15. Lower Campaspe Valley WSPA

15.1 Conceptualisation

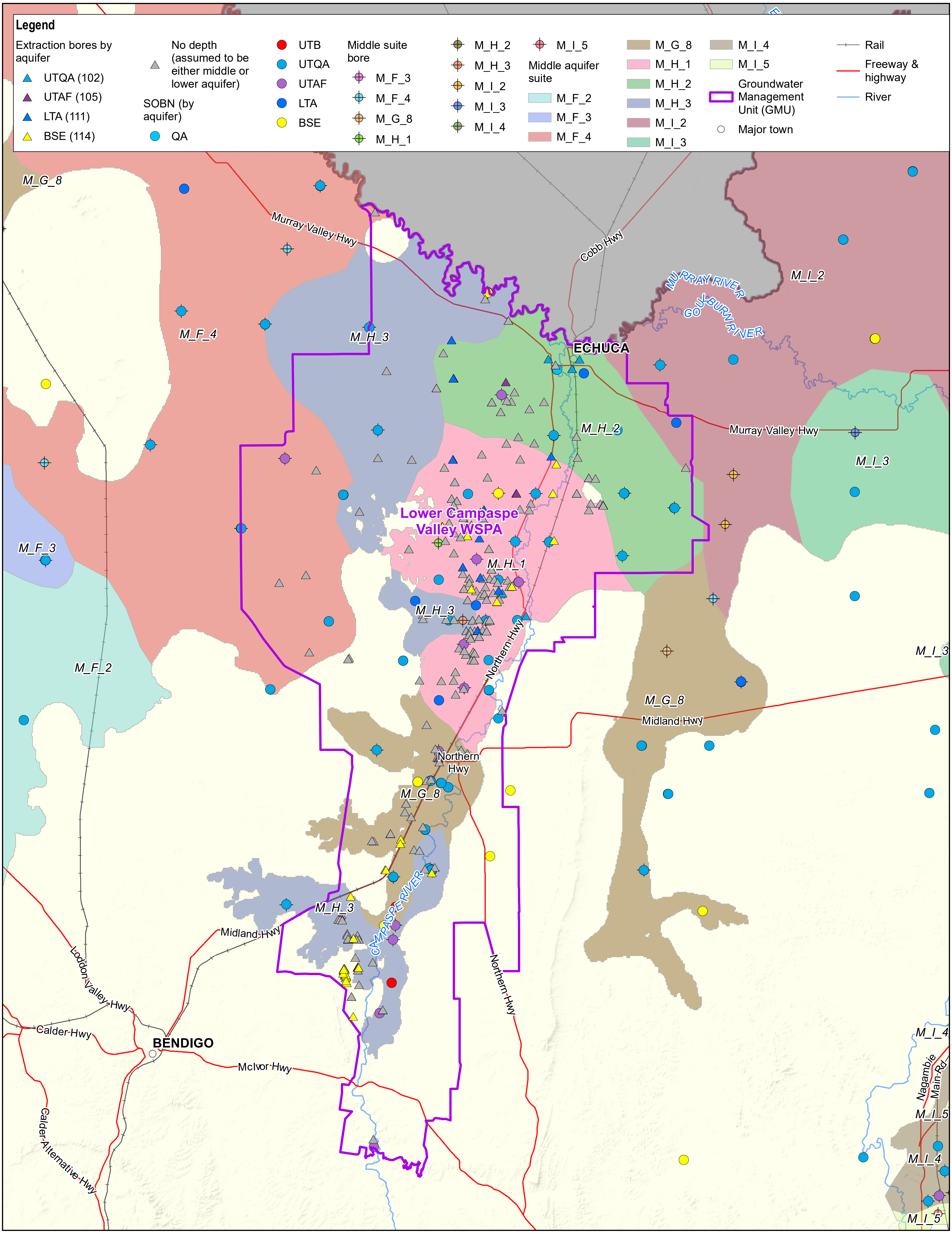
The hydrogeological conceptualisation elements relevant to this study are summarised in Table 77 and a map of the GMU is presented in Figure 192. It is noted that a significant volume of information was collated to inform the hydrogeological conceptual understanding of the GMU. The information that is directly relevant to the modelling are in bold or colour coded within Table 77.

Table 77 Lower Campaspe Valley WSPA – Tabulated conceptualisation

GMU summary								
Lower Campaspe Valley WSPA is situated in north-central Victoria, with the northern boundary of the GMU being the Murray River as shown in Figure 9. Lower Campaspe Valley WSPA covers an area of 2,154 km^2 and within this area, the WSPA pertains to all formations below the surface except in areas where it is overlain by the Shepparton Irrigation WSPA and the region north of the Waranga Western Channel; in these locations the Lower Campaspe Valley WSPA applies from 25 m and beyond. The Lower Campaspe Valley WSPA was intended to primarily manage the groundwater resources of the Calivil Formation (UTAF) and the Renmark Group (LTA); the PCV of 55,875 ML/year primarily relates to confined aquifers. However, it is noted that this aquifer could be considered a transitional aquifer in some areas – particularly in the southern portion of the WSPA where land surface is sloped and overburden may be thin, absent or non-continuous. Groundwater in the Lower Campaspe Valley WSPA is predominately used for domestic and stock use and for licensed uses such as irrigating dairy pastures and agricultural crops, as well as urban supply for Elmore township. It is noted that some of the resource developed includes shoestring sand segments in the Shepparton Formation aquifer. Lower Campaspe Valley WSPA is managed by GMW and occurs within the Goulburn Groundwater Basin.								
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	Coonambidgal Formation (QA)	-	-	0	NA	0	0	Low
	Shepparton Formation (UTQA)	U_N_1 (1%), U_N_2 (10%), U_N_3 (6%), U_N_4 (40%), U_N_5 (10%), U_P_1 (24%), U_O_9 (0.2%), U_Q_3 (0.2%), U_QQ_2 (0.7%)	93%	36	Irrigation, domestic, stock, dairy	188	322	Medium
Middle	Calivil Formation (UTAF)	M_H_1 (18%), M_H_2 (15%), M_H_3 (20%), M_F_4 (11%), M_G_8 (7%), M_I_2 (2%)	73%	31	Irrigation	22,821 (21,822)	32,583 (31,845)	Low
Lower	Renmark Group (LTA)	L_J_1 (8%), L_J_2 (34%), L_K_1 (2%)	44%	12	Irrigation, domestic	13,343 (8,486)	16,636 (12,384)	Low
Basement	Cretaceous and Permian Sediments (CPS)	-	-	0	NA	0	0	Low
	Basement Rocks (BSE)	B_I_1 (44%), B_I_2 (7%), B_J_1 (10%), B_M_1, (1%) B_Y_1 (5%)	66%	7	Dewatering, dairy, irrigation	5,408	6,320	Medium
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. Note that volumes listed above do include 30,308 ML of unassigned use (from total use of 41,752 ML) due to unknown depths (this is 44,229 ML of entitlement).								

Characteristic and importance	Description	Degree of understanding
Intended aquifer		
Aquifer thickness within GMU (range, based on VAF)	Max: 83.3 m, Average: 26.8 m	High
Aquifer extent	Regional, extensive	High
Likelihood of inter-aquifer flow	High as study area aquifers are semi-confined thus there is potential for groundwater – surface water interaction and inter-aquifer leakage.	Moderate
Likelihood of groundwater – surface water interaction	Moderate (transitional so likely to occur in unconfined aquifers of the GMU)	Moderate
Representative Suite	**M_H_1**	**Moderate. 58% of GMU extraction occurs within the middle aquifer including the unassigned bore extraction (8,000 ML). This Suite has the largest extraction when unassigned bore extraction is not included.** **Likely issue with bore data since 79% of extraction does not occur within defined/relevant 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)	1,933 mg/L (WMIS) Variable across GMU (CDM Smith (2022)	High Based on WMIS and CDM Smith (2022)
Groundwater yield	Variable across GMU	Low Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1972 to 2021**	**High**
Spatial clustering of licensed bores in relation to Suites	**Yes, M_H_1**	**Based on DEECA density mapping and licenced bore data.**
Groundwater use		
Licensed groundwater use	**29,689 ML**	**High (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	8,523 ML	High (Based on historical VWA data, year 2010/11)
Maximum historic groundwater use	**50,259 ML**	**High (Based on historical VWA data, year 2018/19)**
Entitlement (Groundwater allocation)	**55,860 ML**	**High (Based on licenced volumes in 2020/21)**

Characteristic and importance	Description	Degree of understanding
Significant drivers of groundwater level variability (primary)	**Pumping for irrigation and dairy**	**Moderate**
Secondary drivers of groundwater level variability	Pumping for town water supply	Moderate
Groundwater use profile	Influenced by seasonality	Moderate
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	Moderate
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	Moderate



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

GHD

DEECA
Sustainable yield review - confined aquifers

Lower Campaspe Valley WSPA
Site location and key features

Project No. 12564066
Revision No. 0
Date 09/02/2024

Figure 192

G:\31\12564066\GIS\Maps\Deliverables\31_12564066_00_KBM_A3P_2.mxd
Print date: 09 Feb 2024 - 08:46

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

15.2 Technical analysis

15.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the confined Suites for Lower Campaspe Valley WSPA (with the exception of the basement aquifer) are shown in Figure 193 and Figure 194; all Suite hydrographs exhibit a general decreasing trend.

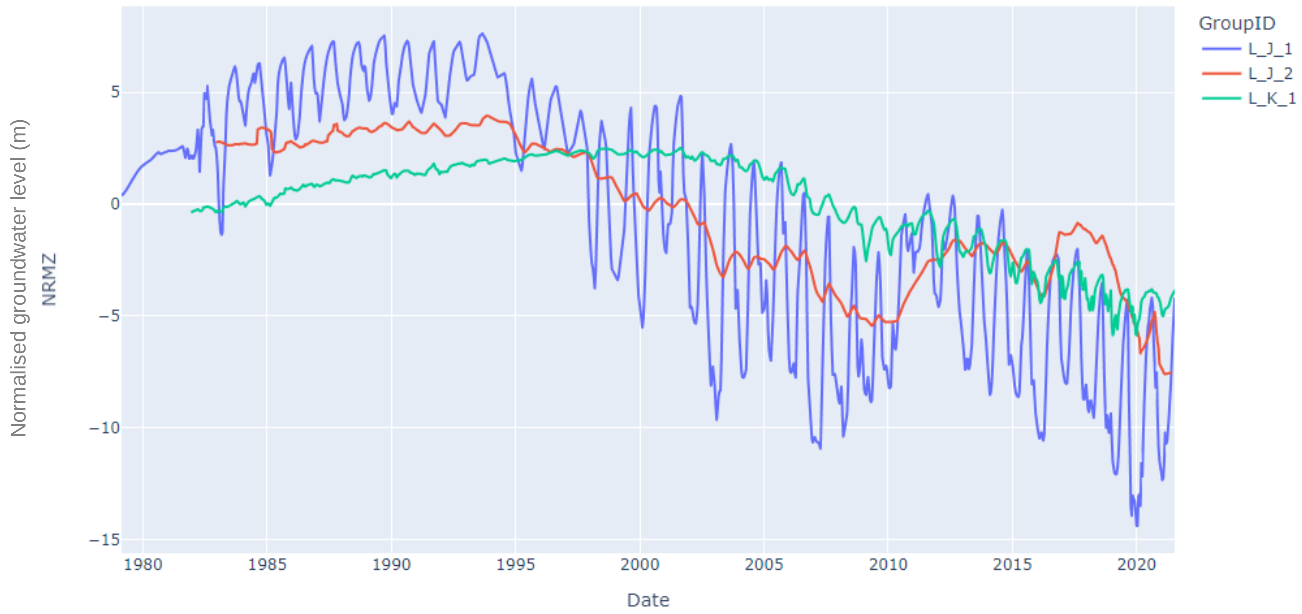


Figure 193 ***Lower Campaspe Valley WSPA Suite Hydrographs for all confined lower aquifers***

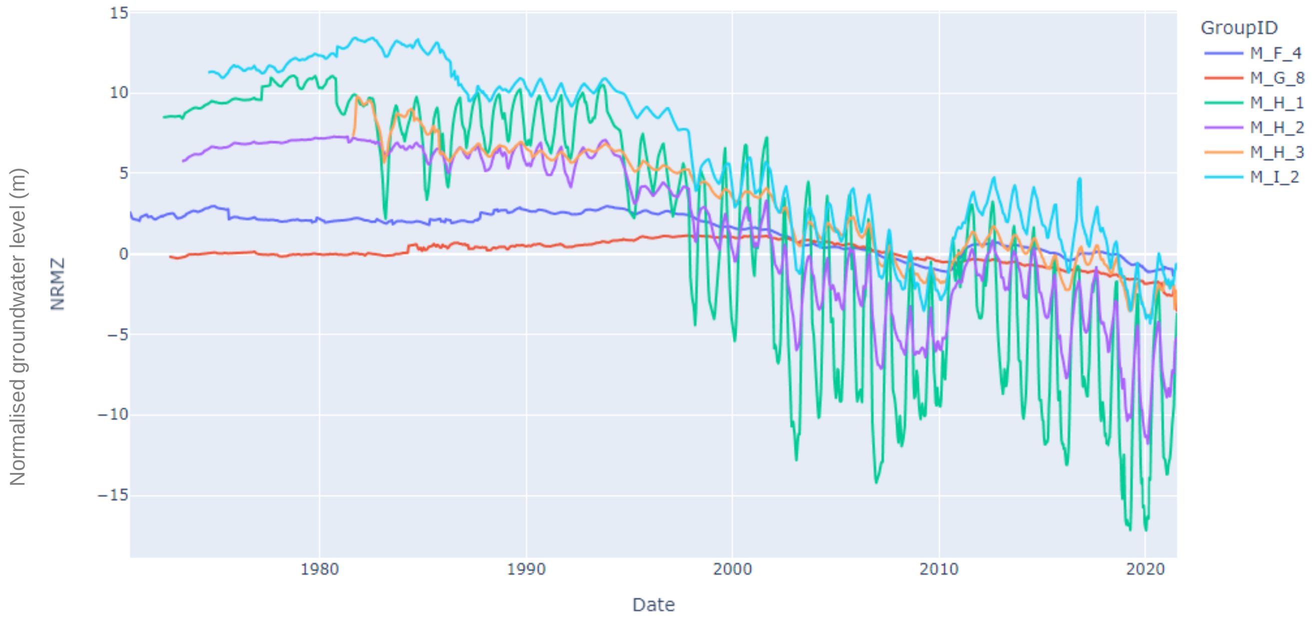


Figure 194 ***Lower Campaspe Valley WSPA Suite Hydrographs for all confined middle aquifers***

The representative Suites analysed for this GMU were Suites M_H_1, M_H_2 and M_H_3. The Representative Suites were selected based on the methodology outlined in section 2.6.4 which identified Suite M_H_1 as the most representative followed by M_H_2 then M_H_3. The process is summarised as follows:

- The greatest volume of extraction occurs within the Middle Aquifer
- The Middle Aquifer pertains to the UTAF which is one of the intended aquifers for this GMU
- Suite L_J_1 covers 8%, L_J_2 covers 34%, M_G_8 covers 7%, M_H_1 covers 18%, M_H_2 covers 15% and M_H_3 covers 20% of the GMU
- Within the Suite area, Suite M_H_1 has eight active SOBN bores, L_J_1 has five SOBN bores and Suites L_J_2, M_H_2 and M_H_3 have four SOBN bores
- Suite bores for M_H_1 and L_J_1 are close to the main cluster of extraction points

The annual recovered Suite hydrographs for the representative Suites for Lower Campaspe Valley WSPA, Suites M_H_1, M_H_2 and M_H_3 are shown in Figure 195.

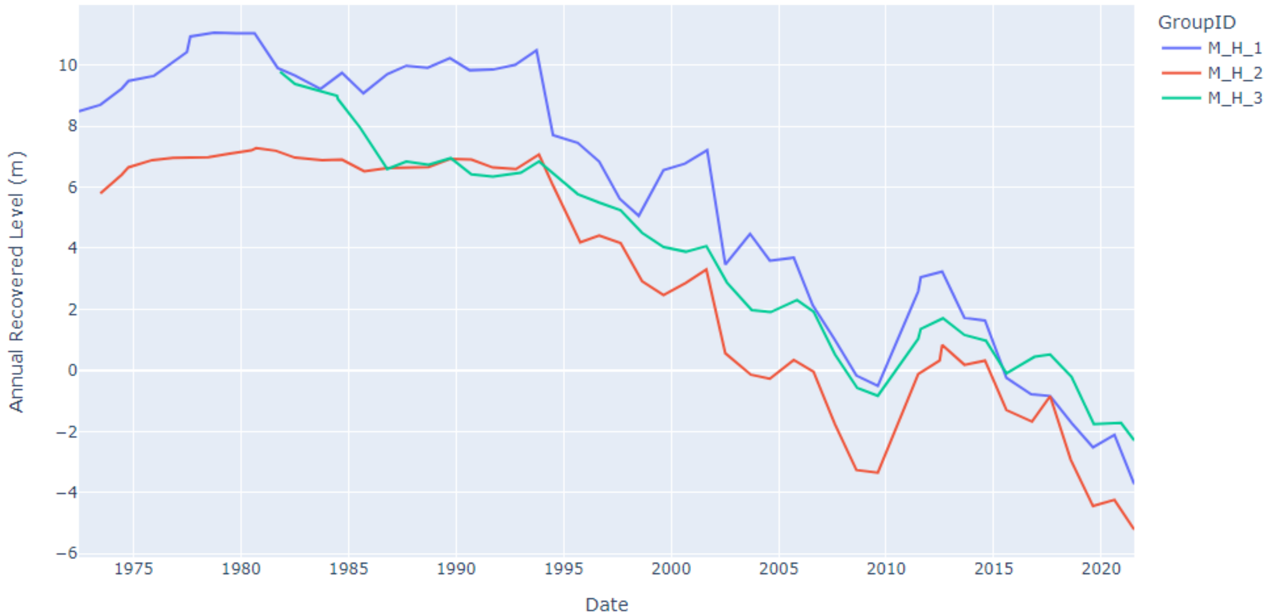


Figure 195 Lower Campaspe Valley WSPA Annual Recovered Level Suite Hydrographs for representative Suites

15.2.2 Pre-development level

To estimate the pre-development level conditions, GHD reviewed the Suite hydrographs of annual recovered levels and assumed that the maximum levels in the early time series data was the best representation of conditions prior to major development within Lower Campaspe Valley WSPA.

The pre-development annual recovered levels are taken to be the maximum level in the early time series data which equates to 11.06 m for Suite M_H_1 in the year 1978/1979, 7.28 m for Suite M_H_2 in the year 1980/1981 and 9.78 m for Suite M_H_3 in the year 1981/1982.

15.2.3 Externalities

Through the conceptualisation, no external influence on groundwater has been inferred for Lower Campaspe Valley WSPA.

15.2.4 Hindcasting

Groundwater use data for Lower Campaspe Valley WSPA is available from 2010/2011 to 2020/2021. The hindcasting methodologies outlined in section 3.3.4.5 were applied to Lower Campaspe Valley WSPA. A summary of the hindcasting results is shown below.

15.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, eight different correlations were developed for Lower Campaspe Valley WSPA as described below and shown in:

Figure 196, which includes:

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

Figure 197, which includes:

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

As shown in Figure 196 and Figure 197 the goodness-of-fit represented by the R^2 decreased when only the annual irrigation usage was used in the correlations with rainfall. The best goodness-of-fit result was shown to be the correlation of the two yearly average annual rainfall with annual groundwater extraction from Lower Campaspe Valley WSPA; this was the correlation adopted for modelling hindcast method H1.

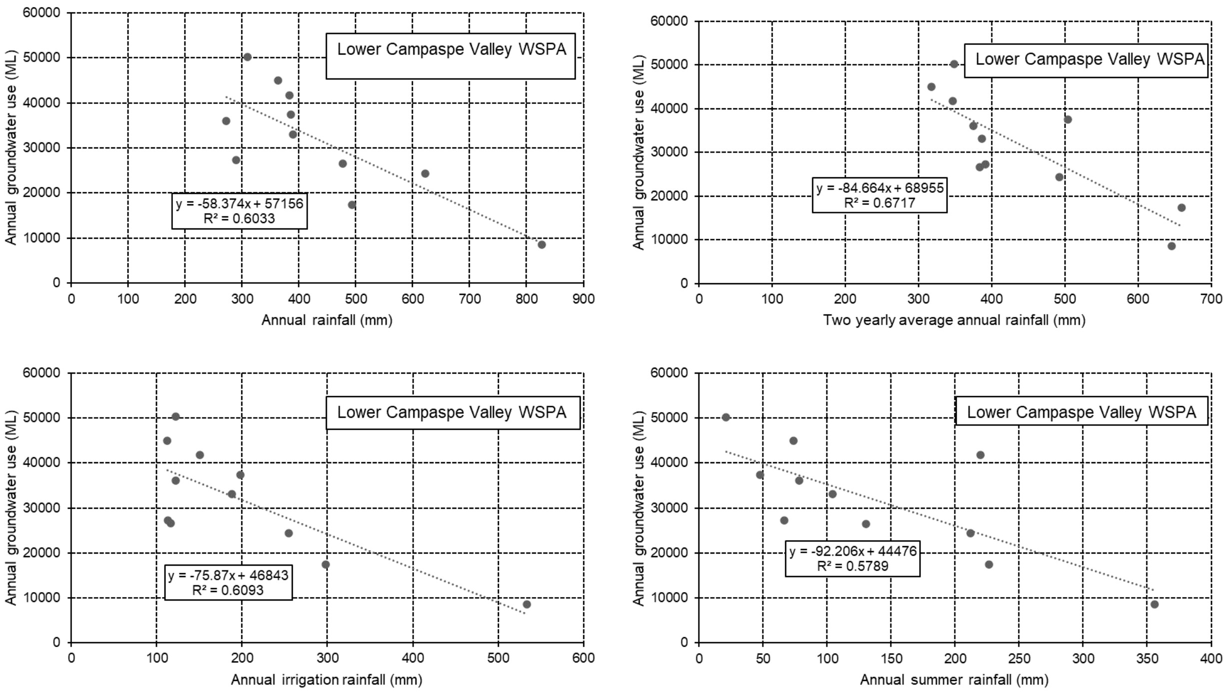


Figure 196 Lower Campaspe Valley WSPA: Hindcast method 1 correlations (Lower Campaspe Valley WSPA and annual groundwater use)

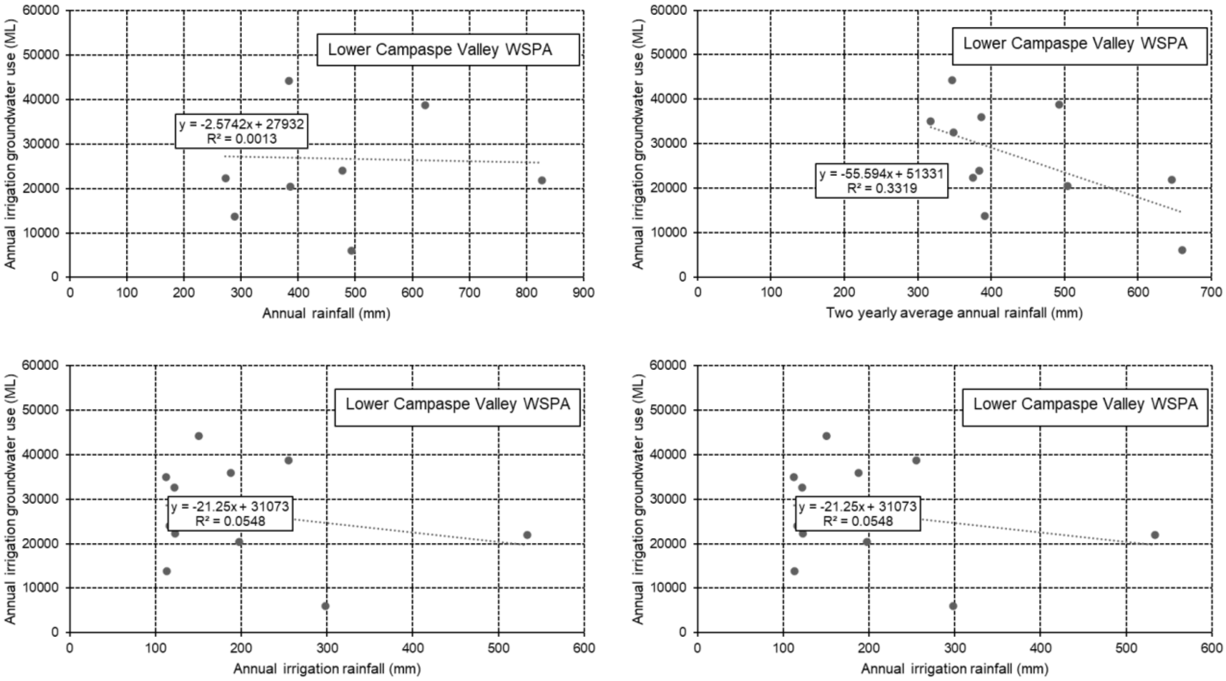


Figure 197 Lower Campaspe Valley WSPA: Hindcast method 1 correlations (Lower Campaspe Valley WSPA and annual irrigation groundwater use)

15.2.4.2 Hindcasting Method 2 (H2)

Four correlations were developed using method H2 as described below and shown in Figure 198:

- Lower Campaspe Valley WSPA use per bore vs annual rainfall
- Lower Campaspe Valley WSPA use per bore vs two yearly average annual rainfall
- Lower Campaspe Valley WSPA use per bore vs annual summer period rainfall
- Lower Campaspe Valley WSPA use per bore vs annual irrigation period rainfall

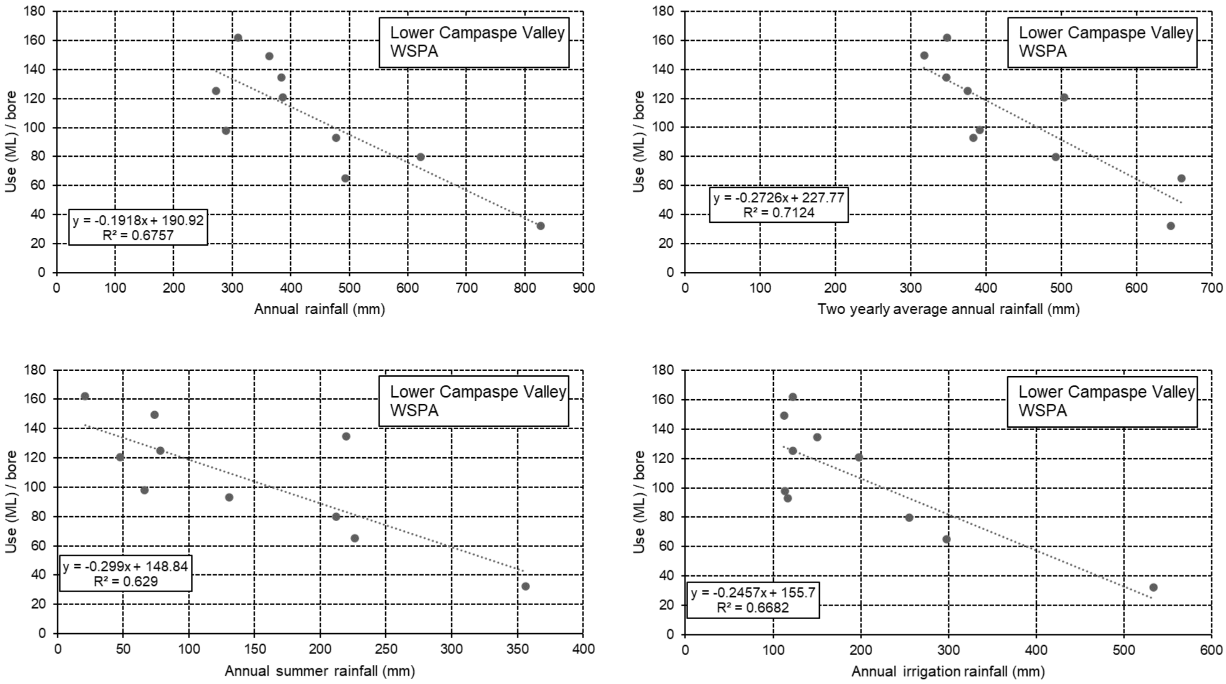


Figure 198 Lower Campaspe Valley WSPA: Hindcast method 2 correlations

As shown in Figure 198 and similar to method H1, the goodness-of-fit represented by the R^2 showed a better correlation of the two yearly average annual rainfall and Lower Campaspe Valley WSPA use per bore. This is the correlation that was modelled for hindcast method H2.

15.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 199:

- 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

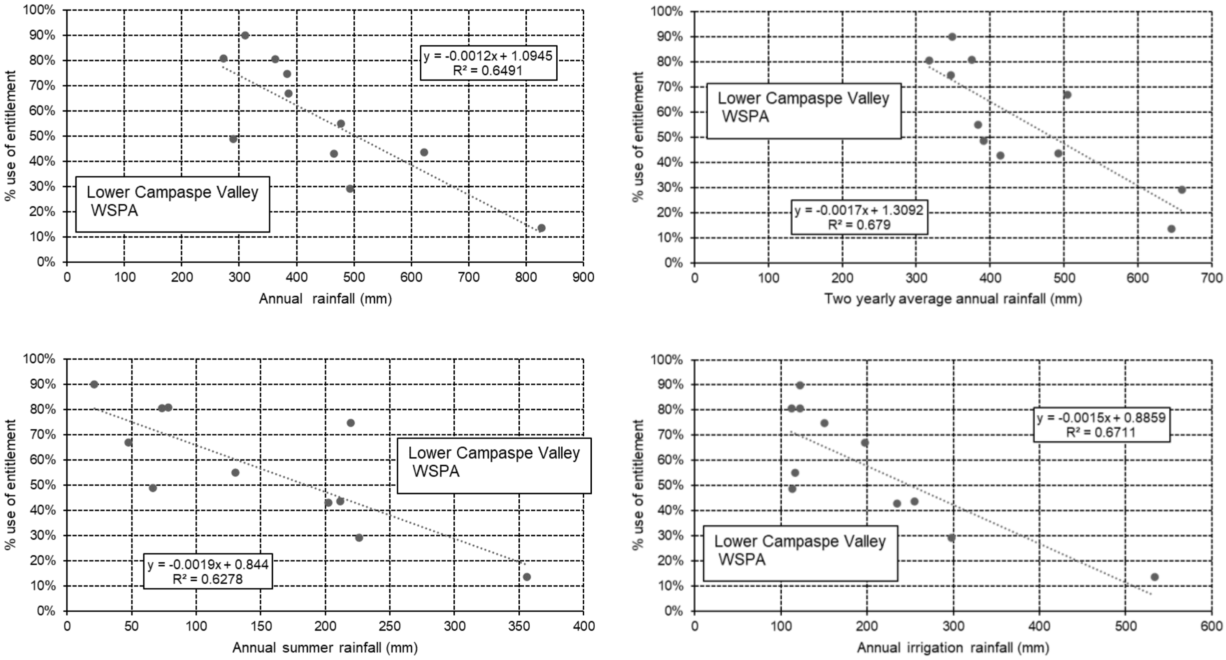


Figure 199 Lower Campaspe Valley WSPA: Hindcast method 3 correlations

As shown in Figure 199 and similar to method H1 and H2, the best goodness-of-fit result was shown to be the correlation of the two yearly average annual rainfall; this correlation was used for the H3 modelling.

15.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 200 and Figure 201 for the hindcasting based on only Lower Campaspe Valley WSPA groundwater use. Figure 200 shows a comparison of the three hindcasting methods against the recorded use only over the recorded use date, while Figure 201 shows the hindcasted data back to 1970/1971.

As shown in Figure 201, 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 and thus provides a higher groundwater extraction estimate than the other two methods. Both sets of 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 Lower Campaspe Valley WSPA.

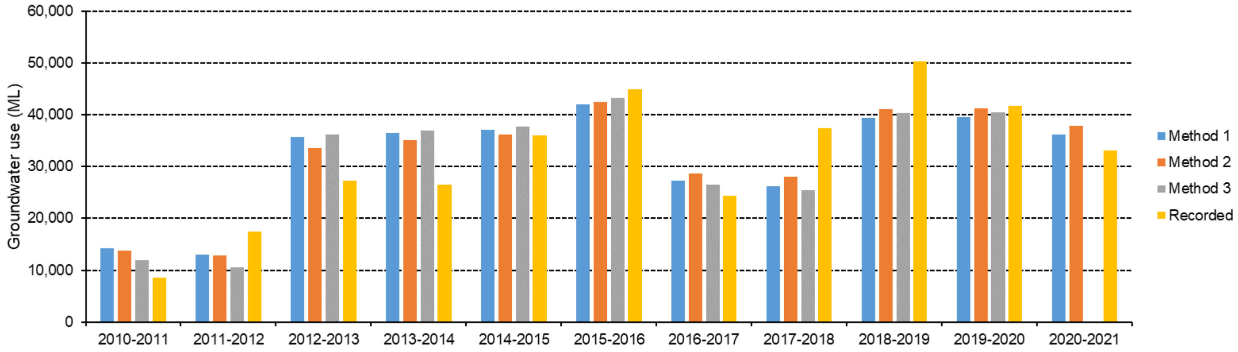


Figure 200 ***Lower Campaspe Valley WSPA: Comparison of hindcasting over recorded use period – Lower Campaspe Valley WSPA only extraction***

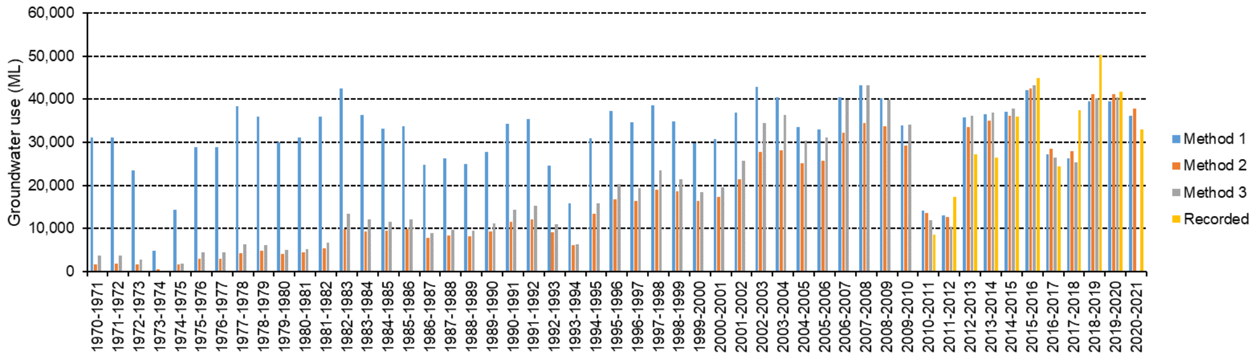


Figure 201 ***Lower Campaspe Valley WSPA: Comparison of hindcasting – Lower Campaspe Valley WSPA only extraction***

15.3 Modelling

15.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 78 summarises the combinations of model inputs run for Lower Campaspe Valley WSPA. Model runs highlighted blue indicate they were run with annual extraction and grey indicates they were run using two yearly average annual extraction.

Table 78 Lower Campaspe Valley 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 (M_H_1, M_H_2 and M_H_3)	✓	✓			✓		✓		✓	✓		✓		✓	✓	✓	✓	✓	✓
Annual extraction – Lower Campaspe Valley WSPA only	✓																		
Two yearly average annual extraction – Lower Campaspe Valley WSPA only		✓																	
Annual extraction – Lower Campaspe Valley WSPA and Externalities																			
Two yearly average annual extraction – Lower Campaspe Valley WSPA and Externalities																			
H1 annual extraction – Lower Campaspe Valley WSPA only					✓														
H1 annual extraction – Lower Campaspe Valley WSPA and Externalities																			
H2 annual extraction – Lower Campaspe Valley WSPA only							✓												
H2 annual extraction – Lower Campaspe Valley WSPA and Externalities																			
H3 annual extraction – Lower Campaspe Valley WSPA only									✓										
H1 two yearly average annual extraction – Lower Campaspe Valley WSPA only										✓									
H1 two yearly average annual extraction – Lower Campaspe Valley WSPA and Externalities																			
H2 two yearly average annual extraction – Lower Campaspe Valley WSPA only												✓							
H2 two yearly average annual extraction – Lower Campaspe Valley WSPA and Externalities																			
S1 annual extraction – Lower Campaspe Valley WSPA only														✓					
S2 annual extraction – Lower Campaspe Valley WSPA only															✓				

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

15.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 78 is presented in Table 79 for the selection of potential representative Suites for Lower Campaspe Valley WSPA. The column heading for M_H_1 is highlighted blue to indicate that this Suite was selected as the most likely representative Suite based on the process outlined in section 15.2.1. 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 M_H_1

A review of the results and statistical summary for Suite M_H_1 shows that model run 1 (highlighted orange) provides the best results when considering all four of the measures, firstly looking at the 95PPU TH and the RMSE of the different model input combinations. However, this model only includes 10 observation points and does not cover the period of pre-development. Considering the need to include a longer historic record in the calibration model, the model with the best results that meets this condition would be model run 7 (highlighted green) which has the highest R^2 and lowest RMSE of the hindcasted models. The graphical model output for this run is shown in Figure 202 and is the preferred model to run predictive models for this Suite within this GMU.

Suite M_H_2

A review of the results and statistical summary for Suite M_H_2 shows that model run 1 (highlighted orange) provides the best results when considering all four of the measures, firstly looking at the 95PPU TH and the RMSE of the 13 different model input combinations. However, this model only includes 10 observation points and does not cover the period of pre-development. Considering the need to include a longer historic record in the calibration model, the model with the best results that meets this condition would be model run 5 which has the highest R^2 and lowest RMSE of the hindcasted models. However, this model is based on hindcast method H1 which had a poor correlation and was unable to capture the decrease in usage historically. Given this, the next best model with hindcasting would be model run 7. The graphical model output for this run is shown in Figure 203 and is the preferred model to run predictive models for this Suite within this GMU.

Suite M_H_3

A review of the results and statistical summary for Suite M_H_3 shows that model runs 9 (highlighted green) and 14 have the best results when considering all four of the measures, firstly looking at the 95PPU TH and the RMSE of the 13 different model input combinations. These two model results show similar statistical results, however the R^2 for model run 9 is much higher than that for model run 14 and also includes a greater number of observation points, covering the defined pre-development period. Given this, the preferred model to progress to predictive modelling is model 9 for this Suite within this GMU. The graphical model output for this run is shown in Figure 204.

Modelling was progressed on the basis of adopting model run 7 for Suite M_H_1 and Suite M_H_2 and model run 9 for Suite M_H_3.

Table 79 Lower Campaspe Valley 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
M_H_1	95PPU TH	3.09	4.71			13.65		5.12		5.59	nan		10.97		4.81	20.64	14.04	5.46	123.69	21.26
	%Obs in 95 PPU	100	90			98		94		96	0		98		100	100	100	91.84	100	95.92
	R^2	95.5	87.8			92.5		92.7		91.3	-20.4		61.5		96.6	97.4	96.4	91.6	90.7	91.2
	RMSE	0.42	0.7			1.17		1.15		1.25	4.7		2.64		0.37	0.32	0.38	1.2	1.26	1.23
	No obs data points	10	10			50		50		10	10		49		10	10	50	50	50	49
	Range of observed levels	5.8	5.8			13.6		13.6		5.8	5.8		13.6		5.8	5.8	13.6	13.6	13.6	13.6
M_H_2	95PPU TH	3.26	11.42			5.58		5.45		5.78	13.65		4.31		3.74	52164.48	23.35	4.49	5.03	3.35
	%Obs in 95 PPU	100	100			97.96		77.55		73.47	100		97.96		100	10	100	95.83	56.25	93.75
	R^2	85.7	90.9			93.1		74.8		73	16.4		92.9		70.7	84.4	60.7	93.2	71.5	94.7
	RMSE	0.69	0.55			1		1.92		1.98	3.49		1.02		0.86	0.63	0.99	0.97	1.97	0.85
	No obs data points	10	10			49		49		10	10		48		10	10	49	49	49	49
	Range of observed levels	5.3	5.3			11.7		11.7		5.3	5.3		11.7		5.3	5.3	11.7	11.7	11.7	11.7
M_H_3	95PPU TH	12.03	9.43			6.81		5.59		2.46	6.5		3.25		2.25	4.24	nan	2.71	3.11	16.59
	%Obs in 95 PPU	100	100			100		67.5		90	97.5		97.5		100	100	0	92.31	10.26	100
	R^2	86	84.5			92.9		39.1		97.8	92.6		95.5		73.4	78.2	77.2	97.1	94	96.2
	RMSE	0.43	0.45			0.87		2.56		0.49	0.89		0.7		0.49	0.45	0.46	0.54	0.78	0.62
	No obs data points	10	10			40		40		10	10		39		10	10	40	40	40	40
	Range of observed levels	3.5	3.5			11.5		11.5		3.5	3.5		11.5	1	3.5	3.5	11.5	11.5	11.5	11.5

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

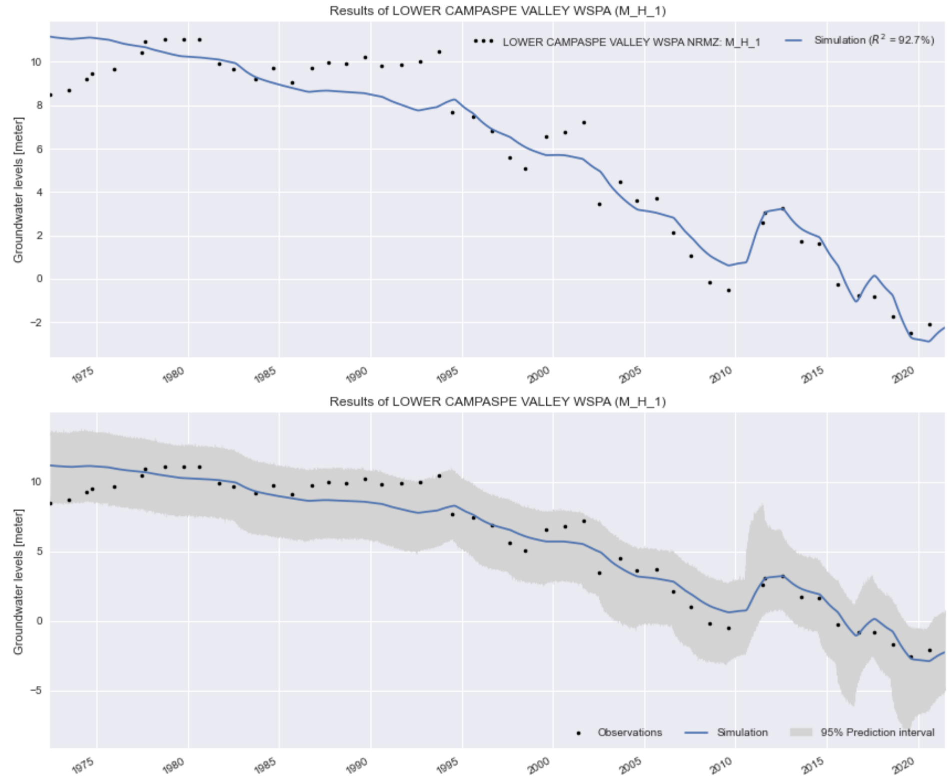


Figure 202 ***Lower Campaspe Valley WSPA Suite M_H_1: model run 7 (Lower Campaspe Valley WSPA annual extraction with hindcast method H2) output hydrographs***

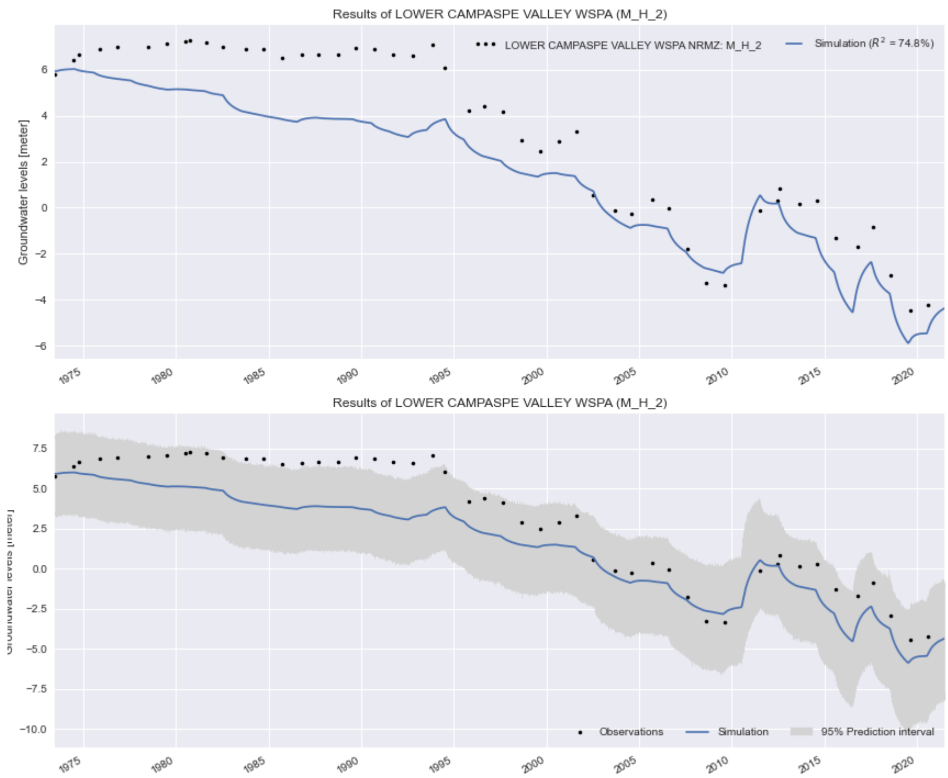


Figure 203 ***Lower Campaspe Valley WSPA Suite M_H_2: model run 7 (Lower Campaspe Valley WSPA annual extraction with hindcast method H2) output hydrographs***

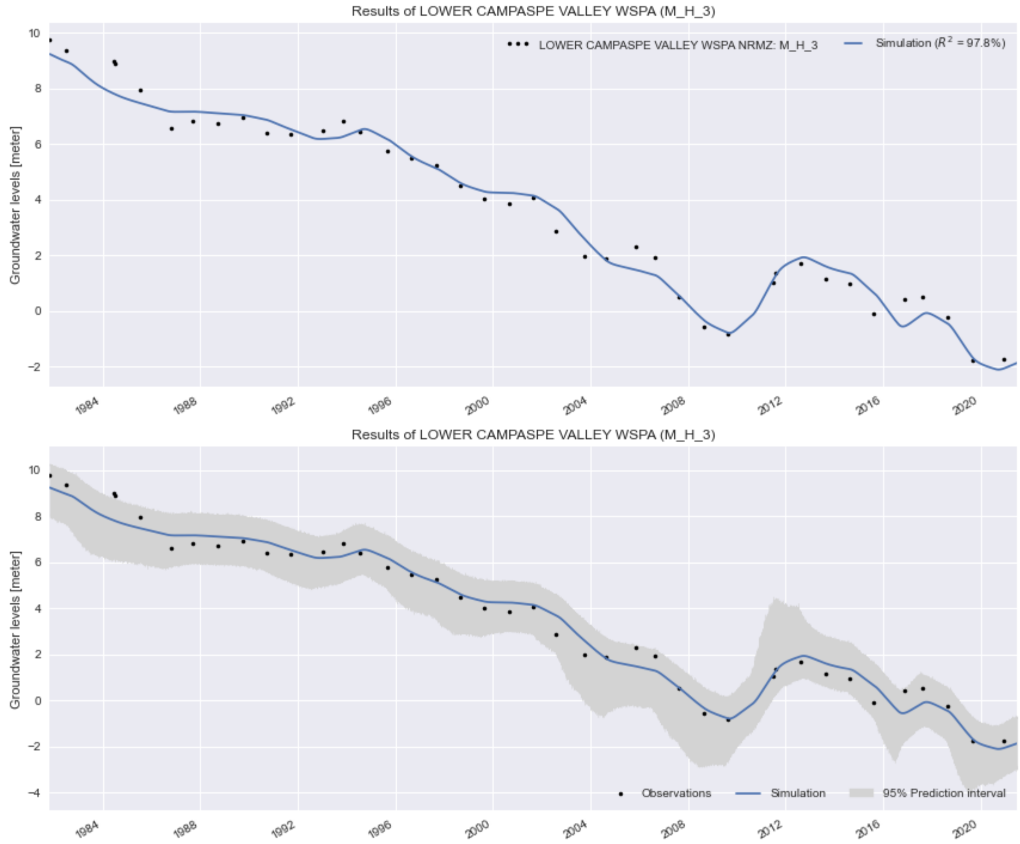


Figure 204 *Lower Campaspe Valley WSPA Suite M_H_3: model run 9 (Lower Campaspe Valley WSPA annual extraction with hindcast method 3) output hydrographs*

15.4 Predictive modelling

15.4.1 Model inputs

The preferred model to run the predictive modelling for Lower Campaspe Valley WSPA was model run 7 for Suites M_H_1 and M_H_2 and model run 9 for Suite M_H_3. The key inputs for the model were the annual hindcasted extraction in Lower Campaspe Valley WSPA. To conduct the forecasting for the 19 scenarios discussed in section 3.5.3, a few factors were required in the calculations, as summarised in Table 80.

Table 80 *Lower Campaspe Valley 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 2018/19)
Value (ML/year)	55,875	55,860	33,050	29,689	50,259

The model run 7 was run for all 19 forecast scenarios on Suites M_H_1 and M_H_2 and model run 9 was run for all 19 forecast scenarios on Suite M_H_3.

15.4.2 Predictive modelling uncertainty

The model output files of the predicted models can be found in the data package provided in 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 205 for scenario 4. As shown in Figure 205, 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 as shown in Figure 206.

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.

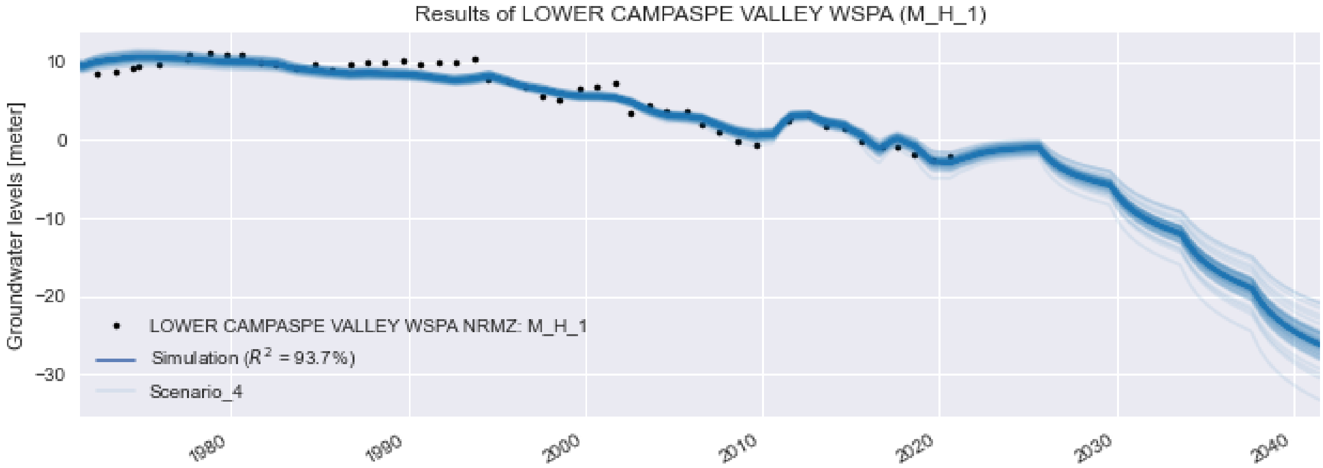


Figure 205 Lower Campaspe Valley WSPA: Suite M_H_1 MCMC analysis for Forecast Scenario 4

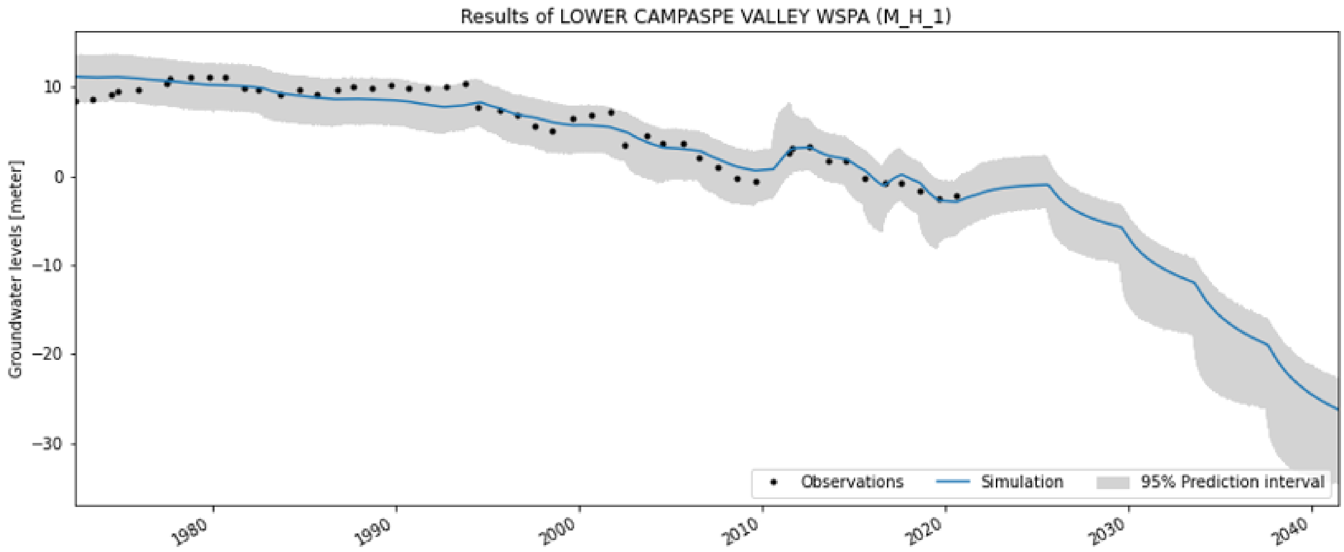


Figure 206 Lower Campaspe Valley WSPA: Suite M_H_1 Forecast Scenario 4 with 95% prediction bands

15.4.3 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. 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 15.2.2, 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 207 for Suite M_H_1. In Figure 207:

- Actual annual groundwater use is represented by the blue column graph between 2010/11 and 2020/2021
- Hindcasted groundwater use is represented by the orange columns between 1971/1972 and 2009/10, and the 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 whereby the earliest data is taken to best reflect pre-development
- The pre-development annual recovered level is taken to be the maximum reading in the early time series data, this was taken to be 11.06 m
- The modelled forecasted annual recovered levels are represented by the purple line in Figure 207

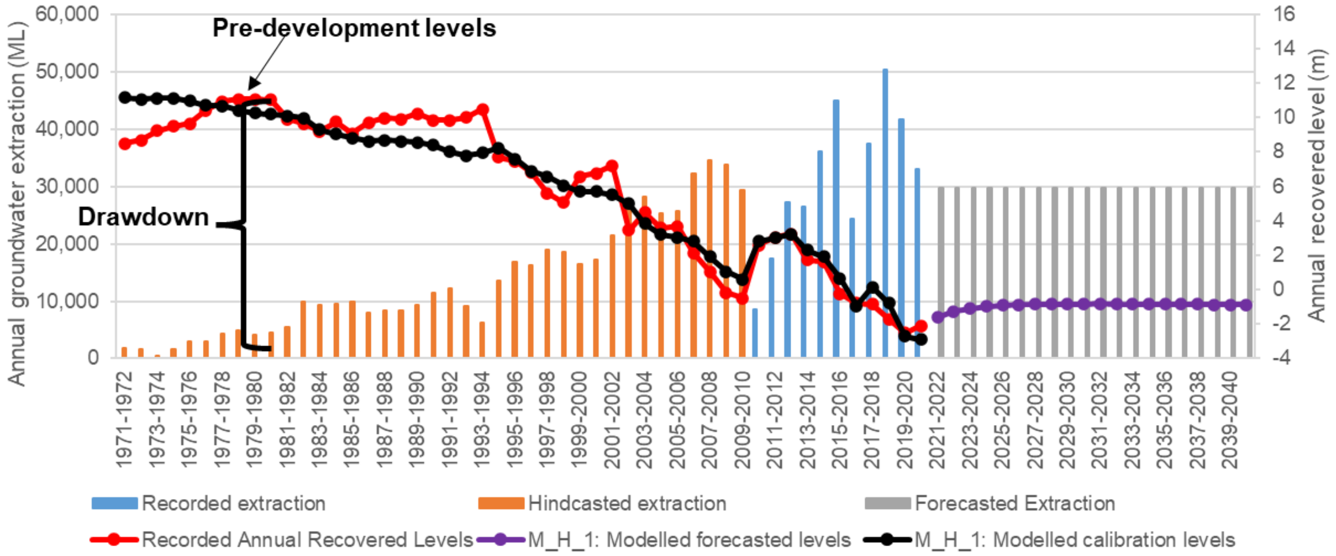


Figure 207 ***Estimating pre-pumping water levels (example from Suite M_H_1)***

For Suite M_H_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 208)
- A graph of the scenarios for specific time periods (Figure 209) to develop the volume to drawdown relationship

For each scenario, a linear regression was applied and the R^2 was calculated. A comparison of each of these graphs shows there was variations in the coefficient of determination between different scenarios and slight variations of in the slope of the linear regression. The same process was applied for Suite M_H_2 and Suite M_H_3, and again, was variations in the coefficient of determination between different scenarios and slight variations of in the slope of the linear regression. As such, the relationship developed using all scenarios was adopted as it best captures this variation between forecast scenarios.

The use-drawdown for all the 19 forecast scenario drawdowns and volumes (both the recorded and forecasted volumes) over each year modelled (1972 to 2041 for Suites M_H_1, 1973 to 2041 for M_H_2 and 1982 to 2041 for

Suite M_H_3) is shown in Figure 208 for Suite M_H_1, Figure 210 for Suite M_H_2 and Figure 211 for Suite M_H_3. 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 30,000 ML. Figure 208 and Figure 211 indicate that at use around 30,000 ML the model forecast drawdown tends to be slightly above the predicted line of best fit, but for Suite M_H_2, they plot closer to the predicted line
- For the same annual use, different drawdowns can be obtained as Pastas predicts a water level for each year. For example, Figure 207 shows a scenario where groundwater use remains constant at around 30,000 ML/year over the 20 year model period
- The correlation in terms of R^2 for groundwater use and drawdown for Suites M_H_1 and M_H_2 is excellent and for Suite M_H_3 is moderate as shown in Figure 208, Figure 210 and Figure 211 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.

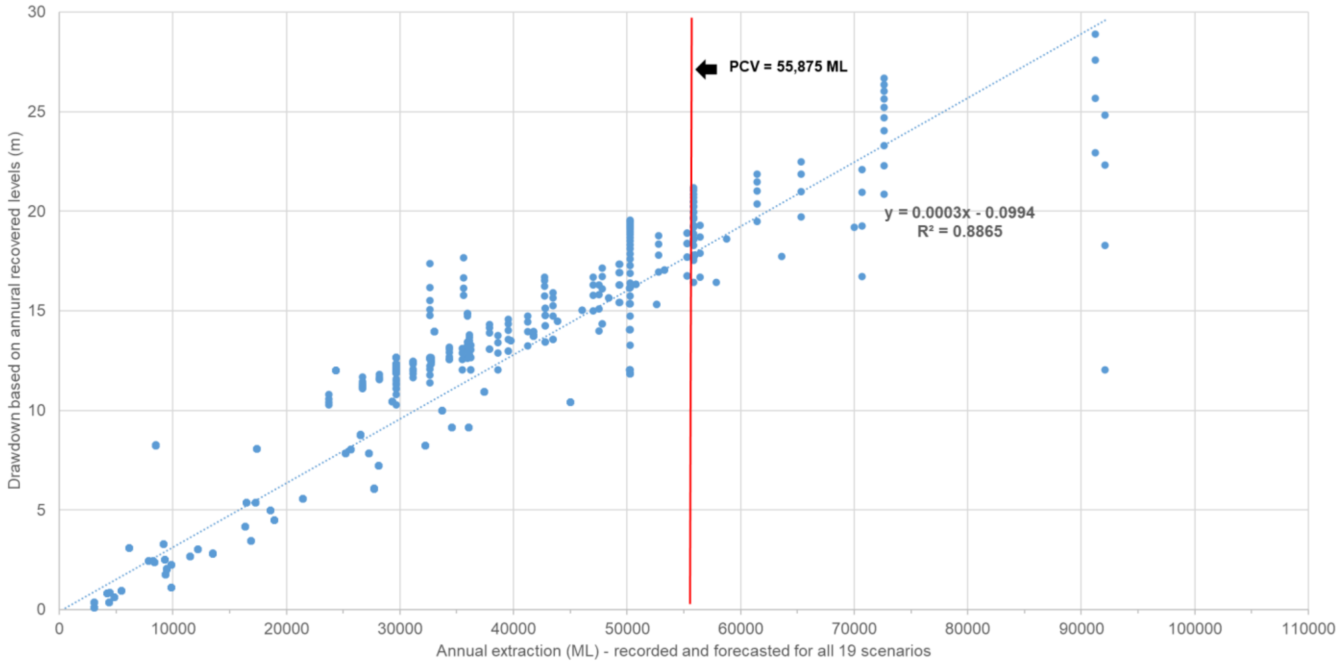


Figure 208 Lower Campaspe Valley WSPA Suite M_H_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <110,000 ML) for all data between 1972 to 2041 and all forecasted scenarios

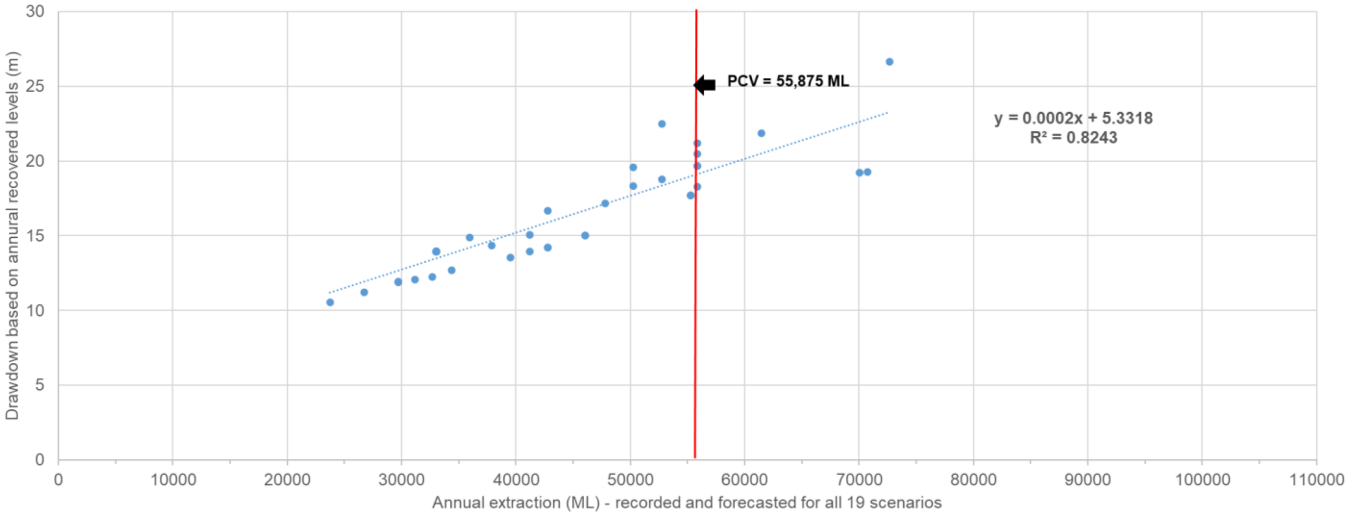


Figure 209 *Lower Campaspe Valley WSPA Suite M_H_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <110,000 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

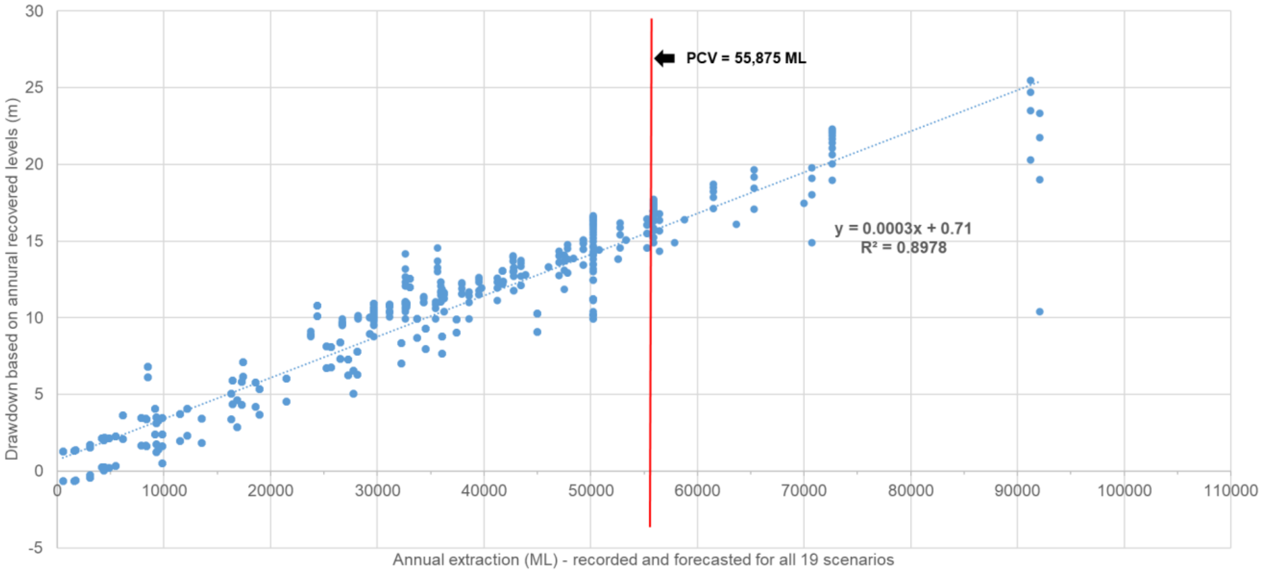


Figure 210 *Lower Campaspe Valley WSPA Suite M_H_2: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <110,000 ML) for all data between 1973 to 2041 and all forecasted scenarios*

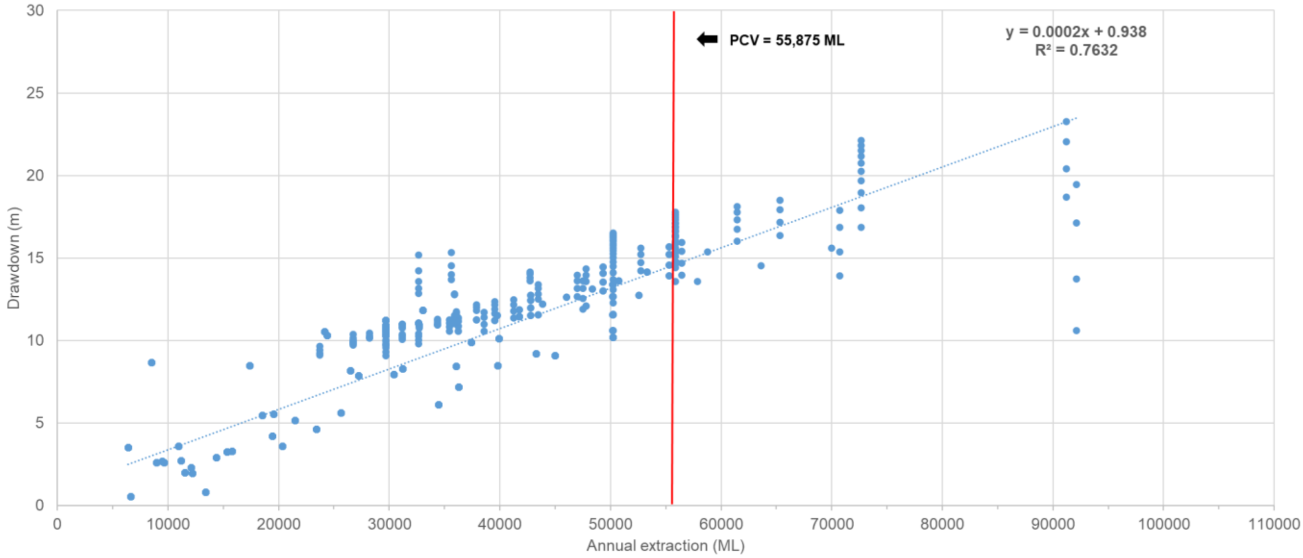


Figure 211 *Lower Campaspe Valley WSPA Suite M_H_3: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <110,000 ML) for all data between 1982 to 2041 and all forecasted scenarios*

15.5 Sustainability metrics

15.5.1 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 groundwater resource sustainability metrics applied to this study were developed by DEECA, as outlined in section 3.6.1.

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 81 and Figure 212 for Suite M_H_1, Table 82 and Figure 213 for Suite M_H_2 and Table 83 and Figure 214 for Suite M_H_3. 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 81 and Figure 212 for Suite M_**I**_1, Table 82 and Figure 213 for Suite M_**I**_2 and Table 83 and Figure 214 for Suite M_H_3. Figure 215 shows graphically and spatially by Suite the drawdowns associated with extraction rates.

A comparison of volumes at drawdown intervals provided by DEECA is shown in Table 84 for Suite M_H_1, M_H_2 and M_H_3. Based on the relationships developed, 5 m of drawdown is predicted to occur with 17,000 ML (which could range from 9,700 to 24,600 ML) of use based on Suite M_H_1, 14,300 ML (which could range from 7,100 to 31,500 ML) of based on Suite M_H_2 and 20,300 (which could range from 10,400 to 26,700 ML) for Suite M_H_3. Whereas, 10 m of drawdown is predicted to occur with 33,700 ML (which could range from 26,400 to 41,200 ML) of use based on Suite M_H_1, 30,900 ML (which could range from 23,800 to 56,500 ML) of based on Suite M_H_2 and 45,300 (which could range from 27,000 to 51,700 ML) for Suite M_H_3.

Table 81 Relationship of Suite drawdown to GMU extraction for Lower Campaspe Valley WSPA Suite M_H_1

Volume (ML/year) for whole of GMU	Based on model prediction of Suite M_H_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
110,000	32.9 (30.6 - 35.1)
105,000	31.4 (29.1 - 33.6)
100,000	29.9 (27.6 - 32.1)
95,000	28.4 (26.1 - 30.6)
90,000	26.9 (24.6 - 29.1)
85,000	25.4 (23.1 - 27.6)
80,000	23.9 (21.6 - 26.1)
75,000	22.4 (20.1 - 24.6)
70,000	20.9 (18.6 - 23.1)
65,000	19.4 (17.1 - 21.6)
60,000	17.9 (15.6 - 20.1)
55,000	16.4 (14.1 - 18.6)
50,000	14.9 (12.6 - 17.1)
45,000	13.4 (11.1 - 15.6)
40,000	11.9 (9.6 - 14.1)
35,000	10.4 (8.1 - 12.6)
30,000	8.9 (6.6 - 11.1)
25,000	7.4 (5.1 - 9.6)
20,000	5.9 (3.6 - 8.1)
15,000	4.4 (2.1 - 6.6)
10,000	2.9 (0.6 - 5.1)
5,000	1.4 (-0.9 - 3.6)
0	-0.1 (-2.4 - 2.1)

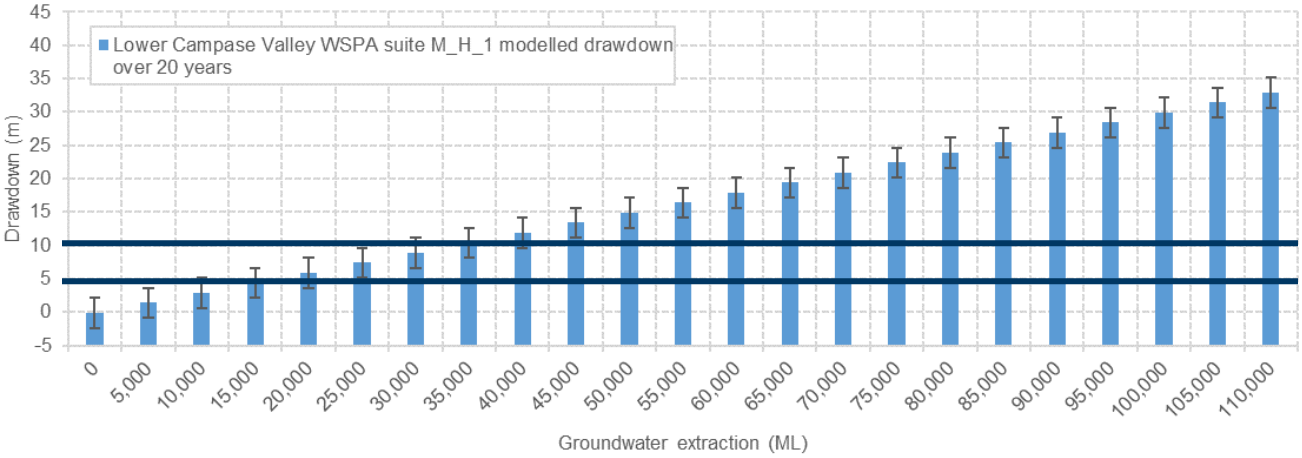


Figure 212 Lower Campaspe Valley WSPA Suite M_H_1: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 82 Relationship of Suite drawdown to GMU extraction for Lower Campaspe Valley WSPA Suite M_H_2

Volume (ML/year) for whole of GMU	Based on model prediction of Suite M_H_2 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
110,000	33.7 (20.7 - 35.9)
105,000	32.2 (19.7 - 34.4)
100,000	30.7 (18.7 - 32.9)
95,000	29.2 (17.7 - 31.4)
90,000	27.7 (16.7 - 29.9)
85,000	26.2 (15.7 - 28.4)
80,000	24.7 (14.7 - 26.9)
75,000	23.2 (13.7 - 25.4)
70,000	21.7 (12.7 - 23.9)
65,000	20.2 (11.7 - 22.4)
60,000	18.7 (10.7 - 20.9)
55,000	17.2 (9.7 - 19.4)
50,000	15.7 (8.7 - 17.9)
45,000	14.2 (7.7 - 16.4)
40,000	12.7 (6.7 - 14.9)
35,000	11.2 (5.7 - 13.4)
30,000	9.7 (4.7 - 11.9)
25,000	8.2 (3.7 - 10.4)
20,000	6.7 (2.7 - 8.9)
15,000	5.2 (1.7 - 7.4)
10,000	3.7 (0.7 - 5.9)
5,000	2.2 (-0.3 - 4.4)
0	0.7 (-1.3 - 2.9)

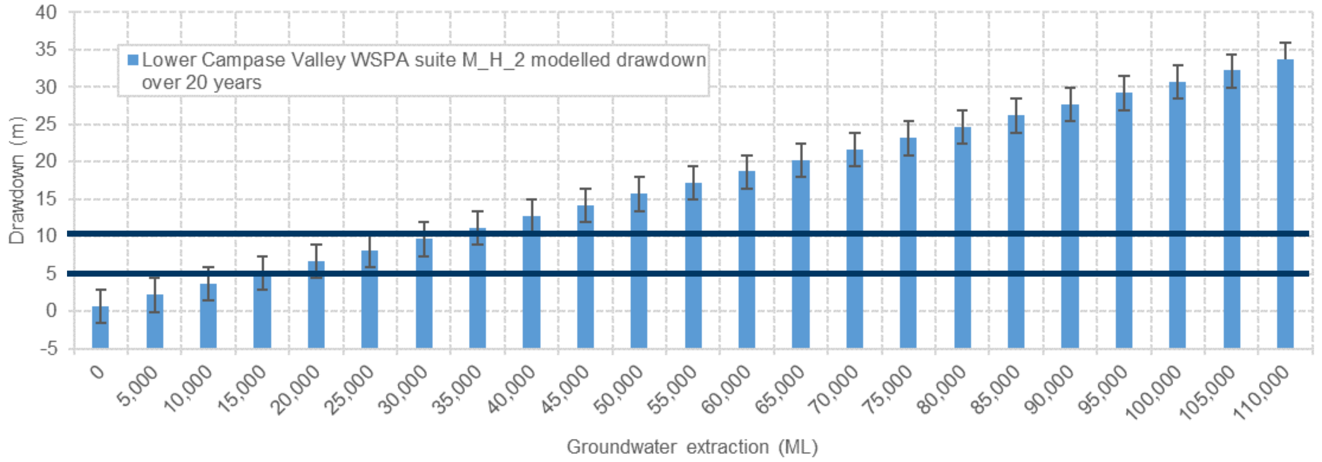


Figure 213 Lower Campaspe Valley WSPA Suite M_H_2: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 83 Relationship of Suite drawdown to GMU extraction for Lower Campaspe Valley WSPA Suite M_H_3

Volume (ML/year) for whole of GMU	Based on model prediction of Suite M_H_3 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
110,000	22.9 (21.7 - 34.9)
105,000	21.9 (20.7 - 33.4)
100,000	20.9 (19.7 - 31.9)
95,000	19.9 (18.7 - 30.4)
90,000	18.9 (17.7 - 28.9)
85,000	17.9 (16.7 - 27.4)
80,000	16.9 (15.7 - 25.9)
75,000	15.9 (14.7 - 24.4)
70,000	14.9 (13.7 - 22.9)
65,000	13.9 (12.7 - 21.4)
60,000	12.9 (11.7 - 19.9)
55,000	11.9 (10.7 - 18.4)
50,000	10.9 (9.7 - 16.9)
45,000	9.9 (8.7 - 15.4)
40,000	8.9 (7.7 - 13.9)
35,000	7.9 (6.7 - 12.4)
30,000	6.9 (5.7 - 10.9)
25,000	5.9 (4.7 - 9.4)
20,000	4.9 (3.7 - 7.9)
15,000	3.9 (2.7 - 6.4)
10,000	2.9 (1.7 - 4.9)
5,000	1.9 (0.7 - 3.4)
0	0.9 (-0.3 - 1.9)

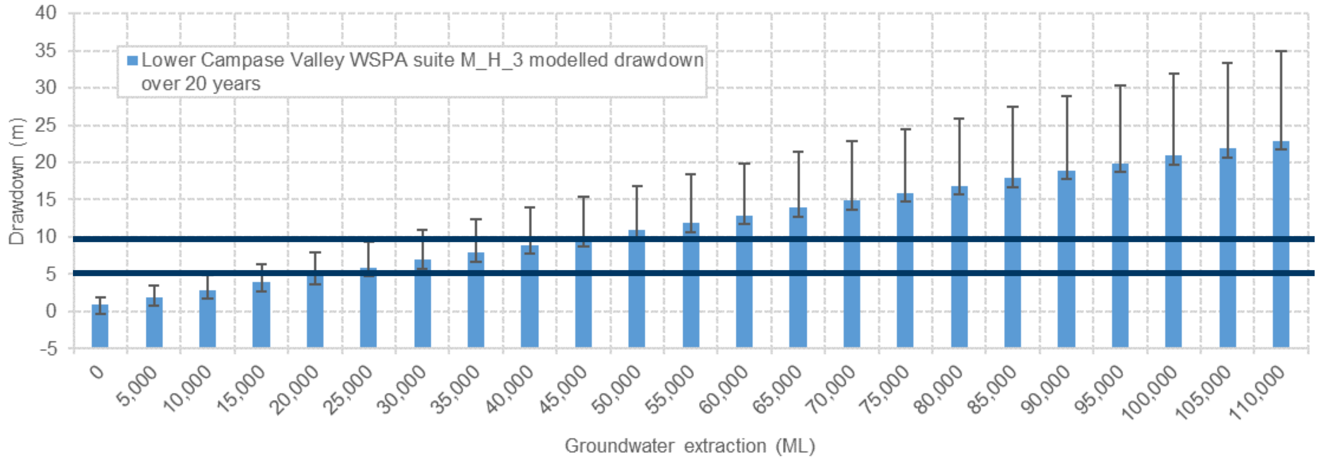
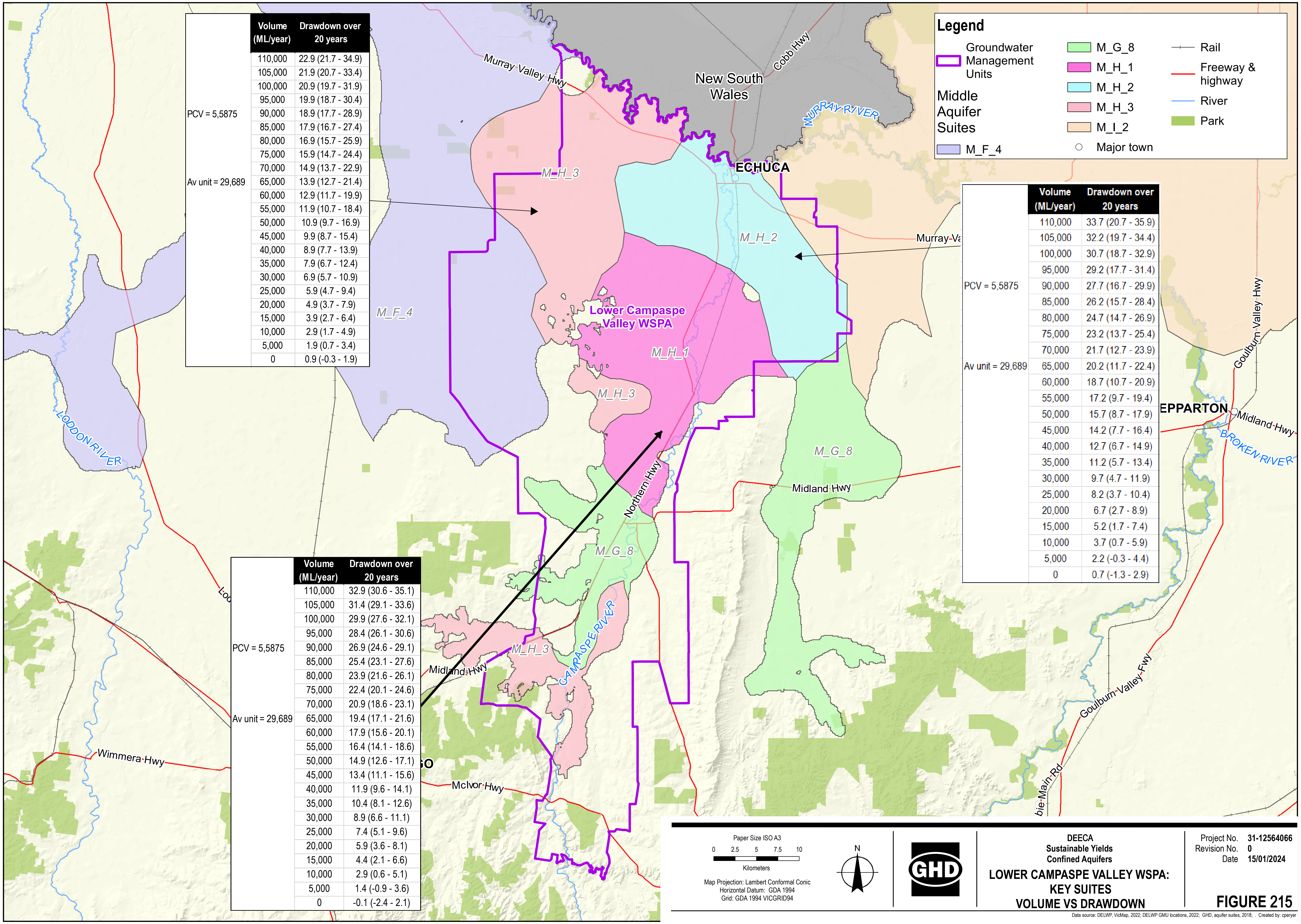


Figure 214 Lower Campaspe Valley WSPA Suite M_H_3: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 84   Predicted GMU volumes for drawdown metrics

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite M_H_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite M_H_2 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite M_H_3 drawdowns (lower limit to upper limit)
5	17,000 (9,700 – 24,600)	14,300 (7,100 – 31,500)	20,300 (10,400 – 26,700)
10	33,700 (26,400 – 41,200)	30,900 (23,800 – 56,500)	45,300 (27,000 – 51,700)



	Volume (ML/year)	Drawdown over 20 years
	110,000	22.9 (21.7 - 34.9)
	105,000	21.9 (20.7 - 33.4)
	100,000	20.9 (19.7 - 31.9)
	95,000	19.9 (18.7 - 30.4)
PCV = 5,5875	90,000	18.9 (17.7 - 28.9)
	85,000	17.9 (16.7 - 27.4)
	80,000	16.9 (15.7 - 25.9)
	75,000	15.9 (14.7 - 24.4)
	70,000	14.9 (13.7 - 22.9)
Av unit = 29,689	65,000	13.9 (12.7 - 21.4)
	60,000	12.9 (11.7 - 19.9)
	55,000	11.9 (10.7 - 18.4)
	50,000	10.9 (9.7 - 16.9)
	45,000	9.9 (8.7 - 15.4)
	40,000	8.9 (7.7 - 13.9)
	35,000	7.9 (6.7 - 12.4)
	30,000	6.9 (5.7 - 10.9)
	25,000	5.9 (4.7 - 9.4)
	20,000	4.9 (3.7 - 7.9)
	15,000	3.9 (2.7 - 6.4)
	10,000	2.9 (1.7 - 4.9)
	5,000	1.9 (0.7 - 3.4)
	0	0.9 (-0.3 - 1.9)

	Volume (ML/year)	Drawdown over 20 years
	110,000	33.7 (20.7 - 35.9)
	105,000	32.2 (19.7 - 34.4)
	100,000	30.7 (18.7 - 32.9)
	95,000	29.2 (17.7 - 31.4)
PCV = 5,5875	90,000	27.7 (16.7 - 29.9)
	85,000	26.2 (15.7 - 28.4)
	80,000	24.7 (14.7 - 26.9)
	75,000	23.2 (13.7 - 25.4)
	70,000	21.7 (12.7 - 23.9)
Av unit = 29,689	65,000	20.2 (11.7 - 22.4)
	60,000	18.7 (10.7 - 20.9)
	55,000	17.2 (9.7 - 19.4)
	50,000	15.7 (8.7 - 17.9)
	45,000	14.2 (7.7 - 16.4)
	40,000	12.7 (6.7 - 14.9)
	35,000	11.2 (5.7 - 13.4)
	30,000	9.7 (4.7 - 11.9)
	25,000	8.2 (3.7 - 10.4)
	20,000	6.7 (2.7 - 8.9)
	15,000	5.2 (1.7 - 7.4)
	10,000	3.7 (0.7 - 5.9)
	5,000	2.2 (-0.3 - 4.4)
	0	0.7 (-1.3 - 2.9)

	Volume (ML/year)	Drawdown over 20 years
	110,000	32.9 (30.6 - 35.1)
	105,000	31.4 (29.1 - 33.6)
	100,000	29.9 (27.6 - 32.1)
	95,000	28.4 (26.1 - 30.6)
PCV = 5,5875	90,000	26.9 (24.6 - 29.1)
	85,000	25.4 (23.1 - 27.6)
	80,000	23.9 (21.6 - 26.1)
	75,000	22.4 (20.1 - 24.6)
	70,000	20.9 (18.6 - 23.1)
Av unit = 29,689	65,000	19.4 (17.1 - 21.6)
	60,000	17.9 (15.6 - 20.1)
	55,000	16.4 (14.1 - 18.6)
	50,000	14.9 (12.6 - 17.1)
	45,000	13.4 (11.1 - 15.6)
	40,000	11.9 (9.6 - 14.1)
	35,000	10.4 (8.1 - 12.6)
	30,000	8.9 (6.6 - 11.1)
	25,000	7.4 (5.1 - 9.6)
	20,000	5.9 (3.6 - 8.1)
	15,000	4.4 (2.1 - 6.6)
	10,000	2.9 (0.6 - 5.1)
	5,000	1.4 (-0.9 - 3.6)
	0	-0.1 (-2.4 - 2.1)

Paper Size ISO A3
0 2.5 5 7.5 10
Kilometres
Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 VICGRID94

DEECA
Sustainable Yields
Confined Aquifers
LOWER CAMPASPE VALLEY WSPA: KEY SUITES VOLUME VS DRAWDOWN

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

FIGURE 215

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

15.6 GMU summary

15.6.1 Findings

Lower Campaspe Valley WSPA primarily relates to the Calivil Formation aquifer (UTAF) and Renmark Group (LTA) aquifer. Groundwater within this GMU is predominately extracted for irrigation purposes. The UTAF falls within the Middle Aquifer Suites, which at Lower Campaspe Valley WSPA are M_H_1 (18%), M_H_2 (15%), M_H_3 (20%), M_F_4 (11%), M_G_8 (7%) and M_I_2 (2%), providing a total GMU coverage of 73%. The identified representative Suites are M_H_1 (most preferred), M_H_2 and M_H_3. 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.

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 for Suites M_H_1 and M_H_2 but a generally better model fit for Suite M_H_3. The best match using the two yearly average annual extraction was model run 12 (two yearly average annual extraction hindcasted using method 2 for Lower Campaspe Valley WSPA and annual recovered levels) for Suite M_H_3.

The application of spatial distribution produced a poorer model fit than the model run using just the annual recorded groundwater usage for Suites M_H_1 and M_H_2. The Suite M_H_3 showed one of the best matches statistically using spatial method 1, however, the statistical results were comparatively better for the model run with hindcast method 3 applied.

Based on an assessment of all model runs, the model run 7 of Lower Campaspe Valley WSPA annual extraction using hindcast method H2 with the annual recovered levels was adopted to undertake the predictive modelling for both Suite M_H_1 and M_H_2. Model run 9 of annual extraction with hindcast method H3 applied was adopted for Suite M_H_3.

The pre-development levels were defined for the three representative Suites based on the early time series Suite data for the annual recovered levels; this resulted in pre-development levels of 11.06 m for Suite M_H_1, 7.28 m for Suite M_H_2 and 9.78 m for Suite M_H_3. 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 M_H_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite M_H_2 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite M_H_3 drawdowns (lower limit to upper limit)
5	17,000 (9,700 – 24,600)	14,300 (7,100 – 31,500)	20,300 (10,400 – 26,700)
10	33,700 (26,400 – 41,200)	30,900 (23,800 – 56,500)	45,300 (27,000 – 51,700)

The model for Suite M_H_1 was assessed as having a “Good” model applicability rating, Suite M_H_2 was assessed as having a “Moderate” rating and Suite M_H_3 was assessed as having an “Excellent” rating using the criteria outlined in section 5.2. Suite M_H_1 would have had a higher rating if the RMSE was lower than 1, it’s noted that it has an RMSE of 1.15.

Given that most of the extraction from the Middle Aquifer is likely to come from Suite M_H_1 and it has very similar coverage to the other two Suites trialled. Suite M_H_1 is considered to be the most representative Suite for Lower Campaspe Valley WSPA.

15.6.2 Limitations

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

- The licenced bore dataset provided by DEECA has 79% of bores assigned to Lower Campaspe Valley WSPA with no depth data and not assigned to a VAF layer and in turn Suite. These bores were assigned to an aquifer and Suite by GHD for this study, based on the predominant aquifer that extraction occurs from for this GMU; in this instance it was split between the UTAF and LTA where both aquifers occurred.
- Lower Campaspe Valley WSPA has a short historic use dataset that dates back only to 2010/2011

15.6.3 Recommendations

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

- The licenced bore dataset provided by DEECA has 79% of bores assigned to Lower Campaspe Valley WSPA with no depth data and not 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.

DEECA to investigate if historic use data can be obtained for Lower Campaspe Valley WSPA.

16. Mid Loddon GMA

16.1 Conceptualisation

The hydrogeological conceptualisation elements relevant to this study are summarised in Table 85 and a map of the GMU is presented in Figure 216. 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 85.

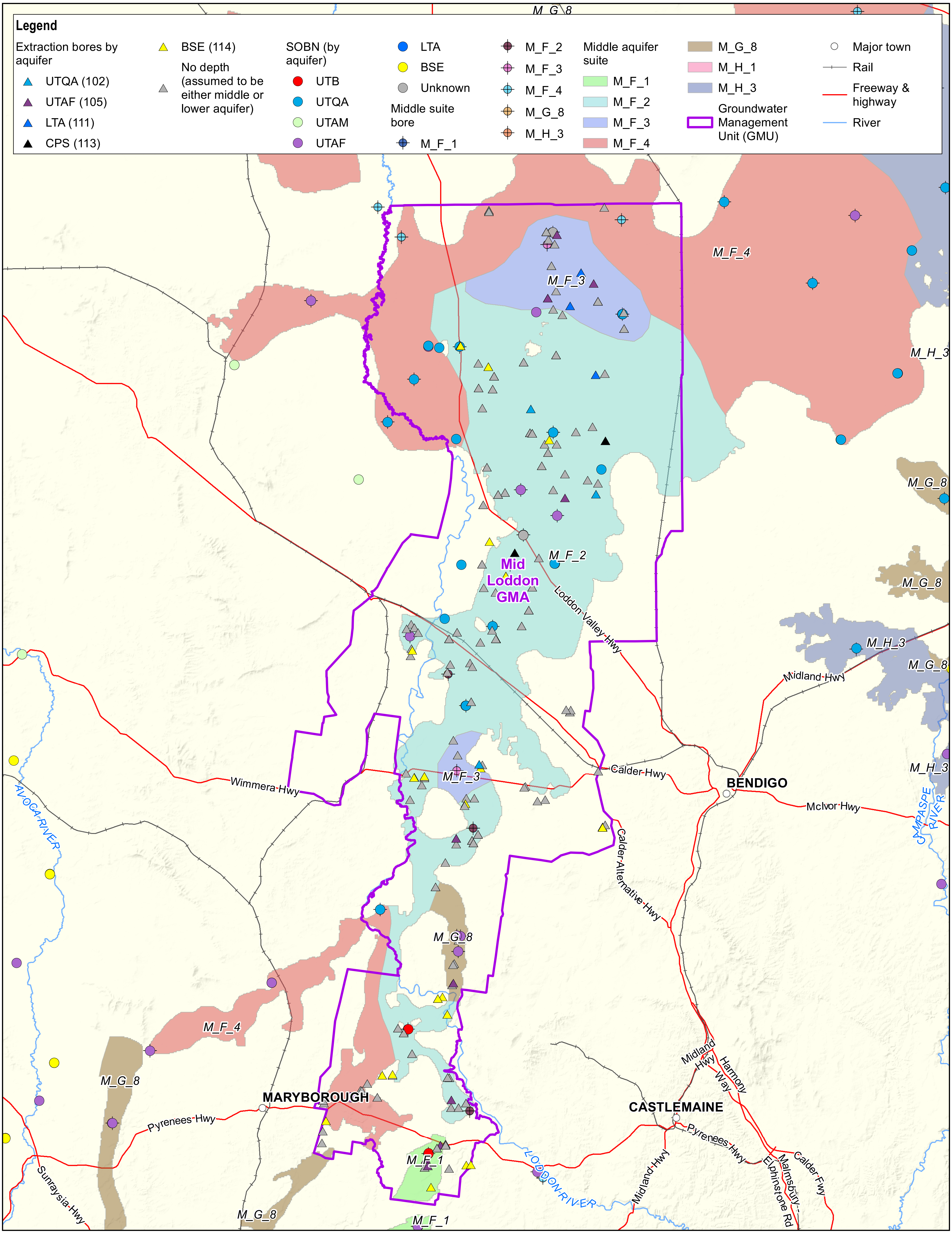
Table 85 Mid Loddon GMA – Tabulated conceptualisation

GMU summary								
Mid Loddon GMA is situated in northern Victoria within the Loddon River Catchment and extends from the foothills of the Great Dividing Range near Moolort in the south and Mitiamo in the north. The GMA covers an area of approximately 3,000 km^2 within the Murray Darling Basin and the Goulburn-Murray Water Resource Plan area under the Murray Darling Basin Plan. The Mid Loddon GMA pertains to all formations below the surface but was intended to primarily manage the groundwater resource of the Calivil Formation (Upper Tertiary Aquifer, UTAF). The PCV (34,037 ML/year) therefore primarily related to confined aquifers. It is noted that north of the GMU, the aquifers are semi-confined to unconfined. Groundwater in the GMA is extracted for domestic and stock use and for licensable uses such as irrigation, commercial (watering of intensive poultry farms) and urban supply. Central Highlands Water has a borefield constructed into the Deep Lead underlying the Moolort plains, however, sustained extraction from the borefield is yet to commence. A compilation of the views and values of Traditional Owners has been prepared for this region, which takes into account culture-based values of water. Aboriginal values and objectives should be considered in future Victorian water management and planning in this region (DEECA, 2019); in particular the Loddon River and Bullock Creek have been identified as waterways of cultural value (DEECA, 2019).								
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	Coonambidgal Formation (QA)	-	-	0	NA	0	0	Low
	Newer Volcanics (UTB)	U_K_1 (2%),	2%	4	NA	6	6	Low
	Shepparton Formation (UTQA)	U_K_2 (26%), U_K_3 (17%), U_K_4 (39%), U_K_5 (2%), U_K_6 (3%), U_K_7 (0.1%), U_K_8 (4%), U_L_8 (1%)	91%	23	Irrigation, dairy, domestic, stock	390	410	Medium
Middle	Calivil Formation (UTAF)	M_F_1 (1%), M_F_2 (37%), M_F_3 (7%), M_F_4 (15%), M_G_8 (1%)	61%	18	Industrial, irrigation, stock, domestic, diary	11,236 (9,790)	21,270 (19,204)	Medium
Lower	Renmark Group (LTA)	L_H_1 (27%)	27%	2	Irrigation	4,510 (3,217)	7,153 (6,310)	Low
Basement	Cretaceous and Permian Sediments (CPS)	--	-	0	Irrigation	487	239	Low
	Basement rocks (BSE)	-	-	1	Commercial, industrial, domestic, stock, dairy	3,518	4,849	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. Note that volumes listed above do include 13,007 ML of unassigned use due to unknown depths (25,515 ML of entitlement). There are two SOBN that monitor unknown formations that are not included in the above table.

Characteristic & importance	Description	Degree of understanding
Intended aquifer (UTAF, highlighted blue above)		
Aquifer thickness within GMU (range, based on VAF)	Max: 78 m, Average: 21 m	High
Aquifer extent	Small, local	High
Likelihood of inter-aquifer flow	High	Low
Likelihood of groundwater – surface water interaction	Low	Low
Representative Suite	**M_F_2**	**Low. 58% of GMU extraction occurs within the middle aquifer when taking into account unassigned extraction. This Suite covers the greatest area.** **Likely issue with bore data since 70% of extraction does not occur within defined/relevant 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)	3,015 mg/L (WMIS) 1,201 – 3,100 mg/L (CDM Smith, 2022)	Medium (WMIS data seems high if irrigation is a major use) Based on WMIS and CDM Smith (2022)
Groundwater yield	<0.5 L/s	Low Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1969-2021**	
Spatial clustering of licensed bores in relation to Suites	**Yes, M_F_2**	**Based on DEECA density mapping and licenced bore data.**
Groundwater use		
Licensed groundwater use	**17,689 ML**	**High (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	2,738 ML	High (Based on historical VWA data, year 2010/11)
Maximum historic groundwater use	**30,310 ML**	**High (Based on historical VWA data, year 2018/19)**
Entitlement (Groundwater allocation)	**33,927 ML**	**High (Based on licenced volumes in 2020/21)**

Characteristic & importance	Description	Degree of understanding
Significant drivers of groundwater level variability (primary)	**Commercial. Irrigation & dairy**	**Moderate**
Secondary drivers of groundwater level variability	Pumping for town water supply	Moderate
Groundwater use profile	Yet to be determined	
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 – Drawdown which may affect the Loddon River	
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

Mid Loddon GMA
Site location and key features

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

Figure 216

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Print date: 16 Jan 2024 - 12:39

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

16.2 Technical analysis

16.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the relevant Suites for Mid Loddon GMA as shown in Figure 217. Generally, the Suite hydrographs show a trend of seasonal fluctuations and thus annual recovered levels. Large seasonal fluctuations are shown in Suite M_F_1 with fluctuations of up to 20 m. All Suite hydrographs show a general decreasing trend with time.

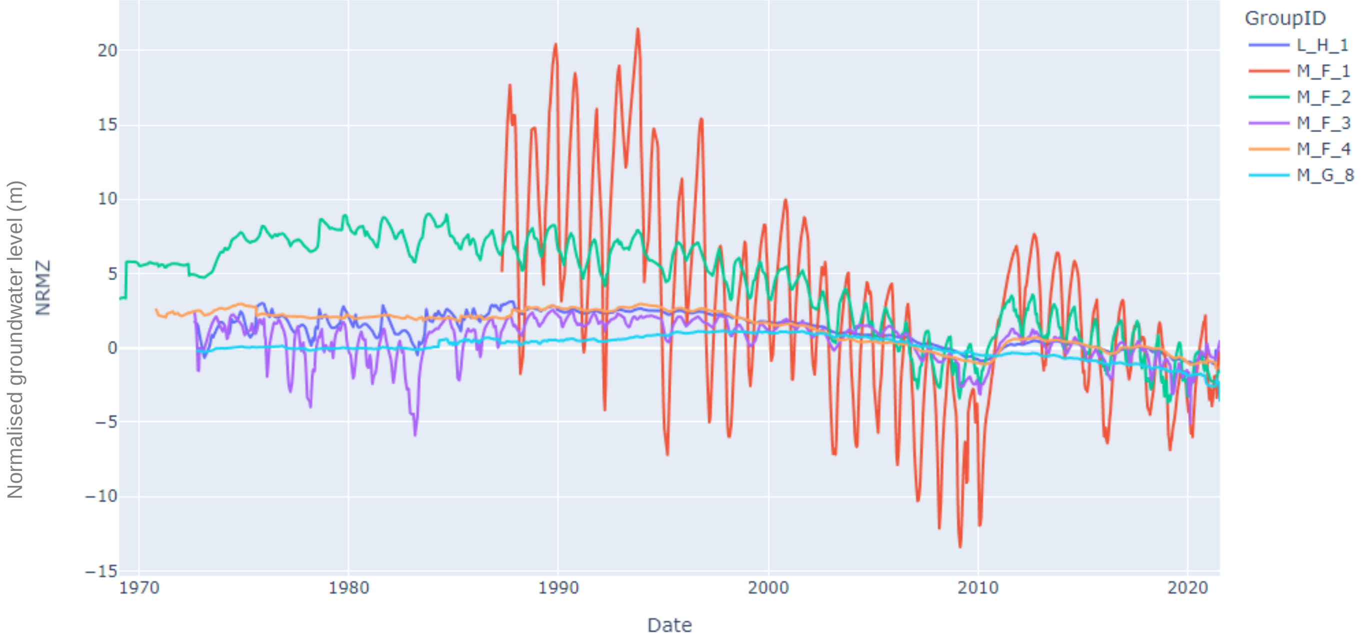


Figure 217 Mid Loddon GMA Suite Hydrographs for all confined aquifers

The representative Suites analysed for this GMU were Suites M_F_2 and M_F_3. The Representative Suites were selected based on the methodology outlined in section 2.6.4 which identified Suite M_F_2 as the most representative followed by M_F_3, based on the following process:

- The greatest volume of extraction occurs within the Middle Aquifer
- The Middle Aquifer pertains to the UTAF, which is the intended aquifer of the GMU
- Suite M_F_1 covers 1% of the GMU, while Suite M_F_2 covers 37%, Suite M_F_3 covers 7%, Suite M_F_4 covers 15% and Suite M_G_8 covers 1%, providing a total coverage of 61%
- Suite M_F_1 has one active SOBN bores within the Suite area, while Suite M_F_2 has eight, Suite M_F_3 has two, Suite M_F_4 has one and Suite M_G_8 has three active SOBN bores
- Suite bores for Suite M_F_3 and M_AF_1 are close to extraction points

The annual recovered Suite hydrographs for the representative Suites for Mid-Loddon GMA, M_F_2 and M_F_3, are shown in Figure 218.

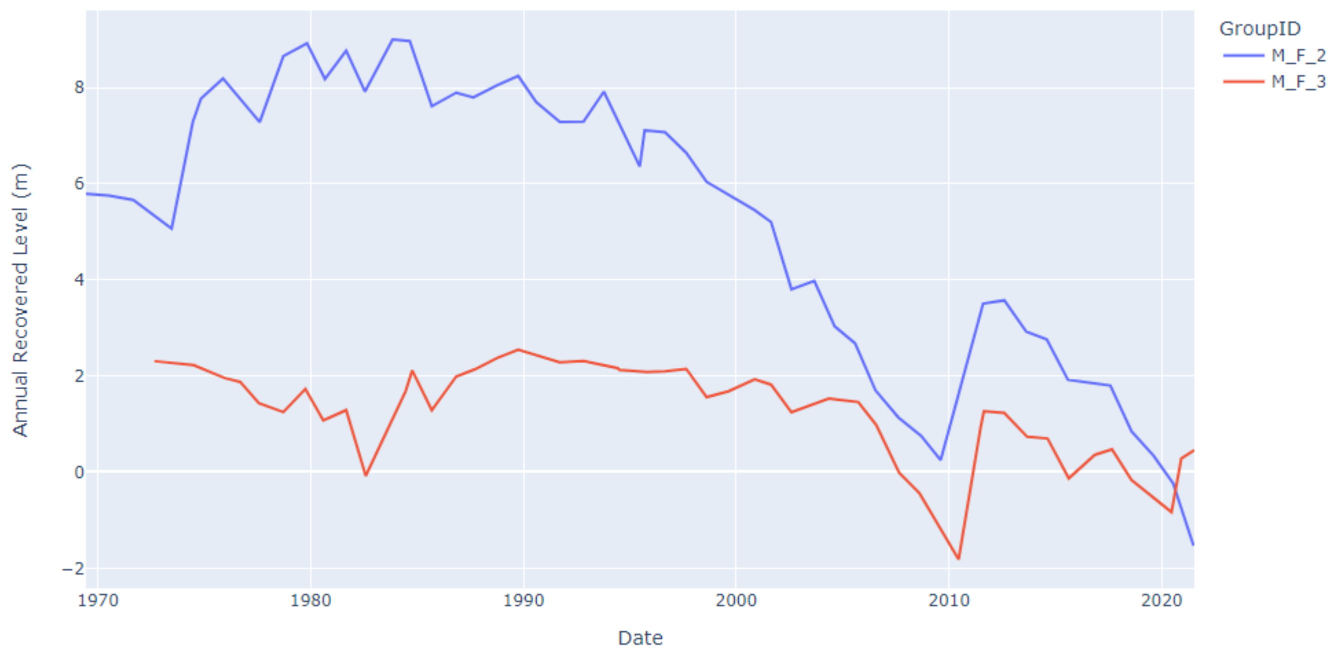


Figure 218 Mid Loddon GMA Annual Recovered Level Suite Hydrographs for representative Suites

16.2.2 Pre-development level

To estimate the pre-development level conditions, GHD reviewed the Suite hydrographs of annual recovered levels and assumed that the maximum levels in the early time series data was the best representation of conditions prior to major development within Mid Loddon GMA for Suite M_F_2. For Suite M_F_3, it was assumed that the early time series data was the best representation of conditions prior to major development within Mid-Loddon GMA; thus, the earliest measurement was adopted as the baseline for pre-development conditions for this Suite.

The pre-development annual recovered levels are taken to be the maximum level in the early time series data which equates to 9.01 m for Suite M_F_2 in the year 1983/1984 and 2.31 m for Suite M_F_3 in the year 1972/1973 (refer further details in section 16.4.3).

16.2.3 Externalities

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

16.2.4 Hindcasting

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

16.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, four different correlations were developed using the annual groundwater extraction as described below and shown in Figure 219:

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

Another four correlations were developed based on annual irrigation extraction as described below and shown in Figure 220:

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

As shown in Figure 219, the goodness-of-fit represented by the R^2 is greatest for annual rainfall with annual groundwater use. When only irrigation groundwater extraction is considered, the goodness-of-fit of groundwater use to rainfall increases all four instances. The greatest R^2 using the annual irrigation groundwater use is when the adopted rainfall is the annual summer rainfall, closely followed by the correlation with annual rainfall. Given the closeness of these two correlations and that the preferred correlation for hindcast method H2 and H3 is with annual rainfall, the annual irrigation groundwater use with annual rainfall has been adopted for hindcast method H1.

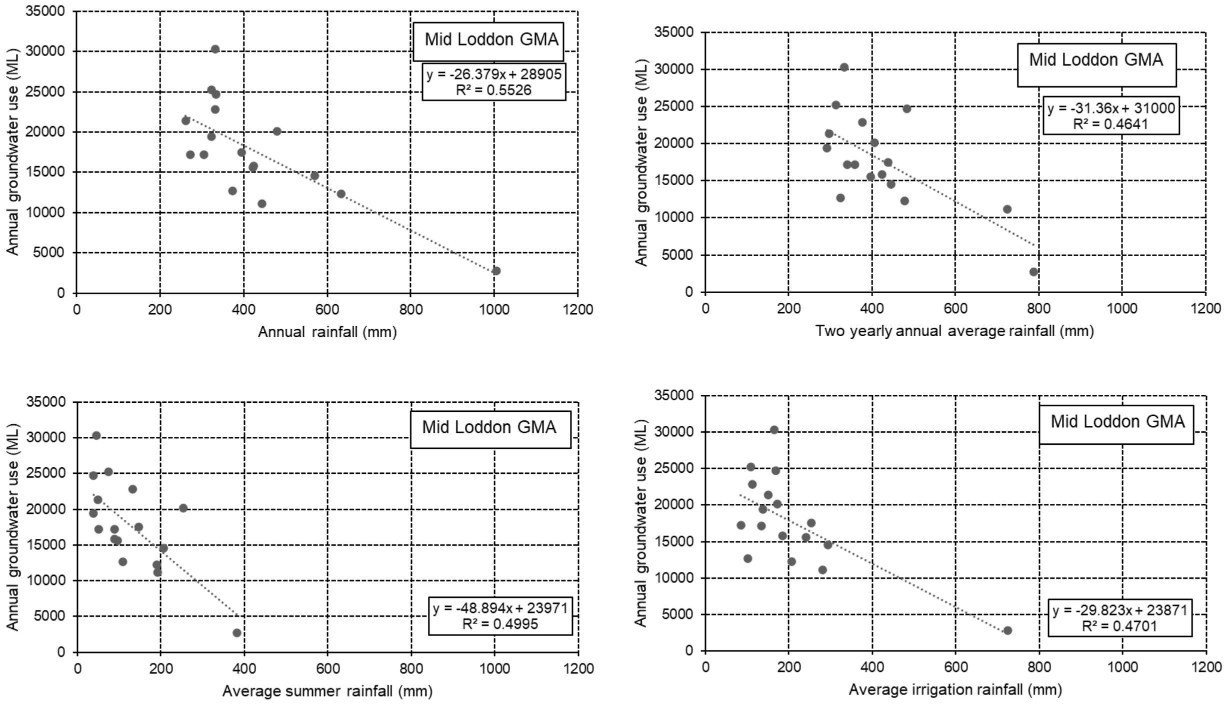
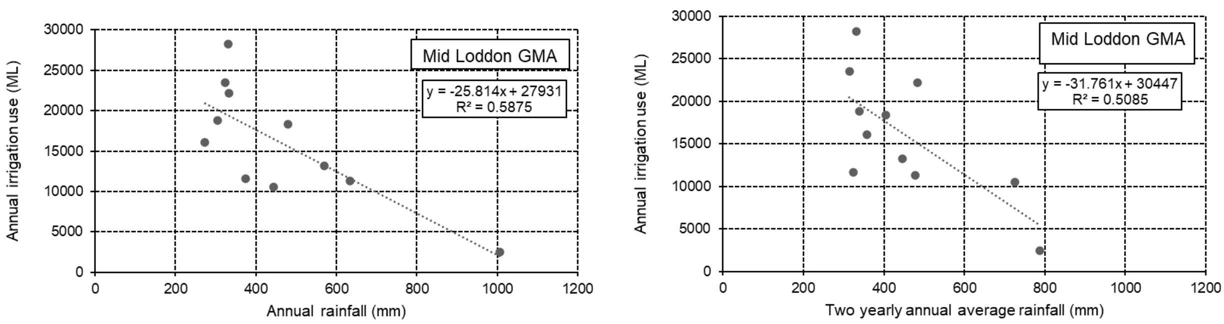


Figure 219 ***Mid Loddon GMA: Hindcast method 1 correlations (Mid Loddon GMA annual extraction)***



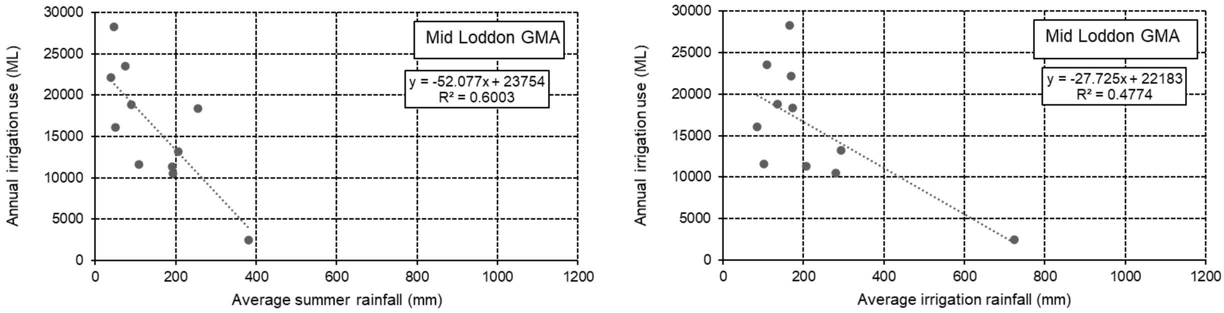


Figure 220 ***Mid Loddon GMA: Hindcast method 1 correlations (Mid Loddon GMA annual irrigation extraction)***

16.2.4.2 Hindcasting Method 2 (H2)

Similar to method H1, eight correlations were developed using method H2 as described below and shown in Figure 221:

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

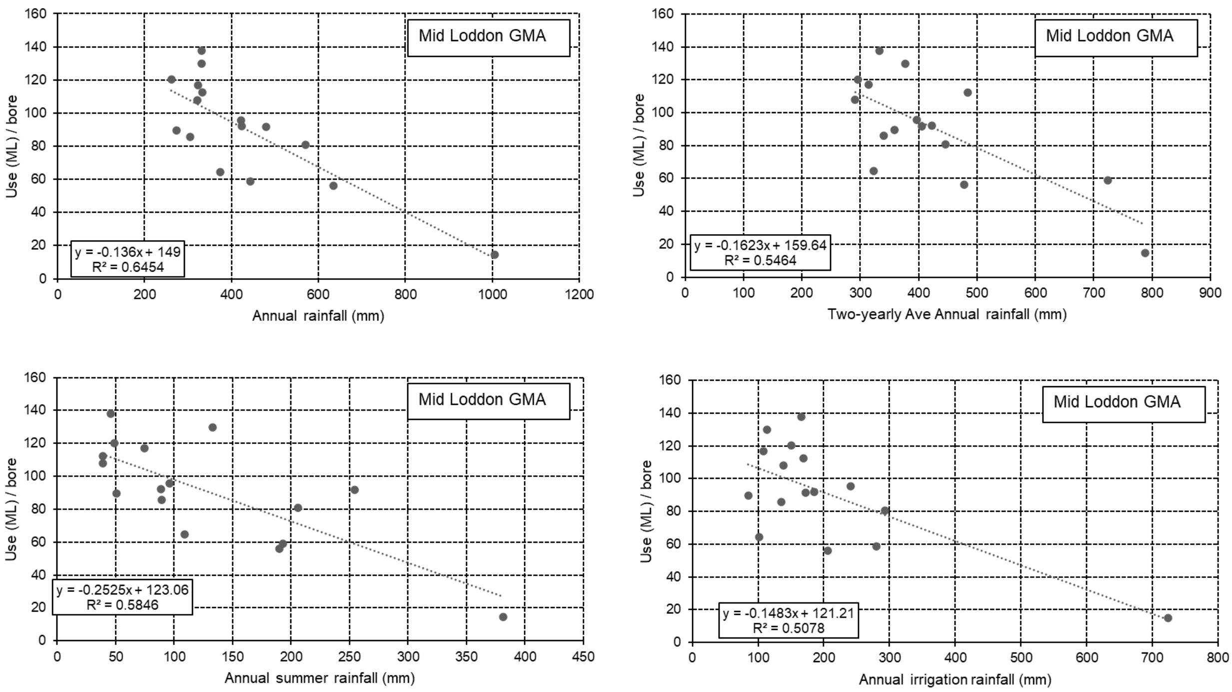


Figure 221 ***Mid Loddon GMA: Hindcast method 2 correlations***

As shown in Figure 221, the goodness-of-fit represented by the R^2 is greatest for annual rainfall with annual groundwater use. The correlation decreased slightly when rainfall was reduced to a smaller period over the year. The annual rainfall has been adopted for hindcast method H2.

16.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 222:

- 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

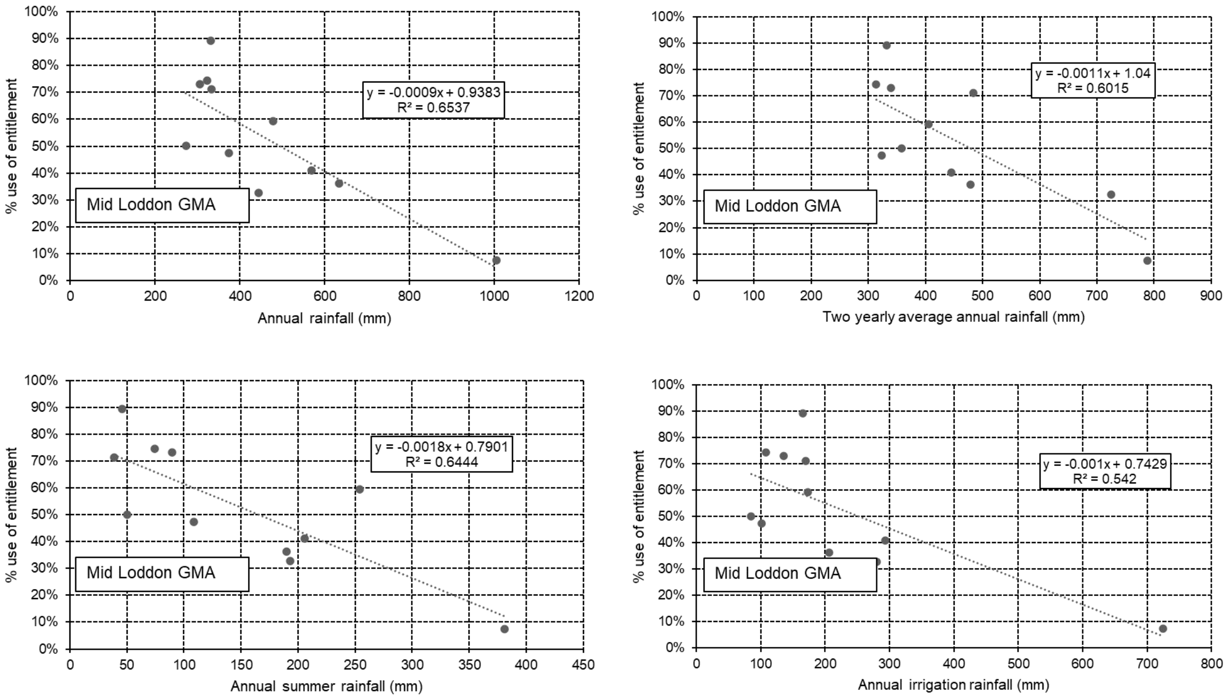


Figure 222 Mid Loddon GMA: Hindcast method 3 correlations

As shown in Figure 222 and similar to method H2, the best goodness-of-fit result was shown to be the correlation with annual rainfall, thus this correlation was adopted for hindcast method H3.

16.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 223 and Figure 224 for the hindcasting based on Mid Loddon GMA groundwater use. Figure 223 shows a comparison of the three hindcasting methods against the recorded use only over the recorded use period, while Figure 224 shows the hindcasted data back to 1968/1969.

As shown in Figure 224, 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 Mid Loddon GMA.

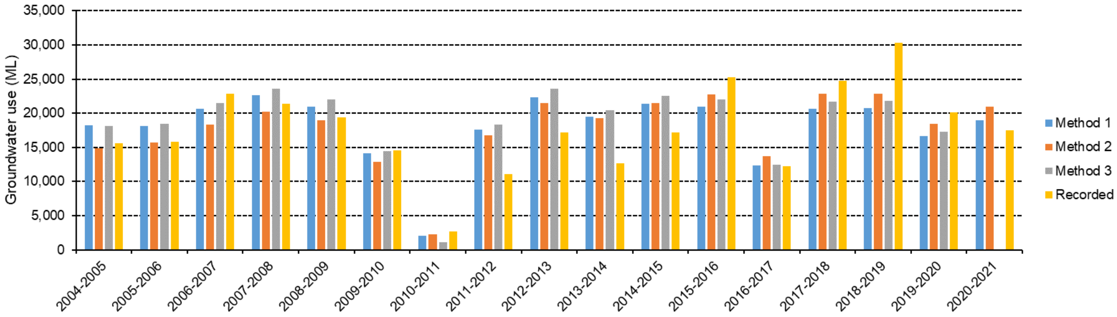


Figure 223 Mid Loddon GMA: Comparison of hindcasting over recorded use period

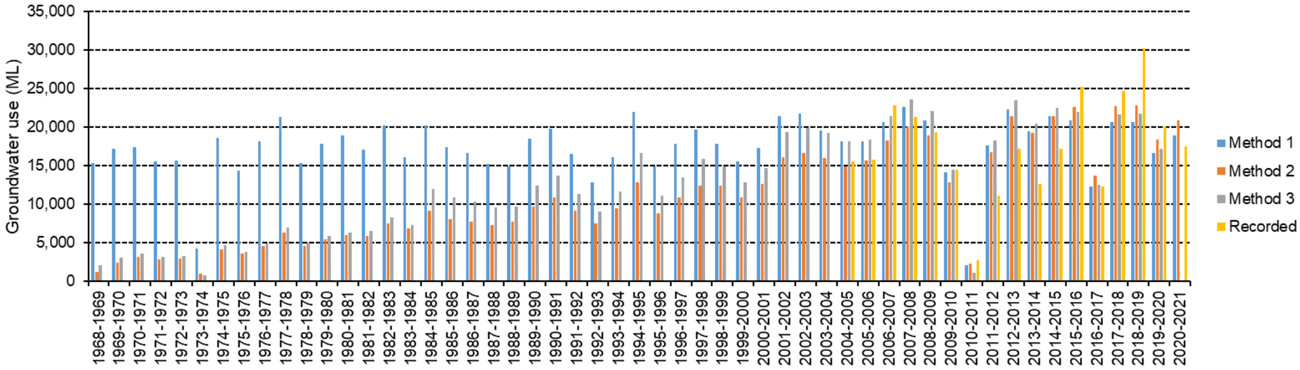


Figure 224 Mid Loddon GMA: Comparison of hindcasting

16.3 Modelling

16.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 86 summarises these combinations of model inputs run for Mid Loddon GMA. Model runs highlighted blue indicate they were run with annual extraction and grey indicates they were run using two yearly average annual extraction.

Table 86 Mid Loddon GMA: summary of model inputs

Model input	Model runs																					
	1	2	3	4	5	6	7	7c	8	9	9c	10	11	12	13	14	15	16	17	18	18c	19
Annual recovered levels for representative Suites (M_F_2 and M_F_3)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Mid Loddon GMA only	✓																					
Annual climate data								✓			✓										✓	
Two yearly average annual extraction – Mid Loddon GMA only		✓																				
Annual extraction – Mid Loddon GMA and Externalities			✓																			
Two yearly average annual extraction – Mid Loddon GMA and Externalities				✓																		
H1 annual extraction – Mid Loddon GMA only					✓																	
H1 annual extraction – Mid Loddon GMA and Externalities						✓																
H2 annual extraction – Mid Loddon GMA only							✓	✓														
H2 annual extraction – Mid Loddon GMA and Externalities									✓													
H3 annual extraction – Mid Loddon GMA only										✓	✓											
H1 two yearly average annual extraction – Mid Loddon GMA only												✓										
H1 two yearly average annual extraction – Mid Loddon GMA and Externalities													✓									

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

16.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 86 is presented in Table 87 for the selection of potential representative Suites for Mid Loddon GMA. The column heading for M_F_2 is highlighted blue to indicate that this Suite was selected as the most likely representative Suite based on the process outlined in section 16.2.1. 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 M_F_2

A review of the results and statistical summary for Suite M_F_2 shows that model run 2 and 15 (highlighted orange) had the best results when considering the four measures which reflect the uncertainty, accuracy and precision of the model of the different model input combinations. However, these models only include 10 to 16 observation points and do not cover the period of pre-development. Considering the need to include a longer historic record in the calibration model, the hindcasted models were looked at in more detail. As the hindcasted models didn't have results as good a result as the models with shorter records, some of the ones with the better statistical results were run with client to see if the model run could be improved. (model runs with a "c" indicates with climate). The model with the best results was model run 9c (highlighted green) which had the highest R^2, lowest RMSE and smallest 95PPU thickness of the hindcasted results. of the hindcasted models.

The graphical model output for model run 9c is shown in Figure 225 and model run 9c has been adopted to progress to predictive modelling.

Suite M_F_3

A review of the results and statistical summary for Suite M_F_3 shows that model run 15 and 16 (highlighted orange) had the best results of the different model input combinations. However, these models only include 10 to 16 observation points and do not cover the period of pre-development. Considering the need to include a longer historic record in the calibration model, the hindcasted models were looked at in more detail. Model run 9 using hindcast model H3 originally had the best model result, but the actual model did not capture the variations in the levels very well as shown in Figure 226. Climate was than applied to the model but the statistics for the model decreased as shown in model run 9c (Figure 227). Given this model run 7 using hindcast method 2 was looked at, however the statistics were still relatively poor and thus climate was applied to see if this could improve model fit (model run 7c). This did improve the model fit but the model did not capture the variations in the levels as shown in Figure 228. Comparing model run 9c to model run 7; model run 7 performed better statistically and thus was adopted as the preferred model for Suite M_F_3. The graphical model output for model run 7 is shown in Figure 229.

Modelling was progressed on the basis of adopting model run 9c for Suite M_F_2 and model run 7 for Suite M_F_3.

Table 87 Mid Loddon GMA: summary of model outputs

Suite	Statistic	Model run															
		1	2	5	7	7c	9	9c	10	12	14	15	16	17	18	18c	19
M_F_2	95PPU TH	2.55	2.07	7.17	7.05	6.19	8.24	4.87	10.48	6.49	4.73	1.56	0	6.75	5.6	6.95	5.6
	%Obs in 95 PPU	100	93.75	100	96.15	94.23	100	92.31	98.08	98.08	100	100	0	100	92.16	90.2	92.16
	R^2	81.9	88.0	81.0	51.4	77.1	76.1	88.8	-11.1	59.9	94.5	86.3	94.3	74.8	79.4	80.3	79.4
	RMSE	0.5	0.41	1.21	1.93	1.32	1.35	0.93	2.92	1.75	0.25	0.39	0.25	1.35	1.22	1.19	1.22
	No obs data points	16	16	52	52	52	52	52	52	52	10	10	10	51	51	51	51
	Range of observed levels	3.8	3.8	9.2	9.2	9.2	9.2	9.2	9.2	9.2	3.2	3.2	3.2	8.8	8.8	8.8	8.8
M_F_3	95PPU TH	2.74	2.67	3.95	3.24	4.2	5.99	4.08	3.73	3.15	1.57	0.77	0.83	12.36	3.91	NA	3.91
	%Obs in 95 PPU	93.75	93.75	97.96	95.92	95.92	97.96	95.92	97.96	95.92	100	90	100	95.83	75	0	75
	R^2	52.5	52.2	8.2	36.8	51.5	51.8	35.4	16.0	39.2	74.1	85.8	83.3	46.2	16.1	44.2	16.1
	RMSE	0.58	0.58	0.92	0.76	0.67	0.66	0.77	0.88	0.75	0.31	0.22	0.21	0.66	0.82	0.71	0.82
	No obs data points	16	16	49	49	49	49	49	49	49	10	10	10	48	48	48	48
	Range of observed levels	3.3	3.3	4.4	4.4	4.4	4.4	4.4	4.4	4.4	2.1	2.1	2.1	4.4	4.4	4.4	4.4

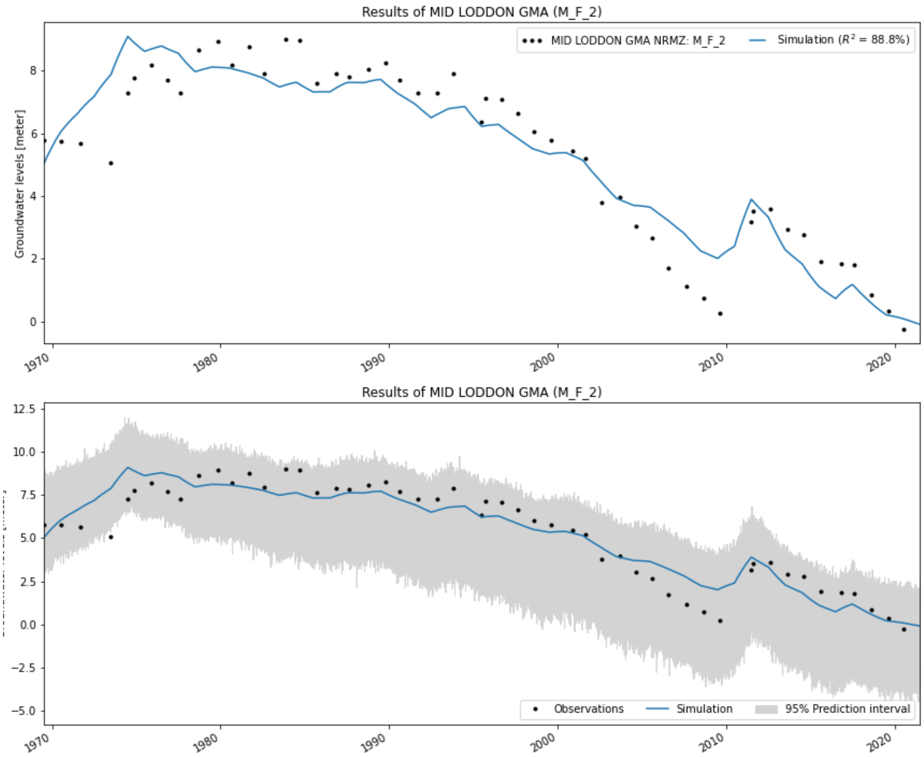


Figure 225 ***Mid Loddon GMA Suite M_F_2: model run 9c (Mid Loddon GMA annual extraction with hindcast method H3 and climate) output hydrographs***

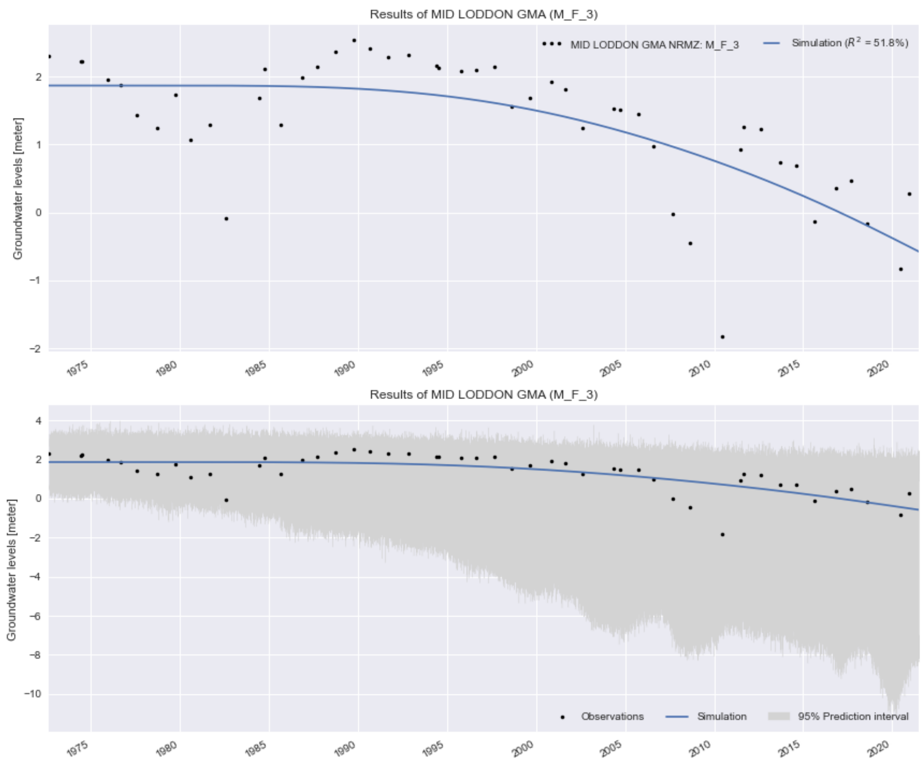


Figure 226 ***Mid Loddon GMA Suite M_F_3: model run 9 (Mid Loddon GMA annual extraction with hindcast method H3) output hydrographs***

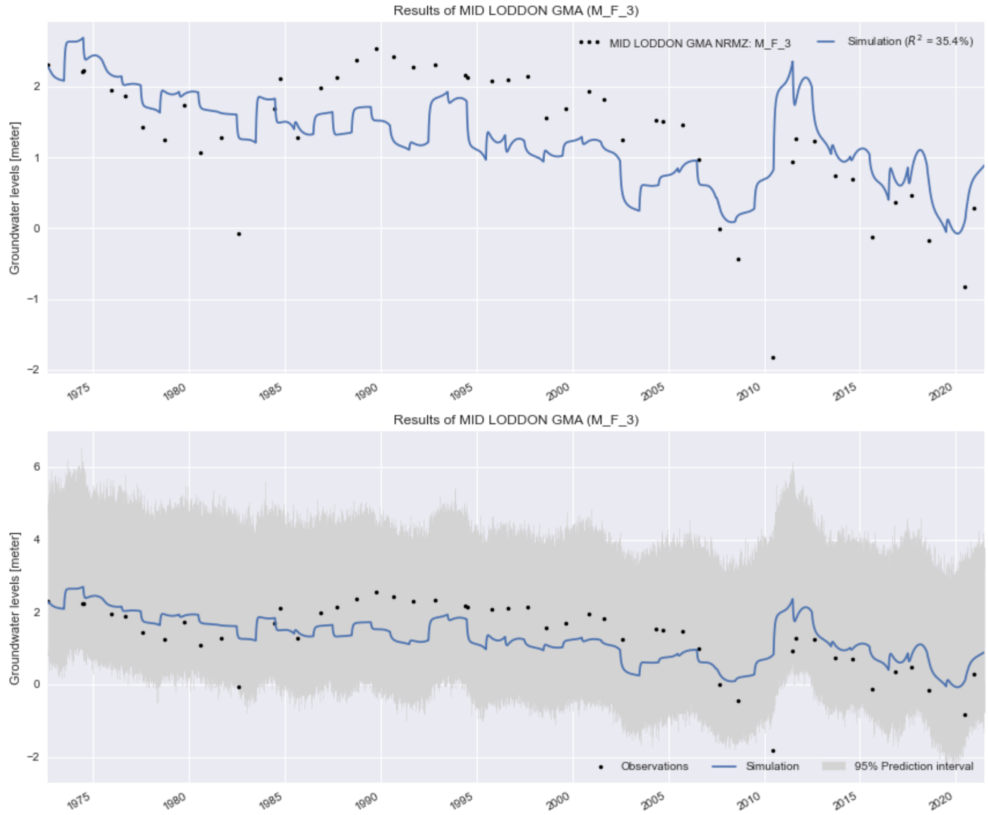


Figure 227 *Mid Loddon GMA Suite M_F_3: model run 9c (Mid Loddon GMA annual extraction with hindcast method H3 and climate) output hydrographs*

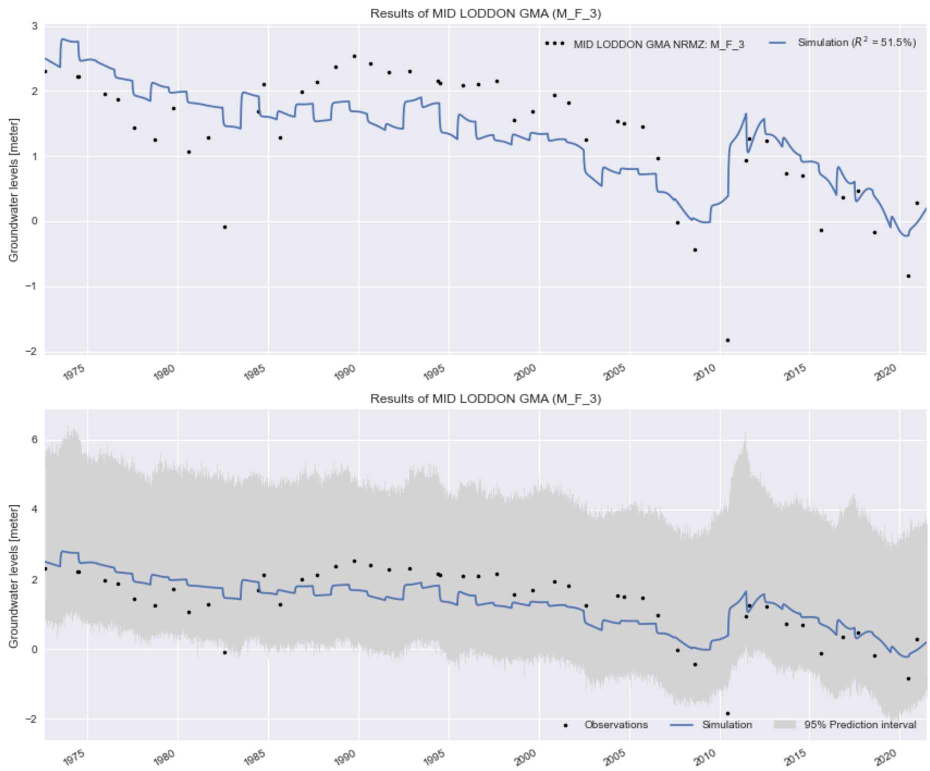


Figure 228 *Mid Loddon GMA Suite M_F_3: model run 7c (Mid Loddon GMA annual extraction with hindcast method H2 and climate) output hydrographs*

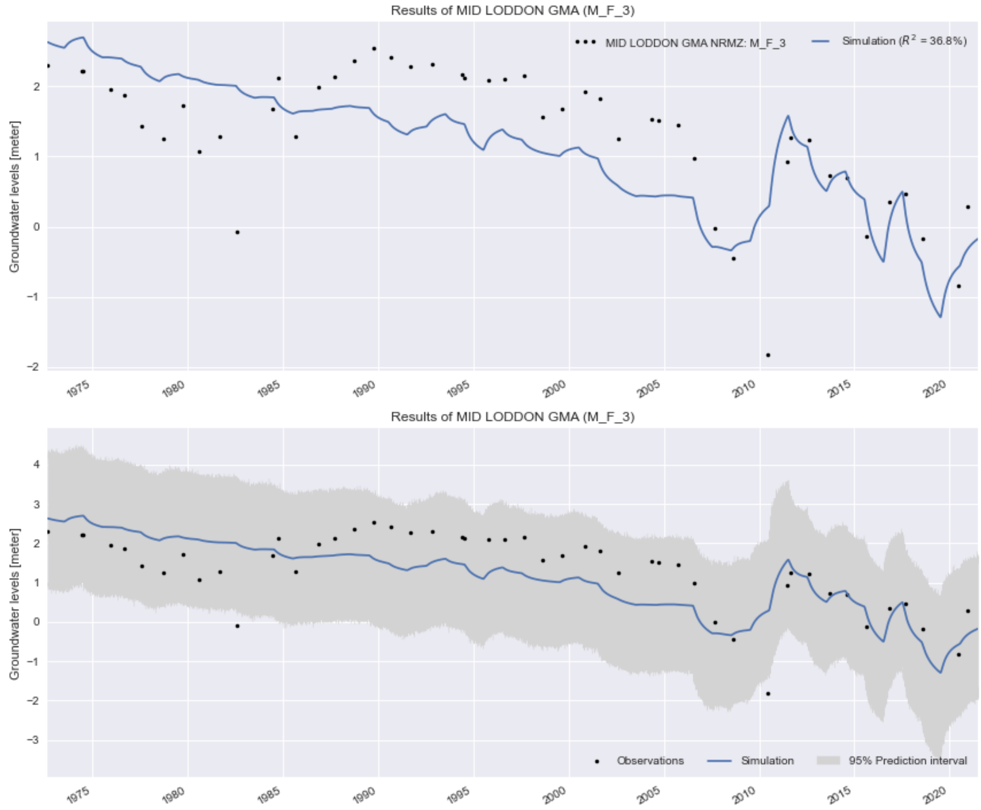


Figure 229 Mid Loddon GMA Suite M_F_3: model run 7 (Mid Loddon GMA annual extraction with hindcast method H2) output hydrographs

16.4 Predictive modelling

16.4.1 Model inputs

The preferred model to run the predictive modelling for Mid Loddon GMA was model run 9c for Suite M_F_2 and model run 7 for Suite M_F_3. The key inputs for the model were the annual recovered levels, climate data and the annual extraction in Mid Loddon GMA. To conduct the forecasting for the 19 scenarios discussed in section 3.5, a few factors were required in the calculations; these factors are summarised in Table 88.

Table 88 Mid Loddon 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 2018/19)
Value (ML/year)	34,037	33,927	17,515	17,689	30,310

16.4.2 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 230 for scenario 17 for Suite M_F_2. As shown in Figure 230, the uncertainty of the model prediction increases as the model predicts further into the future. Comparing with the graphical output for the same scenario, some of the MCMC realisations fall outside the 95% prediction interval bands, however, most fall within them, as shown in Figure 231.

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.

It is noted that forecast scenario 4 Suite M_F_2 was not able to produce 95% prediction interval limit data thus this scenario is not included in the assessment.

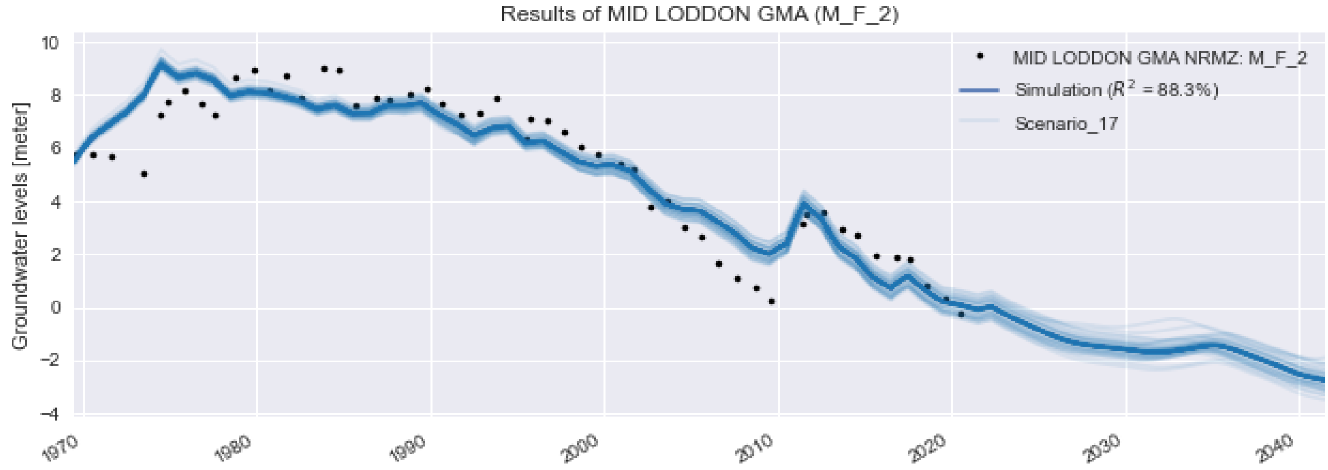


Figure 230 Mid Loddon GMA: Suite M_F_2 MCMC analysis for Forecast Scenario 17

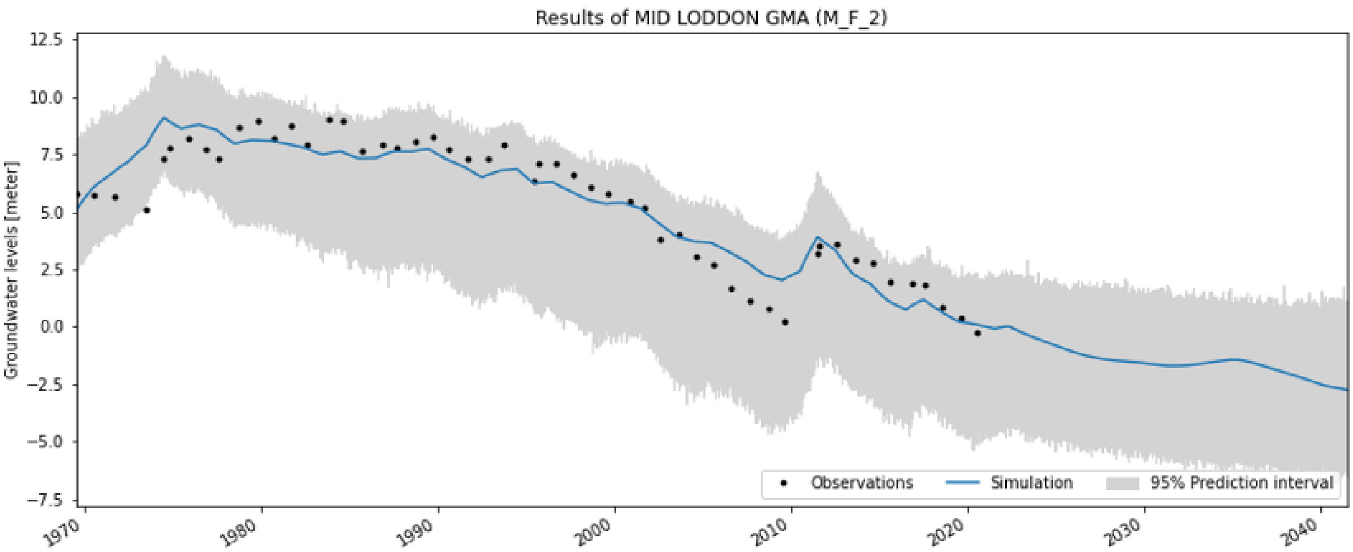


Figure 231 Mid Loddon GMA: Suite M_F_2 Forecast Scenario 17 with 95% prediction bands

16.4.3 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 Mid Loddon 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 16.2.2, 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 232 for Suite M_F_2 hydrograph of annual recovered levels. In Figure 232:

– 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 between 1968/1969 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 maximum readings in the early time series which equate to 9.0 m

The modelled forecasted annual recovered levels are represented by the purple line in Figure 232.

The calibration annual recovered levels are represented by the black line in Figure 232.

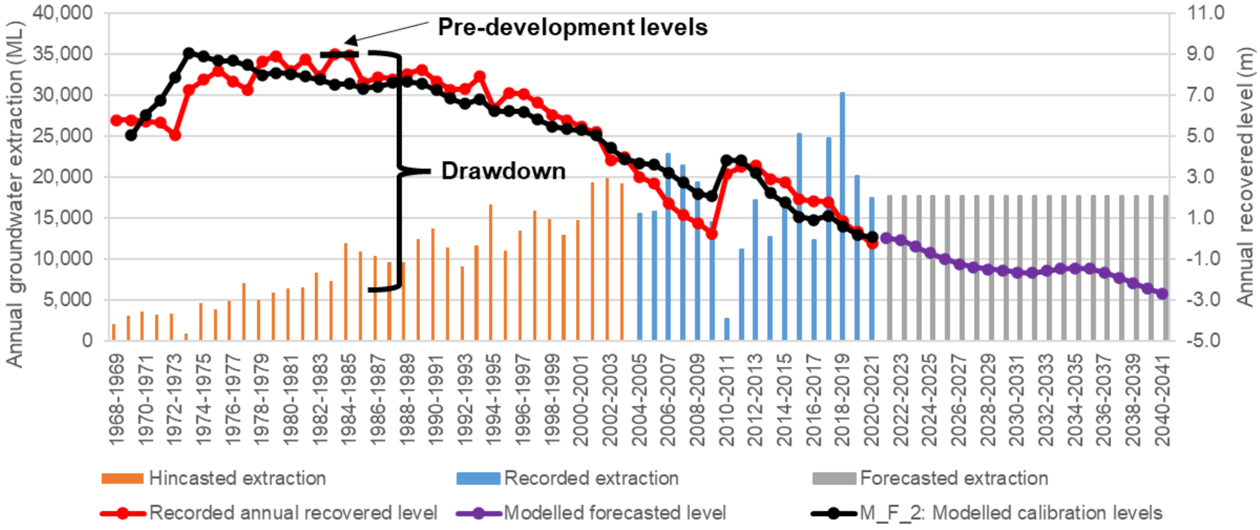


Figure 232 Estimating pre-pumping water levels (example from Suite M_F_2)

For Suite M_F_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 233) and a graph of the scenarios for specific time periods (Figure 234) 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 there was variations in the coefficient of determination between different scenarios and variations of in the slope of the linear regression The same process was applied for Suite M_F_3 and again, there was only slight changes in the coefficient of determination between the graphs and generally no changes in the slope of regression.

The use-drawdown for all the 18 forecast scenario drawdowns and volumes (both the recorded and forecasted volumes) over each year modelled (1970 to 2041) is shown in Figure 233 for Suite M_F_2 and all 19 forecast scenarios (1970 to 2041) are shown in Figure 235 for M_F_3. Note the abscissa range of the chart has been clipped and does not show forecast drawdowns for the higher use scenarios (more improbable volumes of 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. The intercept in Figure 234 is quite large, this is attributed to that there is no data included during the pre-development in inform drawdowns at low extraction volumes.
– Average use is around 18,000 ML, Figure 233 indicates that at this volume the model forecast drawdown tends to occur below the predicted line of best fit for Suite M_F_2. Figure 235 indicates that at this volume, the model forecast drawdown tends to occur around the predicted line of best fit for Suite M_F_3.

– For the same annual use, different drawdowns can be obtained as Pastas predicts a water level for each year. For example, Figure 232 shows a scenario where groundwater use remains constant at around 18,000 ML/year over the next 20 years.
– The correlation for groundwater use and drawdown is moderate for Suite M_F_2 and is excellent for Suite M_F_3
– 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.

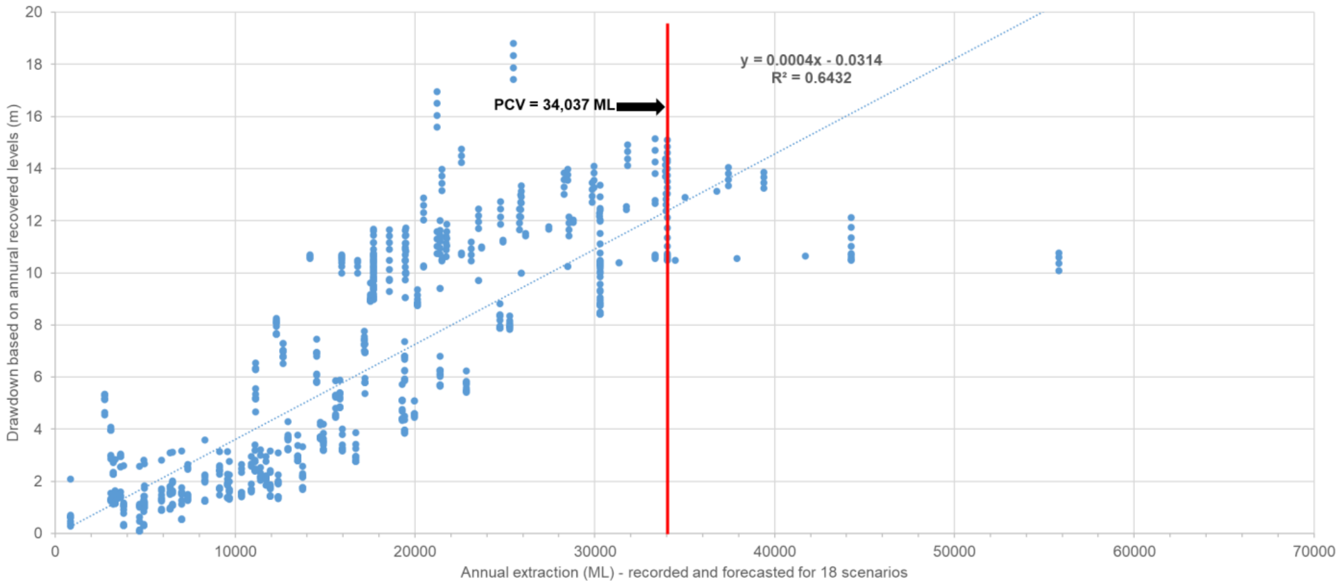


Figure 233 ***Mid Loddon GMA Suite M_F_2: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <70,000 ML) for all data between 1970 to 2041 for the 18 forecasted scenarios***

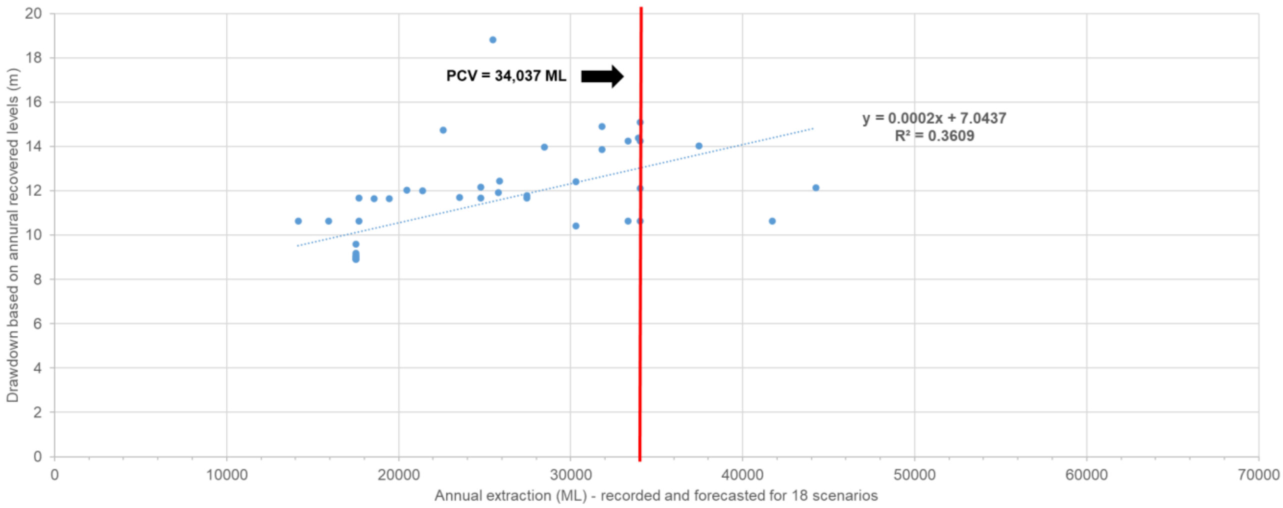


Figure 234 ***Mid Loddon GMA Suite M_F_2: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <70,000 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios***

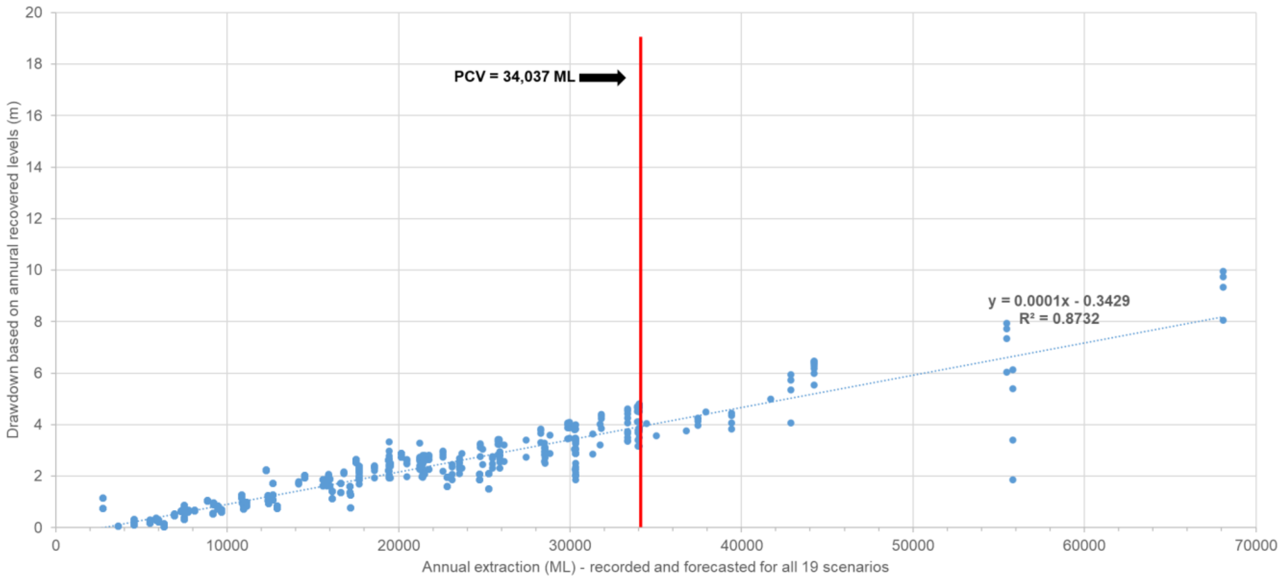


Figure 235 *Mid Loddon GMA Suite M_F_3: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <70,000 ML) for all data between 1973 to 2041 and all forecasted scenarios*

16.5 Sustainability metrics

16.5.1 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 89 for Mid Loddon GMA Suite M_F_2 and Table 90 for Mid Loddon GMA Suite M_F_3 (noting Mid Loddon GMA has a current PCV of 34,307 ML/year). The relationship between drawdown and extraction volumes at the lower and upper bands of the 95% prediction interval are shown in Table 89 and Figure 236 for Suite M_F_2, and Table 90 and Figure 237 for Suite M_F_3.

The two Mid Loddon GMA Suites M_F_2 and M_F_3 have different drawdown-use relationships. Suite M_F_3 generally requires more volume to be extracted to reach a 5 m drawdown than Suit M_F_2. A comparison of volumes at drawdown intervals provided by DEECA is shown in Table 91 for Suite M_F_2 and M_F_3. Based on the relationships developed, 5 m of drawdown is predicted to occur based on an extraction volume of 12,600 ML (but could vary down from 1,900 to 23,900 ML) based on Suite M_F_2 and 53,400 ML (but could vary down from 39,300 to 66,800 ML) based on Suite M_F_3. Whereas 10 m of drawdown is predicted to occur based on an extraction volume of 25,100 ML (but could vary down from 9,000 to 40,600 ML) based on Suite M_F_2 and 103,400 ML (but could vary down from 89,300 to 116,800 ML) based on Suite M_F_3.

Table 89 *Relationship of Suite drawdown to GMU extraction for Mid Loddon GMA Suite M_F_2*

Volume (ML/year) for whole of GMU	Based on model prediction of Suite M_F_2 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
75,000	30 (20.3 - 56.2)
70,000	28 (18.8 - 52.7)
65,000	26 (17.3 - 49.2)
60,000	24 (15.8 - 45.7)
55,000	22 (14.3 - 42.2)

Volume (ML/year) for whole of GMU	Based on model prediction of Suite M_F_2 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
50,000	20 (12.8 - 38.7)
45,000	18 (11.3 - 35.2)
40,000	16 (9.8 - 31.7)
35,000	14 (8.3 - 28.2)
30,000	12 (6.8 - 24.7)
25,000	10 (5.3 - 21.2)
20,000	8 (3.8 - 17.7)
15,000	6 (2.3 - 14.2)
10,000	4 (0.8 - 10.7)
5,000	2 (-0.7 - 7.2)
0	0 (-2.2 - 3.7)

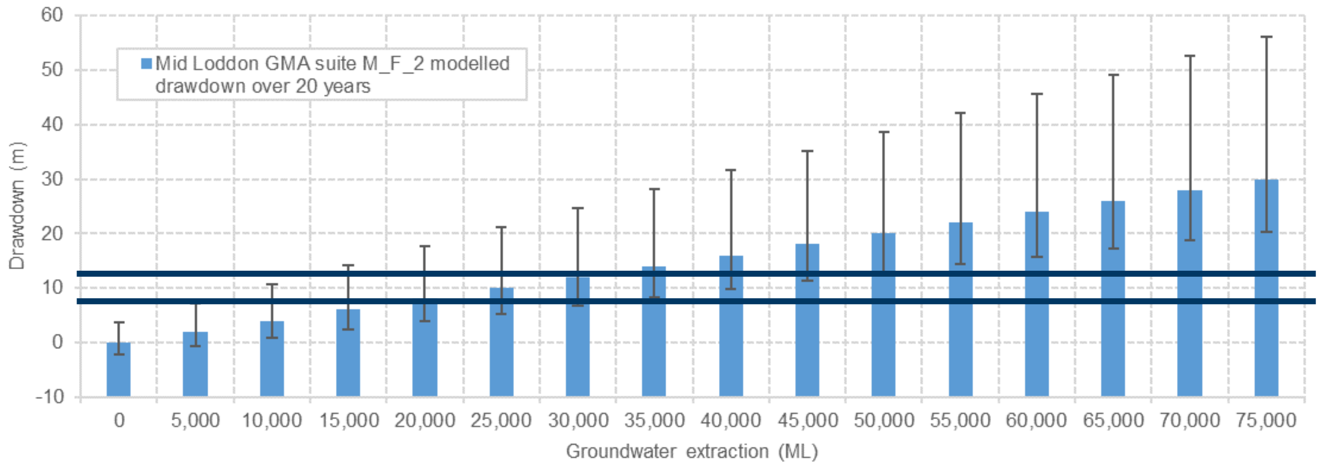


Figure 236 *Mid Loddon GMA Suite M_F_2: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)*

Table 90 Relationship of Suite drawdown to GMU extraction for Mid Loddon GMA Suite M_F_3

Volume (ML/year) for whole of GMU	Based on model prediction of Suite M_F_3 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
105,000	10.2 (8.8 - 11.6)
100,000	9.7 (8.3 - 11.1)
95,000	9.2 (7.8 - 10.6)
90,000	8.7 (7.3 - 10.1)
85,000	8.2 (6.8 - 9.6)
80,000	7.7 (6.3 - 9.1)
75,000	7.2 (5.8 - 8.6)
70,000	6.7 (5.3 - 8.1)
65,000	6.2 (4.8 - 7.6)
60,000	5.7 (4.3 - 7.1)
55,000	5.2 (3.8 - 6.6)
50,000	4.7 (3.3 - 6.1)
45,000	4.2 (2.8 - 5.6)
40,000	3.7 (2.3 - 5.1)
35,000	3.2 (1.8 - 4.6)
30,000	2.7 (1.3 - 4.1)
25,000	2.2 (0.8 - 3.6)
20,000	1.7 (0.3 - 3.1)
15,000	1.2 (-0.2 - 2.6)
10,000	0.7 (-0.7 - 2.1)
5,000	0.2 (-1.2 - 1.6)
0	-0.3 (-1.7 - 1.1)

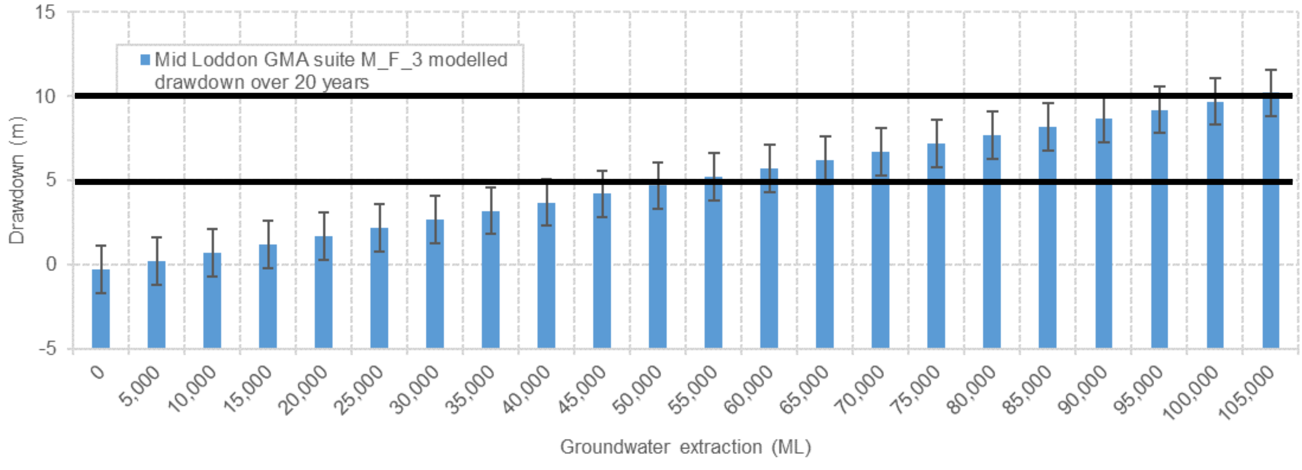
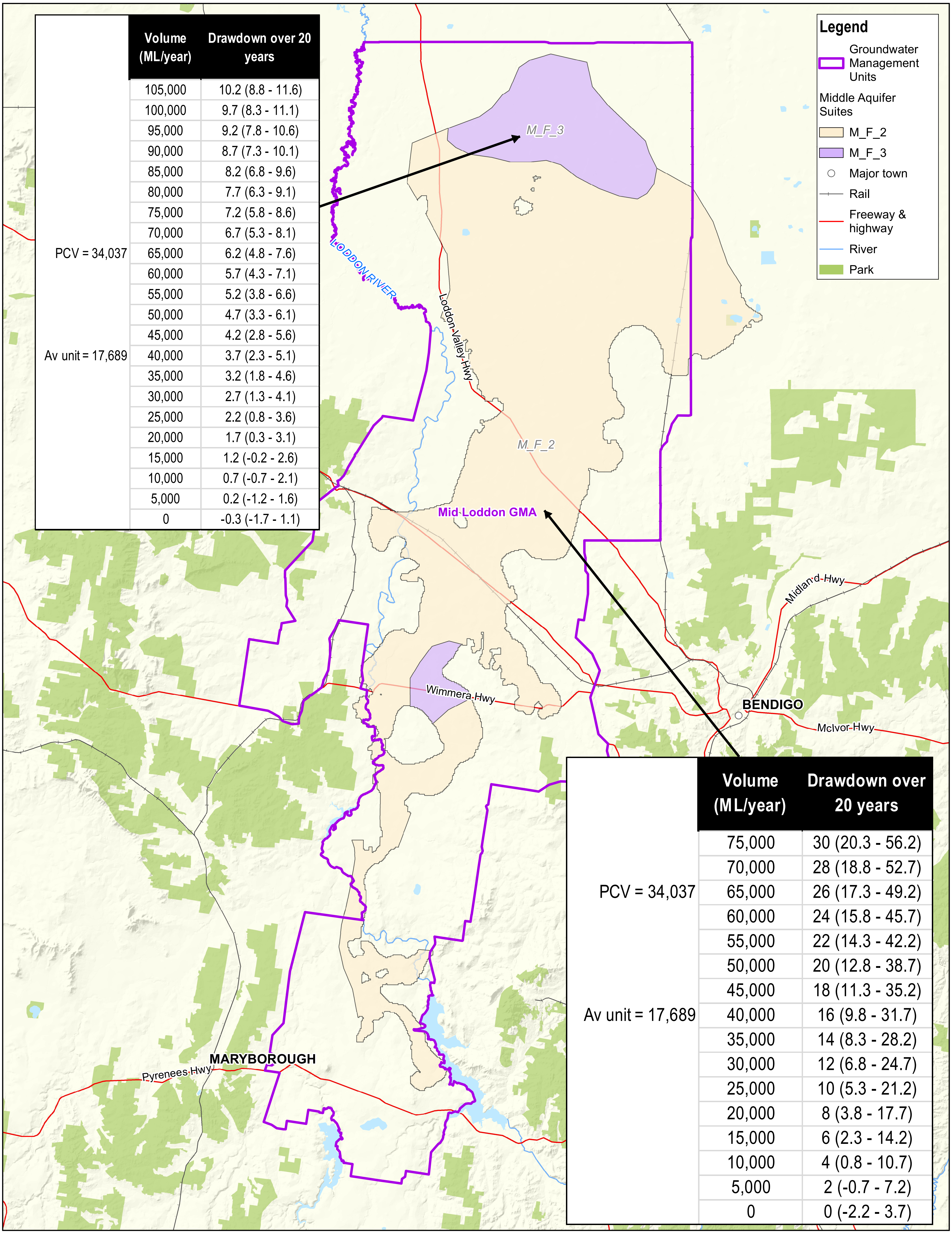


Figure 237 Mid Loddon GMA Suite M_F_3: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 91 Predicted GMU volumes for drawdown metrics

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite M_F_2 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite M_F_3 drawdowns (lower limit to upper limit)
5	12,600 (1,900 – 23,900)	53,400 (39,300 – 66,800)
10	25,100 (9,000 – 40,600)	103,400 (89,300 – 116,800)



	Volume (ML/year)	Drawdown over 20 years
	105,000	10.2 (8.8 - 11.6)
	100,000	9.7 (8.3 - 11.1)
	95,000	9.2 (7.8 - 10.6)
	90,000	8.7 (7.3 - 10.1)
	85,000	8.2 (6.8 - 9.6)
	80,000	7.7 (6.3 - 9.1)
	75,000	7.2 (5.8 - 8.6)
	70,000	6.7 (5.3 - 8.1)
PCV = 34,037	65,000	6.2 (4.8 - 7.6)
	60,000	5.7 (4.3 - 7.1)
	55,000	5.2 (3.8 - 6.6)
	50,000	4.7 (3.3 - 6.1)
	45,000	4.2 (2.8 - 5.6)
Av unit = 17,689	40,000	3.7 (2.3 - 5.1)
	35,000	3.2 (1.8 - 4.6)
	30,000	2.7 (1.3 - 4.1)
	25,000	2.2 (0.8 - 3.6)
	20,000	1.7 (0.3 - 3.1)
	15,000	1.2 (-0.2 - 2.6)
	10,000	0.7 (-0.7 - 2.1)
	5,000	0.2 (-1.2 - 1.6)
	0	-0.3 (-1.7 - 1.1)

	Volume (ML/year)	Drawdown over 20 years
	75,000	30 (20.3 - 56.2)
	70,000	28 (18.8 - 52.7)
PCV = 34,037	65,000	26 (17.3 - 49.2)
	60,000	24 (15.8 - 45.7)
	55,000	22 (14.3 - 42.2)
	50,000	20 (12.8 - 38.7)
	45,000	18 (11.3 - 35.2)
Av unit = 17,689	40,000	16 (9.8 - 31.7)
	35,000	14 (8.3 - 28.2)
	30,000	12 (6.8 - 24.7)
	25,000	10 (5.3 - 21.2)
	20,000	8 (3.8 - 17.7)
	15,000	6 (2.3 - 14.2)
	10,000	4 (0.8 - 10.7)
	5,000	2 (-0.7 - 7.2)
	0	0 (-2.2 - 3.7)

Paper Size ISO A3
0 2.5 5 7.5 10
Kilometers
Map Projection: Mercator Auxiliary Sphere
Horizontal Datum: WGS 1984
Grid: WGS 1984 Web Mercator Auxiliary Sphere

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GHD

DEECA
Sustainable Yields
Confined Aquifers

MID LODDON GMA:
KEY SUITES
VOLUME VS DRAWDOWN

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

FIGURE 238

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

16.6 GMU summary

16.6.1 Findings

Mid Loddon GMA primarily relates to the Calivil Formation aquifer (UTAF), where groundwater is predominately extracted for irrigation purposes. The UTAF falls within the Middle Aquifer Suites, which at Mid Loddon GMA comprise M_F_1 (1%), M_F_2 (37%), M_F_3 (7%), M_F_4 (15%) and M_G_8 (1%) providing a total GMU coverage of 61%. The identified representative Suites are M_F_2 (most preferred) and M_F_3. 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.

Application of two yearly annual average extraction, instead of annual extraction, generally showed an improved model fit based on the statistical analysis across the model runs; the exception to this was for hindcast method 1 for Suite M_F_2. The application of spatial distribution produced an improved model compared to annual extraction and two yearly annual average extraction including when hindcasting was applied to these use datasets. However, the spatial distributions models are based on a smaller input dataset. It is noted that the quality of the model results did not increase when spatial distribution methodology was combined with hindcasting methodology.

Based on an assessment of all model runs, the model run 9c of annual extraction with hindcast method H3 and climate was adopted to undertake the predictive modelling for Suite M_F_2. As it was found that adding climate to the hindcasted dataset improved the model results. For Suite M_F_3, after assessing all the model runs, model run 7 was adopted to undertake predictive modelling as it provided a balance between capturing the fluctuations of the observed data with the statistical result.

The pre-development levels were defined for the two representative Suites, based on the maximum annual recovered levels for Suite M_F_2 and the early time series data for Suite M_F_3. This resulted in pre-development levels of 9.01 m for Suite M_F_2 and 2.31 m for Suite M_F_3. The drawdowns were calculated based on these pre-development levels and the simulated levels from each of the 19 forecast scenarios (except M_F_2 did not included scenario 4).

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

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite M_F_2 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite M_F_3 drawdowns (lower limit to upper limit)
5	12,600 (1,900 – 23,900)	53,400 (39,300 – 66,800)
10	25,100 (9,000 – 40,600)	103,400 (89,300 – 116,800)

The model for Suite M_F_2 was assessed as having an “Excellent” model applicability rating, Suite M_F_3 was assessed as having a “Moderate” rating using the criteria outlined in section 5.2. As well as having a higher applicability rating, Suite M_F_2 also provides a more conservative estimate of the two Suites.

Given the coverages of the Suites and that 58% of extraction is likely to come from the Middle Aquifer Suites, Suite M_F_2 is considered to be the most representative Suite for Mid Loddon GMA.

16.6.2 Limitations

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

- The licenced bore dataset provided by DEECA has 70% of bores assigned to Mid Loddon 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.

- Scenario 4 for Suite M_F_2 failed to simulate the levels, thus scenario 4 is not included in the use-drawdown graph for this Suite
- The spread in drawdown at a particular volume could be due to climate influence for Suite M_F_2

16.6.3 Recommendations

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

- The licenced bore dataset provided by DEECA has 70% of bores assigned to Mid Loddon 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.

17. Giffard GMA

17.1 Conceptualisation

The hydrogeological conceptualisation elements relevant to this study are summarised in Table 92 and a map of the GMU is presented in Figure 239. 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 92.

Table 92 Giffard GMA – Tabulated conceptualisation

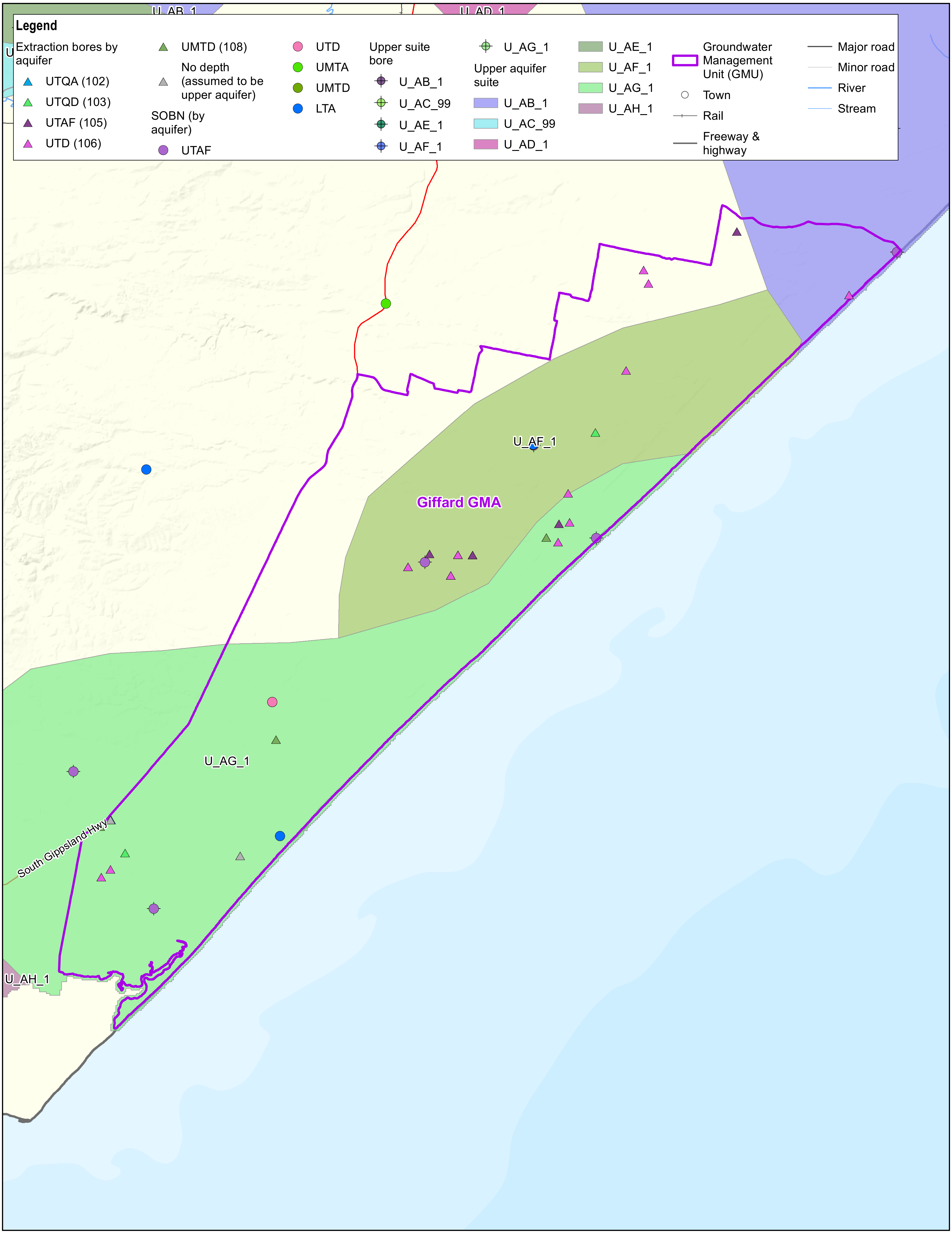
GMU summary								
Giffard GMA is located within the Gippsland Basin and extends south from Golden Beach to McLoughlins Beach. The northern boundary of the GMA is the southern limit of the Baragwanath Anticline, and the coast forms the southern boundary of the GMA (Jacobs 2019), covering an area of approximately 676 km^2. The Giffard GMA pertains to formations between 50 m and 200 m below ground level but was intended to primarily manage groundwater resources of the Boisdale Formation (Upper Tertiary Aquifer fluvial, UTAF). The PCV (5,689 ML/year) therefore relates to confined aquifers. It is noted that the GMA overlies the Yarram WSPA. Groundwater within the Giffard GMA is primarily used for irrigation purposes (Australian Government 2018[6]). Jacobs (2019) found that groundwater levels were previously declining until recently, and indicated that levels have stabilised, suggesting that a new equilibrium has been reached.								
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	Undifferentiated sediments (QA)	-	-	0	NA	0		Low
	Haunted Hills Gravels (UTQA)	-	-	0	Industrial	0		Low
	Nuntin clay (UTQD)	U_AB_1 (6%)	6%	0	Dairy, domestic, stock	0		Low
Middle	Boisdale Formation (UTAF)	U_AF_1 (32%), U_AG_1 (42%	75%	5	Irrigation, dairy, domestic, stock	2,618 (137)	5,689 (270)	Medium
	Jemmy's Point Formation (UTD)	-	-	0	Industrial, irrigation, domestic, stock	0		Low
Lower	Gippsland Limestone/Lakes Entrance Formation (UMTD)	-	-	1	Irrigation	0		Low
	M2C aquifer/Seaspray Sands (LMTA)	-	-	0	NA	0		Low
	Latrobe Group (LTA)	L_O_1 (98%), L_O_2 (2%),	100%	0	NA	0		Low
Basement	Basement rocks	-	-	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. In some instances, bore depth is not available or it has been inferred that usage is likely incorrectly assigned; where possible, incorrectly assigned usage has been reallocated, as indicated within the brackets.								

[6] Australian Government 2018, Bioregional Assessments, last update 8 January 2018, **https://www.bioregionalassessments.gov.au/assessments/11-context-statement-gippsland-basin-bioregion/1144-groundwater-planning-and-use**

Note that volumes listed above do not include 102 ML of unassigned use due to unknown depths. 34 ML, 1,640 ML and 424 ML has been reassigned from the aquitards (UTQD, UTD and UMTD respectively) to UTAF as extraction (included above) from aquitards is unlikely likely represents a data error.

Characteristic and importance	Description	Degree of understanding
Intended aquifer (UTAF, highlighted blue in table above)		
Aquifer thickness within GMU (range, based on VAF)	Max: 77 m, Average: 20 m	High
Aquifer extent	Small, local	High
Likelihood of inter-aquifer flow	Medium	Low
Likelihood of groundwater – surface water interaction	High - groundwater/surface water interaction via the Merriman Creek	High (O'Neill *et al*, 2021)
Representative Suite	**U_AG_1**	**Low. GMU extraction from Middle Aquifer taken to predominately occur in 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)	1,347 mg/L (WMIS) 601 – 1,200 mg/L (CDM Smith)	Medium Based on WMIS and CDM Smith (2022)
Groundwater yield	0 – 0.5 L/s	Low –very low yields for this GMU Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**2001-2021**	
Spatial clustering of licensed bores in relation to Suites	**Yes, U_AG_1 and U_AF_1**	**Based on DEECA density mapping and licenced bore data.**
Groundwater use		
Licensed groundwater use	**2,475 ML**	**High (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	845 ML	High (Based on historical VWA data, year 2011/12)
Maximum historic groundwater use	**5,548 ML**	**High (Based on historical VWA data, year 2018/19)**
Entitlement (Groundwater allocation)	**5,689 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 stock or domestic use	Moderate
Groundwater use profile	Seasonal (~Oct-Apr irrigation season)	Low

Characteristic and importance	Description	Degree of understanding
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	Moderate
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	Moderate



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0 1.5 3 4.5 6

Kilometers

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

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DEECA
Sustainable yield review - confined aquifers

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

Giffard GMA
Site location and key features

Figure 239

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Print date: 16 Jan 2024 - 12:34

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

17.2 Technical analysis

17.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the Giffard GMA confined Suites as shown in Figure 240. Generally, the Suite hydrographs show the seasonal fluctuations and hence recovered water levels.

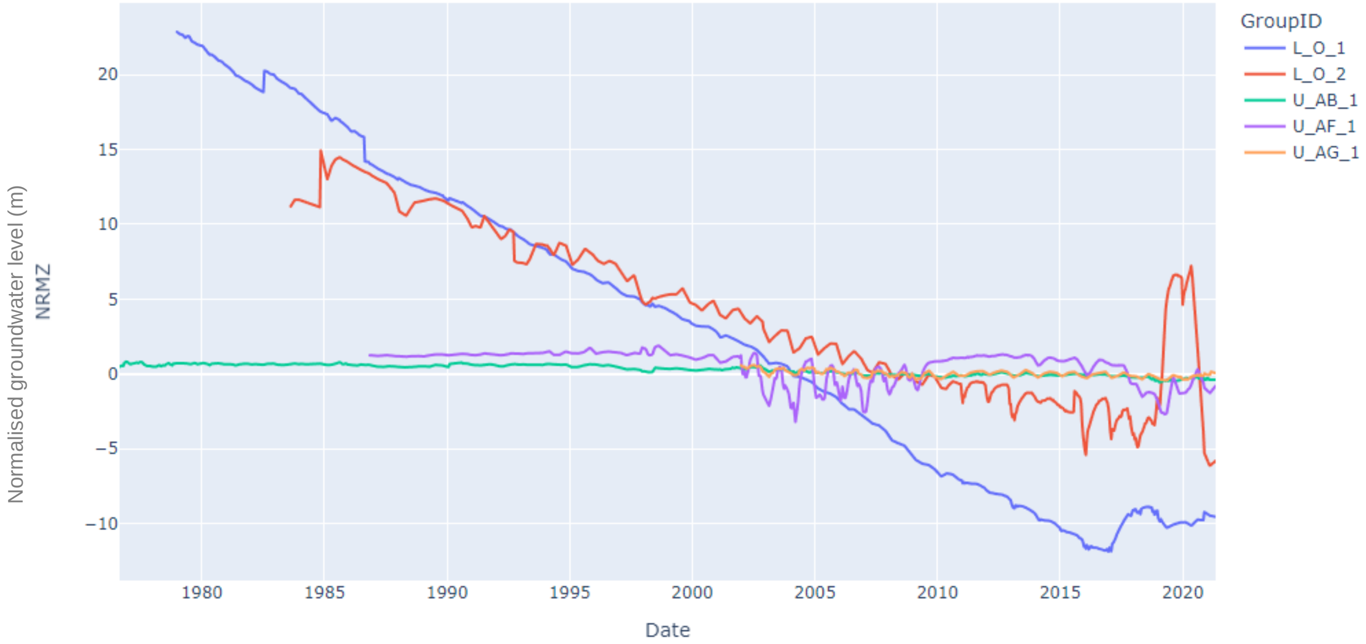

Figure 240 Giffard GMA Suite Hydrographs for all confined aquifers

The representative Suites analysed for this GMU were Suites U_AF_1 and U_AG_1. The Representative Suites were selected based on the methodology outlined in section 2.6.4 which identified Suite U_AG_1 as the most representative followed by U_AF_1. The process is summarised as follows:

- The greatest volume of extraction occurring within the Upper Aquifer
- The Upper Aquifer pertains to the UTAF which is the intended aquifer for this GMU
- Suite U_AF_1 covers 32% of the GMU and U_AG_1 covers 42%
- Within the Suite area, Suite U_AF_1 has two active SOBN bores and Suite U_AG_1 has three active SOBN bores
- One Suite bore for each Suite U_AG_1 and U_AF_1 are close to extraction points

The annual recovered Suite hydrographs for the representative Suites for Giffard GMA, U_AF_1 and U_AG_1 are shown in Figure 241.

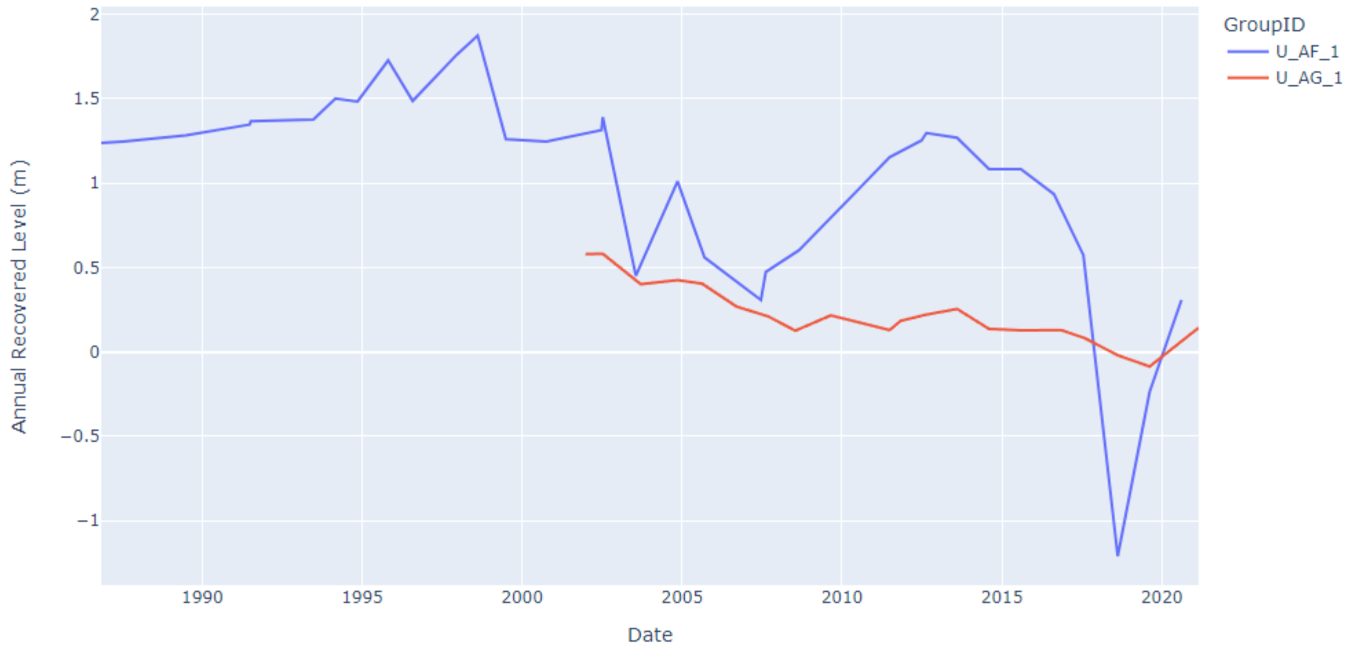

Figure 241 Giffard GMA Annual Recovered Level Suite Hydrographs for representative Suites

17.2.2 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 Giffard GMA for Suites U_AF_1 and U_AG_1.

The pre-development annual recovered levels are taken to be the average level of the average of the first 13 readings in the early time series data which equates to 1.46 m for Suite U_AF_1. The pre-development annual recovered levels are taken to be the average level of the first 2 readings in the early time series data which equates to 0.58 m for Suite U_AG_1 (refer further details in section 17.4.3).

17.2.3 Externalities

Through the conceptualisation, no external influence was inferred for Giffard GMA.

17.2.4 Hindcasting

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

17.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, four different correlations were developed as described below and shown in Figure 242:

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

As shown in Figure 242, the goodness-of-fit represented by the R^2 is greatest for annual rainfall with annual groundwater use. The correlation decreased when rainfall was reduced to only part of the year through summer rainfall and irrigation rainfall. Thus, the annual rainfall with annual groundwater use was modelled for hindcast method H1.

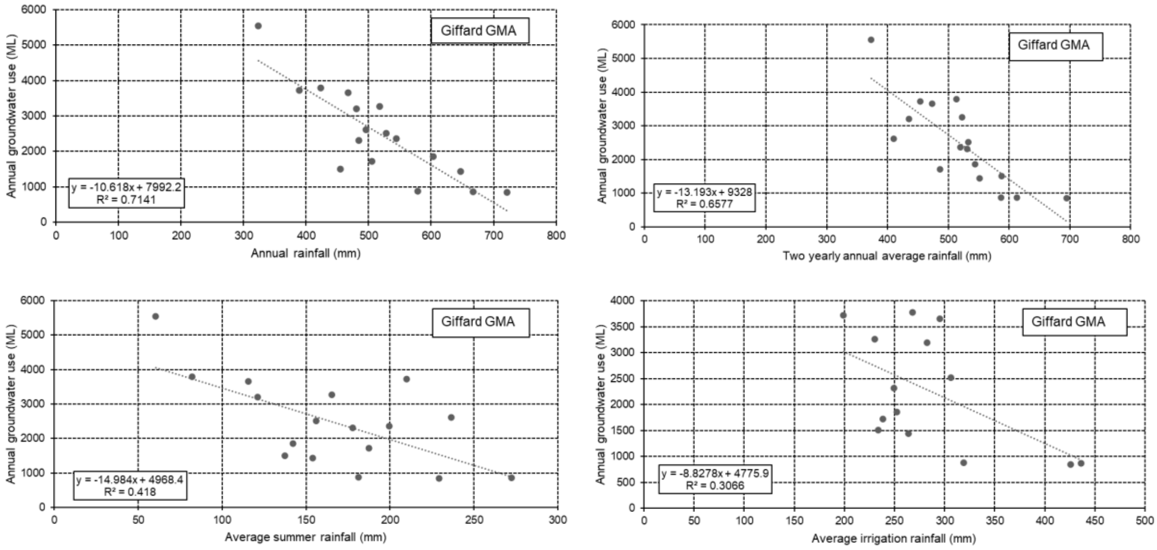

Figure 242 ***Giffard GMA: Hindcast method 1 correlations (Giffard GMA only)***

17.2.4.2 Hindcasting Method 2 (H2)

Similar to method H1, eight correlations were developed using method H2 as described below and shown in Figure 243:

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

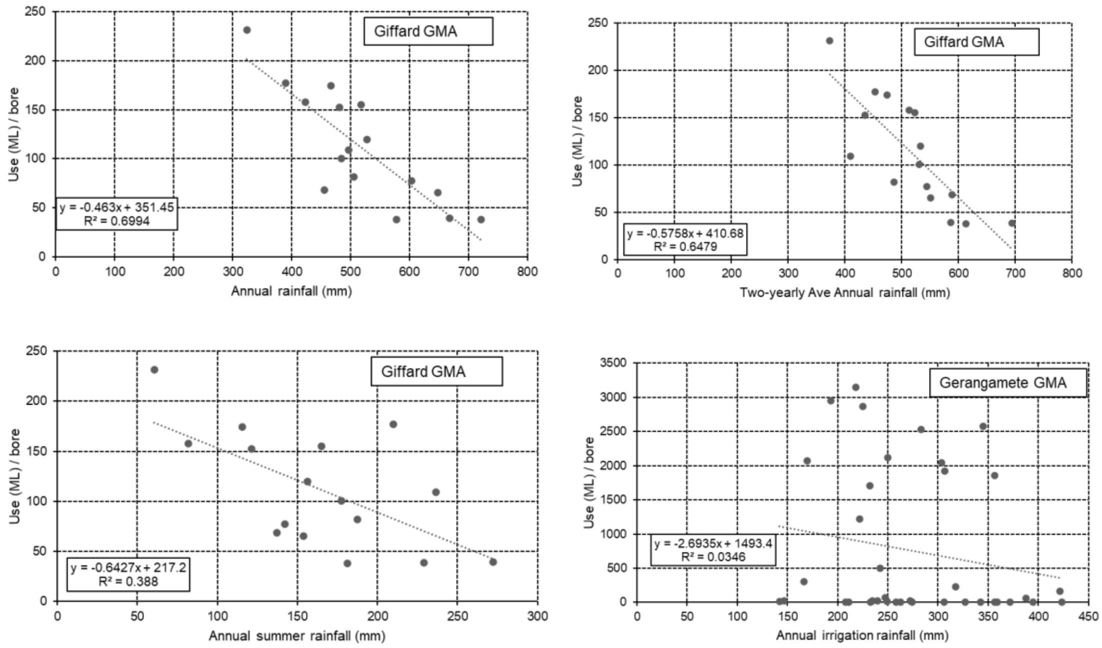

Figure 243 ***Giffard GMA: Hindcast method 2 correlations (Giffard GMA only)***

As shown in Figure 243 and similar to method H1, the goodness-of-fit is greatest for annual rainfall with annual groundwater use. The correlation decreased when rainfall was reduced to only part of the year through summer rainfall and irrigation rainfall. Thus, the annual rainfall with annual groundwater use was modelled for hindcast method H2.

17.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H2 as described below and shown in Figure 244:

- 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 rain

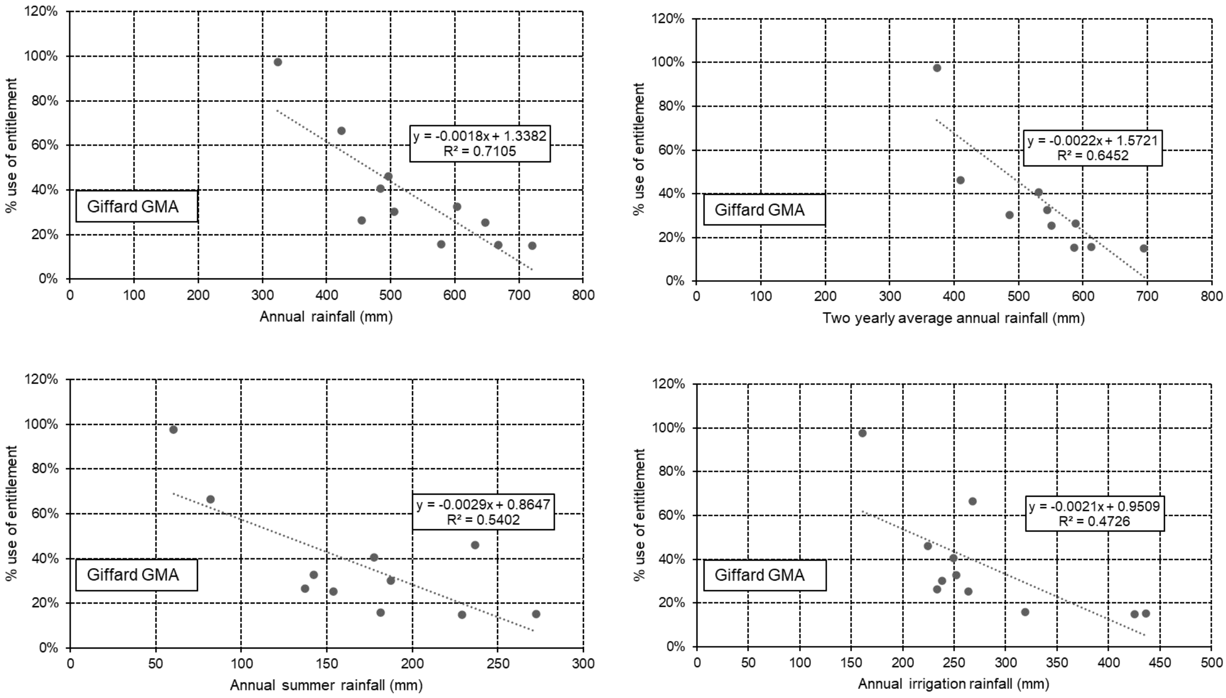

Figure 244 Giffard GMA: Hindcast method 3 correlations

As shown in Figure 244 and similar to method H1 and H2, the best goodness-of-fit was shown through the correlation of the annual rainfall with annual groundwater extraction. This is the correlation modelled for hindcast method H3.

17.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 245 and Figure 246 for the hindcasting based on Giffard GMA groundwater use. Figure 245 shows a comparison of the three hindcasting methods against the recorded use only, over the recorded use date and Figure 246 shows the hindcasted data back to 1968/1969.

As shown in Figure 246, 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 and thus, results in a higher groundwater extraction estimate than the other two methods. Both sets of 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 Giffard GMA.

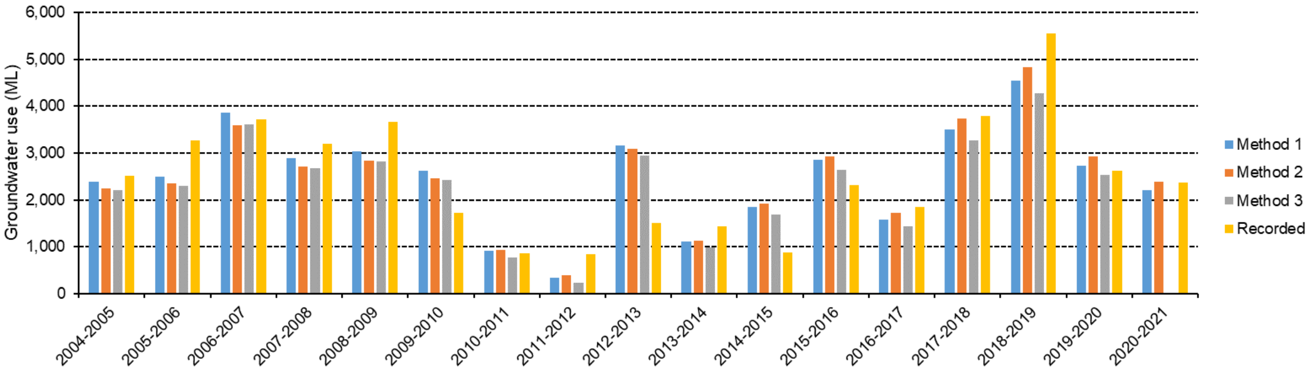

Figure 245 Giffard GMA: Comparison of hindcasting over recorded use period

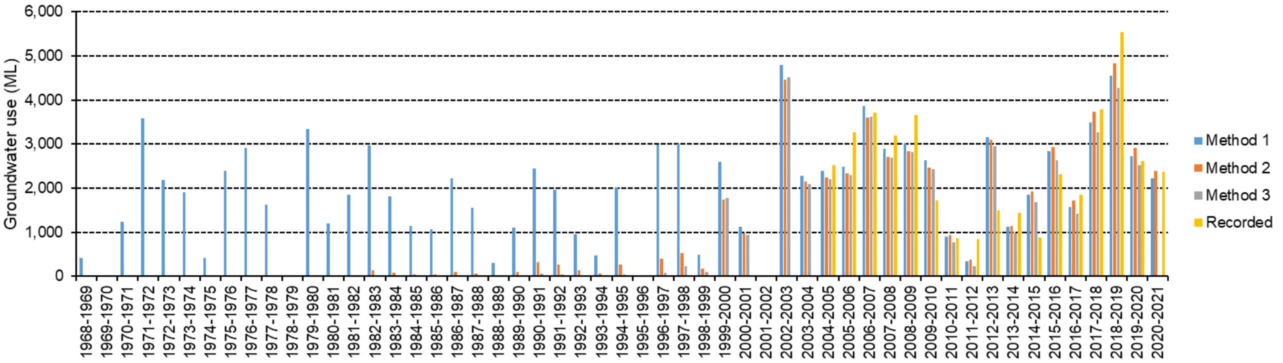

Figure 246 Giffard GMA: Comparison of hindcasting

17.3 Modelling

17.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 93 summarises the combinations of model inputs run for Giffard GMA. Model runs highlighted blue were run with annual extraction and while those highlighted grey were run using two yearly average annual extraction.

Table 93 Giffard 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 (U_AF_1 and U_AG_1)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Giffard GMA only	✓																		
Two yearly average annual extraction – Giffard GMA only		✓																	
Annual extraction – Giffard GMA and Externalities			✓																
Two yearly average annual extraction – Giffard GMA and Externalities				✓															
H1 annual extraction – Giffard GMA only					✓														
H1 annual extraction – Giffard GMA and Externalities						✓													
H2 annual extraction – Giffard GMA only							✓												
H2 annual extraction – Giffard GMA and Externalities								✓											
H3 annual extraction – Giffard GMA only									✓										
H1 two yearly average annual extraction – Giffard GMA only										✓									
H1 two yearly average annual extraction – Giffard 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 – Giffard GMA only												✓							
H2 two yearly average annual extraction – Giffard GMA and Externalities													✓						
S1 annual extraction – Giffard GMA only														✓					
S2 annual extraction – Giffard GMA only															✓				
S3 annual extraction – Giffard GMA only																✓			
S1 annual extraction and H1 annual extraction – Giffard GMA only																	✓		
S2 annual extraction and H2 annual extraction – Giffard GMA only																		✓	
S3 annual extraction and H3 annual extraction – Giffard GMA only																			✓

17.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 93 is presented in Table 94 for the selection of potential representative Suites for Giffard GMA. The column heading for U_AG_1 is highlighted blue to indicate that this Suite was selected as the most likely representative Suite based on the process outlined in section 17.2.1. 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 U_AF_1

A review of the results and statistical summary for Suite U_AF_1 shows that model run 16 (highlighted orange) had the best results (defined as the runs with the smallest 95PPU thickness and then considering the other three statistical measures) of the 13 different model input combinations. However, this model only included 10 observation points and did not cover the period of pre-development. Considering the need to include a longer historic record in the calibration model, the hindcasted models were looked at in more detail. Based on the hindcasted models, model run 7 (highlighted green) was found to have the best statistical results with the longest dataset. The graphical model output for this run is shown in Figure 247. It is noted that the three spatial distribution model runs showed similar results and when hindcasting was combined with spatial distribution, the quality of the statistical results decreased.

Suite U_AG_1

A review of the results and statistical summary for Suite U_AG_1 shows that model run 16 (highlighted orange) had the best results (using the same approach as above) of the 13 different model input combinations. However, this model only included 10 observation points and did not cover the period of pre-development. Considering the need to include a longer historic record in the calibration model, the hindcasted models were looked at in more detail. Based on the hindcasted models, model run 12 (highlighted green) was found to have the best statistical results with the longest dataset. The graphical model output for model run 12 is shown in Figure 248.

Based on these results, modelling was progressed on the basis of adopting model 7 for Suite U_AF_1 and model 12 for Suite U_AG_1.

Table 94 Giffard GMA: summary of model outputs

Suite	Statistic	Model run												
		1	2	5	7	9	10	12	14	15	16	17	18	19
U_AF_1	95PPU TH	1.19	1.37	1.52	1.11	1.18	1.51	1.14	0.86	0.43	0.65	1	0.93	1.21
	%Obs in 95 PPU	93.75	100	91.43	97.14	97.14	94.12	97.06	100	90	100	96.55	93.1	76.47
	R^2	85.8	79.2	64.1	79.6	78.0	63.6	79.4	95.5	98.2	99.4	85.6	91.9	85.5
	RMSE	0.24	0.29	0.36	0.27	0.28	0.36	0.27	0.17	0.1	0.06	0.24	0.18	0.23
	No obs data points	16	16	35	35	35	34	34	10	10	10	29	29	34
	Range of observed levels	2.5	2.5	3.1	3.1	3.1	3.1	3.1	2.5	2.5	2.5	3.1	3.1	3.1
U_AG_1	95PPU TH	0.37	0.56	0.72	0.71	0.71	0.65	0.65	4.71	0.18	0.15	0.72	0.54	0.54
	%Obs in 95 PPU	93.75	87.5	75	65	65	90	90	100	90	100	57.89	47.37	47.37
	R^2	72.7	62.4	-137.3	-165.6	-196.3	71.6	71.6	86.9	80.8	86.9	-216.9	-138.5	-138.5
	RMSE	0.07	0.09	0.27	0.29	0.3	0.09	0.09	0.04	0.04	0.04	0.31	0.27	0.27
	No obs data points	16	16	20	20	20	20	20	10	10	10	19	19	19
	Range of observed levels	0.5	0.5	0.7	0.7	0.7	0.7	0.7	0.3	0.3	0.3	0.7	0.7	0.7

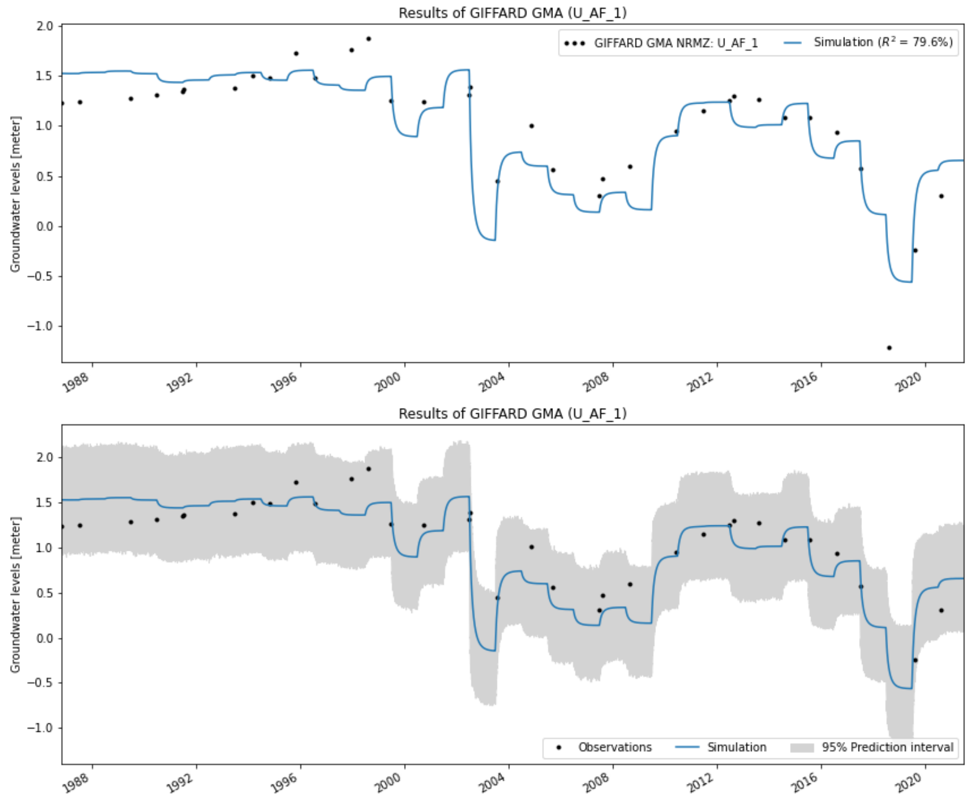

Figure 247 ***Giffard GMA Suite U_AF_1: model run 7 (Giffard GMA annual extraction with hindcast method H2) output hydrographs***

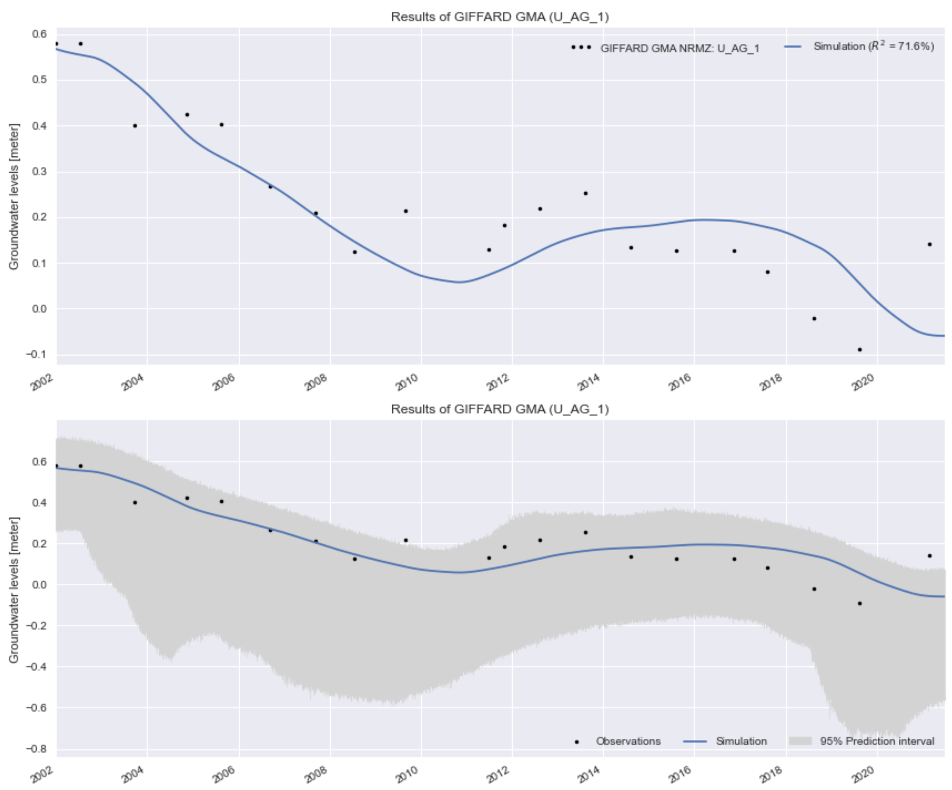

Figure 248 ***Giffard GMA Suite U_AG_1: model run 12 (Giffard GMA two yearly average annual extraction with hindcast method H2) output hydrographs***

17.4 Predictive modelling

17.4.1 Model inputs

The preferred model to run the predictive modelling for Giffard GMA was model run 7 for Suite U_AF_1 and model 12 for Suite U_AG_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 95.

Table 95 Giffard 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 2018/19)
Value (ML/year)	5,689	5,689	2,366	2,475	5,548

17.4.2 Predictive model uncertainty

The model output files of the predicted models can be found in the data package provided as part of Appendix E. It is noted that the figures from these results show both the calibration period and the predictive period.

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 249 for scenario 4 for Suite U_AG_1. As shown in Figure 249, the uncertainty of the model prediction increases as the model predicts further into the future. Comparing with the graphical output for the same scenario, some of the MCMC realisations fall outside the 95% prediction interval bands as shown in Figure 250; however, the majority fall within the bands.

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.

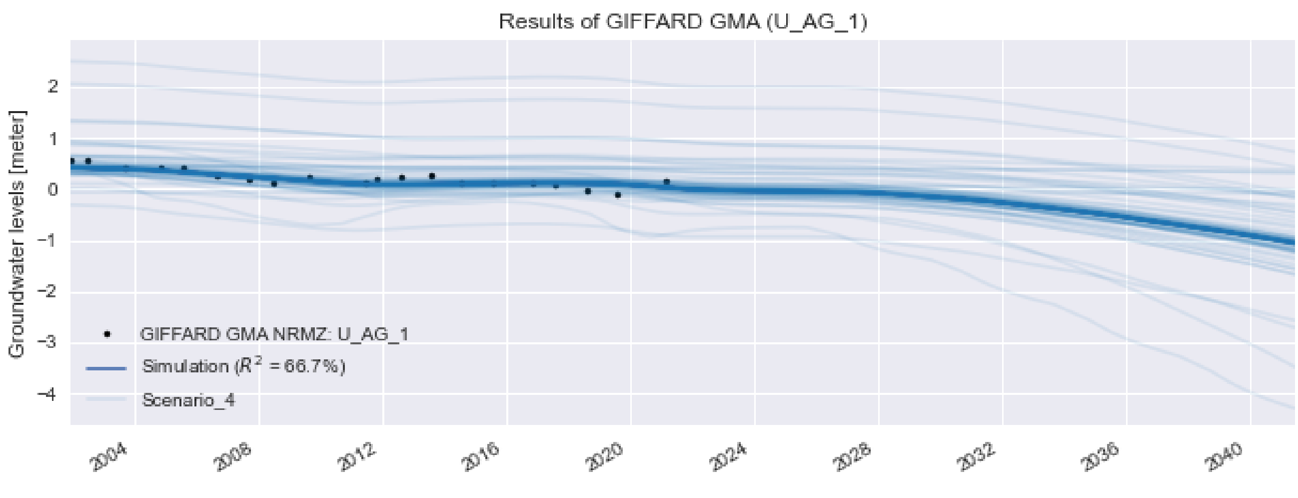

Figure 249 Giffard GMA: Suite U_AG_1 MCMC analysis for Forecast Scenario 4

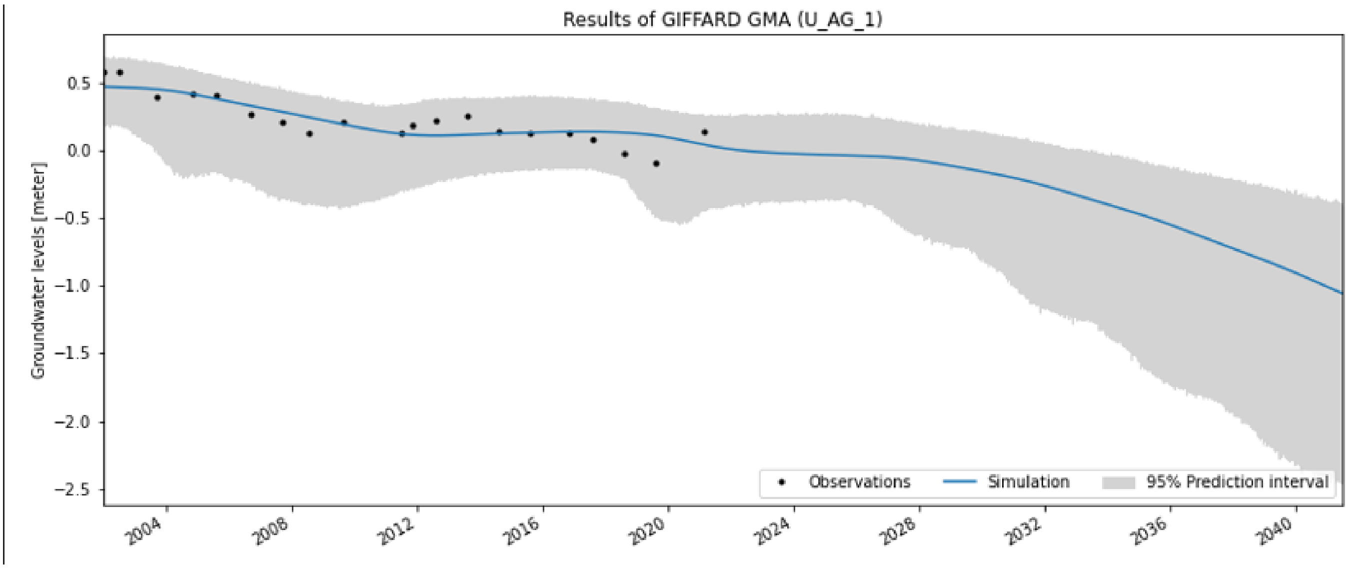

Figure 250 Giffard GMA: Suite U_AG_1 Forecast Scenario 4 with 95% prediction bands

17.4.3 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 Giffard 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 17.2.2, 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 251 for Suite U_AF_1 hydrograph of annual recovered levels. In Figure 251:

- 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 between 1982/1983 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, where the earliest data is taken to best reflect the pre-development levels
- In the case of Figure 251, the pre-development annual recovered levels are taken to be the average of the first 13 measurements which equate to 1.46 m
- The modelled forecasted annual recovered levels are represented by the purple line in Figure 251
- The calibration annual recovered levels are represented by the black line in Figure 251

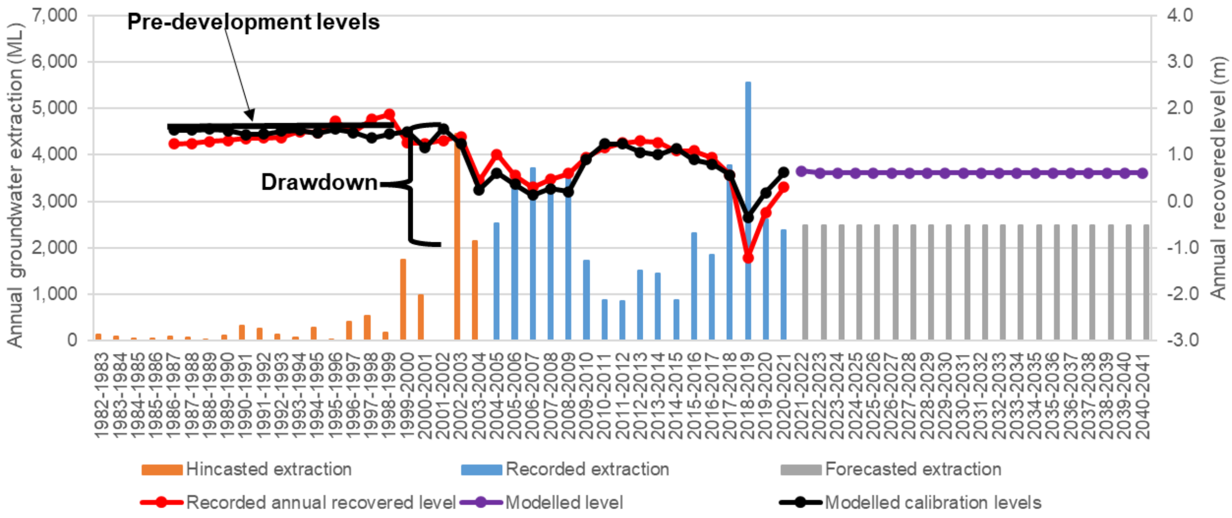

Figure 251 ***Estimating pre-pumping water levels (example from Suite U_AF_1)***

For Suite U_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 252) and a graph of the scenarios for specific time periods (Figure 253) 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 variation in the coefficient of determination and a slight variation (generally 0.0001 change) in the slope of the line of best fit. The same process was applied for Suite U_AG_1, however, there was some variations in the coefficient of determination and the slope of the line of best fit between the graphs. The use-drawdown relationship of all forecasted scenarios was adopted to encompass this variation.

The use-drawdown for all the 19 forecast scenario drawdowns and volumes (both the recorded and forecasted volumes) over each year modelled (1987 to 2041) is shown in Figure 252 for Suite U_AF_1 and Figure 254 for Suite U_AG_1 (2002 to 2041). Note the abscissa range of the chart has been clipped and does not show forecast drawdowns for the higher use scenarios (more improbable volumes 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 2,500 ML. Figure 252 and Figure 254 indicates that at this use the model forecast drawdowns tends to plot close to or 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 251 shows a scenario where groundwater use remains constant at around 2,500 ML/year over the next 20 years.
– The correlation for groundwater use and drawdown for Suite U_AF_1 is excellent as shown in Figure 252
– The correlation of groundwater use and drawdown for U_AG_1 is moderate as shown in Figure 254
– 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.

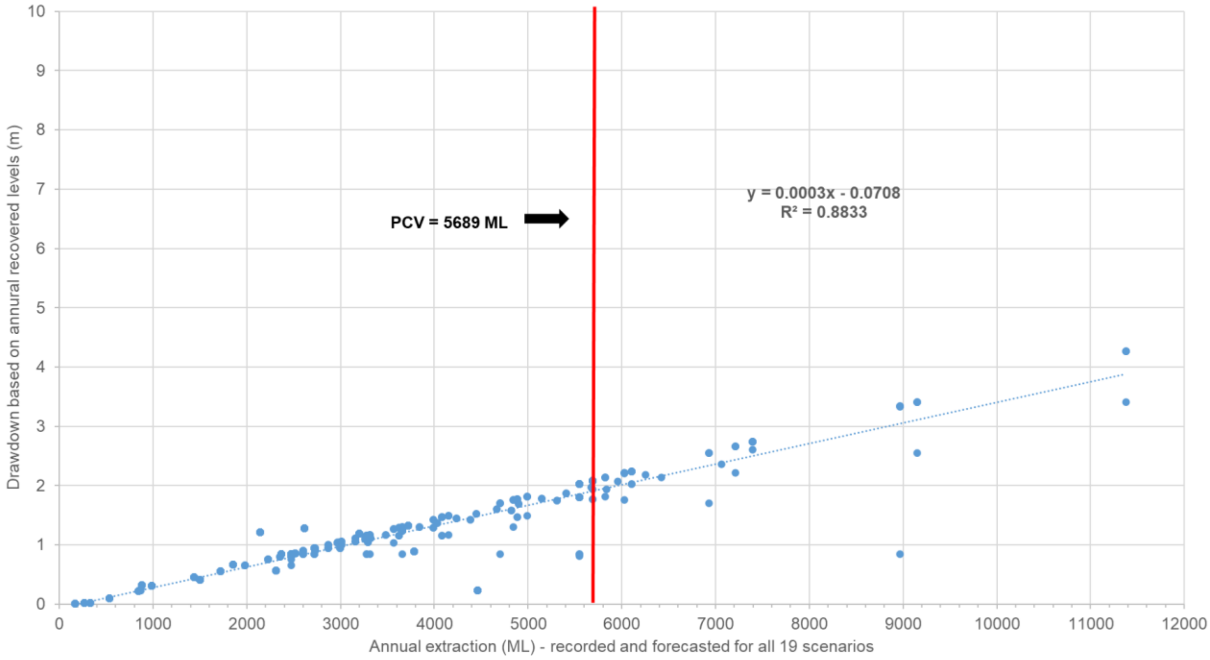

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Figure 252 *Giffard GMA Suite U_AF_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <12,000 ML) for all data between 1987 to 2041 and all forecasted scenarios*

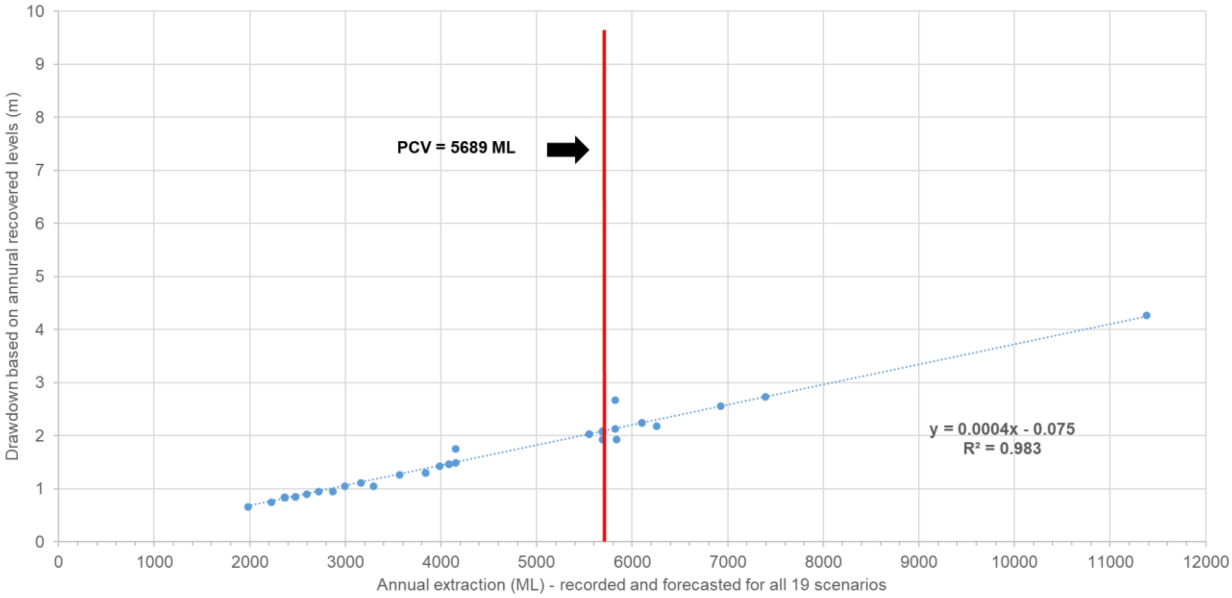


Figure 253 *Giffard GMA Suite U_AF_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <12,000 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

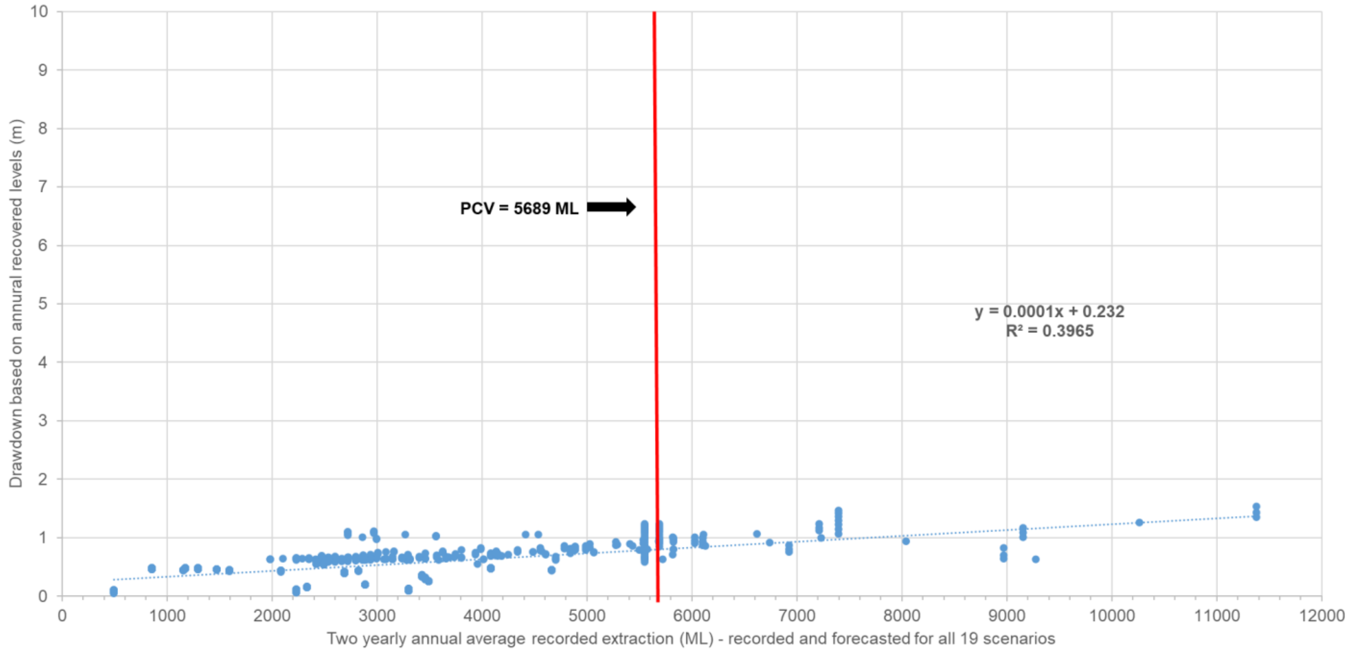


Figure 254 ***Giffard GMA Suite U_AG_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <12,000 ML) for all data between 2002 to 2041 and all forecasted scenarios***

17.5 Sustainability metrics

17.5.1 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 96 for Giffard GMA Suite U_AF_1 and Table 97 for Giffard GMA Suite U_AG_1 (noting Giffard GMA has a current PCV of 5,689 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 96 and Figure 255 for Suite U_AF_1, and Table 97 and Figure 256 for Suite U_AG_1.

The two Giffard GMA Suites U_AF_1 and U_AG_1 have a different drawdown-use relationship. Suite U_AG_1 shows greater variability and uncertainty when comparing the drawdown to use relationships based on the 95% prediction interval bands. That is for example, the variation in drawdown based on the 95% prediction bands at a volume of 30,000 ML is 8.4 m to 12.4 m of drawdown for Suite U_AF_1 and 2.5 m to 6.4 m of drawdown at Suite U_AG_1 (reflected in the error bars of Figure 255 and Figure 256 respectively).

A comparison of volumes at drawdown intervals provided by DEECA is shown in Table 98 for Suite U_AF_1 and U_AG_1. Based on the relationships developed, it is predicted that 5 m of drawdown would occur at a use of 16,900 ML (but could vary from 13,600 to 18,700 ML) based on Suite U_AF_1 and 47,700 ML (but could vary from 23,000 to 67,700 ML) based on Suite U_AG_1. Whereas it is predicted that 10 m of drawdown would occur at a use of 33,600 ML (but could vary from 26,100 to 35,400 ML) based on Suite U_AF_1 and 97,700 ML (but could vary from 48,000 to 124,200 ML) based on Suite U_AG_1

Table 96 *Relationship of Suite drawdown to GMU extraction for Giffard GMA Suite U_AF_1*

Volume (ML/year) for whole of GMU	Based on model prediction of Suite U_AF_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
50,000	14.9 (14.4 - 20.4)
45,000	13.4 (12.9 - 18.4)
40,000	11.9 (11.4 - 16.4)
35,000	10.4 (9.9 - 14.4)
30,000	8.9 (8.4 - 12.4)
25,000	7.4 (6.9 - 10.4)
20,000	5.9 (5.4 - 8.4)
15,000	4.4 (3.9 - 6.4)
10,000	2.9 (2.4 - 4.4)
5,000	1.4 (0.9 - 2.4)
0	-0.1 (-0.6 - 0.4)

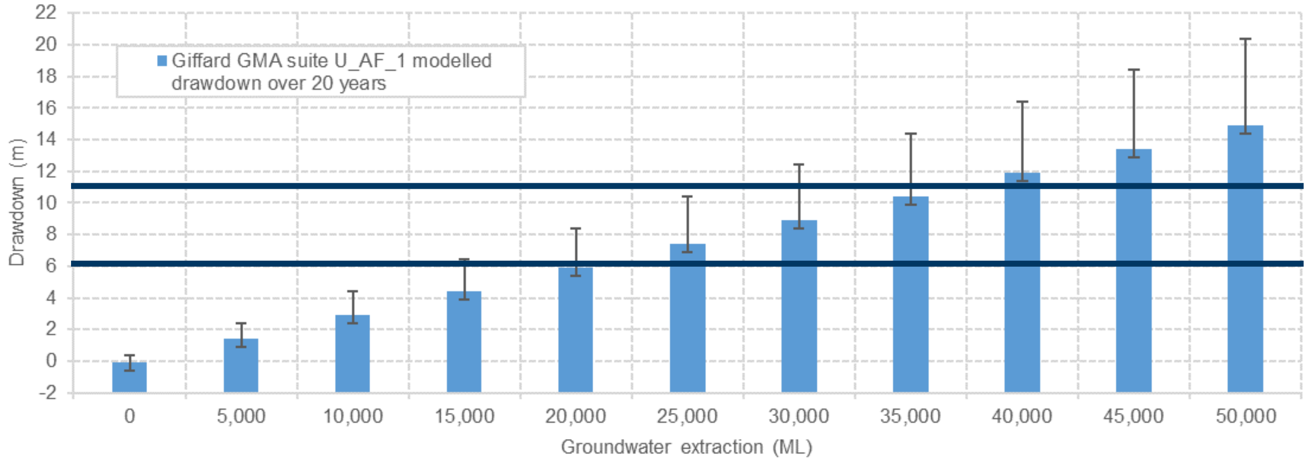


Figure 255 *Giffard GMA Suite U_AF_1: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)*

Table 97 Relationship of Suite drawdown to GMU extraction for Giffard GMA Suite U_AG_1

Volume (ML/year) for whole of GMU	Based on model prediction of Suite U_AG_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
100,000	10.2 (8.1 - 20.4)
90,000	9.2 (7.3 - 18.4)
80,000	8.2 (6.5 - 16.4)
70,000	7.2 (5.7 - 14.4)
60,000	6.2 (4.9 - 12.4)
50,000	5.2 (4.1 - 10.4)
40,000	4.2 (3.3 - 8.4)
30,000	3.2 (2.5 - 6.4)
20,000	2.2 (1.7 - 4.4)
10,000	1.2 (0.9 - 2.4)
0	0.2 (0.1 - 0.4)

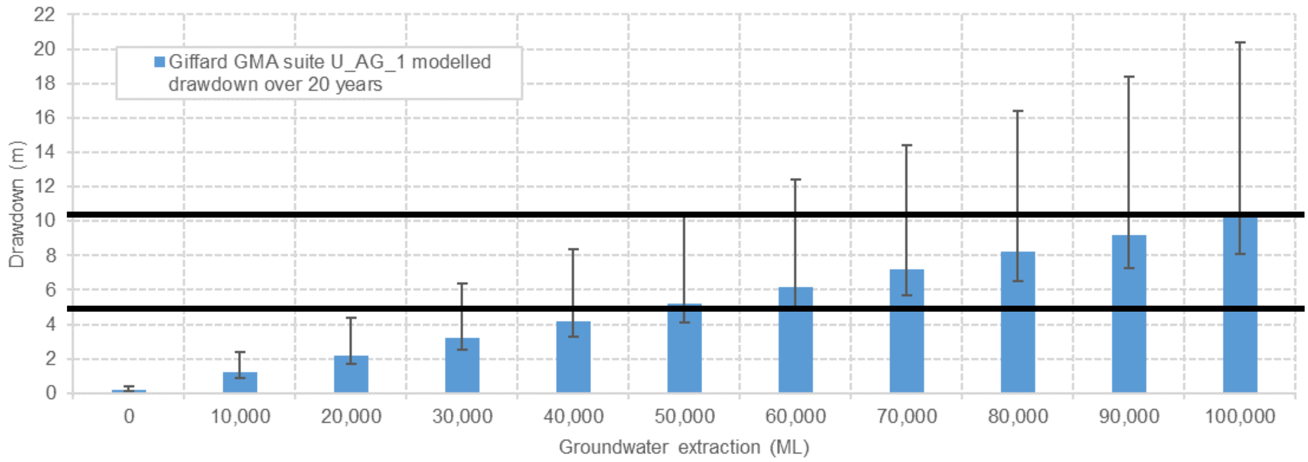
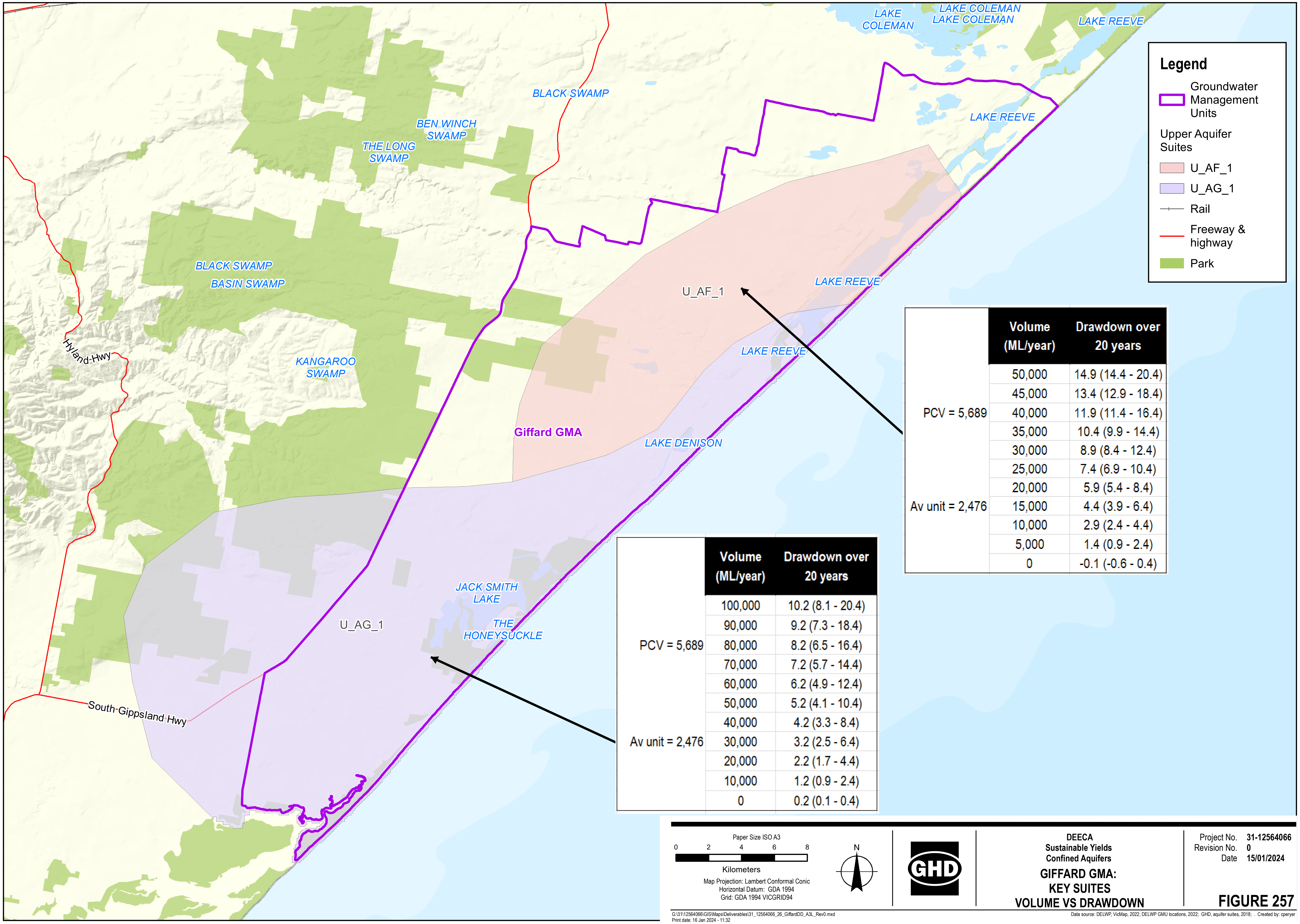


Figure 256 Giffard GMA Suite U_AG_1: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 98 Predicted GMU volumes for drawdown metrics

Drawdown (m) for unconfined aquifer	Predicted volumes (ML) for GMU based on Suite U_AF_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite U_AG_1 drawdowns (lower limit to upper limit)
5	16,900 (13,600 – 18,700)	47,700 (23,000 – 67,700)
10	33,600 (26,100 – 35,400)	97,700 (48,000 – 124,200)



	Volume (ML/year)	Drawdown over 20 years
PCV = 5,689	50,000	14.9 (14.4 - 20.4)
	45,000	13.4 (12.9 - 18.4)
	40,000	11.9 (11.4 - 16.4)
	35,000	10.4 (9.9 - 14.4)
	30,000	8.9 (8.4 - 12.4)
	25,000	7.4 (6.9 - 10.4)
	20,000	5.9 (5.4 - 8.4)
Av unit = 2,476	15,000	4.4 (3.9 - 6.4)
	10,000	2.9 (2.4 - 4.4)
	5,000	1.4 (0.9 - 2.4)
	0	-0.1 (-0.6 - 0.4)

	Volume (ML/year)	Drawdown over 20 years
	100,000	10.2 (8.1 - 20.4)
	90,000	9.2 (7.3 - 18.4)
PCV = 5,689	80,000	8.2 (6.5 - 16.4)
	70,000	7.2 (5.7 - 14.4)
	60,000	6.2 (4.9 - 12.4)
	50,000	5.2 (4.1 - 10.4)
	40,000	4.2 (3.3 - 8.4)
Av unit = 2,476	30,000	3.2 (2.5 - 6.4)
	20,000	2.2 (1.7 - 4.4)
	10,000	1.2 (0.9 - 2.4)
	0	0.2 (0.1 - 0.4)

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

DEECA
Sustainable Yields
Confined Aquifers

GIFFARD GMA:
KEY SUITES
VOLUME VS DRAWDOWN

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

FIGURE 257

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Print date: 16 Jan 2024 - 11:32

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

17.6 GMU summary

17.6.1 Findings

Giffard GMA primarily relates to the Boisdale Formation aquifer (UTAF), where groundwater is predominately extracted from this aquifer for irrigation purposes. The UTAF generally falls within the Middle Aquifer Suites, but within Giffard GMA, the UTAF falls within the Upper Aquifer Suites, namely U_AF_1 (32%) and U_AG_1 (42%), which provide a total GMU coverage of 74%. The identified representative Suites are U_AG_1 (most preferred) and U_AF_1. The Suite hydrographs for the representative Suites show that groundwater levels are relatively stable with seasonal fluctuations and thus recovered water levels, which were adopted for the assessment.

Application of two yearly annual average extraction, instead of annual extraction, showed a poorer model fit based on the statistical analysis across the model runs with no hindcasting applied. When hindcasting was applied, the two yearly annual average extraction provided better statistical model results than the annual extraction for Suite U_AG_1. For Suite U_AF_1, when hindcasting was applied, the difference between the two yearly annual average and annual extraction was minimal.

The application of spatial distribution produced statistically better model results than the model runs of annual extraction or two yearly annual average extraction, are based on a smaller dataset that doesn't incorporate the pre-development period. It is noted that the quality of the result decreased 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 hindcast method H2 was adopted to undertake the predictive modelling for Suite U_AF_1 and model run 12 of two yearly average annual extraction with hindcast method H2 was adopted to undertake the predictive modelling for Suite U_AG_1.

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 1.46 m for Suite U_AF_1 and 0.58 m for Suite U_AG_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) for unconfined aquifer	Predicted volumes (ML) for GMU based on Suite U_AF_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite U_AG_1 drawdowns (lower limit to upper limit)
5	16,900 (13,600 – 18,700)	47,700 (23,000 – 67,700)
10	33,600 (26,100 – 35,400)	97,700 (48,000 – 124,200)

The model for Suite U_AF_1 was assessed as having an "Excellent" model applicability rating and the model for Suite U_AG_1 was assessed as having a "Moderate" rating using the criteria outlined in section 5.2. For both 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 coverage of the Suites, Suite U_AG_1 was the preferred Suite for Giffard GMA. However, no drawdown/limited drawdown was shown in Suite U_AG_1 associated with groundwater extraction, which in turn impacts the final drawdown/yield table results. Thus, consideration will need to be made as whether U_AF_1 results are adopted instead.

17.6.2 Limitations

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

- The licenced bore dataset provided by DEECA has 2% of bores assigned to Giffard 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.
- Model Calibration was between 0-5500 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 6 times the calibration range are being made to meet the 10 m drawdown metric (for U_AF_1) . Further checks and potential re-calibration may be required as rates increase for the GMUs.

17.6.3 Recommendations

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

- The licenced bore dataset provided by DEECA has 2% of bores assigned to Giffard 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.

18. Moe GMA

18.1 Conceptualisation

The hydrogeological conceptualisation elements relevant to this study are summarised in Table 99 and a map of the GMU is presented in Figure 258. 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 99.

Table 99 Moe GMA – Tabulated conceptualisation

GMU summary

Moe GMA is located in the northwestern corner of the Gippsland Basin and covers the Moe Swamp Basin. The topography varies across the GMA from the peaks in the alpine region to the north of the GMA to the lowlands near the Moe River and then up to the Strzelecki Ranges in the south (Jacobs 2019).

Land use tends to vary with topography, with native vegetation in the highlands and agricultural in the lowlands. The agricultural land is primarily used for dryland grazing/perennial pasture with some irrigation of pasture and crops to support the dairy industry (Jacobs 2019). More broadly across Moe GMA, groundwater use is predominately used for irrigation (approximately 70% of entitlement), dairy cooling and wash down (Australia Government 2018).

The Moe GMA pertains to all formations 25 m below the ground surface but was intended to primarily manage the groundwater resource of the Childers Formation (Lower Tertiary Aquifer, LTA). The PCV (8,200 ML/year) therefore primarily related to confined aquifers. The Gippsland Ground Model (DEDJTR 2015) indicates that the Childers Formation is recharge by outcropping in the southern and northwestern margin of Moe Basin.

Hydrostratigraphy summary

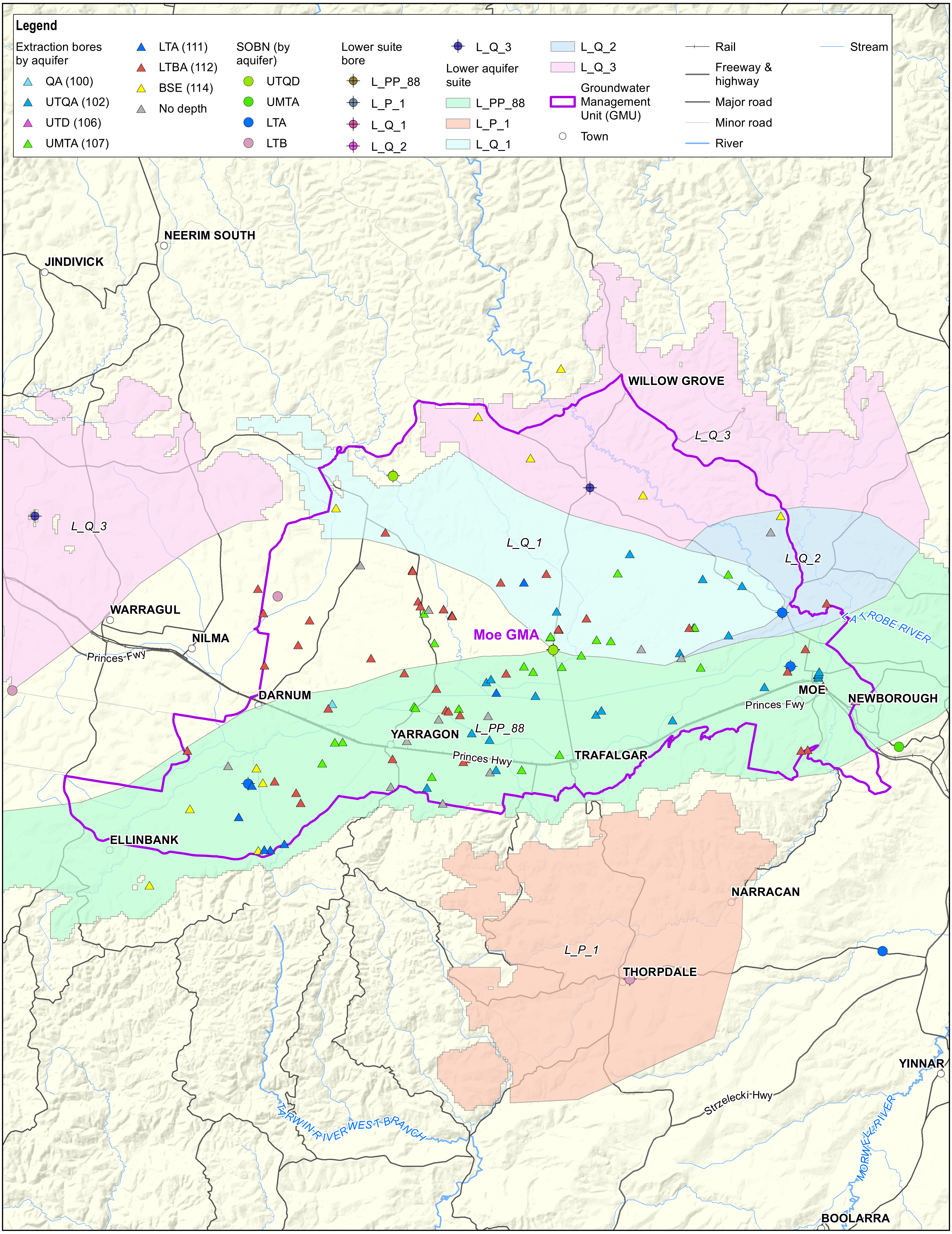
Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Use volumes ML (2019/20)	Entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Undifferentiated sediments (QA)	-	-	0	Dairy, stock	0	0	Low
	Haunted Hills Formation (UTQA)	-	-	0	Domestic, stock, dairy, dewatering	102	261	Low
	Yallourn Formation (UTQD)	U_AJ_1 (13%), U_AJ_2 (11%), U_AK_1 (64%)	89%	1	NA	0	0	Medium
Middle	Yarragon Formation (UMTA)	M_R_1 (58%)	58%	1	Irrigation, stock, domestic, dairy	204	475	Low
Lower	Childers Formation (LTA)	L_PP_88 (43%), L_Q_2 (4%)	46%	4	Domestic, dairy, stock, irrigation	221	1,588	Low
	Thorpdale Volcanics (LTBA)	L_Q_1 (22%), L_Q_3 (13%),	36%	4	Urban, commercial, irrigation, domestic, stock, dairy	27	365	Low
Basement	Basement rocks (BSE)	B_S_1 (15%)	15%	0	Commercial, irrigation, domestic, stock, dairy	6	494	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.

Note that volumes listed above do not include 5 ML of unassigned use due to unknown depths (699 ML of entitlement) or 2 ML of entitlement from the UTQD.

Characteristic and importance	Description	Degree of understanding
Intended aquifer (LTA, highlighted blue above)		
Aquifer thickness within GMU (range, based on VAF)	Max: 330 m, Average: 59 m	High
Aquifer extent	Small, local	High
Likelihood of inter-aquifer flow	High	High (GHD, 2010)
Likelihood of groundwater – surface water interaction	Medium – at margins of GMA	Low (Jacobs, 2019)
Representative Suite	**L_Q_1 or L_PP_88**	**Low. 49% of GMU extraction comes from within the lower aquifer.**
Current hydrological condition of representative aquifer		
Representative Suite trend	Increasing	Medium (Suite data current to 1998)
Groundwater quality (average salinity based on WMIS and CDM Smith spatial segment(s) with highest coverage)	0 – 600 mg/L (CDM Smith, 2022)	Low Based on CDM Smith (2022)
Groundwater yield	<0.5 L/s (based on referenced data; should be much higher based on GHD experience)	Low – data should indicate higher yields Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1973-2021**	
Spatial clustering of licensed bores in relation to Suites	No	Based on DEECA density mapping and licenced bore data.
Groundwater use		
Licensed groundwater use	**826 ML**	**High (Based on average historical VWA data over 15 years)**
Minimum historic groundwater use	191 ML	High (Based on historical VWA data, year 2010/11)
Maximum historic groundwater use	**1,447 ML**	**High (Based on historical VWA data, year 2006/07)**
Entitlement (Groundwater allocation)	**3,762 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 stock or domestic use	Moderate

Characteristic and importance	Description	Degree of understanding
Groundwater use profile	Seasonal (~Oct-Apr irrigation season)	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

N

GHD

DEECA
Sustainable yield review - confined aquifers

Moe GMA
Site location and key features

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

Figure 258

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Print date: 16 Jan 2024 - 12:39

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

18.2 Technical analysis

18.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the relevant Suites for Moe GMA as shown in Figure 259. Generally, the Suite hydrographs show a trend of seasonal fluctuations and thus annual recovered levels. Suite M_R_1 shows significant, rapid changes in groundwater levels to its data limit in the late 1990s. Suite L_Q_3 shows periods of abrupt drops in levels prior to 1990. Suites L_Q_1, L_Q_2, L_PP_88 and L_Q_3 all show a decreasing trend with time.

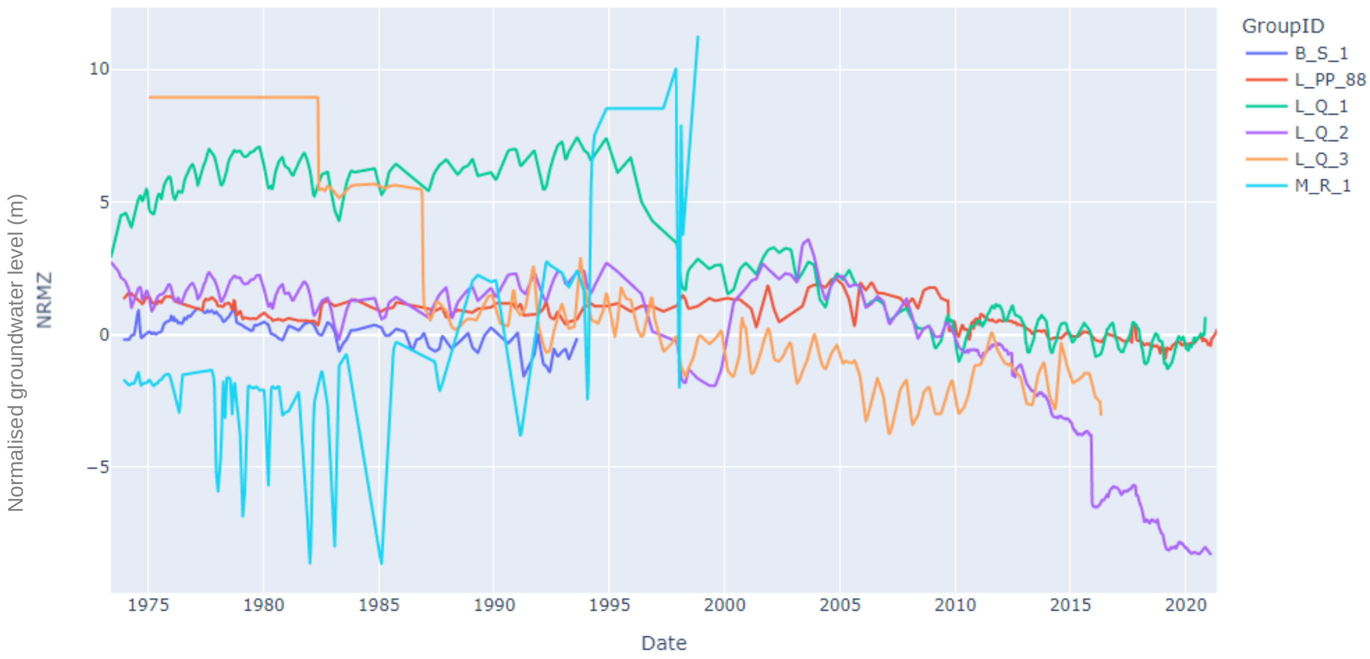


Figure 259 ***Moe GMA Suite Hydrographs for all confined aquifers***

The representative Suites analysed for this GMU were Suites L_Q_1 and L_PP_88. The Representative Suites were selected based on the methodology outlined in section 2.6.4 which identified Suite L_PP_88 as the most representative followed by L_Q_1. The process is summarised as follows:

- The greatest volume of extraction occurs within the Lower Aquifer
- Suite L_PP_88 contains the greatest number of extraction bores
- The Lower Aquifer pertains to the LTA and LTBA, the LTA is the intended aquifer of the GMU
- The LTA and LTBA are assumed to be hydraulically connected as there is no confining layer between the two aquifers
- Suite L_Q_1 covers 22% of the GMU, while Suite L_PP_88 covers 43%, providing a total coverage of 65%
- Suite L_Q_1 has three active SOBN bores within the Suite area, while Suite L_PP_88 has three
- Suite bores for L_PP_88 are close to extraction points

The annual recovered Suite hydrograph for the representative Suites for Moe GMA, L_Q_1 and L_PP_88, is shown in Figure 260. It is noted with Suite L_PP_88, there were three instances of the same maximum water level occurring more than once in a given year. Where this occurred, the maximum level was recorded consecutively over a few weeks to a few months; in these instances, the middle date was set as the date of the maximum level.

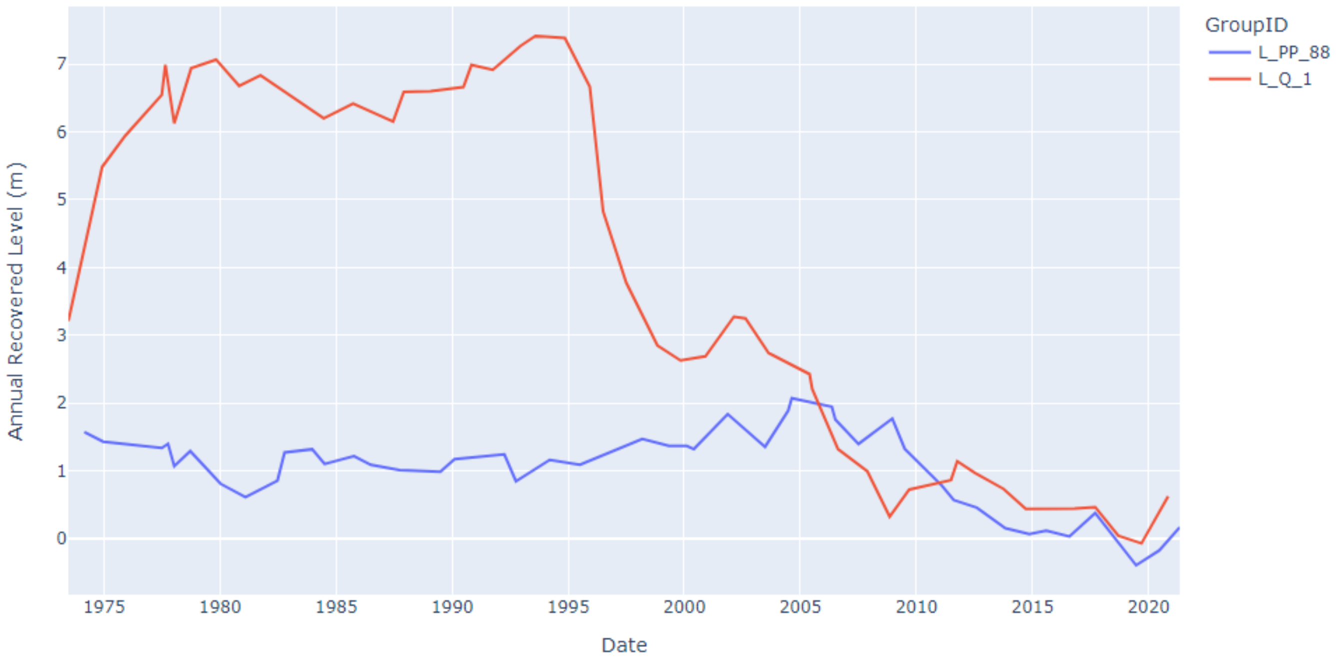


Figure 260 Moe GMA Annual Recovered Level Suite Hydrographs for representative Suites

18.2.2 Pre-development level

To estimate the pre-development level conditions, GHD reviewed the Suite hydrographs of annual recovered levels and assumed that the maximum levels in the early time series data was the best representation of conditions prior to major development within Moe GMA for Suite L_Q_1. For Suite L_PP_88 it was assumed that the maximum levels prior to major development was the best representation of pre-development conditions within Moe GMA for this Suite.

The pre-development annual recovered levels are taken to be the average level of three readings in the early time series data between 1977/1978 to 1979/1980 which equates to 7.00 m for Suite L_Q_1. The pre-development annual recovered levels are taken to be the maximum level prior to major development, which equates to 2.07 m for Suite L_PP_88 (refer further details in section 18.4.3).

18.2.3 Externalities

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

18.2.4 Hindcasting

Groundwater use data for Moe GMA is available from 2006/2007 to 2020/2021. The hindcasting methodologies outlined in section 3.3.4.5 were applied to Moe GMA. A summary of the hindcasting results is shown in the following sections.

18.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, four different correlations were developed using the annual groundwater extraction as described below and shown in Figure 261:

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

Another four correlations were developed based on annual irrigation extraction as described below and shown in Figure 262:

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

As shown in Figure 261, the goodness-of-fit represented by the R^2 is greatest for the two yearly average annual rainfall with annual groundwater use. When only irrigation groundwater extraction is considered, the goodness-of-fit of groundwater use to summer rainfall or irrigation rainfall increases. The two yearly annual average rainfall with annual groundwater use has been adopted for hindcast method H1.

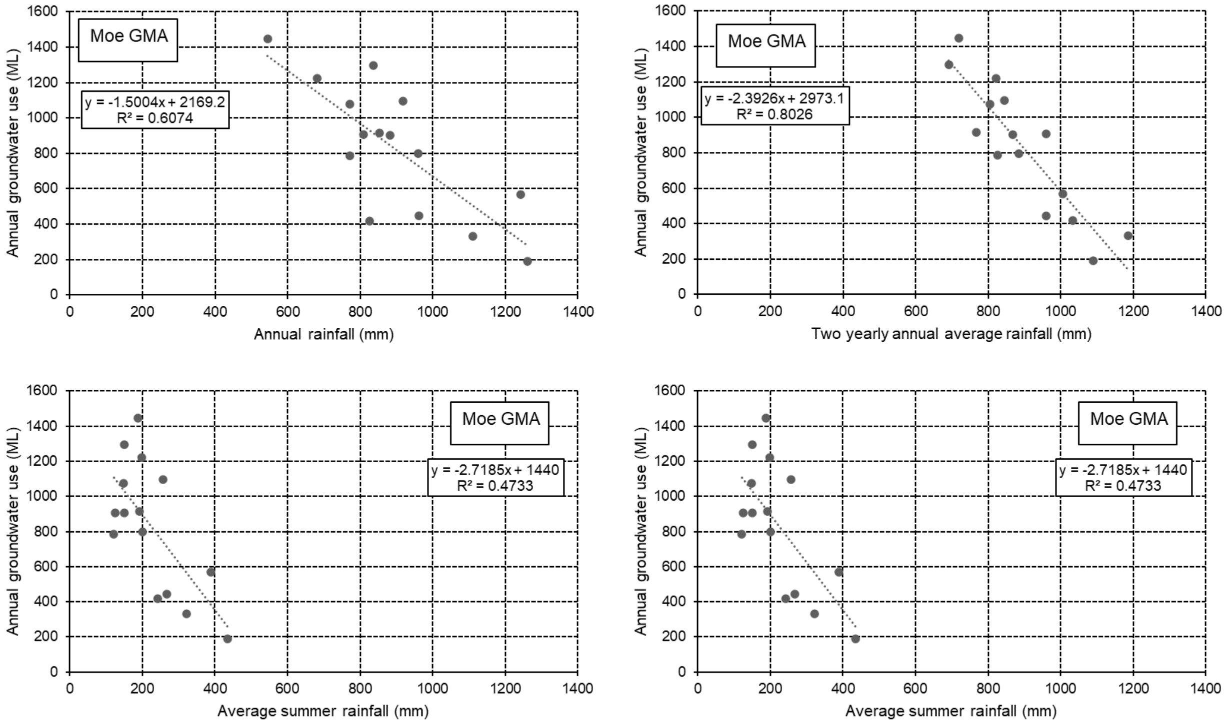


Figure 261   Moe GMA: Hindcast method 1 correlations (Moe GMA annual extraction)

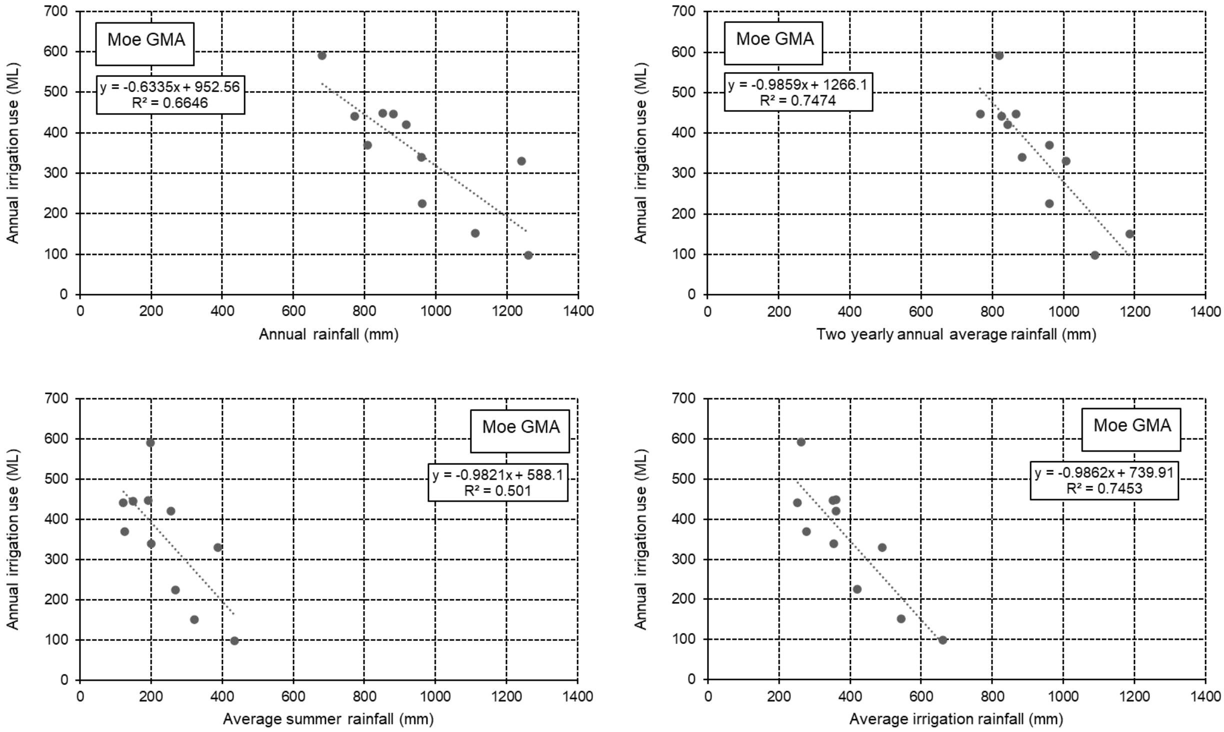
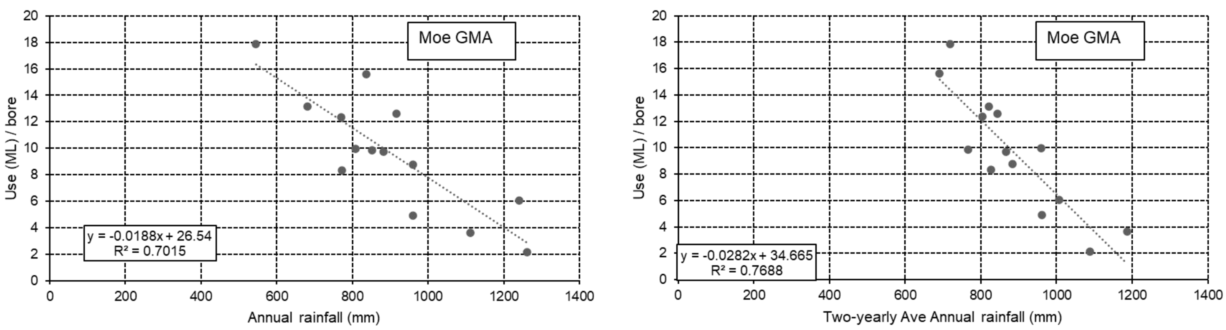


Figure 262 Moe GMA: Hindcast method 1 correlations (Moe GMA annual irrigation extraction)

18.2.4.2 Hindcasting Method 2 (H2)

Similar to method H1, eight correlations were developed using method H2 as described below and shown in Figure 263:

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



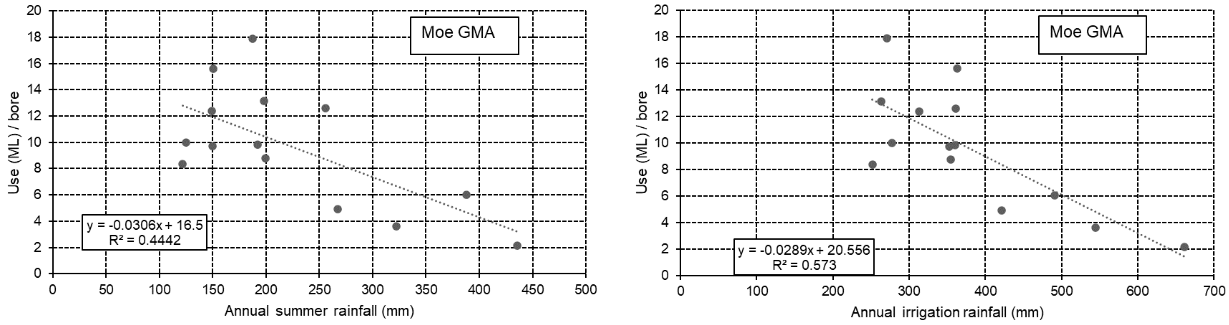


Figure 263 Moe GMA: Hindcast method 2 correlations

As shown in Figure 263, the goodness-of-fit represented by the R^2 is greatest for two yearly average annual rainfall with the use by bore. The correlation decreased slightly when rainfall was reduced to a smaller period over the year. The two yearly average annual rainfall has been adopted for hindcast method H2.

18.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 264:

- 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

–

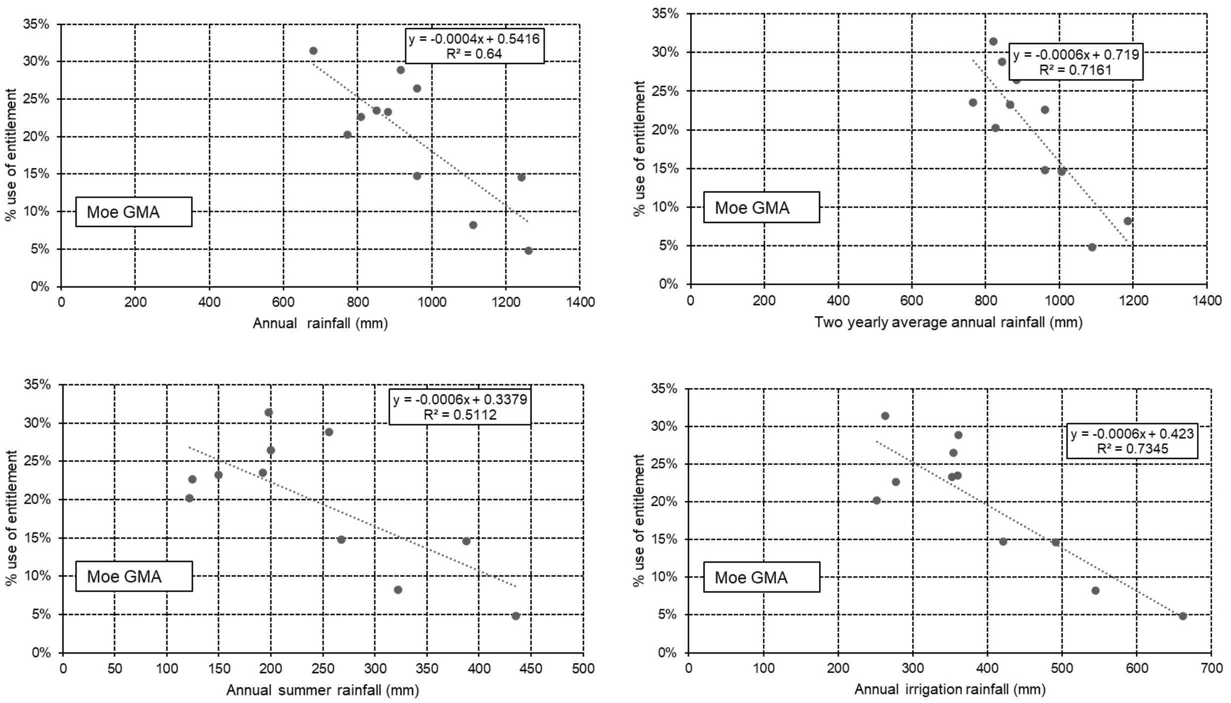


Figure 264 Moe GMA: Hindcast method 3 correlations

As shown in Figure 264, the best goodness-of-fit result was shown to be the correlation with annual irrigation rainfall, however, this is closely followed by the two-yearly average annual rainfall. The correlation of annual irrigation rainfall was adopted for hindcast method H3.

18.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 265 and Figure 266 for the hindcasting based on Moe GMA groundwater use. Figure 265 shows a comparison of the three hindcasting methods against the recorded use only over the recorded use date, while Figure 266 shows the hindcasted data back to 1972/1973.

As shown in Figure 266, 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 2 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 Moe GMA.

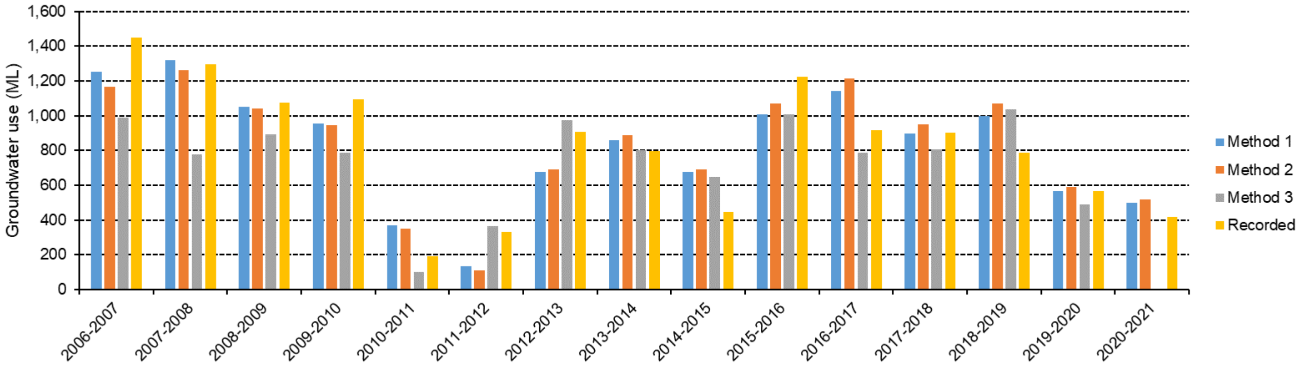


Figure 265 Moe GMA: Comparison of hindcasting over recorded use period

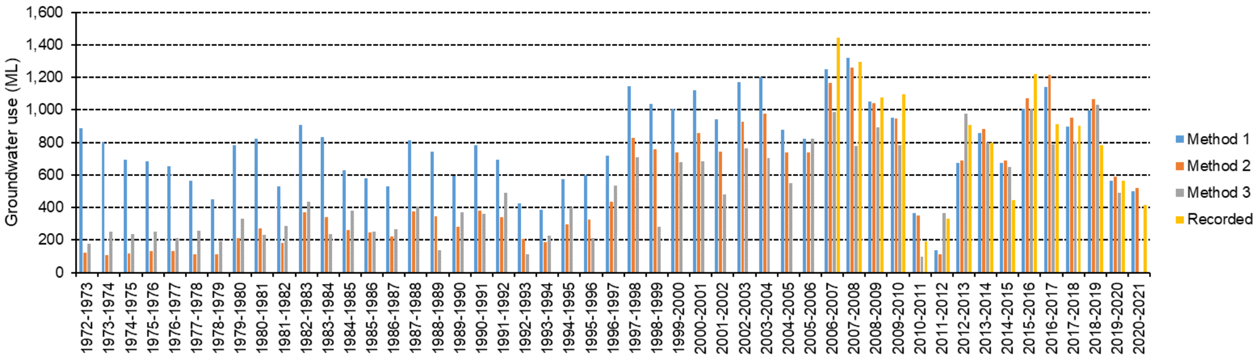


Figure 266 Moe GMA: Comparison of hindcasting

18.3 Modelling

18.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 100 summarises these combinations of model inputs run for Moe GMA. Model runs highlighted blue indicate they were run with annual extraction and grey indicates they were run using two yearly average annual extraction.

Table 100 Moe 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_Q_1 and L_PP_88)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Moe GMA only	✓																		
Two yearly average annual extraction – Moe GMA only		✓																	
Annual extraction – Moe GMA and Externalities			✓																
Two yearly average annual extraction – Moe GMA and Externalities				✓															
H1 annual extraction – Moe GMA only					✓														
H1 annual extraction – Moe GMA and Externalities						✓													
H2 annual extraction – Moe GMA only							✓												
H2 annual extraction – Moe GMA and Externalities								✓											
H3 annual extraction – Moe GMA only									✓										
H1 two yearly average annual extraction – Moe GMA only										✓									
H1 two yearly average annual extraction – Moe 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 – Moe GMA only												✓							
H2 two yearly average annual extraction – Moe GMA and Externalities													✓						
S1 annual extraction – Moe GMA only														✓					
S2 annual extraction – Moe GMA only															✓				
S3 annual extraction – Moe GMA only																✓			
S1 annual extraction and H1 annual extraction – Moe GMA only																	✓		
S2 annual extraction and H2 annual extraction – Moe GMA only																		✓	
S3 annual extraction and H3 annual extraction – Moe GMA only																			✓

18.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 100 is presented in Table 101 for the selection of potential representative Suites for Moe GMA. The column heading for L_PP_88 is highlighted blue to indicate that this Suite was selected as the most likely representative Suite based on the process outlined in section 18.2.1. 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_Q_1

A review of the results and statistical summary for Suite L_Q_1 shows that model runs 15 and 16 (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. Model run 15 and 16 have the smallest 95PPU thickness and RMSE, the highest percentage observations in the 95PPU band and a relatively high R^2. However, these models only include 10 observation points and do not cover the period of pre-development. Considering the need to include a longer historic record in the calibration model, the hindcasted models were looked at in more detail. Based on the hindcasted models, model run 7 (highlighted green) was found to have the best statistical results with the longest dataset. The graphical model output for model run 7 is shown in Figure 267. Given the results, modelling was progressed on the basis of adopting model run 7 for Suite L_Q_1.

Suite L_PP_88

A review of the results and statistical summary for Suite L_PP_88 shows that model runs 1, 2 and 16 (highlighted orange) had the best results of the 13 different model input combinations. However, these models only included 10 to 14 observation points and did not cover the period of pre-development. Considering the need to include a longer historic record in the calibration model, the hindcasted models were looked at in more detail. Based on the hindcasted models, model run 7 (highlighted green) was found to have the best statistical results with the longest dataset. The graphical model output for model run 7 is shown in Figure 268. As such, modelling was progressed on the basis of adopting model 7 for Suite L_PP_88.

Modelling was progressed on the basis of adopting model run 7 for Suite L_Q_1 and L_PP_88.

Table 101 Moe GMA: summary of model outputs

Suite	Statistic	Model run												
		1	2	5	7	9	10	12	14	15	16	17	18	19
L_Q_1	95PPU TH	1.16	1.27	4.65	4.55	4.68	4.77	8.4	1.19	0.51	0.5	18.83	10.93	10.93
	%Obs in 95 PPU	100	100	89.58	91.67	97.92	89.58	91.67	100	100	100	89.36	100	100
	R^2	57.8	51.6	92.5	85.9	84.7	92.6	41.3	88.0	88.6	88.7	54.6	86.8	86.8
	RMSE	0.22	0.24	0.73	1.01	1.05	0.73	2.06	0.13	0.12	0.12	1.8	0.97	0.97
	No obs data points	14	14	48	48	48	48	48	10	10	10	47	47	47
	Range of observed levels	1.2	1.2	7.5	7.5	7.5	7.5	7.5	1.2	1.2	1.2	7.5	7.5	7.5
L_PP_88	95PPU TH	1.13	1.11	2.66	18.62	10.74	2.34	2.15	1	NA	0.74	10.13	2.14	2.14
	%Obs in 95 PPU	92.86	100	95.83	89.58	89.58	95.83	91.67	100	0	100	89.36	91.49	91.49
	R^2	93.8	93.2	12.1	57.2	56.7	16.3	32.7	60.3	62.8	63.3	58.1	6.3	56.5
	RMSE	0.19	0.19	0.53	0.37	0.37	0.51	0.46	0.21	0.2	0.2	0.36	0.54	0.54
	No obs data points	14	14	48	48	48	48	48	10	10	10	47	47	47
	Range of observed levels	2.2	2.2	2.5	2.5	2.5	2.5	2.5	1.2	1.2	1.2	2.5	2.5	2.5

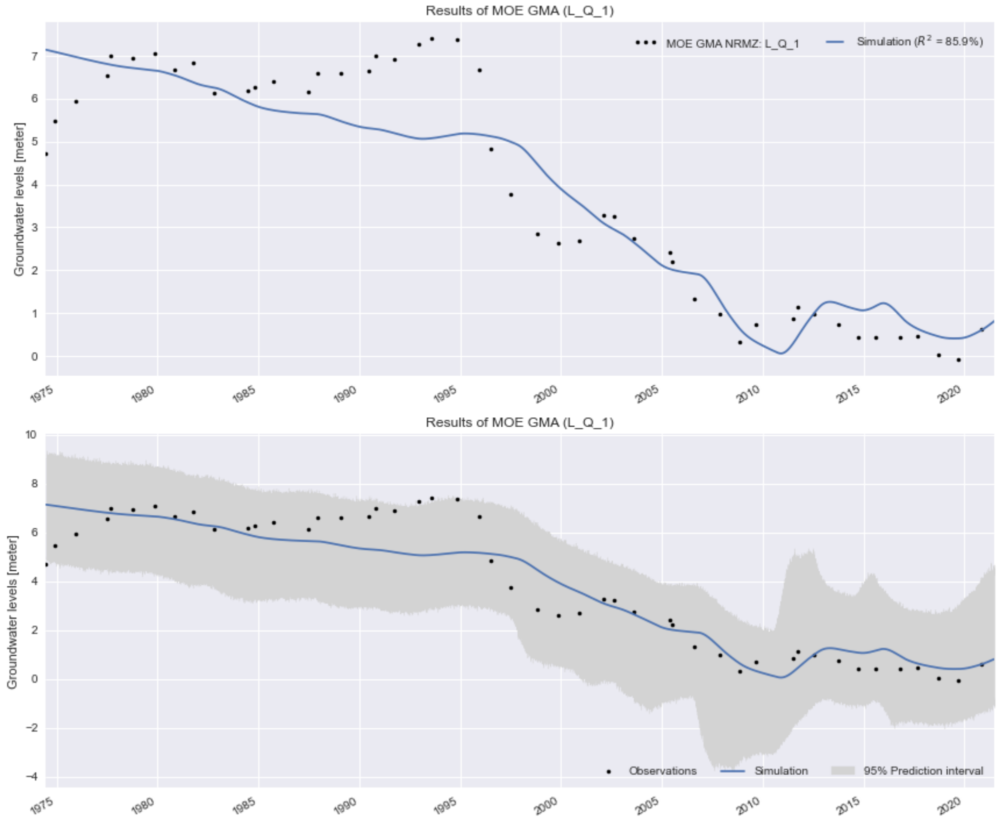


Figure 267 ***Moe GMA Suite L_Q_1: model run 7 (Moe GMA annual extraction with hindcast method H2) output hydrographs***

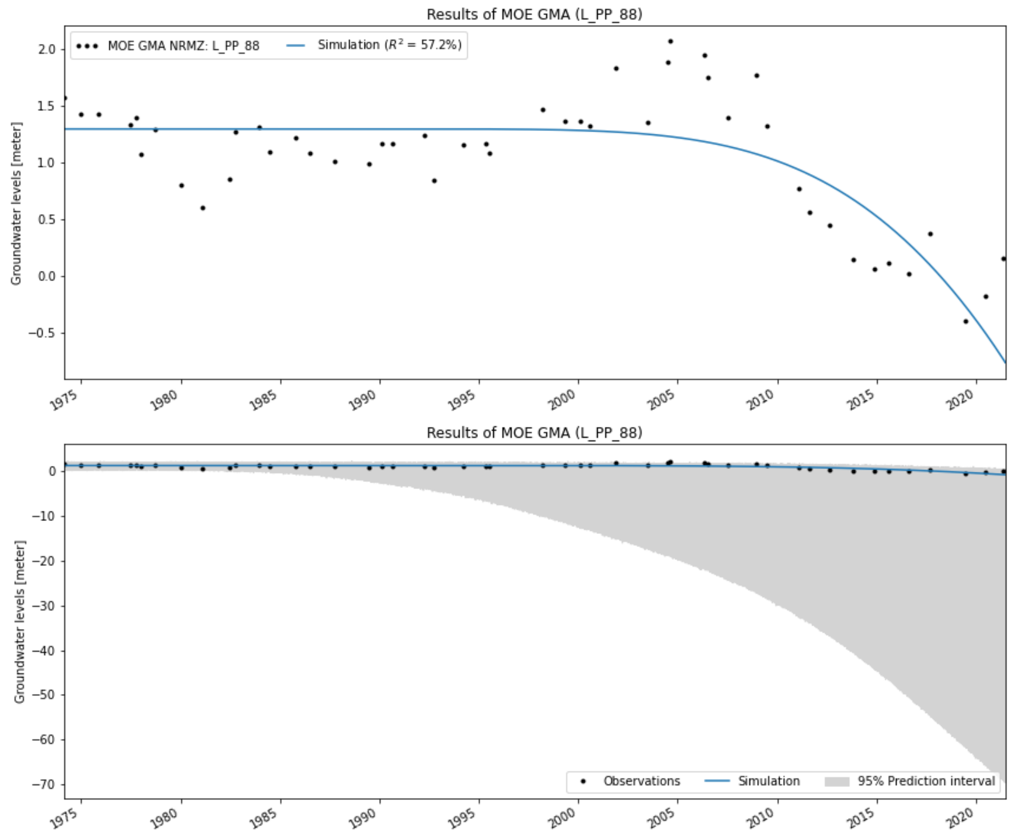


Figure 268 ***Moe GMA Suite L_PP_88: model run 7 (Moe GMA annual extraction with hindcast method H2) output hydrographs***

18.4 Predictive modelling

18.4.1 Model inputs

The preferred model to run the predictive modelling for Moe GMA was model run 7 for Suite L_Q_1 and L_PP_88. 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 102.

Table 102 Moe 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)	8,200	3,762	416	826	1,447

18.4.2 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 269 for scenario 16. As shown in Figure 269, 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 as shown in Figure 270.

– 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.

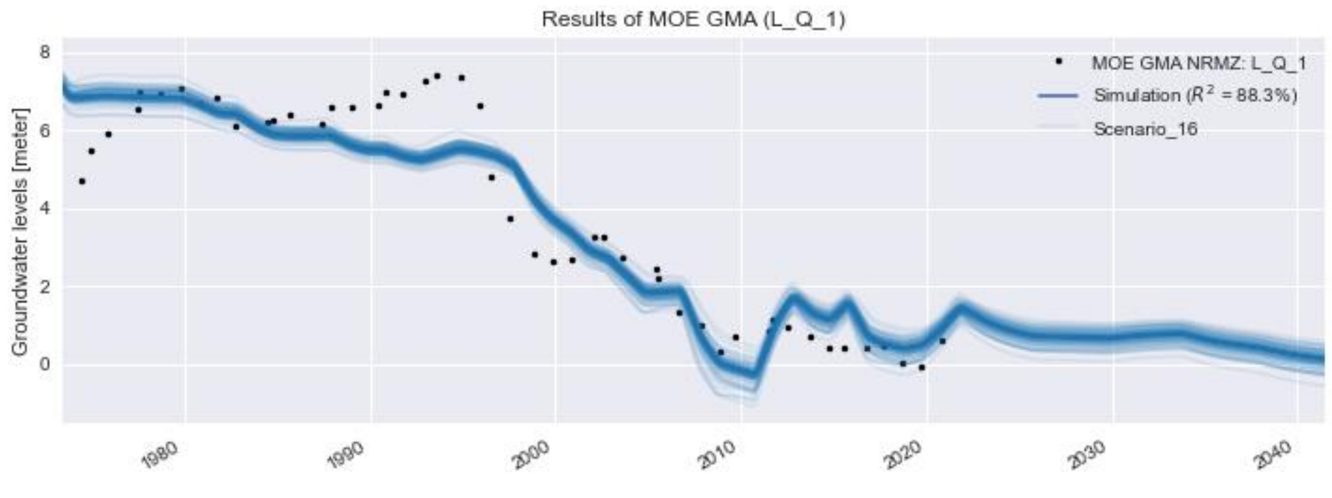


Figure 269 Moe GMA: Suite L_Q_1 MCMC analysis for Forecast Scenario 16

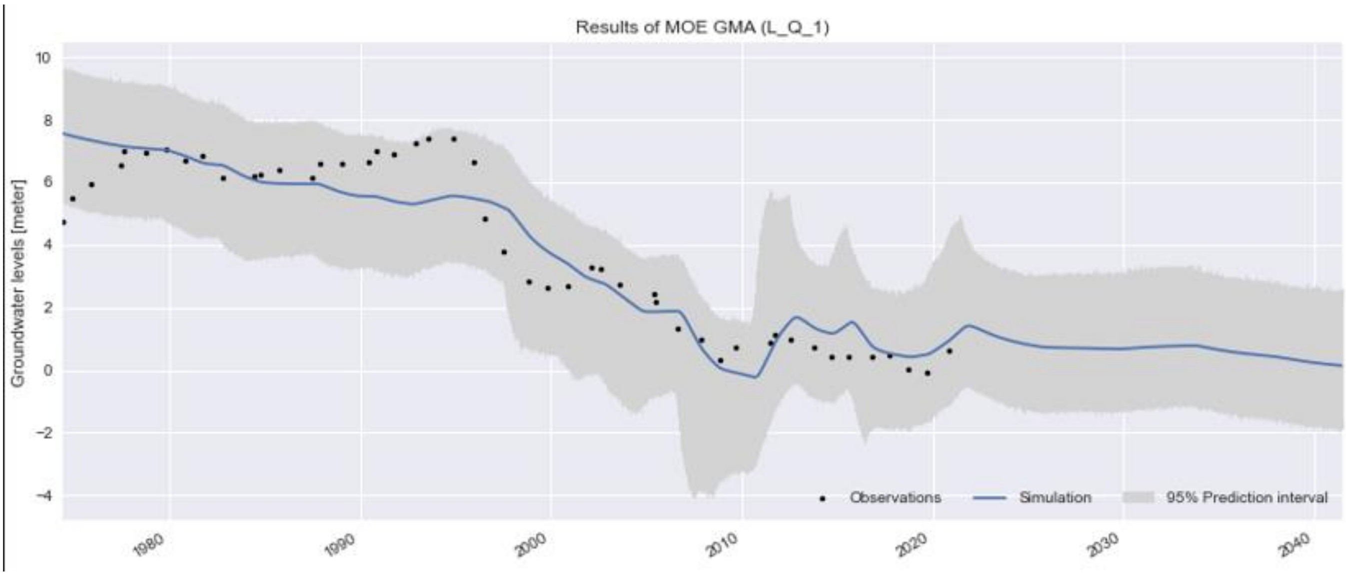


Figure 270 Moe GMA: Suite L_Q_1 Forecast Scenario 16 with 95% prediction bands

18.4.3 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 Moe 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 18.2.2, 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 271 for Suite L_Q_1 hydrograph of annual recovered levels. In Figure 271:

- 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 1972/1973 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 average of the maximum annual recovered levels between 1977/1978 to 1979/1980 which is 7.00 m

The modelled forecasted annual recovered levels are represented by the purple line in Figure 271.

The calibration annual recovered levels are represented by the black line in Figure 271.

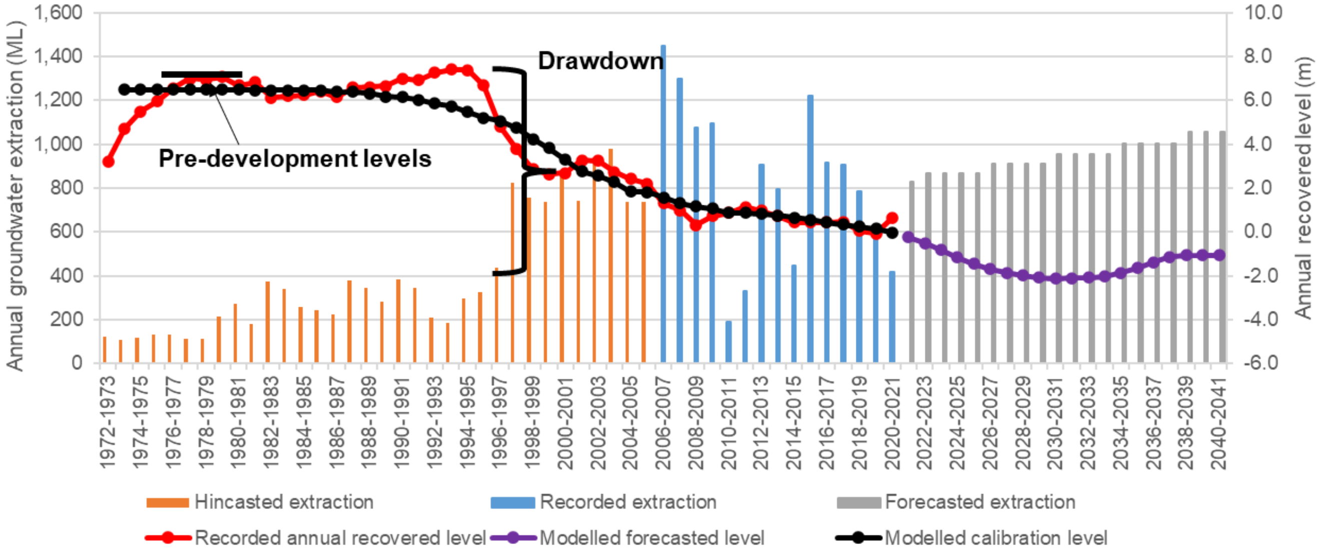


Figure 271 ***Estimating pre-pumping water levels (example from Suite L_Q_1)***

For Suite L_Q_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 272) and a graph of the scenarios for specific time periods (Figure 273) 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 variation in the coefficient of determination and slope of the linear line. The same process was applied for Suite L_PP_88 and again, there was variation in the coefficient of determination between the graphs. Given this, the correlation developed based on all scenarios was adopted to encompass 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 272 for Suite L_Q_1 (1974 to 2041) and Figure 274 for L_PP_88 (1974 to 2041). Note the abscissa range of the chart has been clipped and does not show forecast drawdowns for the higher use scenarios (more improbable volumes of 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. The models tend to underpredict at the specified times of pre-development which contributes to the intercept value.
- Average use is around 800 ML, Figure 272 for Suite L_Q_1 indicates this at this volume the model forecast drawdown tends to occur around the predicted line of best fit. For Suite L_PP_88, Figure 274 indicates that at this volume the model forecast drawdown tends to occur 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 271 shows a scenario where groundwater use increases every four years or so over the next 20 years
- The correlation for groundwater use and drawdown for Suite L_Q_1 is excellent as shown in Figure 272. The correlation for Suite L_PP_88 is poor as shown in Figure 274
- 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.

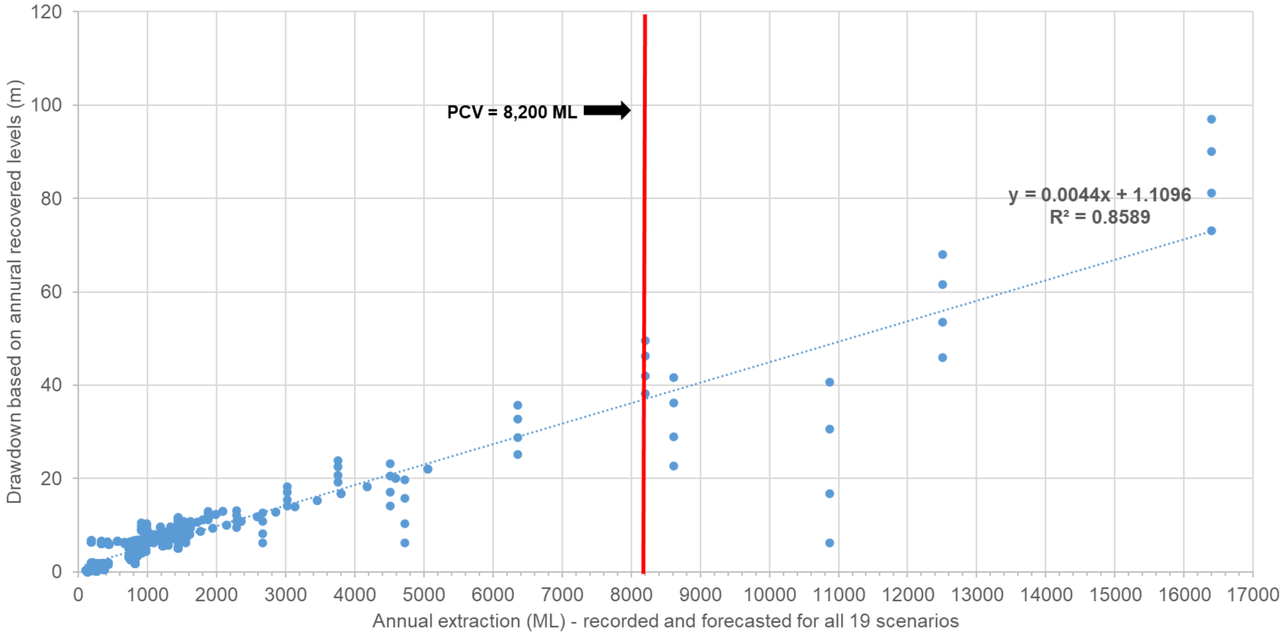


Figure 272 ***Moe GMA Suite L_Q_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <17,000 ML) for all data between 1974 to 2041 and all forecasted scenarios***

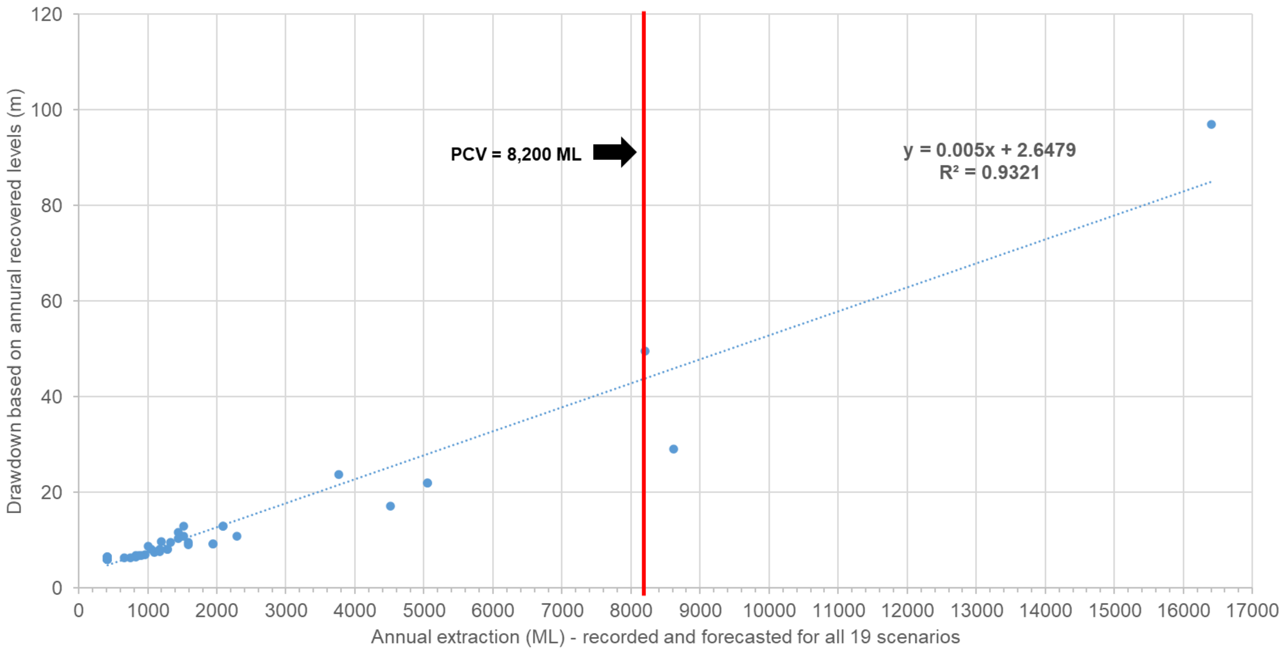


Figure 273 ***Moe GMA Suite L_Q_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <17,000 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios***

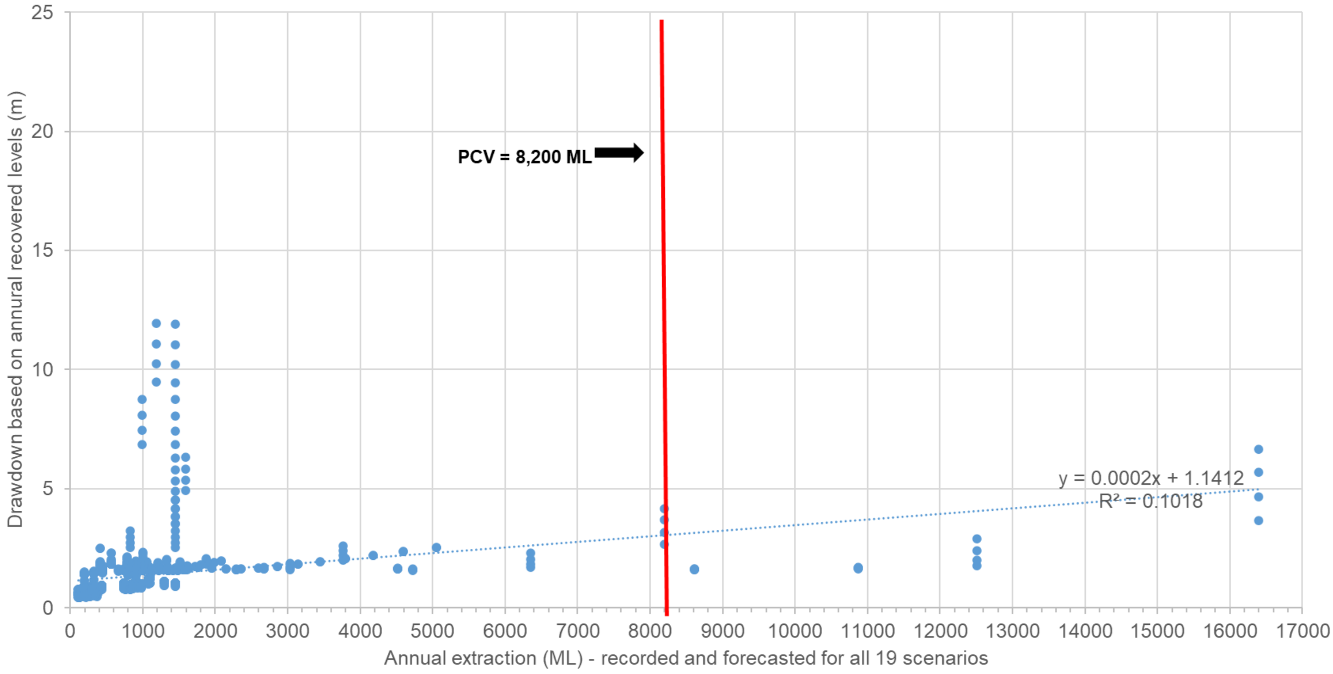


Figure 274 ***Moe GMA Suite L_PP_88: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <17,000 ML) for all data between 1974 to 2041 and all forecasted scenarios***

18.5 Sustainability metrics

18.5.1 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 103 for Moe GMA Suite L_Q_1 and Table 104 for Moe GMA Suite L_PP_88 (noting Moe GMA has a current PCV of 8,200 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 103 and Figure 275 for Suite L_Q_1, and Table 104 and Figure 276 for Suite L_PP_88.

The two Moe GMA Suites L_Q_1 and L_PP_88 have different drawdown-use relationship. A comparison of volumes at drawdown intervals provided by DEECA is shown in Table 105 for Suite L_Q_1 and Suite L_PP_88. Based on the modelling, it is predicted that 5 m of drawdown would occur from extraction volumes of 900 ML (but could vary from 500 to 1,400 ML) based on Suite L_Q_1 and 19,300 ML (this could vary from 1,800 to 23,900 ML) based on Suite L_PP_88. Whereas it is predicted that 10 m of drawdown would occur from extraction volumes of 2,000 ML (but could vary from 1,200 to 2,600 ML) based on Suite L_Q_1 and 44,300 ML (this could vary from 8,000 to 48,900 ML) based on Suite L_PP_88.

Table 103 Relationship of Suite drawdown to GMU extraction for Moe GMA Suite L_Q_1

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_Q_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
15,000	67.1 (63.9 - 111)
14,000	62.7 (59.7 - 103.7)
13,000	58.3 (55.5 - 96.4)
12,000	53.9 (51.3 - 89.1)
11,000	49.5 (47.1 - 81.8)
10,000	45.1 (42.9 - 74.5)
9,000	40.7 (38.7 - 67.2)
8,000	36.3 (34.5 - 59.9)
7,000	31.9 (30.3 - 52.6)
6,000	27.5 (26.1 - 45.3)
5,000	23.1 (21.9 - 38)
4,000	18.7 (17.7 - 30.7)
3,000	14.3 (13.5 - 23.4)
2,000	9.9 (9.3 - 16.1)
1,000	5.5 (5.1 - 8.8)
0	1.1 (0.9 - 1.5)

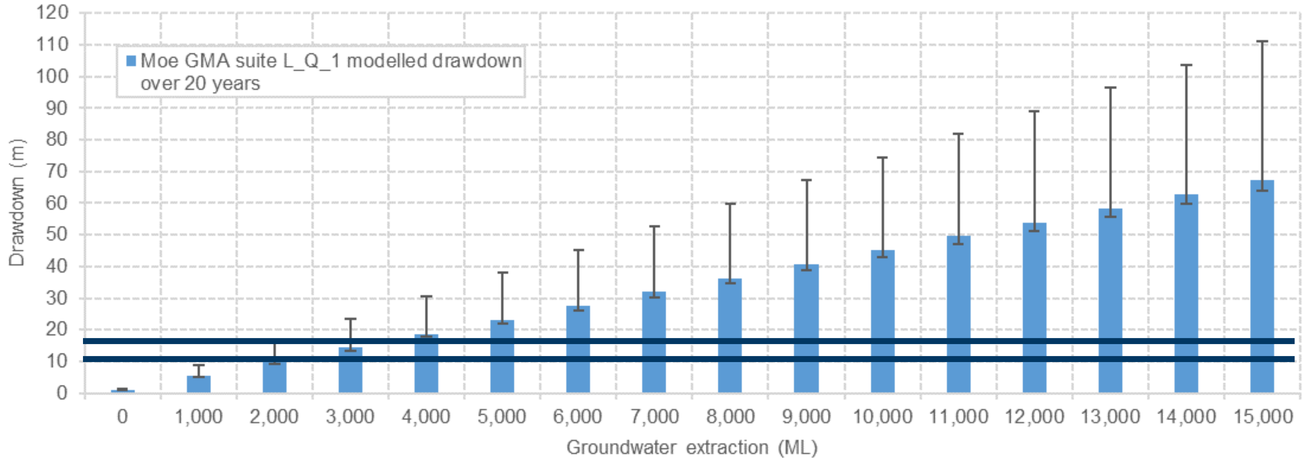


Figure 275 Moe GMA Suite L_Q_1: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 104 Relationship of Suite drawdown to GMU extraction for Moe GMA Suite L_PP_88

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_PP_88 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
50,000	11.1 (10.2 - 43.6)
45,000	10.1 (9.2 - 39.6)
40,000	9.1 (8.2 - 35.6)
35,000	8.1 (7.2 - 31.6)
30,000	7.1 (6.2 - 27.6)
25,000	6.1 (5.2 - 23.6)
20,000	5.1 (4.2 - 19.6)
15,000	4.1 (3.2 - 15.6)
10,000	3.1 (2.2 - 11.6)
5,000	2.1 (1.2 - 7.6)
0	1.1 (0.2 - 3.6)

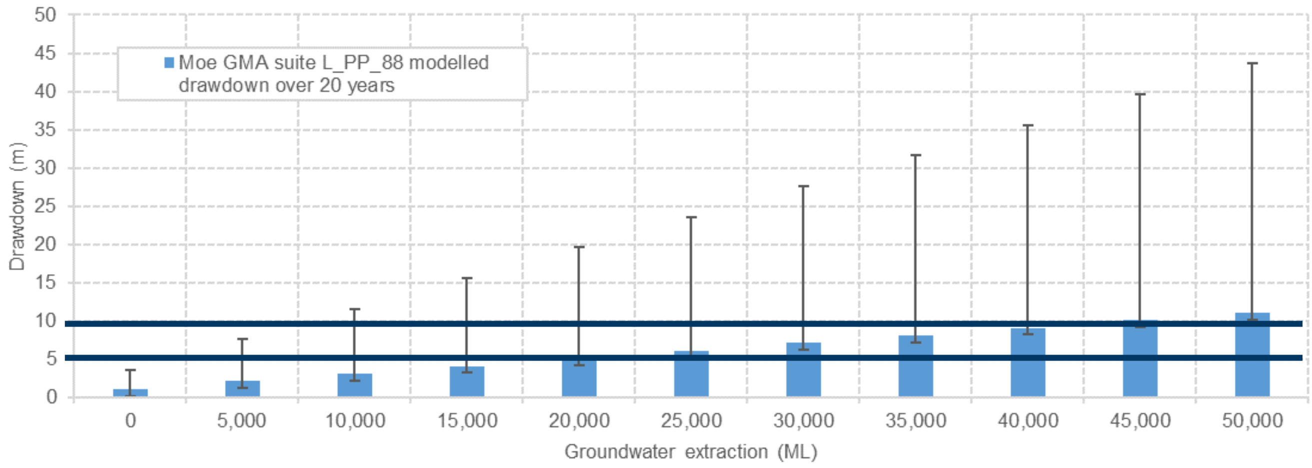
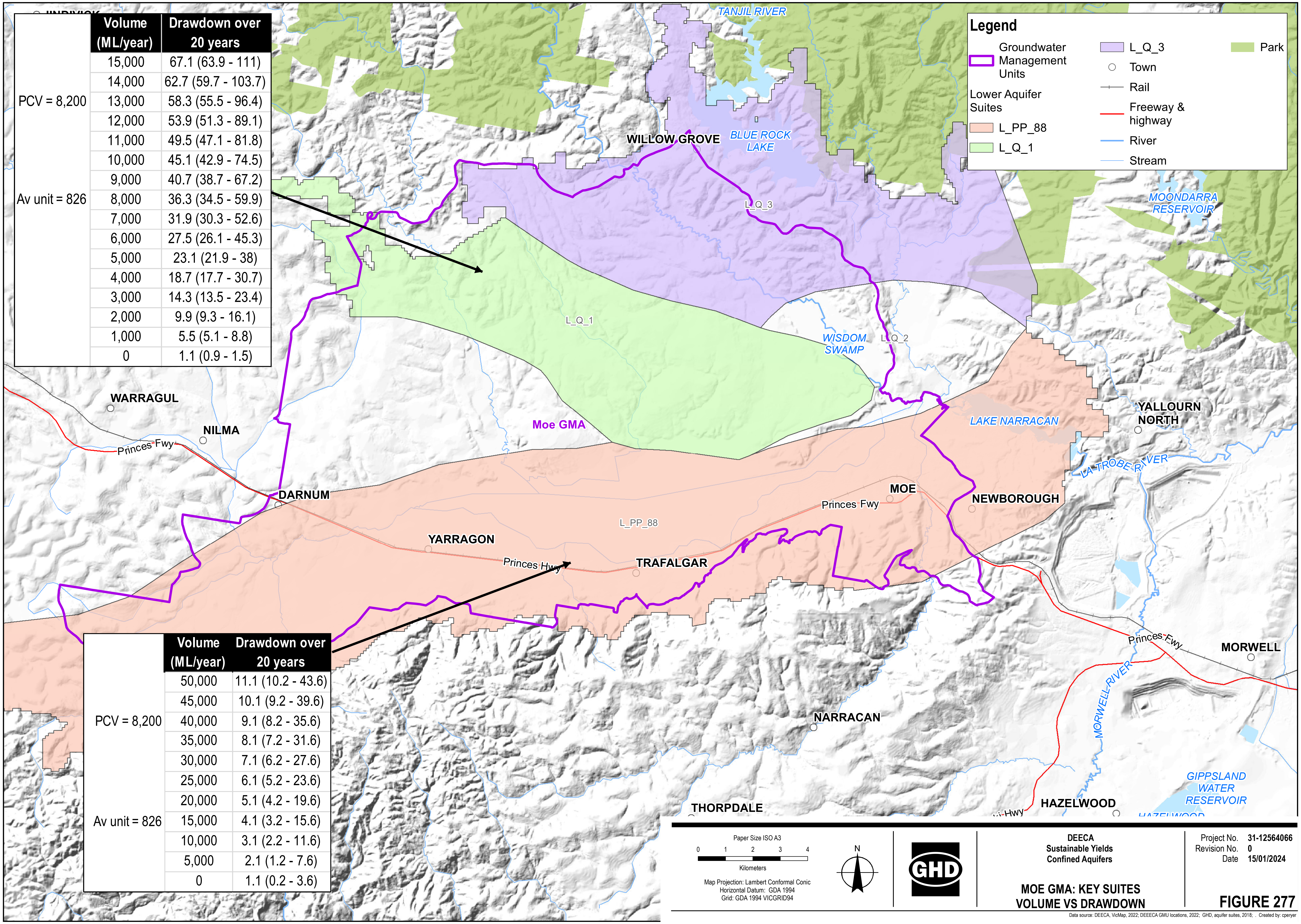


Figure 276 Moe GMA Suite L_PP_88: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 105 Predicted volumes for drawdown metrics

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite L_Q_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite L_PP_88 drawdowns (lower limit to upper limit)
5	900 (500 – 1,400)	19,300 (1,800 – 23,900)
10	2,000 (1,200 – 2,600)	44,300 (8,000 – 48,900)



	Volume (ML/year)	Drawdown over 20 years
PCV = 8,200	15,000	67.1 (63.9 - 111)
	14,000	62.7 (59.7 - 103.7)
	13,000	58.3 (55.5 - 96.4)
	12,000	53.9 (51.3 - 89.1)
	11,000	49.5 (47.1 - 81.8)
	10,000	45.1 (42.9 - 74.5)
	9,000	40.7 (38.7 - 67.2)
Av unit = 826	8,000	36.3 (34.5 - 59.9)
	7,000	31.9 (30.3 - 52.6)
	6,000	27.5 (26.1 - 45.3)
	5,000	23.1 (21.9 - 38)
	4,000	18.7 (17.7 - 30.7)
	3,000	14.3 (13.5 - 23.4)
	2,000	9.9 (9.3 - 16.1)
	1,000	5.5 (5.1 - 8.8)
	0	1.1 (0.9 - 1.5)

	Volume (ML/year)	Drawdown over 20 years
PCV = 8,200	50,000	11.1 (10.2 - 43.6)
	45,000	10.1 (9.2 - 39.6)
	40,000	9.1 (8.2 - 35.6)
	35,000	8.1 (7.2 - 31.6)
	30,000	7.1 (6.2 - 27.6)
	25,000	6.1 (5.2 - 23.6)
	20,000	5.1 (4.2 - 19.6)
Av unit = 826	15,000	4.1 (3.2 - 15.6)
	10,000	3.1 (2.2 - 11.6)
	5,000	2.1 (1.2 - 7.6)
	0	1.1 (0.2 - 3.6)

18.6 GMU summary

18.6.1 Findings

Moe GMA primarily relates to the Childers Formation aquifer (LTA), where groundwater is predominately extracted for irrigation purposes. The LTA falls within the Lower Aquifer Suites, which at Moe GMA comprises L_PP_88 (43%) and L_Q_2 (4%) providing a total GMU coverage of 47%. The identified representative Suites are L_PP_88 (most preferred) and L_Q_1. Suite L_Q_1 was included as it lies within the Thorpdale Volcanics which is assumed to be hydraulically connected to the LTA (due to no confining layer) and Suite L_Q_1 covers 22% of the GMU. 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.

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. However, the two yearly annual average results were still similar to the annual extraction when hindcasting was not included in the model run.

The application of spatial distribution produced an improved statistical model fit for Suite L_Q_1. For Suite L_PP_88 spatial distribution only decreased the 95PPU thickness for one of the runs but in this same run significantly decreased the R^2. The quality of the model fit decreased for both Suites when spatial distribution methodology was combined with hindcasting methodology.

Based on an assessment of all model runs, and the need to incorporate longer datasets to cover the pre-development period, model run 7 of annual extraction with hindcast method H3 was adopted to undertake the predictive modelling for Suite L_Q_1 and Suite L_PP_88.

The pre-development levels were as the maximum levels in the early time series data for Suite L_Q_1 and the maximum levels prior to major development for Suite L_PP_88. This resulted in pre-developments levels of 7.00 m for Suite L_Q_1 and 2.07 m for Suite L_PP_88. 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_Q_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite L_PP_88 drawdowns (lower limit to upper limit)
5	900 (500 – 1,400)	19,300 (1,800 – 23,900)
10	2,000 (1,200 – 2,600)	44,300 (8,000 – 48,900)

The model for Suite L_PP_88 was assessed as having a “Poor” model applicability rating and the model for Suite L_Q_1 was assessed as having a “Good” rating using the criteria outlined in section 5.2. For both 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 this assessment, including that Suite L_PP_88 covers a larger portion of the GMA than Suite L_Q_1 and contains a greater number of extraction bores; Suite L_PP_88 is adopted as the most representative Suite for Moe GMA. However, as L_PP_88 has a very low R^2 and was rated as having a “Poor” model applicability, consideration will need to be made as to whether Suite L_Q_1 is adopted instead.

18.6.2 Limitations

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

- The licenced bore dataset provided by DEECA has 6% of bores assigned to Moe 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.

- It is noted with L_PP_88, there were three instances of the same maximum water level occurring more than once in a given year. Where this occurred, the maximum level was recorded consecutively over a few weeks to a few months; in these instances, the middle date was set as the date of the maximum level.
- 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.
- Model Calibration was between 0-1,500 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 30 times the calibration range are being made to meet the 10 m metric (Suite L_PP_88). Further checks and potential re-calibration may be required as rates increase for the GMUs.
- L_PP_88 has a very low R^2 so consideration will need to be made as whether L_Q_1 results are adopted instead

18.6.3 Recommendations

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

- The licenced bore dataset provided by DEECA has 6% of bores assigned to Moe 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.

19. Orbost GMA

19.1 Conceptualisation

The hydrogeological conceptualisation elements relevant to this study are summarised in Table 106 and a map of the GMU is presented in Figure 278. 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 106.

Table 106 Orbost GMA – Tabulated conceptualisation

GMU summary
Orbost GMA is within the Gippsland Basin and covers an area of approximately 36 km^2 just west of Orbost along the Snowy River floodplain. Orbost GMA pertains to formations between 20 m and 45 m below the ground surface and was intended to primarily manage the groundwater resource of the Curlip Gravels (Upper Tertiary Quaternary Aquifer, UTQA). As the Curlip Gravel aquifer is assumed to be confined or semi-confined (Jacobs 2019), the PCV (1,217 ML/year) therefore relates to confined or semi-confined aquifers. Groundwater quality of the Curlip Gravels aquifer is of good quality west of Princess Highway Bridge with lower groundwater quality to the east (Jacobs 2019). Previous investigations found that the groundwater levels in the GMA are rising and groundwater use is reducing (GHD 2018, Jacobs 2019). Groundwater use in the Orbost GMA is predominately for irrigation (90% of entitlement), dairy cooling and wash down (Australian Government 2018).

Hydrostratigraphy summary

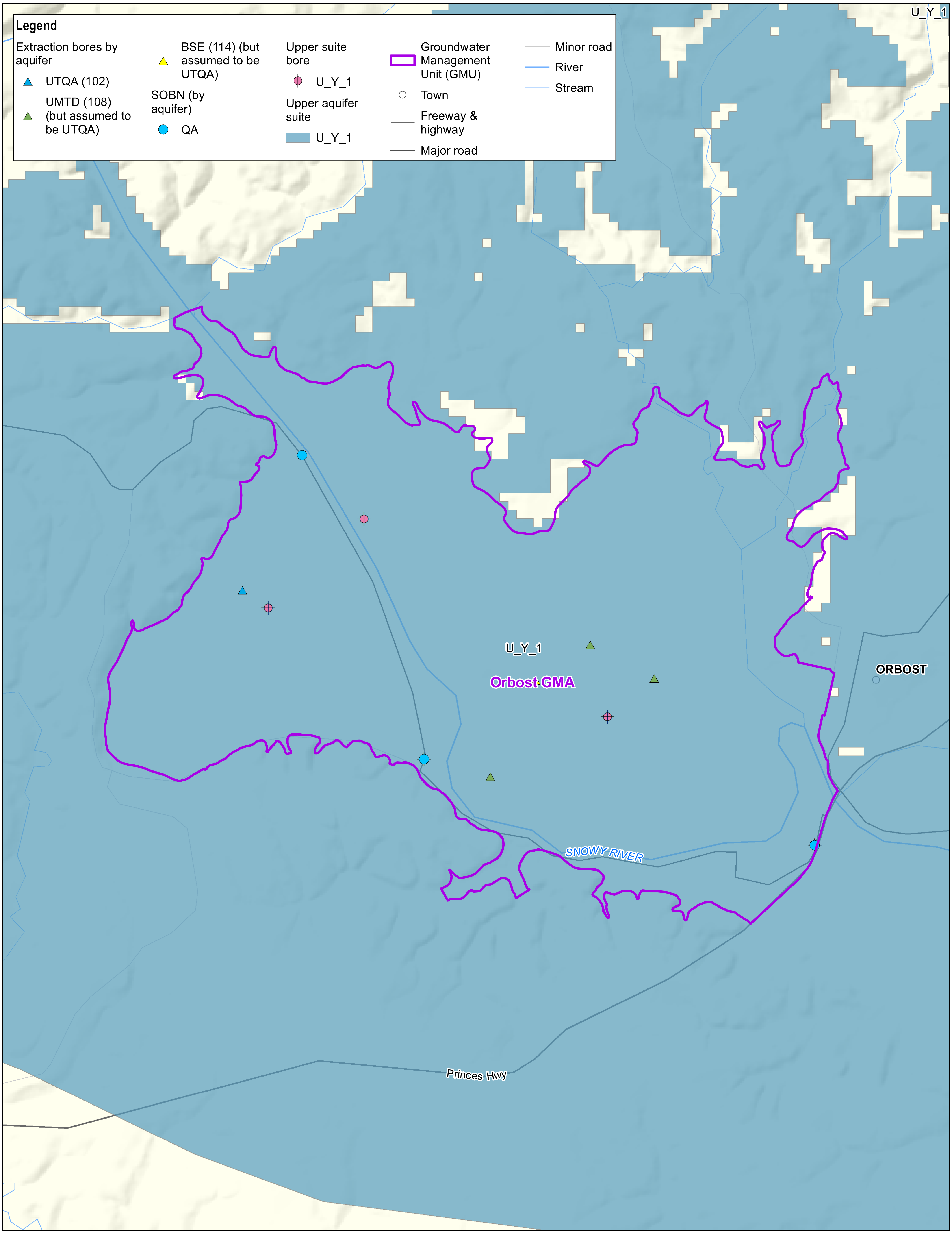
Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Use volumes ML (2019/20)	Entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Undifferentiated sediments (QA, 100)	-	-	3	NA	0	0	Low
	Curlip Gravels (Upper Tertiary Quaternary Aquifer, UTQA).	U_Y_1 (100%)	100%	0	Dairy, stock	5	17	Low
Middle	Tambo River Formation (UMTD)	-	-	0	Irrigation	173	839	Low
Basement	Basement rocks (BSE)	B_R_1 (7%)	7%	0	Investigation	63	362	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.

Characteristic and importance	Description	Degree of understanding
Intended aquifer		
Aquifer thickness within GMU (range, based on VAF)	Max: 28 m, Average: 9 m	High
Aquifer extent	Extensive, regional	High
Likelihood of inter-aquifer flow	High	High (GHD, 2010)
Likelihood of groundwater – surface water interaction	High	High (GHD, 2010)
Representative Suite	**U_Y_1**	**Low. 1% of GMU extraction occurs within this Suite, which relates to the most relevant GMU aquifer.** **Likely issue with bore data since 99% of extraction does not occur within defined/relevant Suites**

Characteristic and importance	Description	Degree of understanding
Current hydrological condition of representative aquifer		
Representative Suite trend	Variable to decreasing	High
Groundwater quality (average salinity based on WMIS and CDM Smith spatial segment(s) with highest coverage)	1,489 mg/L (WMIS) 0-600 mg/L (CDM Smith (2022))	Low Based on WMIS (2022) Based on CDM Smith (2022)
Groundwater yield	0 – 0.5 L/s (based on referenced data; should be much higher based on GHD experience)	Low – should be higher yields Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	2001-2021	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	**294 ML**	**High (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	59 ML	High (Based on historical VWA data, year 2020/21)
Maximum historic groundwater use	**578 ML**	**High (Based on historical VWA data, year 2008/09)**
Entitlement (Groundwater allocation)	**1,217 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	None identified	
Groundwater use profile	Seasonal (~Oct-Apr irrigation season)	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)	

Characteristic and importance	Description	Degree of understanding
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 0.3 0.6 0.9 1.2

Kilometers

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

N

GHD

DEECA
Sustainable yield review - confined aquifers

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

Orbost GMA
Site location and key features

Figure 278

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Print date: 16 Jan 2024 - 12:42

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

19.2 Technical analysis

19.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the relevant Suites for Orbost GMA as shown in Figure 279. Generally, the Suite hydrographs show a trend of seasonal fluctuations and thus annual recovered levels. Suite B_R_1 shows a period between 2012 and 2016 with anomalous data, however, this data is not used in this assessment.

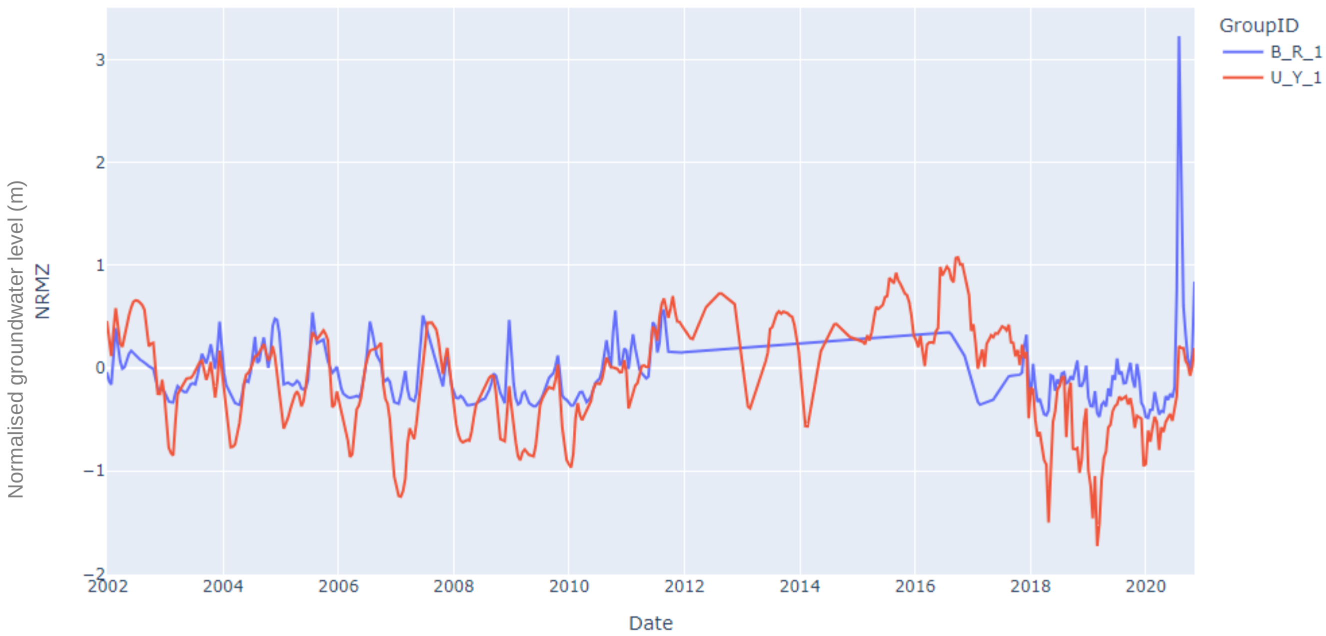


Figure 279 Orbost GMA Suite Hydrographs for all confined aquifers

The representative Suite analysed for this GMU was Suite U_Y_1. 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 Upper Aquifer
- The Upper Aquifer pertains to the UTAF, which is the intended aquifer of the GMU
- Suite U_Y_1 covers 100% of the GMU
- Suite U_Y_1 has 2 active SOBN bores within the Suite area
- Some of the Suite bores for U_Y_1 are close to extraction points

The annual recovered Suite hydrographs for the representative Suite U_Y_1 for Orbost GMA, is shown in Figure 280.

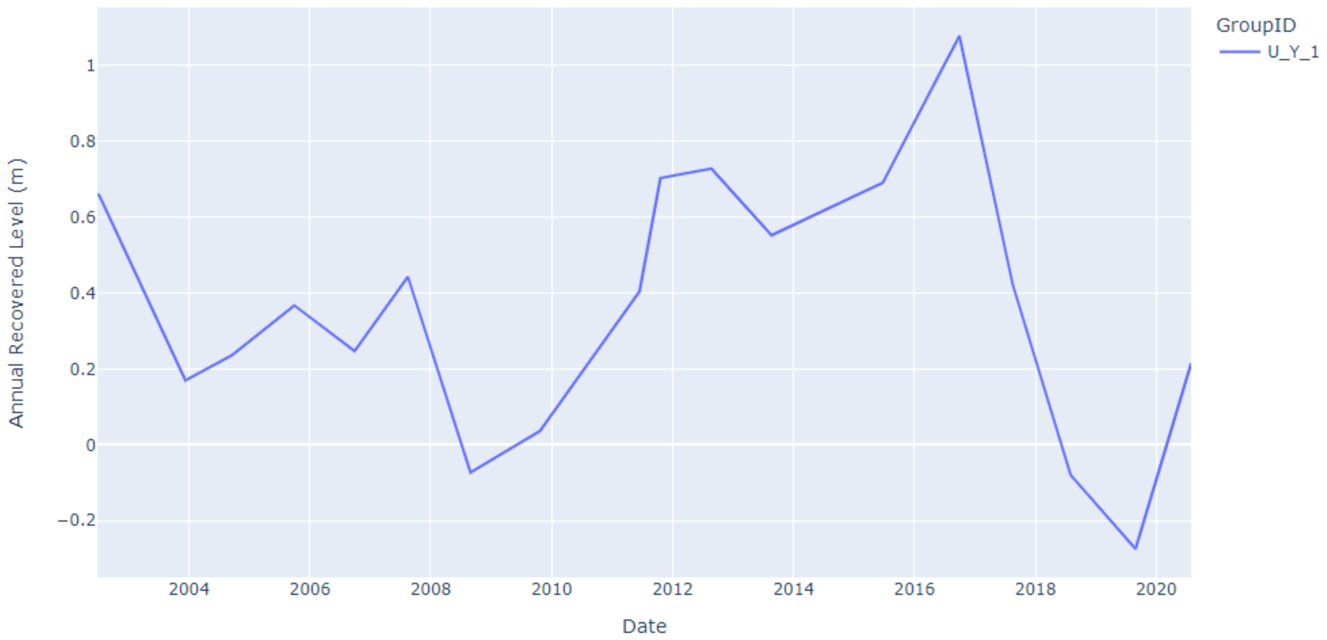


Figure 280 Orbost GMA Annual Recovered Level Suite Hydrographs for representative Suites

19.2.2 Pre-development level

To estimate the pre-development level conditions, GHD reviewed the Suite hydrographs of annual recovered levels and assumed that the maximum levels in the early time series data was the best representation of conditions prior to major development within Orbost GMA for Suite U_Y_1.

The pre-development annual recovered levels are taken to be the average level of the average of the first two readings in the early time series data between 2001/2002 and 2002/2003 which equates to 0.66 m for Suite U_Y_1 (refer further details in section 19.4.3).

19.2.3 Externalities

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

19.2.4 Hindcasting

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

19.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, four different correlations were developed using the annual groundwater extraction as described below and shown in Figure 281:

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

Another four correlations were developed based on annual irrigation extraction as described below and shown in Figure 282:

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

As shown in Figure 281, the goodness-of-fit represented by the R^2 is greatest for the annual rainfall with annual groundwater use. When only irrigation groundwater use is considered, the R^2 increases for the annual rainfall correlation as shown in Figure 282; this is the correlation adopted for method H1.

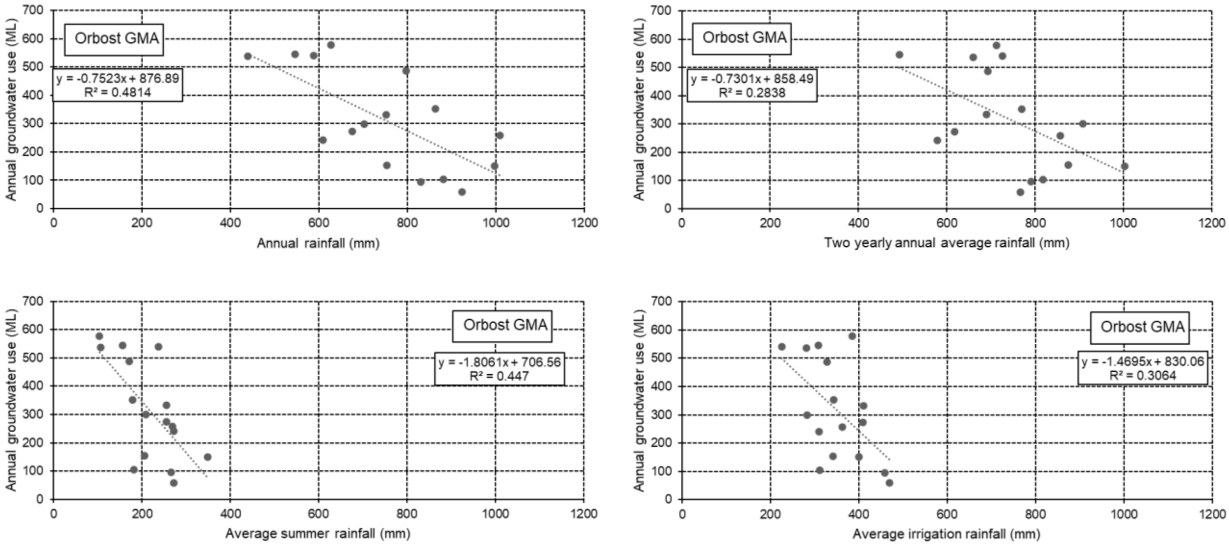


Figure 281 Orbost GMA: Hindcast method 1 correlations (Orbost GMA annual extraction)

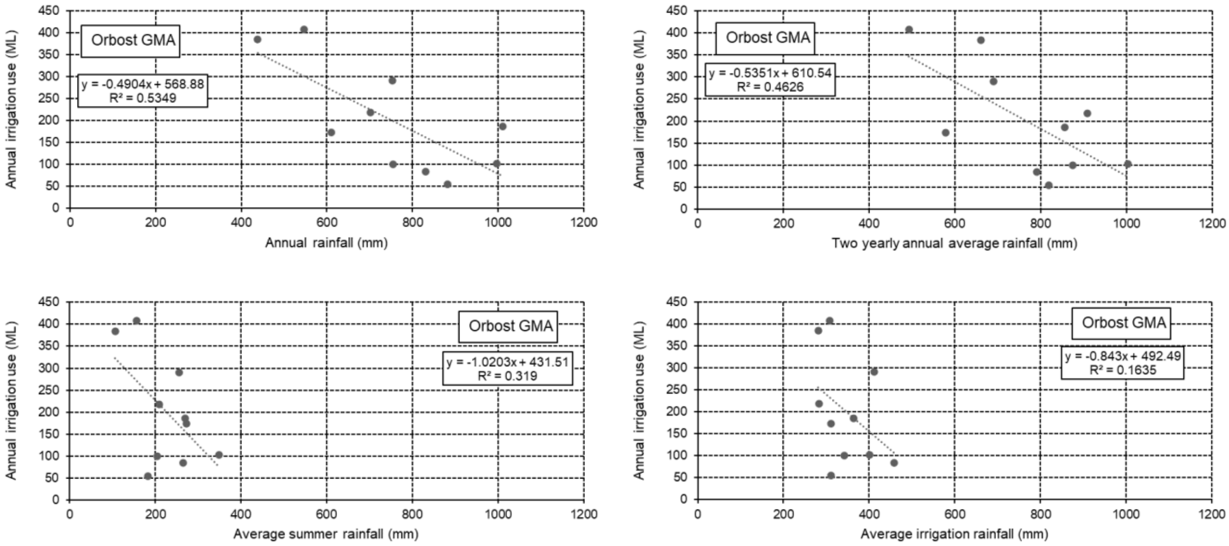


Figure 282 Orbost GMA: Hindcast method 1 correlations (Orbost GMA annual irrigation extraction)

19.2.4.2 Hindcasting Method 2 (H2)

Similar to method H1, four correlations were developed using method H2 as described below and shown in Figure 283:

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

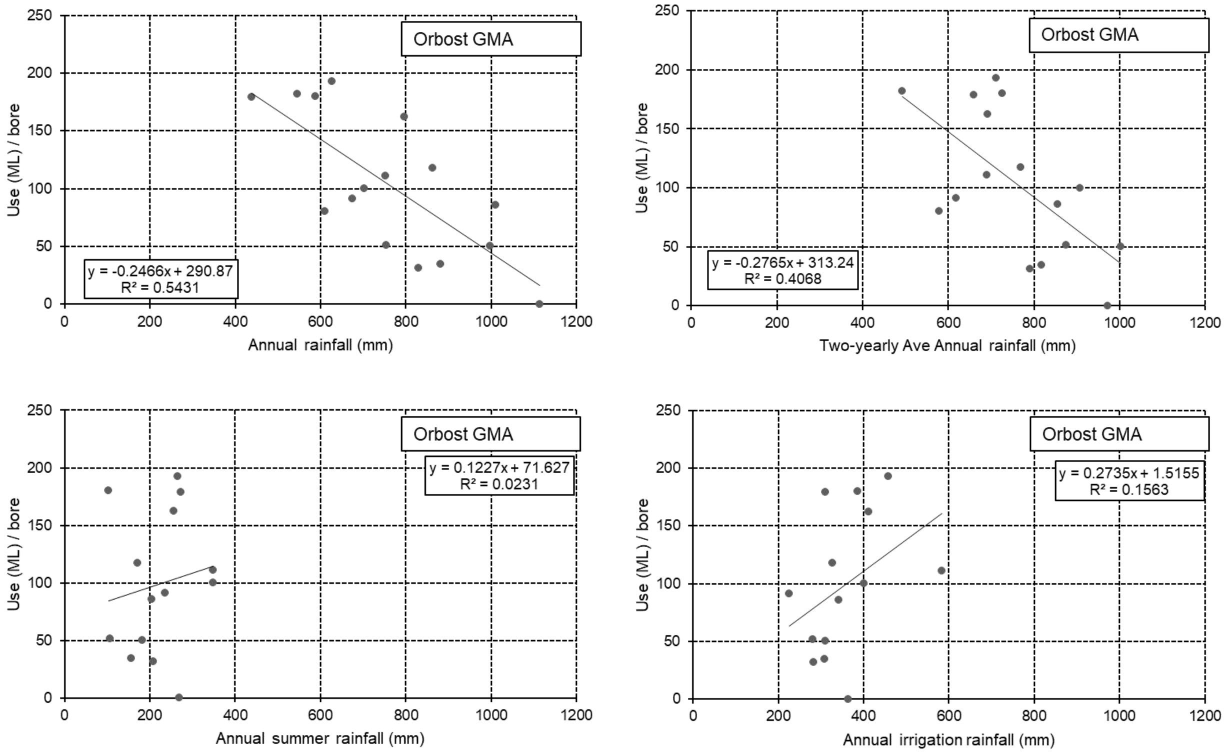


Figure 283 Orbost GMA: Hindcast method 2 correlations

As shown in Figure 283, the goodness-of-fit represented by the R^2 is highest for the correlation with annual rainfall. Thus, the correlation with annual rainfall has been adopted for hindcast method H2.

19.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 284:

- 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

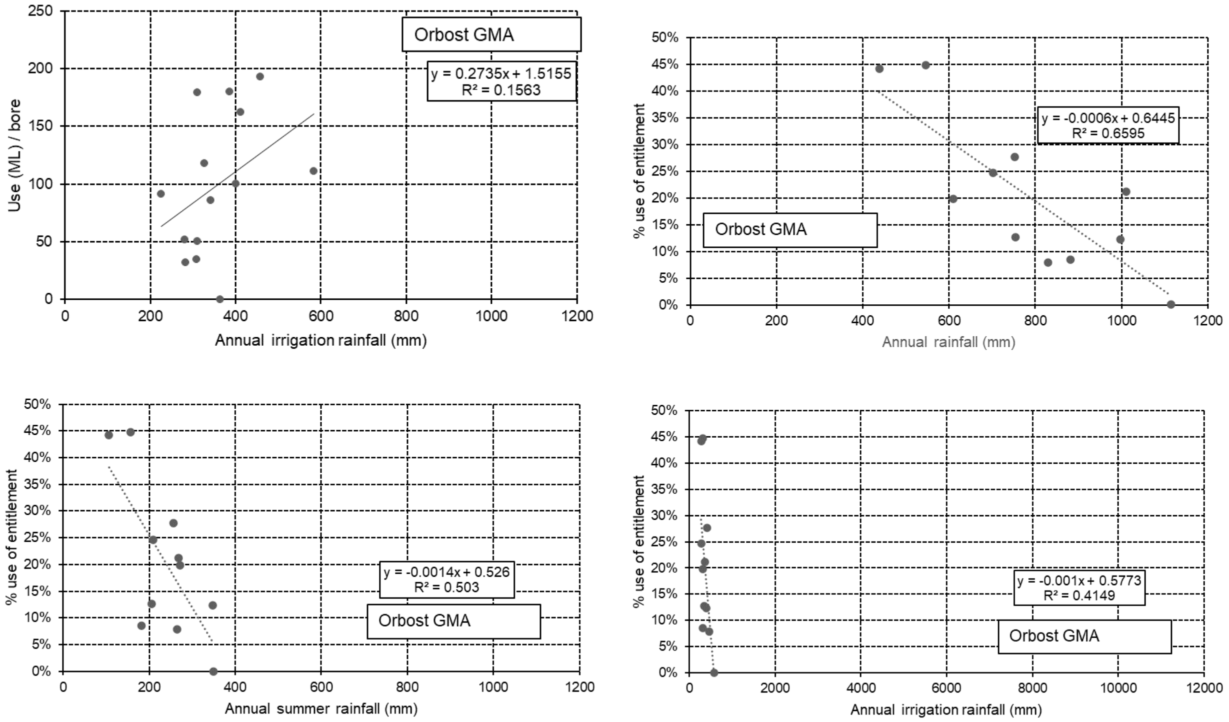


Figure 284 ***Orbost GMA: Hindcast method 3 correlations***

As shown in Figure 284 and similar to method H1 and H2, the goodness-of-fit represented by the R^2 is highest for the correlation with annual rainfall. Thus, the correlation with annual rainfall has been adopted for hindcast method H3.

19.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 285 and Figure 286 for the hindcasting based on Orbost GMA groundwater use. Figure 285 shows a comparison of the three hindcasting methods against the recorded use only over the recorded use date and Figure 286 shows the hindcasted data back to 2001/2002 (start of hydrograph period).

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 Orbost GMA.

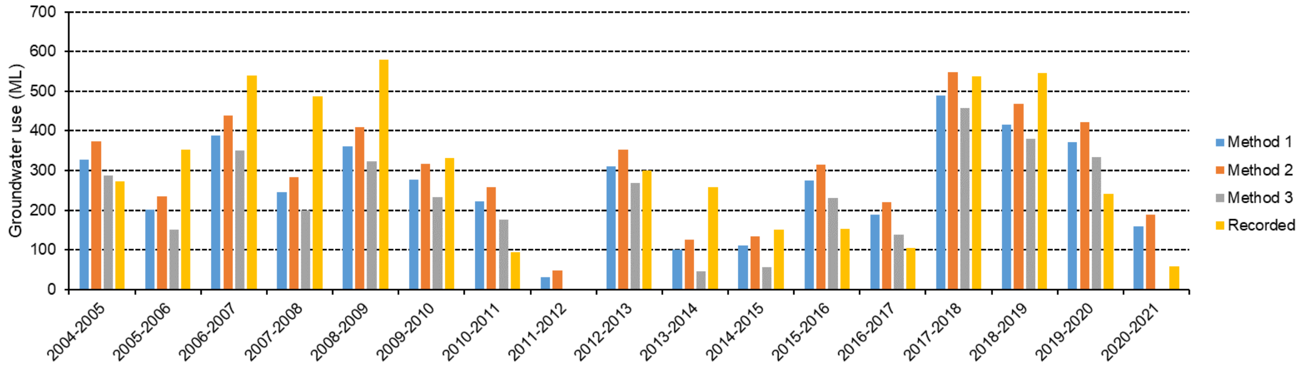


Figure 285 ***Orbost GMA: Comparison of hindcasting over recorded use period***

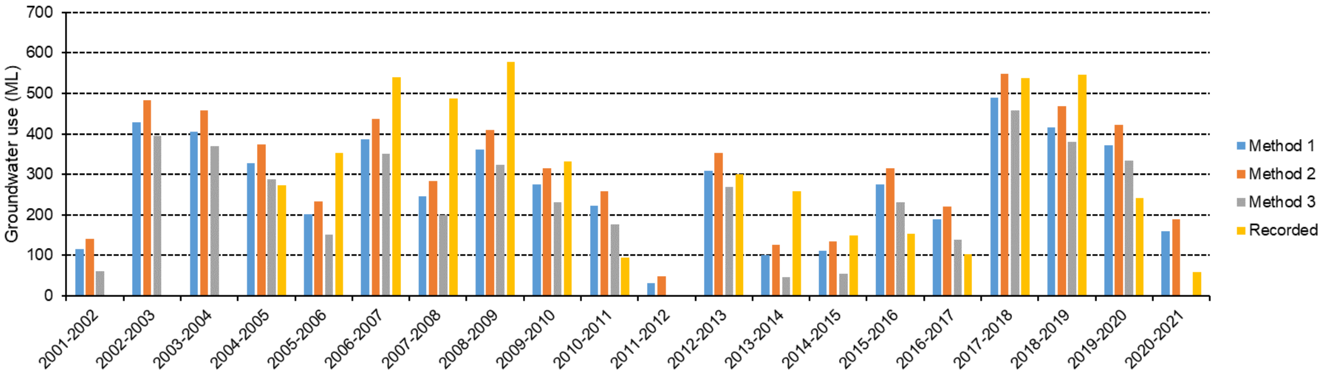


Figure 286 Orbost GMA: Comparison of hindcasting

19.3 Modelling

19.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 107 summarises these combinations of model inputs run for Orbost GMA. Model runs highlighted blue indicate they were run with annual extraction and grey indicates they were run using two yearly average annual extraction.

Table 107 Orbost GMA: summary of model inputs

Model input	Model runs																			
	1	2	3	4	5	6	7	8	9	10	11	12	12c	13	14	15	16	17	18	19
Annual recovered levels for representative Suites (U_Y_1)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Orbost GMA only	✓																			
Annual climate data													✓							
Two yearly average annual extraction – Orbost GMA only		✓																		
Annual extraction – Orbost GMA and Externalities			✓																	
Two yearly average annual extraction – Orbost GMA and Externalities				✓																
H1 annual extraction – Orbost GMA only					✓															
H1 annual extraction – Orbost GMA and Externalities						✓														
H2 annual extraction – Orbost GMA only							✓													
H2 annual extraction – Orbost GMA and Externalities								✓												
H3 annual extraction – Orbost GMA only									✓											
H1 two yearly average annual extraction – Orbost GMA only										✓										
H1 two yearly average annual extraction – Orbost GMA and Externalities											✓									

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

19.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 107 is presented in Table 108 for the representative Suite, U_Y_1 for Orbost GMA which was selected using the process outlined in section 19.2.1. 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 U_Y_1

A review of the results and statistical summary for Suite U_Y_1 shows that model run 12 (highlighted green) 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. Model runs 10, 12 and 17 show very similar results considering the measures in Table 108. The main differences between model 12 and the other two models (10 and 17) is that the 95PPU thickness is slightly smaller and R^2 is slightly higher. To see if the model fit could be improved further, climate was added to model run 12 represented as model run 12c in Table 108. Adding climate did not have a large effect on the model results, the main change was an increase to the 95PPU thickness. The graphical model output for model run 12 is shown in Figure 287.

For Suite U_Y_1, model run 12 has been adopted to progress to predictive modelling.

Table 108 Orbost GMA: summary of model outputs

Suite	Statistic	Model run													
		1	2	5	7	9	10	12	12c	14	15	16	17	18	19
U_Y_1	95PPU TH	1.05	0.91	0.98	0.94	0.99	0.87	0.83	1.32	1.23	1.26	1.32	0.87	1.43	1.43
	%Obs in 95 PPU	93.75	93.75	94.74	94.74	94.74	94.74	94.74	100	100	100	100	100	94.44	94.44
	R^2	68.2	73.7	66.0	68.4	63.9	72.7	74.4	74.6	65.3	29.3	84.9	72.3	66.1	66.1
	RMSE	0.21	0.19	0.21	0.2	0.21	0.18	0.18	0.18	0.24	0.34	0.16	0.19	0.21	0.21
	No obs data points	16	16	19	19	19	19	19	19	10	10	10	18	18	18
	Range of observed levels	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4

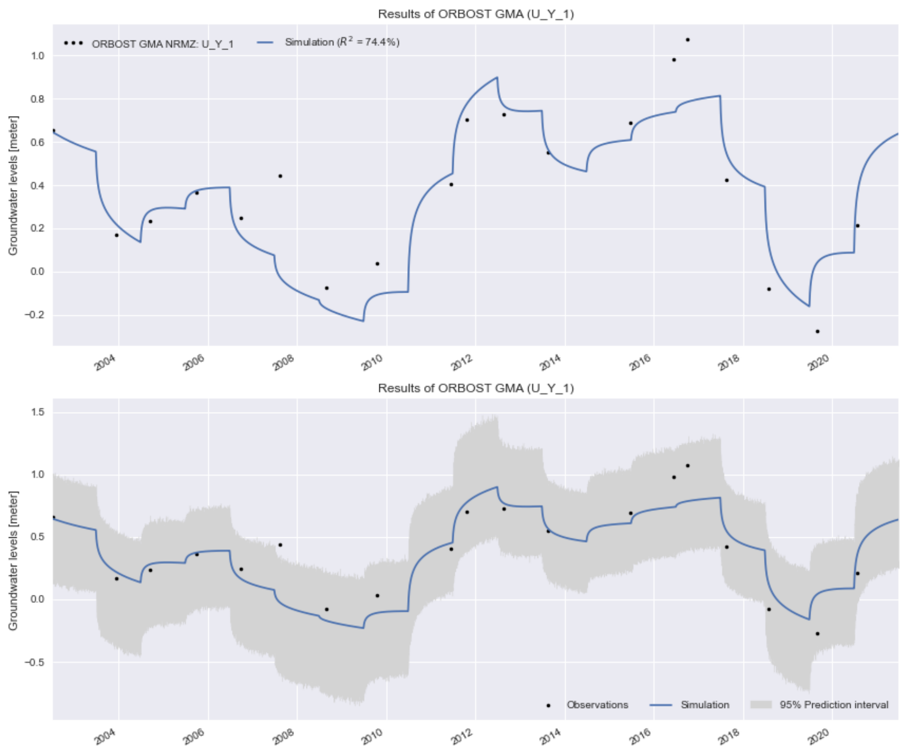


***Figure** 287 Orbost GMA Suite U_Y_1: model run 12 (Orbost GMA two yearly average annual extraction with hindcast method 2) output hydrographs*

19.4 Predictive modelling

19.4.1 Model inputs

The preferred model to run the predictive modelling for Orbost GMA was model run 12 for the representative Suite. The key inputs for the model were the annual recovered levels and the two yearly average annual extraction hindcasted with method H2 in Orbost 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 109.

***Table 109** Orbost 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 2008/09)
Value (ML/year)	1,217	1,217	59	294	367

19.4.2 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 288 for scenario 11. As shown in Figure 288, 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 majority of the MCMC realisations tend to fall within the 95% prediction interval bands, however there are some realisations that fall outside of this as shown in Figure 289.

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.

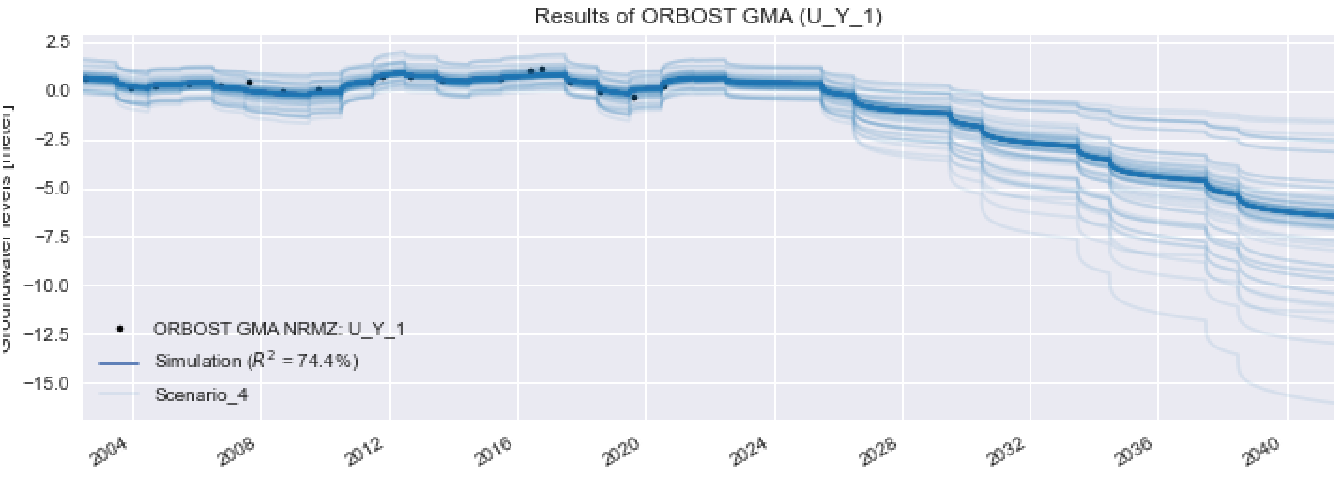


Figure 288 Orbost GMA: Suite U_Y_1 MCMC analysis for Forecast Scenario 4

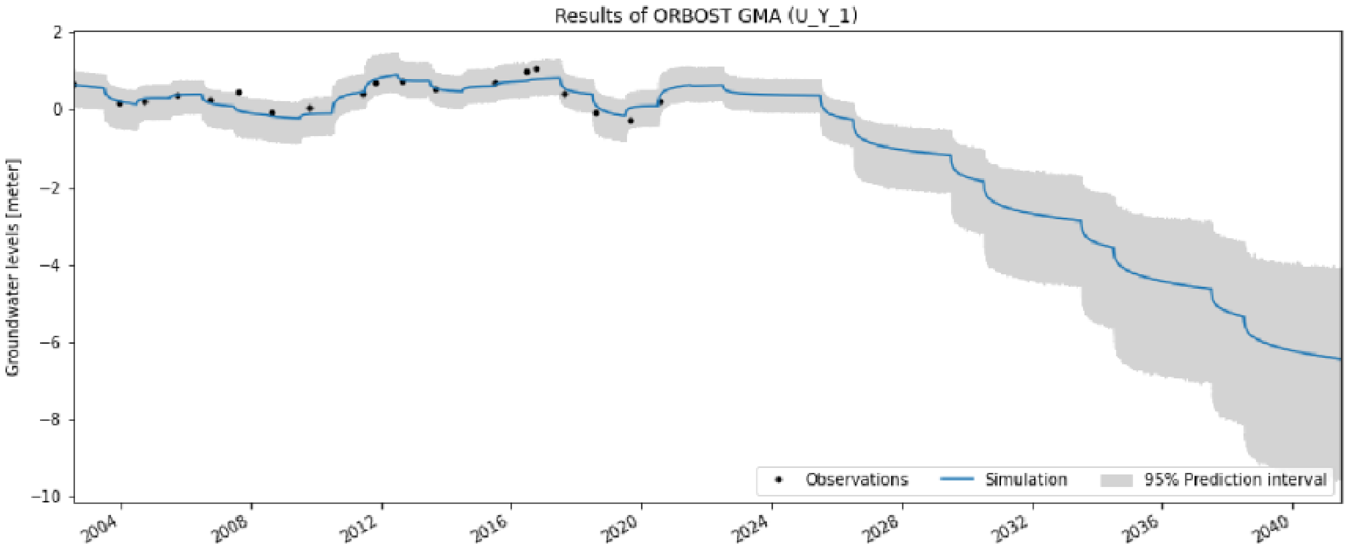


Figure 289 Orbost GMA: Suite U_Y_1 Forecast Scenario 4 with 95% prediction bands

19.4.3 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 Orbost 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 19.2.2, 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 290 for Suite U_Y_1 hydrograph of annual recovered levels. In Figure 290:

– Two yearly average annual groundwater use based on recorded data is represented by the blue column graph between 2004/2005 and 2020/2021
– Hindcasted two yearly average annual groundwater use is represented by the orange columns on 2002/2003 and 2003/2004
– 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, where the earliest data is taken to best reflect the pre-development levels
– In this case, the pre-development annual recovered levels are taken to be the average of the first two measurements, which equate to 0.66 m
– The modelled forecasted two yearly average annual recovered levels are represented by the purple line in Figure 290
– The calibration annual recovered levels are represented by the black line in Figure 290

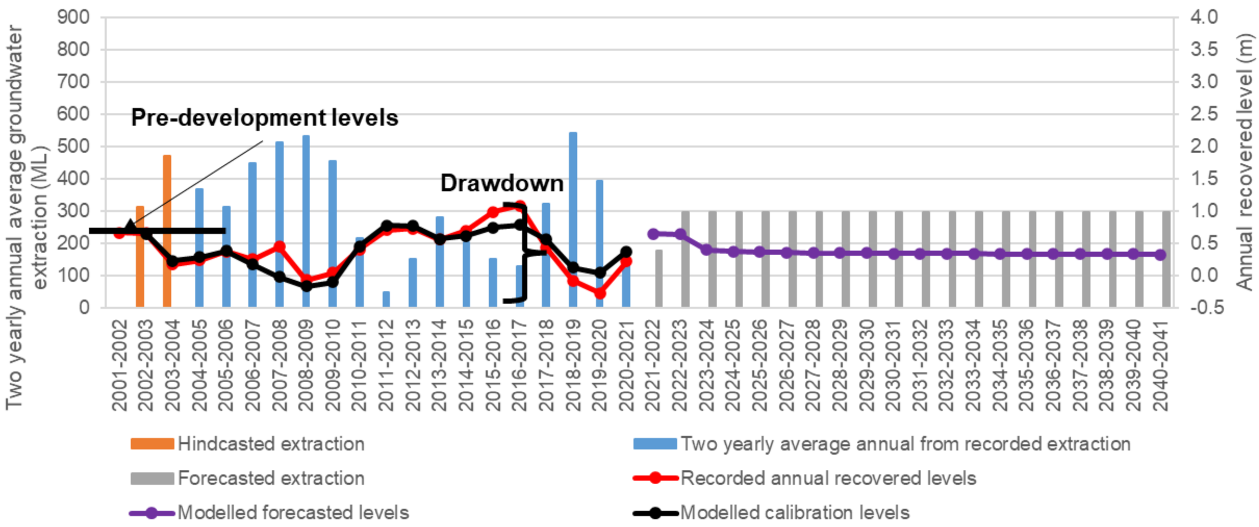


Figure 290 Estimating pre-pumping water levels (example from Suite U_Y_1

For Suite U_Y_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 291) and a graph of the scenarios for specific time periods (Figure 292) 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 variation in the coefficient of determination and slope of the line of best fit. Given this, the correlation developed based on all scenarios was adopted to encompass these variations.

The use-drawdown for all the 19 forecast scenario drawdowns and volumes (both the recorded and forecasted volumes) over each year modelled (2003 to 2041) is shown in Figure 291 for Suite U_Y_1. Note the abscissa range of the chart has been clipped and does not show forecast drawdowns for the higher use scenarios (more improbable scenarios that are two times the current 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 300 ML, and at this volume the model forecast drawdown falls around the predicted line of best fit as shown in Figure 291
– For the same annual use, different drawdowns can be obtained as Pastas predicts a water level for each year. For example, Figure 290 shows a scenario where groundwater use remains constant at around 294 ML/year over the next 20 years.
– The correlation for groundwater use and drawdown for Suite U_Y_1 is excellent as shown in Figure 291
– 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.

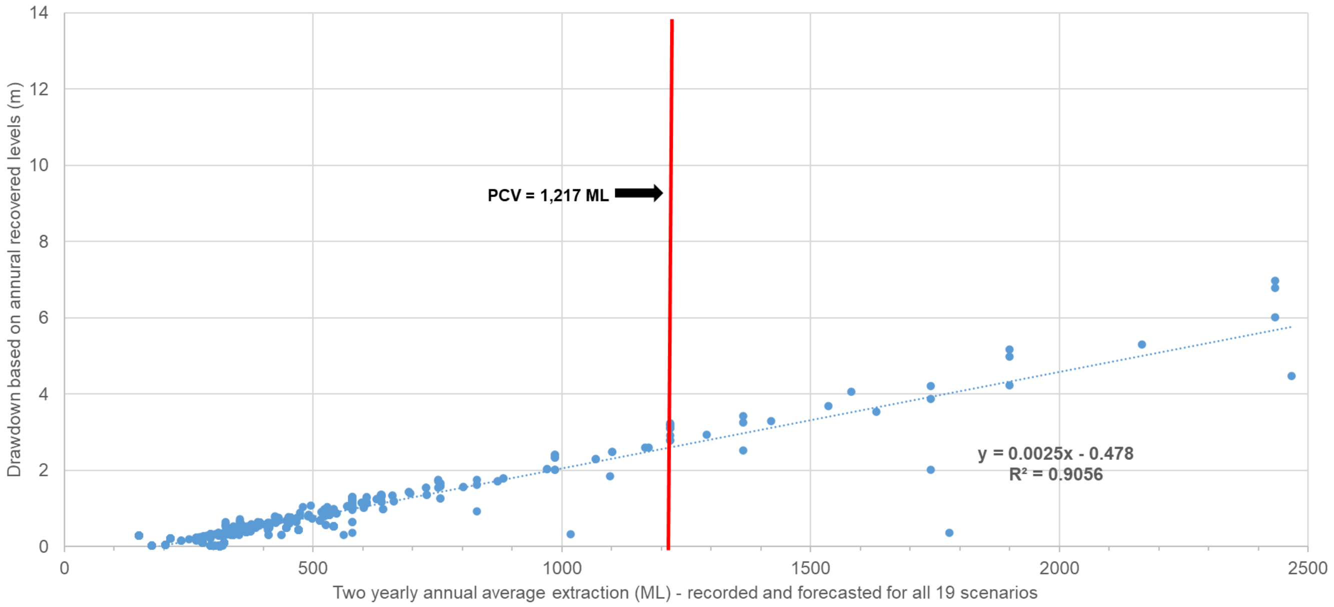


Figure 291 Orbost GMA Suite U_Y_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <2,500 ML) for all data between 2003 to 2041 and all forecasted scenarios

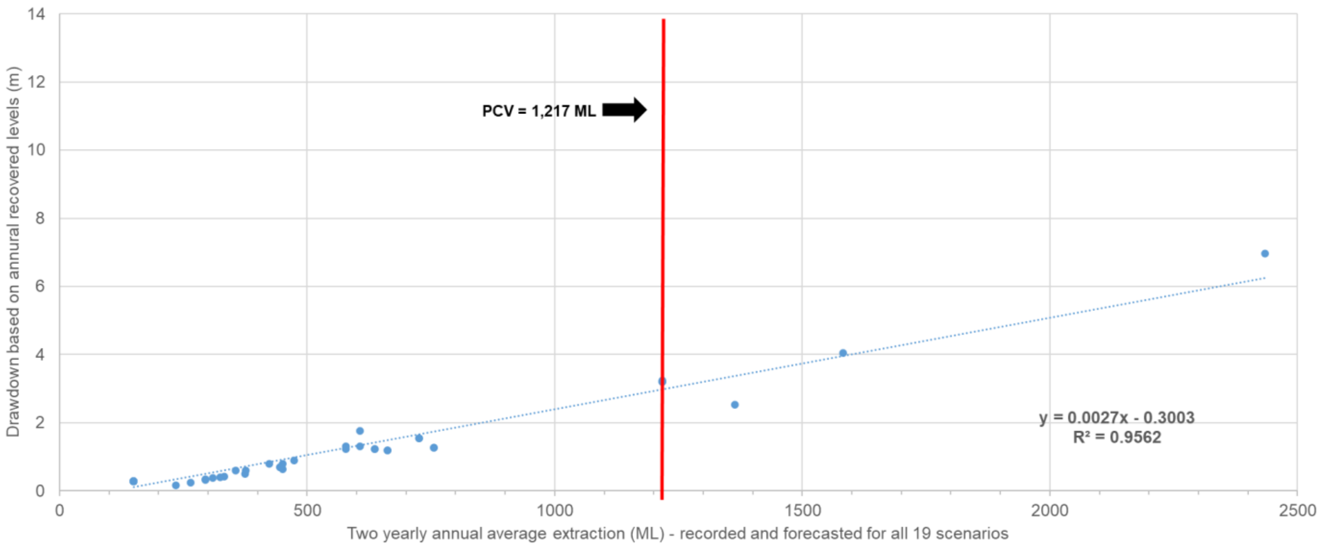


Figure 292 Orbost GMA Suite U_Y_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <2,500 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios

19.5 Sustainability metrics

19.5.1 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 110 for Orbost GMA Suite U_Y_1 (noting Orbost GMA has a current PCV of 1,217 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 110 for Suite U_Y_1.

It's noted that Suite U_Y_1 represents the upper aquifer in Orbost GMA, which is conceptualised as being unconfined, as such, the Suite is assessed against the unconfined metrics provided by DEECA. A comparison of volumes at drawdown intervals provided by DEECA is shown in Table 111 for Suite U_Y_1. Based on Suite U_Y_1, 5 m of drawdown is predicted to occur at a groundwater extraction volume of 2,200 ML which could range from 1,500 ML to 2,900 ML based on the 95% prediction intervals. Whereas 10 m of drawdown is predicted to occur at a groundwater extraction volume of 4,200 ML which could range from 3,000 ML to 5,400 ML based on the 95% prediction intervals.

Table 110 Relationship of Suite drawdown to GMU extraction for Orbost GMA Suite U_Y_1

Volume (ML/year) based on two yearly annual average for whole of GMU	Based on model prediction of Suite U_Y_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
4,250	10.1 (7.8 - 14.5)
4,000	9.5 (7.3 - 13.6)
3,500	8.3 (6.3 - 11.9)
3,250	7.6 (5.8 - 11)
3,000	7 (5.3 - 10.1)
2,750	6.4 (4.8 - 9.3)
2,500	5.8 (4.3 - 8.4)
2,250	5.1 (3.8 - 7.5)
2,000	4.5 (3.3 - 6.6)
1,750	3.9 (2.8 - 5.8)
1,500	3.3 (2.3 - 4.9)
1,250	2.6 (1.8 - 4)
1,000	2 (1.3 - 3.1)
750	1.4 (0.8 - 2.3)
500	0.8 (0.3 - 1.4)
250	0.1 (-0.2 - 0.5)
0	-0.5 (-0.7 - -0.4)

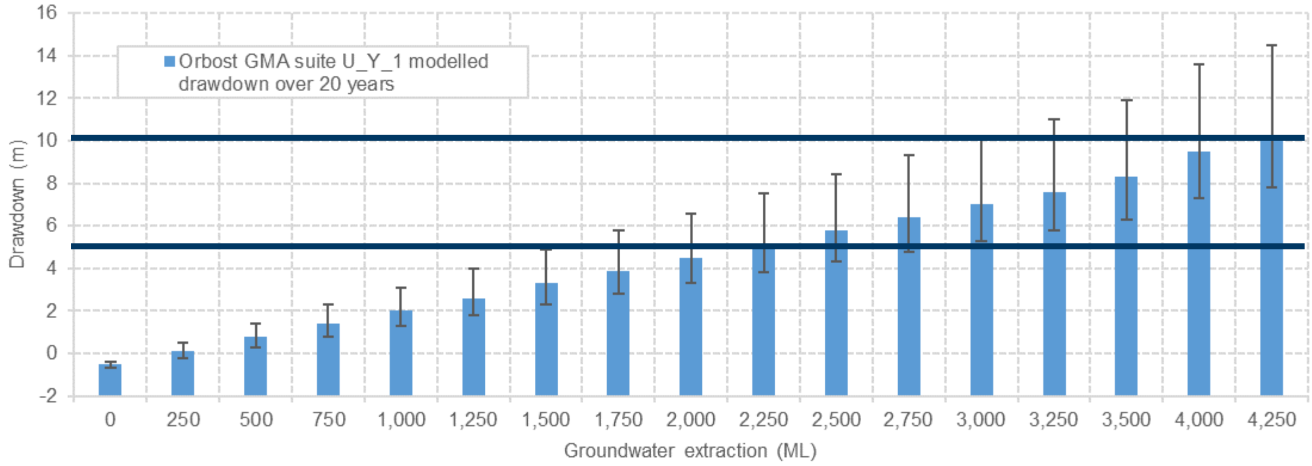
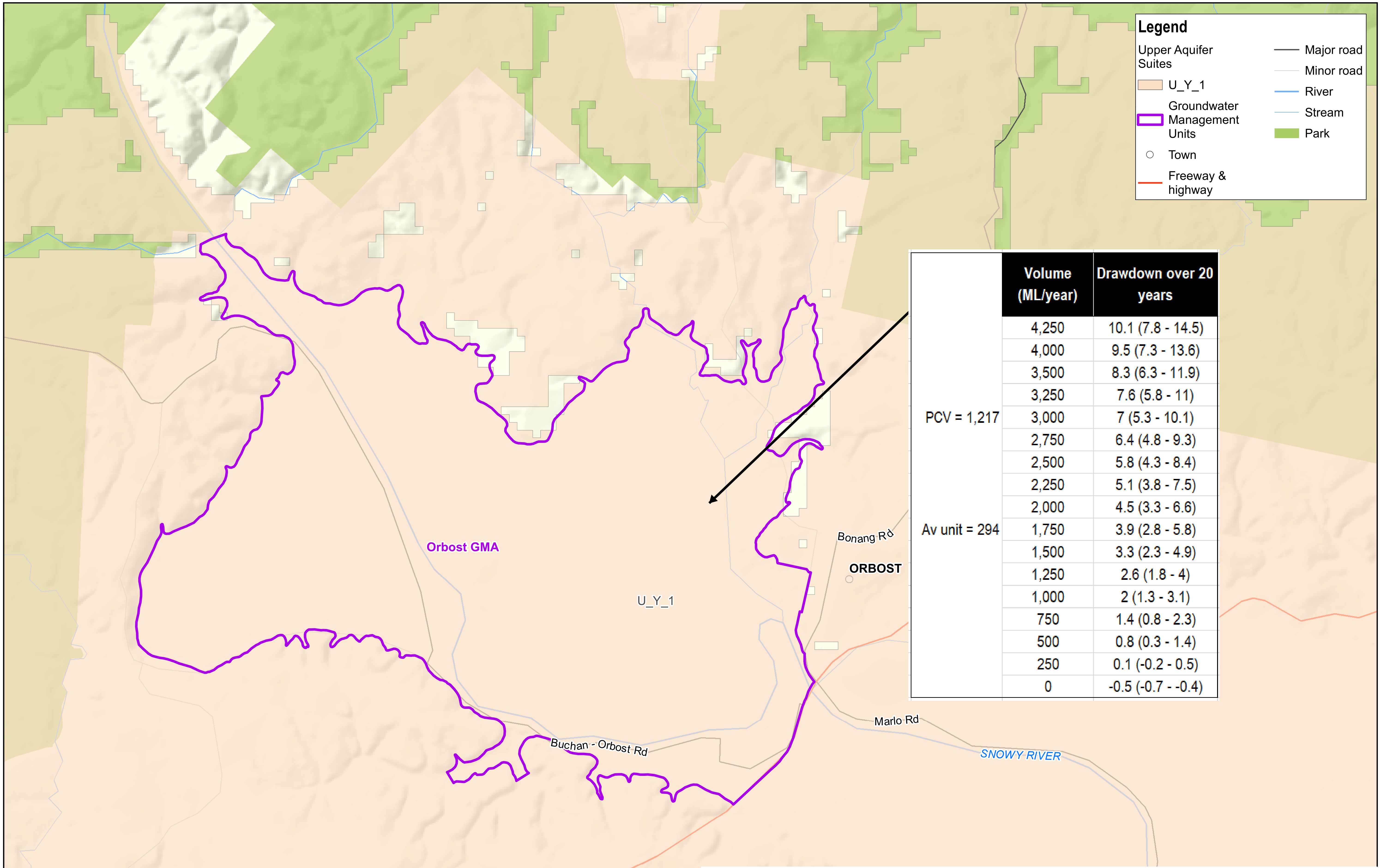


Figure 293 Orbost GMA Suite U_Y_1: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 111 Predicted volumes for drawdown metrics

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite U_Y_1 drawdowns (lower limit to upper limit)
5	2,200 (1,500 – 2,900)
10	4,200 (3,000 – 5,400)



	Volume (ML/year)	Drawdown over 20 years
PCV = 1,217	4,250	10.1 (7.8 - 14.5)
	4,000	9.5 (7.3 - 13.6)
	3,500	8.3 (6.3 - 11.9)
	3,250	7.6 (5.8 - 11)
	3,000	7 (5.3 - 10.1)
	2,750	6.4 (4.8 - 9.3)
	2,500	5.8 (4.3 - 8.4)
	2,250	5.1 (3.8 - 7.5)
	2,000	4.5 (3.3 - 6.6)
Av unit = 294	1,750	3.9 (2.8 - 5.8)
	1,500	3.3 (2.3 - 4.9)
	1,250	2.6 (1.8 - 4)
	1,000	2 (1.3 - 3.1)
	750	1.4 (0.8 - 2.3)
	500	0.8 (0.3 - 1.4)
	250	0.1 (-0.2 - 0.5)
	0	-0.5 (-0.7 - -0.4)

Paper Size ISO A3

0 0.3 0.6 0.9 1.2

Kilometers

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

N

GHD

DEECA
Sustainable Yields
Confined Aquifers

ORBOST GMA: KEY SUITES
VOLUME VS DRAWDOWN

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

FIGURE 294

G:\31\12564066\GIS\Maps\Deliverables\31_12564066_18_OrbostDD_A3L_Rev0.mxd
Print date: 16 Jan 2024 - 09:47

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

19.6 GMU summary

19.6.1 Findings

Orbost GMA primarily relates to the Curlin Gravels aquifer (UTQA), with groundwater predominately extracted for irrigation purposes. The UTQA falls within the Upper Aquifer Suites, which at Orbost GMA comprises Suite U_Y_1 (100%); thus, the identified representative Suite is U_Y_1. The Suite hydrographs for the representative Suites show seasonal fluctuations and thus recovered water levels, which were adopted for the assessment.

Application of two yearly annual average extraction instead of annual average generally showed an improved 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 H2 to extrapolate extraction into the past. The model using hindcast method 3 showed a poor model fit compared to the other hindcast methods regardless of the extraction regime adopted.

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 12 for Orbost GMA two yearly average annual extraction hindcasted using method H2 with the annual recovered levels was adopted to undertake the predictive modelling for Suite U_Y_1.

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 pre-developments levels of 0.66 m for Suite U_Y_1. The drawdowns were calculated based on these pre-development levels and the simulated levels from each of the 19 forecast scenarios. The resultant use – drawdown plots showed variations in the correlation equations depending on whether the correlation was based on each scenario or all the scenarios combined. As such, the correlation using all scenarios over the modelled timeframes was adopted in order to estimate drawdown from a given use.

Suite U_Y_1 has been conceptualised to occur in an unconfined aquifer and as such has different DEECA drawdown metrics to be assessed against. The volumes estimated for a given drawdown for each Suite is shown below.

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite U_Y_1 drawdowns (lower limit to upper limit)
5	2,200 (1,500 – 2,900)
10	4,200 (3,000 – 5,400)

The model for Suite U_Y_1 was assessed as having an “Excellent” model applicability rating using the criteria outlined in section 5.2.

19.6.2 Limitations

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

- The Suite hydrograph commences in 2001/2002. It is unknown when development occurred prior to this date. This limits analysis to a smaller dataset compared to other GMUs
- The correlation used to hindcast the extraction data back and then calculate the two yearly average annual extraction was relatively low (R^2 = 0.54). However, this is only used to infill three years of data
- The correlation developed is based on a two yearly average annual groundwater use
- Model calibration for suite U_Y_1 was completed using a groundwater extraction range of approximately 50-550 ML/year (below the current PCV of 1,217 ML/year, or around 45% 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 8 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

19.6.3 Recommendations

No further recommendations to those discussed in section 32 for all 25 GMUs were identified for Orbost GMA.

20. Rosedale GMA

20.1 Conceptualisation

The hydrogeological conceptualisation elements relevant to this study are summarised in Table 112 for zone 1 of the GMA, Table 113 for zone 2 of the GMA and Table 114 for zone 3 of the GMA, with a map of the GMU presented in Figure 311. 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 each table.

Table 112 Rosedale GMA Zone 1 – Tabulated conceptualisation

GMU summary								
Rosedale GMA is located in the Gippsland Basin and lies beneath several other GMAs including the Denison, Sale and Wa De Lock GMAs and above the Stratford GMA. Rosedale GMA is broken down into three zones, each of these zones pertains to different depths: – Rosedale GMA Zone 1 (covering an area of approximately 960 km^2) pertains to formations between 50 m and 150 m below the ground surface – Rosedale GMA Zone 2 (covering an area of approximately 1,270 km^2) pertains to formations between 25 m and 350 m below the ground surface – Rosedale GMA Zone 3 (covering an area of approximately 413 km^2) pertains to formations between 200 m and 300 m below the ground surface All were intended to primarily manage the groundwater resource of the Morwell Formation Aquifer (M2C) (Upper/Lower Mid Tertiary Aquifer, UMTA/LMTA). The PCV (22,372 ML/year) for Rosedale GMA applies to all three zones and therefore primarily relates to confined aquifers. Groundwater use in the Rosedale GMA is predominately used for irrigation (57% of entitlements) and power generation in the Latrobe Valley (Australian Government 2018[7]).								
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	Undifferentiated sediments (QA)	-	-	0	NA	0	0	Low
	Haunted Hills Formation (UTQA)	-	-	0	Domestic	0	8	Low
Middle	Jemmy's Point Formation (UTD)	-	-	0	Irrigation, dairy, domestic, stock	6	130	Low
	Balook Formation (UMTA)	M_R_1 (2%)	2%	0	Irrigation	0	120	Low
	Gippsland Limestone (UMTD)	-	-	0	NA	0	0	Low
Lower	M2C aquifer (LMTA)	M_R_1 (2%)	2%	0	NA	0	0	Low
	Traralgon seams and aquifers (LTA)	L_O_1 (0.1%), L_O_2 (0.1%), L_PP_88 (1.2%) L_P_1 (0.5%)	2%	0	Domestic, stock	0	120	Low
Basement	Basement rocks (BSE)	B_S_1 (0.1%)	0.1%	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 106 ML assigned to Rosedale GMA but unable to be assigned to a zone due to deficiencies in spatial information.								

[7] Australian Government 2018, Bioregional Assessments, last update 8 January 2018, **https://www.bioregionalassessments.gov.au/assessments/11-context-statement-gippsland-basin-bioregion/1144-groundwater-planning-and-use**

Characteristic & importance	Description	Degree of understanding
Intended aquifer (UMTA and LMTA, highlighted blue above)		
Aquifer thickness within GMU (range, based on VAF)	Max: 463 m, Average: 241 m	High Note that thickness values include layer UMTD
Aquifer extent	Regional, extensive	High
Likelihood of inter-aquifer flow	Low	Low
Likelihood of groundwater – surface water interaction	Low	Low
Representative Suite	**None identified**	**Low. 100% of GMU (Zone 1) extraction occurs within Suite M_ID_0, which contains insufficient data based on the original Suite development (SKM, 2014)**
Current hydrological condition of representative aquifer		
Representative Suite trend	None identified	Low
Groundwater quality (average salinity based on WMIS and CDM Smith spatial segment(s) with highest coverage)	<1,200 mg/L	Low Based on CDM Smith (2022)
Groundwater yield	0.5 – 5 L/s	Low Based on 107 in CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1974-2021**	
Spatial clustering of licensed bores in relation to Suites	No	Based on DEECA density mapping and licenced bore data.
Groundwater use		
Licensed groundwater use	**8,828 ML for all of Rosedale GMA**	**Low – insufficient data to split by zone (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	3,117 ML for all Rosedale GMA	Low – insufficient data to split by zone (Based on historical VWA data, year 2010/11)
Maximum historic groundwater use	**18,923 ML for all Rosedale GMA**	**Low – insufficient data to split by zone (Based on historical VWA data, year 2012/13)**
Entitlement (Groundwater allocation)	**22,272 ML for all of Rosedale GMA**	**Low – insufficient data to split by zone (Based on licenced volumes in 2020/21)**

Characteristic & importance	Description	Degree of understanding
Significant drivers of groundwater level variability (primary)	**Irrigation. Commercial/Industrial**	**Moderate**
Secondary drivers of groundwater level variability	Pumping for town water supply	Moderate
Groundwater use profile	Variable -driven by mining activities	Low
External Influence	**Latrobe Valley Mines and potentiall Offshore extractions**	
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	Moderate
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	Moderate

Table 113 Rosedale GMA Zone 2 – Tabulated conceptualisation

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	Undifferentiated sediments (QA)	U_AD_1 (13%) U_Z_1 (2%)	14%	0	Irrigation	159	261	Low
	Haunted Hills Formation (UTQA)	U_AC_99 (18%) U_AE_1 (3%)	21%	0	Irrigation, domestic, stock, dairy	153	368	Low
	Nuntin Clay (UTQD)	-	-	0	Domestic, dairy, stock	76	271	Low
Middle	Boisdale (Wurruk Sand) (UTAF)	M_O_2 (26%) M_P_1 (8%) U_AB_1 (3%)	37%	2	Irrigation	0	53	Low
	Jemmy's Point Formation (UTD)	-	-		Irrigation, domestic, stock, dairy	477	918	Low
	Balook Formation (UMTA)	-	-	0	Irrigation, domestic, stock, dairy	2,067	3,410	Low
Lower	M2C aquifer (LMTA)	-	-	0	NA	0	0	Low
	Traralgon seams and aquifers (LTA)	L_O_1 (53.2%), L_O_2 (1%),	54%	0	Irrigation, domestic, stock	1,621	3,143	Low
Basement	Basement rocks (BSE)	-	-	0	Irrigation, domestic, stock	1,029	1,758	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 355 ML of unassigned use due to unknown depths (599 ML of entitlement) and 106 ML assigned to Rosedale GMA but unable to be assigned to a zone due to deficiencies in spatial information.

Characteristic and importance	Description	Degree of understanding
Intended aquifer		
Aquifer thickness within GMU (range, based on VAF)	Max: 684 m, Average: 342 m	High
Aquifer extent	Regional, extensive	High
Likelihood of inter-aquifer flow	Low	Low
Likelihood of groundwater – surface water interaction	Low	Low
Representative Suite	**M_O_2**	**Low. 20% of GMU (Zone 2) 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)	1,222 mg/L (WMIS) <1,200 mg/L (CDM Smith, 2022)	Moderate Based on WMIS and CDM Smith (2022)
Groundwater yield	0.5 – 5 L/s	Low Based on 107 in CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1970-2021**	
Spatial clustering of licensed bores in relation to Suites	**Yes, M_O_2**	**Based on DEECA density mapping and licenced bore data.**
Groundwater use		
Licensed groundwater use	**8,828 ML for all of Rosedale GMA**	**Low – insufficient data to split by zone (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	3,117 ML for all Rosedale GMA	Low - insufficient data to split by zone (Based on historical VWA data, year 2010/11)
Maximum historic groundwater use	**18,923 ML for all Rosedale GMA**	**Low - insufficient data to split by zone (Based on historical VWA data, year 2012/13)**
Entitlement (Groundwater allocation)	**22,272 ML for all of Rosedale GMA**	**Low – insufficient data to split by zone (Based on licenced volumes in 2020/21)**
Significant drivers of groundwater level variability (primary)	**Irrigation. Commercial/Industrial**	**Moderate**
Secondary drivers of groundwater level variability	None identified	
Groundwater use profile	Variable -driven by mining activities	Low

Characteristic and importance	Description	Degree of understanding
External Influence	**Latrobe Valley Mines**	
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	Moderate
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	Moderate

Table 114 Rosedale GMA Zone 3 – Tabulated conceptualisation

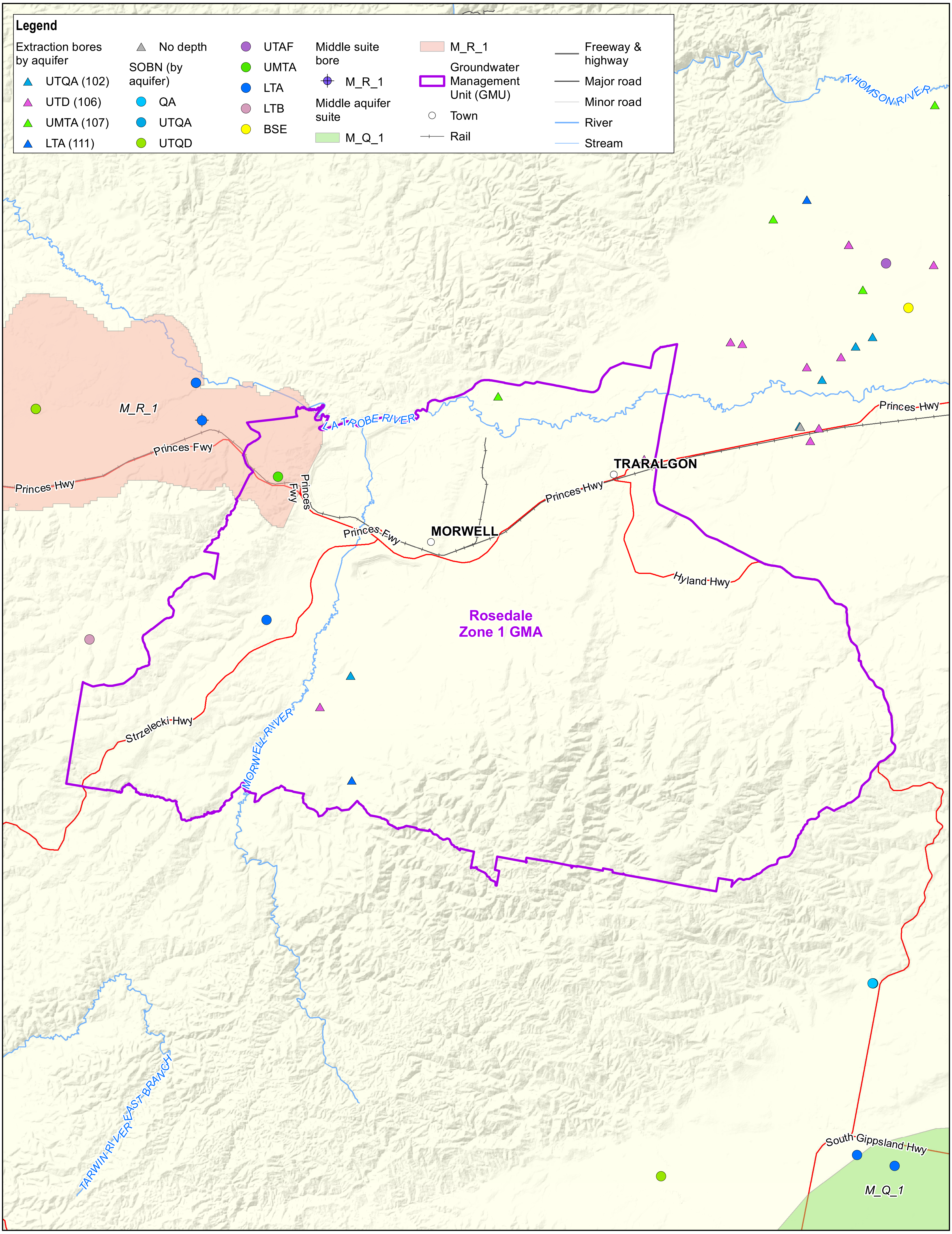
Hydrostratigraphy summary								
Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Use volumes ML (2019/20)	Entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Undifferentiated sediments (QA)	U_AD_1 (7%)	7%	0	NA	0	0	Low
	Haunted Hills Formation (UTQA)	U_AE_1 (3%)	3%	0	NA	0	0	Low
	Nuntin Clay (UTQD)	-	-	0	NA	0	0	Low
Middle	Boisdale (Wurruk Sand) (UTAF)	M_O_1 (32%) M_O_2 (30%) M_P_1 (13%) U_AB_1 (16%)	91%	0	NA	0	0	Low
	Jemmy's Point Formation (UTD)	-	-	0	NA	0	0	Low
	Balook Formation (UMTA)	-	-	0	Irrigation	778	1280	Low
	Gippsland Limestone (UMTD)	-	-	0	NA	0	0	Low
Lower	M2C aquifer (LMTA)	-	-	0	NA	0	0	Low
	Traralgon seams and aquifers (LTA)	L_O_1 (89%)	89%	0	NA	0	0	Low
Basement	Basement rocks (BSE)	-	-	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 106 ML assigned to Rosedale GMA but unable to be assigned to zone due to deficiencies in spatial information.

Characteristic and importance	Description	Degree of understanding
Intended aquifer		
Aquifer thickness within GMU (range, based on VAF)	Max: 777 m, Average: 507 m	High
Aquifer extent	Regional, extensive	High
Likelihood of inter-aquifer flow	Low	Low
Likelihood of groundwater – surface water interaction	Low	Low
Representative Suite	**None identified**	**Low. 100% of GMU (Zone 3) extraction occurs within Suite M_ID_0, which contains insufficient data based on the original Suite development (SKM, 2014)**
Current hydrological condition of representative aquifer		
Representative Suite trend	None identified	Low
Groundwater quality (average salinity based on WMIS and CDM Smith spatial segment(s) with highest coverage)	571 mg/L (WMIS) <1,200 mg/L (CDM Smith, 2022)	Moderate Based on WMIS and CDM Smith (2022)
Groundwater yield	0.5 – 5 L/s	Low Based on 107 in CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1976-2021**	
Spatial clustering of licensed bores in relation to Suites	No	Based on DEECA density mapping and licenced bore data.
Groundwater use		
Licensed groundwater use	**8,828 ML for all of Rosedale GMA**	**Low – insufficient data to split by zone (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	3,117 ML for all Rosedale GMA	Low - **insufficient data to split by zone** (Based on historical VWA data, year 2010/11)
Maximum historic groundwater use	**18,923 ML for all Rosedale GMA**	**Low - insufficient data to split by zone (Based on historical VWA data, year 2012/13)**
Entitlement (Groundwater allocation)	**22,272 ML for all of Rosedale GMA**	**Low – insufficient data to split by zone (Based on licenced volumes in 2020/21)**
Significant drivers of groundwater level variability (primary)	Irrigation. Commercial/Industrial	Moderate
Secondary drivers of groundwater level variability	None identified	

Characteristic and importance	Description	Degree of understanding
Groundwater use profile	Variable – driven by mining activities	Low
External Influence	**Latrobe Valley Mines**	
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	Moderate
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	Moderate



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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

Rosedale GMA: Zone 1
Site location and key features

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

Figure 295a

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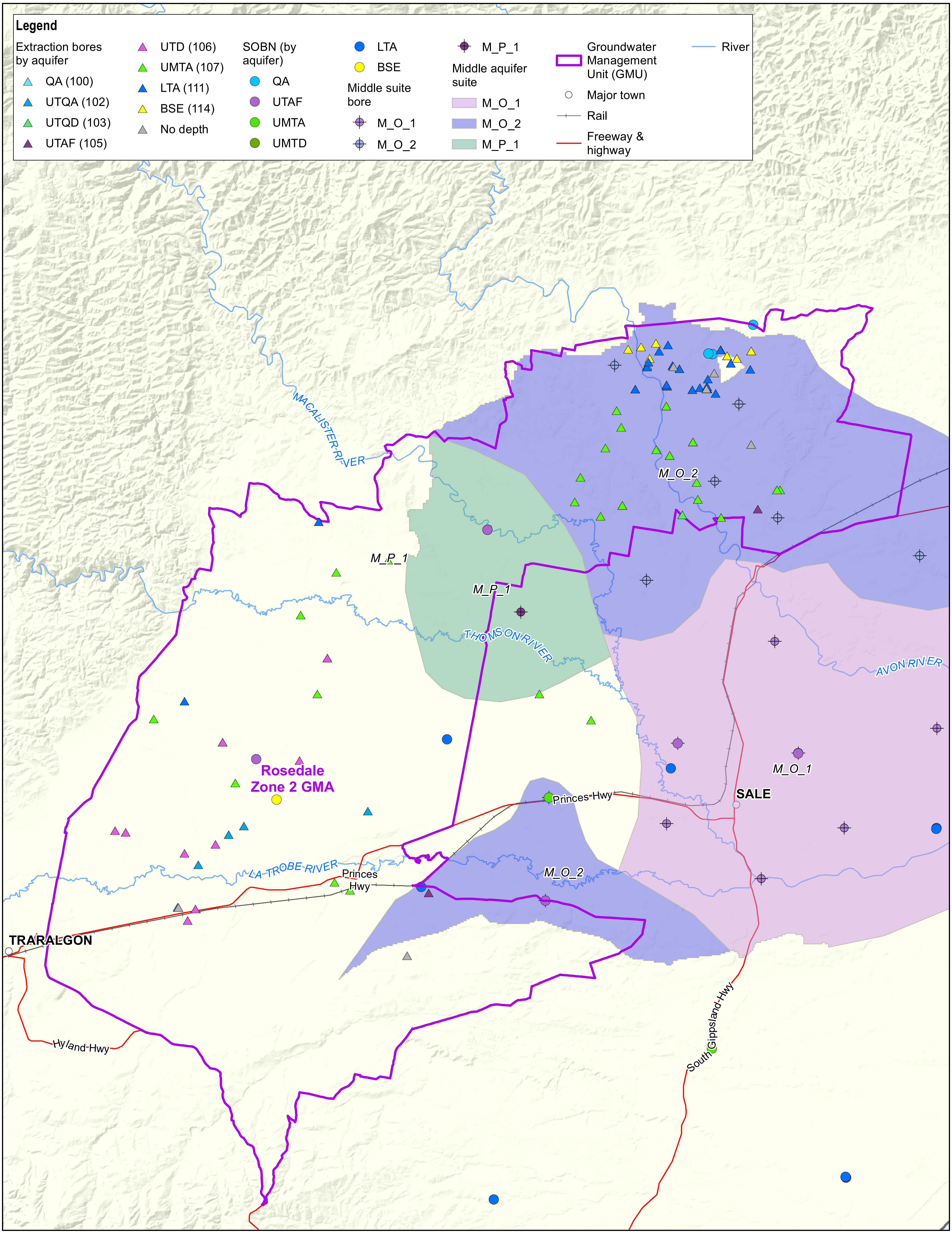
Data source: DELWP, VicMap, 2022; DELWP, GMUs, 2022; DELWP, SOBN, 2022; GHD, aquifer suites, 2018; DELWP, extraction bores, 2022 Created by: cperyer



Paper Size ISO A3

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Kilometers

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
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DEECA
Sustainable yield review - confined aquifers

Rosedale GMA: Zone 2
Site location and key features

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

Figure 295b

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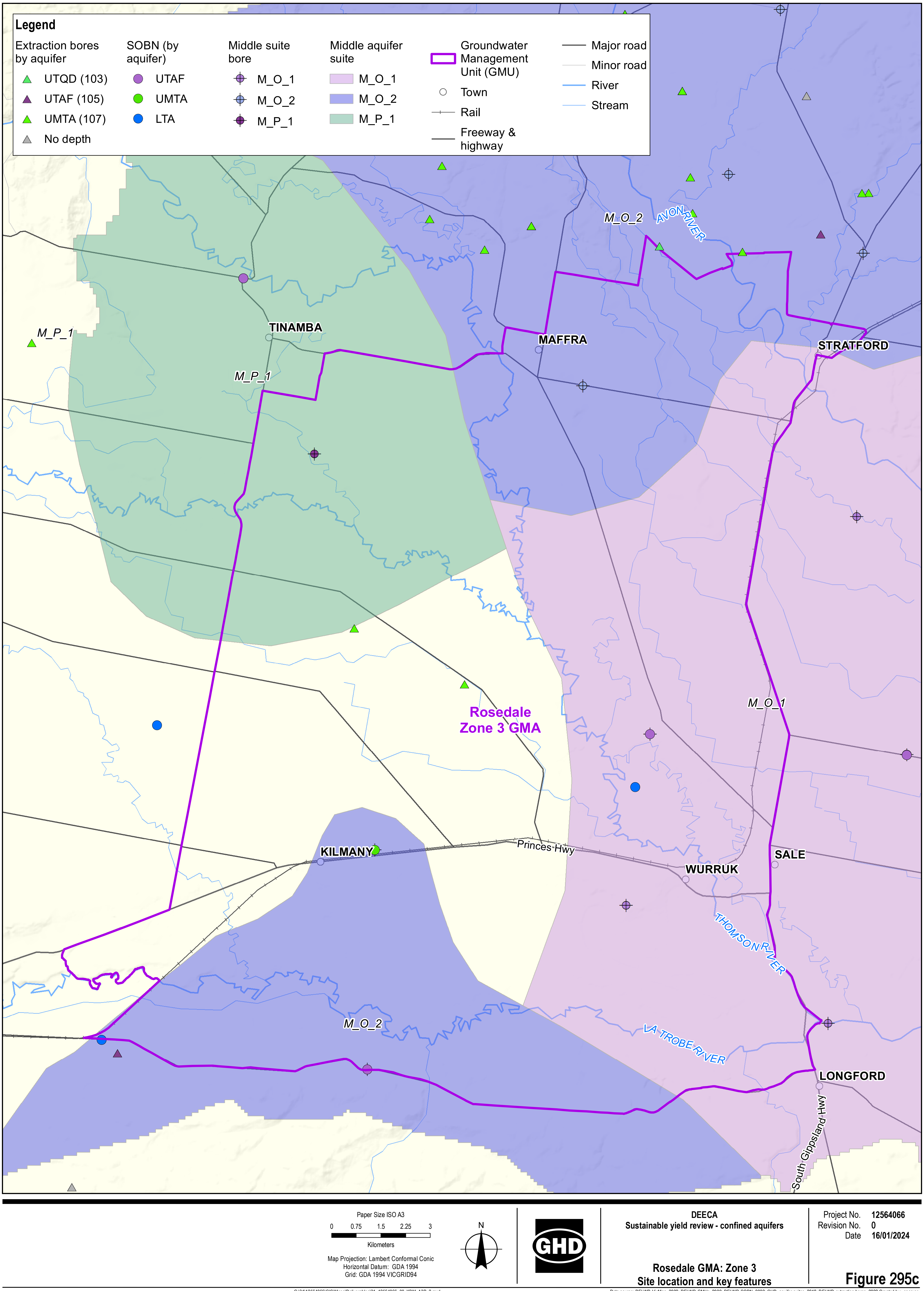

DEECA
Sustainable yield review - confined aquifers

Rosedale GMA: Zone 3
Site location and key features

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

Figure 295c

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

20.2 Technical analysis

20.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs generated for the relevant Suites for Rosedale GMA are shown in Figure 296, Figure 297 and Figure 298. It is noted that Suite L_O_1 consistently appears in all three zones for Rosedale GMA. The data for M_R_1 in Figure 296, shows sudden changes and ends prior to 2000, however, this Suite is not considered further in this assessment. Suite M_P_1 in Figure 297 and Figure 298 does not show seasonality in its response and thus would not exhibit annual recovered levels.

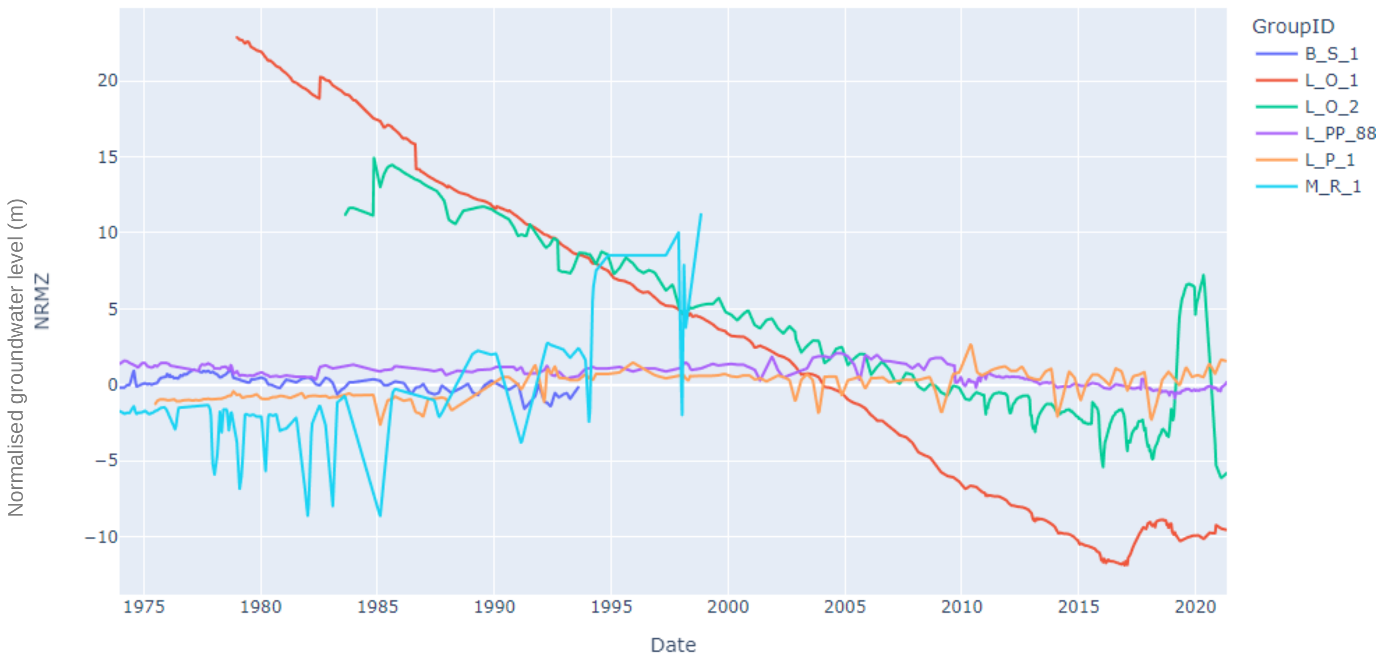


Figure 296 Rosedale GMA Zone 1 Suite Hydrographs for all confined aquifers

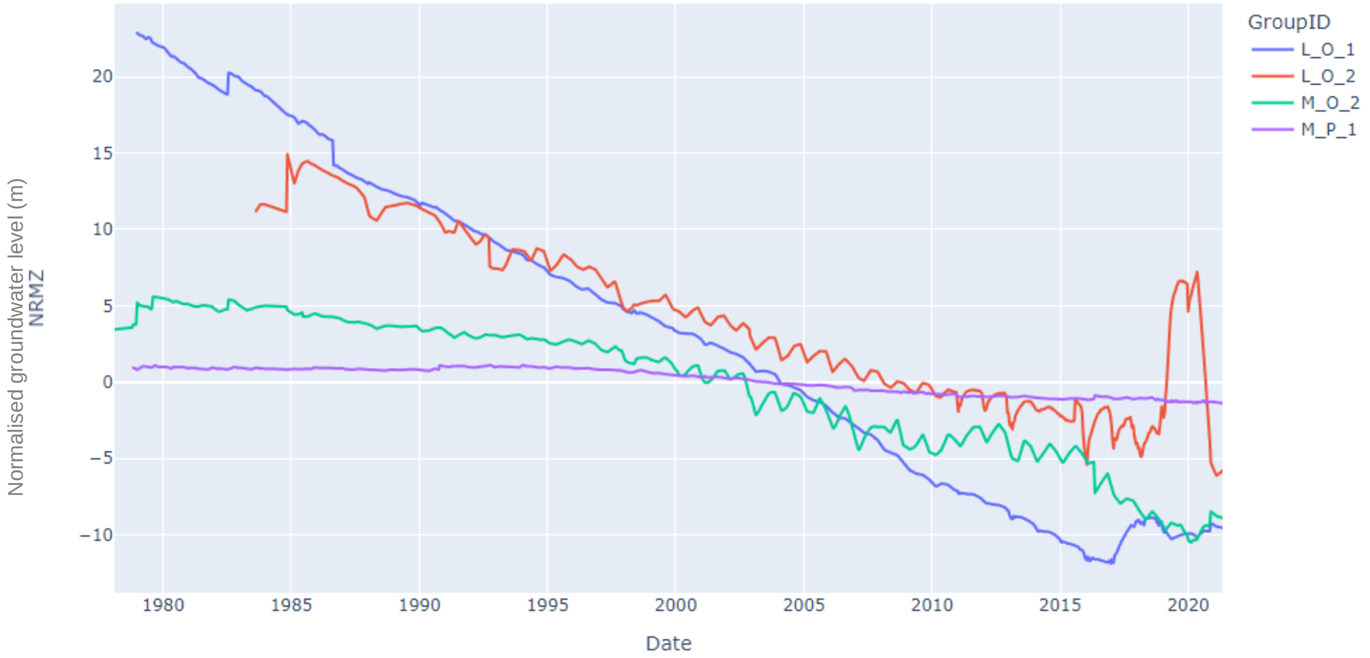


Figure 297 ***Rosedale GMA Zone 2 Suite Hydrographs for all confined aquifers***

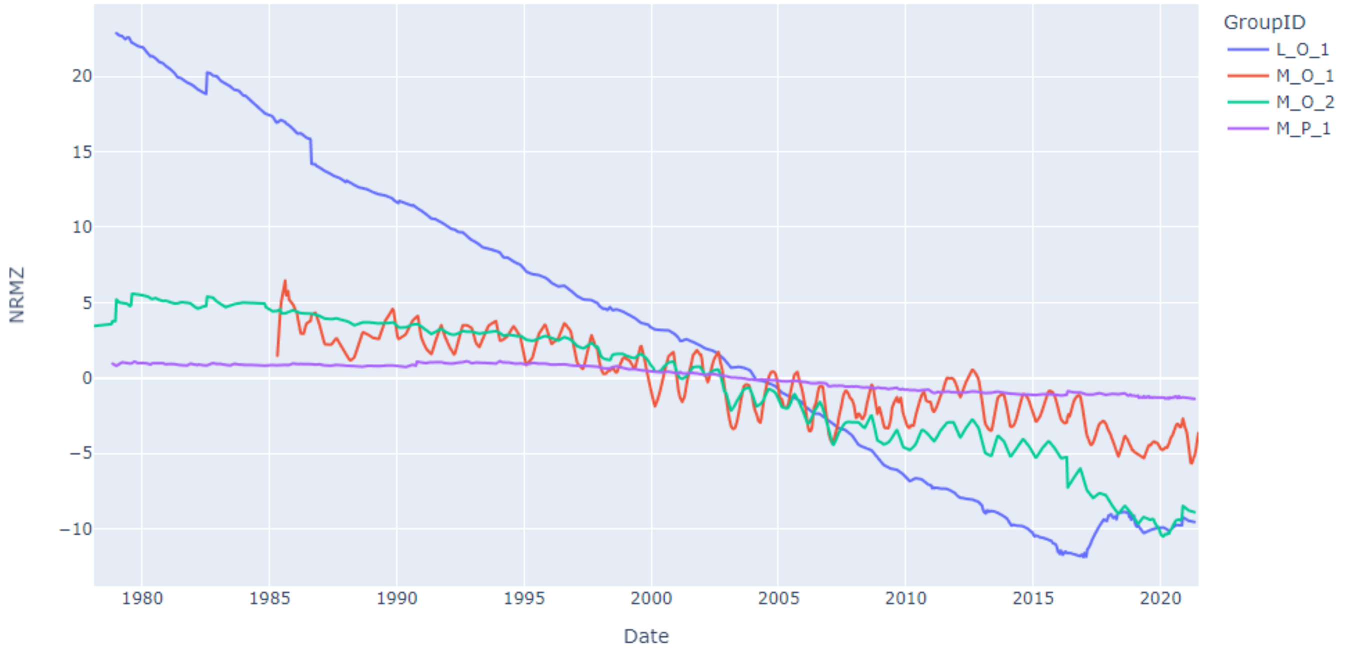


Figure 298 ***Rosedale GMA Zone 3 Suite Hydrographs for all confined aquifers***

The representative Suite analysed for this GMU was Suite M_O_2. 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 Middle Aquifer with much of the other extraction occurring outside of Suite areas within the GMU
- The greatest volumes of extraction occurs within zone 2 of Rosedale GMA
- The Middle Aquifer pertains to the UMTA, which is one of the intended aquifers of the GMU

– Suite M_O_2. covers 17% of the GMU
– Suite M_O_2 has no active SOBN bores within the GMU
– Suite M_O_2 is close to extraction points

The annual recovered Suite hydrographs for the representative Suite M_O_2 for Rosedale GMA, is shown in Figure 299.

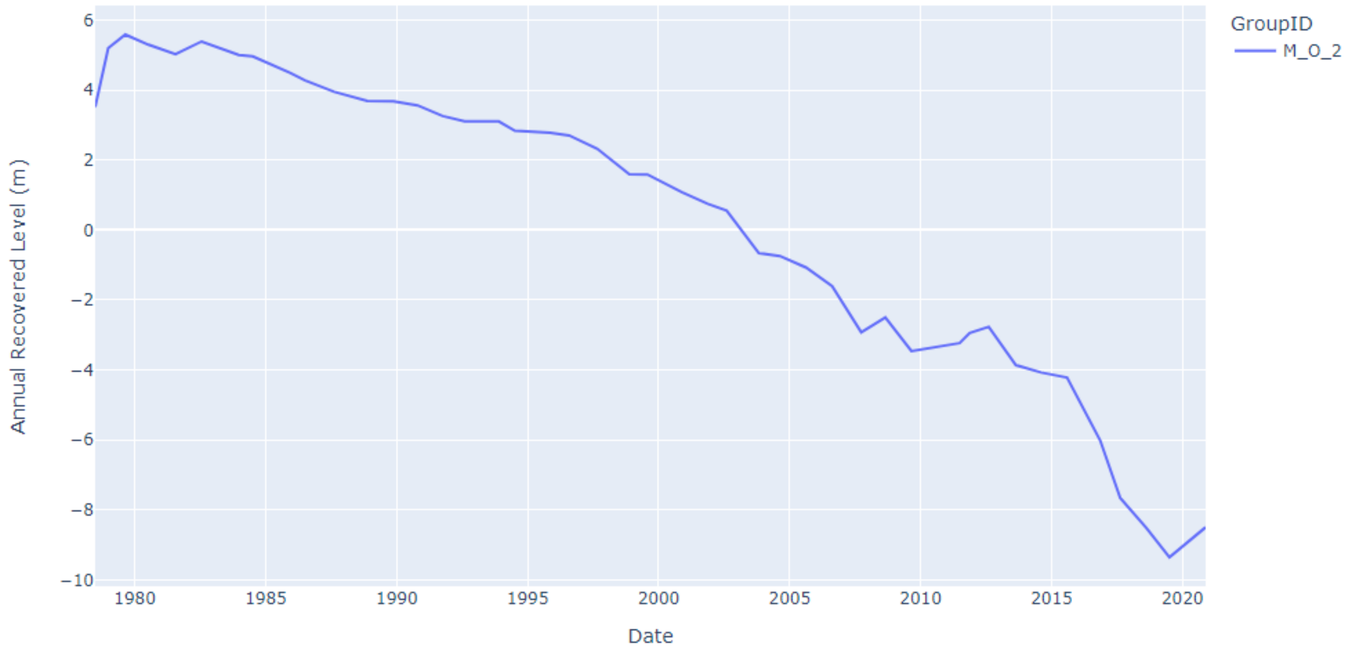


Figure 299 Rosedale GMA Annual Recovered Level Suite Hydrographs for representative Suites

20.2.2 Pre-development level

To estimate the pre-development level conditions, GHD reviewed the Suite hydrographs of annual recovered levels and assumed that the maximum levels in the early time series data was the best representation of conditions prior to major development within Rosedale GMA for Suite M_O_2.

The pre-development annual recovered levels is taken to be the maximum level in the early time series data in 1979/1980 which equates to 5.58 m for Suite M_O_2 (refer further details in section 20.4.3).

20.2.3 Externalities

As identified through the conceptualisation, Rosedale GMA may be influenced by extraction occurring at the Latrobe Valley Mines (in the underlying aquifer system) and also by offshore oil and gas extraction. To test the influence of this extraction, data was obtained to incorporate into the model.

Figure 300 shows the Rosedale GMA annual groundwater extraction volumes, the Latrobe Valley Mines extraction volumes, offshore extraction volumes and the combined volumes. Note that where extraction does not occur in both Rosedale GMA and Latrobe Valley Mines or Rosedale GMA and Offshore or all three datasets, that year of data cannot be incorporated into the model without hindcasting. It is noted that the Latrobe Valley Mines extraction is typically more than double the extraction of Rosedale GMA and would already incorporate some of the extraction occurring in Rosedale GMA. Offshore extraction is generally more than double the extraction at Rosedale GMA.

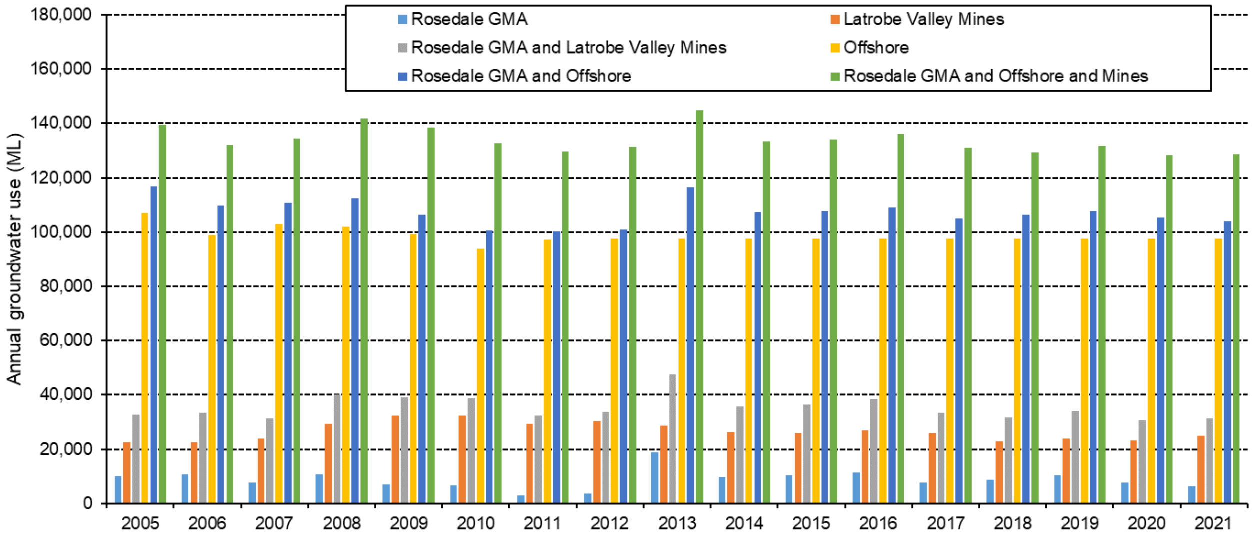


Figure 300 Rosedale GMA and externalities – groundwater use

20.2.4 Hindcasting

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

20.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, four different correlations were developed using the annual groundwater extraction as described below and shown in Figure 301:

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

Four additional correlations were developed using annual irrigation extraction as described below and shown in Figure 302:

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

Four additional correlations were developed incorporating the annual extraction from the Latrobe Valley Mines as described below and shown in Figure 303:

- Annual rainfall vs annual groundwater extraction at Rosedale GMA and Latrobe Valley Mines
- Two yearly average annual rainfall vs annual groundwater extraction at Rosedale GMA and Latrobe Valley Mines
- Annual summer period rainfall vs annual groundwater extraction at Rosedale GMA and Latrobe Valley Mines
- Annual irrigation period rainfall vs annual groundwater extraction at Rosedale GMA and Latrobe Valley Mines

Four additional correlations were developed incorporating the annual extraction from Offshore as described below and shown in Figure 304:

- Annual rainfall vs annual groundwater extraction at Rosedale GMA and Offshore
- Two yearly average annual rainfall vs annual groundwater extraction at Rosedale GMA and Offshore
- Annual summer period rainfall vs annual groundwater extraction at Rosedale GMA and Offshore
- Annual irrigation period rainfall vs annual groundwater extraction at Rosedale GMA and Offshore

Four additional correlations were developed incorporating the annual extraction from the Latrobe Valley Mines and Offshore as described below and shown in Figure 305:

- Annual rainfall vs annual groundwater extraction at Rosedale GMA, Offshore and Latrobe Valley Mines
- Two yearly average annual rainfall vs annual groundwater extraction at Rosedale GMA, Offshore and Latrobe Valley Mines
- Annual summer period rainfall vs annual groundwater extraction at Rosedale GMA, Offshore and Latrobe Valley Mines
- Annual irrigation period rainfall vs annual groundwater extraction at Rosedale GMA, Offshore and Latrobe Valley Mines

As shown in Figure 301, the goodness-of-fit represented by the R^2 is low across all four correlations developed. The correlation with annual irrigation rainfall and annual rummer rainfall are very similar. When only annual irrigation groundwater use is considered (Figure 302), all correlations increased with annual irrigation rainfall showing the highest R^2; this is the correlation adopted for method H1 without considering external influence. When external influence is considered by incorporating extraction from the Latrobe Valley Mines, the R^2 was low across all four correlations, with the highest correlation being with annual summer rainfall; this was adopted with method H1 when considering this externality. When Offshore extraction was incorporated as the only externality (Figure 304), the R^2 was again low across all correlations, with the highest correlation being with annual summer rainfall; this was adopted with method H1 when considering this externality. When both Offshore and Latrobe Valley Extraction was incorporated as the only externality (Figure 305), the R^2 was again low across all correlations, with the highest correlation being with annual summer rainfall; this was adopted with method H1 when considering both these externalities.

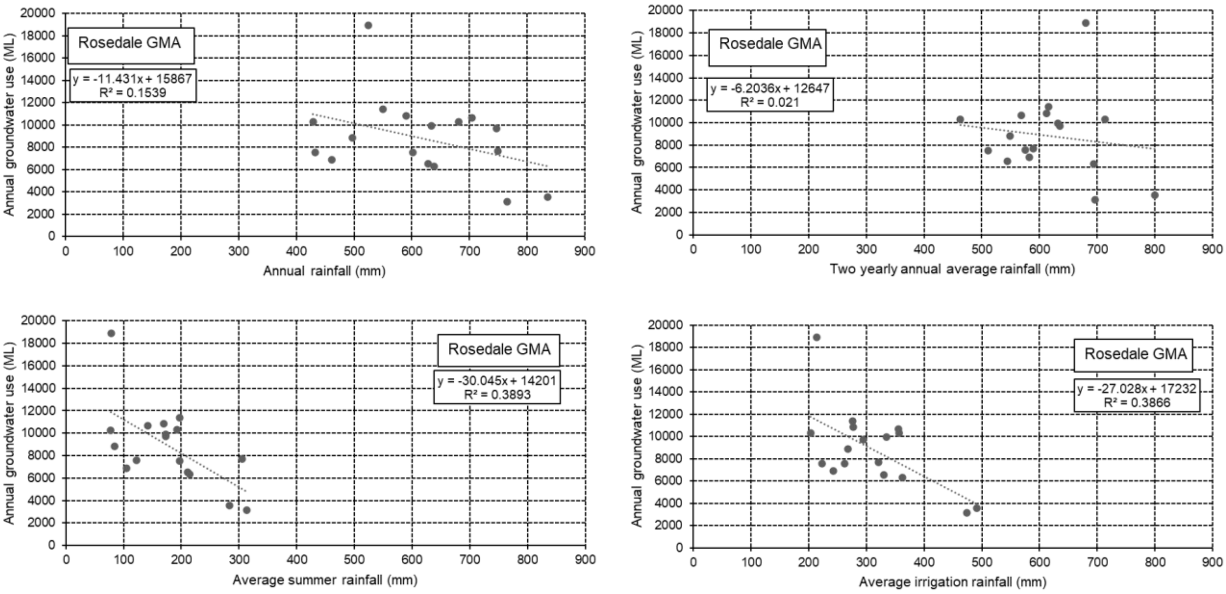


Figure 301 Rosedale GMA: Hindcast method 1 correlations (Rosedale GMA annual extraction)

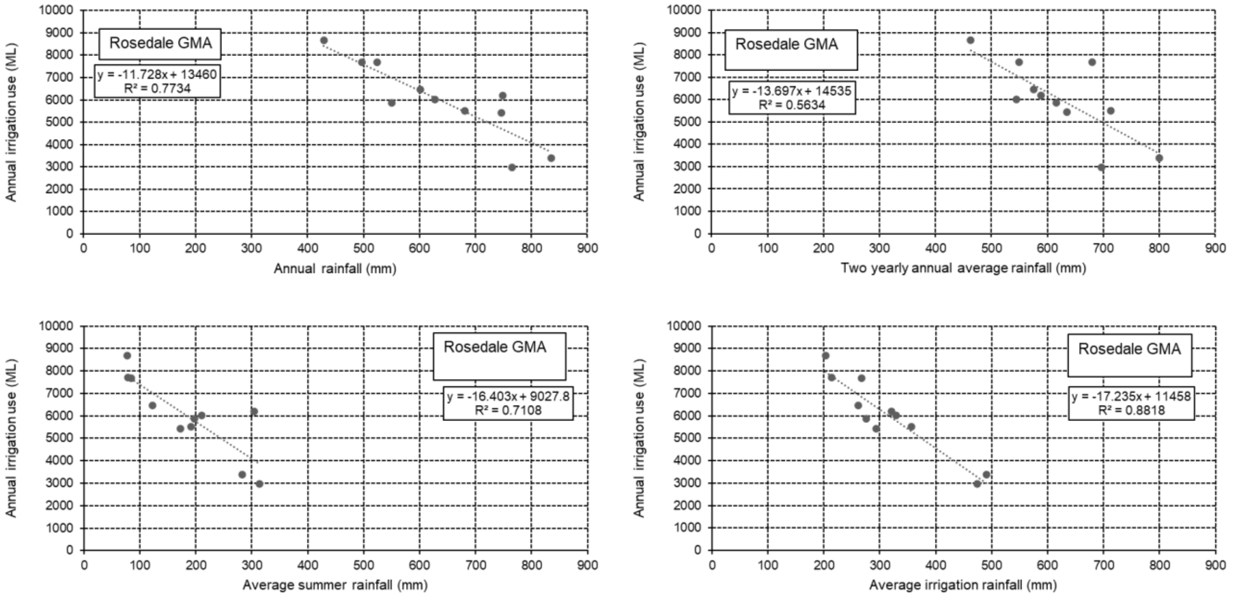


Figure 302 Rosedale GMA: Hindcast method 1 correlations (Rosedale GMA annual irrigation extraction)

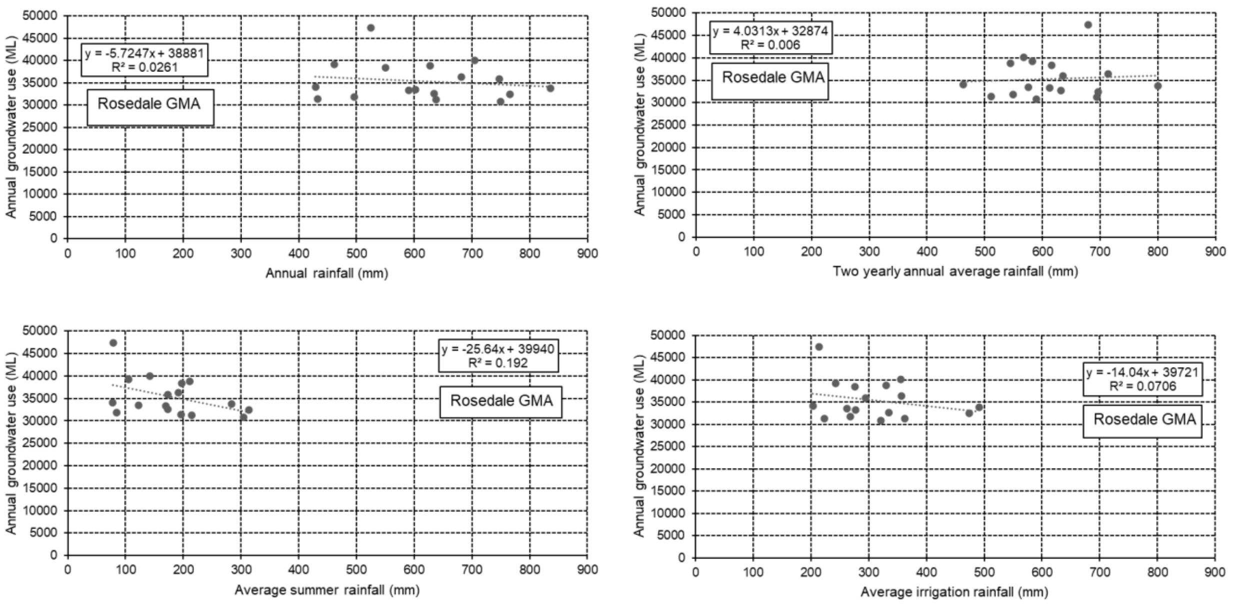


Figure 303 Rosedale GMA: Hindcast method 1 correlations (Rosedale GMA annual extraction with Latrobe Valley Mines extraction)

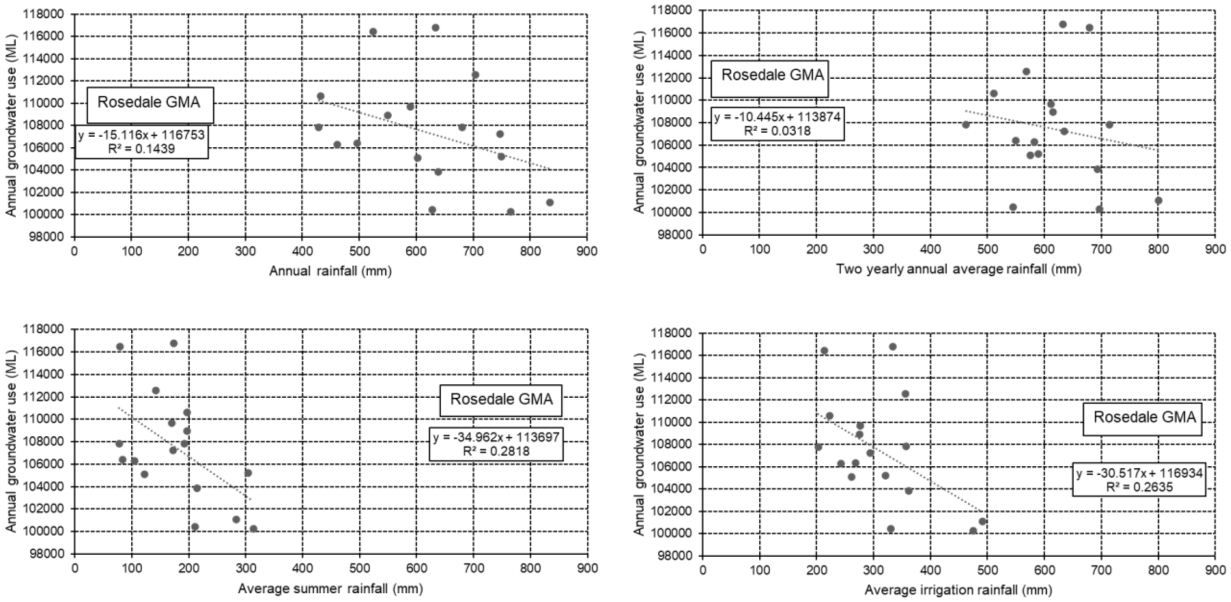


Figure 304 Rosedale GMA: Hindcast method 1 correlations (Rosedale GMA annual extraction with Offshore extraction)

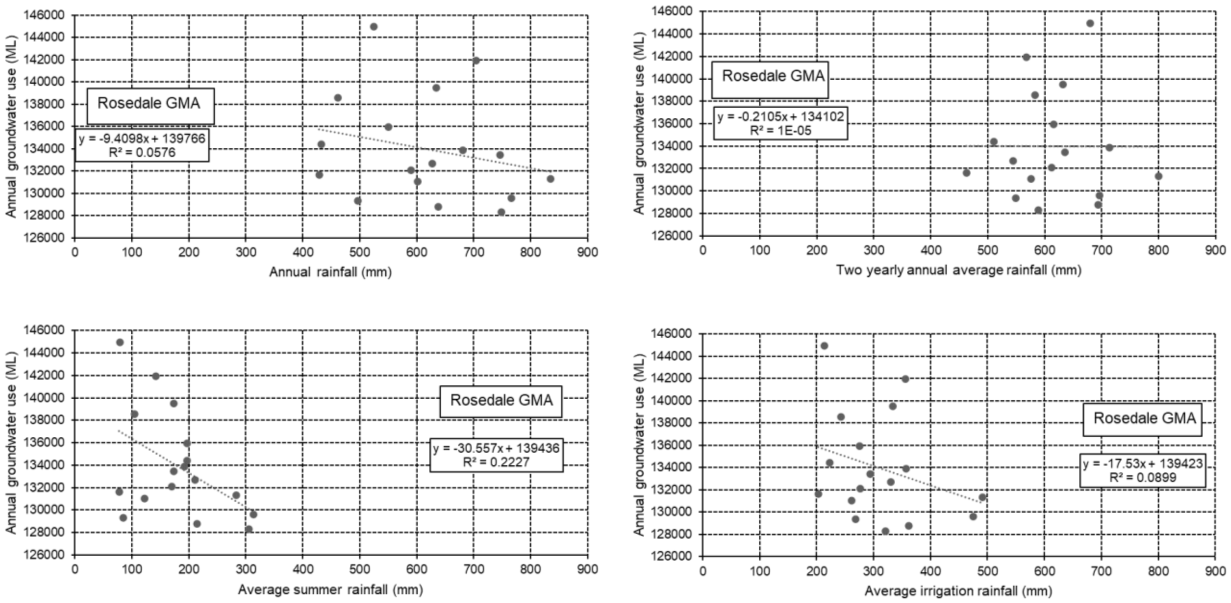


Figure 305 Rosedale GMA: Hindcast method 1 correlations (Rosedale GMA annual extraction with Latrobe Valley Mines and Offshore extraction)

20.2.4.2 Hindcasting Method 2 (H2)

Four correlations were developed using method H2 as described below and shown in Figure 306:

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

An additional four correlations were developed to incorporate extraction within the Latrobe Valley Mines as described below and shown in Figure 307:

- Combined Rosedale GMA and Latrobe Valley Mine use per Rosedale GMA bore vs annual rainfall
- Combined Rosedale GMA and Latrobe Valley Mine use per Rosedale GMA bore vs two yearly average annual rainfall
- Combined Rosedale GMA and Latrobe Valley Mine use per Rosedale GMA bore vs annual summer period rainfall
- Combined Rosedale GMA and Latrobe Valley Mine use per Rosedale GMA bore vs annual irrigation period rainfall

An additional four correlations were developed to incorporate extraction from Offshore as described below and shown in Figure 308:

- Combined Rosedale GMA and Offshore use per Rosedale GMA bore vs annual rainfall
- Combined Rosedale GMA and Offshore use per Rosedale GMA bore vs two yearly average annual rainfall
- Combined Rosedale GMA and Offshore use per Rosedale GMA bore vs annual summer period rainfall
- Combined Rosedale GMA and Offshore use per Rosedale GMA bore vs annual irrigation period rainfall

An additional four correlations were developed to incorporate extraction from both Offshore and the Latrobe Valley Mines as described below and shown in Figure 309:

- Combined Rosedale GMA, Offshore and Latrobe Valley Mines use per Rosedale GMA bore vs annual rainfall
- Combined Rosedale GMA, Offshore and Latrobe Valley Mines use per Rosedale GMA bore vs two yearly average annual rainfall
- Combined Rosedale GMA, Offshore and Latrobe Valley Mines use per Rosedale GMA bore vs annual summer period rainfall
- Combined Rosedale GMA, Offshore and Latrobe Valley Mines useper Rosedale GMA bore vs annual irrigation period rainfall

As shown in Figure 306, the goodness-of-fit represented by the R^2 is low across all four correlations. The highest R^2 is the correlation with annual summer rainfall. Thus, the correlation with annual summer rainfall has been adopted for hindcast method H2 when Latrobe Valley Mine extractions are not considered. When extraction from the Latrobe Valley Mines is incorporated (Figure 307), the R^2 of the correlations generally decrease. Similar to Figure 306, the highest R^2 when Latrobe Valley Mine extraction was considered was when annual summer rainfall was adopted. Thus, annual summer rainfall has been adopted for hindcast method H2 when Latrobe Valley Mine extractions are considered. When Offshore extraction was incorporated as the only externality (Figure 308, Figure 304), the R^2 was again low across all correlations, with the highest correlation being with annual summer rainfall; this was adopted with method H2 when considering this externality. When both Offshore and Latrobe Valley Extraction was incorporated as the only externality (Figure 309), the R^2 was again low across all correlations, with the highest correlation being with annual summer rainfall; this was adopted with method H2 when considering both these externalities.

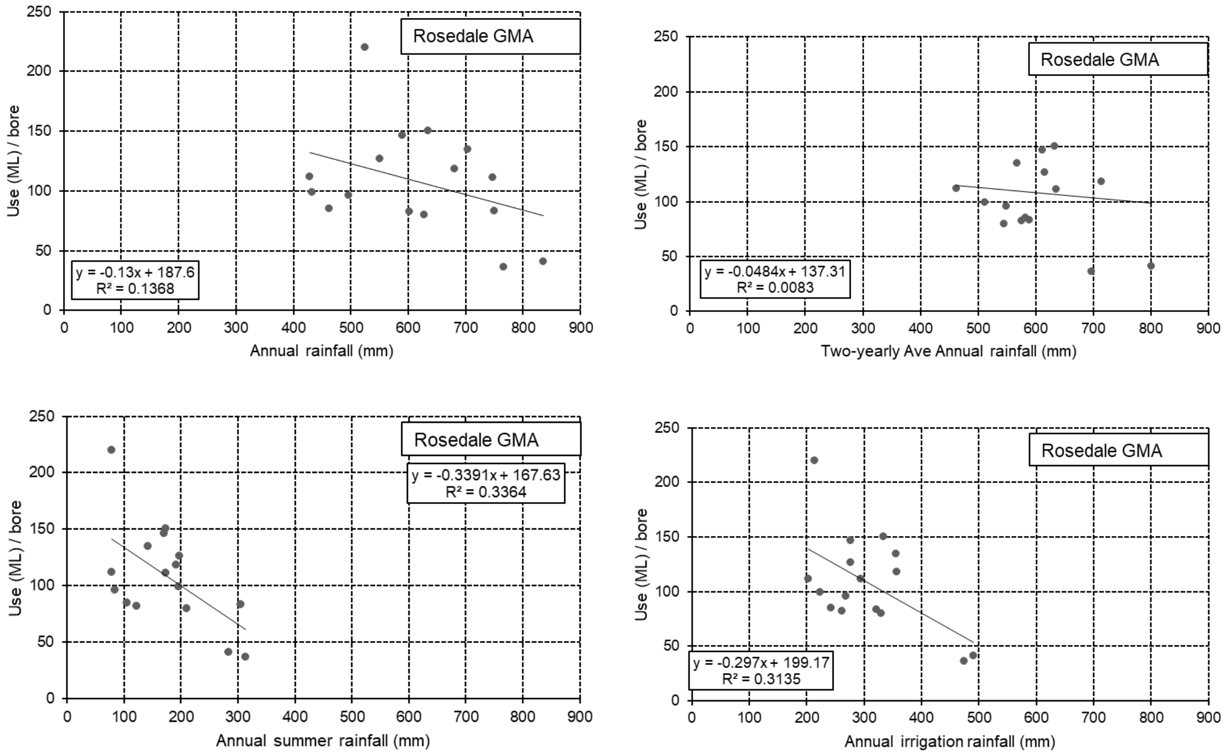


Figure 306 Rosedale GMA: Hindcast method 2 correlations (Rosedale GMA only extraction)

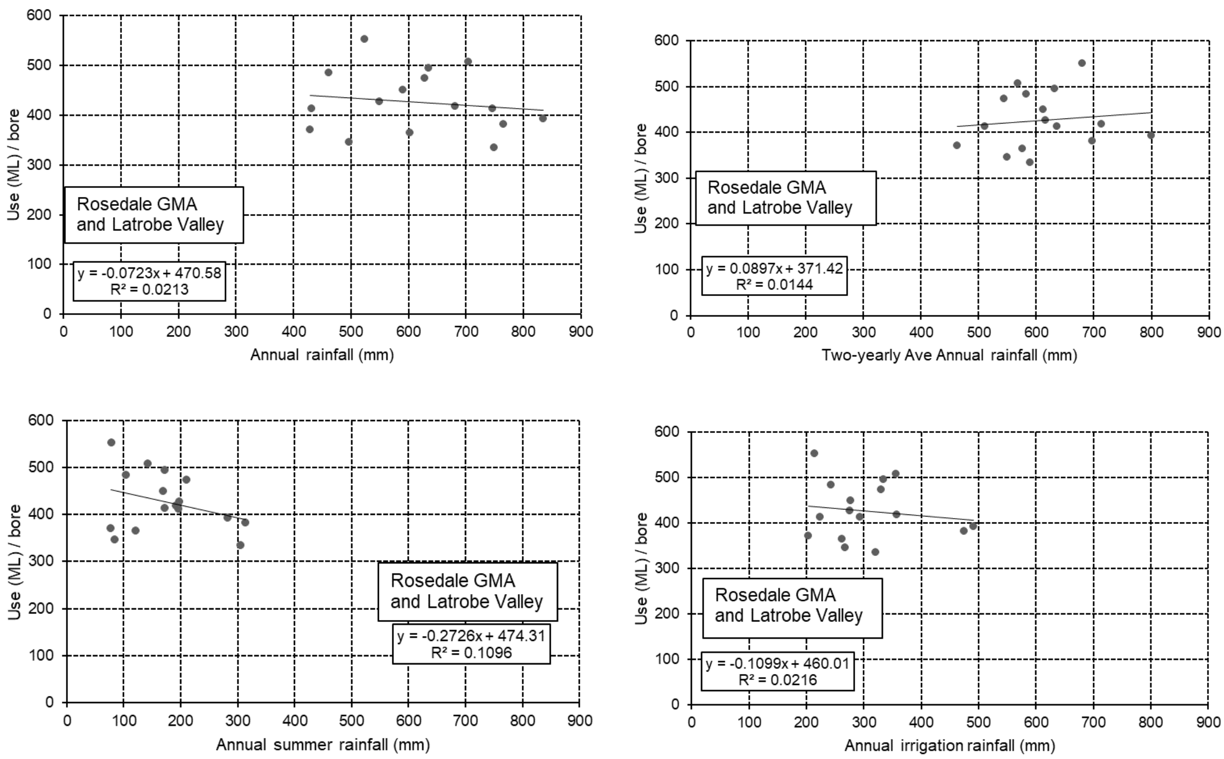


Figure 307 Rosedale GMA: Hindcast method 2 correlations (Rosedale GMA and Latrobe Valley mines extraction)

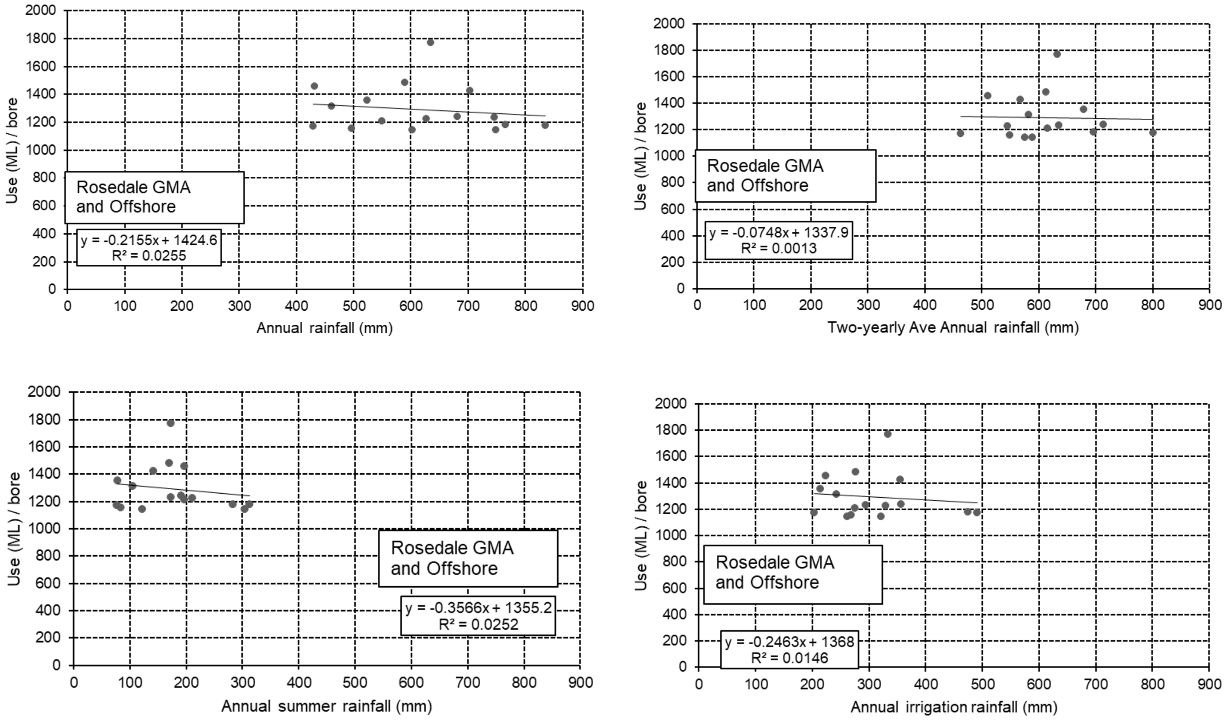


Figure 308 Rosedale GMA: Hindcast method 2 correlations (Rosedale GMA and Offshore extraction)

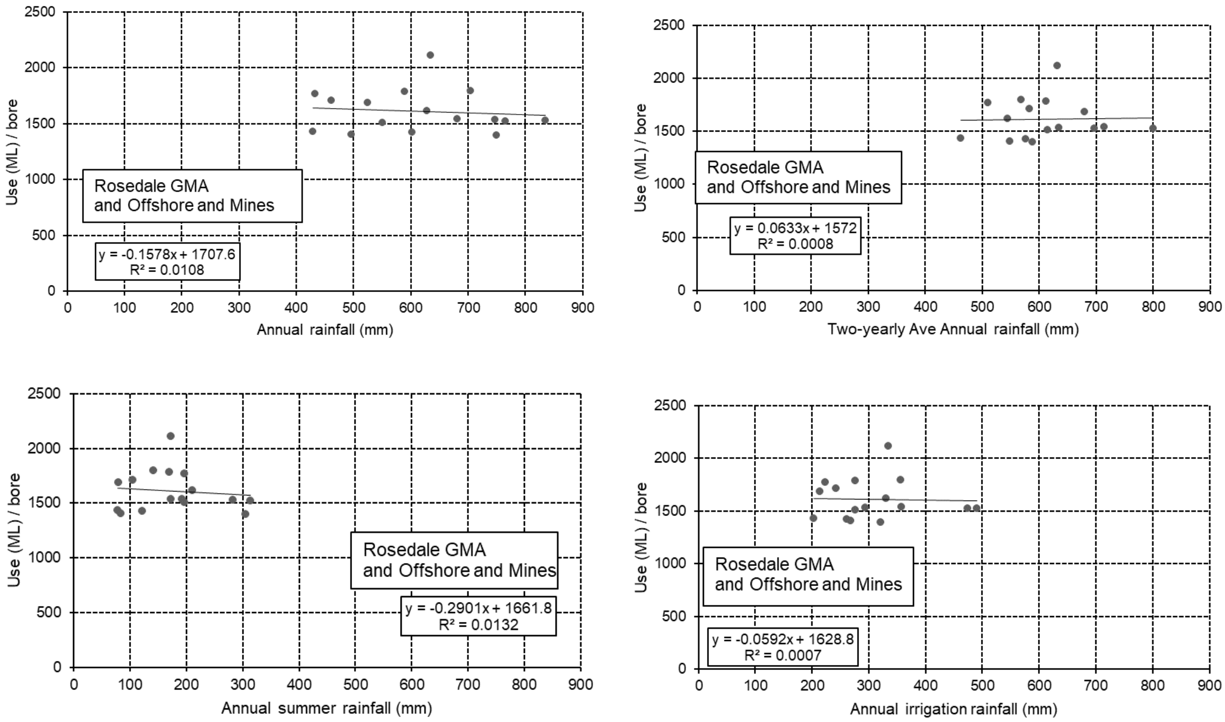


Figure 309 Rosedale GMA: Hindcast method 2 correlations (Rosedale GMA, Offshore and Latrobe Valley Mines extraction)

20.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 310:

- 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

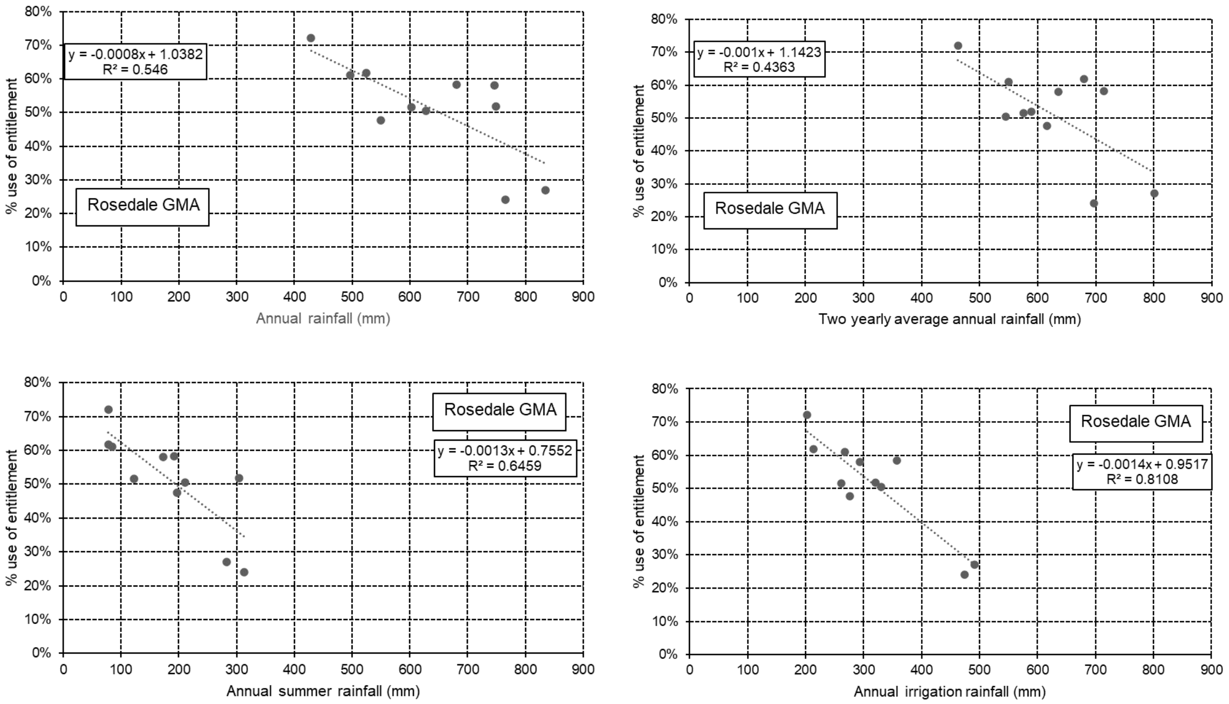


Figure 310 Rosedale GMA: Hindcast method 3 correlations (Rosedale GMA only extraction)

As shown in Figure 310, the goodness-of-fit represented by the R^2 was similar to that from method H1 when only annual irrigation extraction was considered. The highest R^2 was the correlation with annual irrigation rainfall followed by the correlation with annual summer rainfall. Thus, the correlation with annual irrigation rainfall has been adopted for hindcast method H3.

20.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 311 and Figure 312 for the hindcasting based on only Rosedale GMA groundwater use. Figure 311 shows a comparison of the three hindcasting methods against the recorded use only (over the recorded use dates) and Figure 312 shows the hindcasted data back to 1973/1974. A comparison of the three input datasets for hindcasting based on the combined Rosedale GMA and Latrobe Valley Mines groundwater use is shown in Figure 313 and Figure 314. Figure 313 shows a comparison of the three hindcasting methods against the recorded use only (over the recorded use dates) and Figure 314 shows the hindcasted data back to 1973/1974.

As shown in Figure 312 and Figure 314, 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 and thus provides a higher groundwater extraction estimate than the other two methods. Hindcasting results show that the smallest average variation of recorded use to estimated use occurs for method 2 when considering Latrobe Valley Mine extraction and method 1 when only Rosedale GMA extraction is considered. As per the issues discussed with method H1 previously, hindcasting method H2 and H3 are expected to provide a more probable estimated groundwater use than method 1 for Rosedale GMA.

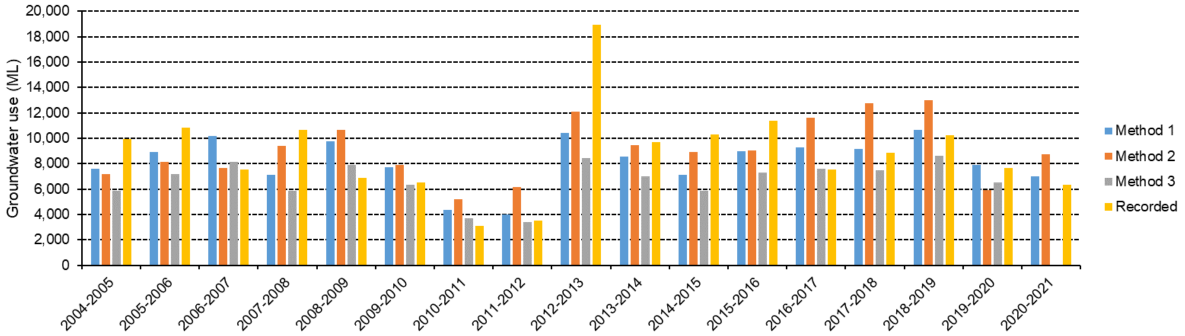


Figure 311 ***Rosedale GMA: Comparison of hindcasting over recorded use period – Rosedale GMA only extraction***

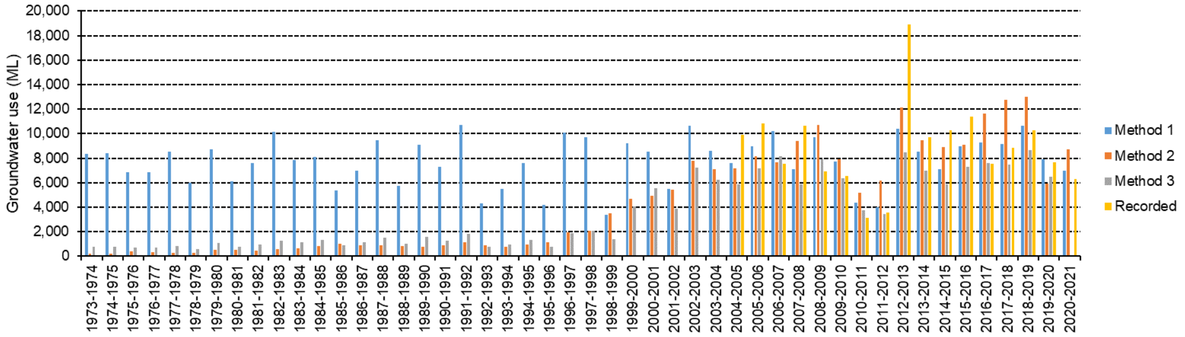


Figure 312 ***Rosedale GMA: Comparison of hindcasting – Rosedale GMA only extraction***

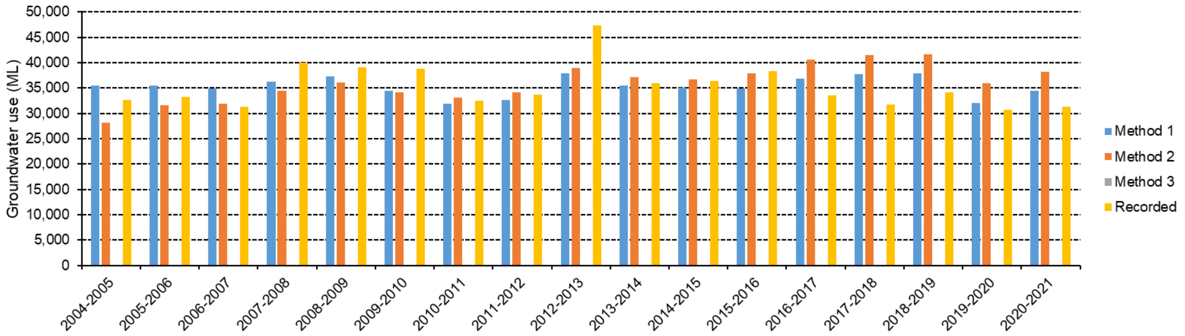


Figure 313 ***Rosedale GMA: Comparison of hindcasting over recorded use period – Rosedale GMA and Latrobe Valley Mines***

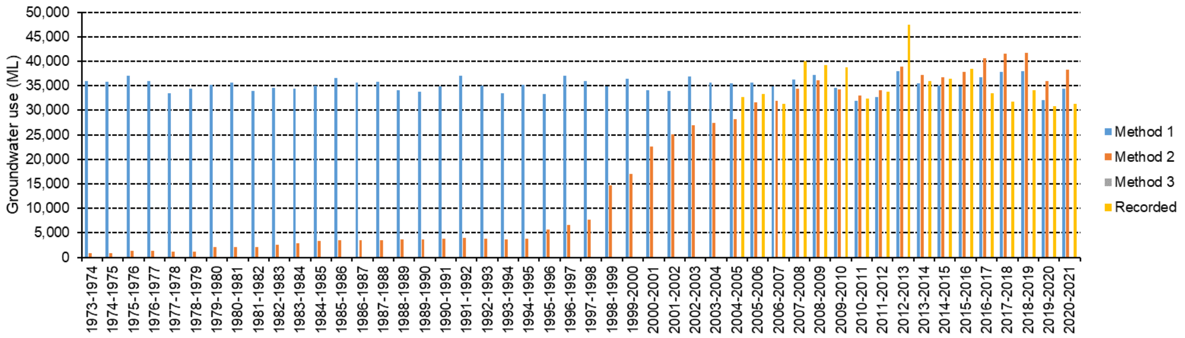


Figure 314 ***Rosedale GMA: Comparison of hindcasting – Rosedale GMA and Latrobe Valley Mines***

20.3 Modelling

20.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 115 summarises these combinations of model inputs run for Rosedale GMA. Model runs highlighted blue indicate they were run with annual extraction and grey indicates they were run using two yearly average annual extraction.

Table 115 Rosedale 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 (M_O_2)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Rosedale GMA only	✓																		
Two yearly average annual extraction – Rosedale GMA only		✓																	
Annual extraction – Rosedale GMA and Externalities			✓																
Two yearly average annual extraction – Rosedale GMA and Externalities				✓															
H1 annual extraction – Rosedale GMA only					✓														
H1 annual extraction – Rosedale GMA and Externalities						✓													
H2 annual extraction – Rosedale GMA only							✓												
H2 annual extraction – Rosedale GMA and Externalities								✓											
H3 annual extraction – Rosedale GMA only									✓										
H1 two yearly average annual extraction – Rosedale GMA only										✓									
H1 two yearly average annual extraction – Rosedale 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 – Rosedale GMA only												✓							
H2 two yearly average annual extraction – Rosedale GMA and Externalities													✓						
S1 annual extraction – Rosedale GMA only														✓					
S2 annual extraction – Rosedale GMA only															✓				
S3 annual extraction – Rosedale GMA only																✓			
S1 annual extraction and H1 annual extraction – Rosedale GMA only																	✓		
S2 annual extraction and H2 annual extraction – Rosedale GMA only																		✓	
S3 annual extraction and H3 annual extraction – Rosedale GMA only																			✓

20.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 115 is presented in Table 116 and Table 117 (only models with externalities included) for the selection of the representative Suite, M_O_2, for Rosedale GMA selected using the process outlined in section 20.2.1. 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 M_O_2

A review of the results and statistical summary for Suite M_O_2 shows that model runs 9 and 12 (highlighted green) had the best results (when considering the four measures which reflect the uncertainty, accuracy and precision of the model) of the different model input combinations. Model run 9 and 12 have the smallest 95PPU thickness and model run 9 has the third highest R^2. The RMSE of the two model runs are not the smallest values when compared to the other runs, but taking into account the three other statistical measures, they are considered the best results. Model run 9 has a lower 95PPU thickness, higher percentage of observations in the 95PPU band, higher R^2 and lower RMSE compared to model run 12. The graphical model output for these model runs (9 and 12) are shown in Figure 315 and Figure 316.

Based on these results, model run 9 has been adopted to progress to predictive modelling for Suite M_O_2.

Table 116 Rosedale GMA: summary of model outputs (without externalities)

Suite	Statistic	Model run												
		1	2	5	7	9	10	12	14	15	16	17	18	19
M_O_2	95PPU TH	25.22	10.91	9.31	14.12	6.36	10.95	6.61	12.01	24.29	7.92	6.8	39.55	39.55
	%Obs in 95 PPU	100	100	97.73	90.91	97.73	97.73	93.18	90	100	80	81.4	90.7	90.7
	R^2	90.9	84.1	97.0	32.2	93.0	97.1	91.6	98.1	72.8	87.7	74.5	92.4	92.4
	RMSE	0.77	1.01	0.73	3.49	1.12	0.72	1.23	0.32	1.21	0.81	2.05	1.12	1.12
	No obs data points	16	16	44	44	44	44	44	10	10	10	43	43	43
	Range of observed levels	8.3	8.3	14.9	14.9	14.9	14.9	14.9	6.6	6.6	6.6	14.9	14.9	14.9

Table 117 Rosedale GMA: summary of model outputs (externalities only)

Suite	Statistic	Model run																	
		3	3a	3b	4	4a	4b	6	6a	6b	8	8a	8b	11	11a	11b	13	13a	13b
M_O_2	95PPU TH	15.89	17.62	18.07	14.62	15.93	17.63	10.79	10.84	10.84	7.82	6.52	6.92	9.08	10.91	9.28	7.72	6.45	6.71
	%Obs in 95 PPU	100	100	100	100	100	100	97.73	97.73	95.45	97.73	95.45	95.45	95.45	95.45	95.45	97.73	93.18	97.73
	R^2	89.3	89.5	89.7	89.1	89.6	89.7	97.0	97.0	97.0	90.6	88.8	89.7	96.9	97.0	96.9	90.3	87.7	89.1
	RMSE	0.83	0.82	0.82	0.84	0.82	0.82	0.74	0.73	0.74	1.3	1.42	1.36	0.75	0.73	0.75	1.32	1.48	1.4
	No obs data points	16	16	16	16	16	16	44	44	44	44	44	44	44	44	44	44	44	44
	Range of observed levels	8.3	8.3	8.3	8.3	8.3	8.3	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9

Note that no letter = mining only, a =offshore, b = offshore and mining

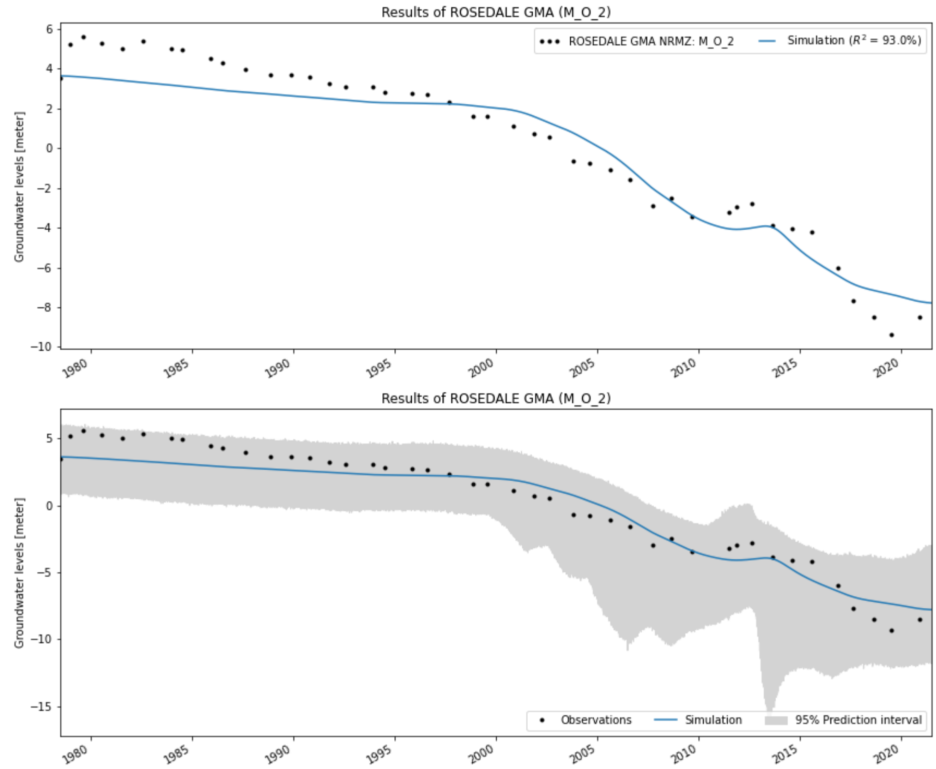


Figure 315 ***Rosedale GMA Suite M_O_2: model run 9 (Rosedale GMA annual extraction with hindcast method 3) output hydrographs***

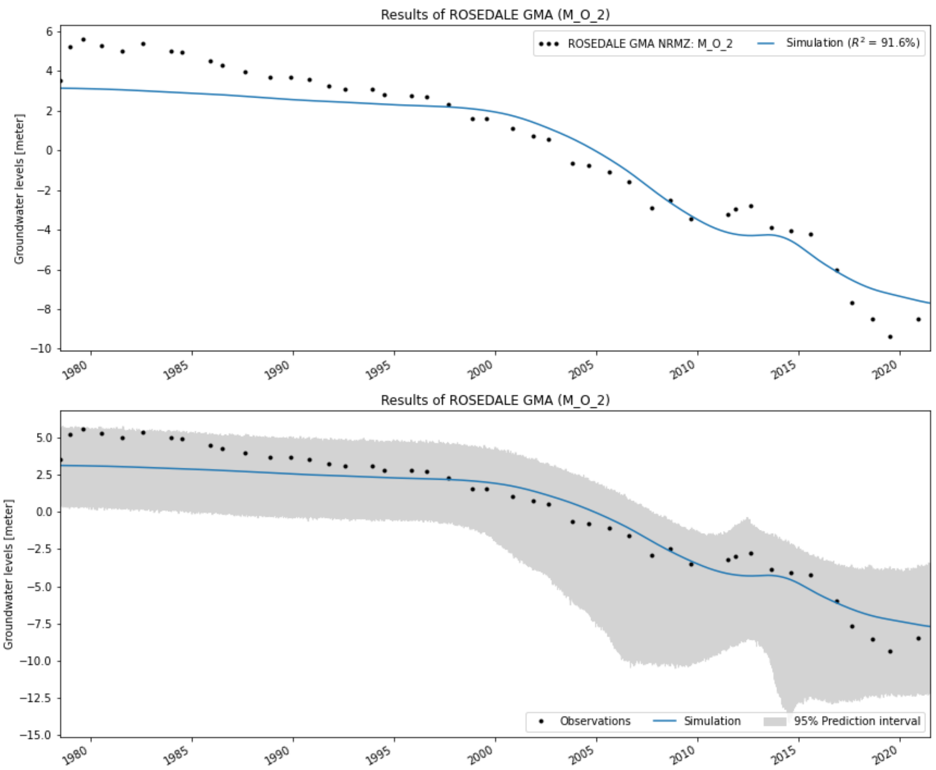


Figure 316 ***Rosedale GMA Suite M_O_2: model run 12 (Rosedale GMA two yearly average annual extraction with hindcast method 2) output hydrographs***

20.4 Predictive modelling

20.4.1 Model inputs

The preferred model to run the predictive modelling for Rosedale GMA was model run 9 for the representative Suites. The key inputs for the model were the annual recovered levels and the annual extraction hindcasted back using method H3 for Rosedale 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 118.

Table 118 Rosedale 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 2012/13)
Value (ML/year)	22,372	22,272	6,319	8,828	18,923

20.4.2 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 317 for scenario 2. As shown in Figure 317, 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 as shown in Figure 318.

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.

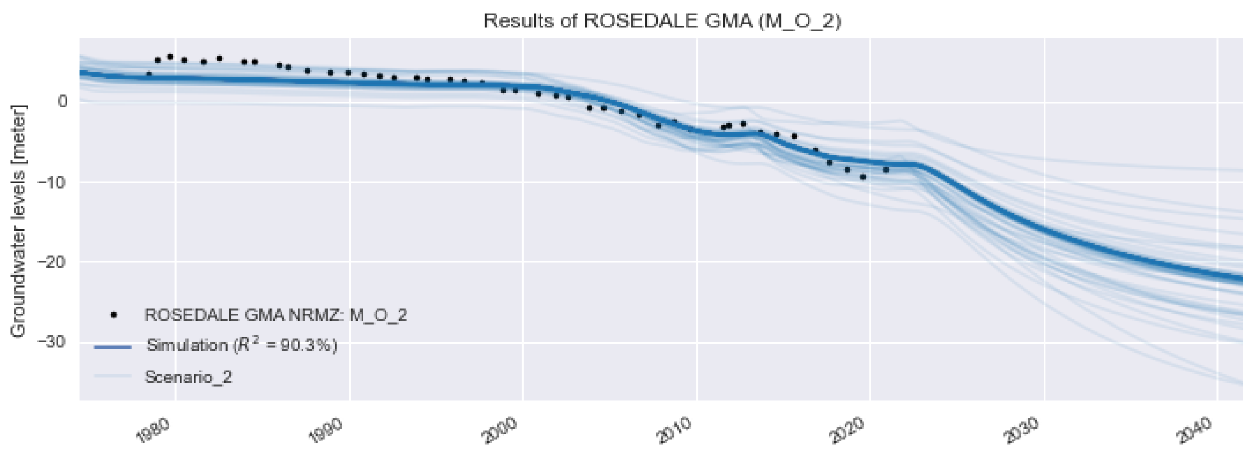


Figure 317 Rosedale GMA: Suite M_O_2 MCMC analysis for Forecast Scenario 2

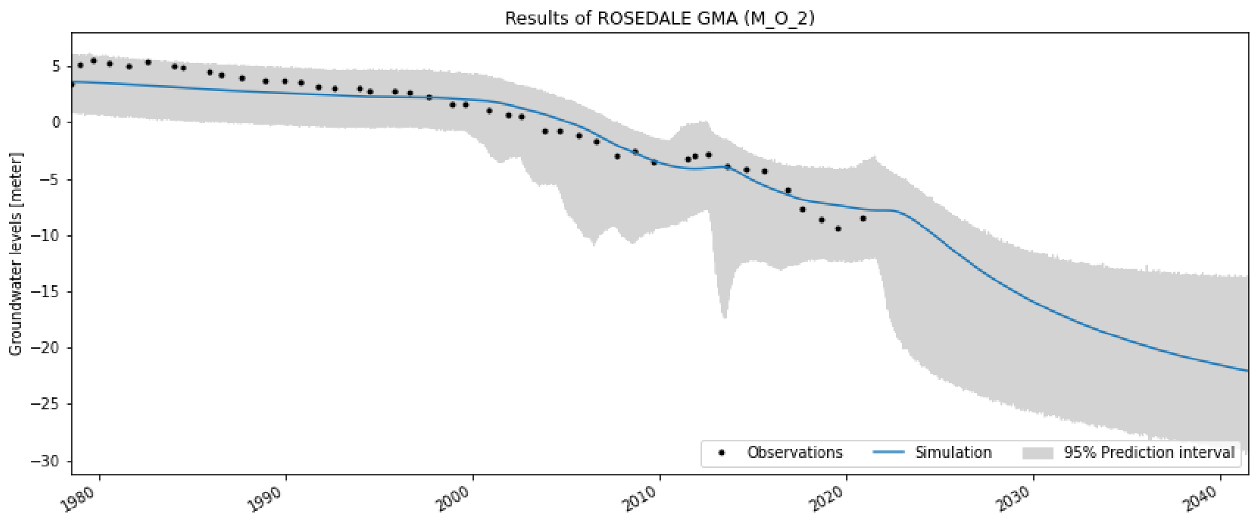


Figure 318 ***Rosedale GMA: Suite M_O_2 Forecast Scenario 2 with 95% prediction bands***

20.4.3 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 Rosedale 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 20.2.2, 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 319 for Suite M_O_2 in Figure 319:

- 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 between 1974/1975 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, where the earliest data is taken to best reflect the pre-development levels
- In this case, the pre-development annual recovered levels are taken to be the third reading which is the maximum level in the early time series data, which is 5.58 m

The modelled forecasted annual recovered levels are represented by the purple line in Figure 319.

The calibration annual recovered levels are represented by the black line in Figure 319.

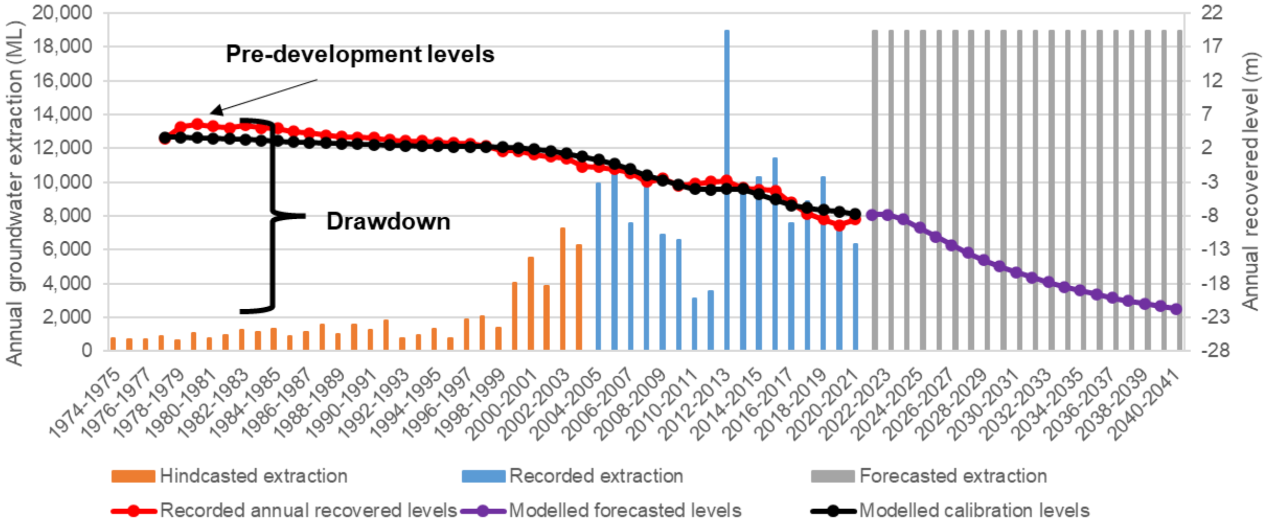


Figure 319 Estimating pre-pumping water levels (example from Suite M_O_2)

For Suite M_O_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 320) and a graph of the scenarios for specific time periods (Figure 321) 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 in the coefficient of determination and the slope of the line of best fit. Given this, the correlation developed based on all scenarios was adopted to encompass these variations.

The use-drawdown for all the 19 forecast scenario drawdowns and volumes (both the recorded and forecasted volumes) over each year modelled (1978 to 2041) is shown in Figure 320 for Suite M_O_2. Note the abscissa range of the chart has been clipped and does not show forecast drawdowns for the higher use scenarios (more improbable scenarios that are two times the current 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. It is noted that the difference between the modelled levels and the observed levels contribute to their being a higher intercept value for this Suite.
- Average use is around 9,000 ML. Figure 320 indicates that at this use volume the model forecast drawdown tends to occur 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 319 shows a scenario where groundwater use remains constant at around 19,000 ML/year over the next 20 years.
- The correlation for groundwater use and drawdown for Suite M_O_2 is good as shown in Figure 320
- 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.

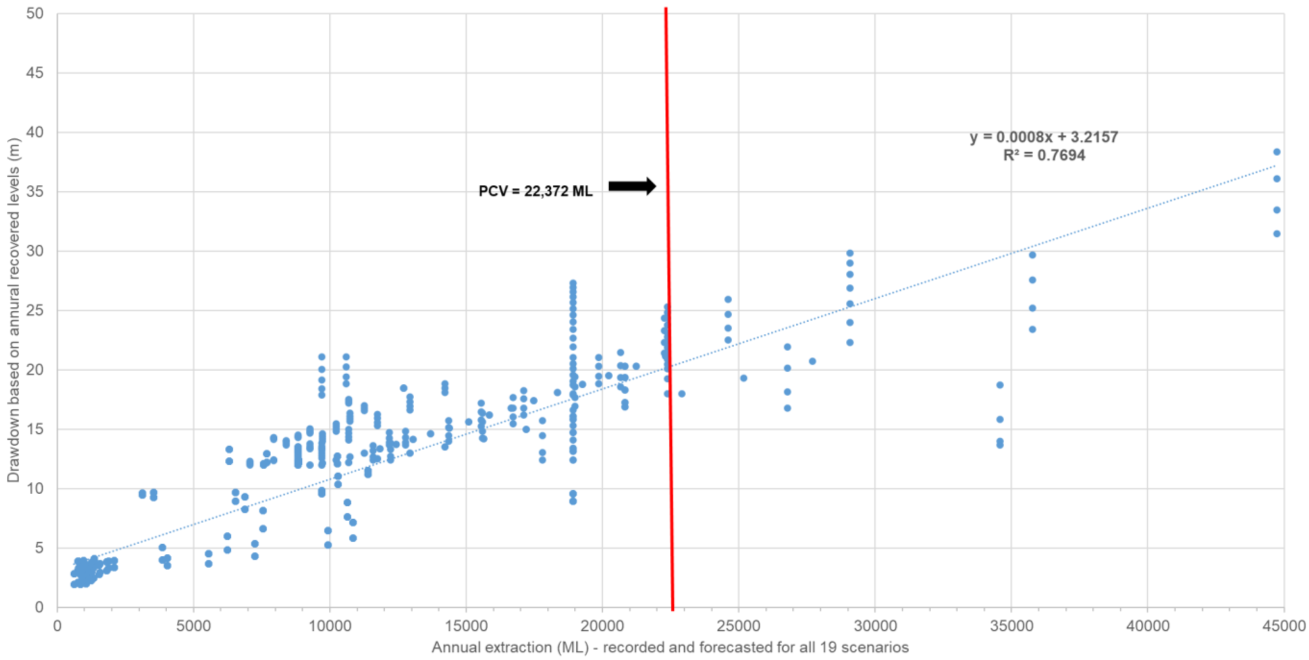


Figure 320 *Rosedale GMA Suite M_O_2: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <45,000 ML) for all data between 1978 to 2041 and all forecasted scenarios*

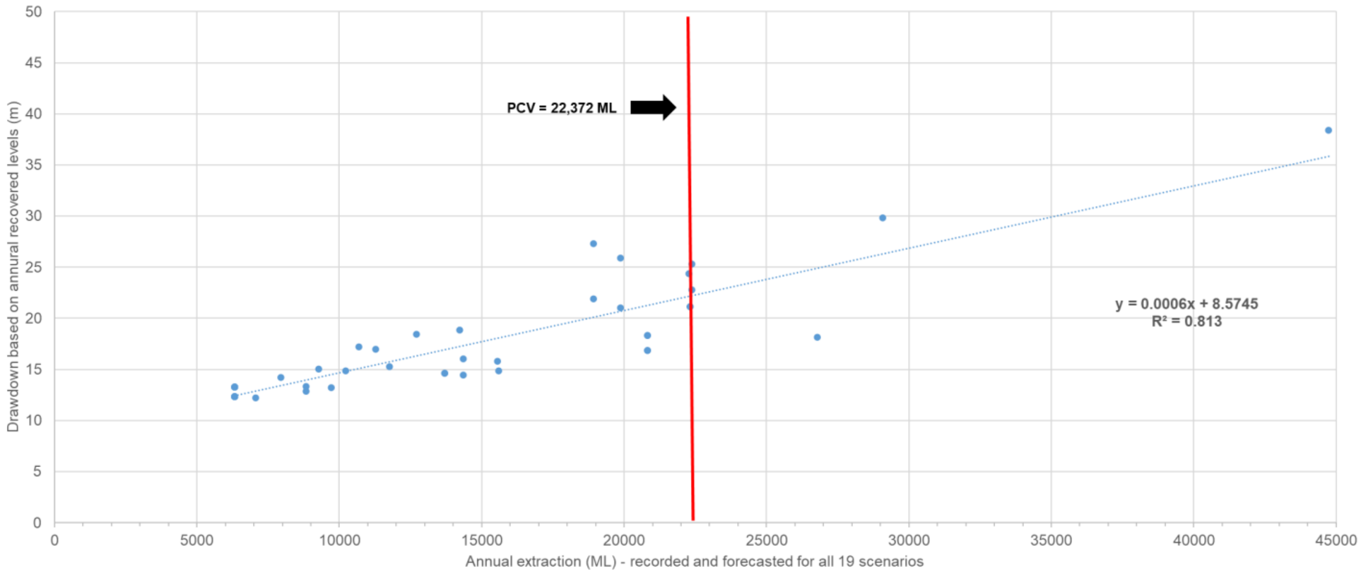


Figure 321 *Rosedale GMA Suite M_O_2: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <45,000 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

20.5 Sustainability metrics

20.5.1 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 119 for Rosedale GMA Suite M_O_2 (noting Rosedale GMA has a current PCV of 22,372 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 119 and Figure 322 for Suite M_O_2.

A comparison of volumes at drawdown intervals provided by DEECA is shown in Table 111 for Suite M_O_2. Based on Suite M_O_2, 5 m of drawdown is predicted to occur at a groundwater extraction volume of 2,200 ML which could range from -500 ML to 6,800 ML based on the 95% prediction intervals. For 10 m of drawdown, the predicted groundwater extraction volume would be 8,500 ML which could range from 4,500 ML to 15,100 ML.

Table 119 Relationship of Suite drawdown to GMU extraction for Rosedale GMA Suite M_O_2

Volume (ML/year) for whole of GMU	Based on model prediction of Suite M_O_2 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
35,000	31.2 (21.9 - 40.5)
32,500	29.2 (20.4 - 38)
30,000	27.2 (18.9 - 35.5)
27,500	25.2 (17.4 - 33)
25,000	23.2 (15.9 - 30.5)
22,500	21.2 (14.4 - 28)
20,000	19.2 (12.9 - 25.5)
17,500	17.2 (11.4 - 23)
15,000	15.2 (9.9 - 20.5)
12,500	13.2 (8.4 - 18)
10,000	11.2 (6.9 - 15.5)
7,500	9.2 (5.4 - 13)
5,000	7.2 (3.9 - 10.5)
2,500	5.2 (2.4 - 8)
0	3.2 (0.9 - 5.5)

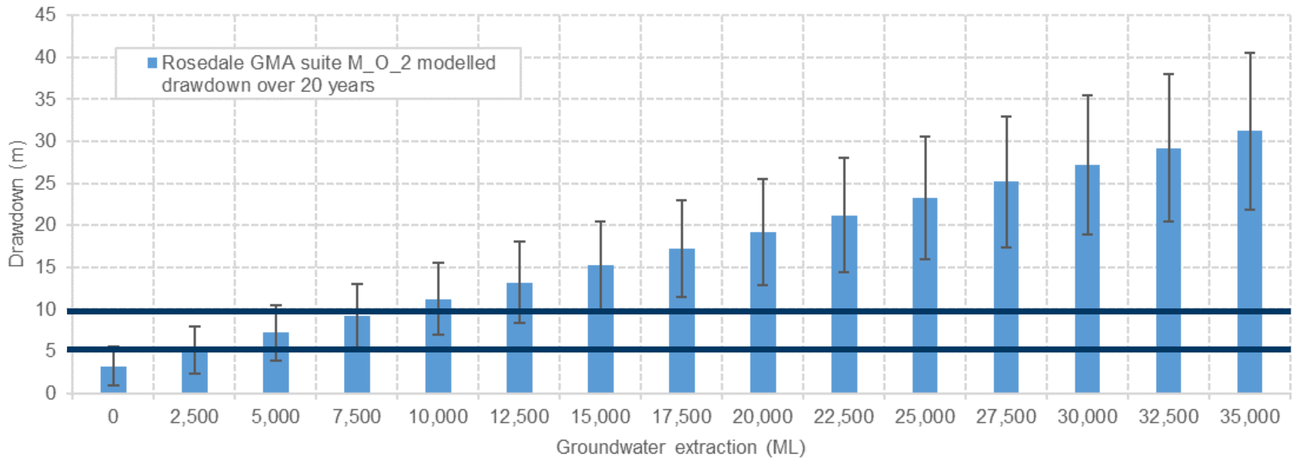
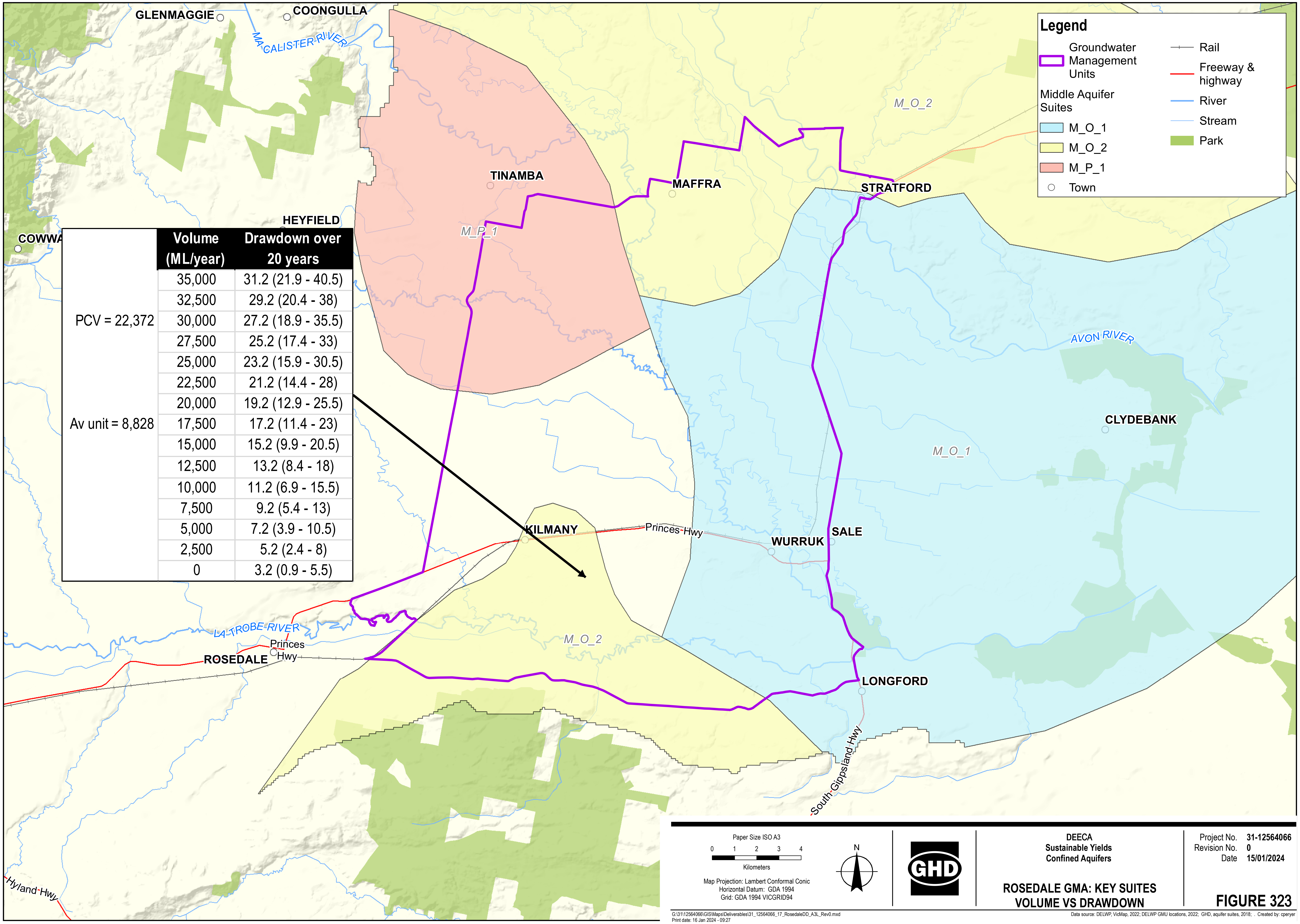


Figure 322 Rosedale GMA Suite M_O_2: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 120 Predicted volumes for drawdown metrics

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite M_O_2 drawdowns (lower limit to upper limit)
5	2,200 (-500 – 6,800)
10	8,500 (4,500 – 15,100)



	Volume (ML/year)	Drawdown over 20 years
PCV = 22,372	35,000	31.2 (21.9 - 40.5)
	32,500	29.2 (20.4 - 38)
	30,000	27.2 (18.9 - 35.5)
	27,500	25.2 (17.4 - 33)
	25,000	23.2 (15.9 - 30.5)
	22,500	21.2 (14.4 - 28)
Av unit = 8,828	20,000	19.2 (12.9 - 25.5)
	17,500	17.2 (11.4 - 23)
	15,000	15.2 (9.9 - 20.5)
	12,500	13.2 (8.4 - 18)
	10,000	11.2 (6.9 - 15.5)
	7,500	9.2 (5.4 - 13)
	5,000	7.2 (3.9 - 10.5)
	2,500	5.2 (2.4 - 8)
	0	3.2 (0.9 - 5.5)

20.6 GMU summary

20.6.1 Findings

Rosedale GMA primarily relates to the Morwell Formation Aquifer (M2C) (Upper/Lower Mid Tertiary Aquifer, UMTA/LMTA) and in the GMA, groundwater is predominately extracted for irrigation purposes. The UMTA/LMTA falls within the Middle Aquifer Suites, which at Rosedale GMA comprises Suites M_O_1 (2%), M_O_2 (17%), M_P_1 (6%) and M_R_1 (2%), providing a total coverage of 26% of the GMU.

Most of the extraction bores are located within Zone 2 of Rosedale GMA, at which Suite M_O_2 covers 26% of the area and 20% of extraction for the GMA. 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, Rosedale GMA may be influenced by extraction occurring from the Latrobe Valley Mines, which is significantly greater than the extraction that occurs within the Rosedale GMA. Of the two hindcasting methods that consider both extraction datasets, the correlations developed to apply the hindcasting were poorer when both datasets were considered rather than the Rosedale only dataset. Extraction from Offshore was also identified as a potentially influencer of Rosedale GMA groundwater levels. However, inclusion of just offshore or offshore and Latrobe Valley Mine extraction produced poorer correlations using the hindcasting methods.

Application of two yearly annual average extraction, instead of annual average, generally showed comparable results based on the statistical analysis across the model runs. The best match using the two yearly average annual extraction was model run 12 (two yearly average annual extraction for Rosedale GMA with hindcast method 2 excluding Latrobe Valley Mines extraction) for Suite M_O_2.

The application of spatial distribution produced a poorer model fit than the model run using only the annual recorded groundwater usage for the whole GMU. The quality of the result did not increase when the spatial distribution methodology was combined with hindcasting methodology.

Based on an assessment of all model runs, the model run 9 for Rosedale GMA only annual extraction with hindcast method 3 and the annual recovered levels was adopted to undertake the predictive modelling for Suite M_O_2.

The pre-development levels were defined for the representative Suite based on the early time series Suite data for the annual recovered levels. This resulted in pre-development annual recovered levels of 5.58 m for Suite M_O_2. 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 M_O_2 drawdowns (lower limit to upper limit)
5	2,200 (-500 – 6,800)
10	8,500 (4,500 – 15,100)

The model for Suite M_O_2 was assessed as having a “Moderate” model applicability rating using the criteria outlined in section 5.2. The modelled calibration levels are lower than recorded pre-development levels (underestimates the levels at low extraction rates). This contributes to an approximate 3 m drawdown intercept in the use-drawdown graph.

20.6.2 Limitations

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

- Groundwater use for Latrobe Valley Mines is not available on a groundwater use by bore basis and thus has not been incorporated into the spatial distribution modelling methodology
- Groundwater use for Latrobe Valley Mines is not available on a GMU basis and thus the portion covering Rosedale GMA would have been double counted when considering externalities
- There is a lack of Suites in the major area of development
- The licenced bore dataset provided by DEECA has 5% of bores assigned to Rosedale GMA with no depth data and thus couldn't be assigned to a VAF layer and in turn Suite. As this was a small percentage of the overall extraction for Rosedale GMA, it was not assigned to an aquifer/Suite.
- Historic data is not available for Rosedale GMA beyond 2004/2005 which limits the available recorded data that can be used in the TFN modelling.
- Much of the extraction does not fall within a Suite. However, this could be due to data issues including bore depth data not being an accurate which in turn leads to incorrect assignment of VAF layer.
- The modelled calibration levels are lower than recorded pre-development levels (underestimates the levels at low extraction rates). This causes an approximate 3 m drawdown intercept in the use-drawdown graph, at zero extraction which is reflected in the results tables.

20.6.3 Recommendations

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

- The licenced bore dataset provided by DEECA has 5% of bores assigned to Rosedale 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.