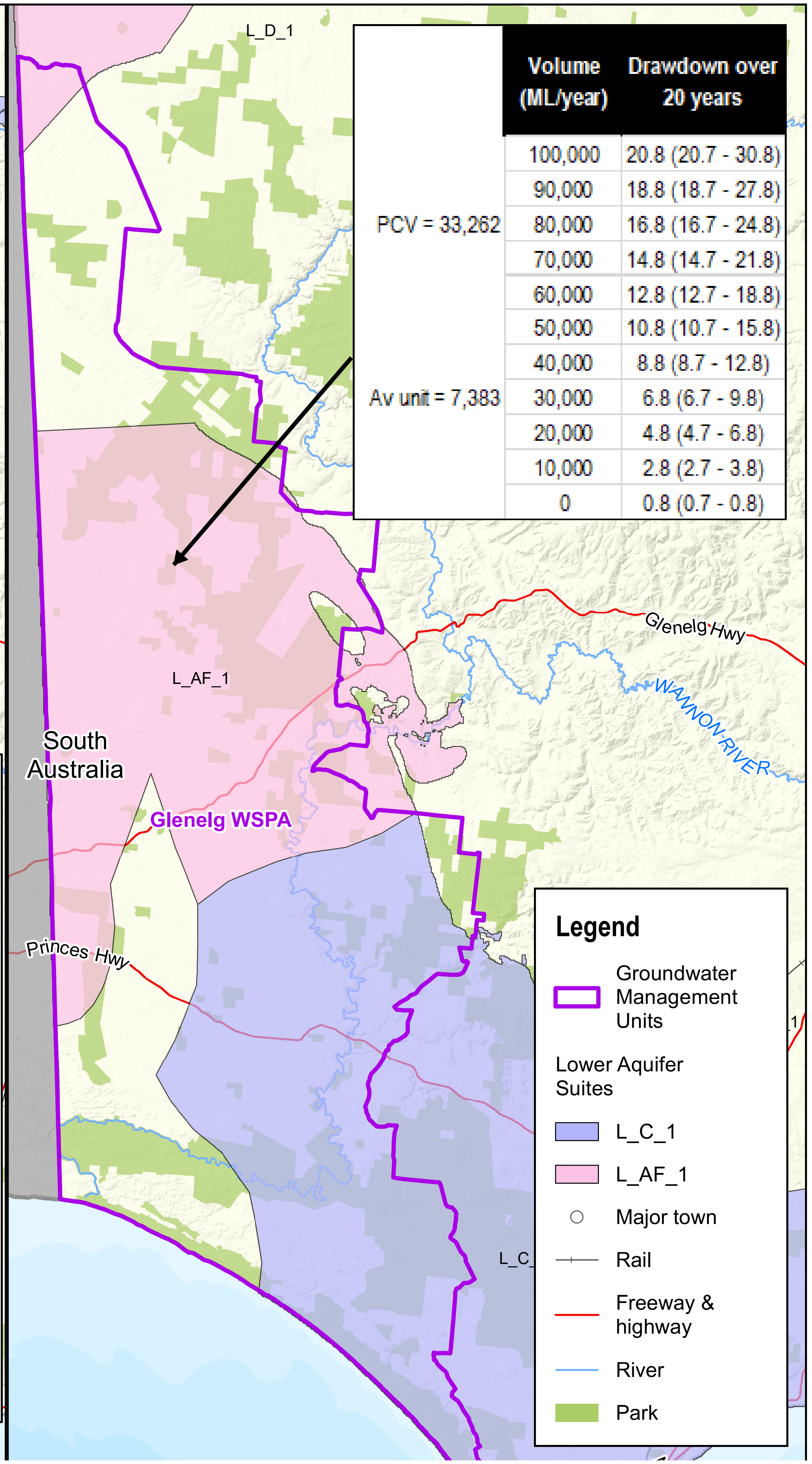
Drawdown (m) confined aquifer	Predicted volumes (ML) for GMU based on Suite L_AF_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite M_AF_1 drawdowns (lower limit to upper limit)	Drawdown (m) unconfined aquifer	Predicted volumes (ML) for GMU based on Suite U_D_8 drawdowns (lower limit to upper limit)
5	20,800 (14,100 – 21,500)	16,100 (11,900 – 16,900)	1	38,000 (9,700 – 60,000)
10	45,800 (30,700 – 46,500)	32,800 (24,400 – 33,500)	2	88,000 (3,100 – 110,000)



	Volume (ML/year)	Drawdown over 20 years
PCV = 33,262	90,000	2 (2.5 - 7.6)
	85,000	1.9 (2.4 - 7.2)
	80,000	1.8 (2.2 - 6.8)
	75,000	1.7 (2.1 - 6.4)
	70,000	1.6 (1.9 - 6)
	65,000	1.5 (1.8 - 5.6)
	60,000	1.4 (1.6 - 5.2)
	55,000	1.3 (1.5 - 4.8)
	50,000	1.2 (1.3 - 4.4)
	45,000	1.1 (1.2 - 4)
	40,000	1 (1 - 3.6)
Av unit = 7,383	35,000	0.9 (0.9 - 3.2)
	30,000	0.8 (0.7 - 2.8)
	25,000	0.7 (0.6 - 2.4)
	20,000	0.6 (0.4 - 2)
	15,000	0.5 (0.3 - 1.6)
	10,000	0.4 (0.1 - 1.2)
	5,000	0.3 (0 - 0.8)
	0	0.2 (-0.2 - 0.4)



	Volume (ML/year)	Drawdown over 20 years
PCV = 33,262	100,000	30.2 (29.9 - 40.2)
	90,000	27.2 (26.9 - 36.2)
	80,000	24.2 (23.9 - 32.2)
	70,000	21.2 (20.9 - 28.2)
	60,000	18.2 (17.9 - 24.2)
	50,000	15.2 (14.9 - 20.2)
	40,000	12.2 (11.9 - 16.2)
Av unit = 7,383	30,000	9.2 (8.9 - 12.2)
	20,000	6.2 (5.9 - 8.2)
	10,000	3.2 (2.9 - 4.2)
	0	0.2 (-0.1 - 0.2)



	Volume (ML/year)	Drawdown over 20 years
PCV = 33,262	100,000	20.8 (20.7 - 30.8)
	90,000	18.8 (18.7 - 27.8)
	80,000	16.8 (16.7 - 24.8)
	70,000	14.8 (14.7 - 21.8)
	60,000	12.8 (12.7 - 18.8)
	50,000	10.8 (10.7 - 15.8)
	40,000	8.8 (8.7 - 12.8)
Av unit = 7,383	30,000	6.8 (6.7 - 9.8)
	20,000	4.8 (4.7 - 6.8)
	10,000	2.8 (2.7 - 3.8)
	0	0.8 (0.7 - 0.8)

Paper Size ISO A3
0 4 8 12 16
Kilometers
Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 VICGRID94

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GHD

DEECA
Sustainable Yields
Confined Aquifers

GLENELG WSPA: KEY SUITES VOLUME VS DRAWDOWN

Project No. 31-12564066
Revision No. 0
Date 15/01/2024

FIGURE 469

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Print date: 06 Feb 2024 - 12:04

Data source: DEECA, VicMap, 2022; DEECA GMU locations, 2022; GHD, aquifer suites, 2018; . Created by: bsmyth

27.6 GMU summary

27.6.1 Findings

Glenelg WSPA primarily relates to the Bridgewater Formation (QA) and the Port Campbell Limestone (UMTA), where groundwater is predominately extracted for irrigation purposes. The QA falls within the Upper Aquifer Suites, which at Glenelg WSPA comprises Suite U_D_8 (92%). The UMTA falls within the Middle Aquifer Suites which comprises Suites M_AF_1, M_AE_1, M_AG_1, M_C_1 and M_C_2, providing a total GMU coverage of 69%. Based on the extraction data provided, after the QA, the aquifer with the next highest extraction is the Dilwyn Formation (LTA) which relates to Suites L_AF_1 (42%) and L_C_1 (30%). The identified representative Suites are U_D_8 (most representative), M_AF_1 and L_AF_1. The Suite hydrographs for the representative Suites show an overall decreasing trend along with seasonal fluctuation and thus recovered water levels, which were adopted for the assessment.

As identified through the conceptualisation, Glenelg WSPA may be influenced by extraction occurring within the border zone. Extraction occurring from the border zones 1A and 2A makes up around 85% of the total extraction when the two datasets are combined. Of the two hindcasting methods that look at both extraction datasets, the correlations developed to apply the hindcasting were improved when the combined datasets were considered rather than the Glenelg WSPA only dataset.

Application of two yearly annual average extraction, instead of annual average, generally showed a poorer model fit based on the statistical analysis across the model runs. Although the model fit was slightly poorer with two yearly average annual extraction, the results were similar to the scenario of annual extraction only with no hindcasting and spatial distribution.

The application of spatial distribution generally had a variable effect on the statistical results depending on the suite and spatial distribution method applied. It is noted that the quality of the result did not increase when spatial distribution methodology was combined with hindcasting methodology.

Based on an assessment of all model runs, model run 6 of Glenelg WSPA and border zone (1A and 2A) annual extraction within hindcast method H1 was adopted to undertake the predictive modelling for Suite U_D_8 and model run 8 of Glenelg WSPA and border zone (1A and 2A) annual extraction within hindcast method H2 was adopted to undertake the predictive modelling for Suites M_AF_1 and L_AF_1. The pre-development levels were defined for the representative Suites based on the early time series Suite data for the annual recovered levels; this resulted in pre-development levels of 1.83 m for Suite L_AF_1, 2.00m for Suite M_AF_1 and 0.5 m for Suite U_D_8. The drawdowns were calculated based on these pre-development levels and the simulated levels from each of the 19 forecast scenarios.

The volumes estimated for a given drawdown for each Suite is shown below.

Drawdown (m) confined aquifer	Predicted volumes (ML) for GMU based on Suite L_AF_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite M_AF_1 drawdowns (lower limit to upper limit)	Drawdown (m) unconfined aquifer	Predicted volumes (ML) for GMU based on Suite U_D_8 drawdowns (lower limit to upper limit)
5	20,800 (14,100 – 21,500)	16,100 (11,900 – 16,900)	1	38,000 (9,700 – 60,000)
10	45,800 (30,700 – 46,500)	32,800 (24,400 – 33,500)	2	88,000 (3,100 – 110,000)

The models for Suites L_AF_1 and M_AF_1 were assessed as having an “Excellent” model applicability rating and Suite U_D_8 was assessed as having a “Moderate” rating using the criteria outlined in section 5.2. Suite U_D_8 is largely unaffected by the Glenelg WSPA/Border zone pumping rates, which influences the correlation of the use-drawdown relationship.

Suite U_D_8 covers the larger portion of the GMU and 52% of extraction from the GMU occurs from this Suite, however, Suite U_D_8 shows less significant drawdowns for higher volumes extracted compared to Suite L_AF_1 and Suite M_AF_1. Since Suite U_D_8 monitors the Bridgewater Formation, an unconfined aquifer, it is likely that it is being recharged by rainfall processes. Given this, and that the border zone extraction is from the middle aquifer, GHD considers Suite M_AF_1 more applicable to represent Glenelg WSPA rather than U_D_8 and L_AF_1 (which were originally considered more representative based on the process outlined in section 27.2.1).

27.6.2 Limitations

In addition to the limitations applicable to all 25 GMUs discussed in section 1.8, the following Glenelg WSPA specific limitations have been identified:

- The licenced bore dataset provided by DEECA has 4% of bores assigned to Glenelg WSPA with no depth data and thus couldn't be assigned to a VAF layer and in turn Suite. This data was not used in the model analysis.
- For Suite U_D_8, it's largely unaffected by the Glenelg WSPA/Border zone pumping rates
- U_D_8 is the preferred Suite when using the normal selection criteria, however, as the Border Zone extraction is within the Middle Aquifer and makes up 85% of the extraction when combined with Glenelg WSPA usage, M_AF_1 then becomes the preferred Suite
- The results for both Suites have the modelled levels using Glenelg WSPA and Border Zone 1A and 2A extractions, but the volumes stated are Glenelg WSPA only in the use-drawdown graphs. The logic for deriving Glenelg WSPA extraction from the combined source is that when extraction of Glenelg WSPA and Border Zone 1A and 2A are combined annually, on average, Glenelg WSPA extraction makes up 15% of this thus 15% of the combined volume has been used in the final relationship.

27.6.3 Recommendations

In addition to the recommendations applicable to all 25 GMUs discussed in section 32, the following Glenelg WSPA specific recommendations have been identified:

- The licenced bore dataset provided by DEECA has 4% of bores assigned to Glenelg WSPA with no depth data and thus couldn't be assigned to a VAF layer and in turn Suite. It is recommended that DEECA obtains the relevant depth and aquifer monitored data for licenced bores within this GMU so accurate VAF layers and Suites can be assigned.

28. Jan Juc GMA

28.1 Conceptualisation

The hydrogeological conceptualisation elements relevant to this study are summarised in Table 171 and a map of the GMU is presented in Figure 470. It is noted that a significant volume of information was collated to inform the hydrogeological conceptual understanding of the GMU. The information that is directly relevant to the modelling are in bold or colour coded within Table 171.

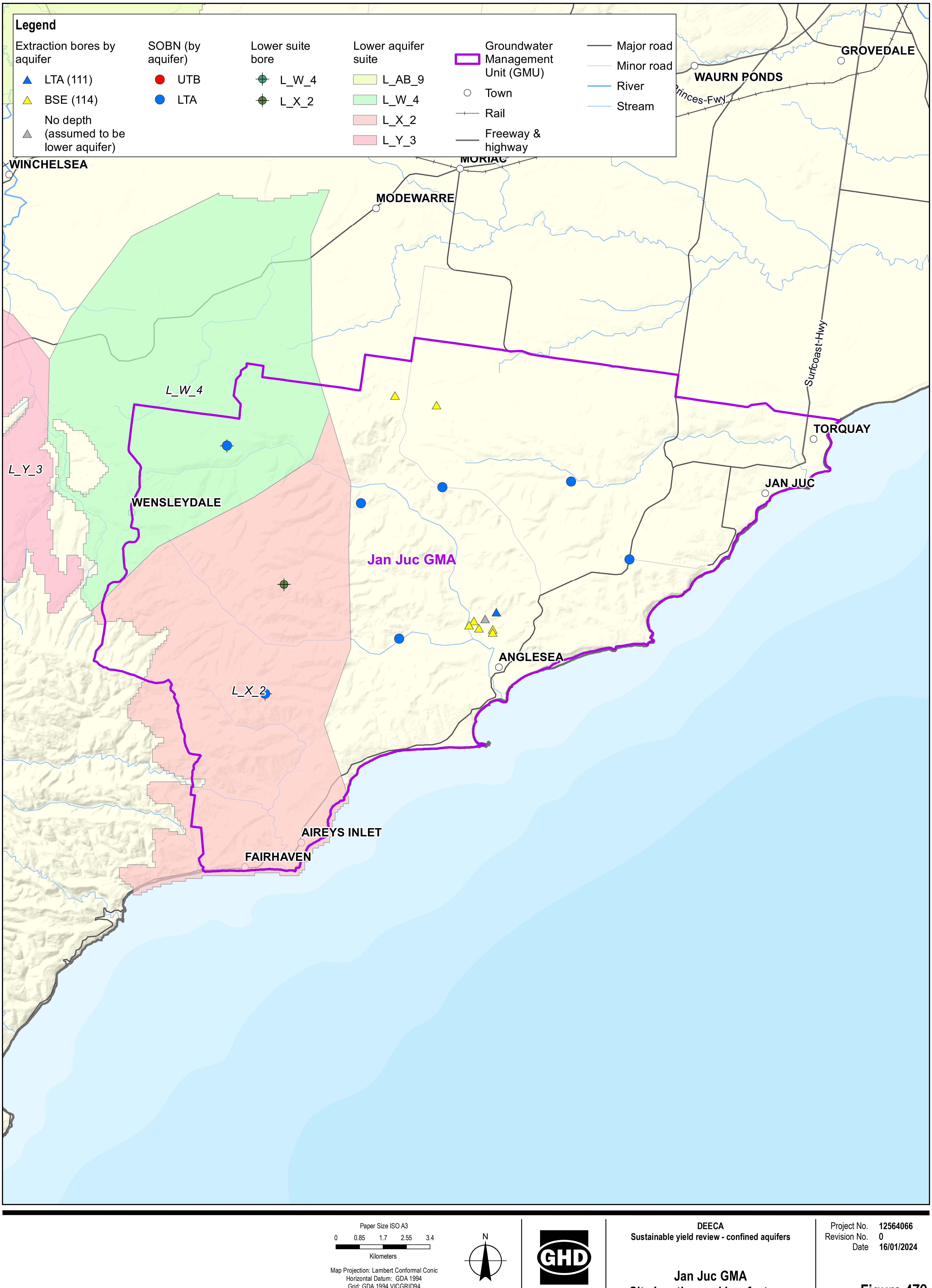
Table 171 Jan Juc GMA – Tabulated conceptualisation

GMU summary								
Jan Juc GMA is located in southwest Victoria in the Torquay Basin and covers an area of approximately 290 km^2. The GMA includes the townships of Anglesea, Aireys Inlet and Torquay. The western boundary coincides with the Torquay basin boundary (Otway Ranges), with the eastern and southern limits marked by Bass Strait. The northern boundary is marked by roads towards the coast. Jan Juc GMA pertains to all formations below the surface through defined spatial zones but was intended to manage groundwater resources of the Eastern View Formation (Lower Tertiary Aquifer, LTA). The PCV (14,250 L/year) therefore pertains to confined and unconfined aquifers (i.e., transitional). Groundwater within the GMA is extracted predominately for municipal supply (City of Geelong by Barwon Water) from the Lower Eastern View Formation, industrial/commercial use (Alcoa) from the Upper Eastern View Formation, with a small number of domestic and stock users. It is noted that Alcoa has now ceased operation and is in the process of filling the pit void. The Eastern View Formation is unconfined along the northern and western margins of the GMA becoming confined to the south. Multiple studies (GHD 2020, CDM Smith 2018[11]) have indicated the potential for the groundwater resource in this GMA to be connected to waterways or wetlands.								
Hydrostratigraphy summary								
Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Use volumes ML (2019/20)	Entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Bridgewater Formation (QA)	-	-	0	NA	0		Low
	Hanson Plain and (UTAM)	U_AS_1 (14%)	14%	0	NA	0		Low
Middle	Gellibrand Marl (UMTD)	-	-	0	NA	0		Low
Lower	Narrawaturk Marl (LMTD)	-	-	0	NA	0		Low
	Eastern View Formation (LTA)	L_W_4 (10%), L_X_2 (30%) M_AA_2 (0%) M_AB_2 (0%) M_AB_3 (0%)	40%	8	Dewatering	0	1,143 (571)	Medium
Basement	Cretaceous and Permian Sediments (CPS)	-	-	0	NA	0	0	Low
	Basement rocks (BSE)	-	-	0	Industrial	78	3,107	Low
Note that volumes listed above are based on the DEECA provided licenced bore dataset with associated VAF layers. Bores have been assigned to a VAF layer based on bore depth where available. In some instances, bore depth is not available and has been reallocated where possible. The reassigned volumes are indicated within the brackets. 571 ML is unassigned due to no depth data being available.								

[11] CDM Smith 2018, Technical Assessment of Groundwater Resources for the Long Term Water Resource Assessment – Southern Victoria study areas, Part 2. Report prepared for DEECA. 17 August 2018.

Characteristic and importance	Description	Degree of understanding
Intended aquifer (LTA, highlighted blue above)		
Aquifer thickness within GMU (range, based on VAF)	Max: 565 m, Average: 144 m	High
Aquifer extent	Small, local	High
Likelihood of inter-aquifer flow	Medium	Low
Likelihood of groundwater – surface water interaction	Low	High
Representative Suite	**Not determined, likely L_W_4 or L_X_2**	**Low. Insufficient data.** **Licensed extraction bores do not occur within any defined Suites**
Current hydrological condition of representative aquifer		
Representative Suite trend	Decreasing	High
Groundwater quality (average salinity based on WMIS and CDM Smith spatial segment(s) with highest coverage)	1558 mg/L (WMIS) 601 – 1,200 mg/L (CDM Smith, 2022)	Low – expect the TDS to be lower Based on WMIS and CDM Smith (2022)
Groundwater yield	5 – 50 L/s	Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1993-2021**	
Spatial clustering of licensed bores in relation to Suites	**Yes, not within a Suite**	**Based on DEECA density mapping and licenced bore data.**
Groundwater use		
Licensed groundwater use	**2,801 ML**	**High (Based on average historical VWA data over 14 years)**
Minimum historic groundwater use	7 ML	High (Based on historical VWA data, year 2017/18)
Maximum historic groundwater use	**7,806 ML**	**High (Based on historical VWA data, year 2011/12)**
Entitlement (Groundwater allocation)	**14,250 ML**	**High (Based on licenced volumes in 2020/21)**
Significant drivers of groundwater level variability (primary)	**Commercial/industrial (quarries/etc)**	**Moderate**
Secondary drivers of groundwater level variability	Pumping for town water supply	Moderate
Groundwater use profile	Stable (even monthly distribution)	Low
External Influence	**None identified**	

Characteristic and importance	Description	Degree of understanding
Groundwater values and risks		
Existing Environmental Values to be protected, relevant to this GMU	Potable water supply Licensed non-potable supply (irrigation, commercial, industrial) Unlicensed non-potable supply (domestic and stock)	
Risks to groundwater values	Direct risks: – Drawdown which may affect access to groundwater by existing users – Drawdown which may affect groundwater dependent ecosystems	
Indicators used to assess impacts to groundwater	– Measured drawdown using pre-determined metrics measured from a pre-determined level for the purpose of this modelling	



DEECA
Sustainable yield review - confined aquifers

Project No. 12564066
Revision No. 0
Date 16/01/2024

Jan Juc GMA
Site location and key features

Figure 470

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Print date: 16 Jan 2024 - 12:38

Data source: DELWP, VicMap, 2022; DELWP, GMUs, 2022; DELWP, SOBN, 2022; GHD, aquifer suites, 2018; DELWP, extraction bores, 2022 Created by: cperyer

28.2 Technical analysis

28.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the relevant Suites for Jan Juc GMA as shown in Figure 471. Generally, the Suite hydrograph does not show a steady trend of seasonal fluctuations. Suite L_X_2 shows a clear declining trend with time, likely due to extraction and Suite L_W_4 shows a slight increasing trend with time.

As these Suites are not within the area of significant use, a comparison was done with hydrographs of State Observation Bores in the area (113004, 119347, 116458, 115873, 119348, 115869, 116459, 116460). This identified that only bore 113004 has a similar hydrograph to L_W_4 which does not show the effects of known extraction as its located north of the borefield.

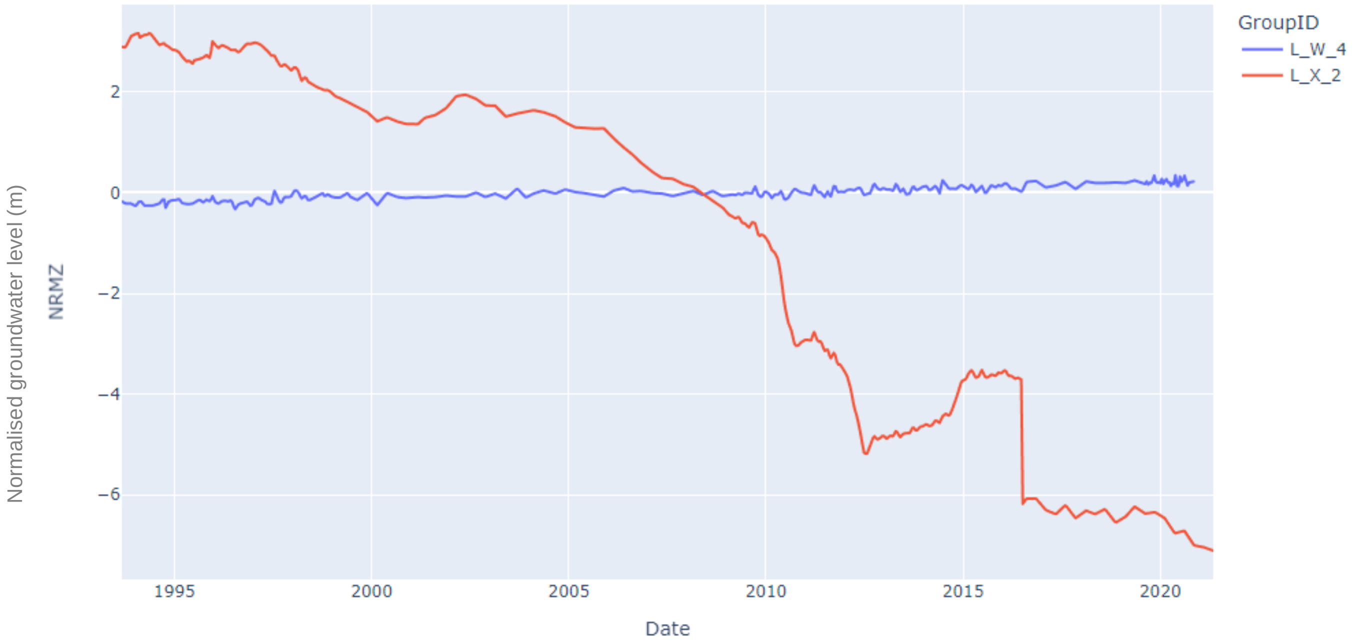


Figure 471 Jan Juc GMA Suite Hydrographs for all confined aquifers

A representative Suite for this GMU could not be defined using the methodology outlined in section 2.6.4, as summarised below:

- The greatest volume of extraction occurs within the Basement Aquifer (likely assigned to the incorrect aquifer layer, which based on the conceptualisation, should be the Lower Aquifer)
- The Lower Aquifer pertains to the LTA, which is the intended aquifer of the GMU
- Suite L_X_2 covers 30% of the GMU, while Suite L_W_4 covers 10% of the GMU
- Both Suites have no active SOBN bores within their Suite Areas
- None of the Suite bores are location close to extraction points

Only Suite L_X_2 was taken forward for the analysis for Jan Juc GMA as Suite L_W_4 did not show any drawdown response to extraction. The annual recovered Suite hydrographs for L_X_2 is shown in Figure 472.

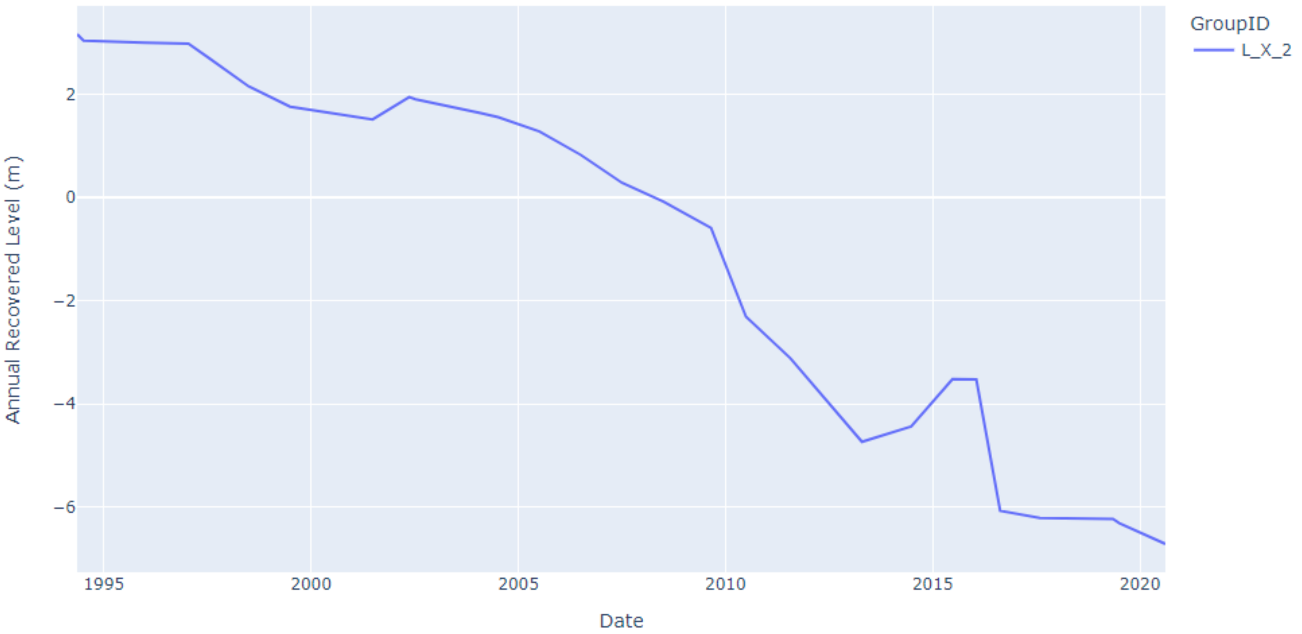


Figure 472 Jan Juc GMA Annual Recovered Level Suite Hydrographs for representative Suites

28.2.2 Pre-development level

To estimate the pre-development level conditions, GHD reviewed the Suite hydrograph of annual recovered levels and assumed that the early time series data was the best representation of conditions prior to major development within Jan Juc GMA for the representative Suite.

The pre-development annual recovered level was taken to be the first reading in the time series data for Suite L_X_2, which occurred in the year 1993/1994 and equates to 3.16 m (refer further details in section 28.4.3).

28.2.3 Externalities

Through the conceptualisation, no external influence was identified for Jan Juc GMA.

28.2.4 Hindcasting

Groundwater use data for Jan Juc GMA is available from 2004/2005 to 2020/2021. The hindcasting methodologies outlined in section 3.3.4.5were applied to Jan Juc GMA. A summary of the hindcasting results is shown in the following sections. It is noted that extraction from Jan Juc GMA is intermittent, with the Anglesea Borefield only being turned on to supplement surface water supply and the Alcoa mine no longer extracting; thus, an association of use to climate is unlikely.

28.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, four different correlations were developed as described below and shown in Figure 473:

- Annual rainfall vs annual groundwater extraction at Jan Juc GMA
- Two yearly average annual rainfall vs annual groundwater extraction at Jan Juc GMA
- Annual summer period rainfall vs annual groundwater extraction at Jan Juc GMA
- Annual irrigation period rainfall vs annual groundwater extraction at Jan Juc GMA

As shown in Figure 473, the goodness-of-fit represented by the R^2 is greatest for annual irrigation rainfall with annual irrigation groundwater use and two yearly average rainfall with annual groundwater use. The correlation decreased when groundwater extraction for the whole GMU was used. Given the result of the correlations for hindcast method H3 in the sections below and that usage for this GMU is not driven by irrigation, the two yearly average annual extraction with annual rainfall has been adopted for hindcast method H1 (i.e., maintaining a consistent type of rainfall across all three methods).

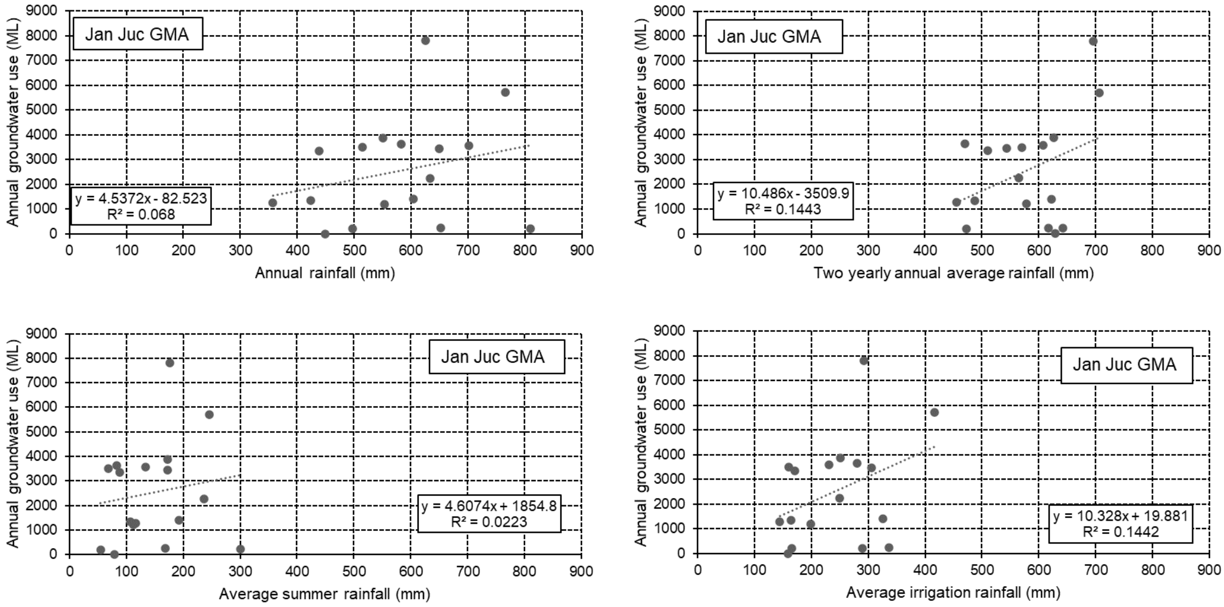
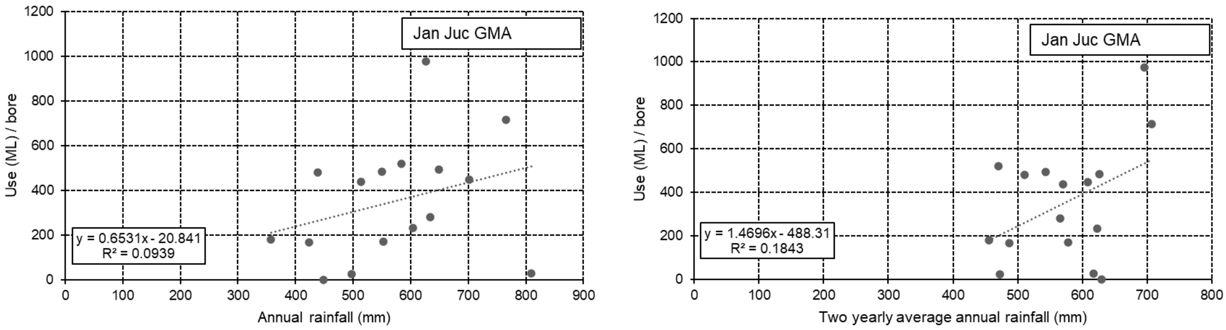


Figure 473 Jan Juc GMA: Hindcast method 1 correlations (Jan Juc GMA annual extraction)

28.2.4.2 Hindcasting Method 2 (H2)

Similar to method H1, eight correlations were developed using method H2 as described below and shown in Figure 474:

- Jan Juc GMA use per Jan Juc GMA bore vs annual rainfall
- Jan Juc GMA use per Jan Juc GMA bore vs two yearly average annual rainfall
- Jan Juc GMA use per Jan Juc GMA bore vs annual summer period rainfall
- Jan Juc GMA use per Jan Juc GMA bore vs annual irrigation period rainfall



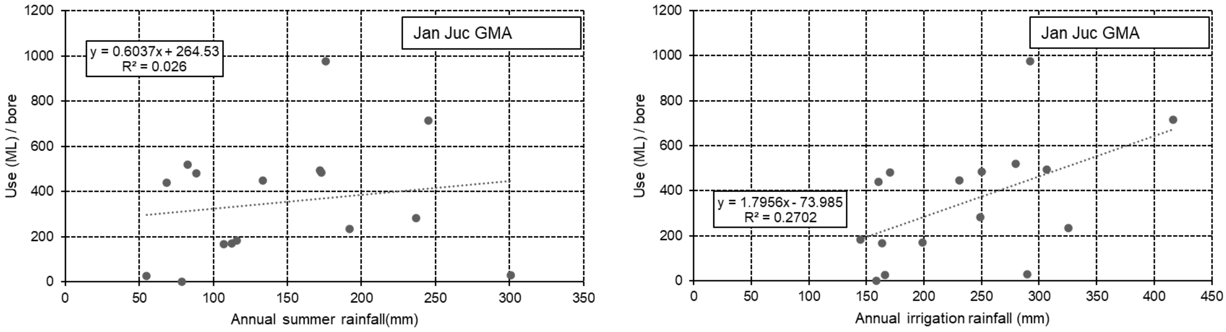


Figure 474 Jan Juc GMA: Hindcast method 2 correlations

As shown in Figure 474, the goodness-of-fit represented by the R^2 is greatest for annual irrigation rainfall with annual groundwater use. The correlation decreased significantly when rainfall was reduced to summer rainfall and when the annual rainfall was adopted. As the GMU is not driven by irrigation use, and to maintain consistency across the three hindcasting methods, the two yearly average annual rainfall with annual groundwater use was modelled for hindcast method H2.

28.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 475:

- Percentage of entitlement vs annual rainfall
- Percentage of entitlement vs two yearly average annual rainfall
- Percentage of entitlement vs annual summer period rainfall
- Percentage of entitlement vs annual irrigation period rainfall

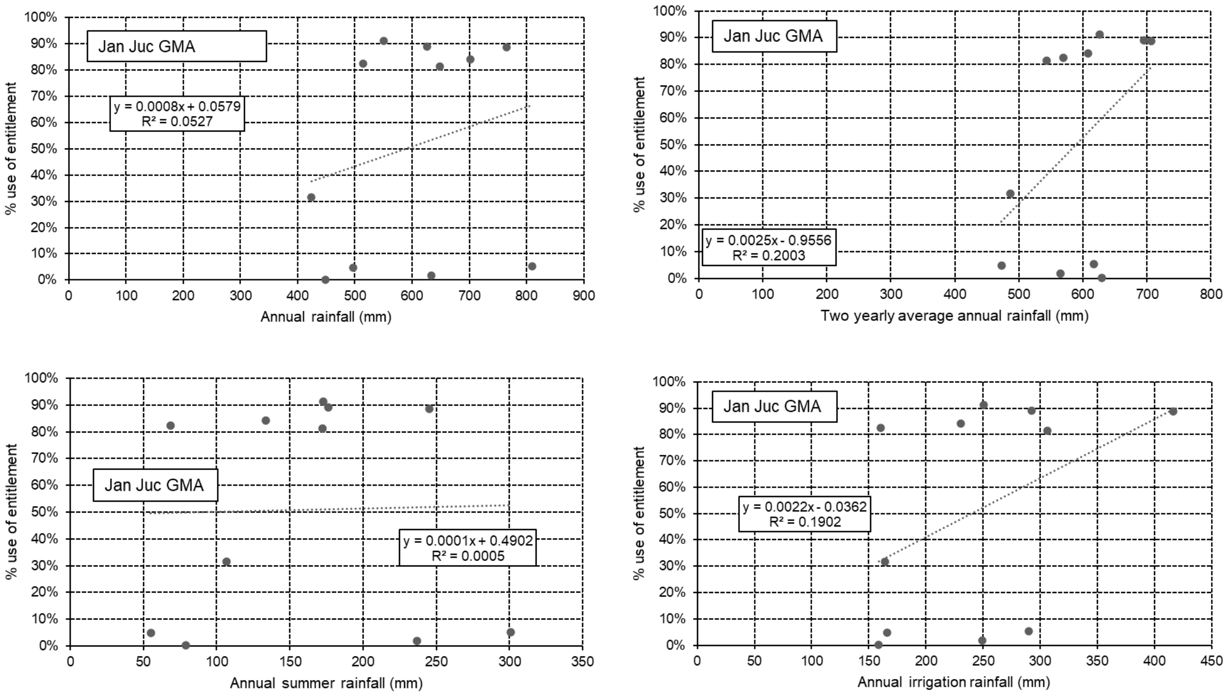


Figure 475 Jan Juc GMA: Hindcast method 3 correlations

As shown in Figure 475 and similar to method H1, the best goodness-of-fit result was obtained through the correlation of two yearly average annual rainfall. Due to this and since groundwater usage in this GMU is not driven by irrigation, two yearly average annual rainfall was the correlation modelled for hindcast method H3.

28.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 476 and Figure 477 for the hindcasting based on Jan Juc GMA groundwater use. Figure 476 shows a comparison of the three hindcasting methods against the recorded use only over the recorded use date and Figure 477 shows the hindcasted data back to 1993/1994.

As shown in Figure 477, groundwater use using method 1 does not decrease historically as there is no factor to account for the changing number of bores extracting over time. A similar effect can be seen in method 3, due to the entitlement being consistent over the period 2009/10 to 2019/20. The hindcasting results show that the smallest average variation of recorded use to estimated use occurs for method 2. Thus, this hindcasting method is expected to provide a more probable estimated groundwater use than the other two methods for Jan Juc GMA.

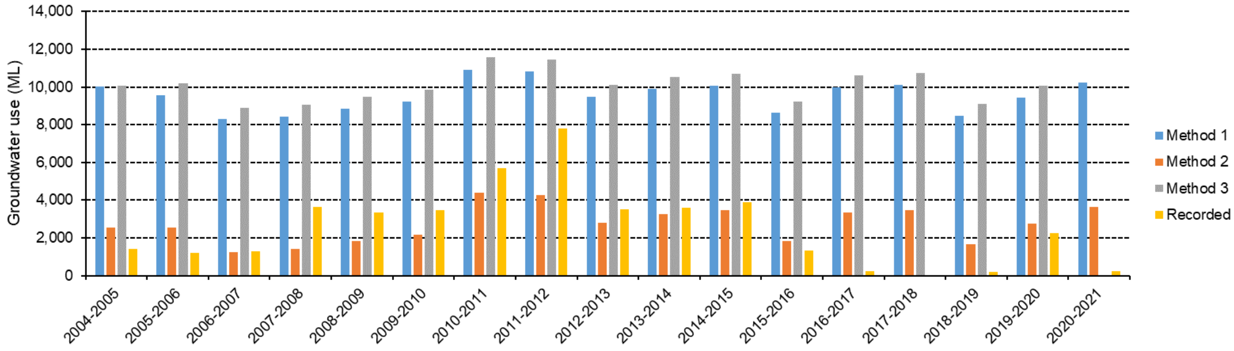


Figure 476 Jan Juc GMA: Comparison of hindcasting over recorded use period

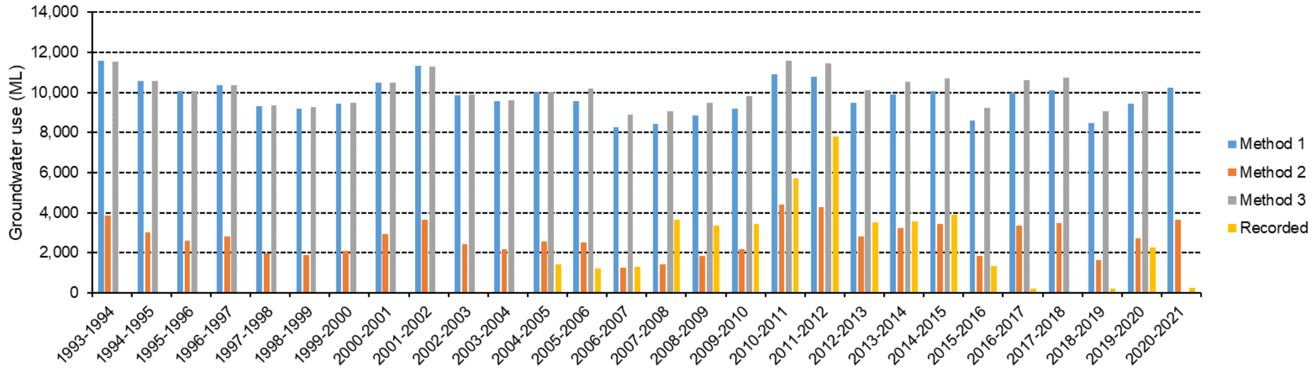


Figure 477 Jan Juc GMA: Comparison of hindcasting

28.3 Modelling

28.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 172 summarises the combinations of model inputs run for Jan Juc GMA. Model runs highlighted blue were run with annual extraction and those highlighted grey were run using two yearly average annual extraction.

Table 172 Jan Juc GMA: summary of model inputs

Model input	Model runs																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Annual recovered levels for representative Suites (L_X_2)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Jan Juc GMA only	✓																		
Two yearly average annual extraction – Jan Juc GMA only		✓																	
Annual extraction – Jan Juc GMA and Externalities			✓																
Two yearly average annual extraction – Jan Juc GMA and Externalities				✓															
H1 annual extraction – Jan Juc GMA only					✓														
H1 annual extraction – Jan Juc GMA and Externalities						✓													
H2 annual extraction – Jan Juc GMA only							✓												
H2 annual extraction – Jan Juc GMA and Externalities								✓											
H3 annual extraction – Jan Juc GMA only									✓										
H1 two yearly average annual extraction – Jan Juc GMA only										✓									
H1 two yearly average annual extraction – Jan Juc GMA and Externalities											✓								

Model input	Model runs																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
H2 two yearly average annual extraction – Jan Juc GMA only												✓							
H2 two yearly average annual extraction – Jan Juc GMA and Externalities													✓						
S1 annual extraction – Jan Juc GMA only														✓					
S2 annual extraction – Jan Juc GMA only															✓				
S3 annual extraction – Jan Juc GMA only																✓			
S1 annual extraction and H1 annual extraction – Jan Juc GMA only																	✓		
S2 annual extraction and H2 annual extraction – Jan Juc GMA only																		✓	
S3 annual extraction and H3 annual extraction – Jan Juc GMA only																			✓

28.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 172 is presented in Table 173 for the selection of potential representative Suites for Jan Juc GMA using the process outlined in section 28.2.1. The statistics summarised include four key statistical measures pf the average 95 PPU thickness (95PPU TH), percentage of observed levels within 95 PPU (%Obs in 95 PPU), R^2 and root mean square error (RMSE) as well as the number of annual recovered level observation points (No obs data points) and the range of observed annual recovered levels.

Suite L_X_2

A review of the results and statistical summary for Suite L_X_2 shows that model runs 7, 12 and 16 (highlighted green) had the best results of the different model input combinations. Model runs 7 and 12 are very similar with the difference being the 95PPU thickness is slightly smaller, the R^2 being slightly higher, and the RMSE being slightly smaller for model run 7. Model run 16 has a smaller 95PPU thickness, higher percentage observations in the 95PPU band, smaller R^2 and larger RMSE value than model run 7. It is also noted that model run 16 applies a spatial distribution method and thus is based on a smaller dataset. A comparison was undertaken of model run 7 with model run 12 and 16. The simulated levels and 95% prediction band limits were plotted for model run 7 along with the simulated levels for model 12 and 16 as shown in Figure 479. This shows that there is very little difference in the estimated simulated levels between model 7 and model 12 and that the dataset for model 16 still falls within the 95% prediction limits of model 7 but has a slightly different hydrograph. To see if model run 7 results could be improved further, climate data was incorporated into the model, however, this did not significantly change the results as shown under 7c in Table 173. Given this, modelling was progressed on the basis of adopting model run 7 for Suite L_X_2. The graphical model output for model run 7 is shown in Figure 478.

Modelling was progressed on the basis of adopting model run 7 for Suite L_X_2.

Table 173 Jan Juc GMA: summary of model outputs

Suite	Statistic	Model run													
		1	2	5	7	7c	9	10	12	14	15	16	17	18	19
L_X_2	95PPU TH	8.72	8.84	9.77	4.22	4.9	9.8	10.22	4.45	5.57	71323.66	3.21	5.28	23.95	23.95
	%Obs in 95 PPU	87.5	93.75	100	92.59	100	100	100	92.59	100	80	100	92.31	100	100
	R^2	87.6	87.6	96.9	97.2	97.5	96.9	96.9	97.0	68.0	69.4	69.6	96.4	96.4	96.4
	RMSE	0.96	0.96	0.6	0.57	0.54	0.6	0.6	0.59	0.8	0.78	0.78	0.62	0.62	0.62
	No obs data points	16	16	27	27	27	27	27	27	10	10	10	26	26	26
	Range of observed levels	8.0	8.0	9.8	9.8	9.8	9.8	9.8	9.8	4.0	4.0	4.0	9.4	9.4	9.4

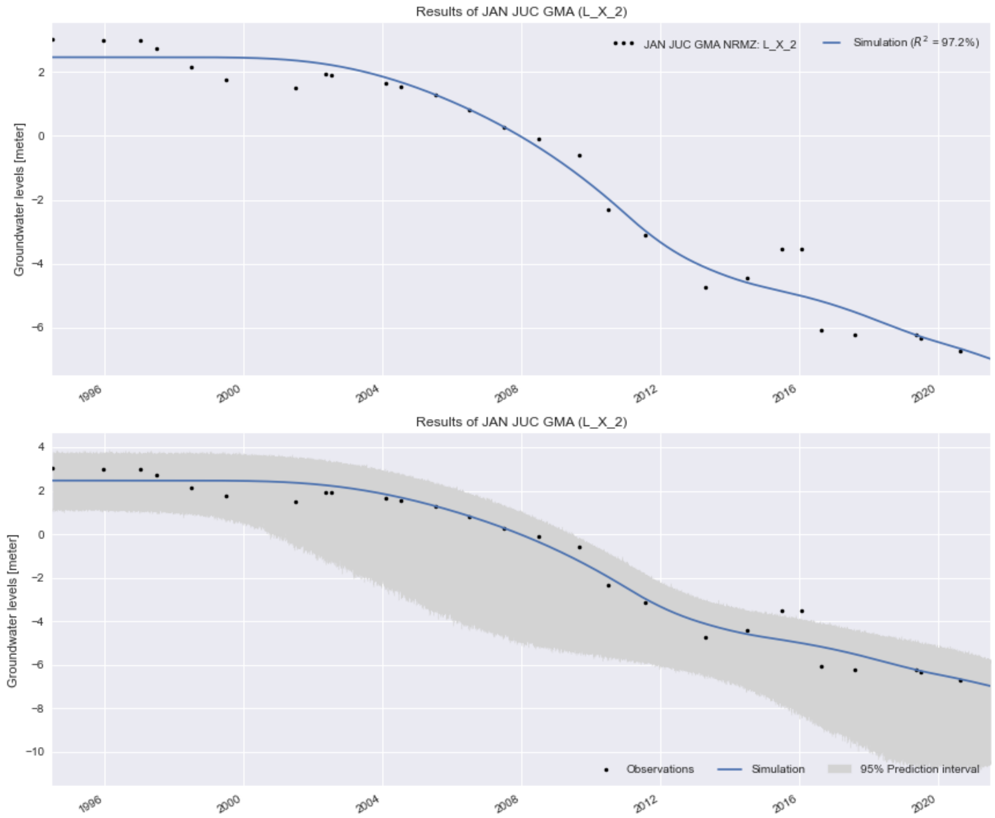


Figure 478 *Jan Juc GMA Suite L_X_2: model run 7 (Jan Juc GMA annual extraction with hindcast method 2) output hydrographs*

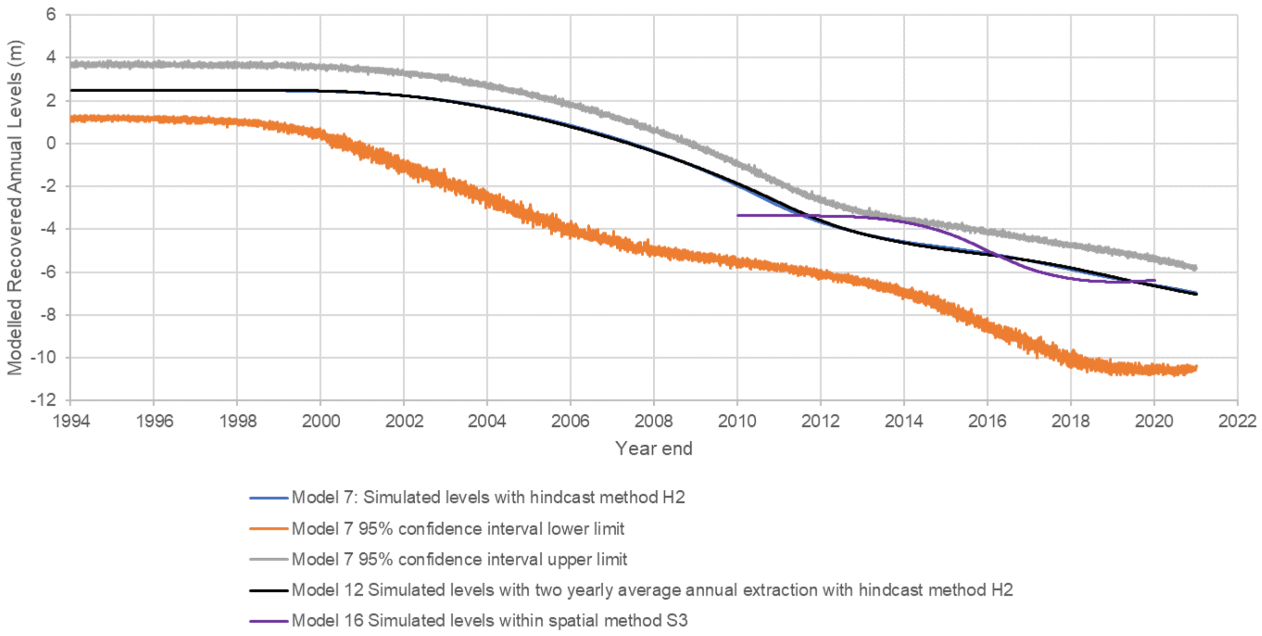


Figure 479 *Jan Juc GMA Suite L_X_2: comparison of model run 7 with model run 12 and 16*

28.4 Predictive modelling

28.4.1 Model inputs

The preferred model to run the predictive modelling for Jan Juc GMA was model run 7 for Suite L_X_2. To conduct the forecasting for the 19 scenarios discussed in section 3.5.3, a few factors were required in the calculations; these factors are summarised in Table 174.

Table 174 Jan Juc GMA: forecast scenario inputs

Input item	PCV	Licenced entitlement (based on 2020/21)	Existing use (based on 2020/2021)	Average use over recorded period (from VWA)	Maximum use over recorded period (from VWA, year 2011/12)
Value (ML/year)	14,250	14,250	245	2,801	7,806

28.4.2 Predictive model uncertainty

The model output files of the predicted models can be found in the data package provided as part of Appendix E.

MCMC predictions were undertaken on each of the forecasted scenarios for Suite L_X_2. An example of one of the outputs is presented in Figure 480 for scenario 4. As shown in Figure 480, the uncertainty of the model prediction increases as the model predicts further into the future. Compared with the graphical output for the same scenario, most of the MCMC realisations tend to fall within the 95% prediction interval bands, however, there are some outliers as shown in Figure 481.

Uncertainty is also accounted for by using 19 forecast scenarios to develop a groundwater use to drawdown relationship (analogous to a Monte Carlo type simulation) where a range of possible outcomes are generated. It is noted however, that the forecast scenarios were not randomly generated, but rather based upon a series of estimated use behaviours.

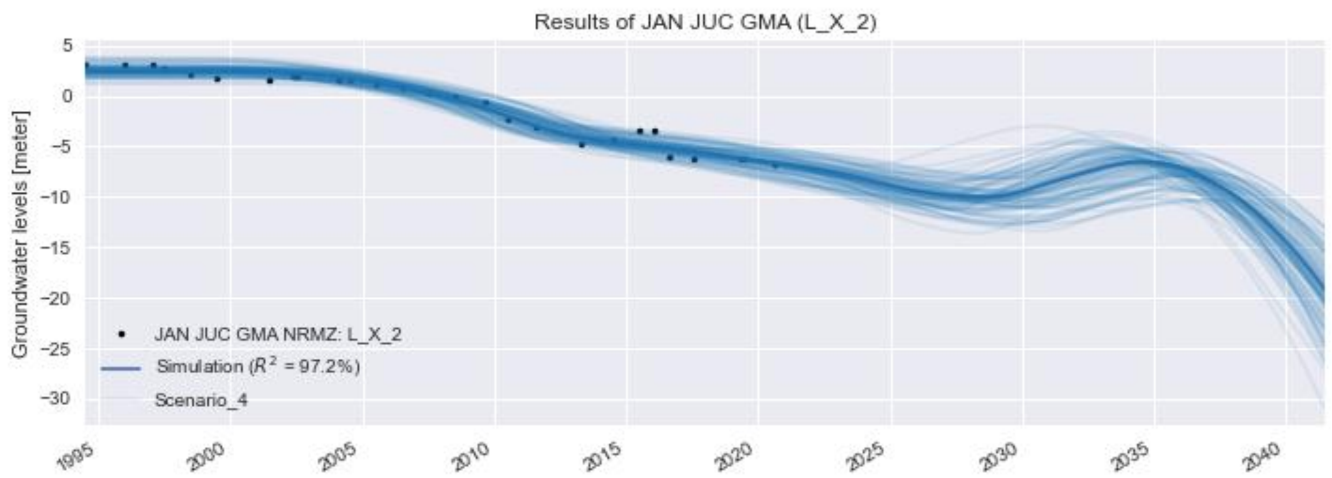


Figure 480 Jan Juc GMA: Suite L_X_2 MCMC analysis for Forecast Scenario 4

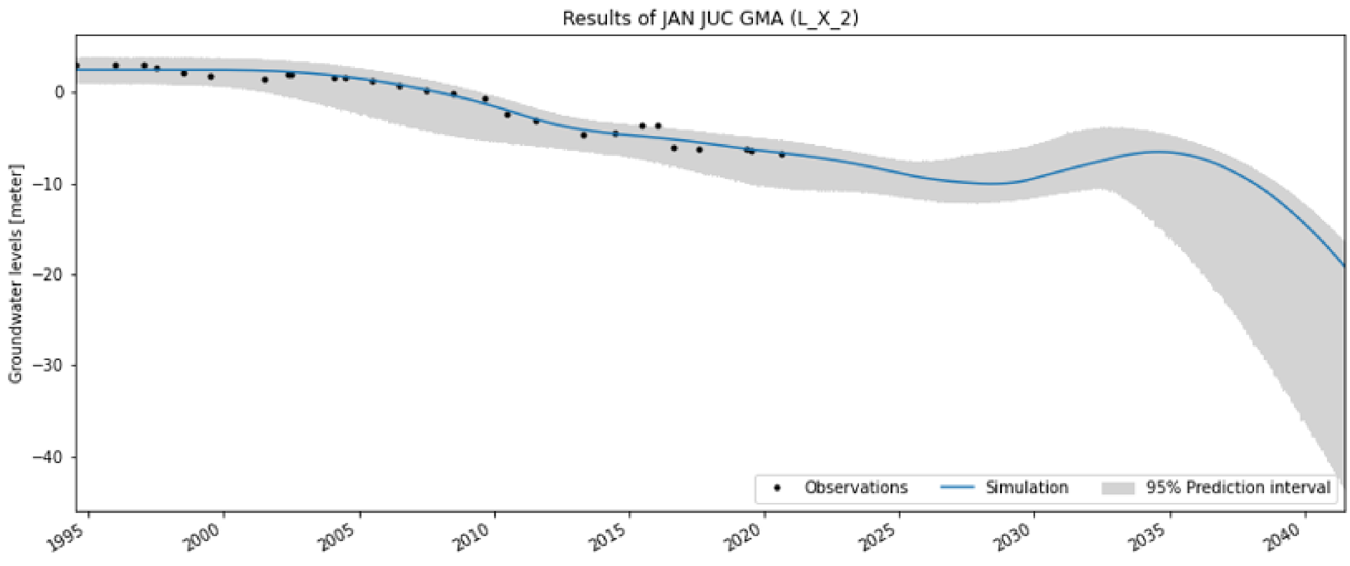


Figure 481 Jan Juc GMA: Suite L_X_2 Forecast Scenario 4 with 95% prediction bands

28.4.3 Extraction vs drawdown

To calculate the drawdown based on the annual recovered levels simulated by the model, the pre-development conditions (pre commencement of extraction) need to be estimated. For Jan Juc GMA, the period of major development is considered to have commenced in the 1960s.

Using the pre-development levels defined in section 28.2.2, the modelled water levels were converted into drawdowns (from this baseline pre-development level) for each of the 19 scenarios. This predevelopment condition is shown in Figure 482 for Suite L_X_2 hydrograph of annual recovered levels. In Figure 482:

- Actual annual groundwater use is represented by the blue column graph between 2004/2005 and 2020/2021
- Hindcasted groundwater use is represented by the orange columns from 1993/1994 to 2004/2005
- Forecasted use is represented by the grey columns after 2021/2022
- The annual recovered water level behaviour based on recorded data is represented by the red line graph
- The pre-development annual recovered levels are taken to be the first reading which was 3.16 m
- The modelled forecasted annual recovered levels are represented by the purple line in Figure 482
- The calibration annual recovered levels are represented by the black line in Figure 482

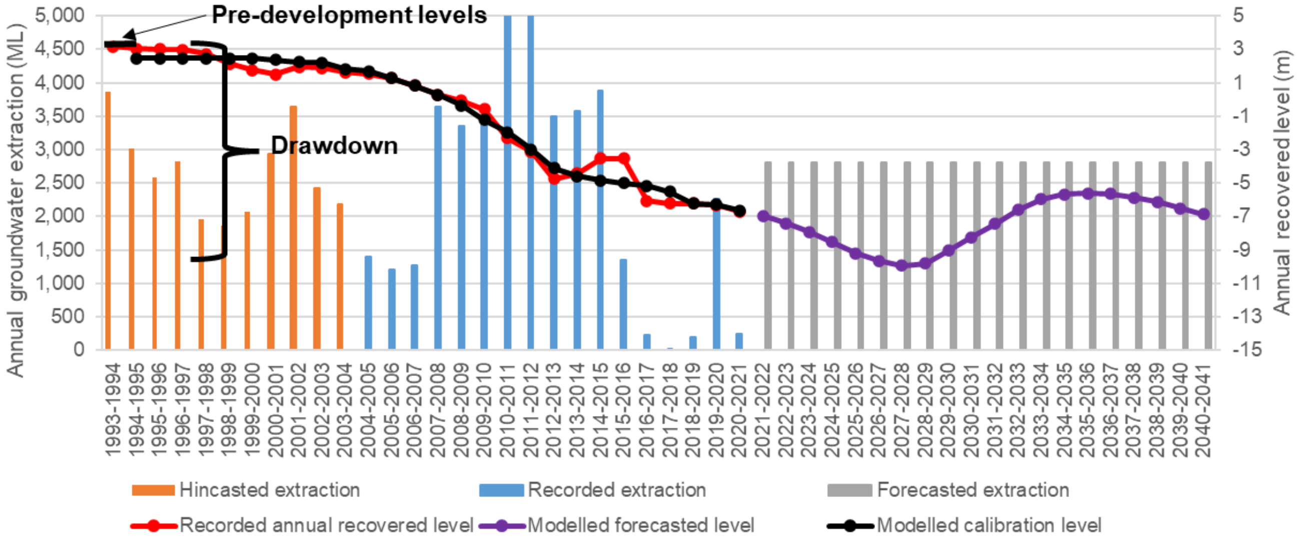


Figure 482 Estimating pre-pumping water levels (example from Suite L_X_2)

For Suite L_X_2, the calculated drawdowns and volumes for each of the scenarios were plotted in individual graphs for each scenario, all scenarios together in the one graph (Figure 483) and a graph of the scenarios for specific time periods (Figure 484) to develop the volume to drawdown relationship. For each scenario, a linear regression was applied and the coefficient of determination (R^2) was calculated. A comparison of each of these graphs shows variations in the coefficient of determination. Given this, the drawdown-use plot of all scenarios was adopted to capture these variations.

The use-drawdown for all the 19 forecast scenario drawdowns and volumes (both the recorded and forecasted volumes) over each year modelled (1995 to 2041) is shown in Figure 483 for Suite L_X_2. Note the abscissa range of the chart has been clipped and does not show forecast drawdowns for the higher use scenarios (more improbable uses of around two times the PCV). Reviewing these figures, the following is noted:

- There should be zero drawdown under zero use and therefore a line of best fit should pass through the origin (0,0) or close to it
- Average use is around 3,000 ML. Figure 483 for Suite L_X_2, indicates that this at this use the model forecast drawdown tends to plot above the predicted line of best fit.
- For the same annual use, different drawdowns can be obtained as Pastas predicts a water level for each year. For example, Figure 482 shows a scenario where groundwater use remains constant at around 3,000 ML/year over the next 20 years
- The correlation for groundwater use and drawdown for Suite L_X_2 is poor as shown in Figure 483.
- The various forecast scenarios generally result in data plotting reasonably close together in a linear trend. The 19 forecast scenarios applied to populate the chart is analogous to a Monte Carlo type simulation where a range of possible outcomes are generated. It is noted however, that the forecast scenarios were not randomly generated, but rather based upon a series of estimated use behaviours.

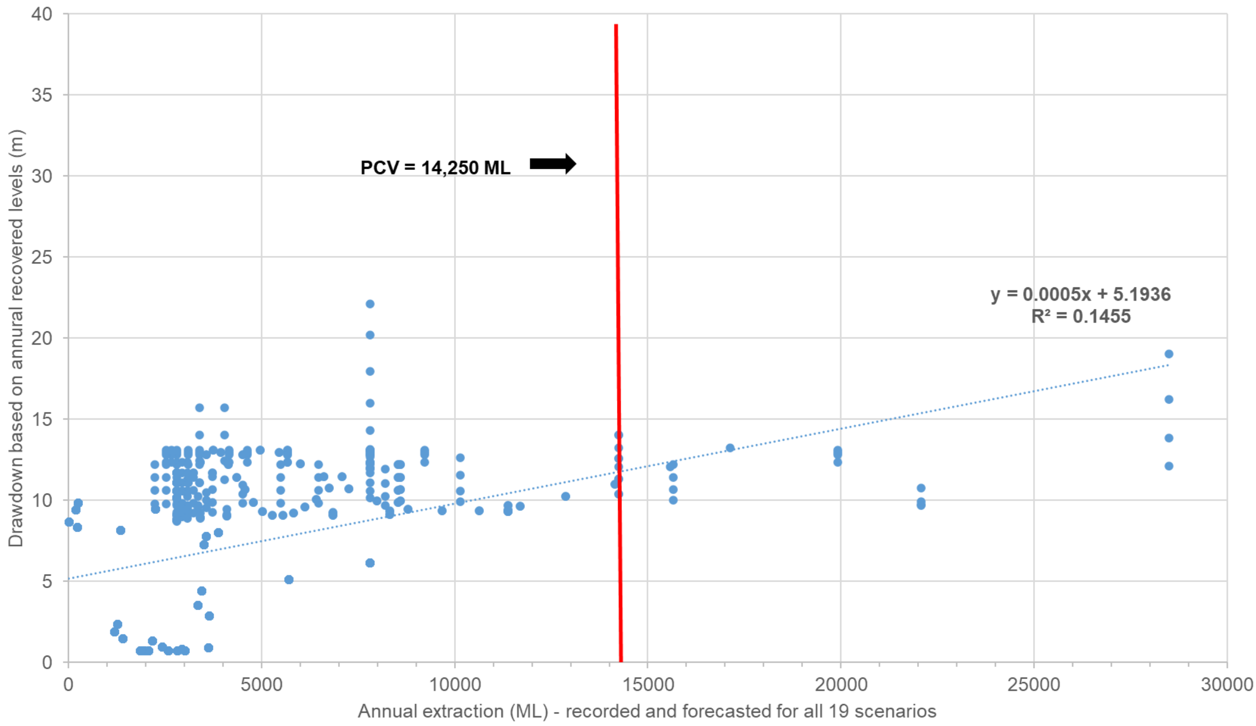


Figure 483 *Jan Juc GMA Suite L_X_2: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <30,000 ML) for all data between 1995 to 2041 and all forecasted scenarios*

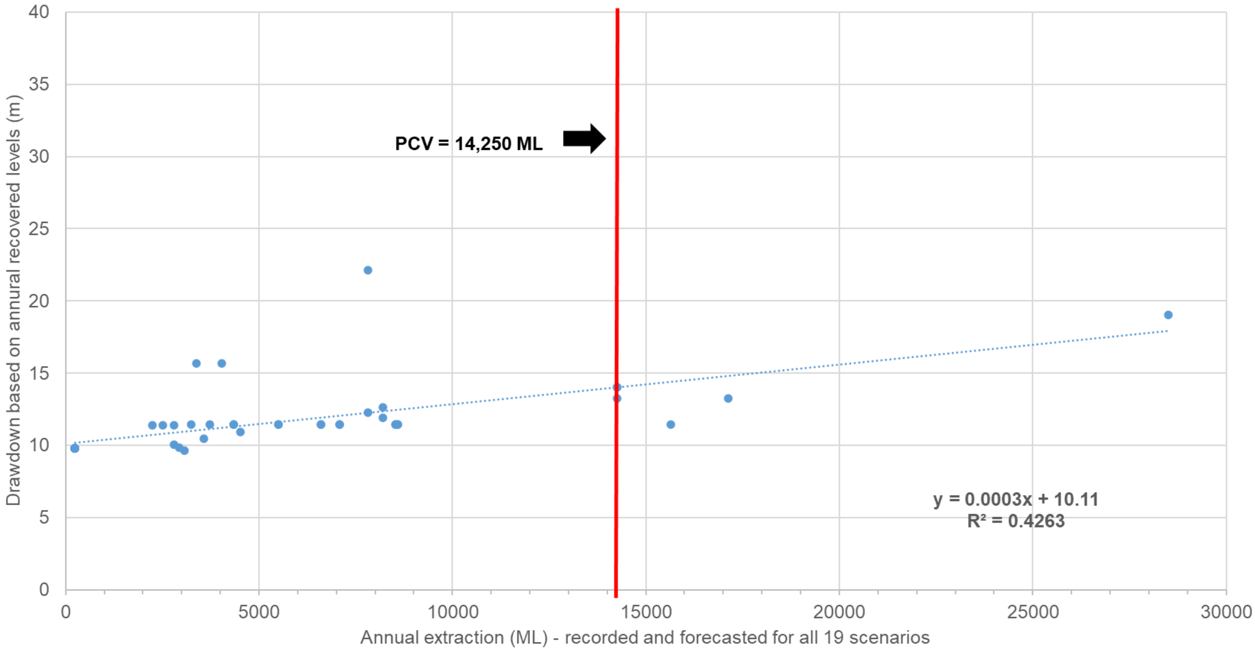


Figure 484 *Jan Juc GMA Suite L_X_2: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <30,000 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

28.5 Sustainability metrics

28.5.1 Application of metrics

Using the use - drawdown relationships developed through the previous step of forecasting aquifer response under a range of use scenarios, groundwater drawdown can be used to compare against groundwater resource sustainability metrics.

The application of these metrics and the relationship developed between drawdown based on the Suite annual recovered levels and extraction volume for the whole GMU, which is shown in Table 175 for Jan Juc GMA Suite L_X_2 (noting Jan Juc GMA has a current PCV of 14,250 ML/year). As part of the modelling, a 95% prediction interval band was applied to the modelling results. The relationship between drawdown and extraction volumes can also be interrogated at the lower and upper bands of the 95% prediction interval as shown in Table 175 and Figure 485 for Suite L_X_2.

A summary of volumes at drawdown intervals provided by DEECA for Suite L_X_2 is shown in Table 176. Based on this, it is predicted that 5 m drawdown could occur from an annual groundwater extraction volume of -400 ML (this could range from -2,700 to 2,700 ML) and that 10 m drawdown could occur from an annual groundwater extraction volume of 9,600 ML (this could range from 3,500 to 15,200 ML).

Table 175 Relationship of Suite drawdown to GMU extraction for Jan Juc GMA Suite L_X_2

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_X_2 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
30,000	20.2 (15.9 - 31.2)
28,000	19.2 (15.1 - 29.6)
26,000	18.2 (14.3 - 28)
24,000	17.2 (13.5 - 26.4)
22,000	16.2 (12.7 - 24.8)
20,000	15.2 (11.9 - 23.2)
18,000	14.2 (11.1 - 21.6)
16,000	13.2 (10.3 - 20)
14,000	12.2 (9.5 - 18.4)
12,000	11.2 (8.7 - 16.8)
10,000	10.2 (7.9 - 15.2)
8,000	9.2 (7.1 - 13.6)
6,000	8.2 (6.3 - 12)
4,000	7.2 (5.5 - 10.4)
2,000	6.2 (4.7 - 8.8)
0	5.2 (3.9 - 7.2)

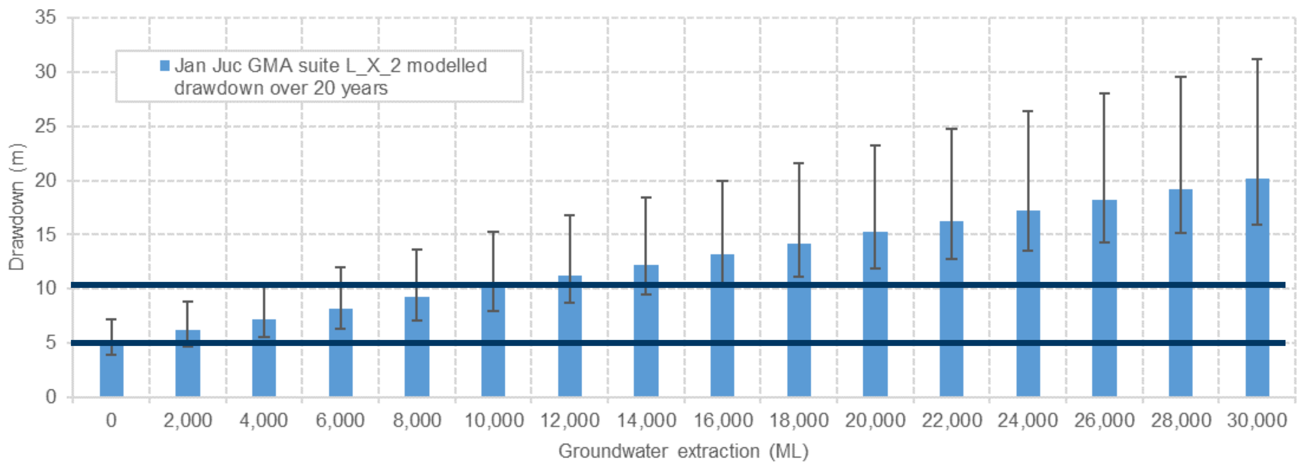
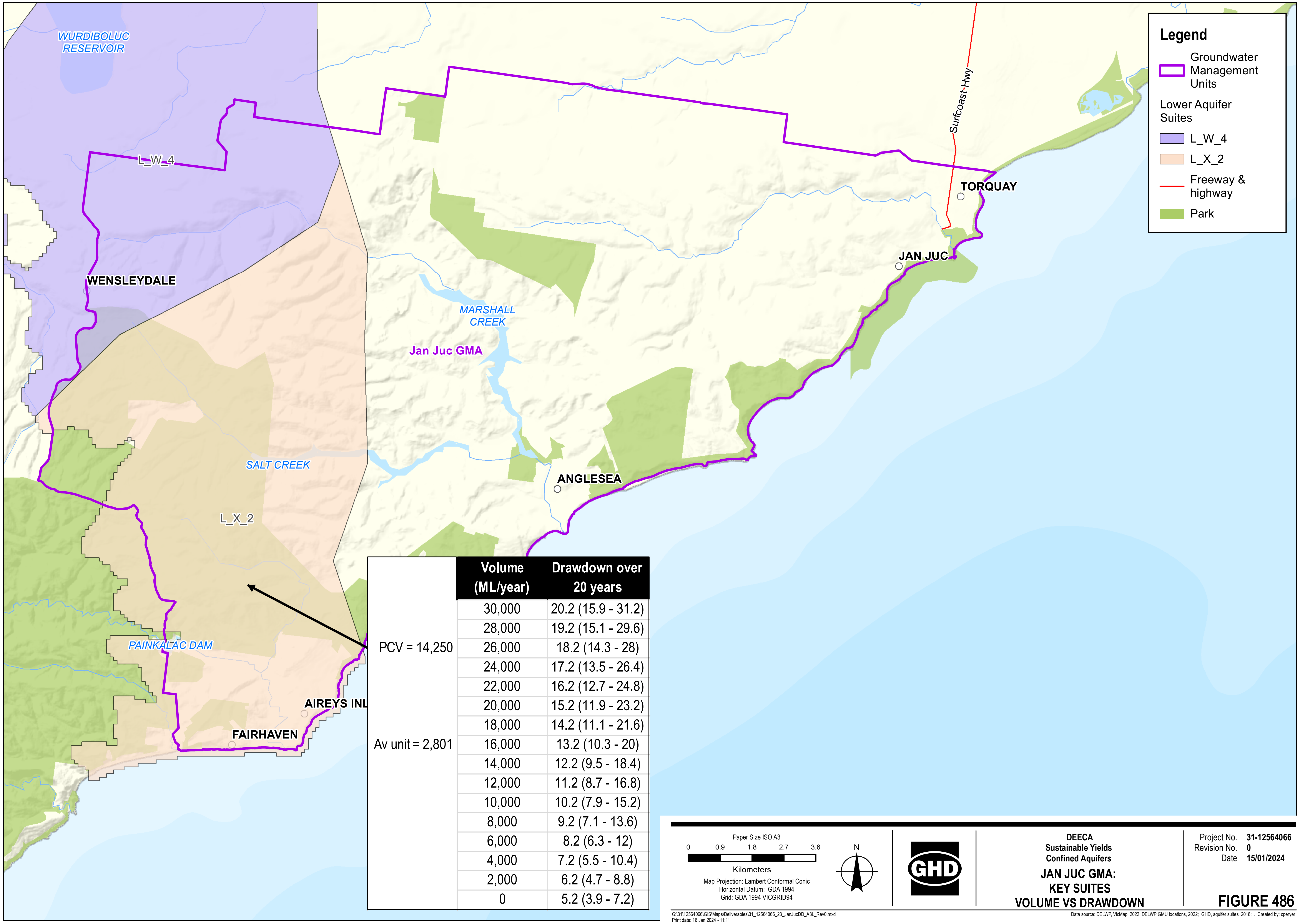


Figure 485 Jan Juc GMA Suite L_X_2: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 176 Predicted volumes for drawdown metrics

Drawdown (m) confined aquifer	Predicted volumes (ML) for GMU based on Suite L_X_2 drawdowns (lower limit to upper limit)
5	-400 (-2,700 – 2,700)
10	9,600 (3,500 – 15,200)



	Volume (ML/year)	Drawdown over 20 years
	30,000	20.2 (15.9 - 31.2)
	28,000	19.2 (15.1 - 29.6)
PCV = 14,250	26,000	18.2 (14.3 - 28)
	24,000	17.2 (13.5 - 26.4)
	22,000	16.2 (12.7 - 24.8)
	20,000	15.2 (11.9 - 23.2)
	18,000	14.2 (11.1 - 21.6)
Av unit = 2,801	16,000	13.2 (10.3 - 20)
	14,000	12.2 (9.5 - 18.4)
	12,000	11.2 (8.7 - 16.8)
	10,000	10.2 (7.9 - 15.2)
	8,000	9.2 (7.1 - 13.6)
	6,000	8.2 (6.3 - 12)
	4,000	7.2 (5.5 - 10.4)
	2,000	6.2 (4.7 - 8.8)
	0	5.2 (3.9 - 7.2)

Paper Size ISO A3
0 0.9 1.8 2.7 3.6
Kilometers
Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 VICGRID94

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GHD

DEECA
Sustainable Yields
Confined Aquifers

JAN JUC GMA:
KEY SUITES
VOLUME VS DRAWDOWN

Project No. 31-12564066
Revision No. 0
Date 15/01/2024

FIGURE 486

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Data source: DELWP, VicMap, 2022; DELWP GMU locations, 2022; GHD, aquifer suites, 2018; . Created by: cperyer

28.6 GMU summary

28.6.1 Findings

Jan Juc GMA primarily relates to the Eastern View Formation aquifer (LTA), where groundwater has predominately been extracted for municipal and mining purposes. The LTA falls within the Lower Aquifer Suites, which at Jan Juc GMA comprise Suites L_W_4 (10%) and L_X_2 (30%) providing a total GMU coverage of 40%. There were no identified representative Suites at the commencement of this study, so both Lower Aquifer Suites were incorporated to this study. The Suite hydrograph for Suite L_X_2 showed an overall decreasing trend with seasonal fluctuation and thus recovered water levels, which were adopted for the assessment. Suite L_W_4 did not show any drawdown response to extraction and thus was excluded from the assessment.

Application of two yearly annual average extraction, instead of annual extraction, generally showed a poorer model fit based on the statistical analysis across the model runs. The incorporation of hindcasting generally improved the model fit and the application of spatial distribution produced a poorer model fit compared to model run 1. The quality of the spatial distribution results reduced when spatial distribution methodology was combined with hindcasting methodology.

Based on an assessment of all model runs, the model run 7 of annual extraction with hindcasting method H2 applied was adopted to undertake the predictive modelling for Suite L_X_2.

The pre-development levels were defined for Suite L_X_2 based on the early time series Suite data for the annual recovered levels; this resulted in pre-development levels of 3.16 m. The drawdowns were calculated based on these pre-development levels and the simulated levels from each of the 19 forecast scenarios.

Suite L_X_2 has been taken as the representative Suite for Jan Juc GMA. The volumes estimated for a given drawdown for each Suite is shown below.

Drawdown (m) confined aquifer	Predicted volumes (ML) for GMU based on Suite L_X_2 drawdowns (lower limit to upper limit)
5	-400 (-2,700 – 2,700)
10	9,600 (3,500 – 15,200)

The model applicability using Suite L_X_2 was assessed as having a “Moderate” model applicability rating using the criteria outlined in section 5.2. Although the calibration model showed good statistical results for the selected model. This did not convert over to the use-drawdown relationship, this might be due to the recovery dataset included in the calibration model but even when this information was excluded from the use-drawdown relationship, it still yielded a low correlation and overestimated drawdown at low extraction rates. It’s noted that this Suite does not occur in the main area of extraction in this GMU which may contribute to this result.

28.6.2 Limitations

In addition to the limitations applicable to all 25 GMUs discussed in section 1.8, the following Jan Juc GMA specific limitations have been identified:

- The licenced bore dataset provided by DEECA has 11% of bores assigned to Jan Juc GMA with no depth data and thus couldn’t be assigned to a VAF layer and in turn Suite. These bores were assigned to an aquifer through this study by GHD, in order to assist with the determination of the representative Suite. However, this data was not used in the model analysis.
- The Lower Aquifer Suites in Jan Juc GMA do not cover the main area of extraction in the GMU and therefore may not represent groundwater levels within this area
- The suite method falls down for Jan Juc GMA for two key reasons:
  - The SOBN coverage is not enough and misses main extraction zone
  - In this case the LTA consist of two distinct aquifer system, and the Suite is only for the lower system but extraction from both is being used for calibration

28.6.3 Recommendations

In addition to the recommendations applicable to all 25 GMUs discussed in section 32, the following Jan Juc GMA specific recommendations have been identified:

- The licenced bore dataset provided by DEECA has 11% of bores assigned to Jan Juc GMA with no depth data and thus couldn’t be assigned to a VAF layer and in turn Suite. It is recommended that DEECA obtains the relevant depth and aquifer monitored data for licenced bores within this GMU.
- The suites used for Jan Juc GMA are updated/revised as they generally do not appear to be representing regional groundwater level/extraction trends, particularly over the last 5 years

29. Newlingrook GMA

29.1 Conceptualisation

The hydrogeological conceptualisation elements relevant to this study are summarised in Table 177 and a map of the GMU is presented in Figure 487. It is noted that a significant volume of information was collated to inform the hydrogeological conceptual understanding of the GMU. The information that is directly relevant to the modelling are in bold or colour coded within Table 177.

Table 177 Newlingrook GMA – Tabulated conceptualisation

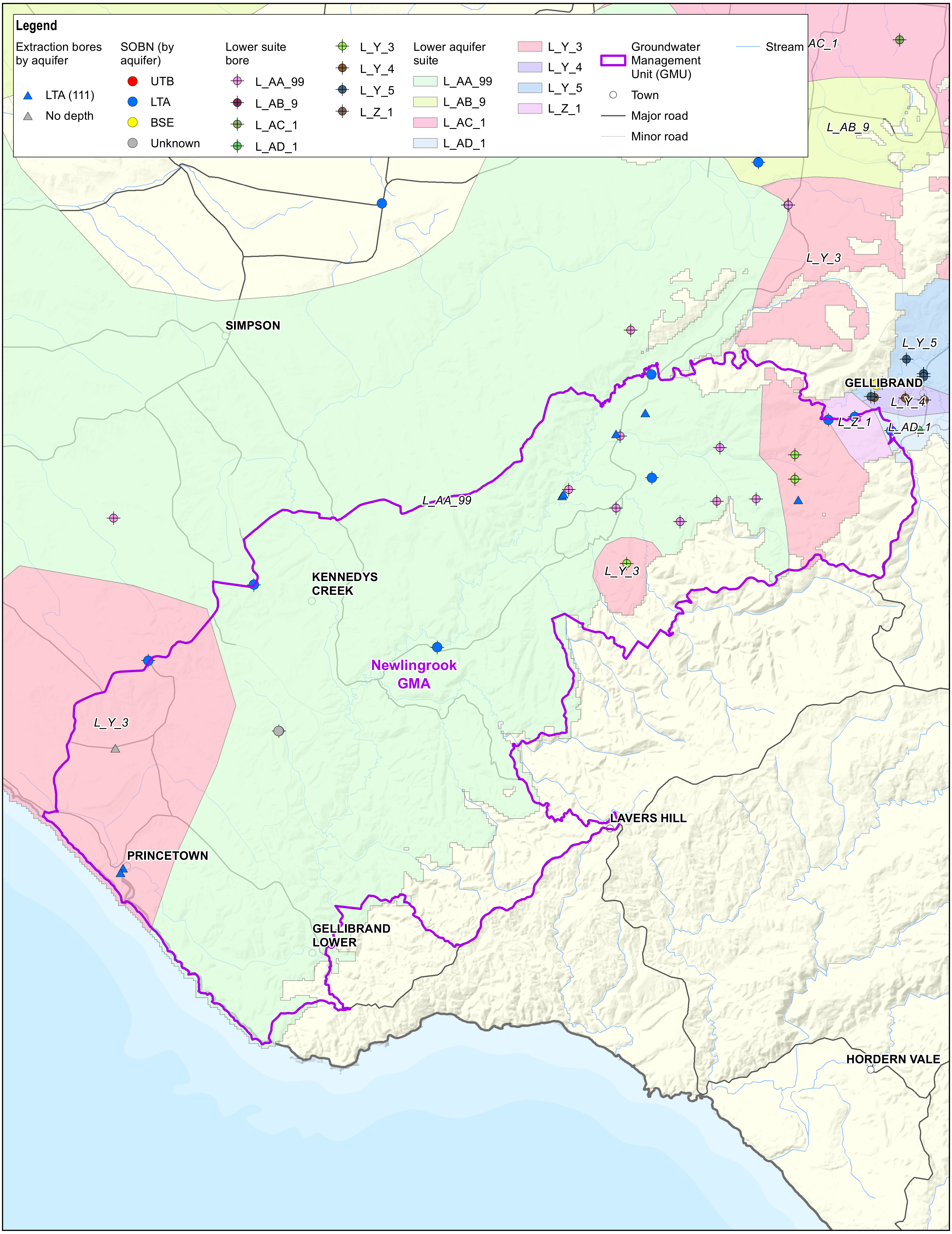
GMU summary
Newlingrook GMA is situated in southwestern Victoria east of Port Campbell, covering an area of 448 km^2. The GMA is bound in the east and northwest by outcropping basement rock, in the northeast by the Gellibrand Saddle, the south by Bass Strait and the Princetown syncline-Ferguson Hill anticline basement feature in the west. Newlingrook GMA pertains to all formations below the ground surface but was intended to primarily manage the groundwater resource of the Pebble Point Formation (Lower Tertiary Aquifer, LTA). The PCV (1,977 ML/year) primarily relates to confined and unconfined aquifers (ie transitional) as the aquifer outcrops in the northwest and east and becomes deeper to the south. Groundwater in the GMA is extracted predominately for urban supply (Wannon Water use it for drought security purposes). Newlingrook GMA has a high urban use compared to other Victorian GMUs. Previous studies (GHD 2006) identified baseflow to the Gellibrand River is likely occurring and thus location and aquifer of extraction will influence the impact to baseflow.

Hydrostratigraphy summary

Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Use volumes ML (2019/20)	Entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Bridgewater Formation (QA)	U_AX_1 (21%)	21%	0	NA	0	0	Low
	Hanson Plain Sand (UTAM)	M_Y_1 (22%),	22%	0	NA	0	0	Low
Middle	Port Campbell Limestone (UMTA)	M_X_3 (1%)	1%	0	NA	0	0	Low
	Gellibrand Marl (UMTD)	-	-	0	NA	0	0	Low
Lower	Clifton Formation (LMTA)	-	-	0	NA	0	0	Low
	Narrawaturk Marl (LMTD)	-	-	0	NA	0	0	Low
	Pebble Point Formation (Dilwyn Formation) (LTA)	L_AA_99 (68%), L_AD_1 (0.2%), L_Y_3 (18%), L_Z_1 (0.8%)	87%	6	Urban, industrial, domestic, stock, dairy	4	1,927	Medium
	Older Volcanics (LTB)	-	-	0	NA	0	0	Low
Basement	Cretaceous and Permian Sediments (CPS)	-	-	0	NA	0	0	Low
	Basement rocks (BSE)	B_X_1 (1%), B_X_3 (31%),	32%	0	NA	0	0	Low

Note that volumes listed above are based on the DEECA provided licenced bore dataset with associated VAF layers. Bores have been assigned to a VAF layer based on bore depth where available. Note that volumes listed above do not include 8 ML of unassigned use due to unknown depths (21 ML of entitlement) and 3 ML assigned to UTQA (10 ML of entitlement) which does not occur within this GMU. There is one SOBN that monitors unknown formations that is not included in the above table.		
Characteristic & importance	**Description**	**Degree of understanding**
Intended aquifer (LTA, highlighted blue above)		
Aquifer thickness within GMU (range, based on VAF)	Max: 593 m, Average: 167 m	High
Aquifer extent	Extensive, regional	High
Likelihood of inter-aquifer flow	Medium	Low
Likelihood of groundwater – surface water interaction	Medium	Low
Representative Suite	**L_AA_99**	**Medium. 56% of GMU extraction occurs within this Suite, which relates to the most relevant GMU aquifer.**
Current hydrological condition of representative aquifer		
Representative Suite trend	Decreasing	High
Groundwater quality (average salinity based on WMIS and CDM Smith spatial segment(s) with highest coverage)	777 mg/L (WMIS) 0 – 600 mg/L (CDM Smith, 2022)	Low -little data available Based on WMIS and CDM Smith (2022)
Groundwater yield	5 – 50 L/s	Low Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1974-2021**	**High**
Spatial clustering of licensed bores in relation to Suites	No	Based on DEECA density mapping and licenced bore data.
Groundwater use		
Licensed groundwater use	**145 ML**	**High (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	8 ML	High (Based on historical VWA data, year 2010/11)
Maximum historic groundwater use	**738 ML**	**High (Based on historical VWA data, year 2014/15)**
Entitlement (Groundwater allocation)	**1,958 ML**	**High (Based on licenced volumes in 2020/21)**
Significant drivers of groundwater level variability (primary)	**Pumping for town water supply**	**Moderate**

Secondary drivers of groundwater level variability	Pumping for stock or domestic use	Moderate
Groundwater use profile	No clear distribution as pumping is to supplement the supply from surface water systems	Low
External Influence	**None identified**	
Groundwater values and risks		
Existing Environmental Values to be protected, relevant to this GMU	Potable water supply Licensed non-potable supply (irrigation, commercial, industrial) Unlicensed non-potable supply (domestic and stock)	
Risks to groundwater values	Direct risks: – Drawdown which may affect access to groundwater by existing users	
Indicators used to assess impacts to groundwater	– Measured drawdown using pre-determined metrics measured from a pre-determined level for the purpose of this modelling	



Paper Size ISO A3

0 1 2 3 4

Kilometers

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 VICGRID94

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DEECA
Sustainable yield review - confined aquifers

Newlingrook GMA
Site location and key features

Project No. 12564066
Revision No. 0
Date 16/01/2024

Figure 487

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Print date: 16 Jan 2024 - 12:41

Data source: DELWP, VicMap, 2022; DELWP, GMUs, 2022; DELWP, SOBN, 2022; GHD, aquifer suites, 2018; DELWP, extraction bores, 2022 Created by: cperyer

29.2 Technical analysis

29.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the relevant Suites for Newlingrook GMA as shown in Figure 488 and Figure 489. Generally, the Suite hydrographs show a trend of seasonal fluctuations and thus annual recovered levels, except Suite L_Y_3 which shows historical highs prior to the 1990s.

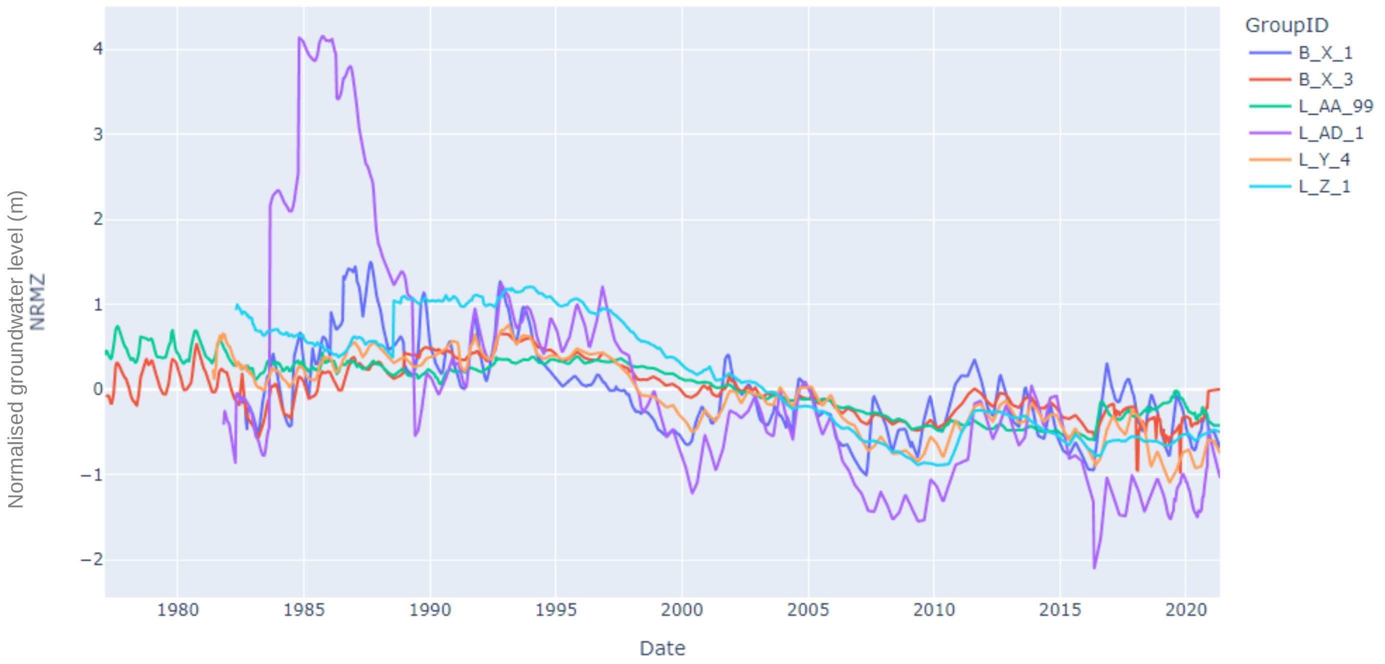


Figure 488 Newlingrook GMA Suite Hydrographs for all confined aquifers (except L_Y_3)

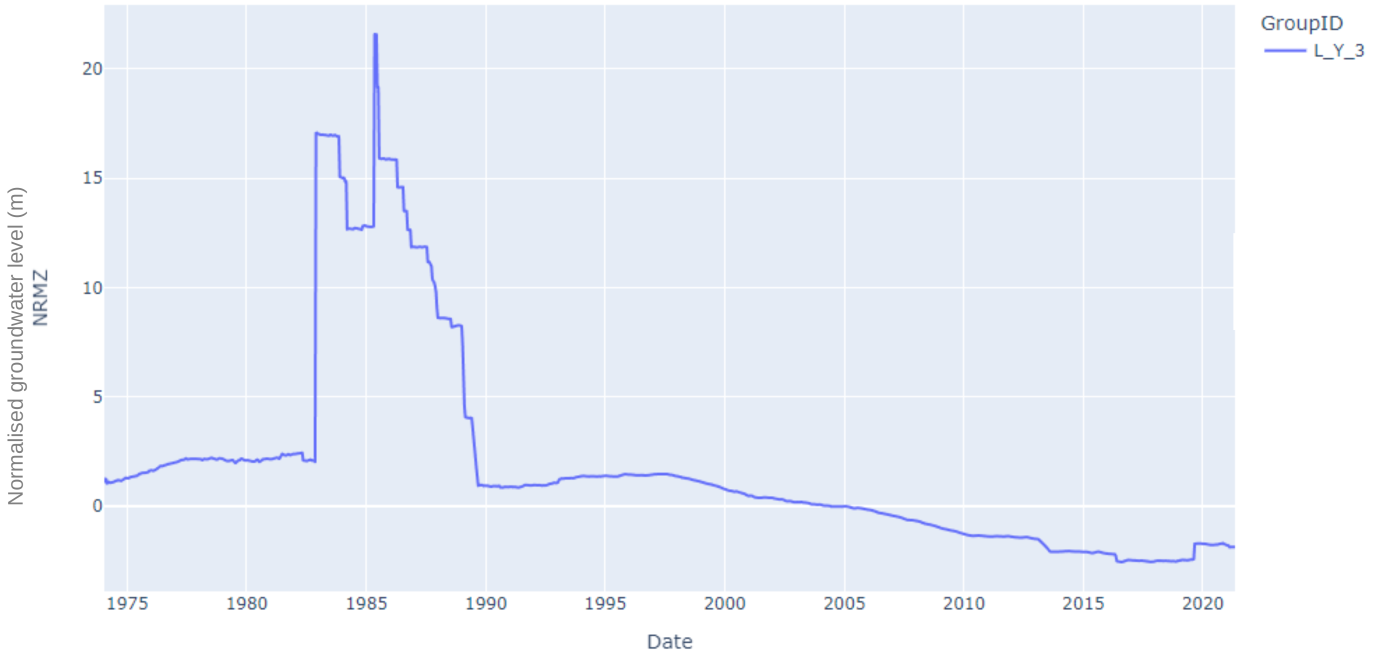


Figure 489 Newlingrook GMA Suite Hydrographs for L_Y_3

The representative Suite analysed for this GMU was Suite L_AA_99. This representative Suite was selected following the methodology outlined in section 2.6.4 and summarised as follows:

– The greatest volume of extraction occurs within the Lower Aquifer
– The Lower Aquifer pertains to the LTA, which is the intended aquifer of the GMU
– Suite L_AA_99 covers 68% of the GMU, while Suite L_AD_1 covers 0.2%, Suite L_Y_3 covers 18% and Suite L_Z_1 covers 0.8%, providing a total coverage of 87%
– Suite L_AA_99 has three active SOBN bores within the Suite area (two of these are within Newlingrook GMA), while Suite L_Y_3 has one
– Some of the Suite bores for L_AA_99 are close to extraction points

The annual recovered Suite hydrographs for representative Suite L_AA_99 for Newlingrook GMA, is shown in Figure 490.

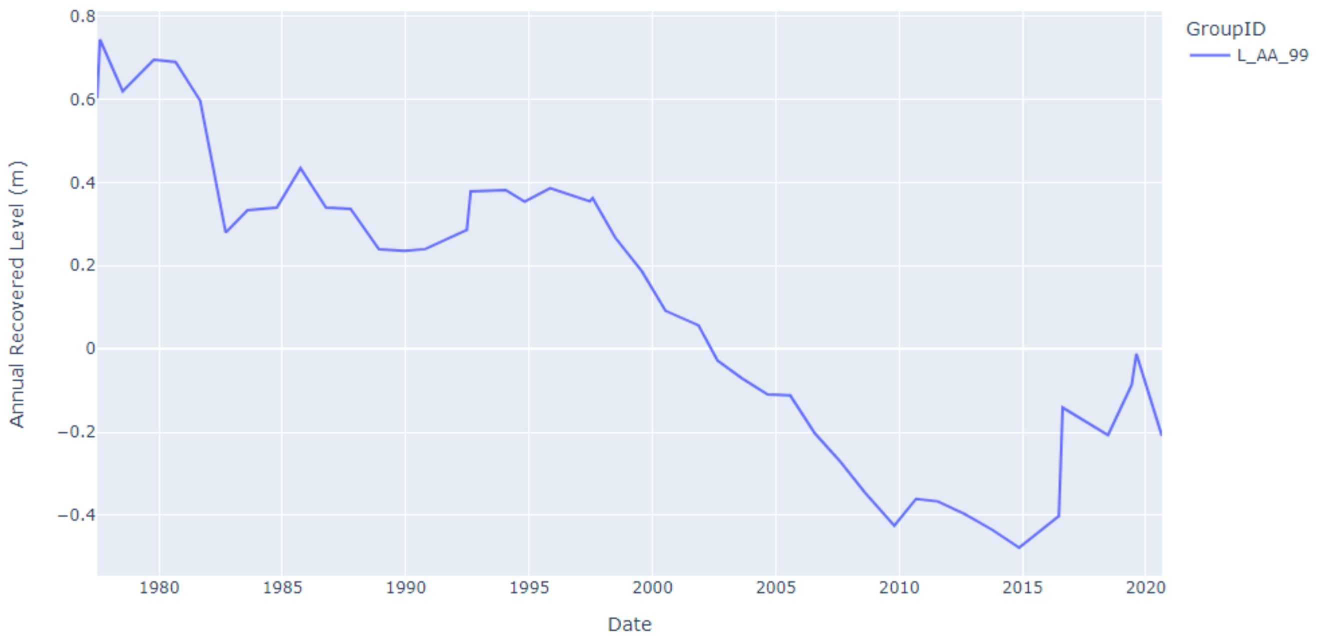


Figure 490 ***Newlingrook GMA Annual Recovered Level Suite Hydrographs for representative Suites***

29.2.2 Pre-development level

To estimate the pre-development level conditions, GHD reviewed the Suite hydrograph of annual recovered levels and assumed that the early time series data was the best representation of conditions prior to major development within Newlingrook GMA for the representative Suite.

The pre-development annual recovered level was taken to be the average of the first six readings in the time series data for Suite L_AA_99, which occur over the years 1976/1977 to 1981/1982 and equates to 0.66 m(refer further details in section 29.4.3).

29.2.3 Externalities

Through the conceptualisation, no external influence was identified for Newlingrook GMA.

29.2.4 Hindcasting

Groundwater use data for Newlingrook GMA is available from 2006/2007 to 2020/2021. The hindcasting methodologies outlined in section 3.3.4.5 were applied to Newlingrook GMA. A summary of the hindcasting results is shown in the following sections. It is noted that as groundwater use in Newlingrook GMA is driven by how much water is needed to supplement surface water supply, the relationship may not be linked to climate. However, for completion and to test this assumption, the hindcasting method have been applied.

29.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, four different correlations were developed using the annual groundwater extraction as described below and shown in Figure 491:

- Annual rainfall vs annual groundwater extraction at Newlingrook GMA
- Two yearly average annual rainfall vs annual groundwater extraction at Newlingrook GMA
- Annual summer period rainfall vs annual groundwater extraction at Newlingrook GMA
- Annual irrigation period rainfall vs annual groundwater extraction at Newlingrook GMA

As shown in Figure 491, the goodness-of-fit represented by the R^2 is greatest for the two yearly average annual rainfall with annual groundwater use; this has been adopted for hindcast method H1.

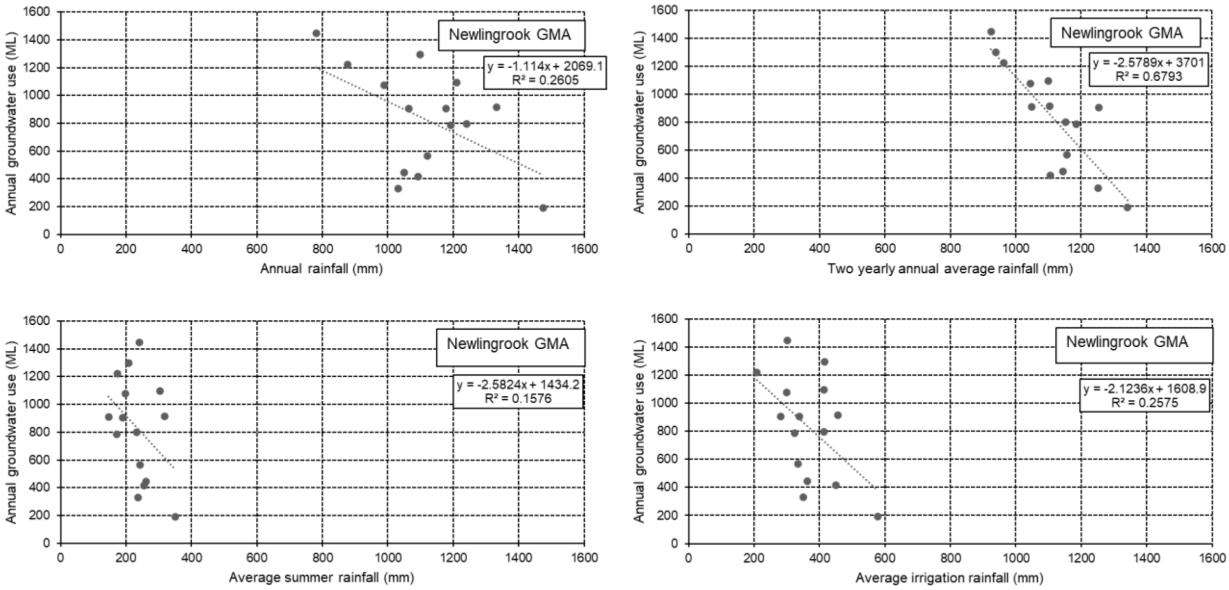


Figure 491 Newlingrook GMA: Hindcast method 1 correlations (Newlingrook GMA annual extraction)

29.2.4.2 Hindcasting Method 2 (H2)

Similar to method H1, four correlations were developed using method H2 as described below and shown in Figure 492:

- Newlingrook GMA use per Newlingrook GMA bore vs annual rainfall
- Newlingrook GMA use per Newlingrook GMA bore vs two yearly average annual rainfall
- Newlingrook GMA use per Newlingrook GMA bore vs annual summer period rainfall
- Newlingrook GMA use per Newlingrook GMA bore vs annual irrigation period rainfall

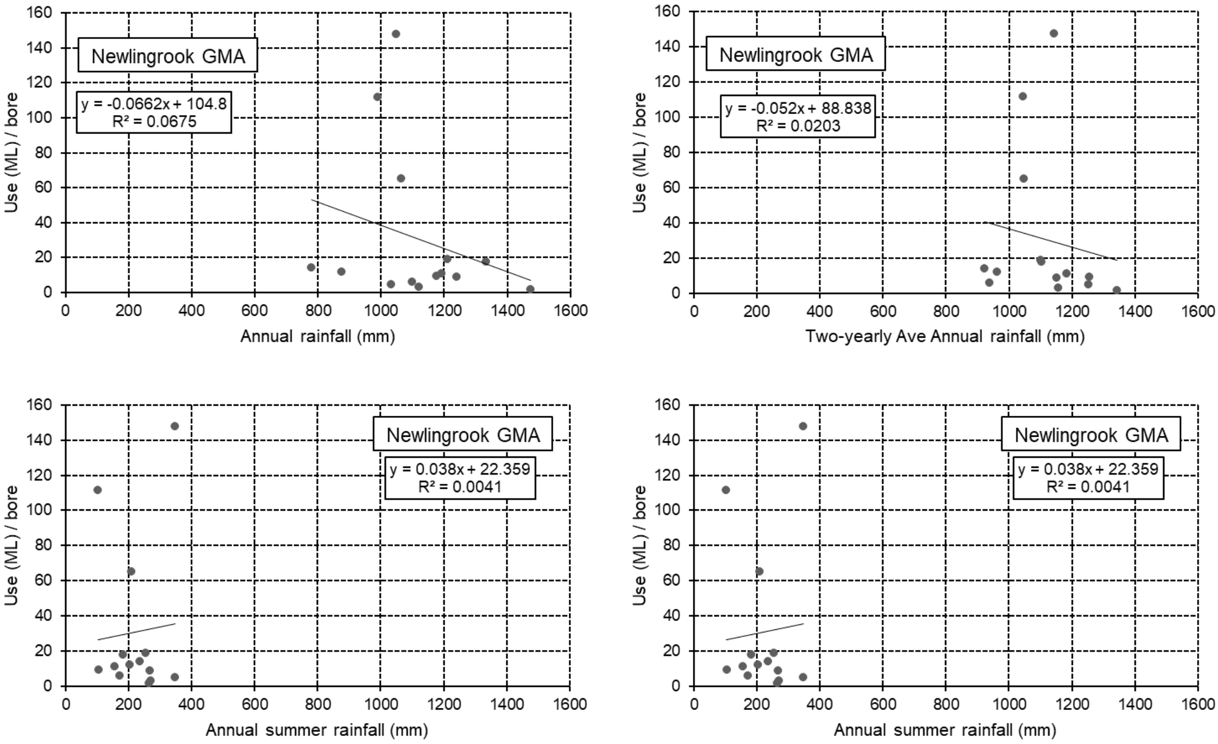


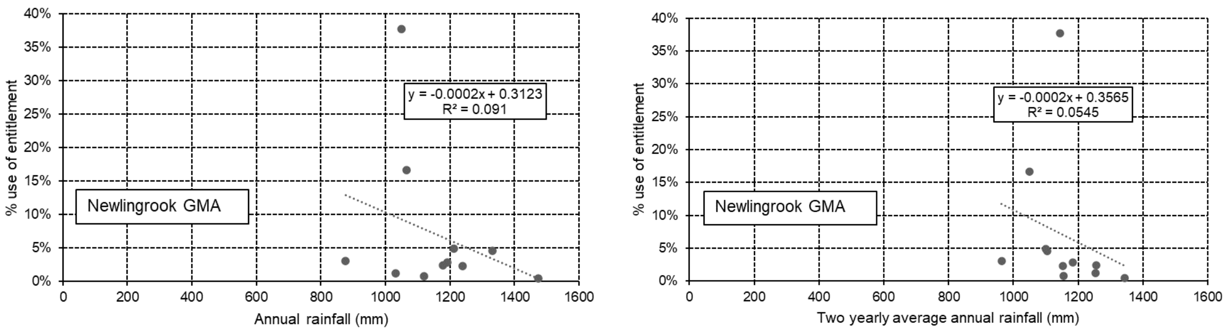
Figure 492 Newlingrook GMA: Hindcast method 2 correlations

As shown in Figure 492, the goodness-of-fit represented by the R^2 is relatively low across all four of the correlations developed. The correlation with annual rainfall has been adopted for hindcast method H2.

29.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 493:

- Percentage of entitlement vs annual rainfall
- Percentage of entitlement vs two yearly average annual rainfall
- Percentage of entitlement vs annual summer period rainfall
- Percentage of entitlement vs annual irrigation period rainfall



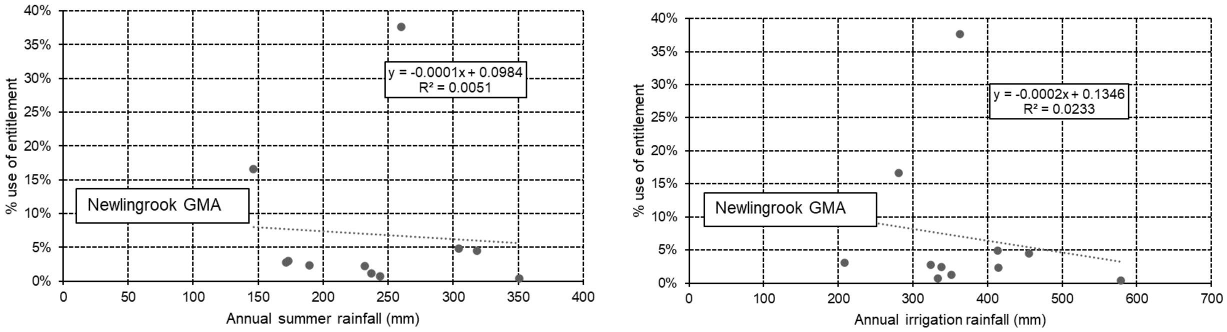


Figure 493 Newlingrook GMA: Hindcast method 3 correlations

As shown in Figure 493 and similar to method H2, the best goodness-of-fit result was relatively low across all four correlations developed. The correlation with annual rainfall has been adopted for hindcast method H3.

29.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 494 and Figure 495 for the hindcasting based on Newlingrook GMA groundwater use. Figure 494 shows a comparison of the three hindcasting methods against the recorded use only over the recorded use date, while Figure 495 shows the hindcasted data back to 1976/1977 (start of hydrograph period).

As shown in Figure 495, groundwater use using method 1 does not decrease historically as there is no factor to account for the changing number of bores extracting over time. The hindcasting results show that the smallest average variation of recorded use to estimated use occurs for method 2. Thus, this hindcasting method is expected to provide a more probable estimated groundwater use than the other two methods for Newlingrook GMA.

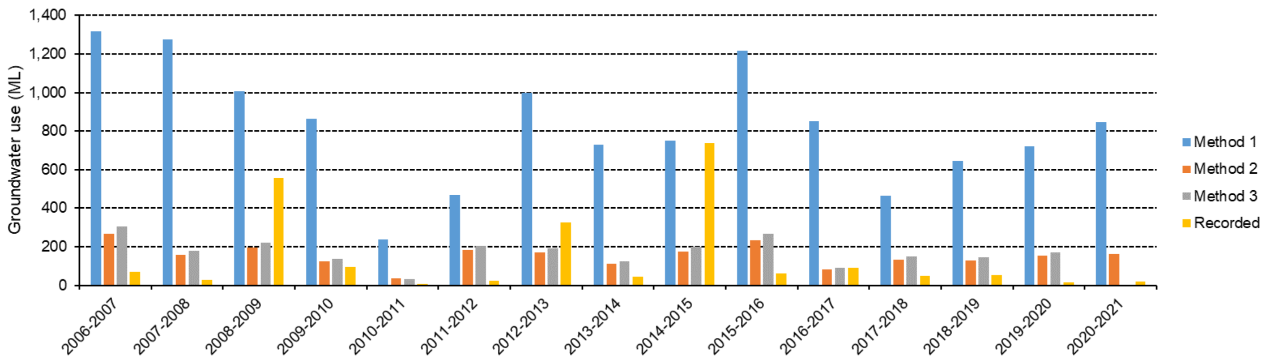


Figure 494 Newlingrook GMA: Comparison of hindcasting over recorded use period

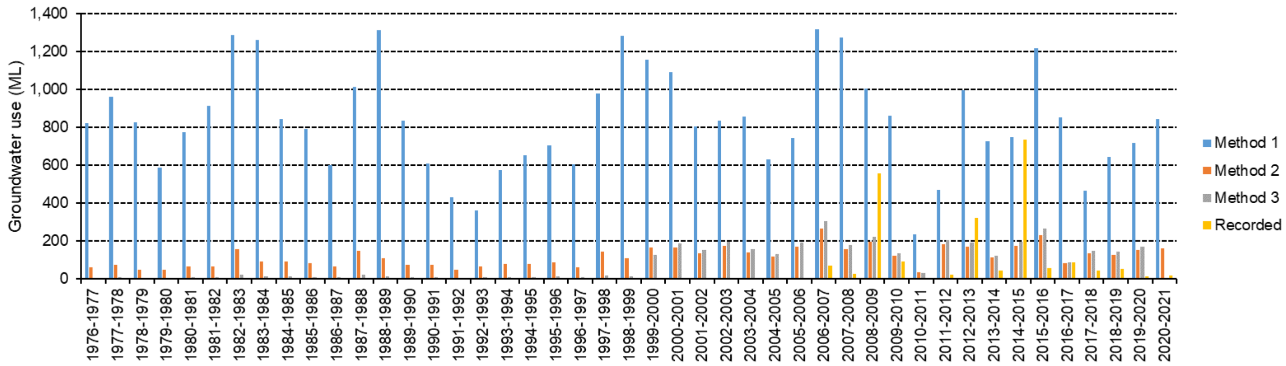


Figure 495 Newlingrook GMA: Comparison of hindcasting

29.3 Modelling

29.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 178 summarises the combinations of model inputs run for Newlingrook GMA. Model runs highlighted blue were run with annual extraction and while those in grey were run using two yearly average annual extraction.

Table 178 Newlingrook GMA: summary of model inputs

Model input	Model runs																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Annual recovered levels for representative Suites (L_AA_99)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Newlingrook GMA only	✓																		
Two yearly average annual extraction – Newlingrook GMA only		✓																	
Annual extraction – Newlingrook GMA and Externalities			✓																
Two yearly average annual extraction – Newlingrook GMA and Externalities				✓															
H1 annual extraction – Newlingrook GMA only					✓														
H1 annual extraction – Newlingrook GMA and Externalities						✓													
H2 annual extraction – Newlingrook GMA only							✓												
H2 annual extraction – Newlingrook GMA and Externalities								✓											
H3 annual extraction – Newlingrook GMA only									✓										
H1 two yearly average annual extraction – Newlingrook GMA only										✓									
H1 two yearly average annual extraction – Newlingrook GMA and Externalities											✓								

Model input	Model runs																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
H2 two yearly average annual extraction – Newlingrook GMA only												✓							
H2 two yearly average annual extraction – Newlingrook GMA and Externalities													✓						
S1 annual extraction – Newlingrook GMA only														✓					
S2 annual extraction – Newlingrook GMA only															✓				
S3 annual extraction – Newlingrook GMA only																✓			
S1 annual extraction and H1 annual extraction – Newlingrook GMA only																	✓		
S2 annual extraction and H2 annual extraction – Newlingrook GMA only																		✓	
S3 annual extraction and H3 annual extraction – Newlingrook GMA only																			✓

29.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 178 is presented in Table 179 for the selection of potential representative Suites for Newlingrook GMA using the process outlined in section 29.2.1. The statistics summarised include four key statistical measures pf the average 95 PPU thickness (95PPU TH), percentage of observed levels within 95 PPU (%Obs in 95 PPU), R^2 and root mean square error (RMSE) as well as the number of annual recovered level observation points (No obs data points) and the range of observed annual recovered levels.

Suite L_AA_99

A review of the results and statistical summary for Suite L_AA_99 shows that model runs 5 and 10 (highlighted orange) had the best results (when considering the four measures which reflect the uncertainty, accuracy and precision of the model) of the 13 different model input combinations. These model runs had a larger 95PPU thickness than model runs 1 and 2 but had a significantly higher R^2. Model runs 5 and 10 showed similar results to model runs 7 and 12, with the main differences being the 95PPU thickness and the R^2. However, models 5 and 10 are based on hindcast method H1 which generally overestimated groundwater use as discussed in section 29.2.4.4.

Given this, model run 7 (highlighted green) was progressed to predictive modelling and the graphical model output for this model run is shown in Figure 496.

Table 179 Newlingrook GMA: summary of model outputs

Suite	Statistic	Model run												
		1	2	5	7	9	10	12	14	15	16	17	18	19
L_AA_99	95PPU TH	0.54	0.45	0.75	0.82	1.43	0.72	0.8	0.75	0.58	0.55	1.21	0.71	0.71
	%Obs in 95 PPU	100	92.86	97.73	100	90.91	97.73	97.73	100	90	100	90.7	65.12	65.12
	R^2	38.0	33.1	85.8	79.1	-137.6	85.9	78.8	32.8	-6.6	24.6	-123.7	79.1	79.1
	RMSE	0.11	0.11	0.13	0.16	0.53	0.13	0.16	0.13	0.16	0.13	0.52	0.16	0.16
	No obs data points	14	14	44	44	44	44	44	10	10	10	43	43	43
	Range of observed levels	0.5	0.5	1.2	1.2	1.2	1.2	1.2	0.5	0.5	0.5	1.2	1.2	1.2

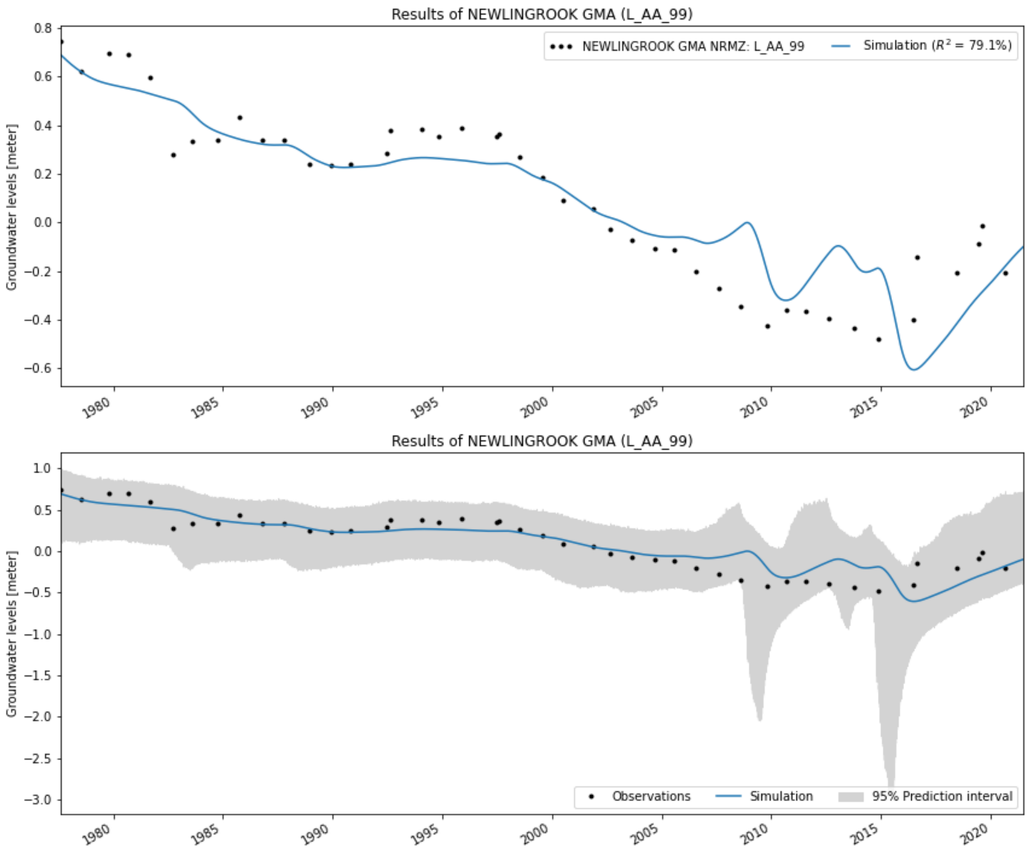


Figure 496 *Newlingrook GMA Suite L_AA_99: model run 7 (Newlingrook GMA annual extraction with hindcast method 2) output hydrographs*

29.4 Predictive modelling

29.4.1 Model inputs

The preferred model to run the predictive modelling for Newlingrook GMA was model run 7 for Suite L_AA_99. The key inputs for the model were the annual recovered levels and the annual extraction hindcasted using method H2 for Newlingrook GMA. To conduct the forecasting for the 19 scenarios discussed in section 3.5.3, a few factors were required in the calculations; these factors are summarised in Table 180.

Table 180 *Newlingrook GMA: forecast scenario inputs*

Input item	PCV	Licenced entitlement (based on 2020/21)	Existing use (based on 2020/2021)	Average use over recorded period (from VWA)	Maximum use over recorded period (from VWA, year 2014/15)
Value (ML/year)	1,977	1,958	21	145	738

29.4.2 Predictive model uncertainty

The model output files of the predicted models can be found in the data package provided as part of Appendix E.

MCMC predictions were undertaken on each of the forecasted scenarios for the representative Suite. An example of one of the outputs is presented in Figure 497 for scenario 4. As shown in Figure 497, the uncertainty in model prediction increased as the model predicts further into the future. Comparing with the graphical output for the same scenario, the MCMC realisations tend to fall within the 95% prediction interval bands with the exception of a few realisations as shown in Figure 498.

Uncertainty is also accounted for by using 19 forecast scenarios to develop a groundwater use to drawdown relationship (analogous to a Monte Carlo type simulation) where a range of possible outcomes are generated. It is noted however, that the forecast scenarios were not randomly generated, but rather based upon a series of estimated use behaviours.

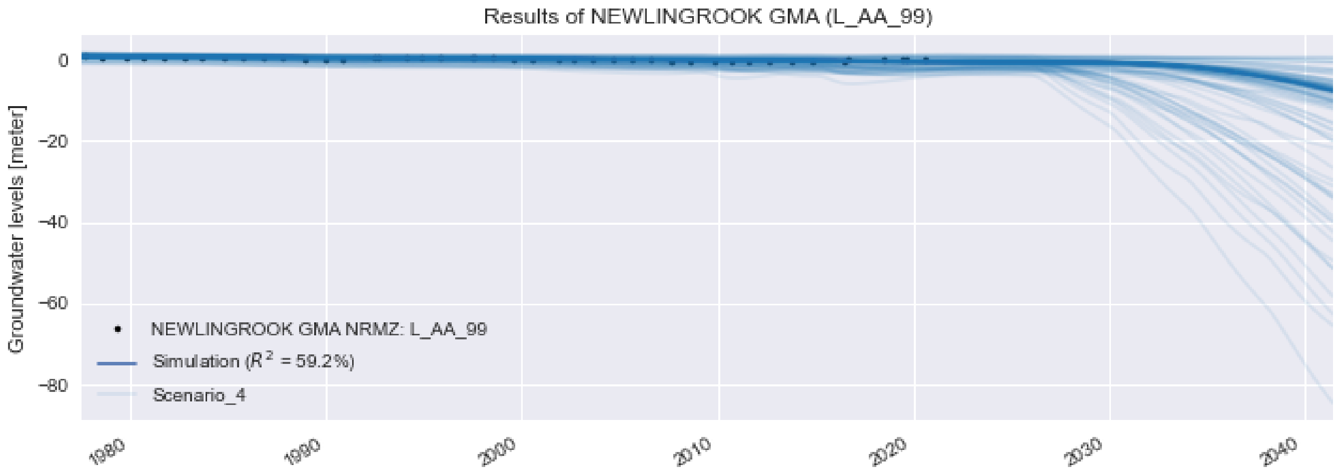


Figure 497 Newlingrook GMA: Suite L_AA_99 MCMC analysis for Forecast Scenario 4

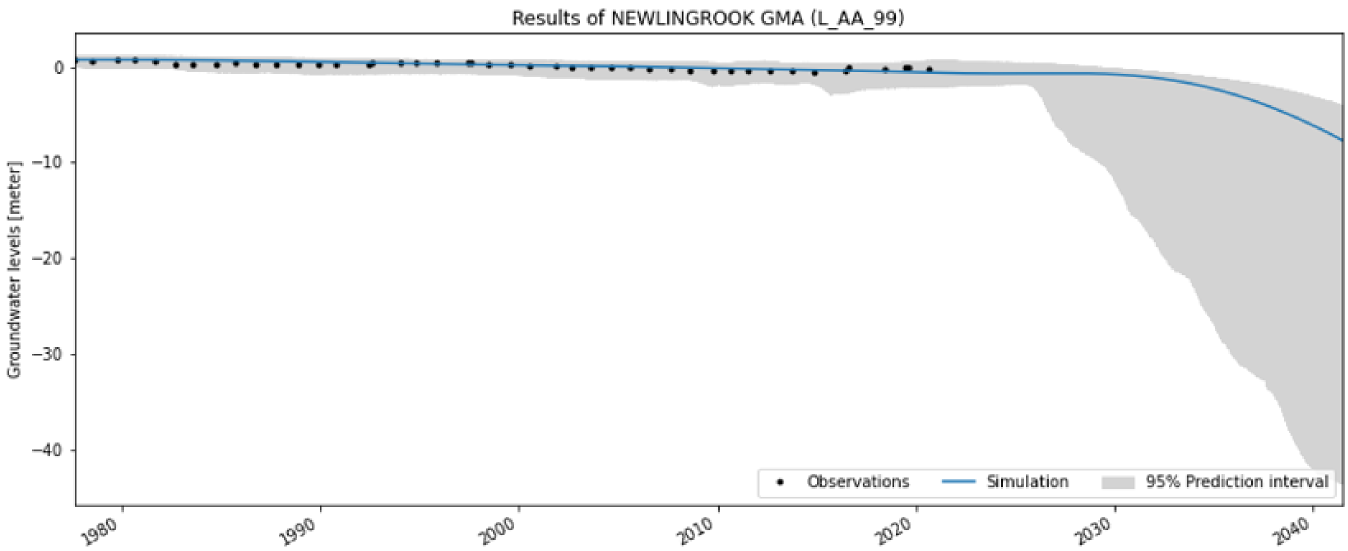


Figure 498 Newlingrook GMA: Suite L_AA_99 Forecast Scenario 4 with 95% prediction bands

29.4.3 Extraction vs drawdown

To calculate drawdown based on the annual recovered levels simulated by the model, the pre-development conditions (pre commencement of extraction) need to be estimated. For Newlingrook GMA, the water level prior to groundwater development was unknown, due to:

- Uncertainty regarding the commencement of development
- The initiation of groundwater development preceding SOBN bore installation and temporal groundwater monitoring

Using the pre-development levels defined in section 29.2.2, the modelled water levels were converted into drawdowns (from this baseline pre-development level) for each of the 19 scenarios. This predevelopment condition is shown in Figure 499 for Suite L_AA_99 through a hydrograph of annual recovered levels.
In Figure 499:

- Actual annual groundwater use is represented by the blue column graph between 2006/2007 and 2020/2021
- Hindcasted groundwater use is represented by the orange columns between 1976/1977 and 2006/2007
- Forecasted use is represented by the grey columns after 2021/2022
- The annual recovered water level behaviour based on recorded data is represented by the red line graph
- The pre-development annual recovered levels are taken to be the average of the first six readings which equate to 0.66 m
- The modelled forecasted annual recovered levels are represented by the purple line in Figure 499
- The calibration annual recovered levels are represented by the black line in Figure 499

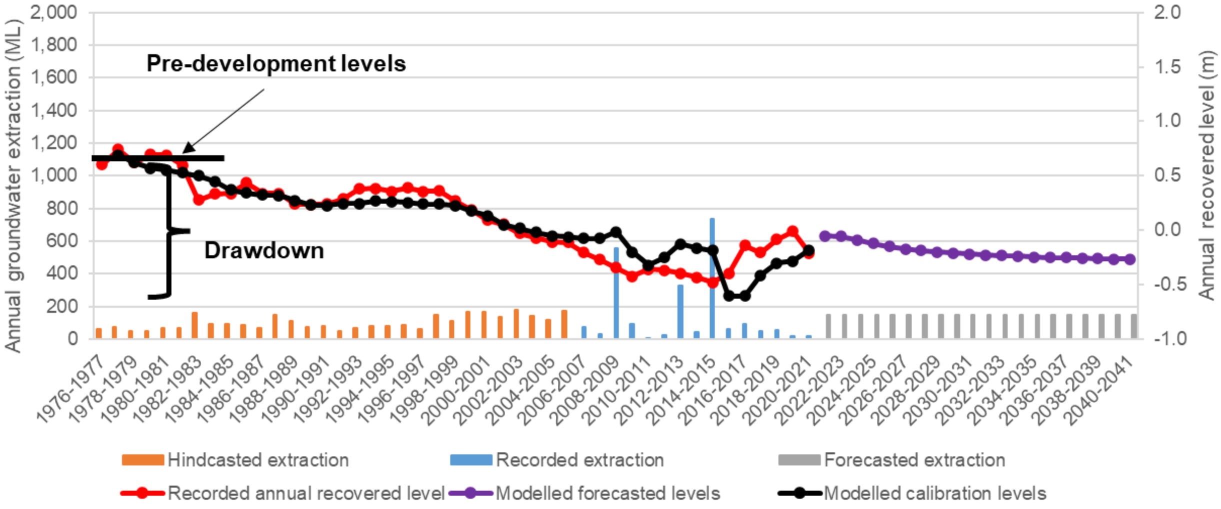


Figure 499 Estimating pre-pumping water levels (example from Suite L_AA_99 using model 7)

For Suite L_AA_99, the calculated drawdowns and volumes for each of the scenarios were plotted in individual graphs for each scenario, all scenarios together in the one graph (Figure 500) and a graph of the scenarios for specific time periods (Figure 501) to develop the volume to drawdown relationship. For each scenario, a linear regression was applied and the coefficient of determination (R^2) was calculated. A comparison of each of these graphs shows significant variation in the coefficient of determination. Given this, the drawdown-use plot of all scenarios was adopted to capture these variations.

The use-drawdown for all the 19 forecast scenario drawdowns and volumes (both the recorded and forecasted volumes) over each year modelled (1993 to 2041) is shown in Figure 500 for Suite L_AA_99. Note the abscissa range of the chart has been clipped and does not show forecast drawdowns for the higher use scenarios (more improbable volumes two times the PCV).

Reviewing these figures, the following is noted:

- There should be zero drawdown under zero use and therefore a line of best fit should pass through the origin (0,0) or close to it
- Average use is around 150 ML. Figure 500 indicates a large spread in the model forecast drawdown result at this usage
- For the same annual use, different drawdowns can be obtained as Pastas predicts a water level for each year. For example, Figure 499 shows a scenario where groundwater use remains constant at around 150 ML/year over the next 20 years.
- The correlation for groundwater use and drawdown for Suite L_AA_99 using model run 7 moderate as shown in Figure 500

– The various forecast scenarios generally result in data plotting reasonably close together in a linear trend. The 19 forecast scenarios applied to populate the chart is analogous to a Monte Carlo type simulation where a range of possible outcomes are generated. It is noted however, that the forecast scenarios were not randomly generated, but rather based upon a series of estimated use behaviours.

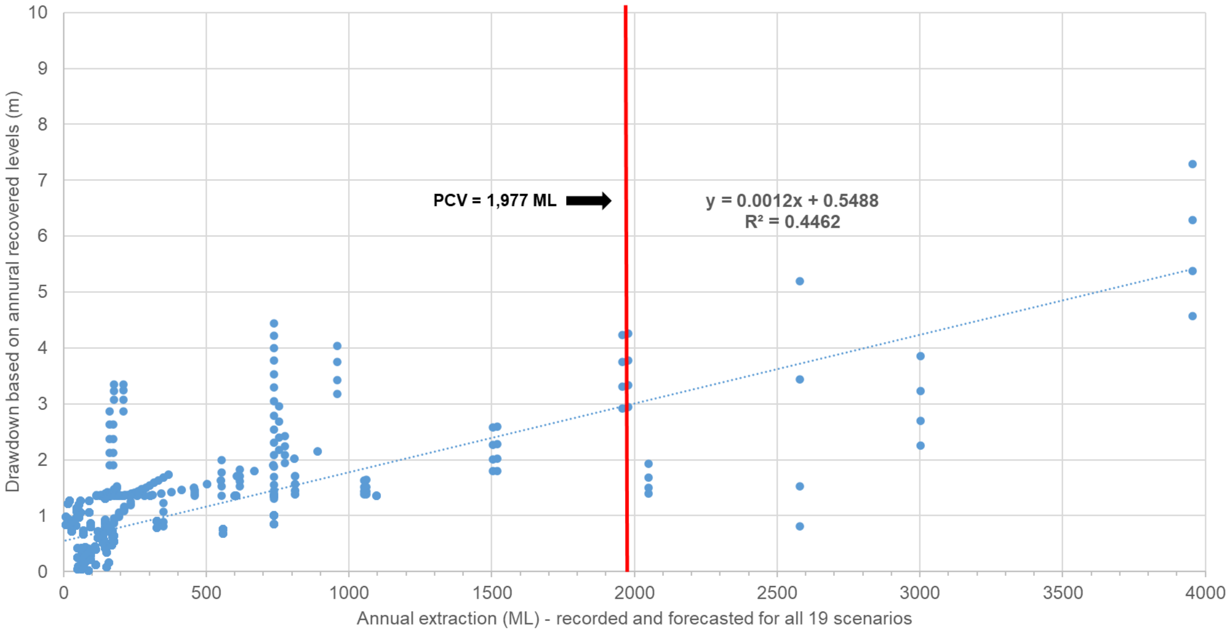


Figure 500 *Newlingrook GMA Suite L_AA_99 Model 7: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <4,000 ML) for all data between 1977 to 2041 and all forecasted scenarios*

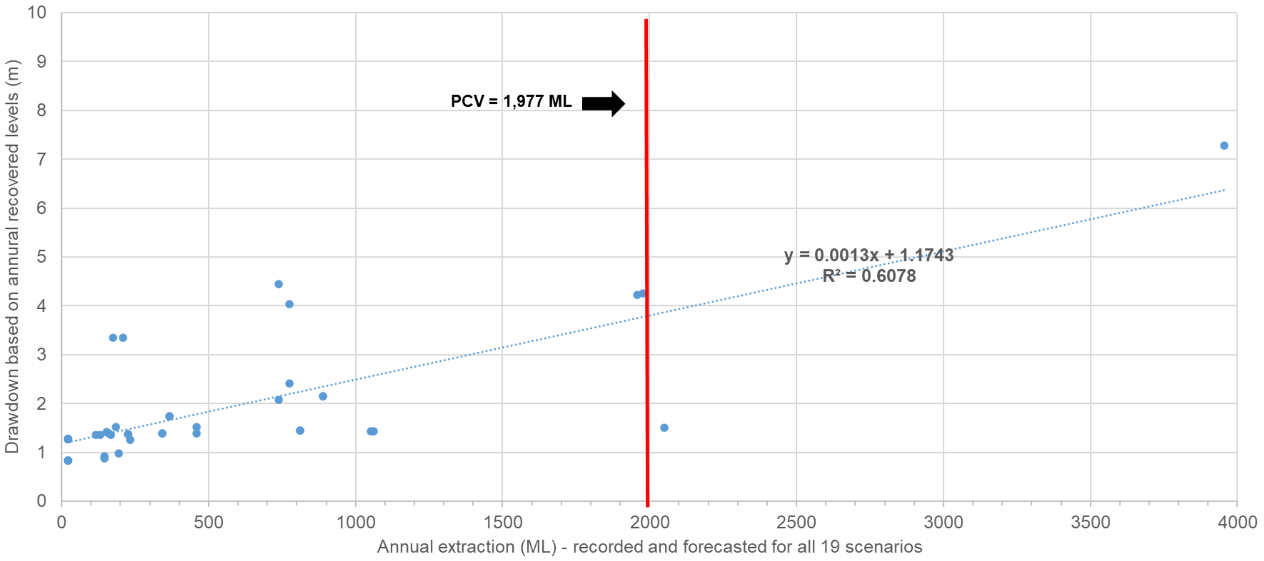


Figure 501 *Newlingrook GMA Suite L_AA_99 Model 7: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <4,000 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

29.5 Sustainability metrics

29.5.1 Application of metrics

Using the use - drawdown relationships developed through the previous step of forecasting aquifer response under a range of use scenarios, groundwater drawdown can be used to compare against groundwater resource sustainability metrics.

The application of these metrics and the relationship developed between drawdown based on the Suite annual recovered levels and extraction volume for the whole GMU, which is shown in Table 181 for Newlingrook GMA Suite L_AA_99 (noting Newlingrook GMA has a current PCV of 1,977 ML/year). As part of the modelling, a 95% prediction interval band was applied to the modelling results. The relationship between drawdown and extraction volumes can also be interrogated at the lower and upper bands of the 95% prediction interval as shown in Table 181 and Figure 502 for Suite L_AA_99.

A summary of volumes at drawdown intervals provided by DEECA for Suite L_AA_99 is shown in Table 182. Based on Suite L_AA_99, 5 m of drawdown is predicted to occur at a groundwater extraction volume of 3,700 ML (which could range from 600 ML to 5,500 ML) and for a 10 m of drawdown, the predicted groundwater extraction volume is 7,900 ML (which could range from 1,200 ML to 11,100 ML).

Table 181 Relationship of Suite drawdown to GMU extraction for Newlingrook GMA Suite L_AA_99

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_AA_99 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
10,000	12.5 (9 - 76.6)
9,000	11.3 (8.1 - 69)
8,000	10.1 (7.2 - 61.4)
7,000	8.9 (6.3 - 53.8)
6,000	7.7 (5.4 - 46.2)
5,000	6.5 (4.5 - 38.6)
4,000	5.3 (3.6 - 31)
3,000	4.1 (2.7 - 23.4)
2,000	2.9 (1.8 - 15.8)
1,000	1.7 (0.9 - 8.2)
0	0.5 (0 - 0.6)

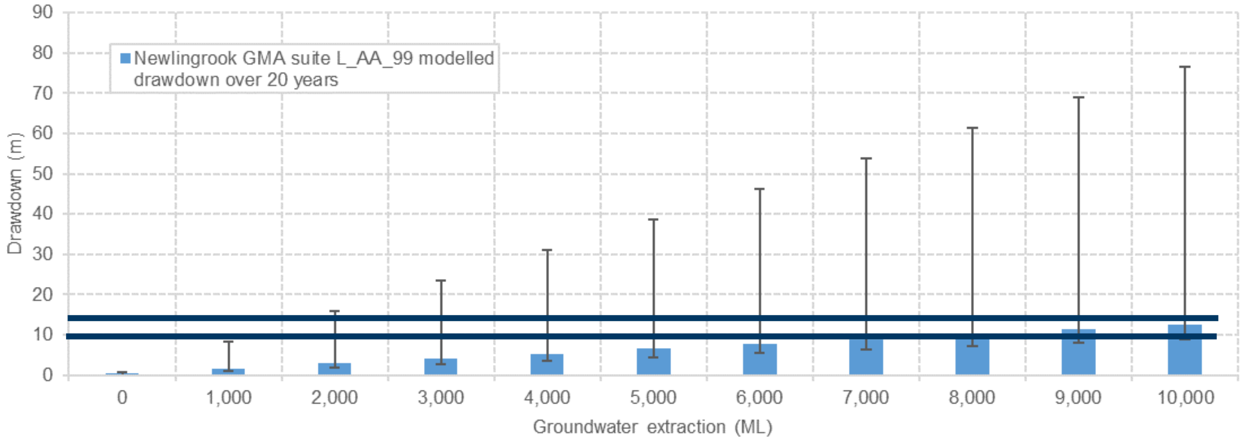
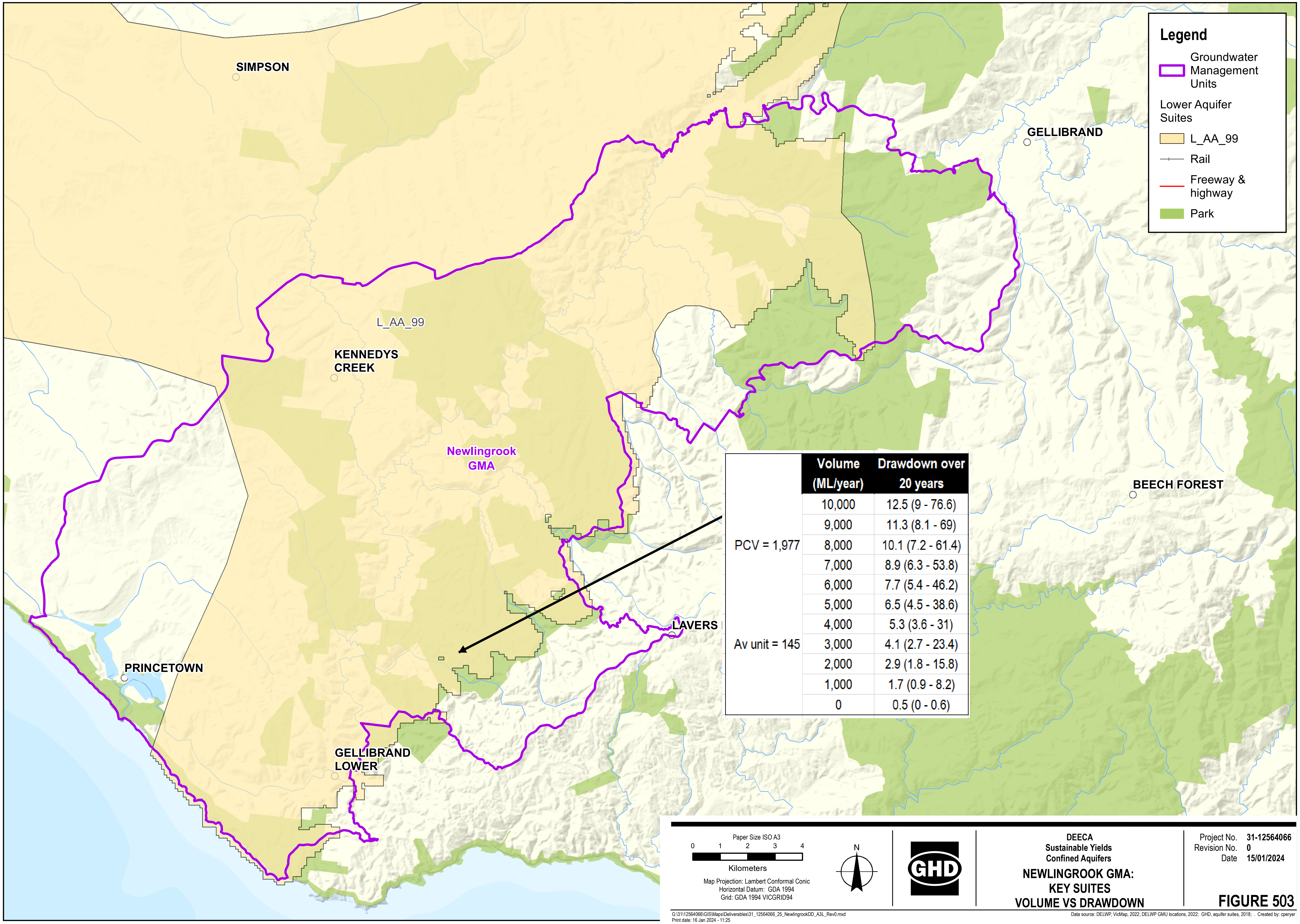


Figure 502 ***Newlingrook GMA Suite L_AA_99: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)***

Table 182 Predicted volumes for drawdown metrics

Drawdown (m) confined aquifer	Predicted volumes (ML) for GMU based on Suite L_AA_99 drawdowns (lower limit to upper limit)
5	3,700 (600 – 5,500)
10	7,900 (1,200 – 11,100)



	Volume (ML/year)	Drawdown over 20 years
PCV = 1,977	10,000	12.5 (9 - 76.6)
	9,000	11.3 (8.1 - 69)
	8,000	10.1 (7.2 - 61.4)
	7,000	8.9 (6.3 - 53.8)
	6,000	7.7 (5.4 - 46.2)
	5,000	6.5 (4.5 - 38.6)
Av unit = 145	4,000	5.3 (3.6 - 31)
	3,000	4.1 (2.7 - 23.4)
	2,000	2.9 (1.8 - 15.8)
	1,000	1.7 (0.9 - 8.2)
	0	0.5 (0 - 0.6)

Paper Size ISO A3

0 1 2 3 4

Kilometers

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 VICGRID94

N

GHD

DEECA
Sustainable Yields
Confined Aquifers

NEWLINGROOK GMA:
KEY SUITES
VOLUME VS DRAWDOWN

Project No. 31-12564066
Revision No. 0
Date 15/01/2024

FIGURE 503

G:\31\12564066\GIS\Maps\Deliverables\31_12564066_25_NewlingrookDD_A3L_Rev0.mxd
Print date: 16 Jan 2024 - 11:25

Data source: DELWP, VicMap, 2022; DELWP GMU locations, 2022; GHD, aquifer suites, 2018; . Created by: cperyer

29.6 GMU summary

29.6.1 Findings

Newlingrook GMA primarily relates to the Pebble Point Formation (LTA), where groundwater is predominately extracted for urban supply purposes. The LTA falls within the Lower Aquifer Suites, which at Newlingrook GMA comprises Suites L_AA_99 (68%), L_AD_1 (0.2%), L_Y_3 (18%) and L_Z_1 (0.8%), providing a total GMU coverage of 87%. The identified representative Suite is L_AA_99. The Suite hydrograph for the representative Suite shows an overall decreasing trend along with seasonal fluctuation and thus recovered water levels, which were adopted for the assessment.

Application of two yearly annual average extraction, rather than annual extraction, generally did not show a significant difference in the results of the statistical analysis across the model runs. The model runs using the hindcasting methods H1 and H2 showed very similar results, however, when hindcasting was not applied, the annual extraction method was slightly better. The best match using the two yearly average annual extraction was model run 10 (two yearly average annual extraction with hindcast method 1 for Newlingrook GMA) for Suite L_AA_99.

The application of spatial distribution produced a poorer model for the base model run for the whole GMU. The quality of the result did not increase when spatial distribution methodology was combined with hindcasting methodology.

Based on an assessment of all model runs, the model run 7 of Newlingrook GMA only annual extraction with hindcast method H2 was adopted to undertake the predictive modelling for Suite L_AA_99.

The pre-development levels were defined for the two representative Suites based on the early time series Suite data for the annual recovered levels; this resulted in pre-developments levels of 0.66 m for Suite L_AA_99.

The volumes estimated for a given drawdown for each Suite is shown below.

Drawdown (m) confined aquifer	Predicted volumes (ML) for GMU based on Suite L_AA_99 drawdowns (lower limit to upper limit)
5	3,700 (600 – 5,500)
10	7,900 (1,200 – 11,100)

The model applicability using Suite L_AA_99 was assessed as having a “Moderate” model applicability rating using the criteria outlined in section 5.2. For this Suite, due to the limited range in calibration volumes, the greater the proposed extraction rates beyond the calibration range leads to a greater potential for drawdown forecast errors.

29.6.2 Limitations

In addition to the limitations applicable to all 25 GMUs discussed in section 1.8, the following Newlingrook GMA specific limitations have been identified:

- The licenced bore dataset provided by DEECA has 26% of bores assigned to Newlingrook GMA with no depth data and thus couldn’t be assigned to a VAF layer and in turn Suite. These bores were assigned to an aquifer through this study by GHD, in order to assist with the determination of the representative Suite. However, this data was not used in the model analysis.
- The drawdown graph shows high sensitivity at low flow rates
- Model calibration for suite L_AA_99 was completed using a groundwater extraction range of approximately 100-800 ML/year (below the current PCV of 1,977 ML/year, or around 35% of the PCV)
- The greater the proposed extraction rates beyond this calibration range the more potential for drawdown forecast errors. In this GMU, drawdown prediction for extraction volumes up to 9 times the calibration range are being made to meet the 10 m drawdown metric.
- Further checks and potential re-calibration may be required as extraction rates increase for this GMU

29.6.3 Recommendations

In addition to the recommendations applicable to all 25 GMUs discussed in section 32, the following Newlingrook GMA specific recommendations have been identified:

- The licenced bore dataset provided by DEECA has 26% of bores assigned to Newlingrook GMA with no depth data and thus couldn't be assigned to a VAF layer and in turn Suite. It is recommended that DEECA obtains the relevant depth and aquifer monitored data for licenced bores within this GMU.

30. Paaratte GMA

30.1 Conceptualisation

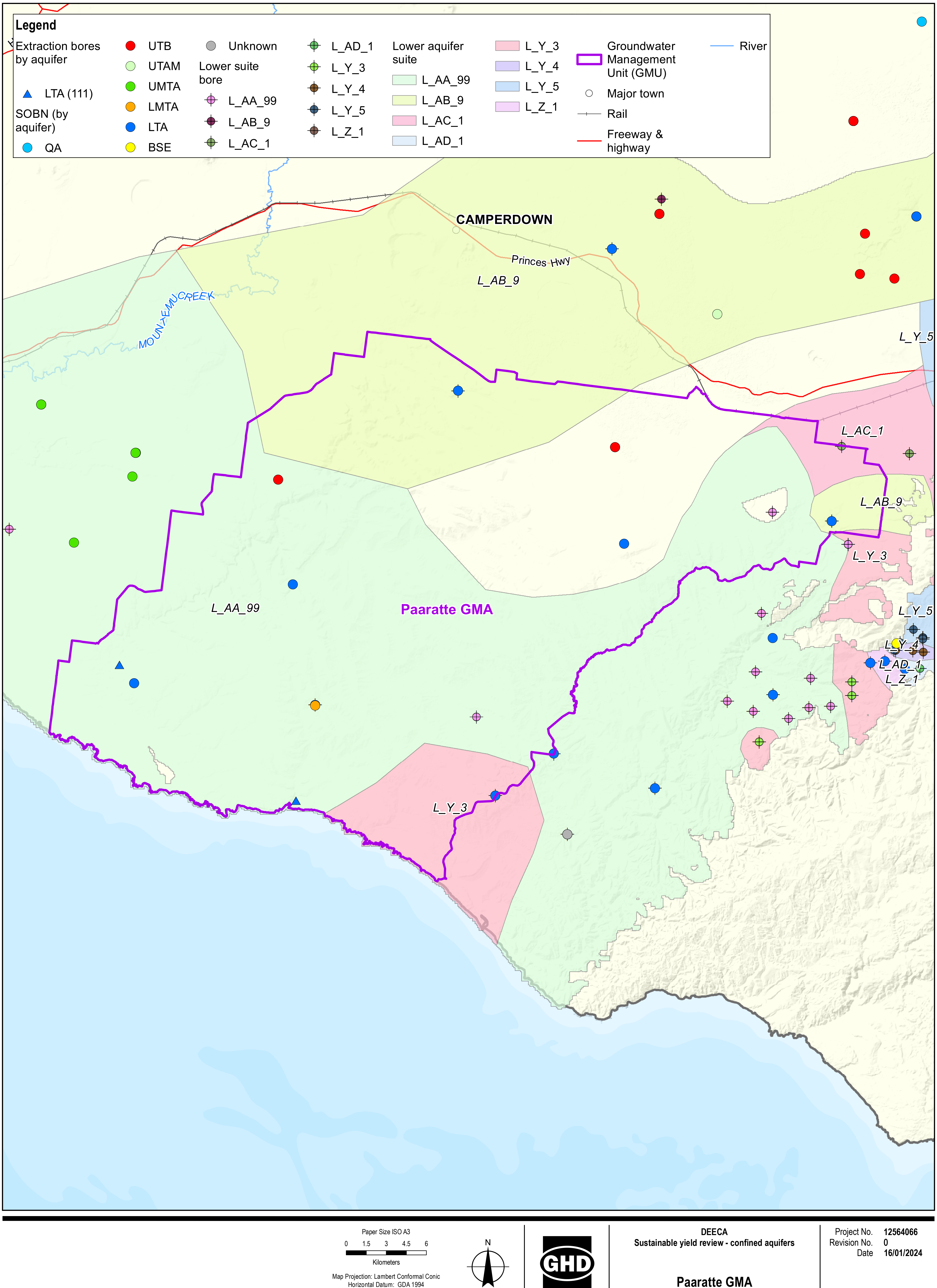
The hydrogeological conceptualisation elements relevant to this study are summarised in Table 183 and a map of the GMU is presented in Figure 504. It is noted that a significant volume of information was collated to inform the hydrogeological conceptual understanding of the GMU. The information that is directly relevant to the modelling are in bold or colour coded within Table 183.

Table 183 Paaratte GMA – Tabulated conceptualisation

GMU summary								
Paaratte GMA is located in southwest Victoria east of Warrnambool and covers an area of approximately 1,346 km^2. The GMA is bound in the south by Bass Strait coastline, in the north by the extent of the Dillwyn Formation from Irrewillipe East to 3 km north of Cobden. The western boundary extends in a line westward from the Cobden region through Nirranda before terminating on the coast west of Port Campbell. The eastern boundary aligns with the inferred recharge area boundary and aligns with the Fergusons Hill Anticline. The depth to which the Paaratte GMA pertains is based on contour lines to describe the upper and lower boundaries of the GMA, generally being depths of greater than 120 m below the ground surface (the GMU depth limit is greater than 200 m below ground level). The GMA was intended to primarily manage the groundwater resource of the Mepunga/Dilwyn Formation (LTA). The PCV (4,606 ML/year) relates to confined aquifers. Groundwater in this GMA is extracted predominately for urban supply, with a small contribution from stock and domestic use. Paaratte GMA has a high urban use in comparison to the other Victorian GMUs.								
Hydrographic summary								
Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Use volumes ML (2019/20)	Entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Quaternary Sediments (QA)	U_X_1 (29%)	29%	0	NA	0	0	Low
	Newer Volcanic Group (UTB)	U_AS_1 (4%), U_AX_1 (30%)	34%	1	NA	0	0	Low
	Hanson Plain Sand (UTAM)	M_Y_1 (56%)	56%	0	NA	0	0	Low
Middle	Port Campbell Limestone (UMTA)	M_X_2 (5%), M_X_3 (36%)	41%	0	NA	0	0	Low
	Gellibrand Marl (UMTD)	-	0%	0	NA	0	0	Low
Lower	Clifton Formation (LMTA)	-	0%	1	NA	0	0	Low
	Narrawaturk Marl (LMTD)	-	0%	0	NA	0	0	Low
	Mepunga/Dilwyn Formation (LTA)	L_AA_99 (60%), L_AB_9 (15%), L_AC_1 (2%), L_Y_3 (5%)	82%	7 (1 in L_AA_99, 2 in L_AB_9)	Urban	304 ML	3,159	High
Basement		B_X_3 (13%)	13%	0	NA	0	0	Low

Characteristic and importance	Description	Degree of understanding
Intended aquifer (LTA, highlighted blue above)		
Aquifer thickness within GMU (range, based on VAF)	Max: 841 m, Average: 304 m	High
Aquifer extent	Regional, extensive	High
Likelihood of inter-aquifer flow	Low	Low
Likelihood of groundwater – surface water interaction	Medium	Low
Representative Suite	**L_AA_99**	**High. 100% of GMU extraction occurs within this Suite, which relates to the most relevant GMU aquifer.**
Current hydrological condition of representative aquifer		
Representative Suite trend	Decreasing	High
Groundwater quality (average salinity based on WMIS and CDM Smith spatial segment(s) with highest coverage)	1,485 mg/L (WMIS) 0 – 600 mg/L (CDM Smith (2022)	Moderate Based on WMIS and CDM Smith (2022)
Groundwater yield	5 – 50 L/s	Low Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1977-2021**	**High**
Spatial clustering of licensed bores in relation to Suites	No	Based on DEECA density mapping and licenced bore data.
Groundwater use		
Licensed groundwater use	**321 ML**	**High (Based on average historical VWA data over 12 years)**
Minimum historic groundwater use	281 ML	High (Based on historical VWA data, year 2020/21)
Maximum historic groundwater use	**367 ML**	**High (Based on historical VWA data, year 2015/16)**
Entitlement (Groundwater allocation)	**3,159 ML**	**High (Based on licenced volumes in 2020/21)**
Significant drivers of groundwater level variability (primary)	**Pumping for town water supply**	**Moderate**
Secondary drivers of groundwater level variability	Pumping for irrigation & dairy	Moderate
Groundwater use profile	Stable (uniform monthly distribution)	Low
External Influence	**None identified**	

Groundwater values and risks		
Existing Environmental Values to be protected, relevant to this GMU	Potable water supply Licensed non-potable supply (irrigation, commercial, industrial) Unlicensed non-potable supply (domestic and stock)	
Risks to groundwater values	Direct risks: – Drawdown which may affect access to groundwater by existing users	
Indicators used to assess impacts to groundwater	– Measured drawdown using pre-determined metrics measured from a pre-determined level for the purpose of this modelling	



DEECA
Sustainable yield review - confined aquifers

Paaratte GMA
Site location and key features

Project No. 12564066
Revision No. 0
Date 16/01/2024

Figure 504

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Print date: 16 Jan 2024 - 12:43

Data source: DELWP, VicMap, 2022; DELWP, GMUs, 2022; DELWP, SOBN, 2022; GHD, aquifer suites, 2018; DELWP, extraction bores, 2022 Created by: cperyer

30.2 Technical analysis

30.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the relevant Suites for Paaratte GMA as shown in Figure 505 and Figure 506. The Suite hydrographs for M_X_2, B_X_3, M_X_3 and L_AA_99 show a trend of seasonal fluctuations and thus annual recovered levels. Suite L_Y_3 shows historical highs prior to the 1990s and Suites L_AB_9 and L_AC_1 show a general increase in groundwater levels with no obvious seasonal variation. The high at Suite L_Y_3 is likely a data error and has not been used in this assessment.

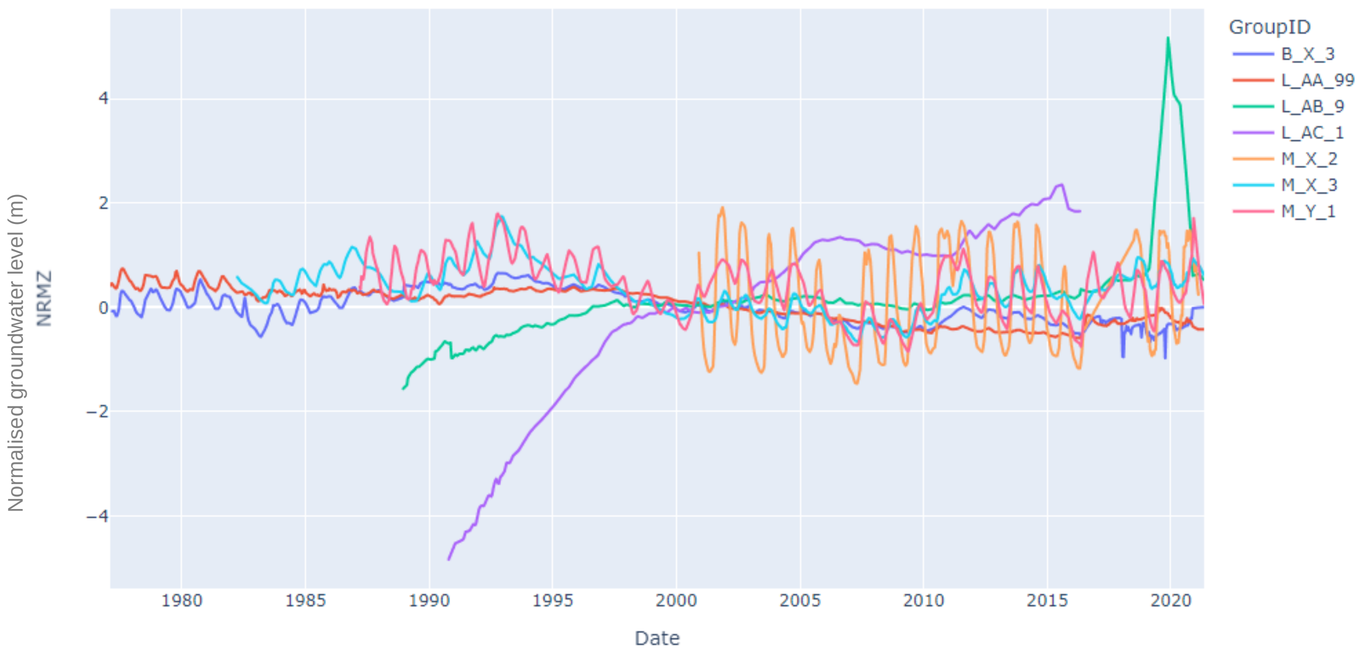


Figure 505 Paaratte GMA Suite Hydrographs for all confined aquifers (except L_Y_3)

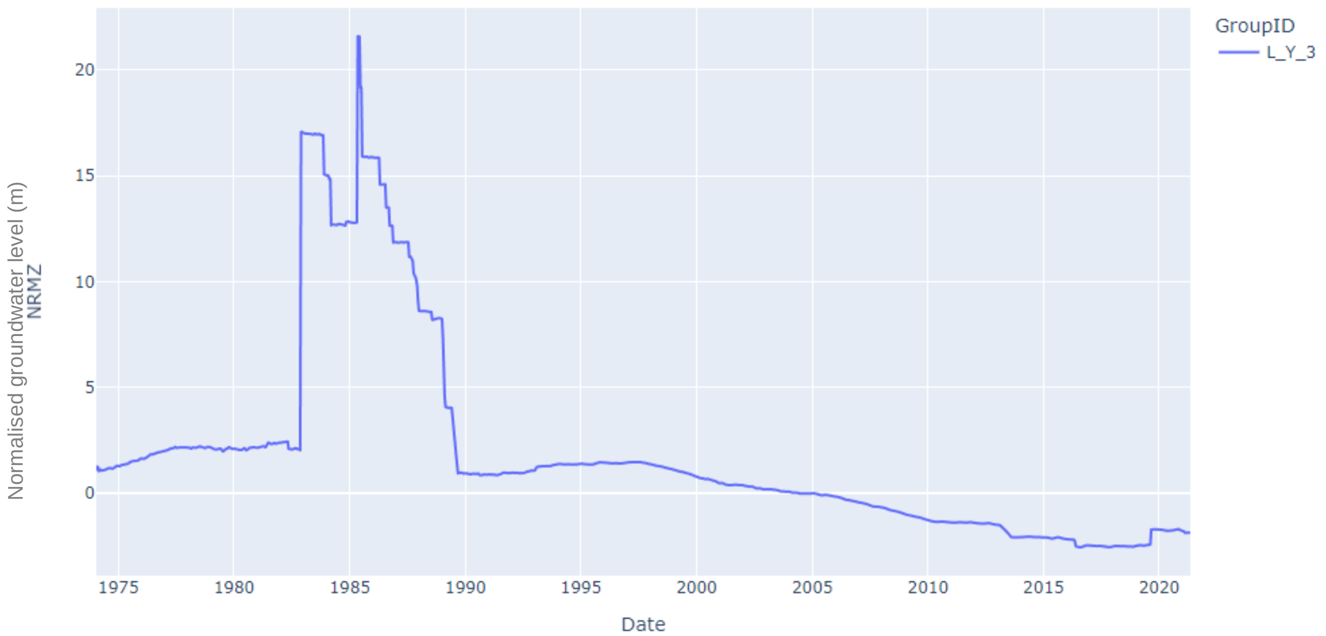


Figure 506 Paaratte GMA Suite Hydrographs for L_Y_3

The representative Suite analysed for this GMU was Suite L_AA_99. This representative Suite was selected following the methodology outlined in section 2.6.4and summarised as follows:

- The greatest volume of extraction occurs within the Lower Aquifer
- The Lower Aquifer pertains to the LTA, which is the intended aquifer of the GMU
- Suite L_AA_99 covers 60% of the GMU
- Suite L_AA_99 has one active SOBN bore within the Suite area
- The Suite bores for L_AA_99 are not close to extraction points

The annual recovered Suite hydrographs for the representative Suite L_AA_99 for Paaratte GMA, is shown in Figure 507.

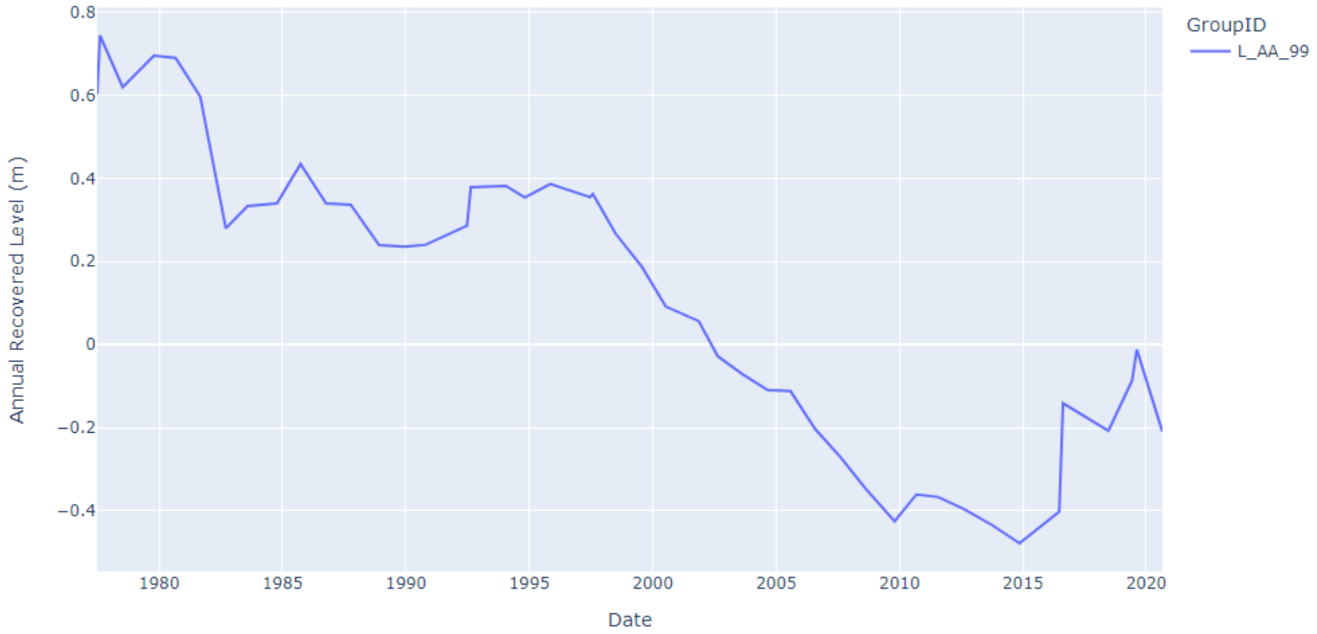


Figure 507 Paaratte GMA Annual Recovered Level Suite Hydrographs for representative Suites

30.2.2 Pre-development level

To estimate the pre-development level conditions, GHD reviewed the Suite hydrograph of annual recovered levels and assumed that the early time series data was the best representation of conditions prior to major development within Paaratte GMA for the representative Suite.

The pre-development annual recovered level was taken to be the average of the first six readings in the time series data for Suite L_AA_99, which occur over the years 1997/1996 to 1981/1982 and equates to 0.66 m.

30.2.3 Externalities

Through the conceptualisation, no external influence was identified for Paaratte GMA (outside of the surrounding GMUs).

30.2.4 Hindcasting

Groundwater use data for Paaratte GMA is available from 2009/2010 to 2020/2021. The hindcasting methodologies outlined in section 3.3.4.5 were applied to Paaratte GMA. A summary of the hindcasting results is shown in the following sections.

30.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, four different correlations were developed using the annual groundwater extraction as described below and shown in Figure 508:

- Annual rainfall vs annual groundwater extraction at Paaratte GMA
- Two yearly average annual rainfall vs annual groundwater extraction at Paaratte GMA
- Annual summer period rainfall vs annual groundwater extraction at Paaratte GMA
- Annual irrigation period rainfall vs annual groundwater extraction at Paaratte GMA

As shown in Figure 508, the goodness-of-fit represented by the R^2 is greatest for the annual irrigation rainfall with annual groundwater use; this is the correlation adopted for method H1.

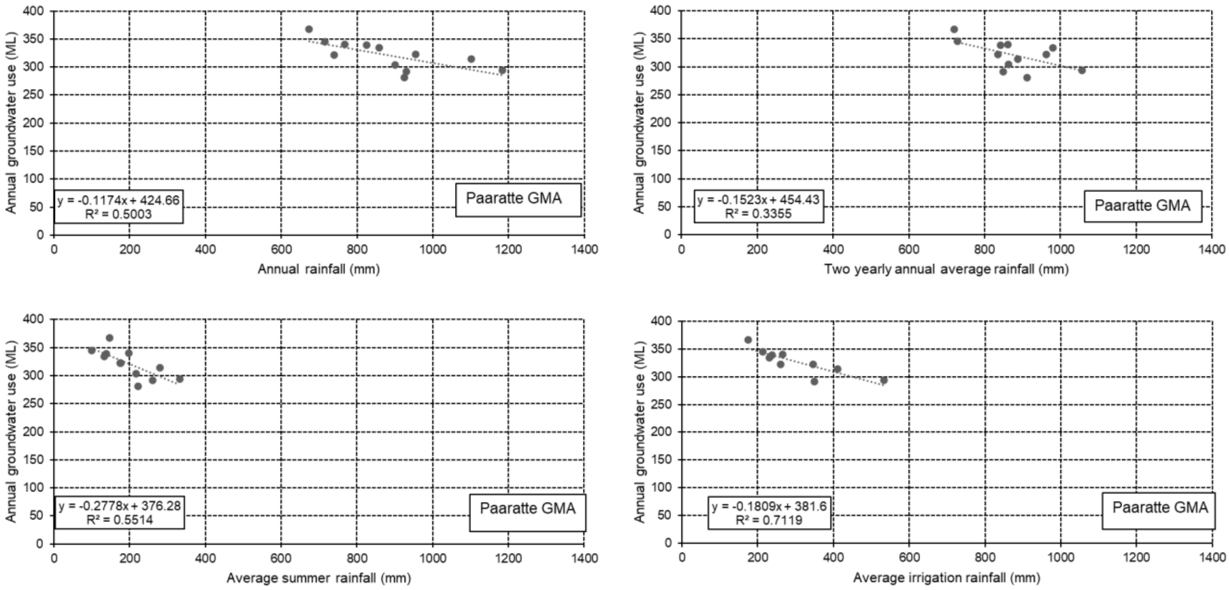


Figure 508 ***Paaratte GMA: Hindcast method 1 correlations (Paaratte GMA annual extraction)***

30.2.4.2 Hindcasting Method 2 (H2)

Similar to method H1, four correlations were developed using method H2 as described below and shown in Figure 509:

- Paaratte GMA use per Paaratte GMA bore vs annual rainfall
- Paaratte GMA use per Paaratte GMA bore vs two yearly average annual rainfall
- Paaratte GMA use per Paaratte GMA bore vs annual summer period rainfall
- Paaratte GMA use per Paaratte GMA bore vs annual irrigation period rainfall

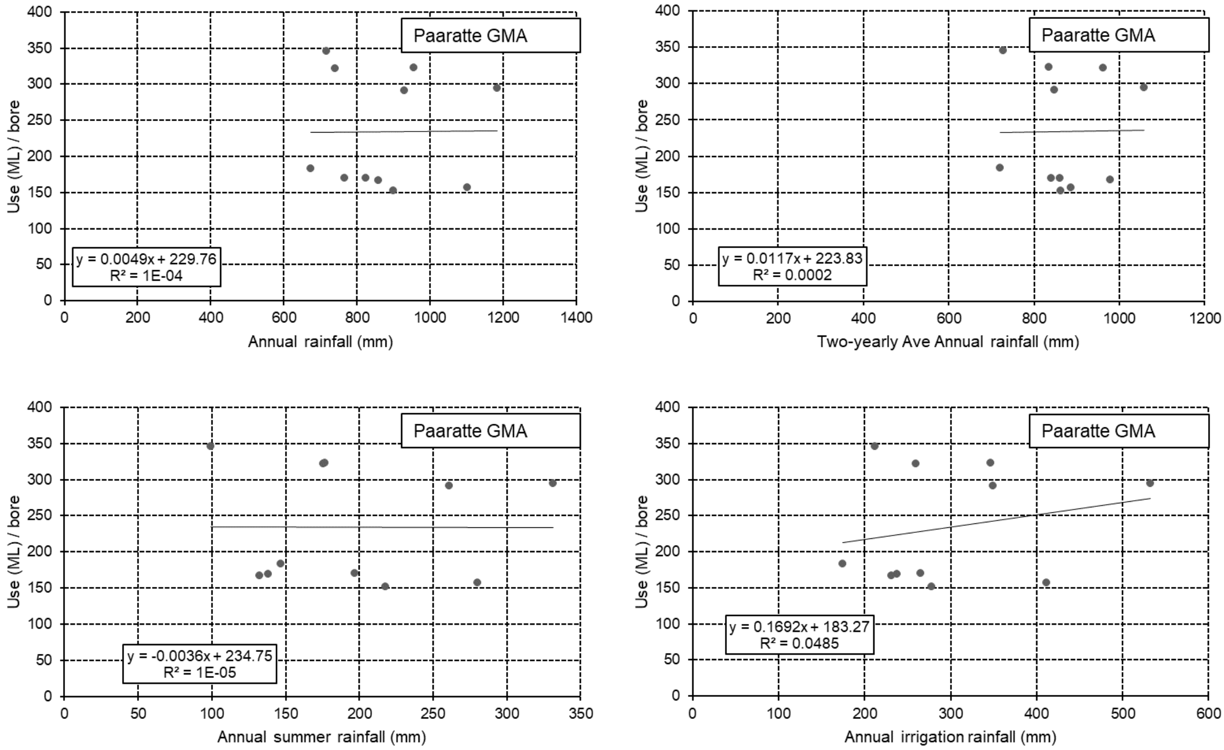


Figure 509 Paaratte GMA: Hindcast method 2 correlations

As shown in Figure 509, the goodness-of-fit represented by the R^2 is low across all four correlations. The highest R^2 is the correlation with annual irrigation rainfall. Thus, the correlation with annual irrigation rainfall has been adopted for hindcast method H2.

30.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 510:

– Percentage of entitlement vs annual rainfall
– Percentage of entitlement vs two yearly average annual rainfall
– Percentage of entitlement vs annual summer period rainfall
– Percentage of entitlement vs annual irrigation period rainfall

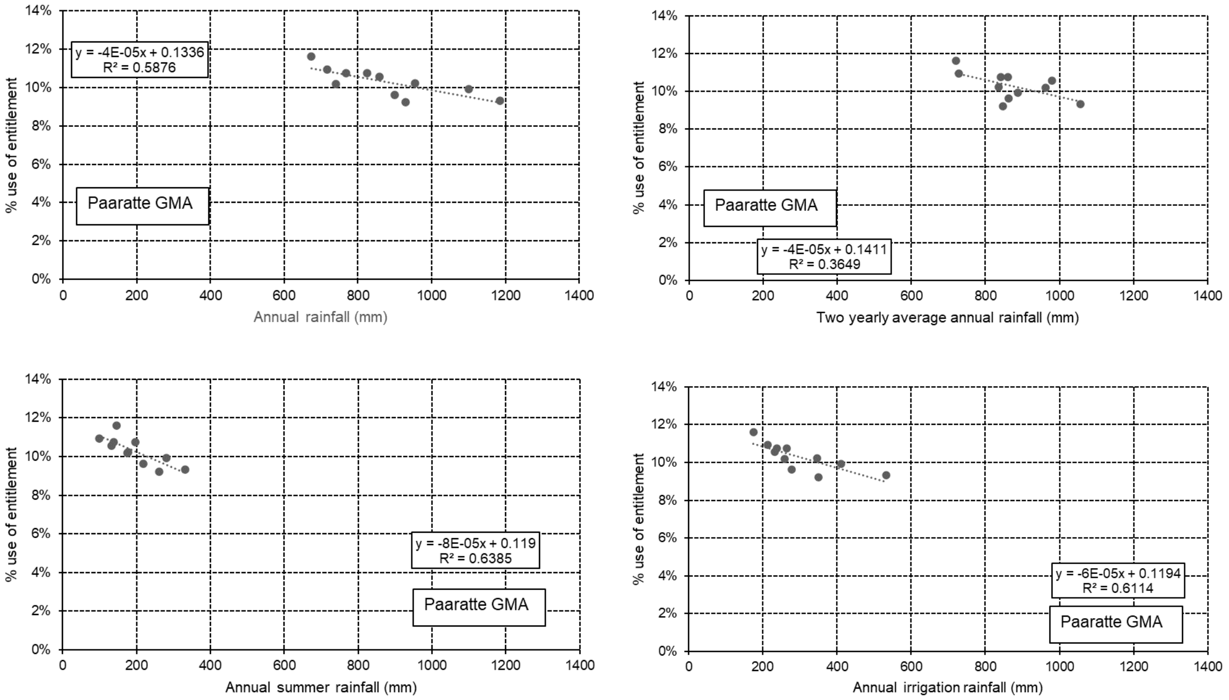


Figure 510 ***Paaratte GMA: Hindcast method 3 correlations***

As shown in Figure 510, the goodness-of-fit represented by the R^2 is highest for the correlations with annual summer rainfall followed by the correlation with annual irrigation rainfall. Thus, the correlation with annual summer rainfall has been adopted for hindcast method H3.

30.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 511 and Figure 512 for the hindcasting based on Paaratte GMA groundwater use. Figure 511 shows a comparison of the three hindcasting methods against the recorded use only over the recorded use date, while Figure 512 shows the hindcasted data back to 1976/1977 (start of hydrograph period).

As shown in Figure 512, groundwater use using method H1 does not decrease historically as there is no factor to account for the changing number of bores extracting over time. The hindcasting results show that the smallest average variation of recorded use to estimated use occurs for method H1; however, this is likely to overestimate when looking at historical extraction. Method H3 shows the second closest estimates to the recorded use and given that this method takes into account the decreasing number of bores into the past, this hindcasting method is expected to provide a more probable estimated groundwater use than the other two methods for Paaratte GMA.

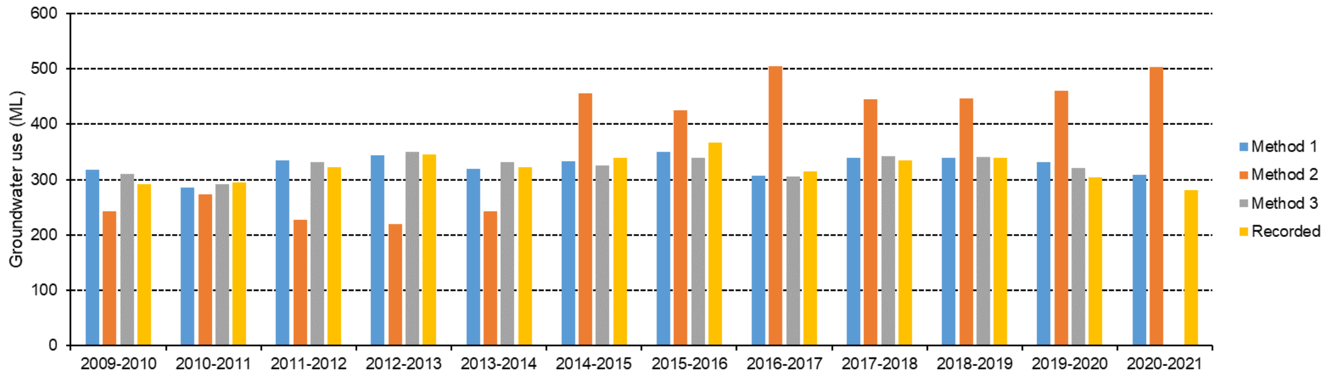


Figure 511 ***Paaratte GMA: Comparison of hindcasting over recorded use period***

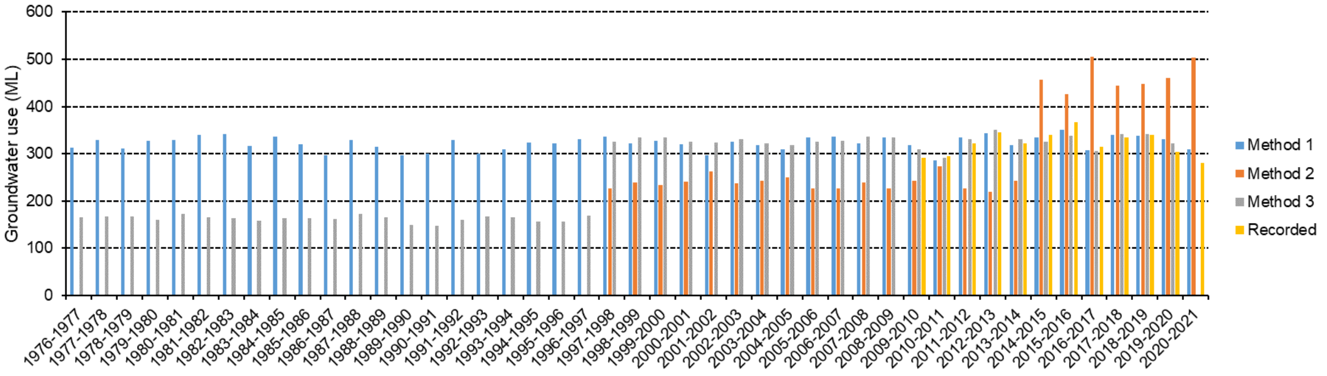


Figure 512 ***Paaratte GMA: Comparison of hindcasting***

30.3 Modelling

30.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 184 summarises the combinations of model inputs run for Paaratte GMA. Model runs highlighted blue were run with annual extraction while those highlighted grey were run using two yearly average annual extraction.

Table 184 Paaratte GMA: summary of model inputs

Model input	Model runs																			
	1	2	3	4	5	6	7	8	9	9c	10	11	12	13	14	15	16	17	18	19
Annual recovered levels for representative Suites (L_AA_99)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Paaratte GMA only	✓																			
Annual climate data																				
Two yearly average annual extraction – Paaratte GMA only		✓																		
Annual extraction – Paaratte GMA and Externalities			✓																	
Two yearly average annual extraction – Paaratte GMA and Externalities				✓																
H1 annual extraction – Paaratte GMA only					✓															
H1 annual extraction – Paaratte GMA and Externalities						✓														
H2 annual extraction – Paaratte GMA only							✓													
H2 annual extraction – Paaratte GMA and Externalities								✓												
H3 annual extraction – Paaratte GMA only									✓	✓										
H1 two yearly average annual extraction – Paaratte GMA only											✓									
H1 two yearly average annual extraction – Paaratte GMA and Externalities												✓								

Model input	Model runs																			
	1	2	3	4	5	6	7	8	9	9c	10	11	12	13	14	15	16	17	18	19
H2 two yearly average annual extraction – Paaratte GMA only													✓							
H2 two yearly average annual extraction – Paaratte GMA and Externalities														✓						
S1 annual extraction – Paaratte GMA only															✓					
S2 annual extraction – Paaratte GMA only																✓				
S3 annual extraction – Paaratte GMA only																	✓			
S1 annual extraction and H1 annual extraction – Paaratte GMA only																		✓		
S2 annual extraction and H2 annual extraction – Paaratte GMA only																			✓	
S3 annual extraction and H3 annual extraction – Paaratte GMA only																				✓

30.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 184 is presented in Table 185 for the selection of potential representative Suites for Paaratte GMA using the process outlined in section 30.2.1. The statistics summarised include four key statistical measures pf the average 95 PPU thickness (95PPU TH), percentage of observed levels within 95 PPU (%Obs in 95 PPU), R^2 and root mean square error (RMSE) as well as the number of annual recovered level observation points (No obs data points) and the range of observed annual recovered levels.

Suite L_AA_99

A review of the results and statistical summary for Suite L_AA_99 shows that model run 9 (highlighted orange) had the best results when considering the four measures which reflect the uncertainty, accuracy and precision of the model of the initial set of different model input combinations. Model run 9 had the smallest 95PPU thickness, the second highest R^2, one of the smallest RMSE values and a relatively high percentage of observation points within the 95PPU band. As there is a groundwater divide in the area, it was assumed reasonable to add climate data to the best model, this resulted in mode run 9c which produced the best results statistically of all the models run for Paaratte GMA. The graphical model output for this model run is shown in Figure 513.

Given the results, model run 9c has been adopted to progress to predictive modelling.

Table 185 Paaratte GMA: summary of model outputs

Suite	Statistic	Model run													
		1	2	5	7	9	9c	10	12	14	15	16	17	18	19
L_AA_99	95PPU TH	0.63	1.24	0.71	0.67	0.58	0.64	0.74	1.14	NA	0.63	0.63	0.62	337.06	337.06
	%Obs in 95 PPU	100	9.09	95.45	95.45	95.45	95.45	95.45	70.45	0	100	100	90.91	100	100
	R^2	6.8	-58.9	83.8	77.1	83.4	89.2	83.7	-49.1	-60.6	0.0	-0.1	62.8	-13.9	-13.9
	RMSE	0.14	0.19	0.14	0.17	0.14	0.11	0.14	0.42	0.2	0.15	0.15	0.13	0.22	0.22
	No obs data points	11	11	44	44	44	44	44	44	10	10	10	22	22	22
	Range of observed levels	0.5	0.5	1.2	1.2	1.2	1.2	1.2	1.2	0.5	0.5	0.5	0.7	0.7	0.7

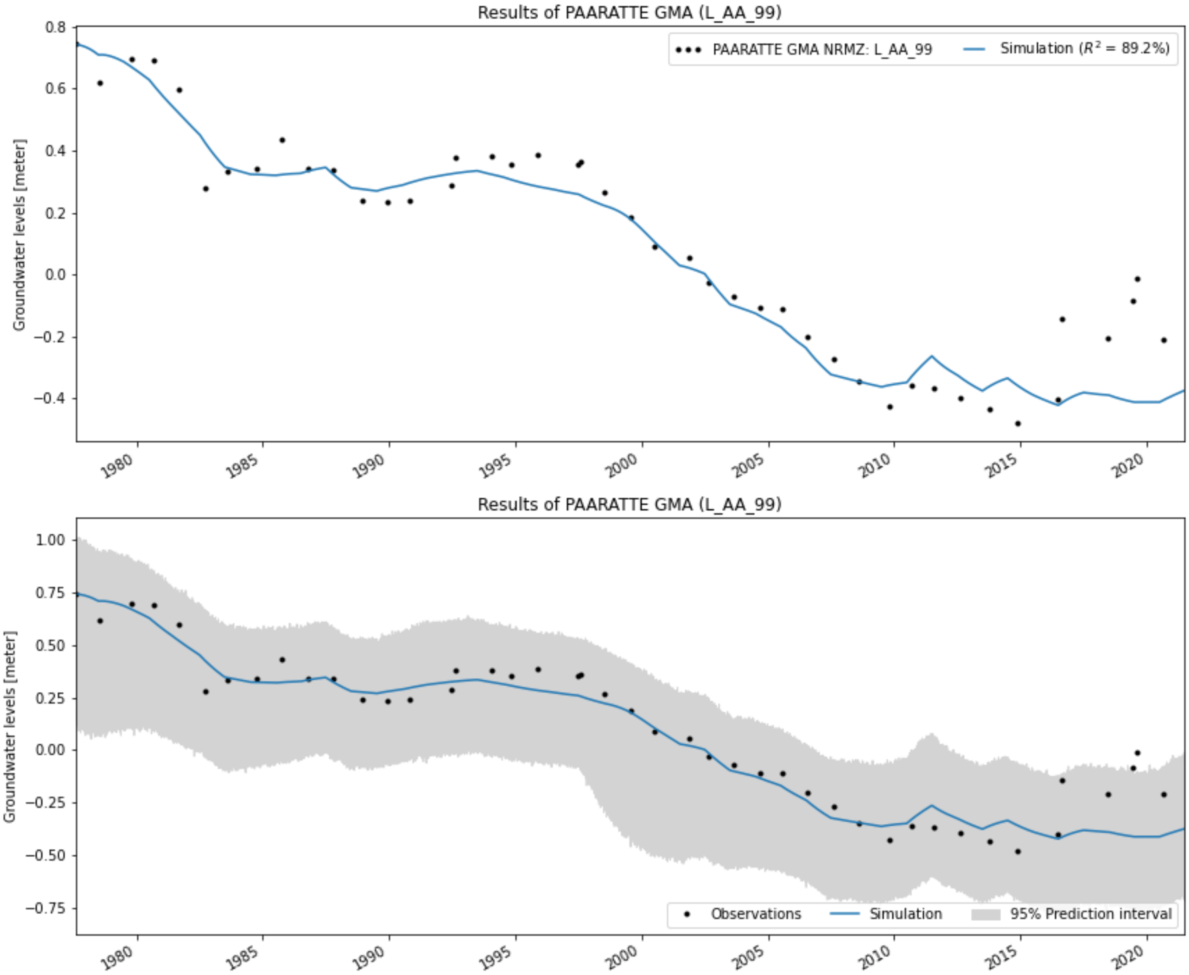


Figure 513 *Paaratte GMA Suite L_AA_99: model run 9 (Paaratte GMA annual extraction with hindcast method 3) output hydrographs*

30.4 Predictive modelling

30.4.1 Model inputs

The preferred model to run the predictive modelling for Paaratte GMA was model run 9c for the representative Suite. The key inputs for the model were the annual recovered levels, the annual extraction hindcasted using method H3 and annual climate data. To conduct the forecasting for the 19 scenarios discussed in section 3.5.3, a few factors were required in the calculations; these factors are summarised in Table 186.

Table 186 *Paaratte GMA: forecast scenario inputs*

Input item	PCV	Licenced entitlement (based on 2020/21)	Existing use (based on 2020/2021)	Average use over recorded period (from VWA)	Maximum use over recorded period (from VWA, year 2015/16)
Value (ML/year)	4,606	3,159	281	321	367

30.4.2 Predictive model uncertainty

The model output files of the predicted models can be found in the data package provided as part of Appendix E.

MCMC predictions were undertaken on each of the forecasted scenarios for the representative Suite. An example of one of the outputs is presented in Figure 514 for scenario 5. As shown in Figure 514, the uncertainty of the model prediction increases as the model predicts further into the future. Comparing with the graphical output for the same scenario, the MCMC realisations tend to fall within the 95% prediction interval bands, however, there are a few realisations plotting outside of this prediction band as shown in Figure 515.

Uncertainty is also accounted for by using 19 forecast scenarios to develop a groundwater use to drawdown relationship (analogous to a Monte Carlo type simulation) where a range of possible outcomes are generated. It is noted however, that the forecast scenarios were not randomly generated, but rather based upon a series of estimated use behaviours.

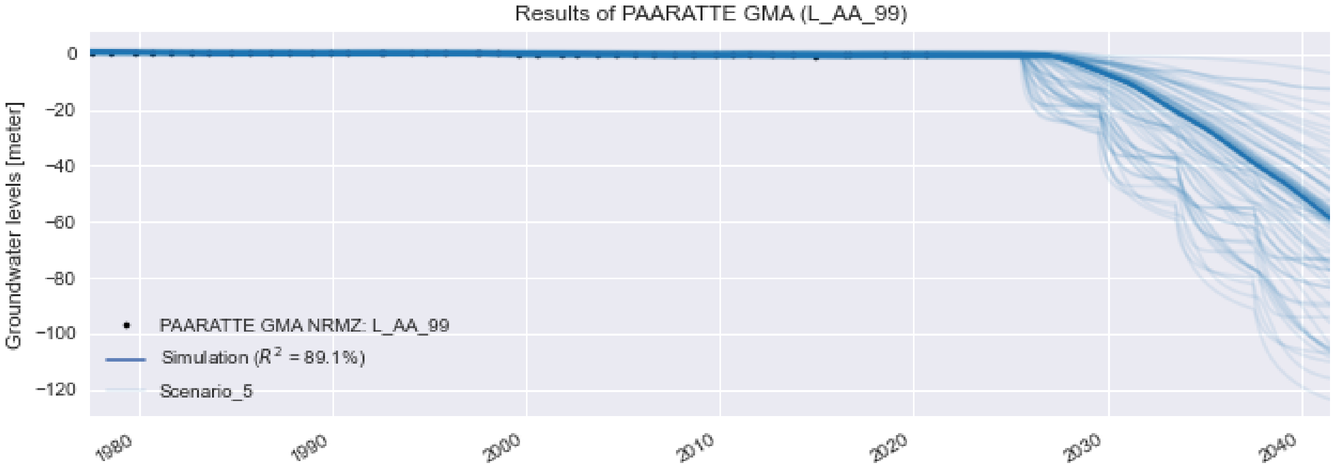


Figure 514 ***Paaratte GMA: Suite L_AA_99 MCMC analysis for Forecast Scenario 5***

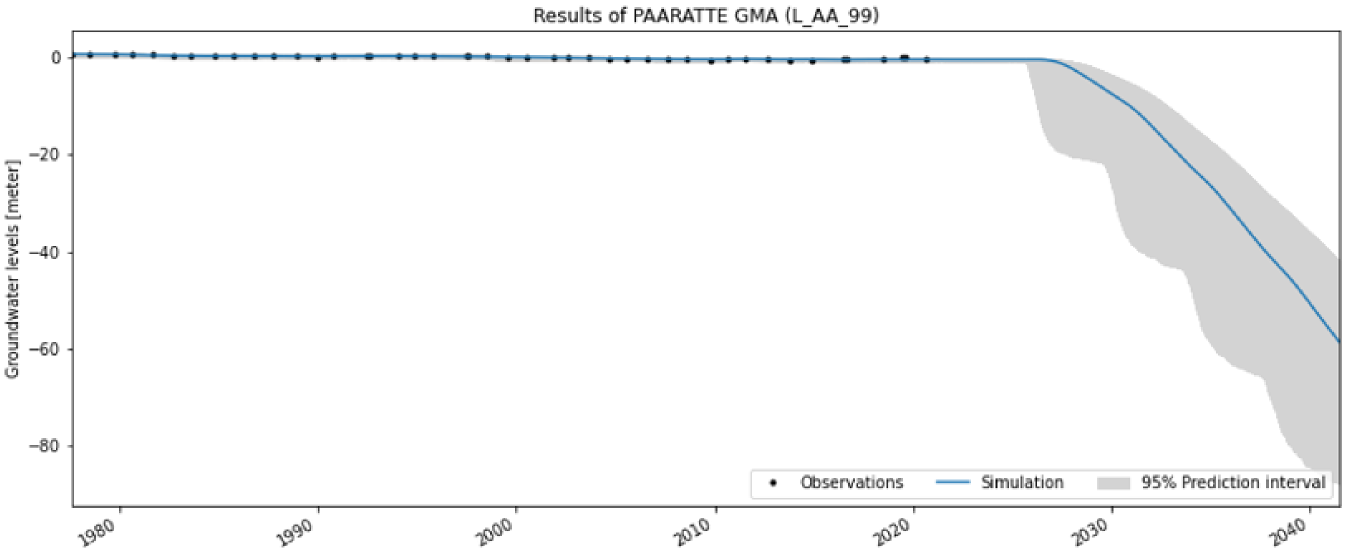


Figure 515 ***Paaratte GMA: Suite L_AA_99 Forecast Scenario 5 with 95% prediction bands***

30.4.3 Extraction vs drawdown

To calculate the drawdown based on the annual recovered levels simulated by the model, the pre-development conditions (pre commencement of extraction) need to be estimated. For Paaratte GMA, the water level prior to groundwater development was unknown, due to:

- Uncertainty regarding the commencement of development in some GMUs
- The initiation of groundwater development preceding SOBN bore installation and temporal groundwater monitoring

Using the pre-development levels defined in section 30.2.2, the modelled water levels were converted into drawdowns (from this baseline pre-development level) for each of the 19 scenarios. This predevelopment condition is shown in Figure 516 for Suite L_AA_99 through the hydrograph of annual recovered levels.

In Figure 516:

- Actual annual groundwater use is represented by the blue column graph between 2009/2010 and 2020/2021
- Hindcasted groundwater use is represented by the orange columns between 1976/1977 and 2009/2010
- Forecasted use is represented by the grey columns after 2021/2022
- The annual recovered water level behaviour based on recorded data is represented by the red line graph
- The pre-development annual recovered levels are taken to be the average of the first six readings which equate to 0.66 m
- The modelled forecasted annual recovered levels are represented by the purple line in Figure 516
- The calibration annual recovered levels are represented by the black line in Figure 516

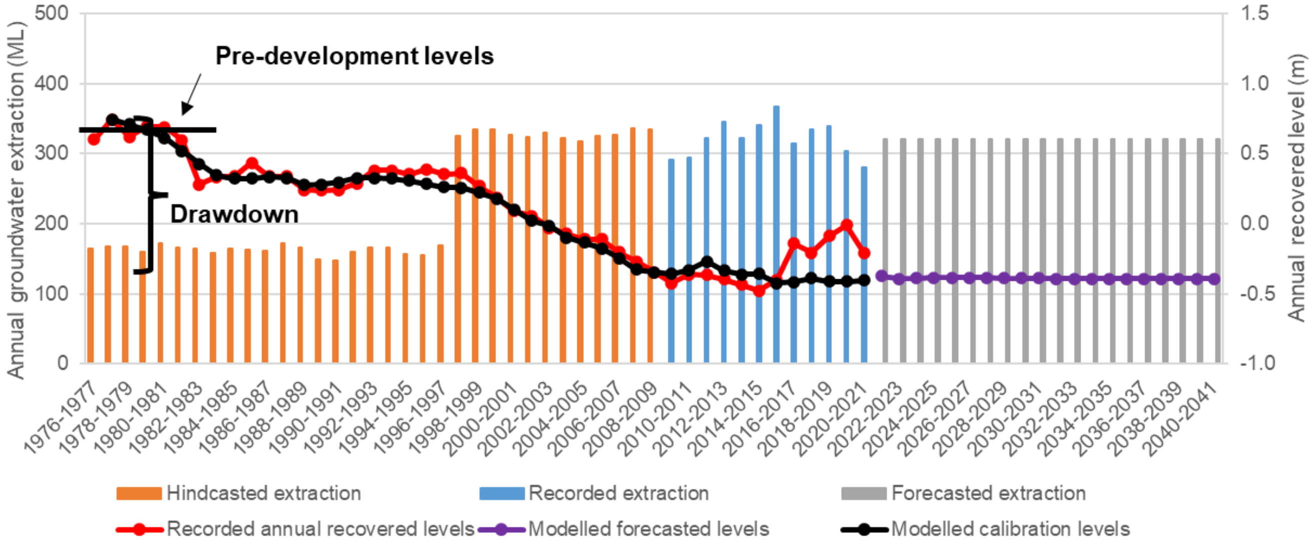


Figure 516 Estimating pre-pumping water levels (example from Suite L_AA_99)

For Suite L_AA_99, the calculated drawdowns and volumes for each of the scenarios were plotted in individual graphs for each scenario, all scenarios together in the one graph (Figure 517) and a graph of the scenarios for specific time periods (Figure 518) to develop the volume to drawdown relationship. For each scenario, a linear regression was applied and the coefficient of determination was calculated. A comparison of each of these graphs shows some variations in the coefficient of determination. Given this, the drawdown-use plot of all scenarios was adopted to capture these variations.

The use-drawdown for all 19 forecast scenario drawdowns and volumes (both the recorded and forecasted volumes) over each year modelled (1977 to 2041) is shown in Figure 517 for Suite L_AA_99. Note the abscissa range of the chart has been clipped and does not show forecast drawdowns for the higher use scenarios (more improbable).

Reviewing these figures, the following is noted:

- There should be zero drawdown under zero use and therefore a line of best fit should pass through the origin (0,0) or close to it
- Average use is around 300 ML. Figure 517 indicates that at this volume of usage the model forecast drawdwon tends to occur around the predicted line of best fit
- For the same annual use, different drawdowns can be obtained as Pastas predicts a water level for each year. For example, Figure 518 shows a scenario where groundwater use remains constant at around 320 ML/year over the next 20 years
- The correlation for groundwater use and drawdown for Suite L_AA_99 is excellent as shown in Figure 517
- The various forecast scenarios generally result in data plotting reasonably close together in a linear trend. The 19 forecast scenarios applied to populate the chart is analogous to a Monte Carlo type simulation where a range of possible outcomes are generated. It is noted however, that the forecast scenarios were not randomly generated, but rather based upon a series of estimated use behaviours.

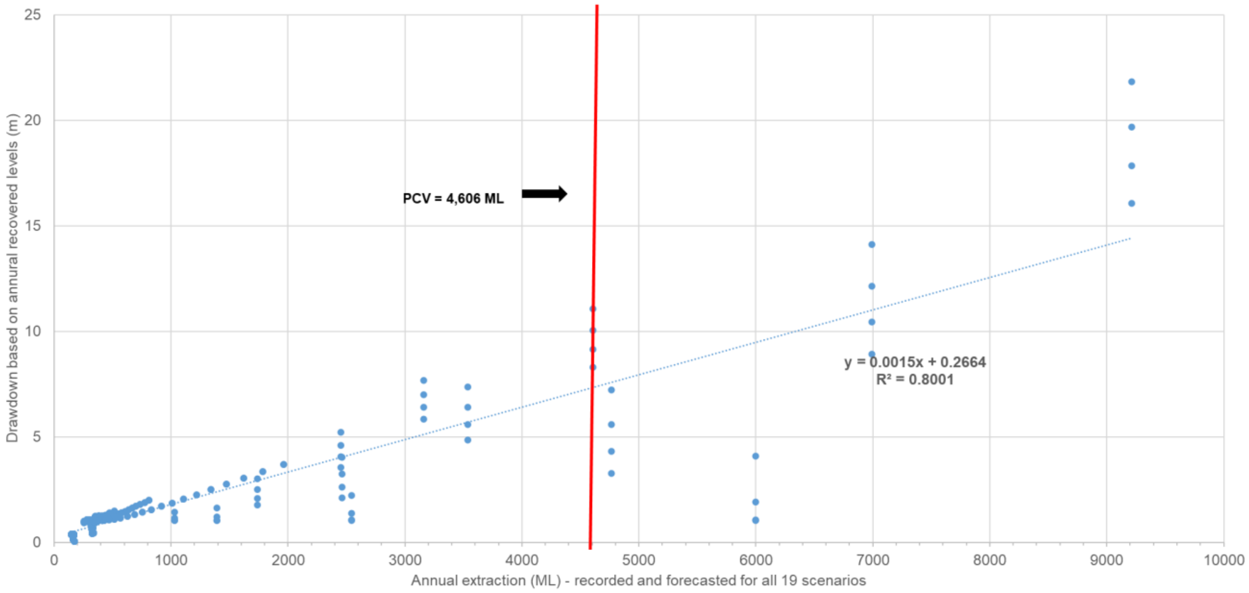


Figure 517 *Paaratte GMA Suite L_AA_99: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <9,500 ML) for all data between 1993 to 2041 and all forecasted scenarios*

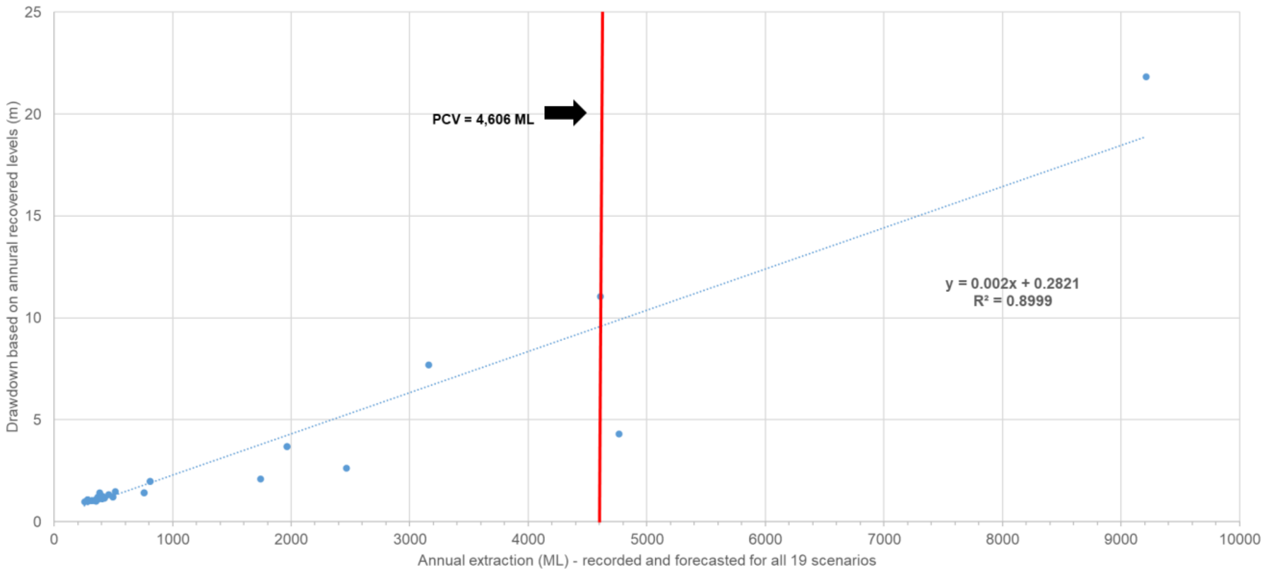


Figure 518 *Paaratte GMA Suite L_AA_99: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <9,500 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

30.5 Sustainability metrics

30.5.1 Application of metrics

Using the use - drawdown relationships developed through the previous step of forecasting aquifer response under a range of use scenarios, groundwater drawdown can be used to compare against groundwater resource sustainability metrics.

The application of these metrics and the relationship developed between drawdown based on the Suite annual recovered levels and extraction volume for the whole GMU, which is shown in Table 187 for Paaratte GMA Suite L_AA_99 (noting Paaratte GMA has a current PCV of 4,606 ML/year). As part of the modelling, a 95% prediction interval band was applied to the modelling results. The relationship between drawdown and extraction volumes can also be interrogated at the lower and upper bands of the 95% prediction interval as shown in Table 187 and Figure 519 for Suite L_AA_99.

A summary of volumes at drawdown intervals provided by DEECA for Suite L_AA_99 is shown in Table 188Table 182. Based on Suite L_AA_99, 5 m of drawdown is predicted to occur at a groundwater extraction volume of 3,200 ML (which could range from 1,500 ML to 4,800 ML) and a 10 m of drawdown is predicted to occur at a groundwater extraction volume of 6,500 ML (which could range from 3,200 ML to 9,800 ML)

Table 187 Relationship of Suite drawdown to GMU extraction for Paaratte GMA Suite L_AA_99

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_AA_99 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
10,000	15.3 (10.2 - 31.2)
9,000	13.8 (9.2 - 28.1)
8,000	12.3 (8.2 - 25)
7,000	10.8 (7.2 - 21.9)
6,000	9.3 (6.2 - 18.8)
5,000	7.8 (5.2 - 15.7)
4,000	6.3 (4.2 - 12.6)
3,000	4.8 (3.2 - 9.5)
2,000	3.3 (2.2 - 6.4)
1,000	1.8 (1.2 - 3.3)
0	0.3 (0.2 - 0.2)

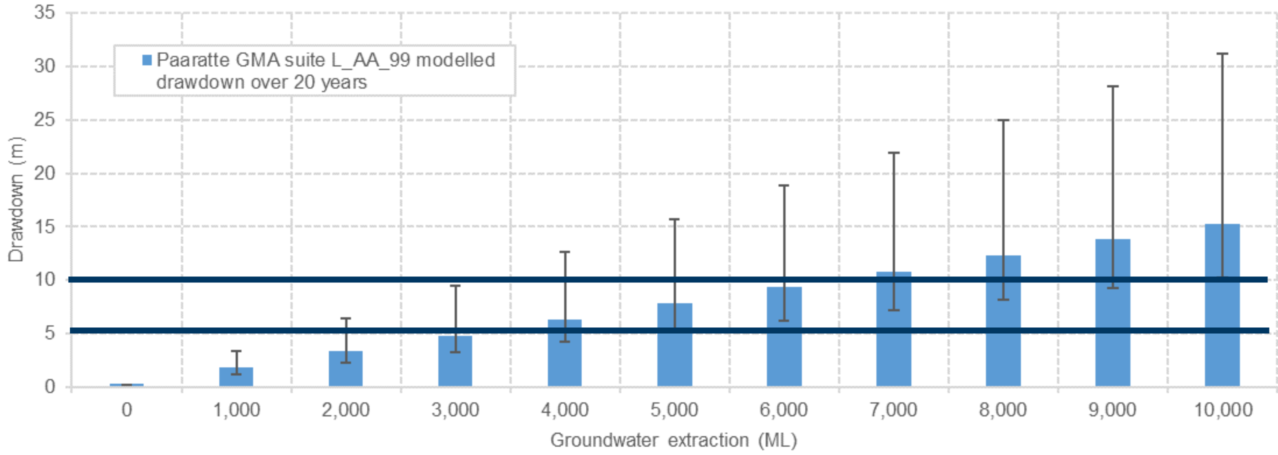
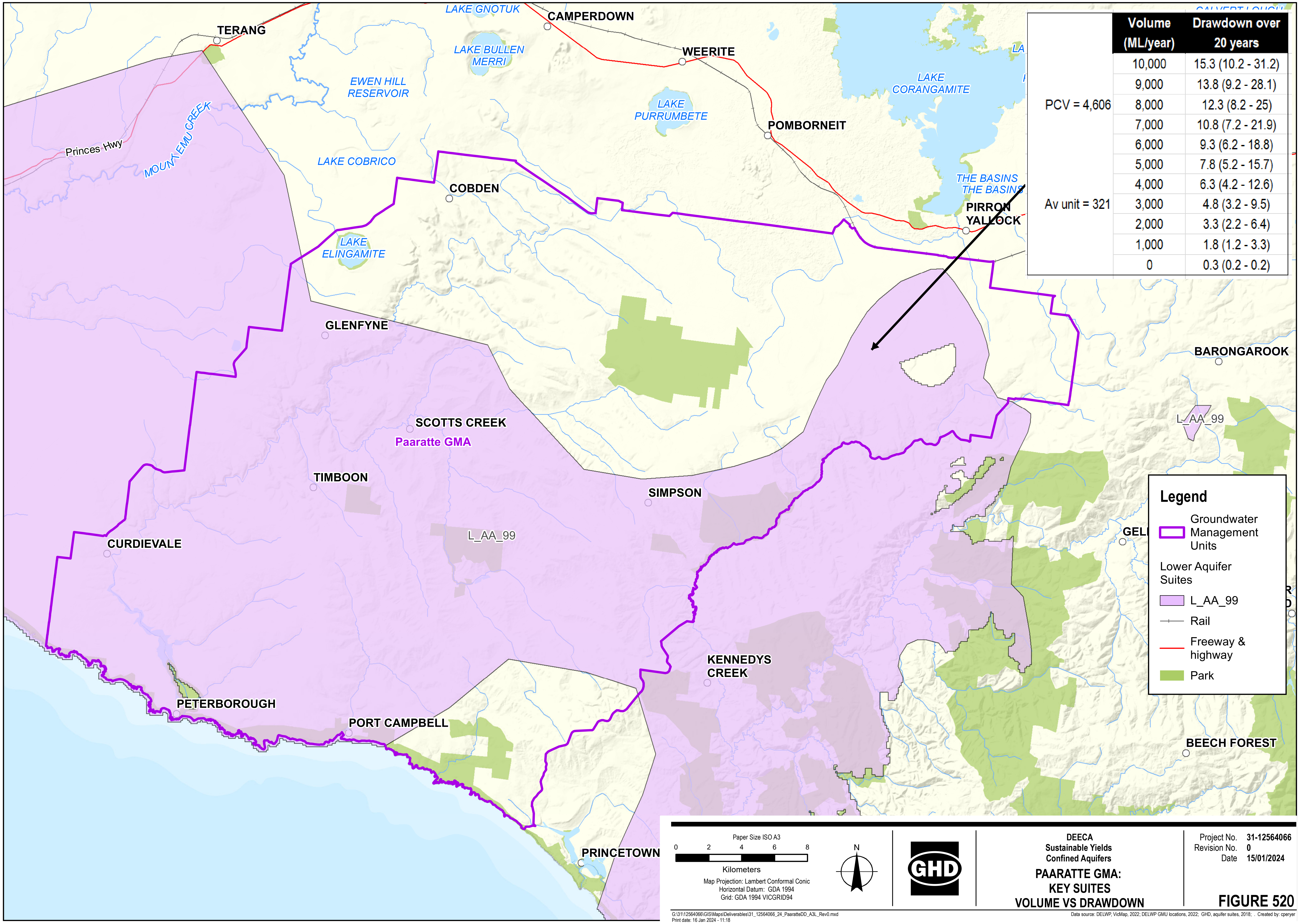


Figure 519 Paaratte GMA Suite L_AA_99: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 188 Predicted volumes for drawdown metrics

Drawdown (m) confined aquifer	Predicted volumes (ML) for GMU based on Suite L_AA_99 drawdowns (lower limit to upper limit)
5	3,200 (1,500 – 4,800)
10	6,500 (3,200 – 9,800)



	Volume (ML/year)	Drawdown over 20 years
PCV = 4,606	10,000	15.3 (10.2 - 31.2)
	9,000	13.8 (9.2 - 28.1)
	8,000	12.3 (8.2 - 25)
	7,000	10.8 (7.2 - 21.9)
	6,000	9.3 (6.2 - 18.8)
	5,000	7.8 (5.2 - 15.7)
	4,000	6.3 (4.2 - 12.6)
Av unit = 321	3,000	4.8 (3.2 - 9.5)
	2,000	3.3 (2.2 - 6.4)
	1,000	1.8 (1.2 - 3.3)
	0	0.3 (0.2 - 0.2)

Paper Size ISO A3
0 2 4 6 8
Kilometers
Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 VICGRID94

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DEECA
Sustainable Yields
Confined Aquifers

PAARATTE GMA: KEY SUITES VOLUME VS DRAWDOWN

Project No. 31-12564066
Revision No. 0
Date 15/01/2024

FIGURE 520

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Print date: 16 Jan 2024 - 11:18

Data source: DELWP, VicMap, 2022; DELWP GMU locations, 2022; GHD, aquifer suites, 2018; . Created by: cperyer

30.6 GMU summary

30.6.1 Findings

Paaratte GMA primarily relates to the Mepunga/Dilwyn Formation aquifer (LTA), where groundwater is predominately extracted for urban supply purposes. The LTA falls within the Lower Aquifer Suites, which at Paaratte GMA comprises Suites L_AA_99 (60%), L_AB_9 (15%), L_AC_1 (2%) and L_Y_3 (55). The identified representative Suite is L_AA_99. The Suite hydrographs for the representative Suite show seasonal fluctuations and thus recovered water levels, which were adopted for the assessment.

Application of two yearly annual average extraction, rather than annual average extraction, generally showed a poorer model fit based on the statistical analysis across the model runs. The best model result, using the two yearly average annual extraction, was the model that included hindcast method H1 to extrapolate extraction into the past.

The application of spatial distribution produced a poorer model for the base model run for the whole GMU. The quality of the result did not increase when spatial distribution methodology was combined with hindcasting methodology.

Based on an assessment of all model runs, model run 9 for Paaratte GMA annual extraction hindcasted using method H3 was the best model result, however this was improved further by adding annual climate data to create model run 9c. Model run 9c was adopted to undertake the predictive modelling for Suite L_AA_99.

The pre-development levels were defined for the Suite based on the early time series Suite data for the annual recovered levels; this resulted in a pre-developments level of 0.66 m for Suite L_AA_99. The drawdowns were calculated based on these pre-development levels and the simulated levels from each of the 19 forecast scenarios.

The volumes estimated for a given drawdown for each Suite is shown below.

Drawdown (m) confined aquifer	Predicted volumes (ML) for GMU based on Suite L_AA_99 drawdowns (lower limit to upper limit)
5	3,200 (1,500 – 4,800)
10	6,500 (3,200 – 9,800)

The model applicability using Suite L_AA_99 was assessed as having an “Excellent” model applicability rating using the criteria outlined in section 5.2. For this Suite, due to the limited range in calibration volumes, the greater the proposed extraction rates beyond the calibration range leads to a greater potential for drawdown forecast errors.

30.6.2 Limitations

In addition to the limitations applicable to all 25 GMUs discussed in section 1.8, the following Paaratte GMA specific limitations have been identified:

- There is a limited recorded annual extraction dataset available for Paaratte GMA
- The licenced bore dataset provided by DEECA has 12% of bores assigned to Paaratte GMA with no depth data and thus couldn’t be assigned to a VAF layer and in turn Suite. These bores were assigned to an aquifer through this study by GHD, in order to assist with the determination of the representative Suite. However, this data was not used in the model analysis.
- Model calibration for suite L_AA_99 was completed using a groundwater extraction range of approximately 150-400 ML/year (below the current PCV of 4,606 ML/year, or around 10% of the PCV)
- The greater the proposed extraction rates beyond this calibration range the more potential for drawdown forecast errors. In this GMU, drawdown prediction for extraction volumes up to 16 times the calibration range are being made to meet the 10m drawdown metric.
- Further checks and potential re-calibration may be required as extraction rates increase for this GMU

30.6.3 Recommendations

In addition to the recommendations applicable to all 25 GMUs discussed in section 32, the following Paaratte GMA specific recommendations have been identified:

- The licenced bore dataset provided by DEECA has 12% of bores assigned to Paaratte GMA with no depth data and thus couldn't be assigned to a VAF layer and in turn Suite. It is recommended that DEECA obtains the relevant depth and aquifer monitored data for licenced bores within this GMU.

31. Portland GMA

31.1 Conceptualisation

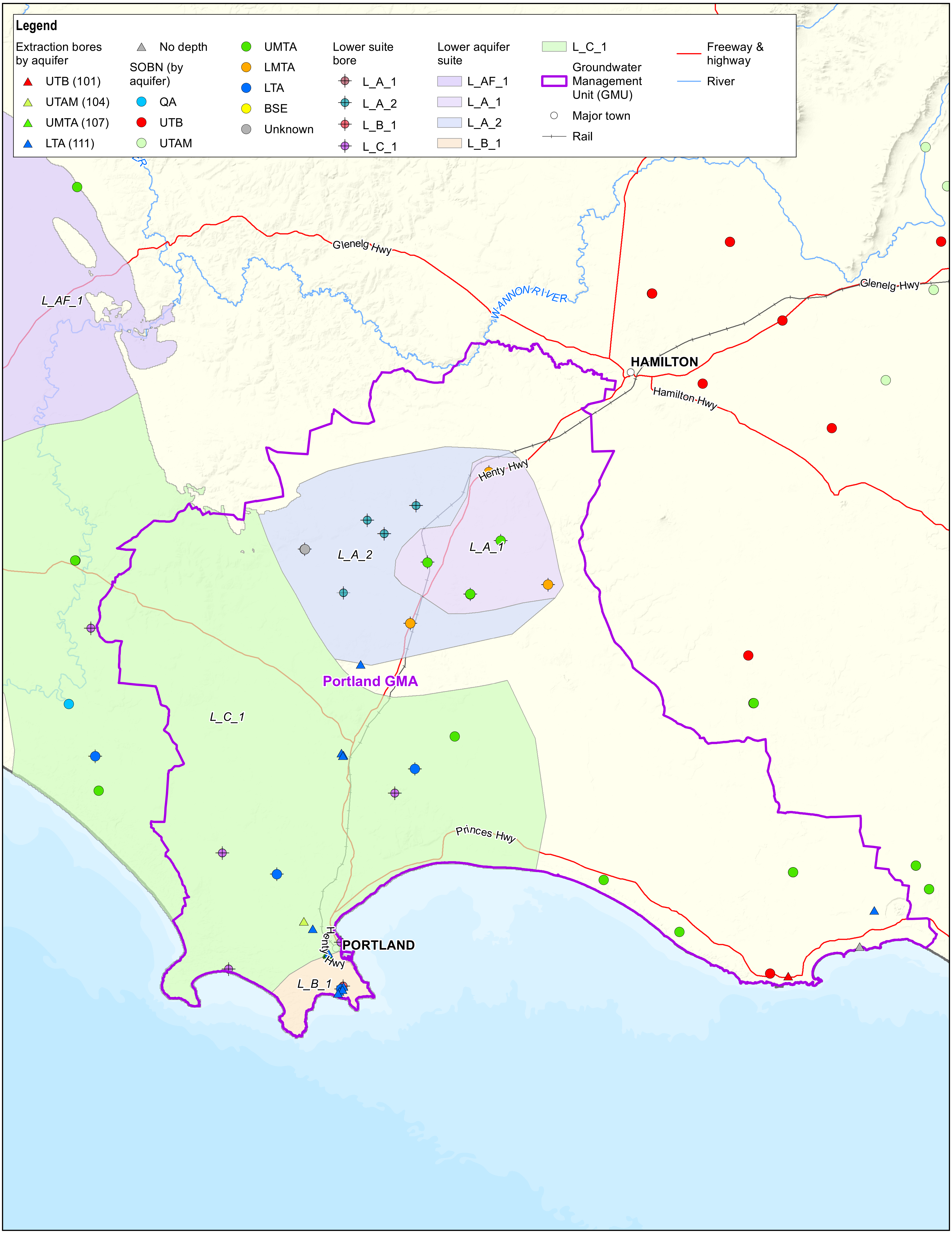
The hydrogeological conceptualisation elements relevant to this study are summarised in Table 189 and a map of the GMU is presented in Figure 521. It is noted that a significant volume of information was collated to inform the hydrogeological conceptual understanding of the GMU. The information that is directly relevant to the modelling are in bold or colour coded within Table 189.

Table 189 Portland GMA – Tabulated conceptualisation

GMU summary								
The Portland GMA is situated in the Otway Basin, covering an area of approximately 4,000 km^2 which includes the western extent of the Basalt Plains of Western Victoria. Represented by the western boundary is a north-south flow line in the Dilwyn Formation from the nose of the Merino high to the coast, whilst the margin of the Merino Block is represented by the northern boundary. The GMA eastern boundary extends to cover Port Fairy and coastline bounds the south as shown in Attachment A, Figure 20. Portland GMA pertains to all formations below 200 m below the ground surface but was primarily intended to manage groundwater resources of the Mepunga/Dilwyn Formation (Lower Tertiary Aquifer, LTA). The PCV (7,795 ML/year) therefore relates to confined aquifers. The Portland GMA is overlain by Condah WSPA and South West Limestone GMA. Groundwater in this GMA is extracted predominately for urban supply, having the highest urban use of any Victorian GMU. DEECA have anecdotally advised that groundwater was also used previously for geothermical use in hospitals and council buildings.								
Hydrostratigraphy summary								
Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Use volumes ML (2019/20)	Entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Quaternary Sediments Bridgewater Formation (QA)	U_D_8 (10%)	10%	0	NA	0	0	Low
	Newer Volcanic Group (UTB)	U_A_1 (1%), U_A_2 (75%), U_B_1 (1%)	77%	0	Urban	311	513	Low
	Hanson Plain Sands (UTAM)	-	-	-	Urban	0	0	Low – WMIS and licensed bore data indicate urban use, which may be incorrect
Middle	Port Campbell Limestone (UMTA)	M_A_2 (5%), M_A_3 (2%), M_A_4 (10%), M_A_5 (2%), M_B_1 (4%), M_C_1 (<1%)	23%	0	Urban	0	0	Low
	Gellibrand Marl (UMTD)	-	0%	0	NA	0	0	Low
Lower	Clifton Formation (LMTA)	-	0%	0	NA	0	0	Low
	Narrawaturk Marl (LMTD)	-	0%	0	NA	0	0	Low
	Mepunga/Dilwyn Formation (LTA)	L_A_1 (6%), L_A_2 (11%), L_B_1 (1%), L_C_1 (41%)	59%	3	Stock, domestic, dairy, irrigation, urban	1,772	6,693	Medium
Basement		B_A_1 (<1%)	<1%	0	NA	0		Low
Note that volumes listed above are based on the DEECA provided licenced bore dataset with associated VAF layers. Bores have been assigned to a VAF layer based on bore depth where available. Note that volumes listed above do not include 311 ML of unassigned use due to unknown depths (588 ML of entitlement)								

GMU summary		
Characteristic and importance	**Description**	**Degree of understanding**
Intended aquifer (LTA, highlighted blue above)		
Aquifer thickness within GMU (range, based on VAF)	Max: 2114 m, Average: 498 m	High
Aquifer extent	Regional, extensive	High
Likelihood of inter-aquifer flow	Low	Low
Likelihood of groundwater – surface water interaction	Medium (in intake areas for the aquifer)	Low
Representative Suite	**L_B_1**	**Medium. 46% of GMU extraction occurs within this Suite, which relates to the most relevant GMU aquifer.**
Current hydrological condition of representative aquifer		
Representative Suite trend	Decreasing	Medium
Groundwater quality (average salinity based on WMIS and CDM Smith spatial segment(s) with highest coverage)	Varies significantly across the GMU	Low Based on CDM Smith (2022)
Groundwater yield	<50 L/s	Low Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1974-2021**	**High**
Spatial clustering of licensed bores in relation to Suites	**Yes, L_B_1**	**Based on DEECA density mapping and licenced bore data.**
Groundwater use		
Licensed groundwater use	**2,606 ML**	**High (Based on average historical VWA data over 15 years)**
Minimum historic groundwater use	2,121 ML	High (Based on historical VWA data, year 2008/09)
Maximum historic groundwater use	**3,244 ML**	**High (Based on historical VWA data, year 2006/07)**
Entitlement (Groundwater allocation)	**7,794 ML**	**High (Based on licenced volumes in 2020/21)**
Significant drivers of groundwater level variability (primary)	**Pumping for town water supply**	**Moderate**
Secondary drivers of groundwater level variability	Pumping for stock or domestic use	Moderate
Groundwater use profile	Stable (even monthly distribution)	Low

GMU summary		
External Influence	**None identified outside of surrounding Victorian GMUs**	
Groundwater values and risks		
Existing Environmental Values to be protected, relevant to this GMU	Potable water supply Licensed non-potable supply (irrigation, commercial, industrial) Unlicensed non-potable supply (domestic and stock)	
Risks to groundwater values	Direct risks: – Drawdown which may affect access to groundwater by existing users	
Indicators used to assess impacts to groundwater	– Measured drawdown using pre-determined metrics measured from a pre-determined level for the purpose of this modelling	



Paper Size ISO A3

0 2.5 5 7.5 10

Kilometers

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 VICGRID94

N

DEECA
Sustainable yield review - confined aquifers

Portland GMA
Site location and key features

Project No. **12564066**
Revision No. **0**
Date **16/01/2024**

Figure 521

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Print date: 16 Jan 2024 - 12:44

Data source: DELWP, VicMap, 2022; DELWP, GMUs, 2022; DELWP, SOBN, 2022; GHD, aquifer suites, 2018; DELWP, extraction bores, 2022 Created by: cperyer

31.2 Technical analysis

31.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the relevant Suites for Portland GMA as shown in Figure 522. The Suite hydrographs show a trend of seasonal fluctuations and thus annual recovered levels. All Suite hydrographs show a general declining trend with Suite L_B_1 showing a sudden decrease between 2001 and 2017 which does not align with the Millenium drought and does not look "real". Thus Suite L_B_1 will not be included in the assessment.

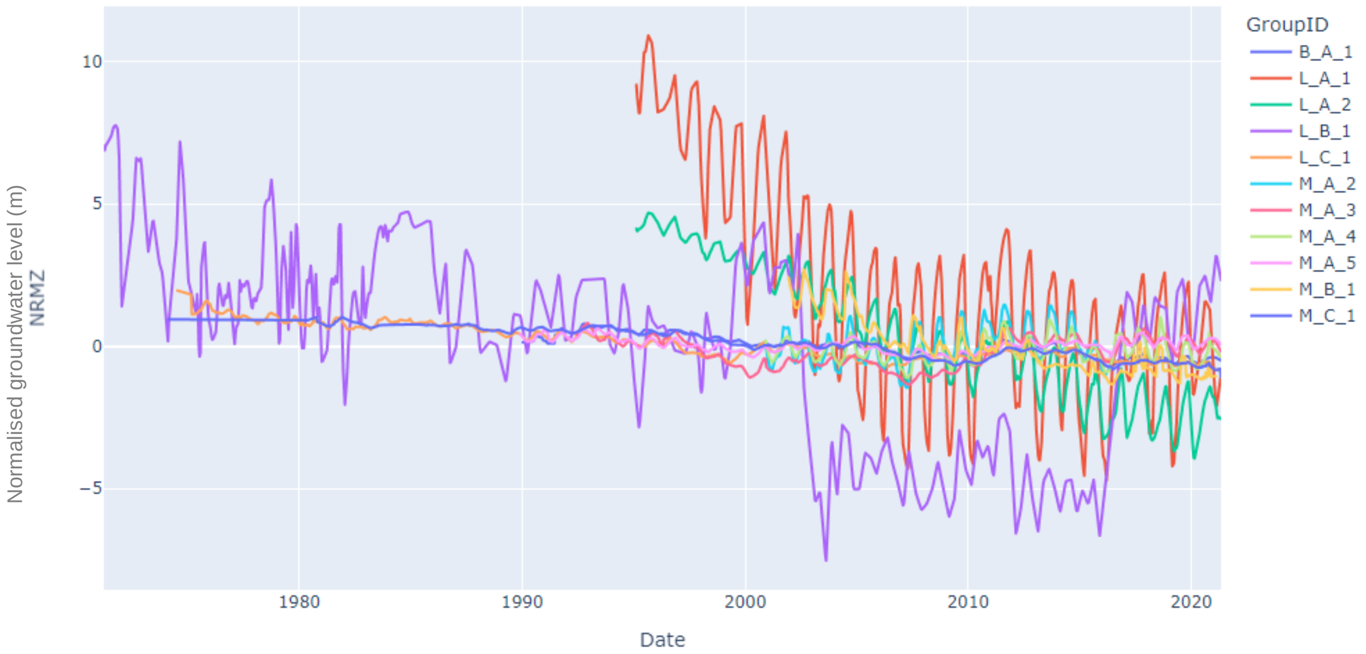


Figure 522 Portland GMA Suite Hydrographs for all confined aquifers

The representative Suites analysed for this GMU were Suites L_A_2 and L_C_1. The Representative Suites were selected based on the methodology outlined in section 2.6.4 which identified Suite L_B_1 as the most representative followed by Suite L_C_1 then L_A_2. However, due to hydrograph issues with L_B_1, analysis did not progress for this Suite and thus L_C_1 was taken forward as the most representative Suite. The process is summarised as follows:

- The greatest volume of extraction occurs within the Lower Aquifer
- The Lower Aquifer pertains to the LTA, which is the intended aquifer of the GMU
- Suite L_A_1 covers 6% of the GMU, while Suite L_A_2 covers 11%, Suite L_B_1 covers 1% and Suite L_C_1 covers 41%
- 41% of extraction occurs within Suite L_B_1, followed by 27% in Suite L_C_1
- Suite L_B_1 has one active SOBN bores within the Suite area
- The Suite bores for Suite L_B_1 are close to extraction points

The annual recovered Suite hydrographs for the representative Suites L_A_2 and L_C_1 for Portland GMA, are shown in Figure 523.

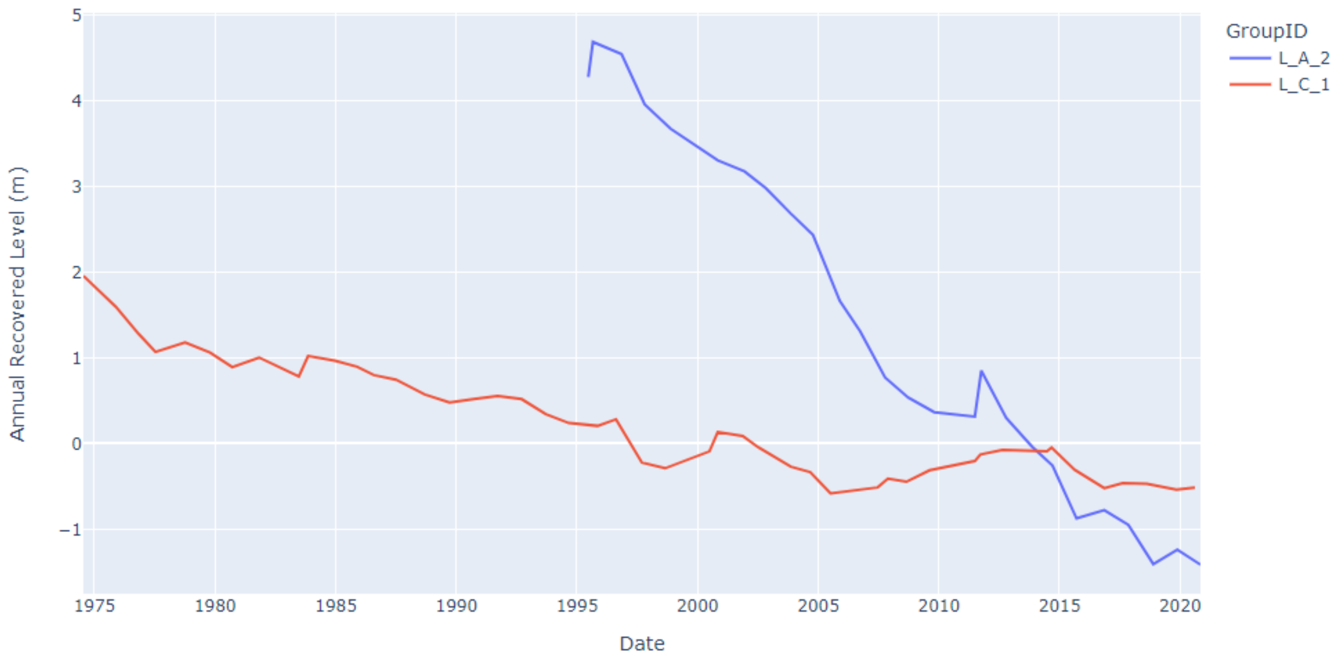


Figure 523 ***Portland GMA Annual Recovered Level Suite Hydrographs for representative Suites***

31.2.2 Pre-development level

To estimate the pre-development level conditions, GHD reviewed the Suite hydrograph of annual recovered levels and assumed that the early time series data was the best representation of conditions prior to major development within Paaratte GMA for the representative Suite.

The pre-development annual recovered level was taken to be the first reading in the time series data for Suite L_C_1, which occurred in the year 1974/1975 and equates to 1.96 m. The pre-development annual recovered level was taken to be the average of the first three readings in the time series data for Suite L_A_2, which occurs over the years 1994/1995 to 1996/1997 and equates to 4.50 m (refer further details in section 31.4.3).

31.2.3 Externalities

Through the conceptualisation, no external influence was identified for Portland GMA (outside of the surrounding GMUs).

31.2.4 Hindcasting

Groundwater use data for Portland GMA is available from 2006/2007 to 2020/2021. The hindcasting methodologies outlined in section 3.3.4.5 were applied to Portland GMA. A summary of the hindcasting results is shown in the following sections. It is noted that as groundwater use in Portland GMA is driven by how much water is needed for town water supply, the relationship may not be linked to climate. However, for completion and to test this assumption, the hindcasting method have been applied.

31.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, four different correlations were developed using the annual groundwater extraction as described below and shown in Figure 524:

- Annual rainfall vs annual groundwater extraction at Portland GMA
- Two yearly average annual rainfall vs annual groundwater extraction at Portland GMA
- Annual summer period rainfall vs annual groundwater extraction at Portland GMA
- Annual irrigation period rainfall vs annual groundwater extraction at Portland GMA

As shown in Figure 524, the goodness-of-fit represented by the R^2 is low across all four correlations developed. The highest R^2 was with the annual irrigation rainfall; this is the correlation adopted for method H1.

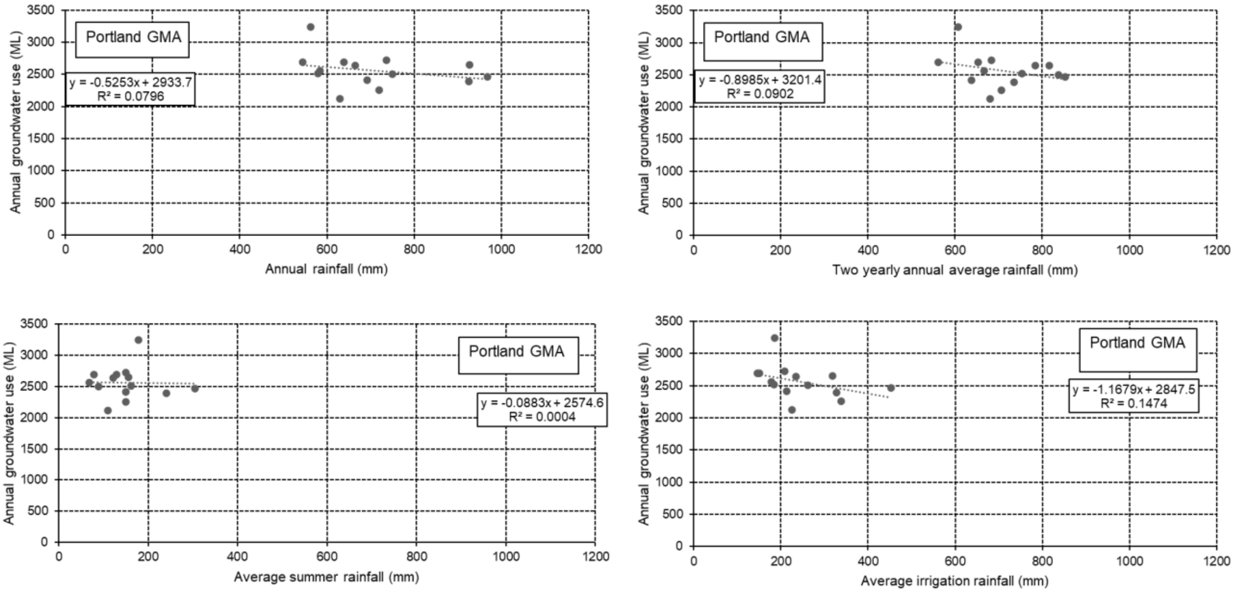


Figure 524 Portland GMA: Hindcast method 1 correlations (Portland GMA annual extraction)

31.2.4.2 Hindcasting Method 2 (H2)

Similar to method H1, four correlations were developed using method H2 as described below and shown in Figure 525:

- Portland GMA use per Portland GMA bore vs annual rainfall
- Portland GMA use per Portland GMA bore vs two yearly average annual rainfall
- Portland GMA use per Portland GMA bore vs annual summer period rainfall
- Portland GMA use per Portland GMA bore vs annual irrigation period rainfall

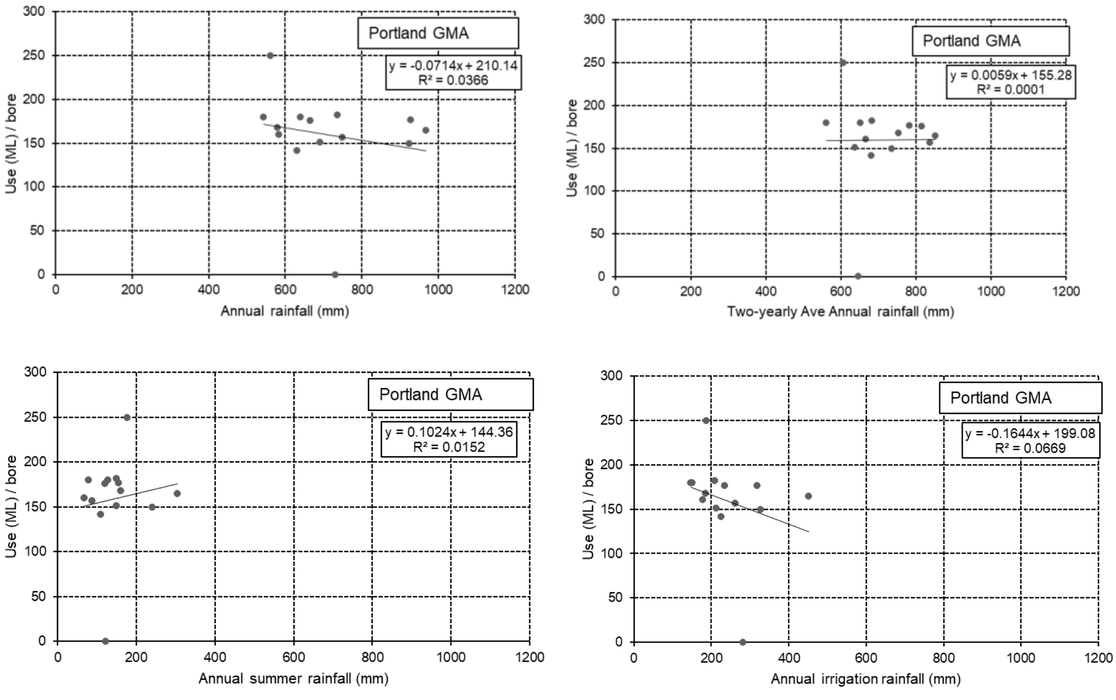


Figure 525 Portland GMA: Hindcast method 2 correlations

As shown in Figure 525, the goodness-of-fit represented by the R^2 is low across all four correlations. The highest R^2 is the correlation with annual irrigation rainfall. Thus, the correlation with annual irrigation rainfall has been adopted for hindcast method H2.

31.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 526:

- Percentage of entitlement vs annual rainfall
- Percentage of entitlement vs two yearly average annual rainfall
- Percentage of entitlement vs annual summer period rainfall
- Percentage of entitlement vs annual irrigation period rainfall

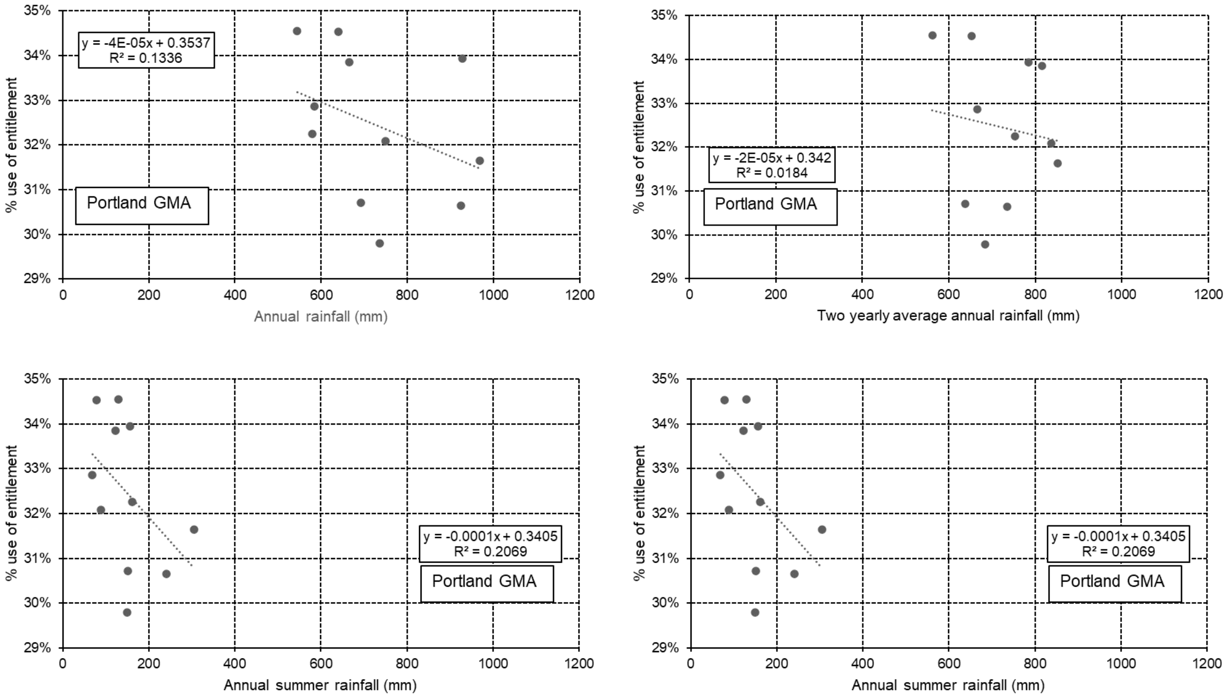


Figure 526 Portland GMA: Hindcast method 3 correlations

As shown in Figure 526, the goodness-of-fit represented by the R^2 was again low across all four correlations. The highest R^2 was the correlation with annual summer rainfall followed by the correlation with annual irrigation rainfall. Thus, the correlation with annual summer rainfall has been adopted for hindcast method H3.

31.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 527 and Figure 528 for the hindcasting based on Portland GMA groundwater use. Figure 527 shows a comparison of the three hindcasting methods against the recorded use only over the recorded use date, while Figure 528 shows the hindcasted data back to 1970/1971 (start of hydrograph period).

As shown in Figure 528, groundwater use using method 1 does not decrease historically as there is no factor to account for the changing number of bores extracting over time. The hindcasting results show that the smallest average variation of recorded use to estimated use occurs for method 1; however, this is likely to overestimate when looking at historical extraction. Method 3 shows the second closest estimates to the recorded use and given that this method takes into account the decreasing number of bores into the past, this hindcasting method is expected to provide a more probable estimated groundwater use than the other two methods for Portland GMA.

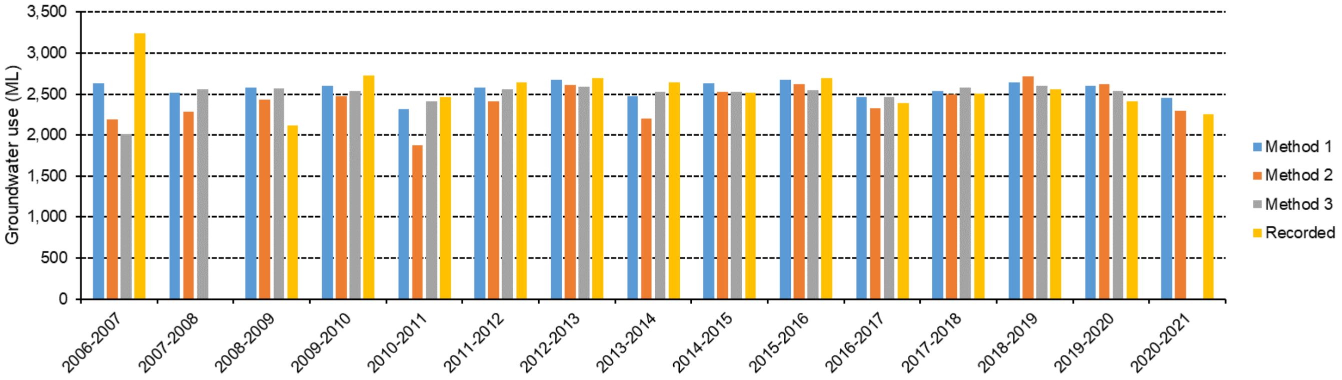


Figure 527 ***Portland GMA: Comparison of hindcasting over recorded use period***

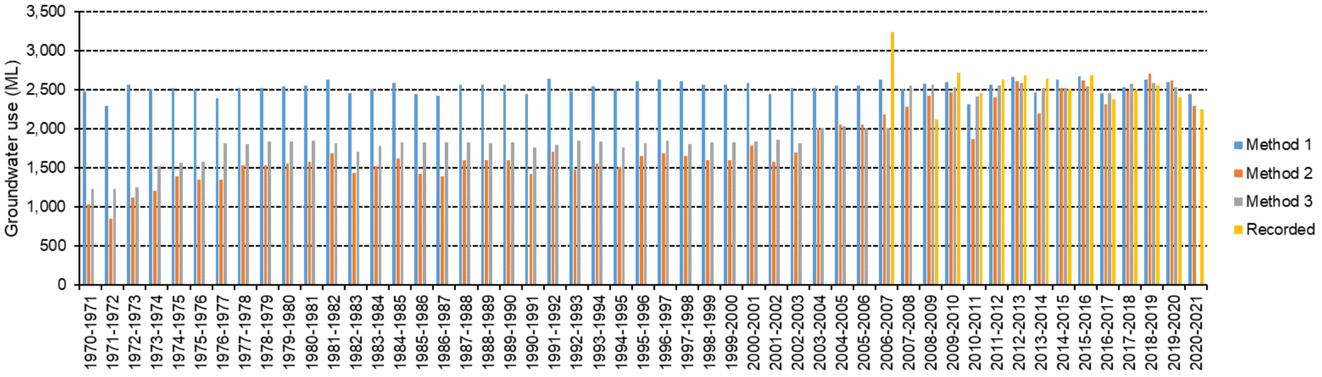


Figure 528 ***Portland GMA: Comparison of hindcasting***

31.3 Modelling

31.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 190 summarises these combinations of model inputs run for Portland GMA. Model runs highlighted blue were run with annual extraction and those highlighted grey were run using two yearly average annual extraction.

Table 190 Portland GMA: summary of model inputs

Model input	Model runs																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Annual recovered levels for representative Suites (L_A_2 and L_C_1)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Portland GMA only	✓																		
Two yearly average annual extraction – Portland GMA only		✓																	
Annual extraction – Portland GMA and Externalities			✓																
Two yearly average annual extraction – Portland GMA and Externalities				✓															
H1 annual extraction – Portland GMA only					✓														
H1 annual extraction – Portland GMA and Externalities						✓													
H2 annual extraction – Portland GMA only							✓												
H2 annual extraction – Portland GMA and Externalities								✓											
H3 annual extraction – Portland GMA only									✓										
H1 two yearly average annual extraction – Portland GMA only										✓									
H1 two yearly average annual extraction – Portland GMA and Externalities											✓								

Model input	Model runs																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
H2 two yearly average annual extraction – Portland GMA only												✓							
H2 two yearly average annual extraction – Portland GMA and Externalities													✓						
S1 annual extraction – Portland GMA only														✓					
S2 annual extraction – Portland GMA only															✓				
S3 annual extraction – Portland GMA only																✓			
S1 annual extraction and H1 annual extraction – Portland GMA only																	✓		
S2 annual extraction and H2 annual extraction – Portland GMA only																		✓	
S3 annual extraction and H3 annual extraction – Portland GMA only																			✓

31.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 190 is presented in Table 191 for the selection of potential representative Suites for Portland GMA. The column heading for Suite L_C_1 is highlighted blue to indicate that this Suite was selected as the most likely representative Suite based on the process outlined in section 31.2.1. The statistics summarised include four key statistical measures pf the average 95 PPU thickness (95PPU TH), percentage of observed levels within 95 PPU (%Obs in 95 PPU), R^2 and root mean square error (RMSE) as well as the number of annual recovered level observation points (No obs data points) and the range of observed annual recovered levels.

Suite L_A_2

A review of the results and statistical summary for Suite L_A_2 shows that model run 7 (highlighted green) indicated the best results when considering the length of the historic record included and the four measures which reflect the uncertainty, accuracy and precision of the model of the 13 different model input combinations. Of this hindcasted datasets, model run 7 has the smallest 95PPU thickness and equal highest R^2 value and equal highest percentage observations within 95PPU band. Given this, model run 7 has been adopted to progress to predictive modelling. The graphical model output for this model run is shown in Figure 529. Its noted that model runs 14 to 19 failed to run for Suite L_A_2.

Suite L_C_1

A review of the results and statistical summary for Suite L_C_1 shows that model runs 14 and 15 (highlighted orange) indicated the best results of the 13 different model input combinations. Model run 14 and 15 had similar results, the main difference was that model run 14 had a slightly larger 95PPU thickness but higher R^2 and slightly smaller RMSE. However, these models do not cover the period of pre-development; considering the need to include a longer historic record and this period in the calibration model, the hindcasted models were assessed to find the best fit. Model runs 5, 7 and 9 all had similar statistical results, however, given Suite L_A_2 the preferred model run was model run 7 and that model run 9 includes a smaller number of years with recorded extraction (more hindcasted data included than model run 5 or 7), model run 7 was selected as the preferred model to progress to predictive modelling. The graphical model output for model run 7 is shown in Figure 530.

Modelling was progressed on the basis of adopting model run 7 for Suite L_A_2 and Suite L_C_1.

Table 191 Portland GMA: summary of model outputs

Suite	Statistic	Model run												
		1	2	5	7	9	10	12	14	15	16	17	18	19
L_A_2	95PPU TH	1.17	1.26	3.54	2.32	2.42	3.5	2.37						
	%Obs in 95 PPU	92.86	92.86	92.59	96.3	92.59	92.59	96.3						
	R^2	95.0	94.9	98.3	98.3	98.3	98.2	98.2						
	RMSE	0.18	0.18	0.26	0.26	0.25	0.27	0.27						
	No obs data points	14	14	27	27	27	27	27						
	Range of observed levels	2.3	2.3	6.1	6.1	6.1	6.1	6.1						
L_C_1	95PPU TH	0.76	0.79	1.26	1.31	1.25	1.14	1.3	0.42	0.33	4307.79	1.21	1.13	1.13
	%Obs in 95 PPU	78.57	78.57	82.98	100	100	95.74	97.87	90	90	80	93.48	4.35	4.35
	R^2	0.1	-1.6	85.1	83.3	86.1	91.3	83.4	88.3	75.7	71.7	85.4	86.4	86.4
	RMSE	0.18	0.18	0.25	0.26	0.24	0.19	0.26	0.06	0.09	0.1	0.24	0.24	0.24
	No obs data points	14	14	47	47	47	47	47	10	10	10	46	46	46
	Range of observed levels	0.5	0.5	2.5	2.5	2.5	2.5	2.5	0.5	0.5	0.5	2.5	2.5	2.5

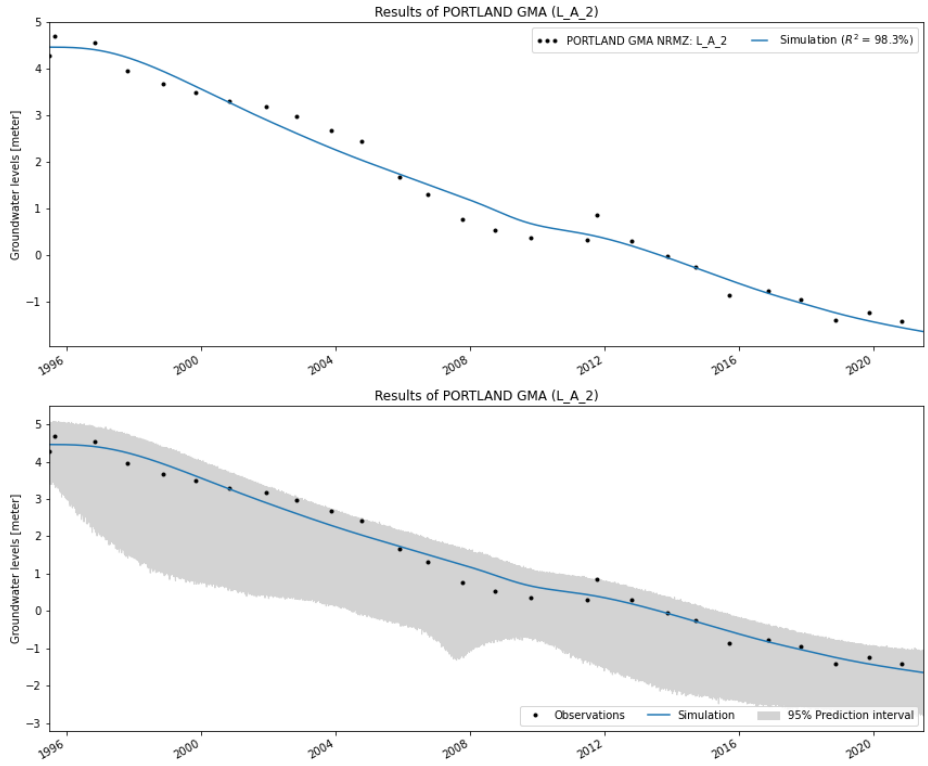


Figure 529 *Portland GMA Suite L_A_2: model run 7 (Portland GMA annual extraction with hindcast method 2) output hydrographs*

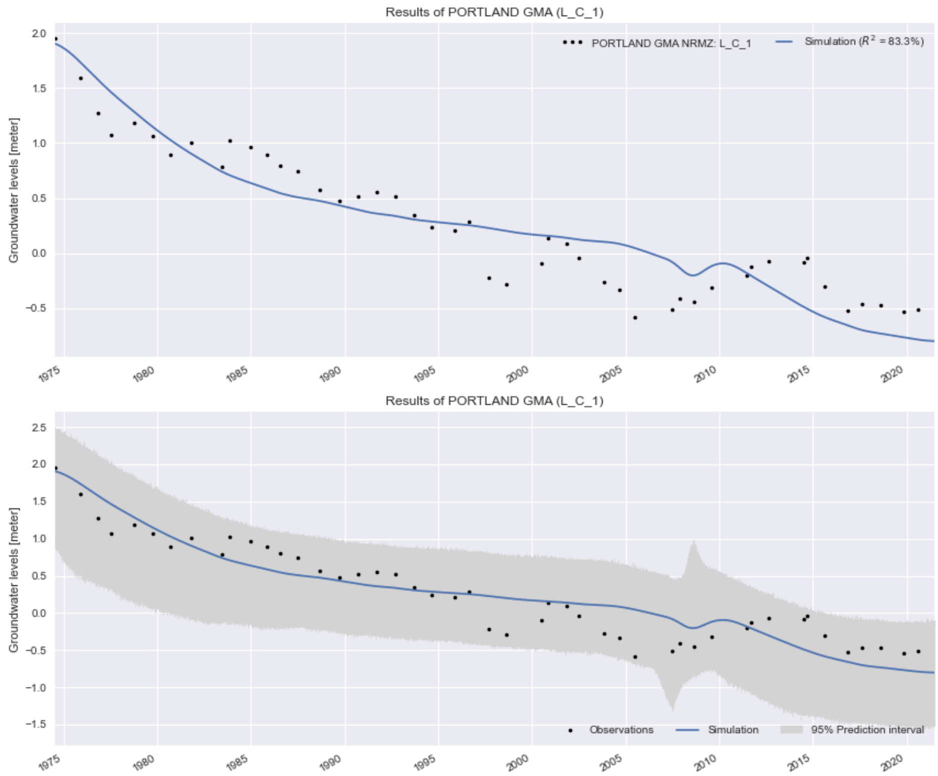


Figure 530 *Portland GMA Suite L_C_1: model run 7 (Portland GMA annual extraction with hindcast method 2) output hydrographs*

31.4 Predictive modelling

31.4.1 Model inputs

The preferred model to run the predictive modelling for Portland GMA was model run 7 for Suite L_A_2 and L_C_1. To conduct the forecasting for the 19 scenarios discussed in section 3.5.3, a few factors were required in the calculations; these factors are summarised in Table 192.

Table 192 Portland GMA: forecast scenario inputs

Input item	PCV	Licenced entitlement (based on 2020/21)	Existing use (based on 2020/2021)	Average use over recorded period (from VWA)	Maximum use over recorded period (from VWA, year 2006/07)
Value (ML/year)	7,795	7,794	2,257	2,606	3,244

31.4.2 Predictive model uncertainty

The model output files of the predicted models can be found in the data package provided as part of Appendix E.

MCMC predictions were undertaken on each of the forecasted scenarios for each of the two Suites. An example of one of the outputs is presented in Figure 531 for scenario 4. As shown in Figure 531, the uncertainty of the model prediction increases as the model predicts further into the future. Comparing with the graphical output for the same scenario, a few of the MCMC realisations fall outside the 95% prediction interval bands as shown in Figure 532.

Uncertainty is also accounted for by using 19 forecast scenarios to develop a groundwater use to drawdown relationship (analogous to a Monte Carlo type simulation) where a range of possible outcomes are generated. It is noted however, that the forecast scenarios were not randomly generated, but rather based upon a series of estimated use behaviours.

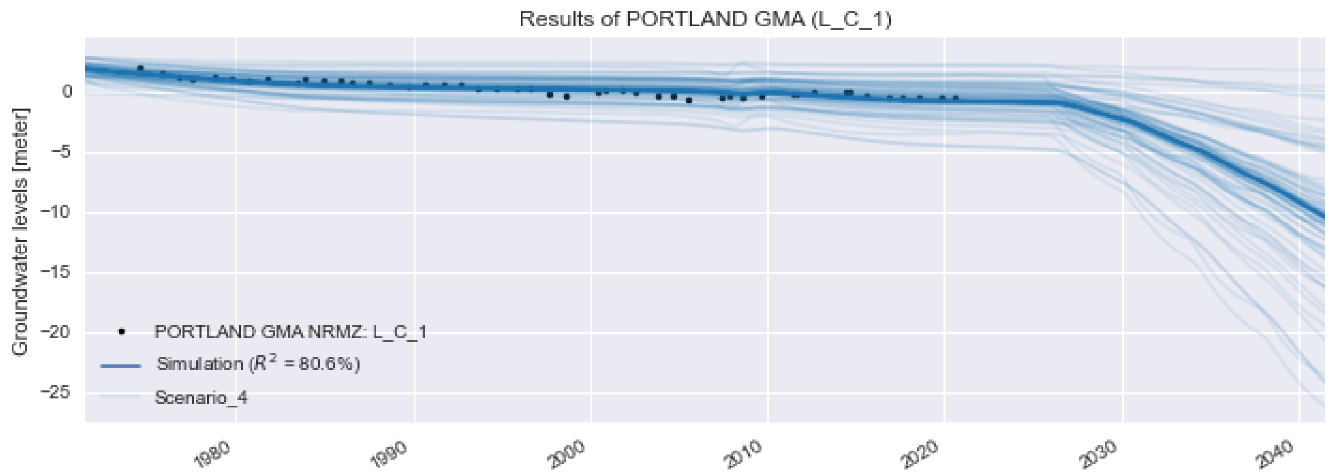


Figure 531 Portland GMA: Suite L_B_1 MCMC analysis for Forecast Scenario 4

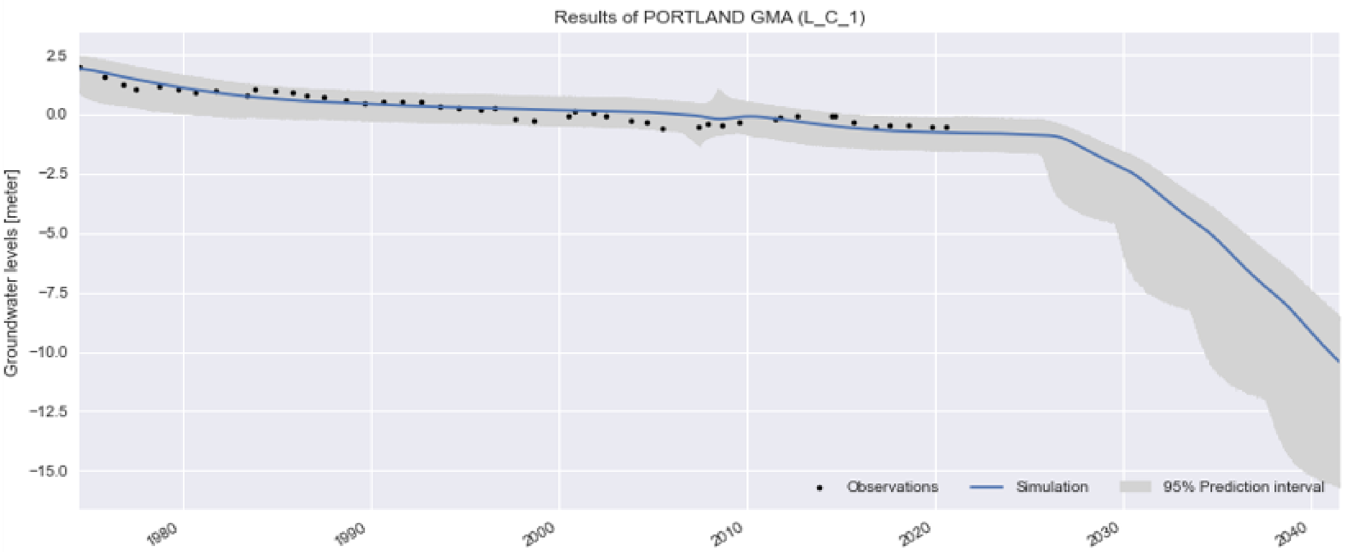


Figure 532 ***Portland GMA: Suite L_B_1 Forecast Scenario 4 with 95% prediction bands***

31.4.3 Extraction vs drawdown

To calculate the drawdown based on the annual recovered levels simulated by the model, the pre-development conditions (pre commencement of extraction) need to be estimated. For Portland GMA, the water level prior to groundwater development was unknown, due to:

– Uncertainty regarding the commencement of development in some GMUs
– The initiation of groundwater development preceding SOBN bore installation and temporal groundwater monitoring

Using the pre-development levels defined in section 31.2.2, the modelled water levels were converted into drawdowns (from this baseline pre-development level) for each of the 19 scenarios. This predevelopment condition is shown in Figure 533 for Suite L_C_1 hydrograph of annual recovered levels. In Figure 533:

– Actual annual groundwater use is represented by the blue column graph between 2006/2007 and 2020/2021
– Hindcasted groundwater use is represented by the orange columns from 1974/1975 to 2006/2007
– Forecasted use is represented by the grey columns after 2021/2022
– The annual recovered water level behaviour based on recorded data is represented by the red line graph
– The pre-development annual recovered levels are taken to be the first reading which equates to 1.96 m
– The modelled forecasted annual recovered levels are represented by the purple line in Figure 533
– The calibration annual recovered levels are represented by the black line in Figure 533

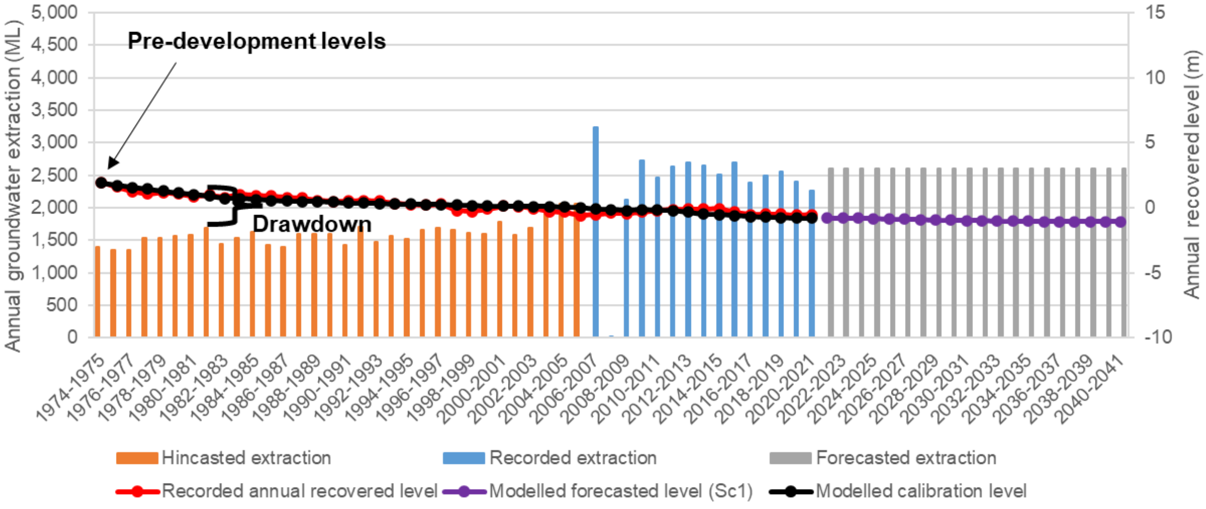


Figure 533 Estimating pre-pumping water levels (example from Suite L_C_1)

For Suite L_C_1, the calculated drawdowns and volumes for each of the scenarios were plotted in individual graphs for each scenario, all scenarios together in the one graph (Figure 534) and a graph of the scenarios for specific time periods (Figure 535) to develop the volume to drawdown relationship. For each scenario, a linear regression was applied and the coefficient of determination (R^2) was calculated. A comparison of each of these graphs shows some variations the coefficient of determination and the slope of the linear line. The same process was applied for Suite L_A_2 and again, there was a slight variation in the coefficient of determination between the graphs. Given this, the correlation developed using all forecasted scenarios was adopted to encompass these slight variations.

The use-drawdown for all the 19 forecast scenario drawdowns and volumes (both the recorded and forecasted volumes) over each year modelled is shown in Figure 534 for Suite L_C_1 and Figure 536 for Suite L_A_2 . Note the abscissa range of the chart has been clipped and does not show forecast drawdowns for the higher use scenarios (more improbable usage over two times the PCV).

Reviewing these figures, the following is noted:

- There should be zero drawdown under zero use and therefore a line of best fit should pass through the origin (0,0) or close to it.
- Average use is around 2,000 ML. Figure 534 and Figure 536 indicates that at use around this volume the model forecast drawdown tends to occur close to the predicted line of best fit for Suite L_C_1 and below the predicted line of best fit for Suite L_A_2
- For the same annual use, different drawdowns can be obtained as Pastas predicts a water level for each year. For example, Figure 533 shows a scenario where groundwater use remains constant at around 2,000 ML/year over the next 20 years
- The correlation for groundwater use and drawdown for Suite L_C_1 is good as shown in Figure 534, however the correlation for Suite L_A_2 is only moderate as shown in Figure 536
- The various forecast scenarios generally result in data plotting reasonably close together in a linear trend. The 19 forecast scenarios applied to populate the chart is analogous to a Monte Carlo type simulation where a range of possible outcomes are generated. It is noted however, that the forecast scenarios were not randomly generated, but rather based upon a series of estimated use behaviours.

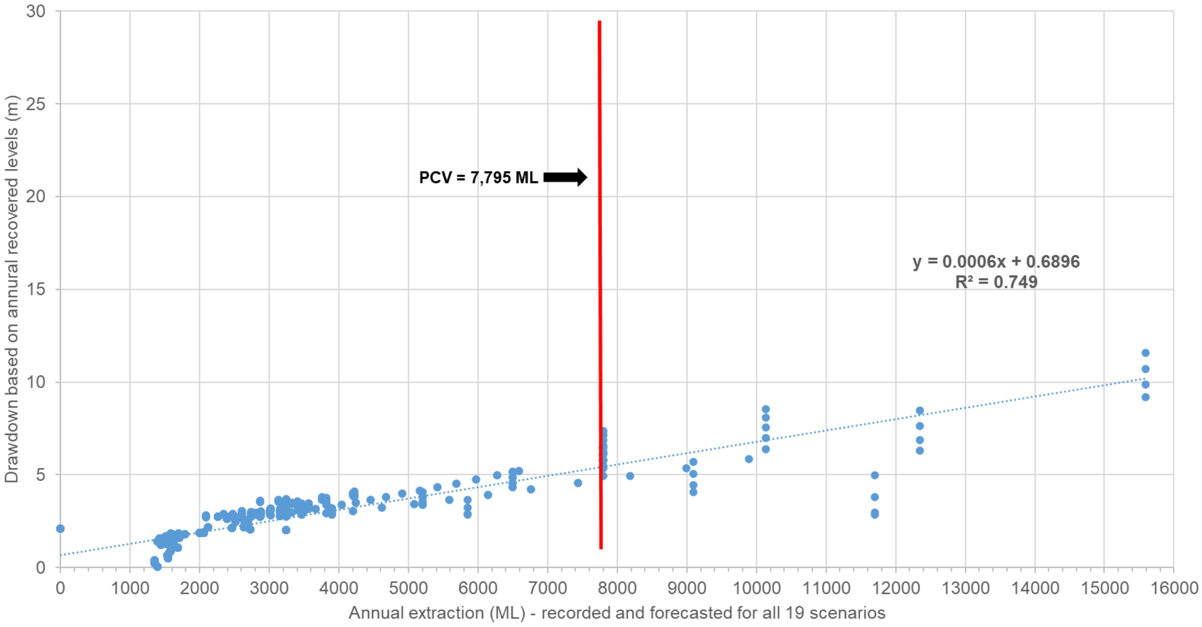


Figure 534 *Portland GMA Suite L_C_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <16,000 ML) for all data between 1975 to 2041 and all forecasted scenarios*

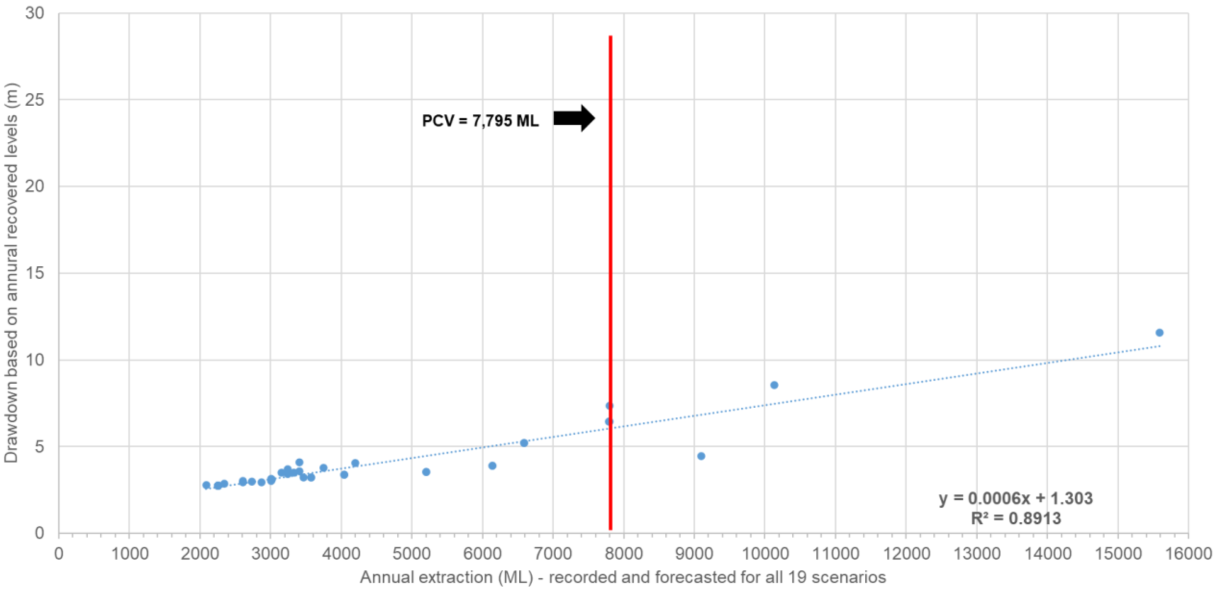


Figure 535 *Portland GMA Suite L_C_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <16,000 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

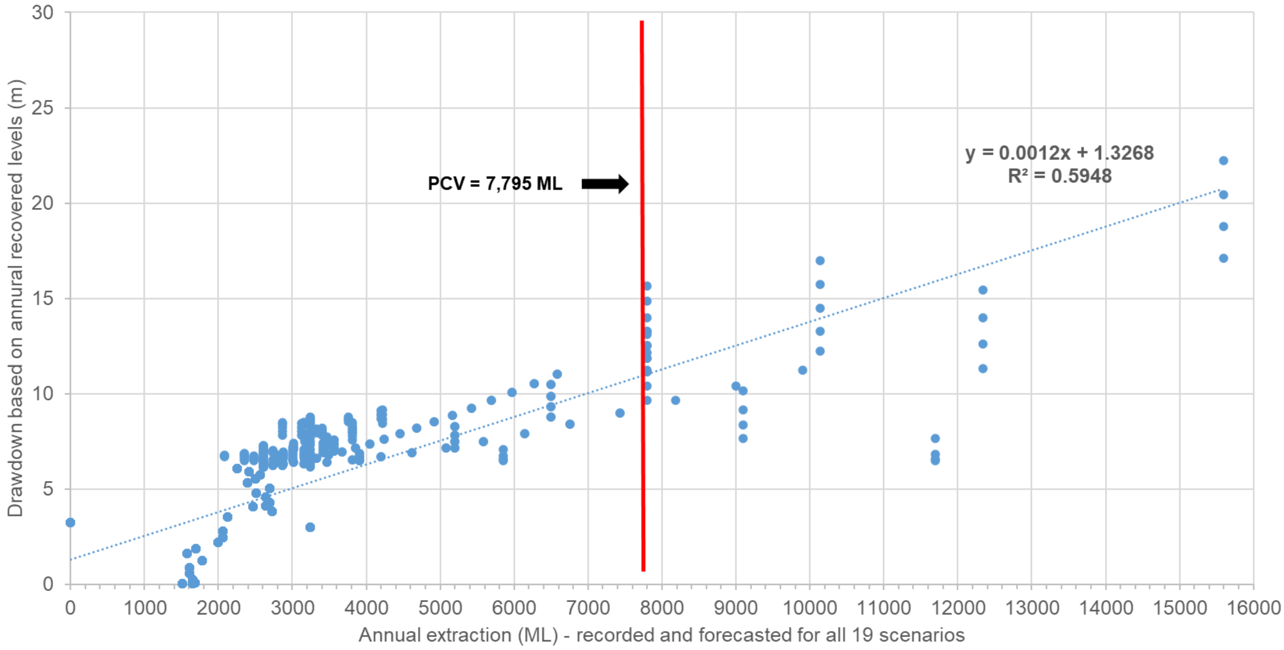


Figure 536 ***Portland GMA Suite L_A_2: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <16,000 ML) for all data between 1995 to 2041 and all forecasted scenarios***

31.5 Sustainability metrics

31.5.1 Application of metrics

Using the use - drawdown relationships developed through the previous step of forecasting aquifer response under a range of use scenarios, groundwater drawdown can be used to compare against groundwater resource sustainability metrics.

The application of these metrics and the relationship developed between drawdown based on the Suite annual recovered levels and extraction volume for the whole GMU, which is shown in Table 193 for Portland GMA Suite L_A_2 and Table 194 for Portland GMA Suite L_C_1 (noting Portland GMA has a current PCV of 7,795 ML/year). As part of the modelling, a 95% prediction interval band was applied to the modelling results. The relationship between drawdown and extraction volumes can also be interrogated at the lower and upper bands of the 95% prediction interval as shown in Table 193 and Figure 537 for Suite L_A_2, and Table 194 and Figure 538 for Suite L_C_1.

The two Portland GMA Suites, L_A_2 and L_C_1, have two different drawdown-use relationships with Suite L_A_2 showing the greatest variability in predicted drawdown for a given use as shown by the error bars in Figure 537 from the 95% prediction interval results. A comparison of volumes at drawdown intervals provided by DEECA is shown in Figure 538 for Suites L_A_2 and L_C_1. This shows that 5 m of drawdown is predicted to occur from 3,100 ML (1,800 to 3,400 ML) of groundwater use based on Suite L_A_2 or from 7,200 ML (4,600 to 8,000 ML) of groundwater use based on Suite L_C_1 and that 10 m of drawdown is predicted to occur from 7,200 ML (4,500 to 7,600 ML) of groundwater use based on Suite L_A_2 or from 15,500 ML (10,200 to 16,300 ML) of groundwater use based on Suite L_C_1.

Table 193 *Relationship of Suite drawdown to GMU extraction for Portland GMA Suite L_A_2*

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_A_2 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
16,000	20.5 (20.1 - 31.9)
15,000	19.3 (18.9 - 30)
14,000	18.1 (17.7 - 28.1)
13,000	16.9 (16.5 - 26.2)
12,000	15.7 (15.3 - 24.3)
11,000	14.5 (14.1 - 22.4)
10,000	13.3 (12.9 - 20.5)
9,000	12.1 (11.7 - 18.6)
8,000	10.9 (10.5 - 16.7)
7,000	9.7 (9.3 - 14.8)
6,000	8.5 (8.1 - 12.9)
5,000	7.3 (6.9 - 11)
4,000	6.1 (5.7 - 9.1)
3,000	4.9 (4.5 - 7.2)
2,000	3.7 (3.3 - 5.3)
1,000	2.5 (2.1 - 3.4)
0	1.3 (0.9 - 1.5)

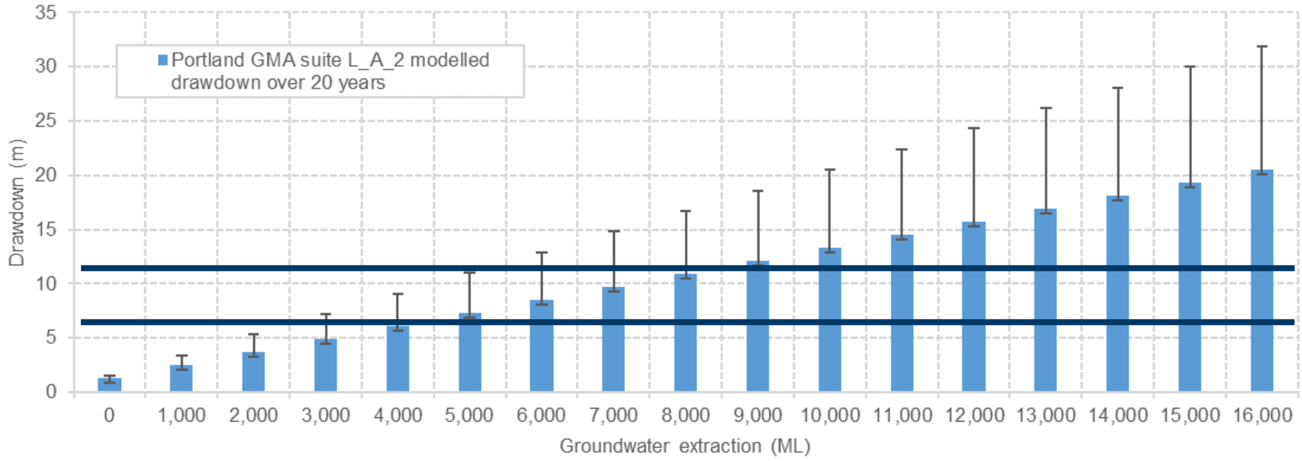


Figure 537 *Portland GMA Suite L_A_2: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)*

Table 194 Relationship of Suite drawdown to GMU extraction for Portland GMA Suite L_C_1

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_C_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
16,000	10.3 (9.8 - 15.2)
15,000	9.7 (9.2 - 14.3)
14,000	9.1 (8.6 - 13.4)
13,000	8.5 (8 - 12.5)
12,000	7.9 (7.4 - 11.6)
11,000	7.3 (6.8 - 10.7)
10,000	6.7 (6.2 - 9.8)
9,000	6.1 (5.6 - 8.9)
8,000	5.5 (5 - 8)
7,000	4.9 (4.4 - 7.1)
6,000	4.3 (3.8 - 6.2)
5,000	3.7 (3.2 - 5.3)
4,000	3.1 (2.6 - 4.4)
3,000	2.5 (2 - 3.5)
2,000	1.9 (1.4 - 2.6)
1,000	1.3 (0.8 - 1.7)
0	0.7 (0.2 - 0.8)

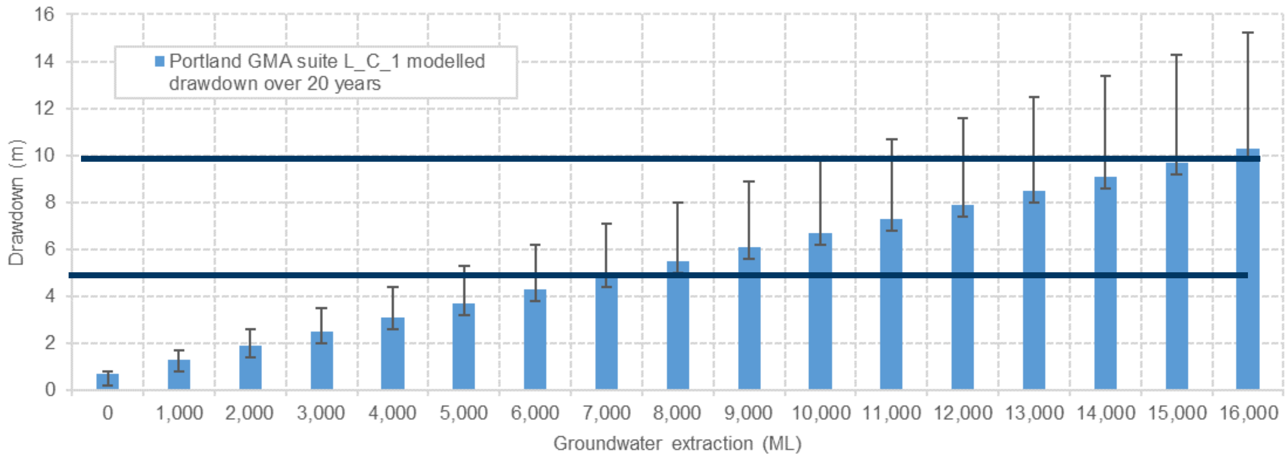
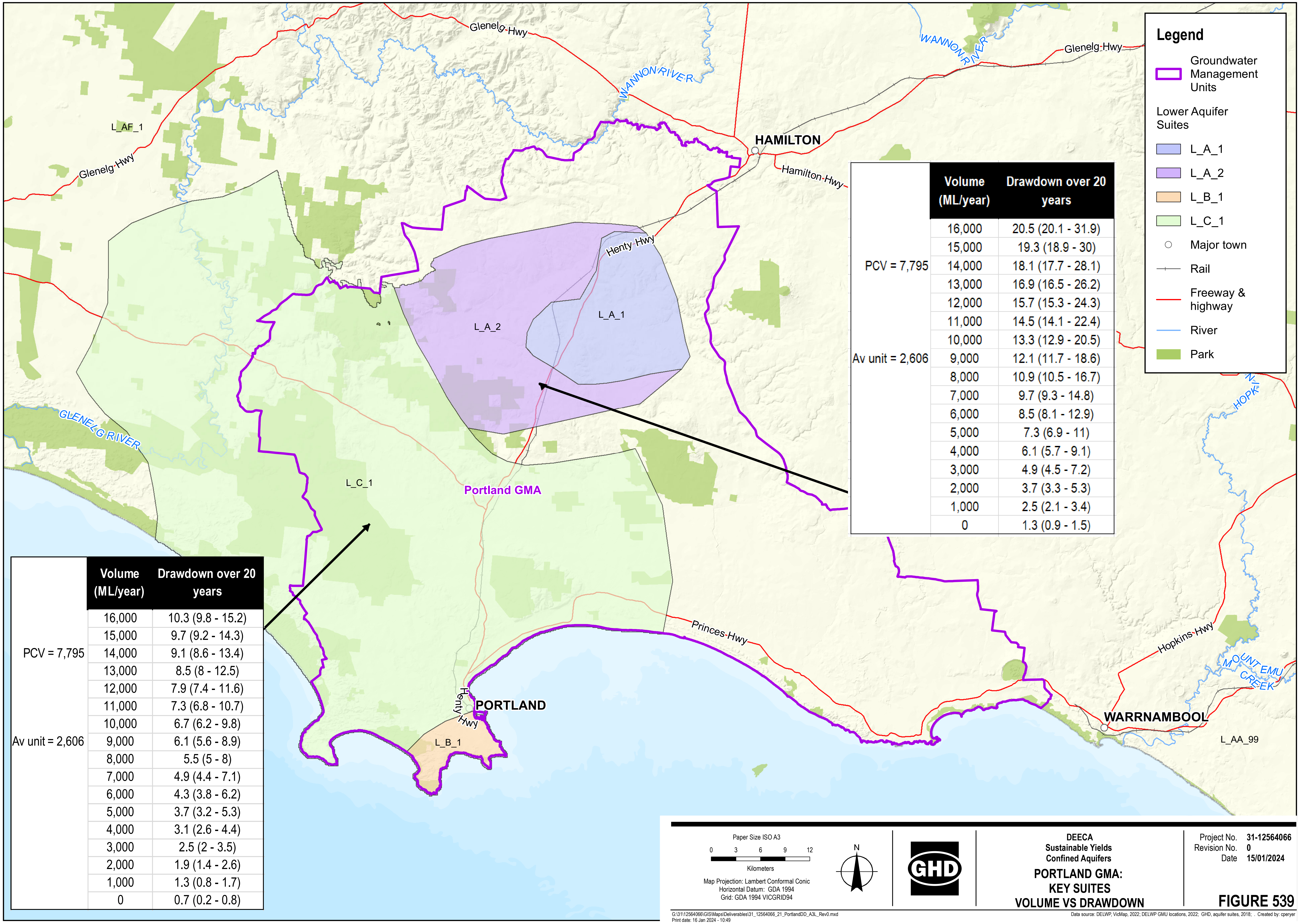


Figure 538 Portland GMA Suite L_C_1: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 195 Predicted GMU volumes for drawdown metrics

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite L_A_2 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite L_C_1 drawdowns (lower limit to upper limit)
5	3,100 (1,800 – 3,400)	7,200 (4,600 – 8,000)
10	7,200 (4,500 – 7,600)	15,500 (10,200 – 16,300)



L_A_1 / L_A_2:

	Volume (ML/year)	Drawdown over 20 years
PCV = 7,795	16,000	20.5 (20.1 - 31.9)
	15,000	19.3 (18.9 - 30)
	14,000	18.1 (17.7 - 28.1)
	13,000	16.9 (16.5 - 26.2)
	12,000	15.7 (15.3 - 24.3)
	11,000	14.5 (14.1 - 22.4)
	10,000	13.3 (12.9 - 20.5)
Av unit = 2,606	9,000	12.1 (11.7 - 18.6)
	8,000	10.9 (10.5 - 16.7)
	7,000	9.7 (9.3 - 14.8)
	6,000	8.5 (8.1 - 12.9)
	5,000	7.3 (6.9 - 11)
	4,000	6.1 (5.7 - 9.1)
	3,000	4.9 (4.5 - 7.2)
	2,000	3.7 (3.3 - 5.3)
	1,000	2.5 (2.1 - 3.4)
	0	1.3 (0.9 - 1.5)

L_C_1:

	Volume (ML/year)	Drawdown over 20 years
	16,000	10.3 (9.8 - 15.2)
	15,000	9.7 (9.2 - 14.3)
PCV = 7,795	14,000	9.1 (8.6 - 13.4)
	13,000	8.5 (8 - 12.5)
	12,000	7.9 (7.4 - 11.6)
	11,000	7.3 (6.8 - 10.7)
	10,000	6.7 (6.2 - 9.8)
Av unit = 2,606	9,000	6.1 (5.6 - 8.9)
	8,000	5.5 (5 - 8)
	7,000	4.9 (4.4 - 7.1)
	6,000	4.3 (3.8 - 6.2)
	5,000	3.7 (3.2 - 5.3)
	4,000	3.1 (2.6 - 4.4)
	3,000	2.5 (2 - 3.5)
	2,000	1.9 (1.4 - 2.6)
	1,000	1.3 (0.8 - 1.7)
	0	0.7 (0.2 - 0.8)

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GHD

DEECA
Sustainable Yields
Confined Aquifers

PORTLAND GMA:
KEY SUITES
VOLUME VS DRAWDOWN

Project No. 31-12564066
Revision No. 0
Date 15/01/2024

FIGURE 539

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Data source: DELWP, VicMap, 2022; DELWP GMU locations, 2022; GHD, aquifer suites, 2018; . Created by: cperyer

31.6 GMU summary

31.6.1 Findings

Portland GMA primarily relates to the Mepunga/Dilwyn Formation aquifer (LTA), where groundwater is predominately extracted for urban supply purposes. The LTA falls within the Lower Aquifer Suites, which at Portland GMA comprises Suites L_A_1 (6%), L_A_2 (11%), L_B_1 (1%) and L_C_1 (41%), providing a total GMU coverage of 59%. Suite L_B_1 showed a sudden decrease between 2001 and 2017 which does not align with the Millenium drought and appears anomolous. Thus, Suite L_B_1 was not included in the assessment. The identified representative Suites are L_A_2 and L_C_1 (most preferred). The Suite hydrographs for the representative Suites show an overall decreasing trend along with seasonal fluctuation and thus recovered water levels, which were adopted for the assessment.

The hindcasted models without spatial distribution showed very similar results across both Suites. Based on an assessment of all model runs and to keep consistency in the models adopted, model run 7 of annual extraction with hindcasting method H2 was adopted to undertake the predictive modelling for Suite L_A_2 and L_C_1.

The pre-development levels were defined for the two potential representative Suites based on the early time series Suite data for the annual recovered levels; this resulted in pre-developments levels of 4.50 m for Suite L_A_2 and 1.96 m for Suite L_C_1. The drawdowns were calculated based on these pre-development levels and the simulated levels from each of the 19 forecast scenarios.

The volumes estimated for a given drawdown for each Suite is shown below.

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite L_A_2 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite L_C_1 drawdowns (lower limit to upper limit)
5	3,100 (1,800 – 3,400)	7,200 (4,600 – 8,000)
10	7,200 (4,500 – 7,600)	15,500 (10,200 – 16,300)

The model applicability using Suite L_C_1 was assessed as having an “Excellent” model applicability rating and Suite L_A_2 was assessed as having a “Good” rating using the criteria outlined in section 5.2. For these Suites, due to the limited range in calibration volumes, the greater the proposed extraction rates beyond the calibration range leads to a greater potential for drawdown forecast errors.

Based on the analysis undertaken, Suite L_C_1 is likely to be more representative for Portland GMA, given that it has the highest coverage of the lower aquifer suites and has the second highest extraction, after L_B_1. However, Suite L_A_2 is likely to provide a more conservative estimate so consideration should be made to whether this Suite is adopted instead.

31.6.2 Limitations

In addition to the limitations applicable to all 25 GMUs discussed in section 1.8, the following Portland GMA specific limitations have been identified:

- The licenced bore dataset provided by DEECA has 12% of bores assigned to Portland GMA with no depth data and thus couldn’t be assigned to a VAF layer and in turn Suite. These bores were assigned to an aquifer through this study by GHD, in order to assist with the determination of the representative Suite. However, this data was not used in the model analysis.
- The spatial dataset used for the modelling is only available to the year 2019/2020. To account for this, annual recorded data from Victorian Water Accounts for the year 2020/2021 has been assigned to bores based on the method described in section 3.5.
- The Suite Hydrograph for L_B_1 shows a sudden decrease between 2001 and 2017 which does not align with the Millenium drought and appears anomalous. Due to this and low level confidence in adjusting the data, GHD consider this Suite should not be used.

- Model calibration was between 0-3,200 ML/year groundwater extraction range. The greater the proposed extraction rates beyond this calibration range the more potential for drawdown forecast errors. In this GMU prediction for extraction volumes up to 5 times the calibration range are being made. Further checks and potential re-calibration may be required as rates increase for the GMUs.
- Further analysis of another suite is recommended for the Portland GMU as it recognised the only suite used has a relative low groundwater level variation compared to some other major areal/extraction suites in the GMU
- Further analysis was conducted on Suite L_A_2 even though it did not have extraction as it did have a greater range of drawdown and number of observations bores making up the Suite
- The analysis shows that less volume is to be extracted from L_A_2 compared to L_C_1 to cause 10m of drawdown. Consideration should be made as to whether L_A_2 be adopted as a conservative estimate.

31.6.3 Recommendations

In addition to the recommendations applicable to all 25 GMUs discussed in section 32, the following Portland GMA specific recommendations have been identified:

- The licenced bore dataset provided by DEECA has 12% of bores assigned to Portland GMA with no depth data and thus couldn’t be assigned to a VAF layer and in turn Suite. It is recommended that DEECA obtains the relevant depth and aquifer monitored data for licenced bores within this GMU.

32. General recommendations

32.1 Technical analysis

32.1.1 Groundwater levels

GHD recommends the following in relation to groundwater level input data for the models:

- Amendments to the Data Upload Tool to fix the errors received when undertaking the upload. This may not be relevant to the statewide application but would be relevant to any future update of Suite water level hydrographs.
- A large number of outliers were identified during the groundwater level data cleansing exercise. It is recommended that the groundwater level data in DEECA's WMIS database undergoes additional quality checks to screen out these outliers prior to upload to WMIS.
- Fundamentally, the method trialled in this study relies upon robust categorisation of groundwater levels into spatial groupings (Suites). Suite definition has occurred on a single occasion, using an approach relying on hydrogeological judgement. As suggested previously by GHD (2017), methods of numerically analysing correlations between bores and classifying bores through algorithms, rather than by inspection, should be considered. Since establishment of such an approach and its associated workflows would take considerable time, this recommendation is simply flagged here as a future consideration if the analysis of groundwater levels by way of Suites is formalised and continued.

32.1.2 Groundwater use

GHD recommends the following in relation to groundwater use input data for the models:

- In relation to the "Use_Ent_Perbore_VAF.shp" dataset:
  - Currently, the groundwater use data by extraction bore does not have the relevant VAF layer attributed to it, thus the extraction cannot be assigned to an aquifer. An approximate assignment to VAF layer can be completed using the VAF spatial dataset and either the bore depth or screen information. However, it is noted that at many [bore] locations this is missing, or the spatial information is missing. The attribution of extraction to an aquifer is critical information. It is suggested that DEECA liaises with stakeholders to obtain the details of the relevant aquifer (VAF layer) from which groundwater is extracted at each licenced bore.
  - There is missing use data for Murrayville GMA and West Wimmera GMA for years 2009/10 and 2010/2011. This dataset should be updated to include Murrayville GMA data for these years.
  - Many of the bores are missing spatial information or they are plotting in offshore Victoria; this should be updated to check that location reflects the correct GMU
  - Many of the bores do not have a GMU assigned or have an assignment based on old GMU names. An update of the dataset is recommended, to reflect current GMU names and to check that GMU assignments are correct.
  - Once the above recommendations are undertaken and groundwater use data is known on an aquifer basis, extraction should be attributed to Suites and the most relevant Suite be reviewed to base the analysis on.
  - The sum of annual data in "Use_Ent_Perbore_VAF.shp" compared to the Victorian Water Accounts showed some differences. Consider undertaking checks of the use data by bore, as compared with that reported by GMU; the aim of this exercise is to ensure consistency in the volumes reported and identify any discrepancies.

- Groundwater use and entitlement by bore should continue to be recorded into the future. This will allow for future updates of the models, based on more robust and accurate datasets.
- A summary of the datasets received where data limitations were identified is provided in section 1.8; some of these reflect the recommendations raised above. Data limitations should be considered in the context of future data analysis in relation to other studies that may rely on this data.
- Regarding file "Tagged meter sites by date.kmz", it is recommended that information is stored in a shapefile rather than KMZ to make this information more easily accessible
- For the hindcasting, it was found the methods developed generally performed lower for GMUs where the main driver was town supply. It is recommended that information be obtained from the relevant RWC on the main influence of town supply requirements so correlations can be better developed in the absence of historic extraction datasets.
- DEECA to investigate whether there is more historical extraction data that can be incorporated into the models rather than adopting data from the applied hindcasting methodologies

32.2 Modelling

GHD recommends the following in relation to the calibration for the models:

- If the major data gaps can be addressed, DEECA should consider if they re-run the models with these updated datasets to see if improved results can be obtained

32.3 Predictive modelling

GHD recommends the following in relation to the predictive models:

- Although GHD has assessed that the applicability of the method for the GMUs, DEECA should review the results for each method to determine if applicable and what level of applicability is suitable for their purposes. Where it has been identified that the method was not applicable for a GMU and there is an existing groundwater model for that area, its recommended that DEECA explore the use of the existing groundwater model for their purposes.
- Where it has been identified that the method was not applicable for a GMU and there is currently no existing groundwater model, DEECA should investigate whether further modelling or another method should be developed for that GMU to inform sustainable management of the resource
- In some GMU cases the model calibration is excellent or good based on GHDs definitions, however the overall method applicability ends up being moderate or poor due to use-drawdown forecast methodology. For some of these GMUs further refinement of the use-drawdown forecasts may be possible by focusing on limited numbers of forecast scenarios (i.e., constant pumping) or removing recovery data.
- The processing of the forecasting datasets when using spatial distribution is quite time consuming and not easily updatable. It is recommended that DEECA review the if the benefit of adding in this complexity outweighs the time to incorporate it.
- Several models were calibrated using a significantly smaller volume ranges than those within the forecasted scenarios (or ultimately to meet the drawdown metrics). It is recommended to undertake further checks and potential re-calibration as extraction rates increase for the GMUs where this occurs.

32.4 Sustainability metrics and sustainable yield

As each Suite is modelled with the whole of GMU extraction, at this stage it is recommended that only one Suite, the representative Suite, be used in DEECA's assessment of sustainable yield for each GMU where this method has been identified as appropriate.

Risk identification is a key aspect in developing sustainable yield estimates and adopting sustainability metrics, and it is suggested that a framework is developed by DEECA to consider all relevant risks when adopting sustainable yield estimates and metrics for each GMU. GMU specific risk profiles or confidence limits should consider:

– Potential for impact to groundwater users, considering:
  - Groundwater users that may cease to be able to access water from existing works
  - Spatial clustering of use
  - Available drawdown in the aquifer system and bores
  - Drivers of groundwater level variability
  - Groundwater use profile/seasonality
  - Regional/community issues
  - Potential for impact to the environment, considering:
  - Inter-aquifer flow/leakage
  - Groundwater salinity increase
  - Impacts to environmental water reserve

The volumes estimated by the model for different drawdown metrics are based on limited information about the system and are estimates only. It is recommended that monitoring of groundwater levels and extraction volumes is continued to be undertaken to assess the drawdown trends associated with extractions from within a GMU and used to inform the ongoing sustainable management of the resource.

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Appendices

Appendix A

Historic context of sustainable yields

A-1 Historical assessment of aquifer sustainability

In the late 1990s, DEECA predecessor agencies established sustainable yields for the groundwater management areas of the State. These sustainable yields were required to ensure that groundwater users had access to economically develop the resource, but to also ensure that the abstractive benefit and environment protection were continued for future generations.

It has been recognised by DEECA that the sustainable yields were often based upon limited data, had uncertainties in both the estimates themselves but also consideration of the risks to the environmental values, and did not consider climate change. Since their original establishment, additional data in terms of abstraction metering, improved monitoring networks and further technical studies have been undertaken, that could further improve the sustainable yield estimate.

DEECA continue to seek a better understanding of the sustainability of the State's groundwater resources and align itself with national groundwater management practice. To this end, DEECA require generic methodologies for assessing both groundwater availability and potential adverse impact from groundwater development. In mid 2021 DEECA commissioned technical studies associated with the State's unconfined aquifer systems, and in late 2021 (this study) commissioned assessment of the State's confined aquifer systems.

Key requirements of DEECA in developing an assessment methodology were:

– Simple and repeatable
– Applicable across all of the State's confined aquifer systems
– Relies on groundwater observations/real data
– Can be readily updated as more current data becomes available
– Quantifies uncertainties
– Risk based
– Relatable to a metric that can be applied to measure the level of impact to be avoided

To this end, GHD has proposed an approach which relies upon the using time series modelling of State Observation Network (SOBN) bore data and groundwater abstraction data to predict future groundwater level responses. These responses are then converted into a metric to assess the condition of the confined aquifer.

A-2 PCV historic context

Most sustainable yield estimates were undertaken in the late 1990s as part of the former Department of Natural Resources and Environment (DNRE) (now DEECA) *Permissible Annual Volume (PAV) Project*. Since this period, numerous technical studies have been undertaken on local or regional scales to update sustainable yield estimates.

The approach that was used to estimate sustainable yield in the original PAV studies was prescribed by the former DNRE (1996), as:

1. Estimating available groundwater volumes, through the following methods:

- Rainfall recharge
- Aquifer throughflow
- Aquifer storage
- Hydrograph fluctuation
- Stream recharge
- Modelling

2. Estimating relevant limitations on the above groundwater volume, through assessment of:

- Discharge to streams – this represents a potential restriction as an allowance needs to be made for any discharge to the surface which must be maintained. This restriction is the inverse of the 'recharge from rivers' method and provides a means of estimating the required or current discharge to streams.

- Regional drawdown – this represents a potential restriction that accounts for the fact that regional drawdown should not exceed a given limit in some areas. This method uses the total aquifer storage to identify the volume which would be allowed, if a limit exists.

- Well interference – this represents a potential restriction considers that the limit on development is often the degree to which interference on neighbouring bores is allowed. This method allows a certain percentage of the aquifer head to be drawn down in cumulative interference and estimates a maximum extraction rate based on a given bore spacing.

- Seawater intrusion – this represents a potential restriction enables a lower limit on aquifer discharge to the coast to be calculated in order to maintain the freshwater - saltwater wedge at an acceptable distance.

A-3 Permissible Annual Volume (PAV) and Permissible Consumptive Volume (PCV)

The use of groundwater resources in a defined management area may be restricted by orders made by the Victorian Minister for Water. Permissible Consumptive Volumes (PCVs) cap the total volume of licensed entitlement in a defined management area. PCVs are specified under section 22A of the *Water Act 1989*, specifically through the following:

(1) the Minister may by Order published in the Government Gazette, declare, in respect of an area or a water system specified in the Order, that the total volume of—

a. both surface water and groundwater; or

b. surface water only; or

c. groundwater only

The determination of PCVs for groundwater extraction in Victoria was typically informed by the sustainable yields estimated through the *PAV Project*. PAV was the historic term used prior to 2005 to represent a PCV and as such, is used interchangeably throughout this report.

The PCVs represent an adaptive management approach, whereby sustainable development coexists with maintaining environmental, social and economic values, however, it is unknown (and not assessed in this study) how these aspects were considered in the PAV Project.

Appendix B

Pastas guidance documentation

This section provides guidance on sourcing, installing and running the open-source Python package Pastas.

Instructions:

- Install anaconda distribution (this allows access to many script editors and allows you to install python packages easily). Alternatively install a script editor application. You can install anaconda from here: **https://www.anaconda.com/products/distribution**
- Once anaconda is installed, you can open it up and you can see all the script editors you have access too. In the instance of this project, we are using Jupyter Notebook.
- You can use anaconda to create an environment that has the necessary packages installed (pandas, numpy, plotly, matlplotlib, pathlib, os, datetime, scipy). You can access environments by navigating to it on the left hand side. Once there you can search install packaged on the right hand side.
- In the instance of pastas, you cannot use the above approach to install the package. To do this you will need to:
  - Open the script editor (Jupyter Notebook)
  - Instructions are available on the github website in terms of what to install and dependencies for the installation. You can read these at the website here: **https://github.com/pastas/pastas**. I have summarised the key steps from here below.
  - Pastas is dependent on the following packages already being installed in the environment (which you can install straight into the environment using anaconda as described in step 3): numpy, matplotlib, pandas and scipy
  - To install pastas, in the script editor, type: pip install pastas
  - The click the run button, if there is no errors when the run is complete it has been successfully installed

Appendix C

Data review and preparation – method documentation

C-1 Data Extraction

The water level data were downloaded from the Water Measurement Information System (WMIS) website, at **http://data.water.vic.gov.au/wgen/state/GW_level_data.zip**.

In the initial run, the data were filtered based on Method and Condition, and saved into two files:

- QSel_MonLevels.xlsx
- QSel_MonLevels_NULLs.csv

The CSV file contains all entries without Method or Condition data.

In future runs, this filtering step will not be required, as the filtering is applied in the coded workflow.

C-2 Initial Processing and Cleaning

Folder: WL_Data_Processing_for_Upload/1_initial_processing

Inputs: QSel_MonLevels.xlsx, QSel_MonLevels_NULLs.csv

Outputs: QSel_Mon_Levels_Initial_Clean.csv

Jupyter Notebook: 1_QSel_MonitoringLevels_InitialProcessing.ipynb

This section performs the required filtering and cleaning of the data to allow effective outlier detection. The key tasks undertaken are:

- Concatenate the two input data tables (vertically stacked)
- Filter the data based on their Condition and Method values
- Format the Date and Time columns into datetime objects, and remove any entries without a valid datetime
- Write the filtered and cleaned data to a new CSV file

The Condition and Method values are filtered based on the below tables:

Table C.1 Filtering Requirements based on CONDITION

Code	Description	Action
A	External Influences	Delete
B	Water Removed/Added	Delete
C	Maintenance Required	Delete
CAV	Bore Has Caved In	Delete
D	Doubt About Accuracy	Delete
DEC	Bore Decommissioned	Delete
F	Bore Flowing	Delete
N	Bore Flooded	Delete
P	Bore Destroyed	Delete
Q	Bore Dry	Delete
S	Site/Bore Works Done	Delete
T	Access/Equipment Problem	Delete
U	Casing Blocked/Bent	Delete
WAT	No Water Left	Delete
Z	Below Instrument	Delete
G	Water Level From NS	Keep
NOT	Not Known	Keep

Code	Description	Action
SAL	Saline Bore	Keep
W	Assumed Reading Date	Keep
X	Water Sample Taken	Keep

Table C.2 Filtering Requirements based on METHOD

Code	Description	Action
AFT	Annual Maintenance After Test	Delete
BEF	Annual Maintenance WL Before Test	Delete
CHK	Annual Maintenance WL Check	Delete
CON	Annual Maintenance Bore Conditions	Delete
MNT	Bore Maintenance	Delete
PUM	Pumping Test	Delete
CHE	Field Chemistry Analyses	Keep
LAB	Lab Chemistry Analyses	Keep
LOG	Data Logger	Keep
MON	Routine Monitoring	Keep
NOT	Not Known	Keep

C-3 Outlier Removal

Folder: WL_Data_Processing_for_Upload/2_outlier_removal

Inputs: QSel_Mon_Levels_Initial_Clean.csv

Outputs: CSV/MovingAverage_Bore_*.csv, figures/inliers/Bore_*.png, figures/outliers/Bore_*.png

Jupyter Notebook: 2_MovingAverage_Calcs.ipynb

This section detects outliers within each individual bore data set using the three sigma method of a rolling mean and tags the data entries accordingly. No data are removed in this section, only classified as inliers or outliers. Graphs of each bore are generated, and separated into different folders based on whether or not the data set contains outliers. The key tasks undertaken are:

– Convert the datetime data into POSIX time (the seconds to or since midnight on 01/01/1970)
– Calculate the rolling mean of the Water Level at the Measuring Point, based on the POSIX time
– Determine outliers, categorised as any data point beyond three sigma (standard deviation) from the rolling mean
– Create graphs demonstrating the raw data, rolling mean and three sigma boundaries
– Write data to a new CSV file for each bore

C-4 Final Preparation for the Upload Tool

Folder: WL_Data_Processing_for_Upload/3_final_prep

Inputs: MovingAverage_Bore_*.csv, GW_elevation.csv.

Outputs: QSel_MonLevels_Cleaned_for_Upload.csv

Jupyter Notebook: 3_Concatenate_for_Data_Upload_Tool.ipynb

This section performs the final concatenation of all bore data back into a single file, cleans and joins the elevation data and calculates the Depth Below Natural Surface (DBNS) and Reduced Water Level (RWL) values.

The key tasks undertaken are:

- Preferentially select the elevation value to use for each measuring point, based on the method the value was obtained. The table below demonstrates the selection process
- Remove any outlier data points from the bore data sets
- Join the selected elevation value to the bore data and calculate DBNS and RWL. The equations used are demonstrated below
- Perform final naming of columns to match requirements of the Data Upload Tool, and split the Datetime column back into separate Date and Time columns
- Undertake QA Checks to ensure data meets the requirements for the Data Upload Tool
- Write the finalised data set to a new CSV file

Table C.3 Preferential Selection of Measuring Point Elevation Method

Method	Rank (lowest value is preferentially selected)
SURVEYED-GROUND INSTR	1
GPS - SKM VALIDATED D	2
NGIS DATA CHECKED	3
GLOBAL POSITIONING SY	4
Static survey and wit	5
Leica RX1250TC RTKGNS	6
SURVEYED-SATELITE	7
DSE LIDAR 10CM ACCURA	8
LIDAR 10CM ACCURACY	9
DIGITAL ELEVATION MOD	10
CONTOUR ESTIMATE	11
SCALED-1:25,000 MAP	12
SCALED-1:63360 CADAST	13
SCALED-1:100,000 MAP	14
VIRTUAL REFERENCE STA	15
CALCULATED MANUALLY	16
NOT KNOWN	17
NULL	18
nan	19

Notes:
The term ‘nan’ indicates a non-applicable metric, as the 95% prediction interval bands could not be estimated and thus the thickness could not be calculated

The equation used for calculating Depth Below Natural Surface (DBNS) is as follows:

$$DBNS = WLMP - (MP - GND)$$

Where WLMP is the Water Level at Measuring Point, MP is the Measuring Point elevation, and GND is the Ground elevation.

The equation used for calculating Reduced Water Level (RWL) is as follows:

$$RWL = MP - WLMP$$

Where MP is the Measuring Point Elevation, and WLMP is the Water Level at Measuring Point.

C-5 The Data Upload Tool

The Data Upload Tool was installed following the instructions in 20170221_DataUploadTool_UserGuide.pdf.

The QSel_MonLevels_Cleaned_for_Upload.csv was used as an input file to the Data Upload Tool, however there were a few issues with the C# GUI, and as such the Python scripts were run individually using the ArcGIS10.8 Python 2 environment.

C-6 GMU Hydrograph Summarisation

This final step utilises the Feature Manipulation Engine (FME) from Safe Software. FME is a useful tool in performing Extract, Transform, Load (ETL) workflows in a visual, easy-to-interpret, codeless manner. This step combines data from different tables in the WaterLevel_Database Access Database, and creates an Excel spreadsheet, with a different tab for the hydrograph of each GMU Suite.

The key tasks undertaken are:

- Perform an inner join between the Suite_Normalised_Value_14dayInterval table and the GMUID and SuiteID columns of the GMU_Suite table
- Rename the SuiteID to GroupID to match the Suite_Sumerised_Data table
- Convert Date column to the format YYYYMMDD
- Add the AvgRLNS column by performing an inner join between with the Suite_Sumerised_Data table
- Calculate the Suite NRMZ value by using the equation: $Suite\ NRMZ = AvgRLNS - NRMZ$
- Sort data by GMUID, then by GroupID, then by SuiteID, then by Date, and write to an Excel Spreadsheet, with a different sheet for each GMU Suite

The full FME workflow is displayed below.

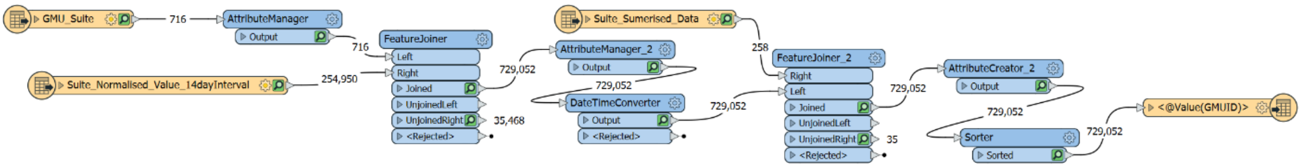


Figure C.1 FME Workflow for creating the GMU Hydrographs

Appendix D

Memo on externalities

Technical Memorandum

30 March 2023

To	Rezina Shams	**Contact No.**	[Enter text]
Copy to	Tim Anderson, Jeff Morgan, Brittany Smyth	**Email**	[Enter text]
From	Tony Cauchi	**Project No.**	12564066
Project Name	Statewide Confined Aquifer Sy		
Subject	Consideration of GMU externalities		

1. Introduction

Following receipt of Technical Review Panel (TRP) comments on GHD's draft Stage 1 project report dated August 2022, this interim technical memorandum aims to outline GHD's suggested process to review external factors (externalities) affecting specific Groundwater Management Units (GMUs), and how such externalities, particularly extraction outside a GMU boundary, are proposed to be considered in GHD's Stage 2 (statewide application).

1.1 Background

The Stage 1 model results for Murrayville Groundwater Management Area (GMA) did not produce a high goodness of fit and indicated a large variation in the 95% confidence intervals. As Murrayville GMA is partially located within the South Australia – Victoria (SA-VIC) Border Zone, groundwater extraction in SA could potentially influence groundwater levels within Murrayville GMA.

1.2 Purpose of this Memorandum

This technical memorandum is provided as an interim communication under our agreement with the Department of Energy, Environment and Climate Action (DEECA). The purpose of this memorandum is to outline an approach to consider externalities as they relate to Murrayville GMA. Specifically, this memo documents the findings of exploring the potential impact of extraction in the Mallee Prescribed Wells Area (PWA) (SA) on Murrayville GMA. DEECA has provided a groundwater model report for the Mallee PWA – Murrayville WSPA (now GMA) Groundwater Model (DWLBC 2006) to assist with this review, as well as extraction data for the Mallee PWA.

This memo is provided to foster discussion in relation to technical matters associated with the project and should not be relied upon in any way or for any purpose.

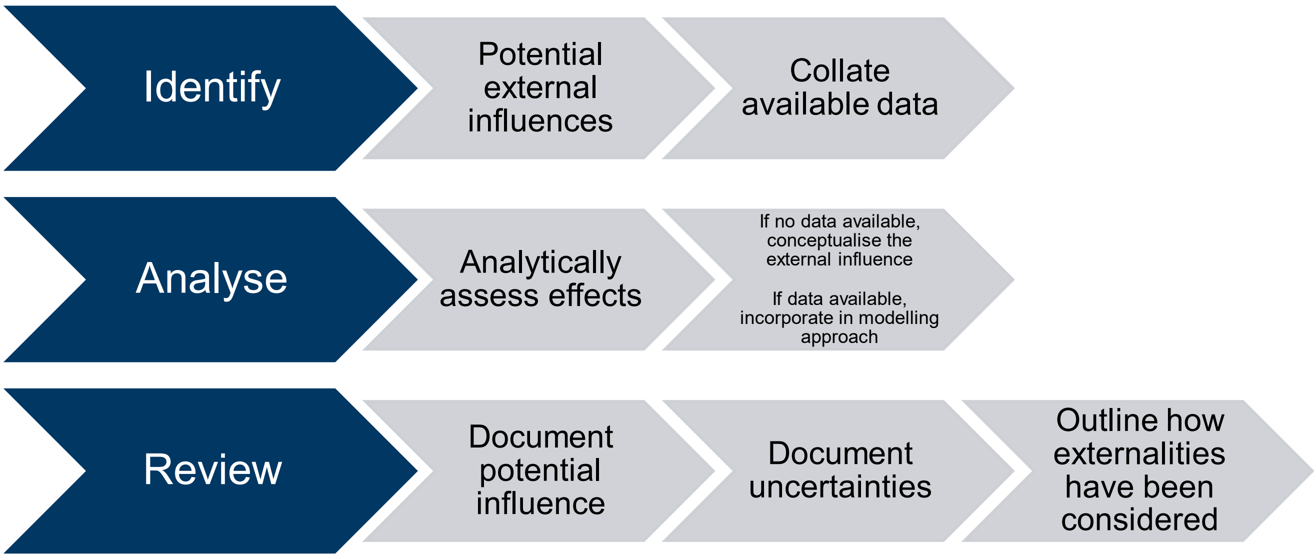
1.3 Scope and limitations

This technical memorandum has been prepared by GHD for the Department of Energy, Environment and Climate Action. It is not prepared as, and is not represented to be, a deliverable suitable for reliance by any person for any purpose. It is not intended for circulation or incorporation into other documents. The matters discussed in this memorandum are limited to those specifically detailed in the memorandum and are subject to any limitations or assumptions specially set out.

GHD has prepared this memorandum on the basis of information provided by the Client and others who provided information to GHD (which may also include Government authorities), which GHD has not independently verified or checked for the purpose of this memorandum. GHD does not accept liability in connection with such unverified information, including errors and omissions in the memorandum which were caused by errors or omissions in that information.

2. Approach

The following approach has been adopted to considering influences of extraction occurring outside the GMU on Murrayville GMA:



3. Identify external influences

The following was identified through the Mallee PWA – Murrayville WSPA (now GMA) Groundwater Model (DWLBC 2006) report:

- Groundwater extraction from Murrayville started in 1995/96
- Groundwater extraction in Murrayville is significantly less than in the Mallee PWA (~5,000 ML/year in Murrayville in 2004/05 compared to ~30,000 ML/year in Mallee PWA)
- Root mean square error (RMSE) is used in calibration, with accuracy increasing as RMSE approaches zero (this is related to another project query raised by DEECA)
- A key limitation of the groundwater model is the lack of accurate pumping data in SA prior to 2002
- The water balance for the Murray Group Limestone (MGL) aquifer under steady state conditions shows an inflow of 20 ML to Victoria and an outflow of 380 ML to SA
- The model was run under a number of scenarios with scenario 1 representing the conditions at the time of modelling (2004/2005), with extractions of 30,660 ML/year in SA and 4,206 ML/year in Victoria during the irrigation season
- Under scenario 1, it was concluded that pumping in SA does not affect groundwater inflows into the Murrayville GMA and that groundwater that is not intercepted by pumping in Victoria flows into SA

(360 ML/year). Also, the cross-border flows in the MGL only represented 0.0001% of volumes stored in that aquifer

- Figure 18 of the report shows a clear seasonal drawdown cone extending from SA into Victoria; this is also reflected in the observed water level elevations
- The 2004/05 water balance for the irrigation season shows that flow from Victoria to SA increased to 1,525 ML/year (from 360 ML/year predicted through the steady state) under these conditions
- A summary of the four scenarios is presented in Table 1
- A spatial summary comparison of modelled and observed data is presented in Figure 1

Table 1 Modelling scenarios

No	Scenario	Extraction from SA (ML/year)	Extraction from Vic (ML/year)	Inflow to SA (ML/year)
0	Steady state	0	0	360
1	2004/05 extraction	30,660	4,200	1,525
2	Full PAV SA, current Vic extraction	53,000	4,200	1,625
3	Full allocations Vic & SA	53,000	9,470	-300
4	Same use in Border Zone	16,000	16,000	-2,675

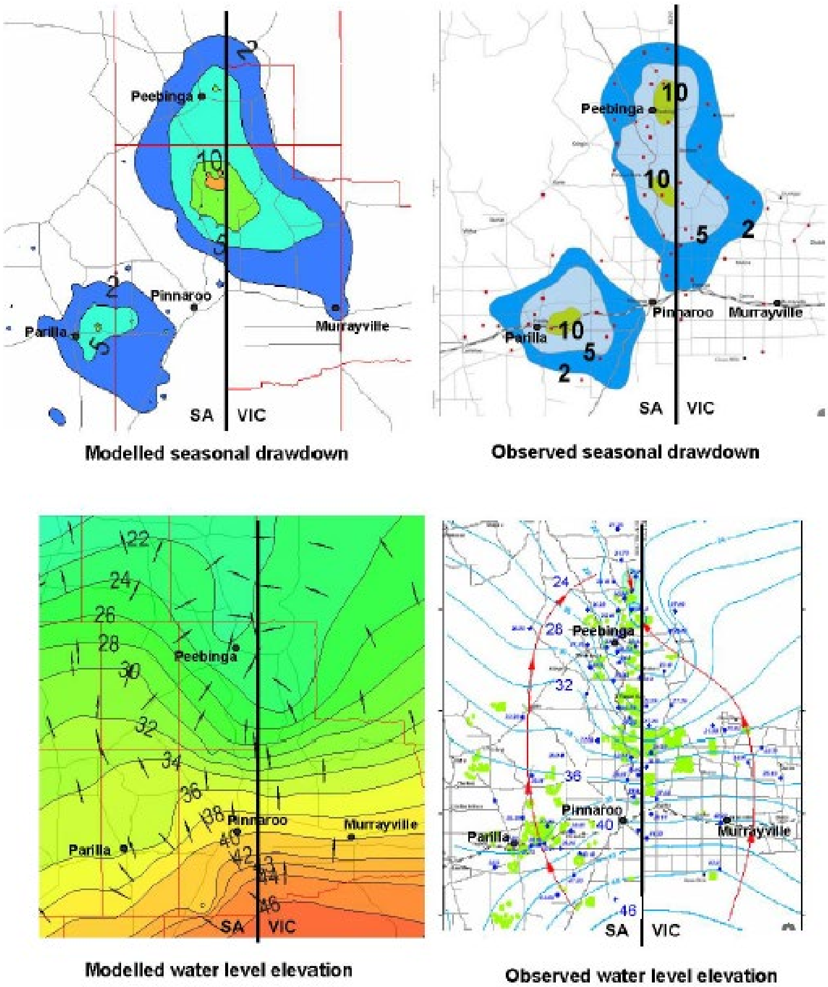


Figure 1 Comparison of modelled and observed data (extract from DWLBC 2006)

GHD originally considered that changes in extraction trends across the border will probably be similar, and therefore the influence on our method would likely be relatively small. However, the fact that the Mallee

This Technical Memorandum is provided as an interim output under our agreement with Department of Energy, Environment and Climate Action. It is provided to foster discussion in relation to technical matters associated with the project and should not be relied upon in any way.

PWA extracts up to eight times the Murrayville GMA extraction indicates that Mallee PWA may have a significant influence on trends. To assess this, historical groundwater use regimes should be compared.

4. Analyse external influences

4.1 Comparison of extraction regimes

Extraction data was provided by DEECA for the Mallee PWA between the years of 2004/2005 and 2021/2022; this was plotted along with available historic extraction data for Murrayville GMA as shown in Figure 2. Although the volumes of extraction within the Mallee PWA are in the order of eight times that of Murrayville GMA, they generally show a similar fluctuation in annual extraction volumes. However, the proportionality between the two change with time.

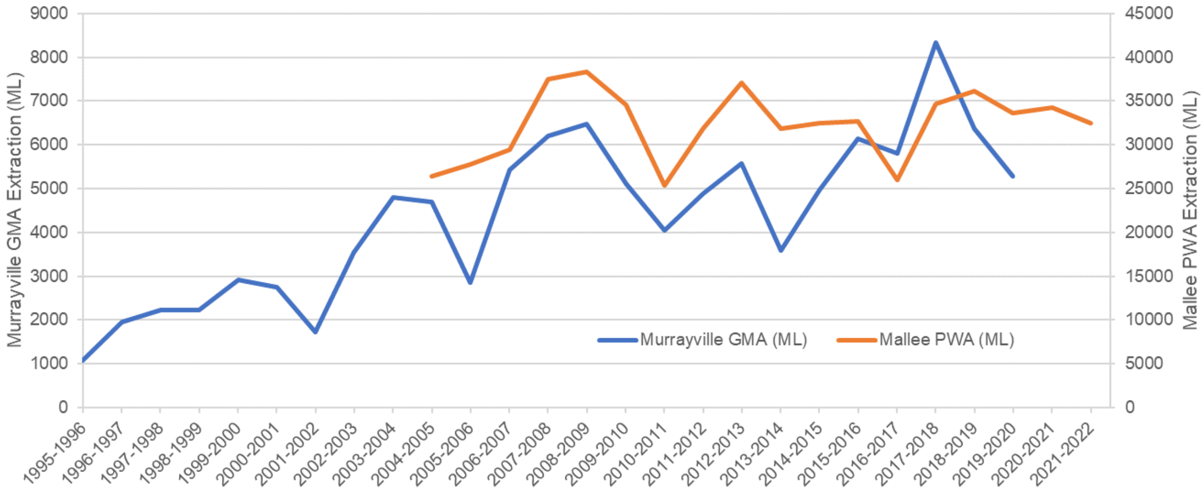


Figure 2 ***Murrayville GMA and Mallee PWA historic extraction***

4.2 Modelling incorporating Mallee PWA extraction data

Another iteration of the Pastas modelling method was undertaken to take into consideration Mallee PWA extraction from 2002 onwards, and to assess if a better match can be obtained. The following modelling was undertaken:

- Assessment using the Victorian Water Accounts extraction data set for Murrayville which dates back to 2004/05 (this is referred to as the Victorian Water Accounts dataset) (refer Figure 3)
- Assessment using the updated historic extraction data set for Murrayville (the GWMW dataset) which dates back to 1995 (Table 2 summarises the differences between the Victorian Water Accounts and Grampians Wimmera Mallee Water annual extraction data for Murrayville GMA) (refer Figure 4).
- Assessment using the updated historic extraction data set for Murrayville GMA, (this is referred to as the GWMW dataset) over the same period as the Victorian Water Accounts data (from 2004/05) (refer Figure 5)
- Assessment using combined total groundwater extraction from both Mallee PWA and Murrayville GMA (refer Figure 6)
- Assessment using combined groundwater extraction from the Mallee PWA from bores within approximately 10 km of the border and Murrayville GMA (refer Figure 7)

For Murrayville GMA, the representative suite was defined as M_AC_2, due to most of the extraction occurring within this suite (it also covers 56% of the GMU). Table 2 summarises the differences between the Victorian Water Accounts and Grampians Wimmera Mallee Water annual extraction data for Murrayville GMA. Table 2 shows that the Victorian Water Accounts volumes are greater than the Grampians Wimmera Mallee Water extraction volumes. Table 3 shows a comparison of the modelling results between that presented in GHD's Stage 1 Pilot study and those listed above. The simulated groundwater levels in the scenario incorporating Mallee PWA extraction from 2004/05 onwards (Figure 6) shows a higher goodness-of-fit and lower RMSE, than the recent modelling undertaken without incorporating Mallee PWA extraction (Figure 5). The results for each new model scenario in Table 3 (those not included in GHD's draft Stage 1 report) are shown schematically in Figure 4 to Figure 7[1].

Table 2 Comparison of Victorian Water Accounts data to GWMW datasets for 2005/06 to 2019/20

Water Year	Victorian Water Accounts (VWA) Annual Extraction (ML)	GWMW Annual Extraction (ML)	Difference (VWA – GWMW datasets)
2005 - 2006	2866	3658	-792
2006 - 2007	5423	5244	179
2007 - 2008	6212	6437	-225
2008 - 2009	6479	6084	395
2009 - 2010	5123	5410	-287
2010 - 2011	4059	4058	1
2011 - 2012	4891	4667	224
2012 - 2013	5568	5389	179
2013 - 2014	3586	3584	1
2014 - 2015	4961	4917	44
2015 - 2016	6131	5738	393
2016 - 2017	5805	4953	852
2017 - 2018	8331	8426	-95
2018 - 2019	6368	5130	1238
2019 - 2020	5285	5315	-30
TOTAL	**81,088**	**79,010**	**2,077**

Table 3 Summary of modelling results

Model details	Goodness of fit – R^2	Root Square Mean Error (RSME)	Figure reference
Annual Average Levels & Historic Extraction Only (from 2004/05 using Vic Water Accounts data) (from Stage 1 Pilot Study)	41.0	0.74	Figure 3
Annual Average Levels & Historic Extraction Only (from 1995 using GWMW Murrayville GMA datasets)	85.1	0.91	Figure 4
Annual Average Levels & Historic Extraction Only (from 2004/05 using GWMW Murrayville GMA datasets)	48.7	0.69	Figure 5
Annual Average Levels & Historic Extraction Only from 2004/05 for both Murrayville GMA (GWMW dataset) and Mallee PWA	80.3	0.43	Figure 6
Annual Average Levels & Historic Extraction Only from 2004/05 for both Murrayville GMA (GWMW dataset) and Mallee PWA within 10 km of MV	46.3	0.71	Figure 7

[1] Note that the vertical and horizontal scales on these comparison graphs are not the same, owing to their automated production through individual scripts, where each graph's scale is determined by the input data and cannot be pre-programmed at this stage.

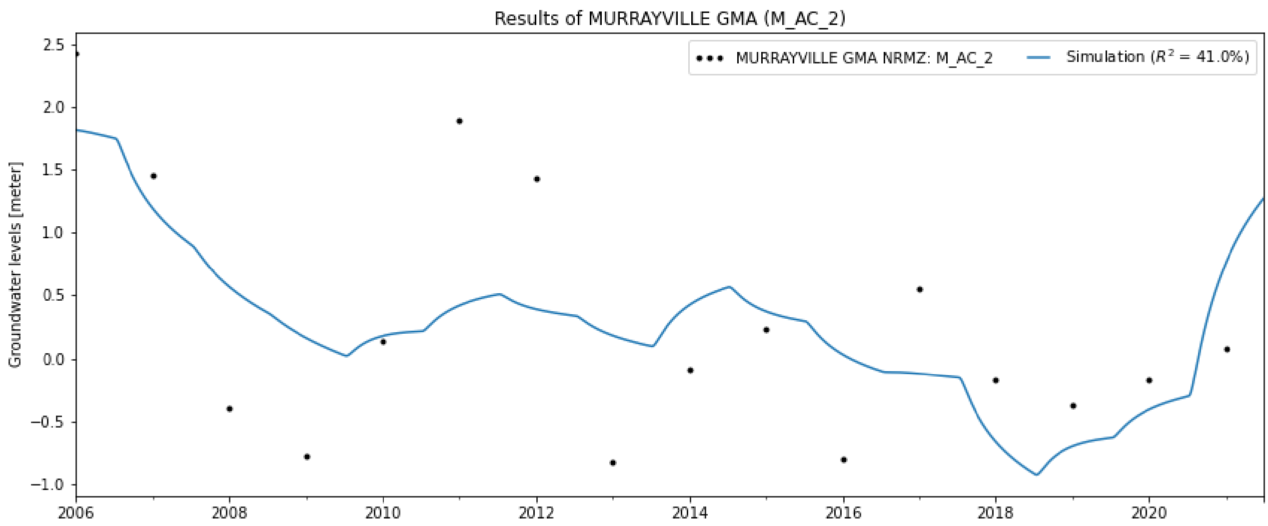


Figure 3 ***Annual Average Levels and Historic Extraction (from 2004/05 using Vic water accounts data)***

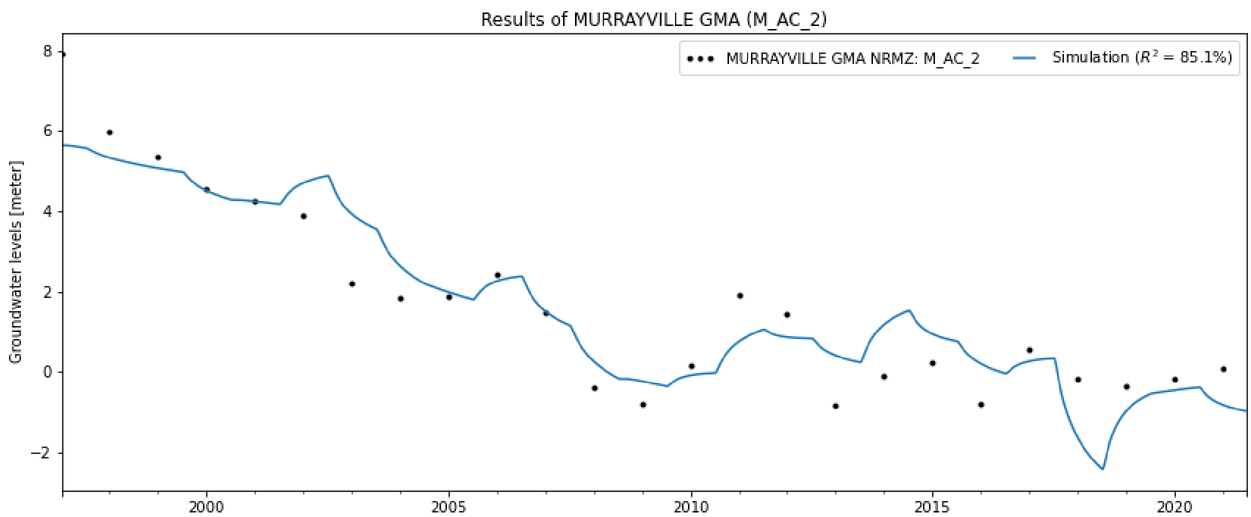


Figure 4 ***Annual Average Levels and Historic Extraction (GWMW supplied annual data from 1995)***

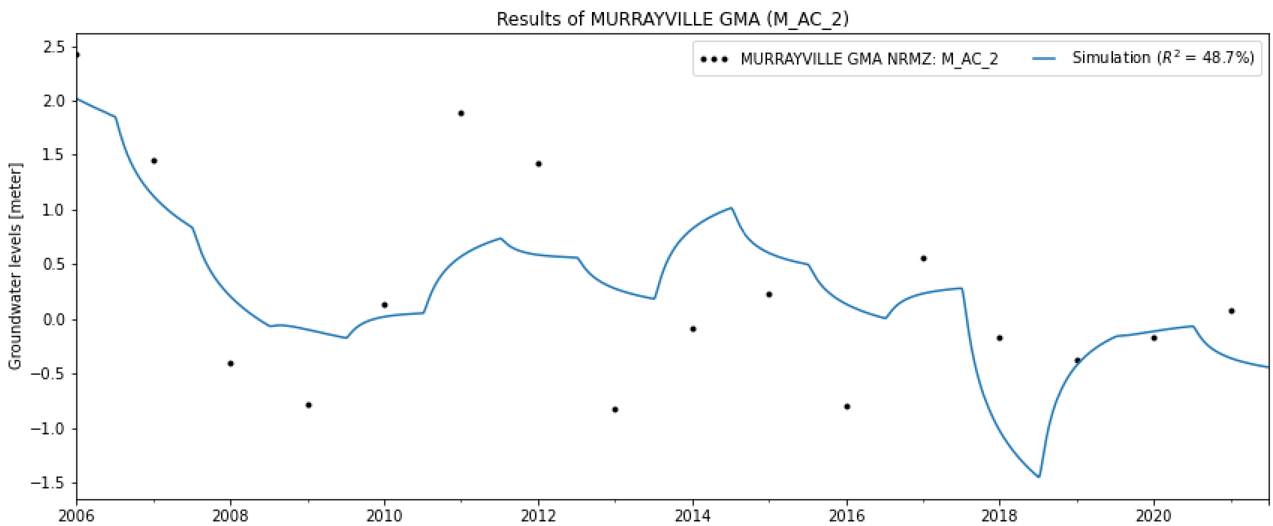


Figure 5 ***Annual Average Levels and Historic Extraction (from 2004/05 using GWMW supplied annual data)***

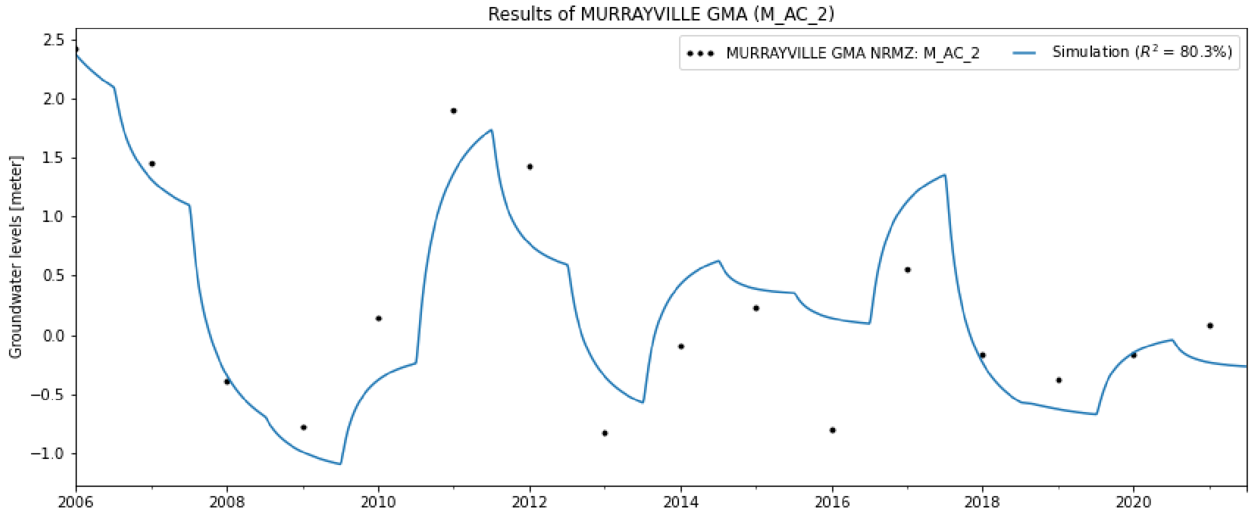


Figure 6 Annual Ave Levels & Historic Extraction Only from 2004/05 for both Murrayville (GWMW supplied data) and Mallee PWA

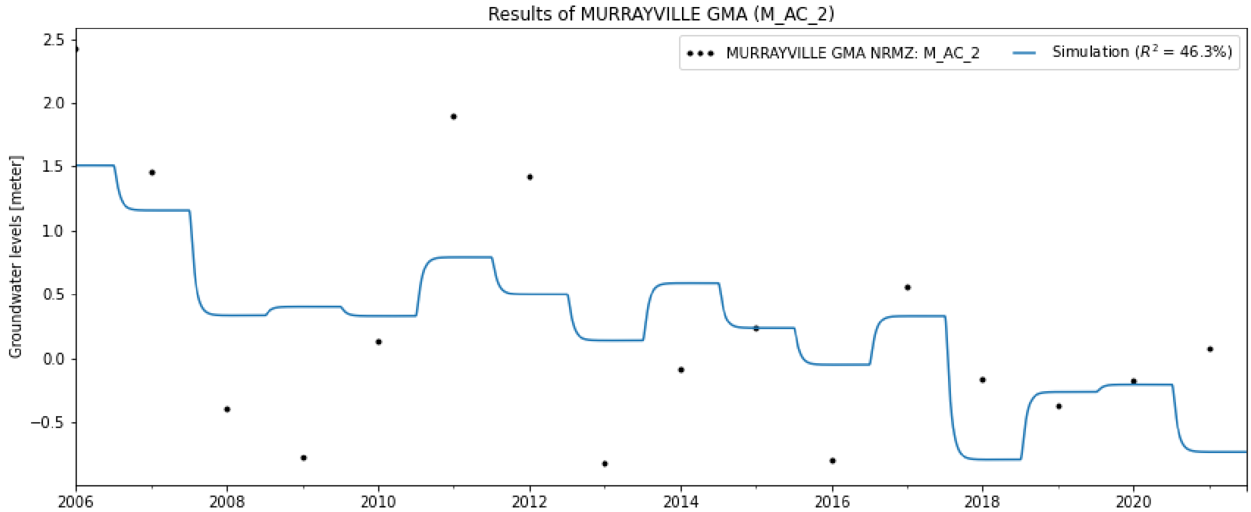


Figure 7 Annual Ave Levels & Historic Extraction Only from 2004/05 for both Murrayville (GWMW supplied data) and Mallee PWA within 10 km of Murrayville

5. Review of external influences

Based on the information gathered and its analysis, GHD notes the following:

- Under the 2004/05 extraction regime, extraction in SA was around 8 times greater than that in Victoria (Vic extraction of 4,206 ML/year and SA extraction of 30,660 ML/year)
- Under the 2004/05 extraction regime, groundwater from the MGL flowed west from Victoria to SA
- When extraction in SA only is increased by 22,340 ML/year (i.e. the difference between scenario 1 to scenario 2, where extraction in Victoria remains the same and only extraction in SA is changed), this has a small effect on the inflow to SA, increasing by 100 ML/year (6% change in inflow).
  When only extraction in Vic is increased by 5,270 ML/year (i.e. the difference between scenario 2 to scenario 3, where extraction in SA remains the same and only extraction in Victoria is changed) the inflow regime changes by 1,925 ML/year (118% change in flow), resulting in the inferred flow direction reversal. Under this scenario, groundwater would flow from SA to Victoria.
- The data presented indicates that changes to extraction in either SA or Victoria affect the water balance, however changes to extraction in Victoria, even small using GWMW supplied data) magnitude changes, could affect the water balance and inter-border flow regime
- The model by DWLBC (2006) indicates the drawdown in Murrayville GMA is likely influenced by extraction from the Mallee PWA
- The extraction regime in Murrayville GMA and Mallee PWA is generally similar based on historic annual usage data
- The comparison of Pastas modelling scenarios shows that the highest goodness of fit, is obtained when only historic groundwater extraction (GWMW dataset 1995-2021)) for Murrayville GMA is modelled (as per section 3, accuracy of model increases as RSME value approaches 0). However, the Mallee PWA data for this complete time frame (1995-2021) is not available to provide a comparison of the results, if both extraction data sets were combined. Therefore, only data from Murrayville from 2004/05 onwards (Figure 5; using GWMW supplied data) was compared, with data from both Murrayville GMA (using GWMW supplied data) and Mallee PWA data from 2004/05 onwards (Figure 6), which is the timeframe that direct comparisons can be made. The results were compared, and the modelling scenario that included all extraction from Murrayville GMA (using GWMW supplied data) and Mallee PWA provided an improved goodness-of-fit and RMSE to the Murrayville GMA only modelling scenario.

6. Conclusion

Drawdown in Murrayville GMA is likely influenced to some degree by extraction from the Mallee PWA, However, both GMUs have similar extraction regimes which may limit the potential impact of Mallee PWA extraction on the Murrayville GMA groundwater levels. This iteration of the GHD modelling indicates that with the additional historic data from Murrayville GMA, greater model accuracy is realised. However, when the same dataset is used over a smaller time scale, the model goodness of fit (R^2) decreases. When total extraction from Mallee PWA is incorporated for the same smaller time period, the model accuracy increases (It is noted that including just a portion of the extraction of Mallee PWA does not improve the R^2).

By considering the Murrayville GMA in isolation of Mallee PWA extraction, the model generally underestimates drawdown (the model simulated values are higher than the observed). The combined Murrayville GMA and Mallee PWA extraction generally overestimates drawdown (the model simulated values are lower than the observed).

7. Recommendation

Based on this assessment, it is proposed that the combined historic Murrayville GMA and Mallee PWA extraction data is used in the assessment and a similar process be undertaken on other GMUs where significant proportionally large scale extraction is occurring in neighbouring (external) areas that may be influencing drawdown within the GMU in question.

GHD welcomes any suggestions to the proposed approach and seeks endorsement from DEECA before its broader application.

Regards

Brittany Smyth
Senior Hydrogeologist

Appendix E

Electronic data files

Electronic files have been provided separately"

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