21. Sale WSPA

21.1 Conceptualisation

The hydrogeological conceptualisation elements relevant to this study are summarised in Table 121 and a map of the GMU is presented in Figure 324. 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 121.

Table 121 Sale WSPA – Tabulated conceptualisation

GMU summary
Sale WSPA is situated in eastern Victoria (as shown in Figure 324) and stretches along part of the Bass Coast. Several rivers run through the GMU including the Thomson, Avon, Latrobe and Macalister Rivers. Sale WSPA covers an area of 1,739 km^2 and within this area, the WSPA pertains to formations between 25 and 200 m below the surface which corresponds to the Boisdale Formation (UTAF); the PCV (21,238 ML/year) primarily relates to confined aquifers. Groundwater use in the GMU is predominately for urban water supply and stock and domestic purposes. The GMU may also be influenced from extraction occurring at the Latrobe Valley Coal Mines, which are around 20 km to the west of Sale WSPA; although this influence is thought to be minor. There is potential for a saltwater intrusion to occur from Lake Wellington if there are continued groundwater level declines in the GMU (Jacobs 2019[8]). Sale WSPA is managed by SRW and occurs within the Gippsland 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	Undifferentiated sediments (QA)	U_AD_1 (8%) U_Z_1 (1%)	9%	0	Domestic, stock, dairy	126	91	Low
	Haunted Hills Formation (UTQA)	U_AE_1 (1%)	1%	0	Irrigation, domestic, stock, dairy	243	410	Low
	Nuntin Clay (UTQD)	-	-	0	Industrial, commercial, irrigation, domestic, stock, dairy	351	813	Low
Middle	Boisdale (Wurruk Sand) (UTAF)	M_O_1 (35%) M_O_2 (12%) M_P_1 (15%) M_P_2 (1%) U_AB_1 (64%)	63% (Middle Suites) 64% (Upper Suites)	8	Urban, industrial, domestic, stock, dairy	5,338	7,345	Medium
	Yallourn Group (UTD)	-	-	0	Urban, commercial, irrigation, domestic, stock	2,253	3,539	Low
	Balook Formation (UMTA)	M_O_2 (12%)	12%	0	Commercial, domestic, stock, irrigation	2,746	4,195	Low

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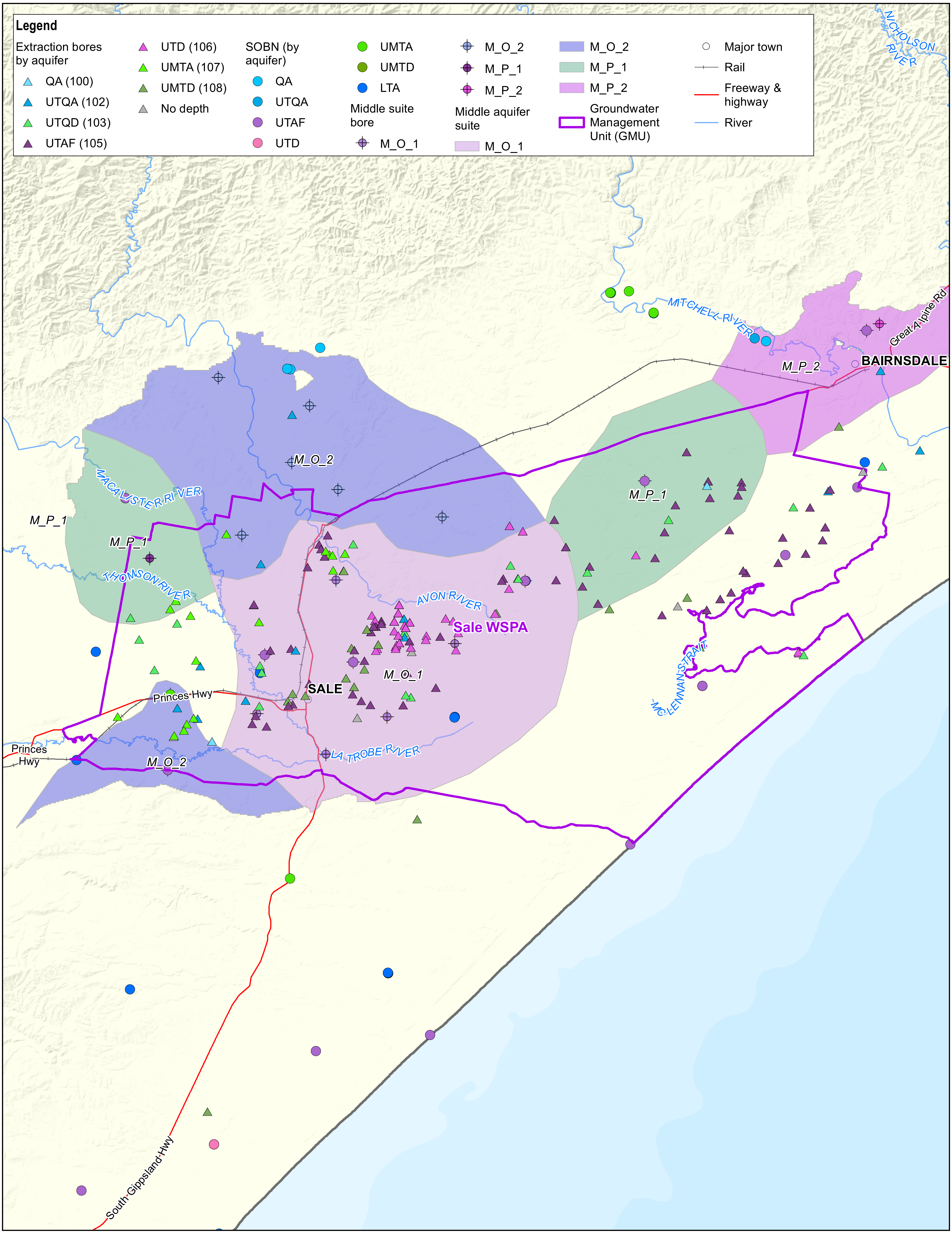
[8] Jacobs 2019, Review of Groundwater Permissible Consumptive Volume in Gippsland Region

Hydrostratigraphy summary								
	Gippsland Limestone (UMTD)	-	-	0	Urban, irrigation, domestic, stock, dairy	1,627	2,672	Low
Lower	Traralgon seams and aquifers (LTA)	L_O_1 (92%)	92%	0	NA	0	0	Low
Basement	Basement rocks (BSE)	-	-	0	Irrigation	232	250	
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 1,099 ML of unassigned use due to unknown depths (1,822 ML of entitlement).								

Characteristic and importance	Description	Degree of understanding
Intended aquifer (UTAF - Boisdale Formation, as shown in blue above)		
Aquifer thickness within GMU (range, based on VAF)	Max: 466 m, Average: 44 m	High
Aquifer extent	Regional	High
Likelihood of inter-aquifer flow	Medium	Low
Likelihood of groundwater – surface water interaction	Low	Low
Representative Suite	**M_O_1**	**Medium. 51% of GMU extraction occurs within this Suite, which relates to the most relevant GMU aquifer.**
Current hydrological condition of representative aquifer		
Representative Suite trend	Decreasing	High
Groundwater quality (average salinity based on WMIS and CDM Smith spatial segment(s) with highest coverage)	0 – 600 mg/L (CDM Smith, 2022)	Low – limited available data Based on CDM Smith (2022)
Groundwater yield	0.5 – 5 L/s	Low Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1985 to 2021**	**High**
Spatial clustering of licensed bores in relation to Suites	**Yes, M_O_1**	**Based on DEECA density mapping and licenced bore data.**
Groundwater use		

Characteristic and importance	Description	Degree of understanding
Licensed groundwater use	**11,029 ML**	**High (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	**6,324 ML**	**High (Based on historical VWA data, year 2011/12)**
Maximum historic groundwater use	**17,867 ML**	**High (Based on historical VWA data, year 2018/19)**
Entitlement (Groundwater allocation)	**21,203 ML**	**High (Based on licenced volumes in 2020/21)**
Significant drivers of groundwater level variability (primary)	**Pumping for town water supply**	**High**
Secondary drivers of groundwater level variability	Pumping for irrigation & dairy	High
Groundwater use profile	Influenced by seasonality however usage throughout the year due to town supply	High
External Influence	**Latrobe Valley Mines**	
Groundwater values and risks		
Existing 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 Saltwater intrusion at Lake Wellington	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 4 6 8

Kilometers

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

N

GHD

DEECA
Sustainable yield review - confined aquifers

Sale WSPA
Site location and key features

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

Figure 324

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Print date: 16 Jan 2024 - 12:54

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

21.2 Technical analysis

21.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the confined Suites for Sale WSPA as shown in Figure 325. The Suite hydrographs show the seasonal fluctuations for Suites M_O_1 and M_O_2 and hence recovered water levels. Suites L_O_1, M_P_1 and M_P_2 show some minor fluctuations likely impacts of pumping. All Suite hydrographs shown in Figure 325 exhibit a decreasing trend. Suite L_O_1 shows an anomalous displacement in the hydrograph between late 1982 and 1986, this data was corrected to bring it in line with the level data before and after this period.

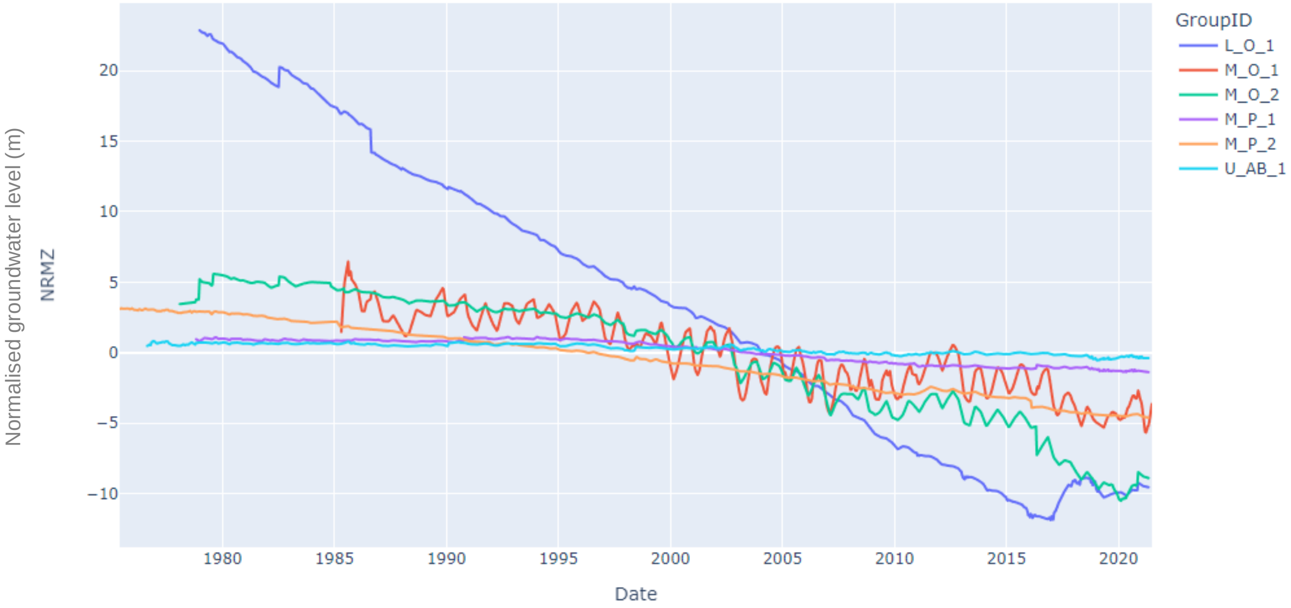


Figure 325 Sale WSPA Suite Hydrographs for all confined aquifers

The representative Suites analysed for this GMU were Suites M_O_1, M_P_1 and U_AB_1. The Representative Suites were selected based on the methodology outlined in section 2.6.4 which identified Suite M_O_1 as the most representative followed by U_AB_1 then M_P_1. The process is summarised as follows:

- The greatest volume of extraction occurs within the Middle Aquifer with 51% of extraction within Suite M_O_1 and 14% within Suite M_P_1
- The Middle Aquifer pertains to the UTAF which is the intended aquifer for this GMU
- Suite M_O_1 covers 35% of the GMU, M_O_2 covers 12%, M_P_1 covers 15%, M_P_2 covers 1% and U_AB_1 covers 64%
- Suite M_O_1 has seven active SOBN bores while U_AB_1 has three active SOBN bores
- Suite bores for M_O_1 and U_AB_1 are close to extraction points

The annual recovered Suite hydrographs for the representative Suites for Sale WSPA, M_P_1, M_O_1 and U_AB_1 are shown in Figure 326.

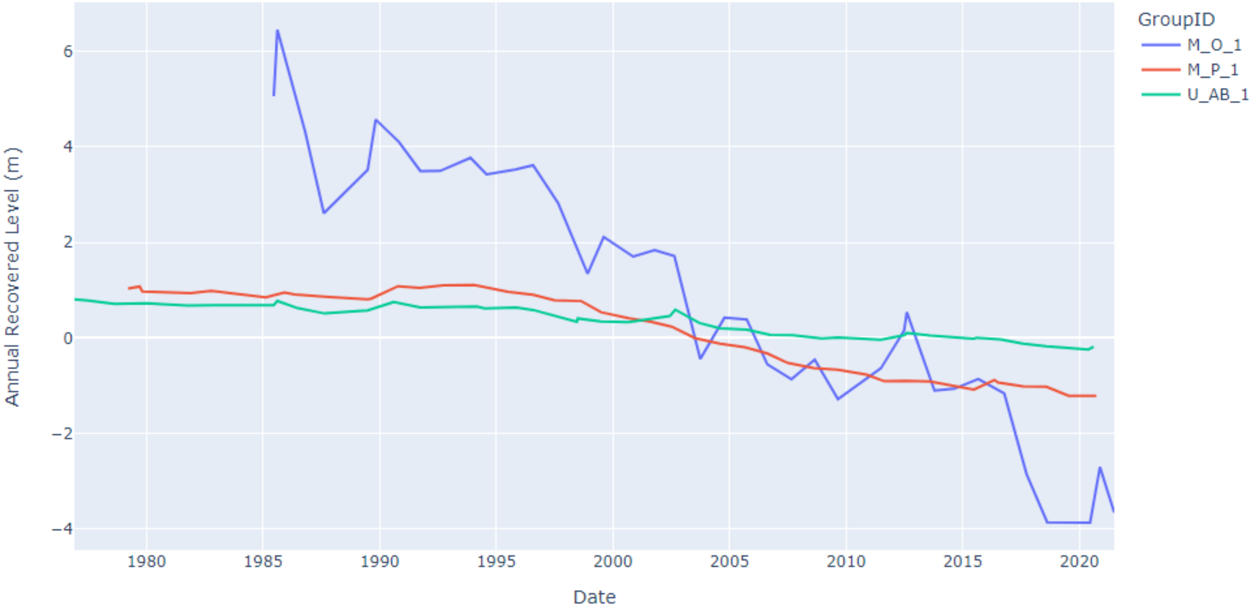


Figure 326 Sale WSPA Annual Recovered Level Suite Hydrographs for representative Suites

21.2.2 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 at the start of the time series data was the best representation of conditions prior to major development within Sale WSPA for Suite M_O_1, M_P_1 and U_AB_1.

The pre-development annual recovered levels was taken to be the maximum level at the start of the time series data, this occurred in the year 1985/1986 for Suite M_O_1 which equated to 6.45 m, over the years 1978/1979 and 1979/1980 for Suite M_P_1 which equated to 1.05 m and in the year 1976/1977 for Suite U_AB_1 which equated to 0.81 m (refer further details in section 21.4.3).

21.2.3 Externalities

As identified through the conceptualisation, Sale WSPA may be influenced by extraction occurring at the Latrobe Valley Mines (in the underlying aquifer system). To test the influence of this extraction, data was obtained from the mines to incorporate into the model.

Figure 327 shows the Sale WSPA annual groundwater extraction volumes, the Latrobe Valley Mines extraction volumes and the combined volumes. Note that where extraction data is not available for both Sale WSPA and Latrobe Valley Mines, 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 Sale WSPA.

It is noted that the Latrobe Valley Mines extraction is primarily for mine stability purposes to support mine development. This extraction regime is different to that for irrigation which is primarily climate driven, and urban which is generally consistent throughout the year. Given this, the extraction from the mines is difficult to hindcast as it is dependent on mining development and operations.

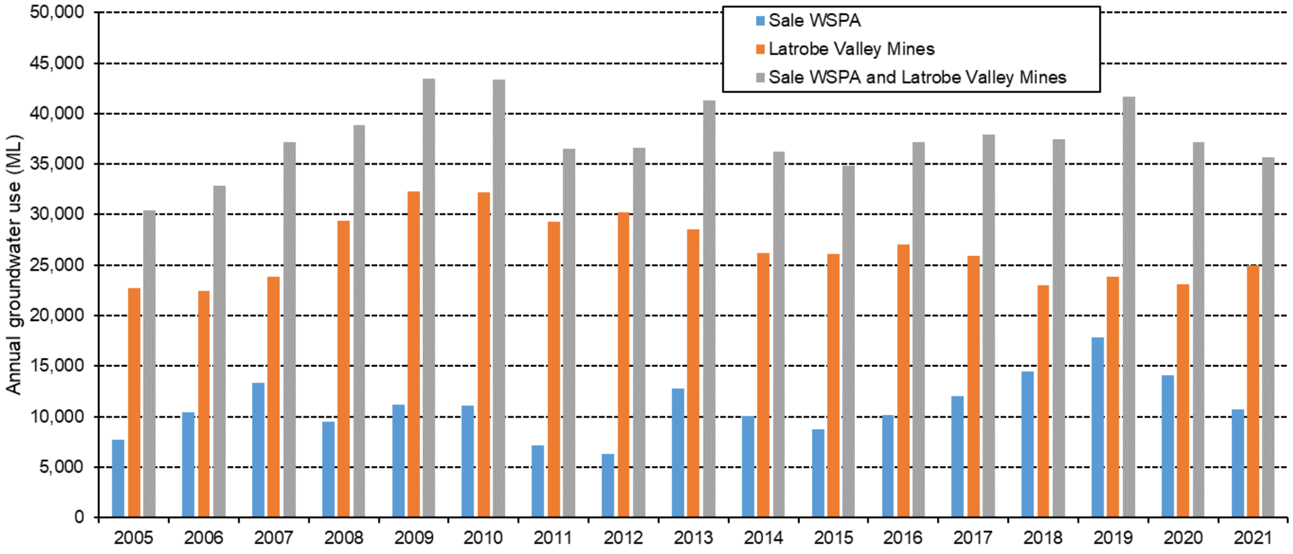


Figure 327 Sale WSPA and Latrobe Valley Mines – groundwater use

21.2.4 Hindcasting

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

21.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, 12 different correlations were developed as described below and shown in the following figures.

Figure 328 shows:

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

Figure 329 shows:

- Annual rainfall vs annual irrigation groundwater extraction at Sale WSPA (annual irrigation groundwater extraction is based on the bore use type from WMIS associated with the licenced bore use data provided by DEECA)
- Two yearly average annual rainfall vs annual irrigation groundwater extraction at Sale WSPA
- Annual summer period rainfall vs annual irrigation groundwater extraction at Sale WSPA
- Annual irrigation period rainfall vs annual irrigation groundwater extraction at Sale WSPA

Figure 330 shows:

- Annual rainfall vs annual combined extraction at Sale WSPA and Latrobe Valley Mines (external influence)
- Two yearly average annual rainfall vs annual combined extraction at Sale WSPA and Latrobe Valley Mines (external influence)
- Annual summer period rainfall vs annual combined extraction at Sale WSPA and Latrobe Valley Mines (external influence)
- Annual irrigation period rainfall vs annual combined extraction at Sale WSPA and Latrobe Valley Mines (external influence)

As shown in Figure 328, Figure 329 and Figure 330, the goodness-of-fit represented by the R^2, decreased when the extraction from the Latrobe Valley Mines (external influence) was included in the groundwater use dataset; this is as expected since the primary driver from the mines is not climate based. The best goodness-of-fit result was shown to be the correlation of the annual rainfall with annual irrigation groundwater extraction from Sale WSPA. The best R^2 including the external influence of the Latrobe Valley Mines was annual groundwater use and annual rainfall as shown in Figure 330. Both these correlations were modelled when hindcasting method H1 is applied in section 21.3.1.

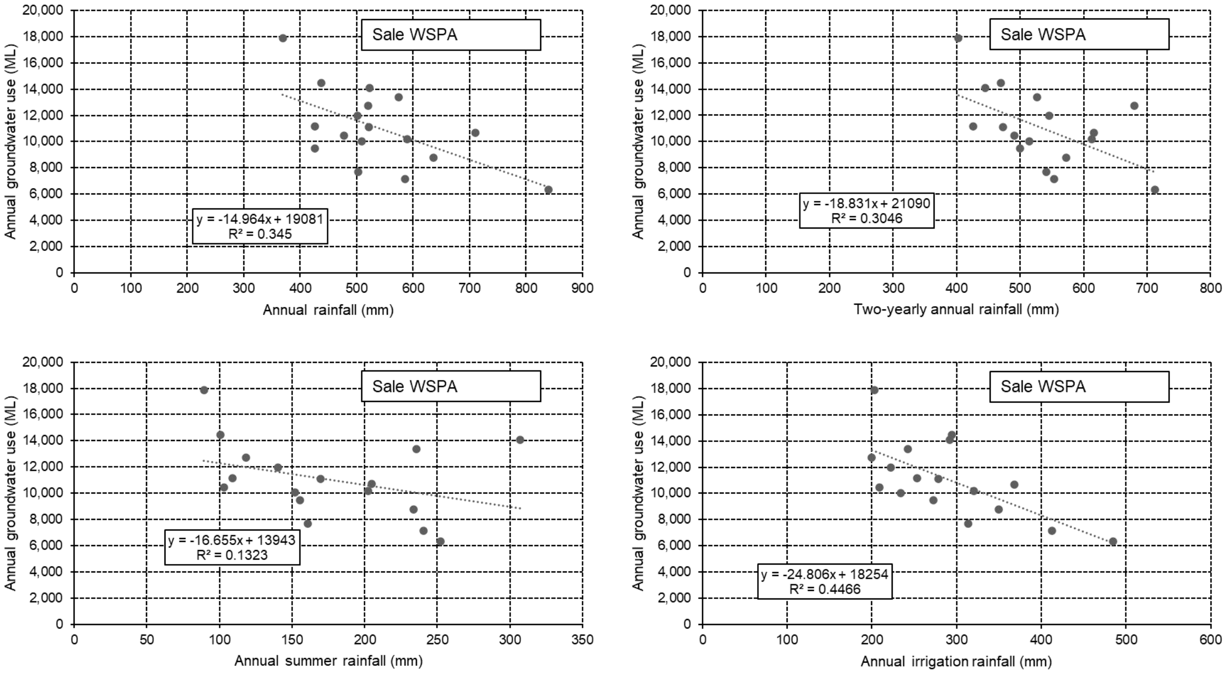


Figure 328 *Sale WSPA: Hindcast method 1 correlations (Sale WSPA and annual groundwater use)*

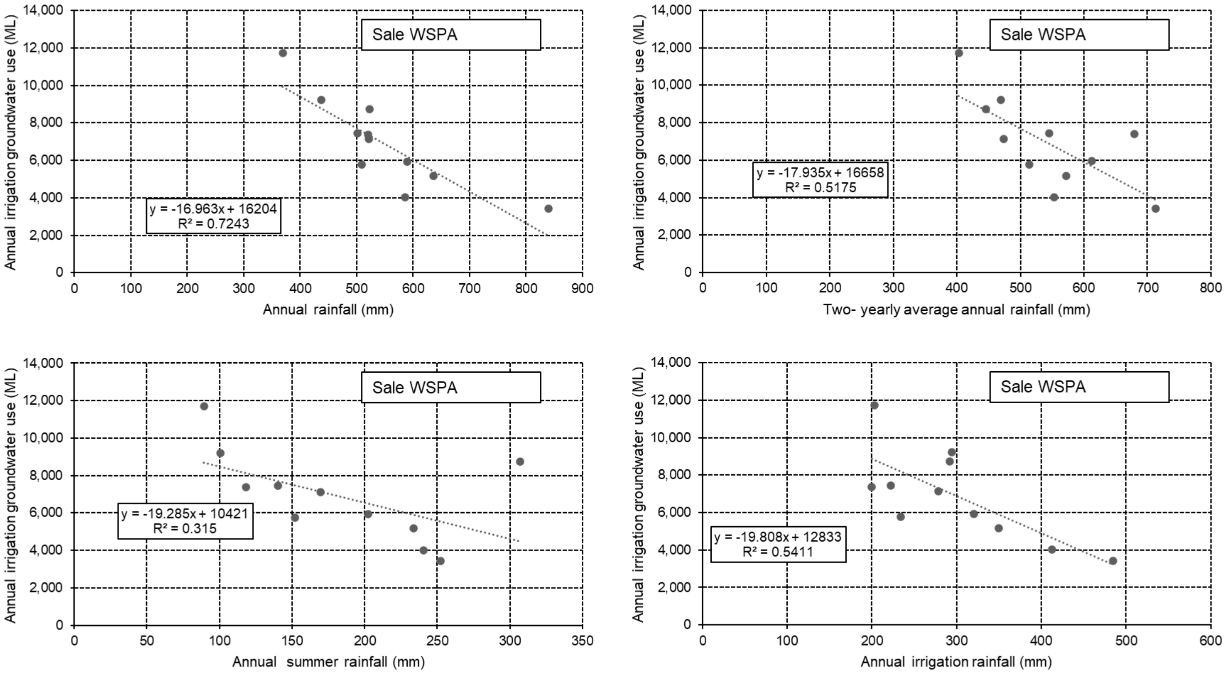


Figure 329 *Sale WSPA: Hindcast method 1 correlations (Sale WSPA and annual irrigation groundwater use)*

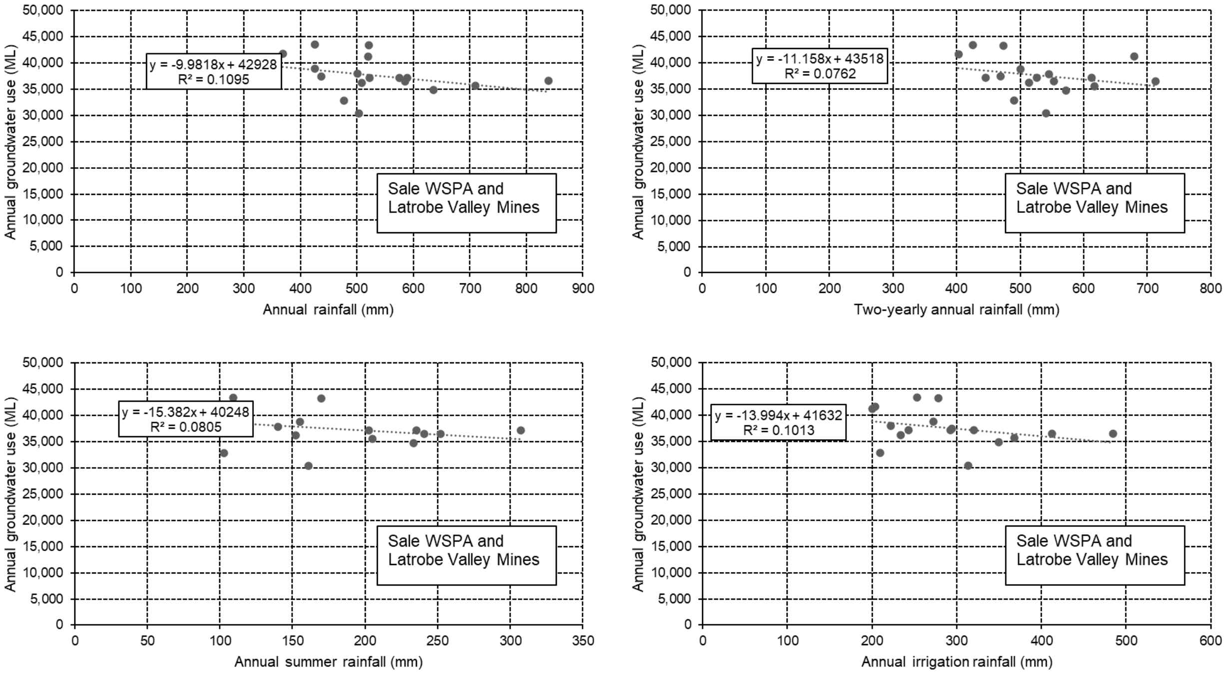


Figure 330 Sale WSPA: Hindcast method 1 correlations (Sale WSPA and Latrobe Valley Mines and annual groundwater use)

21.2.4.2 Hindcasting Method 2 (H2)

Eight correlations were developed using method H2 as described below.

Figure 331 shows:

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

Figure 332 shows:

- Sale WSPA and Latrobe Valley Mine use per Sale WSPA bore vs annual rainfall
- Sale WSPA and Latrobe Valley Mine use per Sale WSPA bore vs two yearly average annual rainfall
- Sale WSPA and Latrobe Valley Mine use per Sale WSPA bore vs annual summer period rainfall
- Sale WSPA and Latrobe Valley Mine use per Sale WSPA bore vs annual irrigation period rainfall

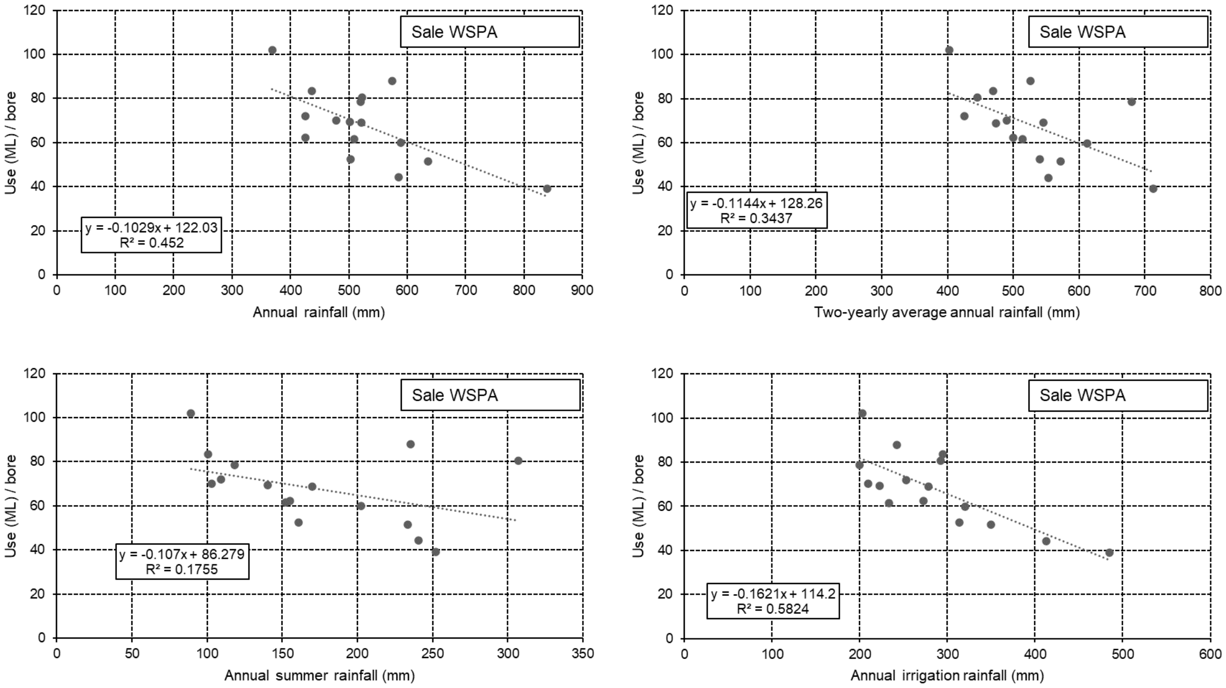


Figure 331 Sale WSPA: Hindcast method 2 correlations (Sale WSPA only)

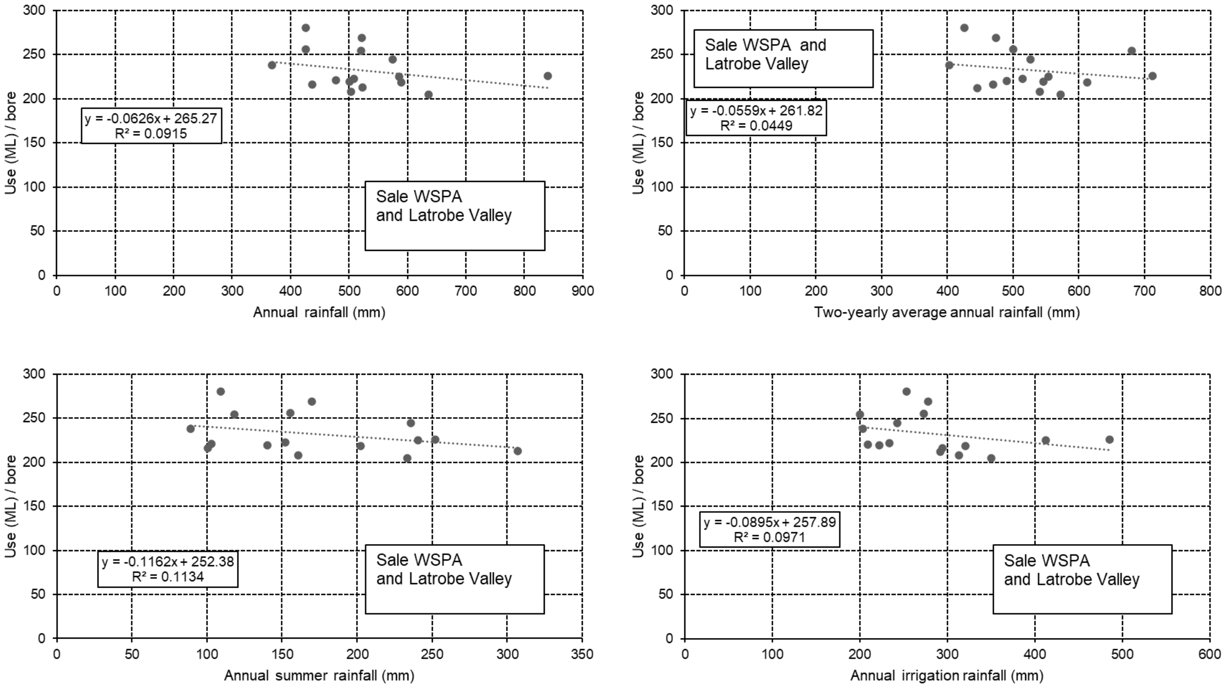


Figure 332 Sale WSPA: Hindcast method 2 correlations (Sale WSPA and Latrobe Valley Mines)

As shown in Figure 331 and similar to method H1, the goodness-of-fit represented by the R^2, decreased in both instances where the extraction from the Latrobe Valley Mines (external influence) was included. The best goodness-of-fit result was shown to be the correlation of the annual irrigation rainfall and Sale WSPA use per bore. This and the Sale WSPA and Latrobe Valley Mine extraction per bore (with annual summer rainfall) were modelled for hindcast method H2; albeit the latter has a very poor fit.

21.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 333:

- 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

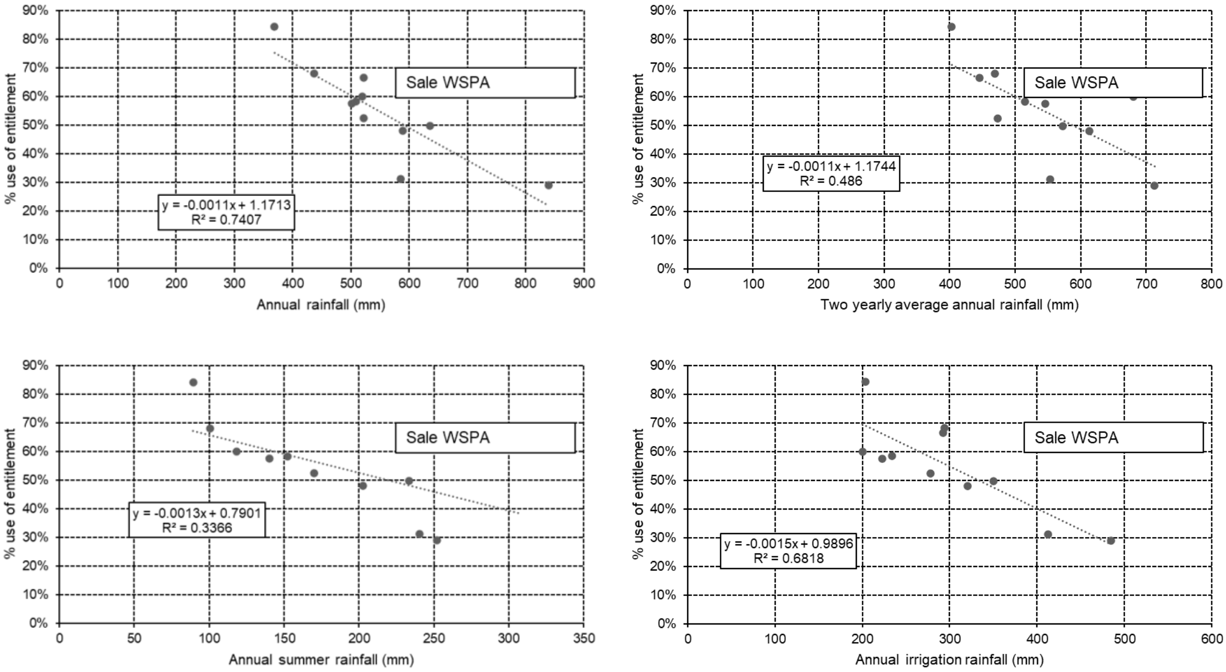


Figure 333 Sale WSPA: Hindcast method 3 correlations

As shown in Figure 333 and similar to method H1 and H2, the best goodness-of-fit result was shown to be the correlation of the annual rainfall; this correlation was adopted as the preferred correlation for Hindcast method H3 for Sale WSPA.

21.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 334 and Figure 335 for the hindcasting based on only Sale WSPA groundwater use. Figure 334 shows a comparison of the three hindcasting methods against the recorded use only (over the recorded use dates) and Figure 335 shows the hindcasted data back to 1974/1975. A comparison of the three input datasets for hindcasting based on the combined Sale WSPA and Latrobe Valley Mines groundwater use is shown in Figure 336 and Figure 337. Figure 337 shows a comparison of the three hindcasting methods against the recorded use only (over the recorded use dates) and shows the hindcasted data back to 1974/1975.

As shown in Figure 335 and Figure 337, 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 H2. Thus, this hindcasting method is expected to provide a more probable estimated groundwater use than the other two methods for Sale WSPA.

As expected, the correlations of rainfall with Sale WSPA only extraction were generally better than that with Sale WSPA and Latrobe Valley Mine extraction since the Latrobe Valley Mine extraction is greater than that for Sale WSPA and is primarily driven by mine development rather than climate conditions.

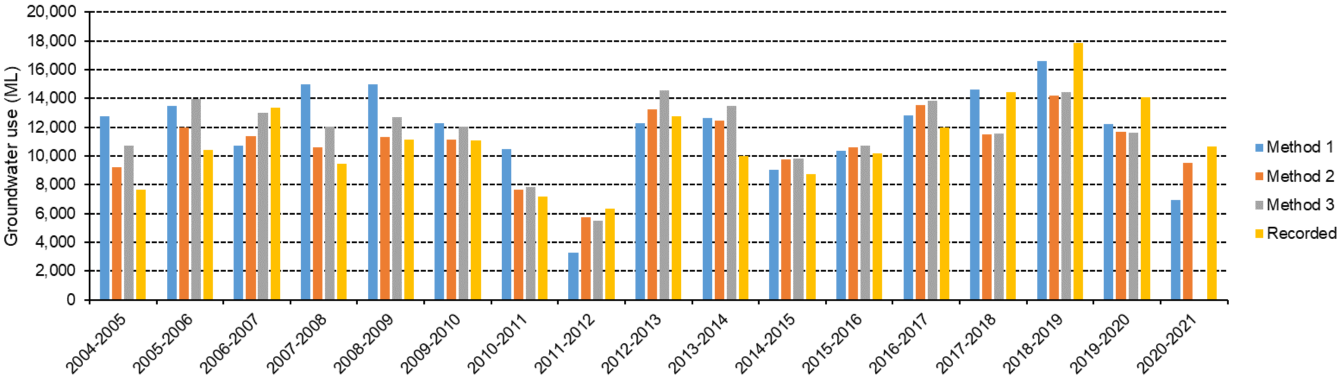


Figure 334 *Sale WSPA: Comparison of hindcasting over recorded use period – Sale WSPA only extraction*

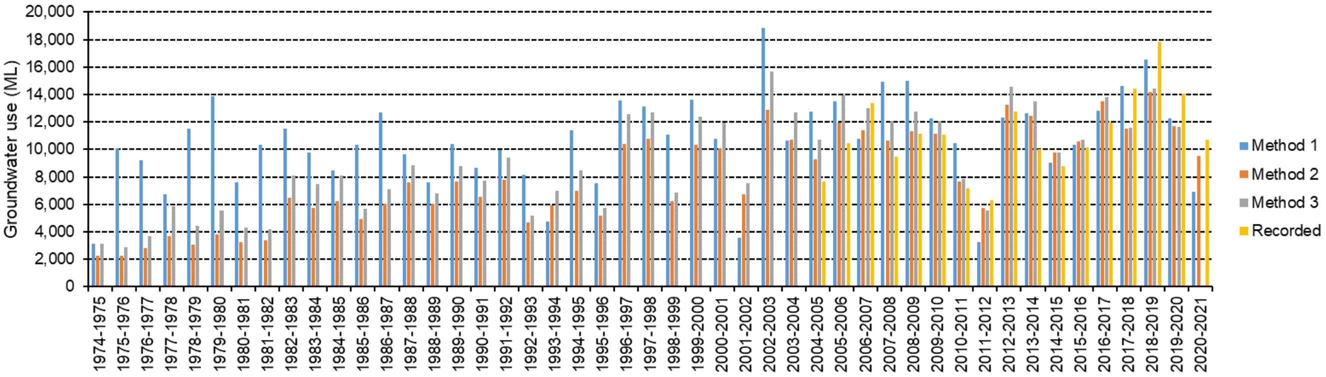


Figure 335 *Sale WSPA: Comparison of hindcasting – Sale WSPA only extraction*

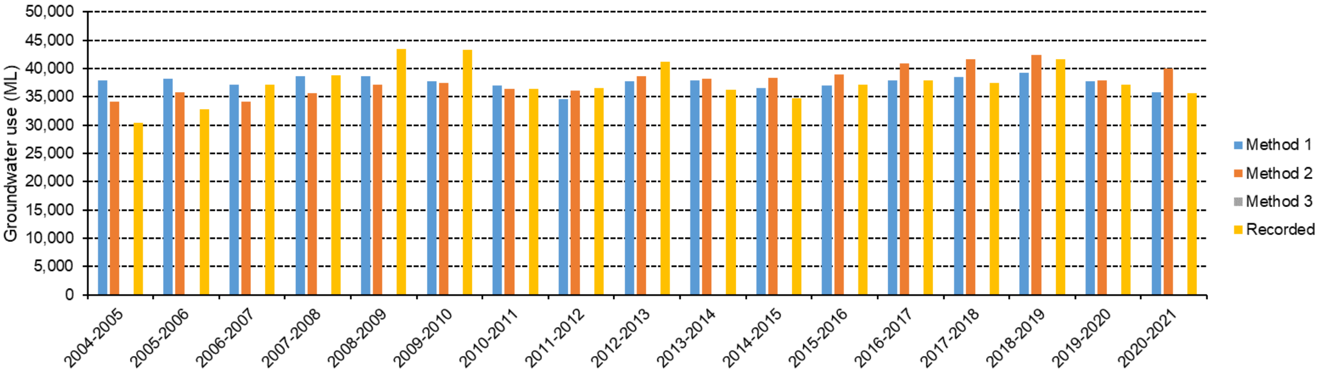


Figure 336 *Sale WSPA: Comparison of hindcasting over recorded use period – Sale WSPA and Latrobe Valley Mines*

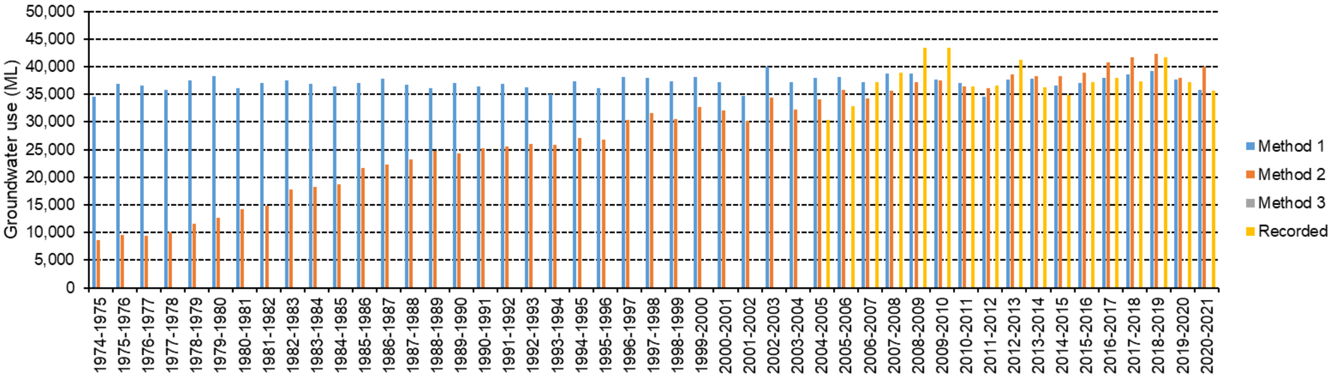


Figure 337 *Sale WSPA: Comparison of hindcasting – Sale WSPA and Latrobe Valley Mines*

21.3 Modelling

21.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 122 summarises these combinations of model inputs run for Sale 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 122 Sale 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_O_1, M_P_1 and U_AB_1)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Sale WSPA only	✓																		
Two yearly average annual extraction – Sale WSPA only		✓																	
Annual extraction – Sale WSPA and Latrobe Valley Mines			✓																
Two yearly average annual extraction – Sale WSPA and Latrobe Valley Mines				✓															
H1 annual extraction – Sale WSPA only					✓														
H1 annual extraction – Sale WSPA and Latrobe Valley Mines						✓													
H2 annual extraction – Sale WSPA only							✓												
H2 annual extraction – Sale WSPA and Latrobe Valley Mines								✓											
H3 annual extraction – Sale WSPA only									✓										
H1 two yearly average annual extraction – Sale WSPA only										✓									
H1 two yearly average annual extraction – Sale WSPA and Latrobe Valley Mines											✓								
H2 two yearly average annual extraction – Sale WSPA only												✓							
H2 two yearly average annual extraction – Sale WSPA and Latrobe Valley Mines													✓						
S1 annual extraction – Sale WSPA only														✓					
S2 annual extraction – Sale 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 – Sale WSPA only																✓			
S1 annual extraction and H1 annual extraction – Sale WSPA only																	✓		
S2 annual extraction and H2 annual extraction – Sale WSPA only																		✓	
S3 annual extraction and H3 annual extraction – Sale WSPA only																			✓

21.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 122 is presented in Table 123 for the selection of representative Suites for Sale WSPA. The column heading for Suite M_O_1 is highlighted blue to indicate that this Suite was selected as the most likely representative Suite based on the process outlined in section 21.2.1. 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_1

A review of the results and statistical summary for Suite M_O_1 shows that model runs 1 and 2 (highlighted orange) show the best results when primarily considering the 95PPU TH, percentage of observed levels within the 95PPU, the RMSE and R^2 of the 19 different model input combinations. It is noted that for these two model runs, they have the smallest 95PPU thickness, lowest RMSE values and two of the highest R^2 values compared to the other runs. However, these models only include 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. Based on the hindcasted models, model run 12 (highlighted green) was found to have the best statistical results with the longest dataset, having the lowest 95PPU thickness and RMSE, and one of the highest R^2 values. The graphical model output for model run 12 is shown in Figure 338 and has been selected as the preferred model to progress to predictive modelling.

Suite M_P_1

A review of the results and statistical summary for Suite M_P_1 shows that model runs 1, 2 and 14 (highlighted orange) show the best results when primarily considering the 95PPU TH, percentage of observed levels within the 95PPU, the RMSE and R^2 of the 19 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. The hindcasted models produced very similar results across all combinations tested (except that with spatial distribution); given this, and to maintain some consistency with models selected, model run 12 was selected as the preferred model to progress to predictive modelling. The graphical model output for model run 12 is shown in Figure 339.

Suite U_AB_1

A review of the results and statistical summary for Suite U_AB_1 shows that model runs 1 and 2 (highlighted orange) show the best results when primarily considering the 95PPU TH, percentage of observed levels within the 95PPU, the RMSE and R^2 of the 19 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. Hindcasted models 7, 9 and 12 all show very similar statistical results; given this, and to maintain some consistency with models selected, model run 12 was selected as the preferred model to progress to predictive modelling. The graphical model output for this run is shown in Figure 340.

Based on these results, modelling was progressed on the basis of adopting model run 12 for the three modelled Suites.

Table 123 Sale 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_O_1	95PPU TH	1.87	1.58	6.44	4.69	6.82	6.24	3.16	5.13	6.73	6.89	6.27	2.99	5.18	32.82	2.39	2.4	5.51	58.76	4.96
	%Obs in 95 PPU	100	93.75	100	93.75	94.59	94.59	97.3	94.59	97.3	94.59	91.89	100	94.59	90	80	80	97.22	100	97.22
	R^2	93	93.8	-64.2	17.7	88.5	89.5	93.2	89.3	88.2	88.5	89.5	92.8	89.3	64.7	71.6	72.7	87.1	87	87.9
	RMSE	0.35	0.33	1.7	1.2	0.87	0.84	0.67	0.84	0.88	0.87	0.84	0.69	0.84	0.87	0.78	0.77	0.91	0.91	0.88
	No obs data points	16	16	16	16	37	37	37	37	37	37	37	37	37	10	10	10	36	36	36
	Range of observed levels	4.4	4.4	4.4	4.4	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	4.4	4.4	4.4	10.3	10.3	10.3
M_P_1	95PPU TH	0.41	0.44	0.56	0.49	0.49	0.48	1.03	2.07	0.63	0.47	0.48	1.05	1.3	0.23	0	68.09	0.67	25612.3	3.11
	%Obs in 95 PPU	100	93.75	81.25	93.75	97.67	95.35	95.35	100	97.67	97.67	95.35	93.02	95.35	100	0	100	95.24	88.1	73.81
	R^2	96.1	95.9	90.6	94.7	98.4	98.8	98.3	88.2	98.5	98.8	98.8	98.3	98.3	82.4	57.1	82.3	98.3	98.8	-75.5
	RMSE	0.06	0.06	0.09	0.06	0.11	0.09	0.11	0.29	0.1	0.09	0.09	0.11	0.11	0.05	0.08	0.05	0.11	0.09	1.09
	No obs data points	16	16	16	16	43	43	43	43	43	43	43	43	43	10	10	10	42	42	42
	Range of observed levels	1.0	1.0	1.0	1.0	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	0.4	0.4	0.4	2.3	2.3	2.3
U_AB_1	95PPU TH	0.2	0.21	0.39	3.68	0.59	0.64	0.51	0.76	0.51	0.61	0.64	0.52	0.8	1.46	0.27	0.43	0.55	3.97	6.88
	%Obs in 95 PPU	93.75	100	100	87.5	95.56	95.56	95.56	91.11	95.56	95.56	95.56	95.56	77.78	80	80	90	95.45	100	100
	R^2	87.2	90.7	33.2	76.3	93.5	93.4	93.9	61	93.7	93.3	93.4	93.1	20.4	77.6	60.7	-4.8	92.5	92.5	91.1
	RMSE	0.04	0.03	0.09	0.05	0.08	0.08	0.08	0.2	0.08	0.08	0.08	0.09	0.29	0.05	0.06	0.11	0.09	0.09	0.09

Suite	Statistic	Model run																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	No obs data points	16	16	16	16	45	45	45	45	45	45	45	45	45	10	10	10	44	44	44
	Range of observed levels	0.4	0.4	0.4	0.4	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.3	0.3	0.3	1.1	1.1	1.1

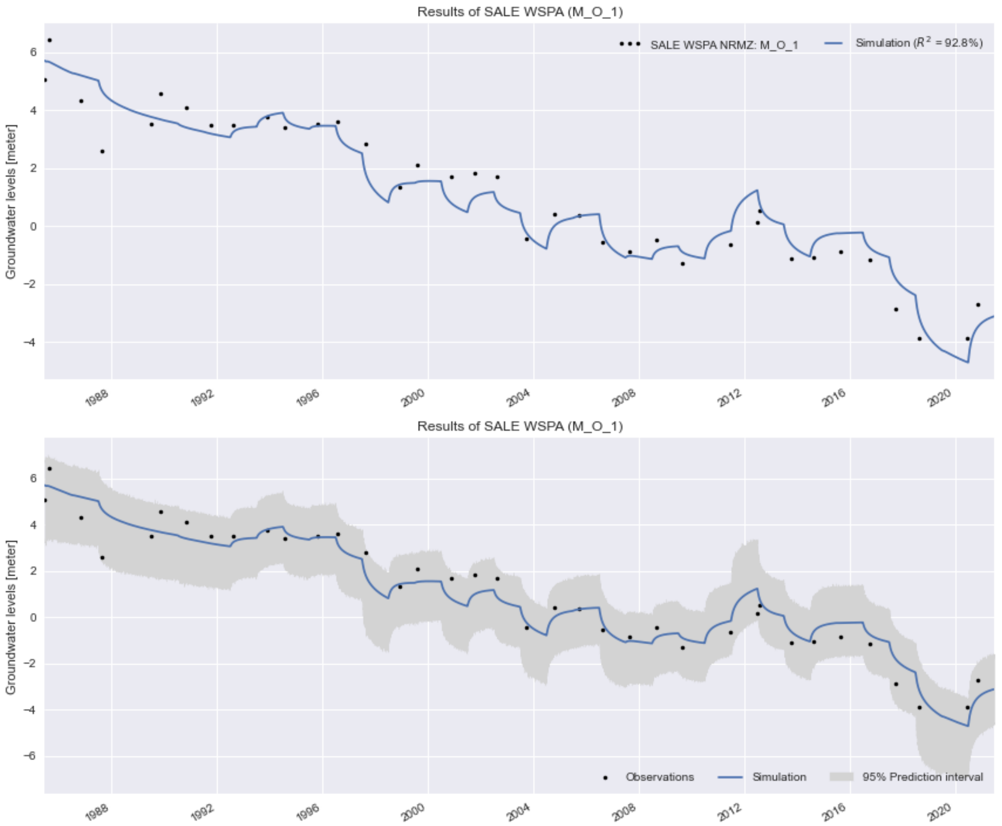


Figure** 338* ***Sale WSPA Suite M_O_1: model run 12 (Sale WSPA two yearly average annual extraction with hindcast method H2) output hydrographs

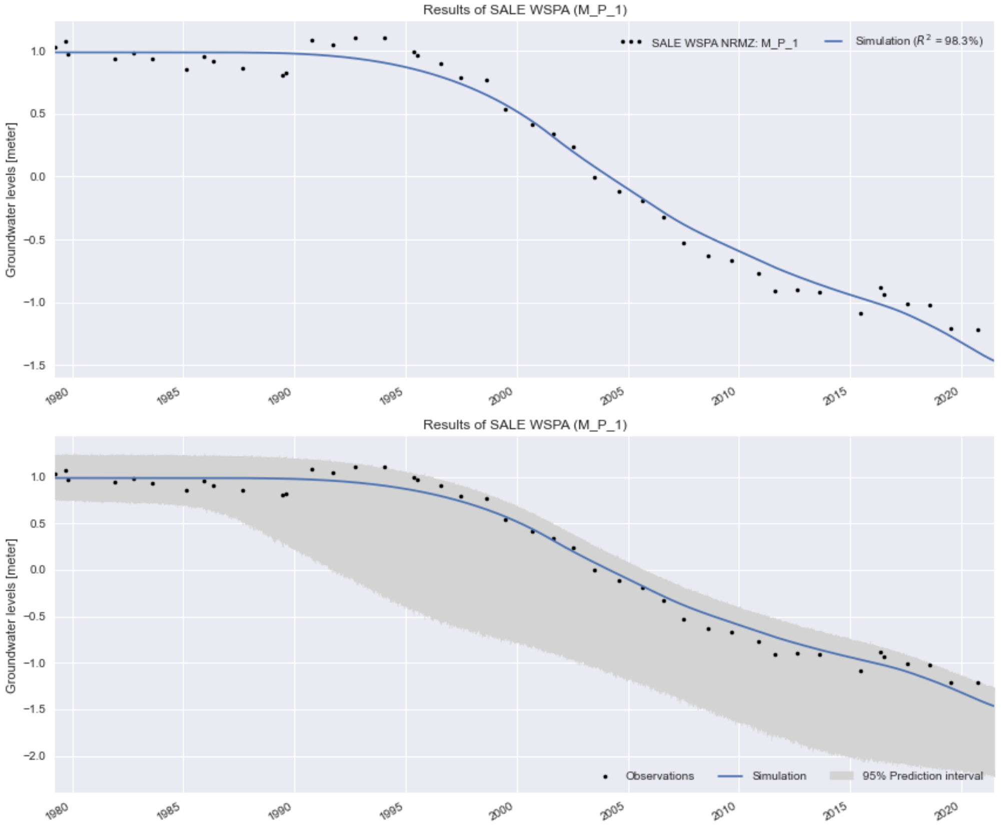


Figure 339 ***Sale WSPA Suite M_P_1: model run 12 (Sale WSPA two yearly average annual extraction with hindcast method H2) output hydrographs***

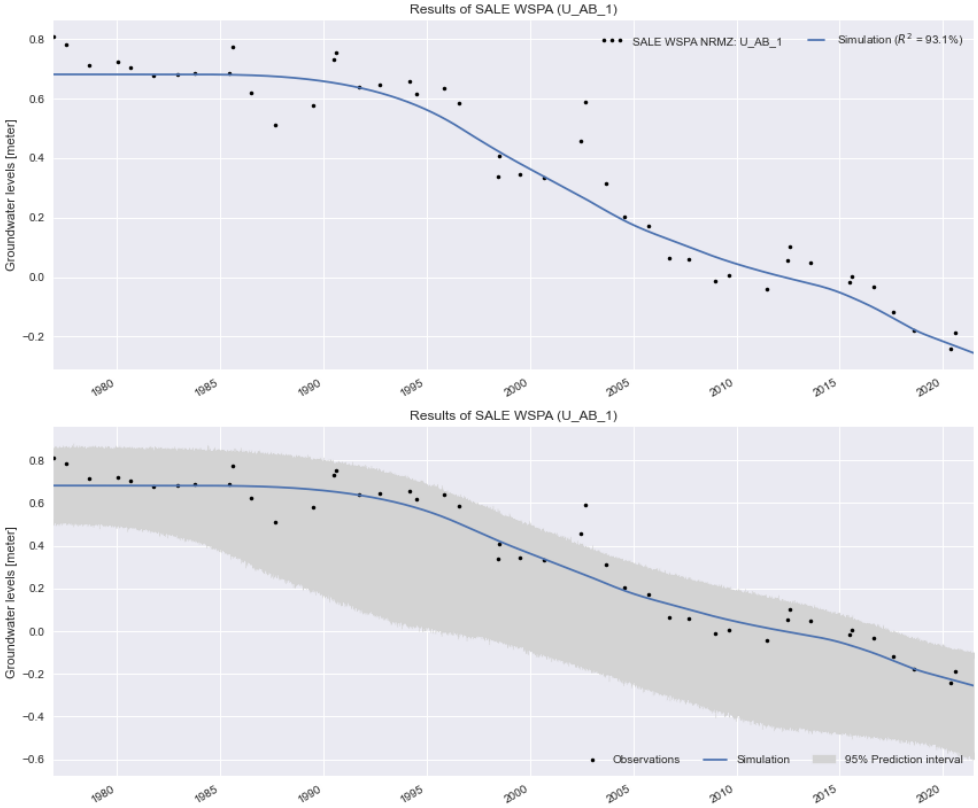


Figure 340 *Sale WSPA Suite U_AB_1: model run 12 (Sale WSPA annual extraction) output hydrographs*

21.4 Predictive modelling

21.4.1 Model inputs

The preferred model to run the predictive modelling for Sale WSPA was model run 12 for the three selected Suites, thus the key inputs for the model were the annual recovered levels and the annual extraction in Sale 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 124.

Table 124 Sale 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)	21,238	21,203	10,653	11,029	17,867

The model run 12 was run for all 19 forecast scenarios on Suites M_O_1, M_P_1 and U_AB_1.

21.4.2 Predictive model uncertainty

The model output files of the predicted models are provided in the data package within Appendix E.

MCMC predictions were undertaken on each of the forecasted scenarios for each of the three Suites. An example of one of the outputs is presented in Figure 341 for scenario 4. As shown in Figure 341, 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 342.

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.

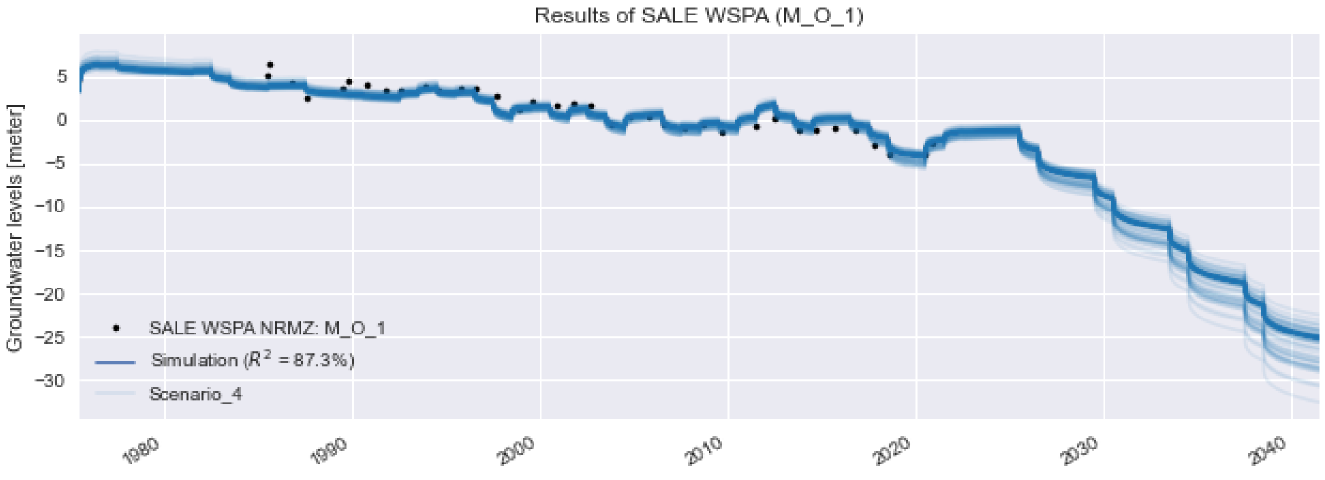


Figure 341 Sale WSPA: Suite M_O_1 MCMC analysis for Forecast Scenario 4

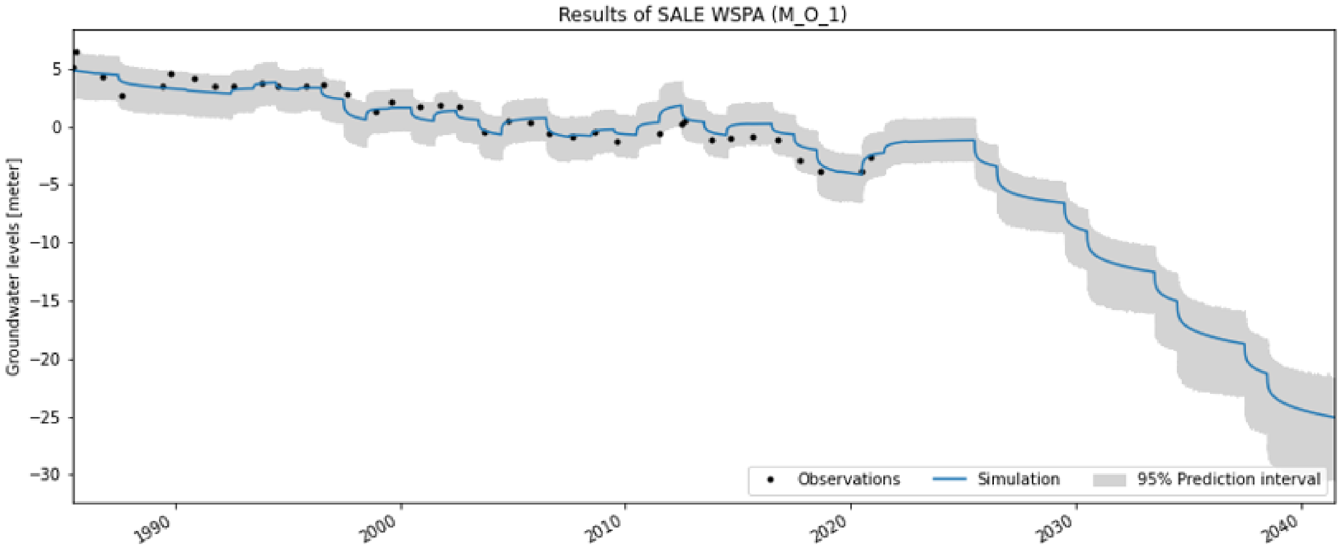


Figure 342 Sale WSPA: Suite M_O_1 Forecast Scenario 4 with 95% prediction bands

21.4.3 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 Sale WSPA, the water level prior to groundwater development was unknown, due to:

- Uncertainty regarding the commencement of development in Sale WSPA
- The initiation of groundwater development preceding SOBN bore installation and temporal groundwater monitoring which comprise the Suite hydrograph bores for Sale WSPA

Using the pre-development levels defined in section 21.2.2, 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 343 for the Suite M_O_1 hydrograph of annual recovered levels. In Figure 343:

- 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 1984/1985 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
- The pre-development annual recovered level is taken to be the second reading which equates to 6.45 m
- The modelled forecasted annual recovered levels are represented by the purple line in Figure 343
- The calibration annual recovered levels are represented by the black line in Figure 343

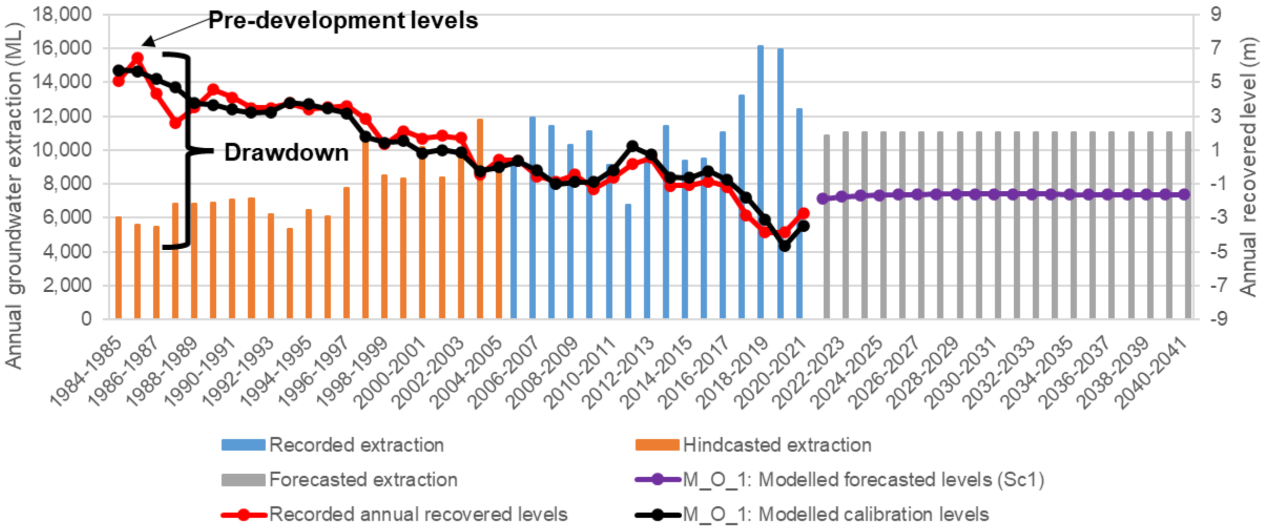


Figure 343 *Estimating pre-pumping water levels (example from Suite M_O_1)*

For Suite M_O_1, the calculated drawdowns and volumes for each of the scenarios were plotted in individual graphs for each scenario to develop the volume to drawdown relationship, all scenarios together in the one graph (Figure 344) and a graph of the scenarios for specific time periods (Figure 345). For each scenario, a linear regression was applied and the coefficient of determination (R^2) was calculated. A comparison of each of these graphs generally shows no significant change in the coefficient of determination and only a 0.0001 variation in the slope of the line. The same process was applied for Suite M_P_1 and U_AB_and it was found that there were variations in the coefficient of determination and in the slope of the line 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 344 for Suite M_O_1, Figure 346 for Suite M_P_1 and Figure 347 for Suite U_AB_1. 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. It is noted that for Suite M_O_1, the difference between the recorded annual recovered level defined as the predevelopment level and the modelled level at the same time is around 0.8 m; this contributes to the y-intercept value for this Suite.
- The average historic use for Sale WSPA is around 11,000 ML; the use-drawdown plot for Suite M_O_1 (Figure 344) and Suite U_AB_1 (Figure 347) shows that the modelled forecast drawdown data plots close to the predicted line of best fit at this usage
- For the same annual use, different drawdowns can be obtained as Pastas predicts a water level for each year. For example, Figure 343 shows a scenario where groundwater use remains constant at around 11,029 ML/year over the next 20 years.
- The correlation for groundwater use and drawdown for Suite M_P_1 and U_AB_1 is poorer than for Suite M_O_1
- 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.

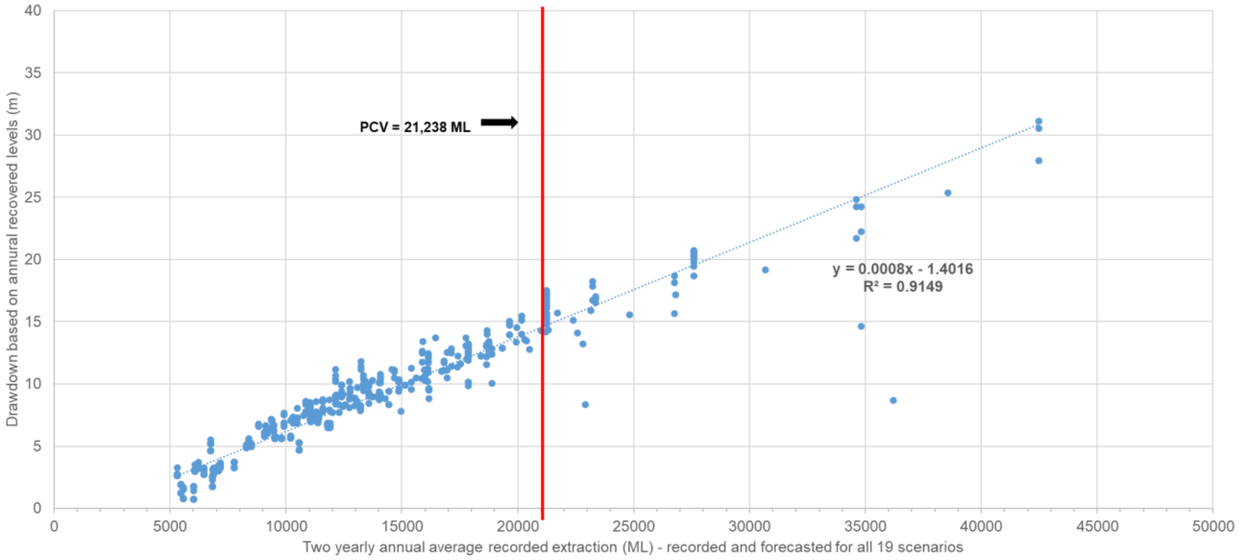


Figure 344 *Sale WSPA Suite M_O_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <45,000 ML) for all data between 1985 to 2041 and all forecasted scenarios*

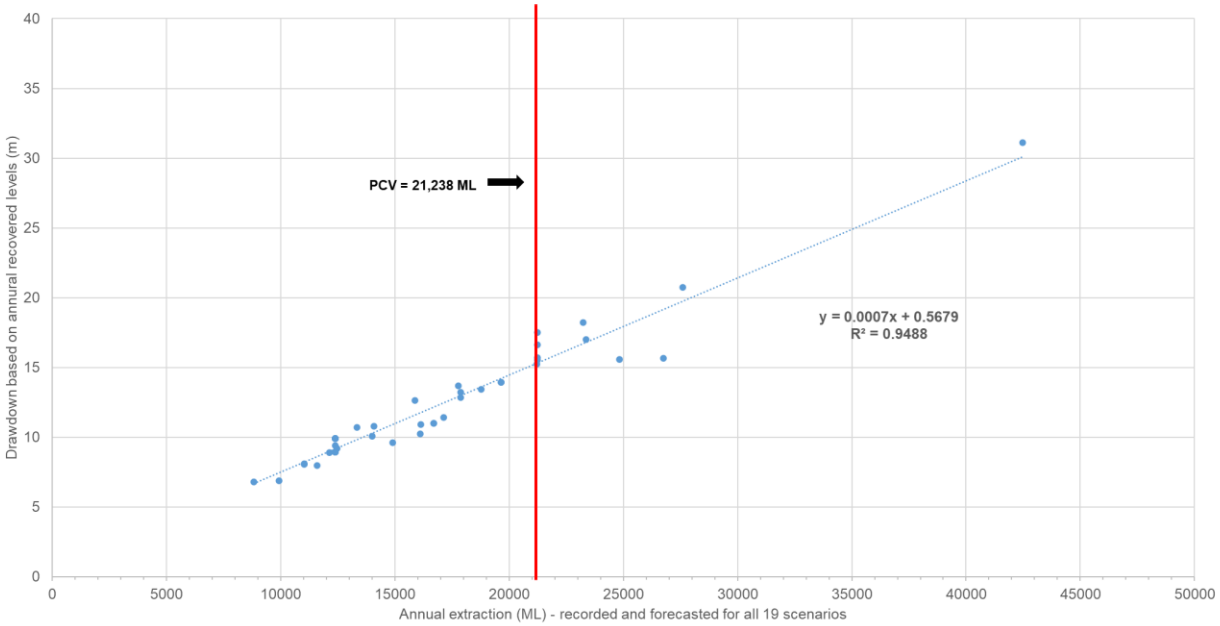


Figure 345 *Sale WSPA Suite M_O_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <45,000 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

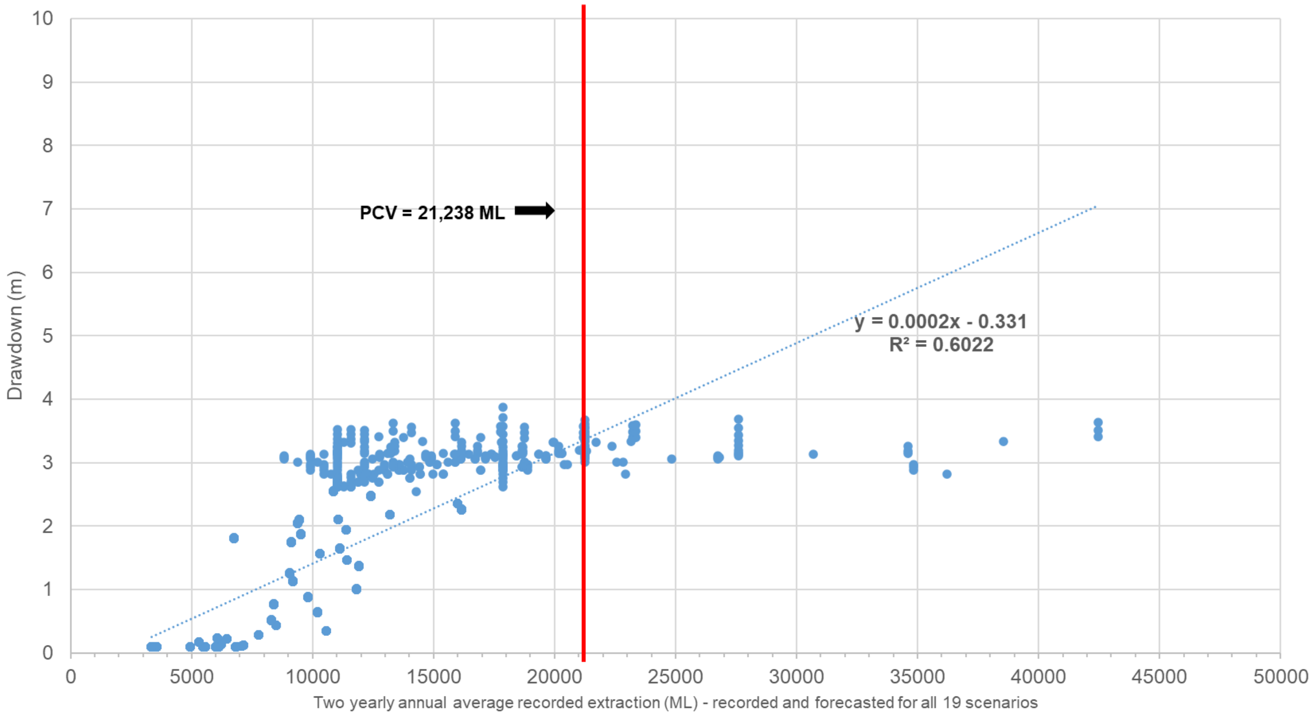


Figure 346 *Sale WSPA Suite M_P_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <45,000 ML) for all data between 1979 to 2041 and all forecasted scenarios*

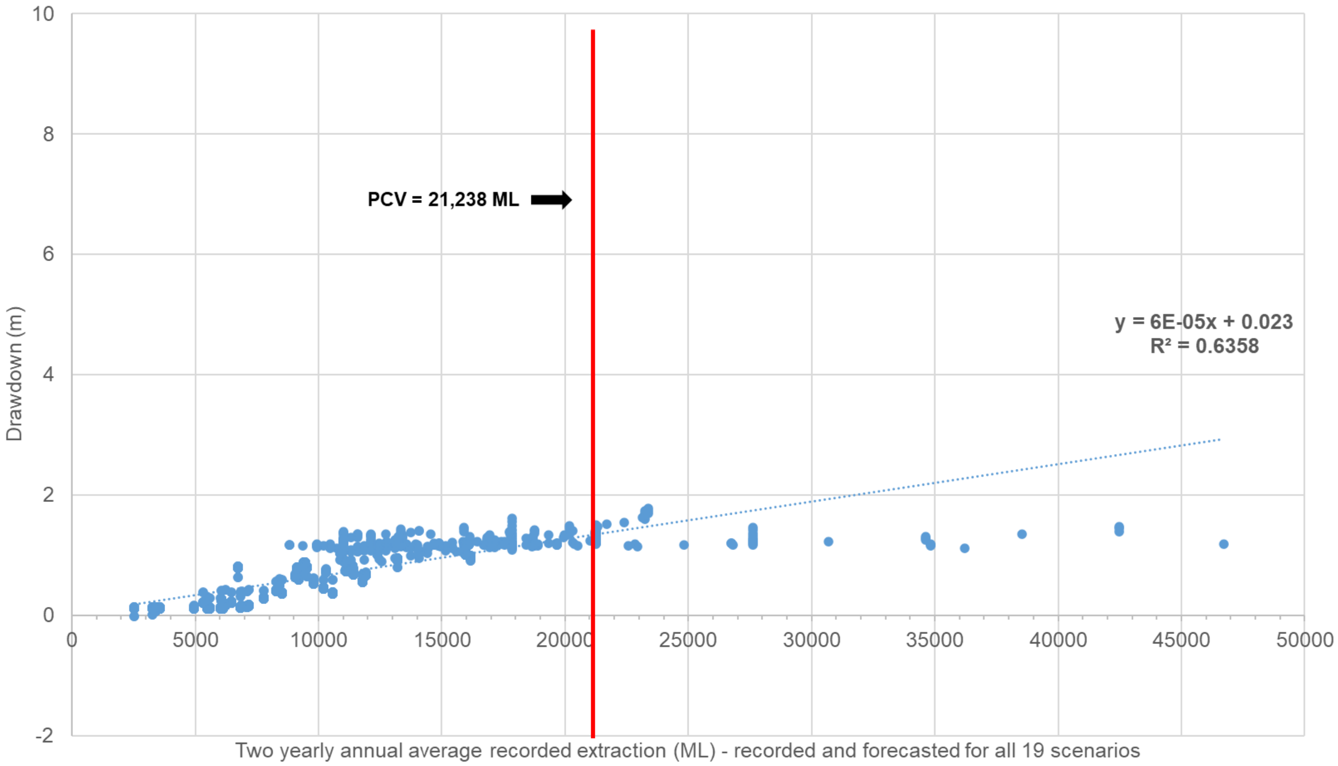


Figure 347 *Sale WSPA Suite U_AB_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <45,000 ML) for all data between 1977 to 2041 and all forecasted scenarios*

21.5 Sustainability metrics

21.5.1 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 125 for Sale WSPA Suite M_O_1, Suite M_P_1 and Suite U_AB_1 (noting Sale WSPA has a current PCV of 21,238 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 125 and Figure 348 for Suite M_O_1, Table 126 and Figure 349 for Suite M_P_1, and Table 127 and Figure 350 for Suite U_AB_1.

Figure 351 shows graphically and spatially by Suite the drawdowns associated with extraction rates. In comparing the three Sale WSPA Suites M_P_1 and U_AB_1, both have lower drawdowns for a given use when compared to Suite M_O_1. In the case of Suite U_AB_1 in particular, the low drawdowns associated with relatively high extraction rates may reflect that the analysis assumed the groundwater extraction in the Suite area occurred entirely from this aquifer, when in reality only a portion was; this may have skewed the predictive results.

A comparison of volumes at drawdown intervals provided by DEECA is shown in Table 128 for Suite M_O_1, M_P_1 and U_AB_1. Considering Suite M_O_1 covers the largest portion of the GMU and 51% of extraction from the GMU occurs from this Suite, this Suite is considered to be most applicable to Sale WSPA. Based on Suite M_O_1, 5 m of drawdown is predicted to occur at a groundwater extraction volume of 8,000 ML which could range from 6,600 ML to 10,900 ML based on the 95% prediction intervals and 10 m of drawdown is predicted to occur at a groundwater extraction volume of 14,300 ML which could range from 12,900 ML to 18,000 ML based on the 95% prediction intervals.

Table 125 Relationship of Suite drawdown to GMU extraction for Sale WSPA Suite M_O_1

Volume (ML/year) for whole of GMU based on two yearly average annual extraction	Based on model prediction of Suite M_O_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
30,000	22.6 (18.4 - 23.7)
28,000	21 (17 - 22.1)
26,000	19.4 (15.6 - 20.5)
24,000	17.8 (14.2 - 18.9)
22,000	16.2 (12.8 - 17.3)
20,000	14.6 (11.4 - 15.7)
18,000	13 (10 - 14.1)
16,000	11.4 (8.6 - 12.5)
14,000	9.8 (7.2 - 10.9)
12,000	8.2 (5.8 - 9.3)
10,000	6.6 (4.4 - 7.7)
8,000	5 (3 - 6.1)
6,000	3.4 (1.6 - 4.5)
4,000	1.8 (0.2 - 2.9)
2,000	0.2 (-1.2 - 1.3)
0	-1.4 (-2.6 - -0.3)

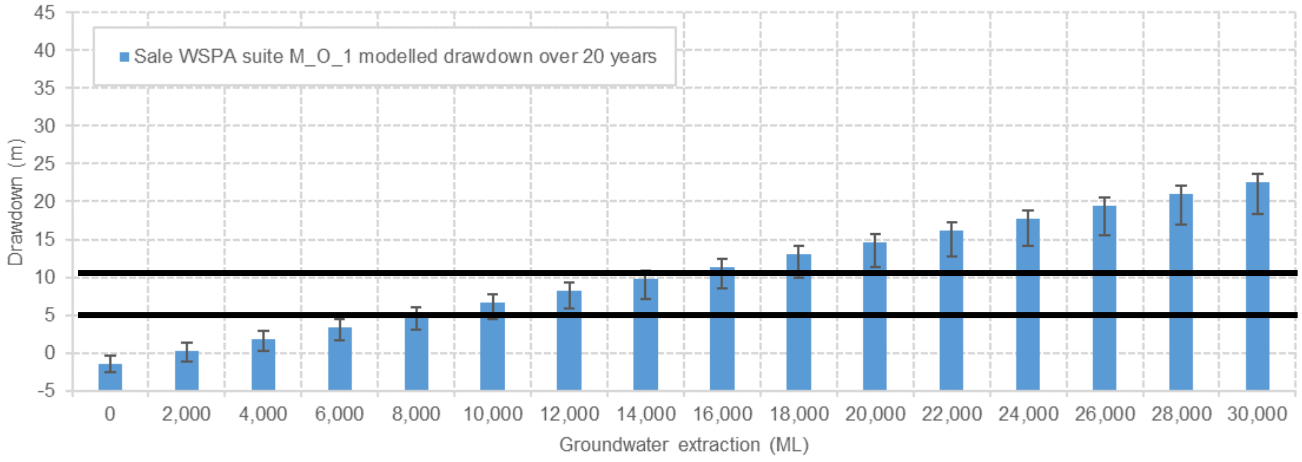


Figure 348 Sale WSPA Suite M_O_1: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 126 *Relationship of Suite drawdown to GMU extraction for Sale WSPA Suite M_P_1*

Volume (ML/year) for whole of GMU based on two yearly average annual extraction	**Based on model prediction of Suite M_P_1 annual recovered levels**
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
60,000	11.7 (11.5 - 12.1)
55,000	10.7 (10.5 - 11.1)
50,000	9.7 (9.5 - 10.1)
45,000	8.7 (8.5 - 9.1)
40,000	7.7 (7.5 - 8.1)
35,000	6.7 (6.5 - 7.1)
30,000	5.7 (5.5 - 6.1)
25,000	4.7 (4.5 - 5.1)
20,000	3.7 (3.5 - 4.1)
15,000	2.7 (2.5 - 3.1)
10,000	1.7 (1.5 - 2.1)
5,000	0.7 (0.5 - 1.1)
0	-0.3 (-0.5 - 0.1)

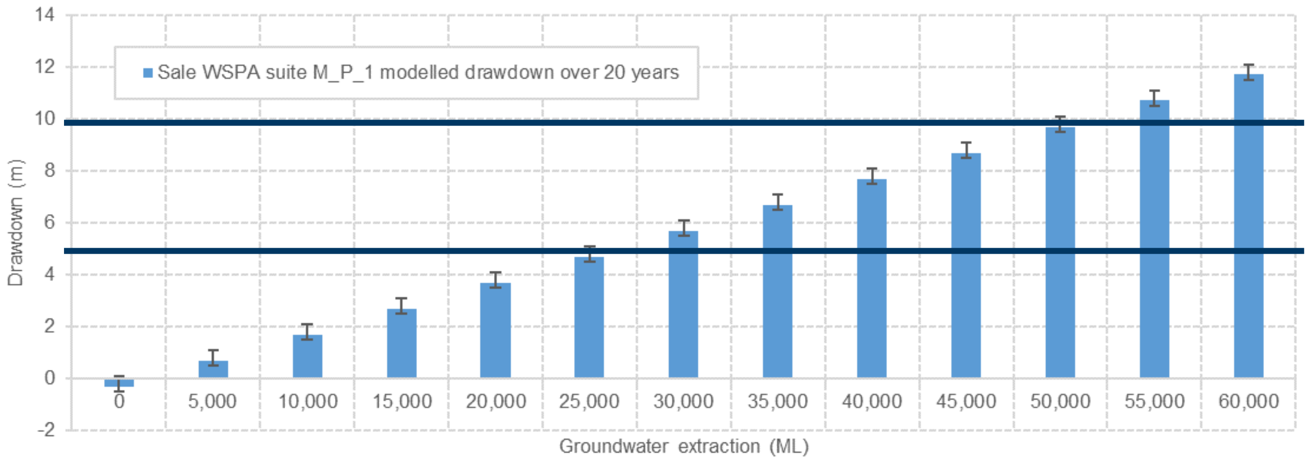


Figure 349 *Sale WSPA Suite M_P_1: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)*

Table 127 Relationship of Suite drawdown to GMU extraction for Sale WSPA Suite U_AB_1

Volume (ML/year) for whole of GMU based on two yearly average annual extraction	Based on model prediction of Suite U_AB_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
60,000	3.6 (3.5 - 5.1)
55,000	3.3 (3.2 - 4.7)
50,000	3 (2.9 - 4.3)
45,000	2.7 (2.6 - 3.9)
40,000	2.4 (2.3 - 3.5)
35,000	2.1 (2 - 3.1)
30,000	1.8 (1.7 - 2.7)
25,000	1.5 (1.4 - 2.3)
20,000	1.2 (1.1 - 1.9)
15,000	0.9 (0.8 - 1.5)
10,000	0.6 (0.5 - 1.1)
5,000	0.3 (0.2 - 0.7)
0	0 (-0.1 - 0.3)

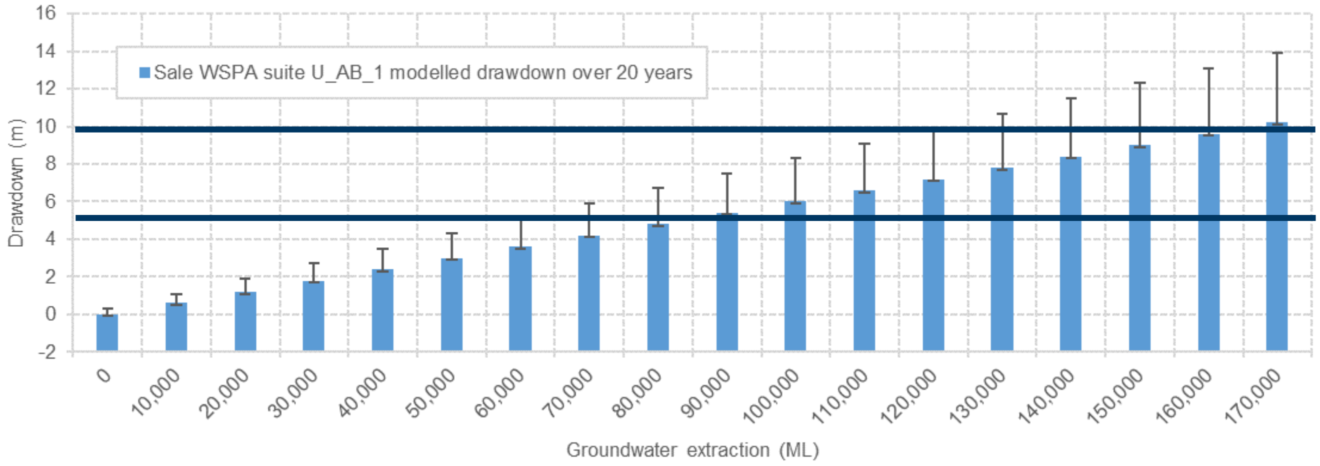
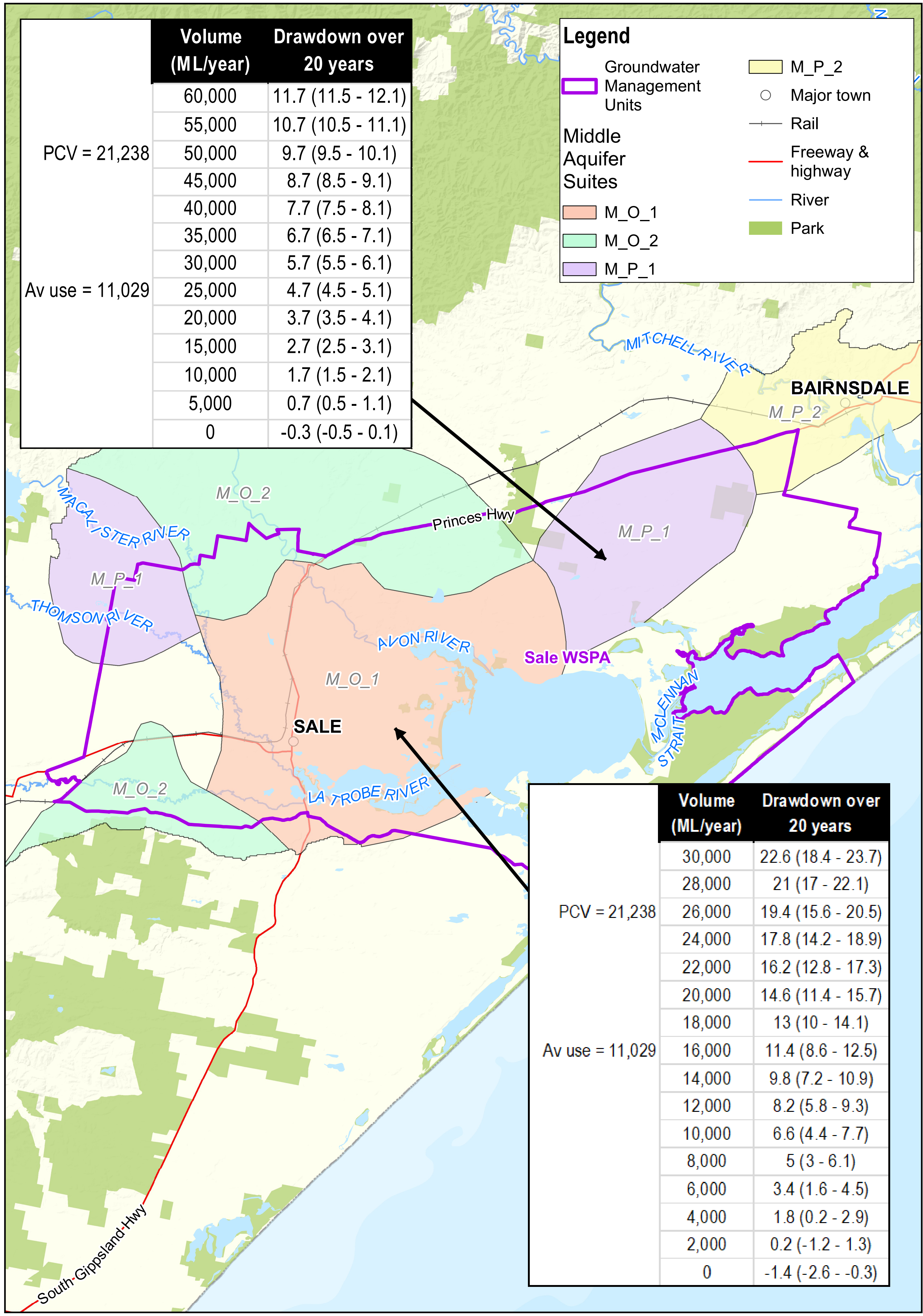


Figure 350 Sale WSPA Suite U_AB_1: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

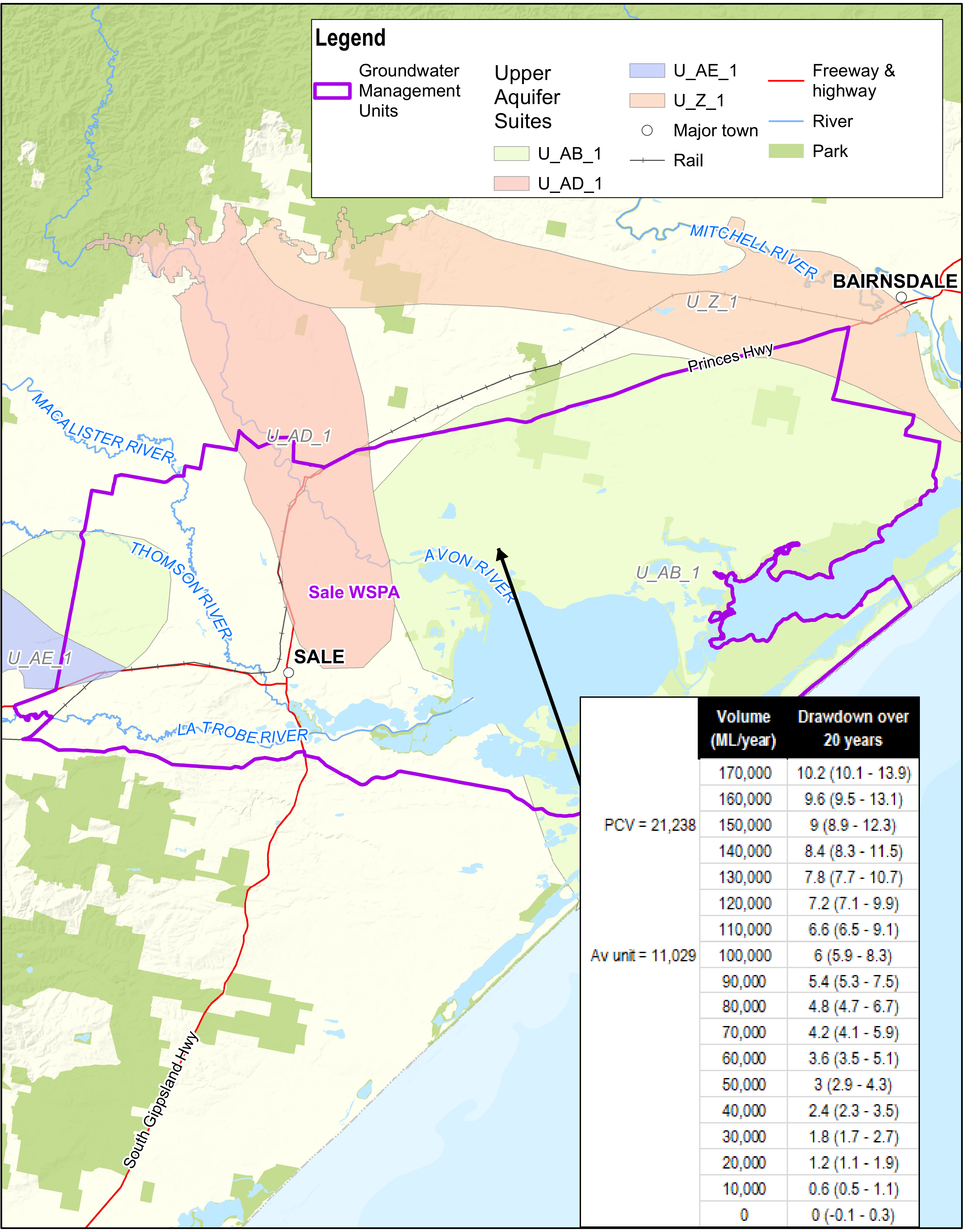
Table 128 Predicted GMU volumes for drawdown metrics

Drawdown (m) for confined aquifer	Predicted volumes (ML) for GMU based on Suite M_O_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite M_P_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite U_AB_1 drawdowns (lower limit to upper limit)
5	8,000 (6,600 – 10,900)	26,700 (24,600 – 27,600)	83,000 (59,300 – 85,600)
10	14,300 (12,900 – 18,000)	51,700 (49,600 – 52,600)	166,300 (121,800 – 169,000)



	Volume (ML/year)	Drawdown over 20 years
	60,000	11.7 (11.5 - 12.1)
	55,000	10.7 (10.5 - 11.1)
PCV = 21,238	50,000	9.7 (9.5 - 10.1)
	45,000	8.7 (8.5 - 9.1)
	40,000	7.7 (7.5 - 8.1)
	35,000	6.7 (6.5 - 7.1)
	30,000	5.7 (5.5 - 6.1)
Av use = 11,029	25,000	4.7 (4.5 - 5.1)
	20,000	3.7 (3.5 - 4.1)
	15,000	2.7 (2.5 - 3.1)
	10,000	1.7 (1.5 - 2.1)
	5,000	0.7 (0.5 - 1.1)
	0	-0.3 (-0.5 - 0.1)

	Volume (ML/year)	Drawdown over 20 years
	30,000	22.6 (18.4 - 23.7)
	28,000	21 (17 - 22.1)
PCV = 21,238	26,000	19.4 (15.6 - 20.5)
	24,000	17.8 (14.2 - 18.9)
	22,000	16.2 (12.8 - 17.3)
	20,000	14.6 (11.4 - 15.7)
	18,000	13 (10 - 14.1)
Av use = 11,029	16,000	11.4 (8.6 - 12.5)
	14,000	9.8 (7.2 - 10.9)
	12,000	8.2 (5.8 - 9.3)
	10,000	6.6 (4.4 - 7.7)
	8,000	5 (3 - 6.1)
	6,000	3.4 (1.6 - 4.5)
	4,000	1.8 (0.2 - 2.9)
	2,000	0.2 (-1.2 - 1.3)
	0	-1.4 (-2.6 - -0.3)



	Volume (ML/year)	Drawdown over 20 years
	170,000	10.2 (10.1 - 13.9)
	160,000	9.6 (9.5 - 13.1)
PCV = 21,238	150,000	9 (8.9 - 12.3)
	140,000	8.4 (8.3 - 11.5)
	130,000	7.8 (7.7 - 10.7)
	120,000	7.2 (7.1 - 9.9)
	110,000	6.6 (6.5 - 9.1)
Av unit = 11,029	100,000	6 (5.9 - 8.3)
	90,000	5.4 (5.3 - 7.5)
	80,000	4.8 (4.7 - 6.7)
	70,000	4.2 (4.1 - 5.9)
	60,000	3.6 (3.5 - 5.1)
	50,000	3 (2.9 - 4.3)
	40,000	2.4 (2.3 - 3.5)
	30,000	1.8 (1.7 - 2.7)
	20,000	1.2 (1.1 - 1.9)
	10,000	0.6 (0.5 - 1.1)
	0	0 (-0.1 - 0.3)

Paper Size ISO A3
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Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
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GHD

DEECA
Sustainable Yields
Confined Aquifers

SALE WSPA: KEY SUITES VOLUME VS DRAWDOWN

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

FIGURE 351

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

21.6 GMU summary

21.6.1 Findings

Sale WSPA primarily relates to the Boisdale Formation aquifer (UTAF) and groundwater is predominately extracted from this aquifer for irrigation purposes. The UTAF falls within the Middle Aquifer Suites and one Upper Aquifer Suite (Suite U_AB_1). The Middle Aquifer Suites that cover Sale WSPA are M_O_1 (35%), M_O_2 (12%), M_P_1 (15%) and M_P_2 (1%) providing a total coverage of 63%; this is similar to the coverage of Suite U_AB_1 (64%). The identified representative Suites are M_O_1 (most preferred), M_P_1 and U_AB_1. The Suite hydrographs for the representative Suites show an overall decreasing trend along with seasonal fluctuation and thus recovered water levels, which were adopted for the assessment.

As identified through the conceptualisation, Sale WSPA may be influenced by extraction occurring from the Latrobe Valley Mines, which is significantly greater than the extraction that occurs within the GMU. 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 Sale only dataset.

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 2 (two yearly average annual extraction for Sale WSPA and Latrobe Valley Mines with annual recovered levels) for Suite M_O_1, Suite M_P_2 and Suite U_AB_1.

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 spatial distribution methodology was combined with hindcasting methodology.

The difference between the Sale WSPA only and the combined Sale WSPA and Latrobe Valley Mines Groundwater Sources model runs were not comparable, with the Sale only extraction model runs generally showing a better result. Given this, it was considered that including this external influence within the Sale WSPA predictive modelling would not result in a substantive difference and thus, was not pursued further.

Based on an assessment of all model runs and the need to include historical data in the selected calibration model, model run 12 of Sale WSPA only two yearly average annual extraction using hindcast method H2 with the annual recovered levels was adopted to undertake the predictive modelling for Suites M_O_1, M_P_1 and U_AB_1.

The pre-development levels were defined for the three representative Suites based on the early time series Suite data or the maximum level in the early time series data for the annual recovered levels. This resulted in pre-development annual recovered levels of 6.45 m for Suite M_O_1, 1.05 m for Suite M_P_1 and 0.81 m for Suite U_AB_1. The drawdowns were calculated based on these pre-development levels and the simulated levels from each of the 19 forecast scenarios.

The models for Suites M_O_1, M_P_1 and U_AB_1 were assessed as having an “Excellent” model applicability rating using the criteria outlined in section 5.2. It’s noted that Suite M_P_1 and U_AB_1 show a relatively subdue reaction to pumping and thus these is a large difference in the use-drawdown relationship compared to Suite M_O_1. In the case of Suite U_AB_1 in particular, the low drawdowns associated with relatively high extraction rates may reflect that the analysis assumed the groundwater extraction in the Suite area occurred entirely from this aquifer, when in reality only a portion was; and this may have skewed the predictive results.

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

Drawdown (m) for confined aquifer	Predicted volumes (ML) for GMU based on Suite M_O_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite M_P_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite U_AB_1 drawdowns (lower limit to upper limit)
5	8,000 (6,600 – 10,900)	26,700 (24,600 – 27,600)	83,000 (59300 – 85,600)
10	14,300 (12,900 – 18,000)	51,700 (49,600 – 52,600)	166,300 (121,800 – 169,000)

Suite M_O_1 was considered the most representative for Sale WSPA.

21.6.2 Limitations

In addition to the limitations applicable to all 25 GMUs discussed in section 1.8, the following Sale WSPA 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
- The licenced bore dataset provided by DEECA has 9% of bores assigned to Sale WSPA 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 Sale WSPA, it was not assigned to an aquifer/Suite.
- Historic data is not available for Sale WSPA beyond 2005/2006 which limits the available recorded data that can be used in the TFN modelling
- Suite M_P_1 and U_AB_1 show a relatively subdue reaction to pumping (if any)
- There is a large difference in results between Suites M_P_1/U_AB_1 and M_O_1. Suite M_O_1 is taken to be more representative as has highest extraction within GMU.

21.6.3 Recommendations

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

- The licenced bore dataset provided by DEECA has 9% of bores assigned to Sale WSPA with no depth data and thus couldn't be assigned to a VAF layer and in turn Suite with the data provided. It is recommended that DEECA obtains the relevant depth and aquifer monitored data for licenced bores within this GMU.

22. Stratford GMA

22.1 Conceptualisation

The hydrogeological conceptualisation elements relevant to this study are summarised in Table 129 for zone 1 of this GMU and Table 130 for zone 2 of this GMU, with a map of the GMU presented in Figure 352. 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 129 Stratford GMA Zone 1 – Tabulated conceptualisation

GMU summary

Stratford GMA is located in the Gippsland Basin. Stratford GMA lies beneath the Sale, Rosedale, Denison and Wa De Lock GMAs, each of which apply to the Quaternary and/or Tertiary aquifers in central Gippsland.

Stratford GMA is divided into two zones, each of which pertains to different depths:

- Stratford GMA Zone 1 (covering an area of approximately 960 km^2) pertains to formations greater than 150 m below the ground surface
- Stratford GMA Zone 2 (covering an area of approximately 3,690 km^2) pertains to formations greater than 350 m below the ground surface

Both zones were intended to primarily manage the groundwater resource of the Latrobe Group Aquifer (Lower Tertiary Aquifer, LTA). The PCV (27,868 ML/year) for Stratford GMA applies to both zones and therefore primarily relates to confined aquifers. Currently, the GMA has a licenced entitlement (37,084 ML/year) greater than the PCV, due to the extractions from the Latrobe Valley coal mines being in the physical area of this GMA. However, the licenced volume and extraction from the mines is not assigned or assessed against this GMA (based on 2019/2020 Victorian Water Accounts).

Groundwater use in the Stratford GMA is predominately used for power generation in the Latrobe Valley and irrigation (3% of entitlement) (Australian Government 2018).

Hydrostratigraphy summary

Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Approx. use volumes ML (2019/20)	Approx entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Undifferentiated sediments (QA)	-	-	0	NA	0	0	Low
	Haunted Hills Formation (UTQA)	-	-	0	NA	0	0	Low
Middle	Jemmy's Point Formation (UTD)	-	-	0	NA	0	0	Low
	Balook Formation (UMTA)	M_R_1 (2%)	2%	1	Unknown	21	190	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%	1	NA	0	0	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.

Characteristic and importance	Description	Degree of understanding
Intended aquifer		
Aquifer thickness within GMU (range, based on VAF)	Max: 386 m, Average: 110 m	High
Aquifer extent	Regional, extensive	High
Likelihood of inter-aquifer flow	High	Low
Likelihood of groundwater – surface water interaction	Medium	Low (Brumley et al, 1981; Walker and Mollica, 1990)
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)	0 – 600 mg/L	Low Based on CDM Smith (2022)
Groundwater yield	<50 L/s	Low Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range		
Spatial clustering of licensed bores in relation to Suites	No	Based on DEECA density mapping and licenced bore data.
Groundwater use		
Licensed groundwater use	**22,625 for all of Stratford GMA**	**Low – insufficient data to split by zone (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	17,225 ML for all of Stratford GMA	Low - insufficient data to split by zone (Based on historical VWA data, year 2011/12)

Maximum historic groundwater use	**27,897 ML for all of Stratford GMA**	**Low - insufficient data to split by zone (Based on historical VWA data, year 2016/17)**
Entitlement (Groundwater allocation)	**37,434 ML for all of Stratford GMA**	**Low – insufficient data to split by zone (Based on licenced volumes in 2020/21)**
Significant drivers of groundwater level variability (primary)	**Commercial/industrial. Irrigation**	**Moderate**
Secondary drivers of groundwater level variability	None identified	
Groundwater use profile	Variable -driven by mining activities	Low
External Influence	**None identified – Latrobe valley mines included in Stratford extraction**	
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

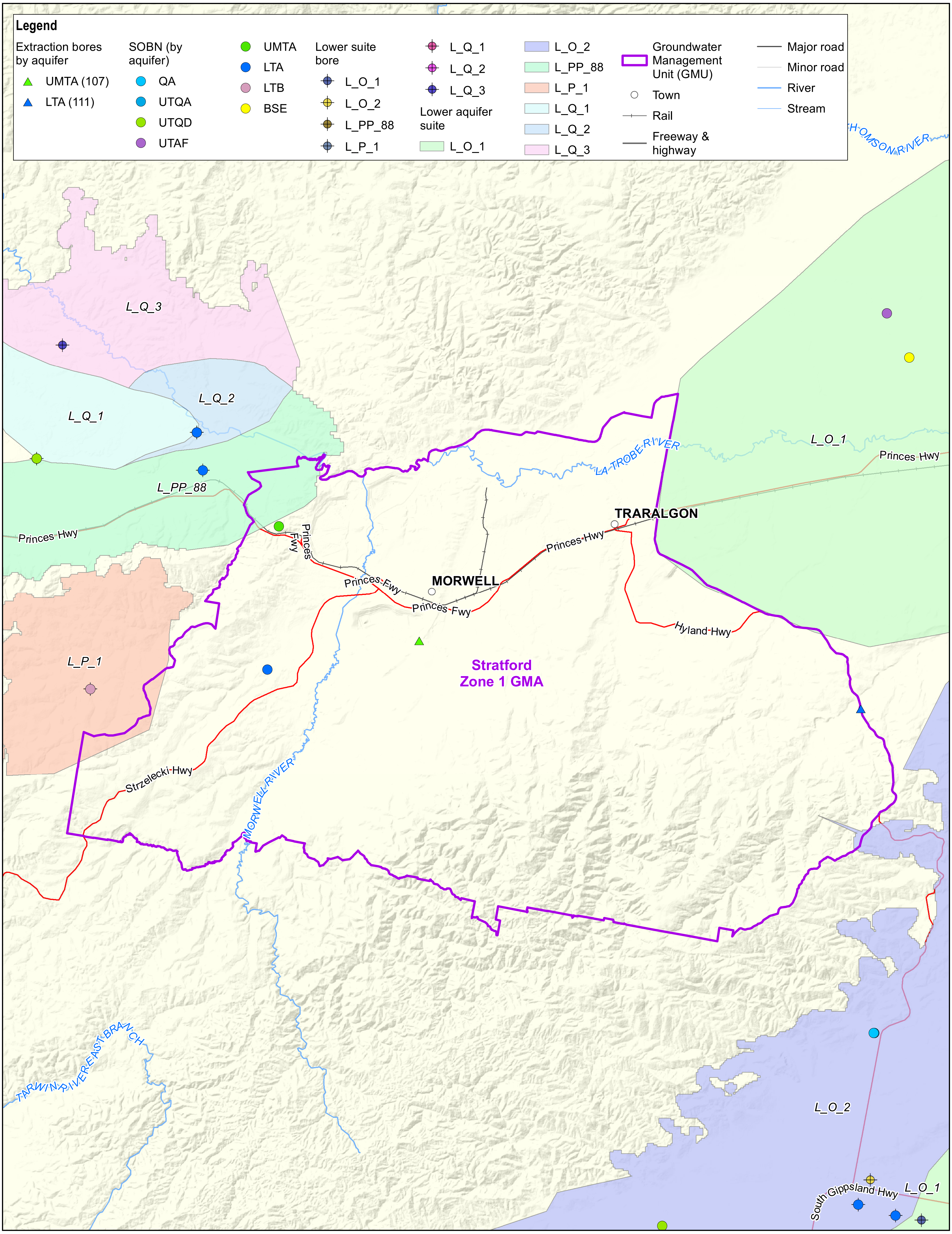
Table 130 Stratford GMA Zone 2 – Tabulated conceptualisation

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 (8%) U_Z_1 (4%)	12%	0	NA	0	0	Low
	Haunted Hills Formation (UTQA)	U_AE_1 (1%) U_Z_3 (3%) U_AC_99 (6%)	11%	0	NA	0	0	Low
	Nuntin Clay (UTQD)	-	-	0	NA	0	0	Low
Middle	Boisdale (Wurruk Sand) (UTAF)	M_O_1 (16%) M_O_2 (15%) M_P_1 (11%) M_P_2 (2%) U_AB_1 (36%)	80%	1	NA	0	0	Low
	Jemmy's Point Formation (UTD)	-	-	0	NA	0	0	Low
	Balook Formation (UMTA)	-	-	1	NA	0	0	Low
	Gippsland Limestone (UMTD)	-	-	0	Irrigation	0	10	Low
Lower	M2C aquifer (LMTA)	-	-	0	NA	0	0	Low
	Traralgon seams and aquifers (LTA)	L_O_1 (72%) L_O_2 (0.3%)	72%	9	Irrigation, Geothermal	13	376	Medium
	Carrajung Volcanics (LTBA, 112)	-	-	0	NA	0	0	Low
Basement	Basement rocks (BSE)	-	-	1	Irrigation, stock	1	210	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: 756 m, Average: 172 m	High
Aquifer extent	Regional, extensive	High
Likelihood of inter-aquifer flow	High	Low
Likelihood of groundwater – surface water interaction	Medium	Low (Brumley et al, 1981; Walker and Mollica, 1990)
Representative Suite	**L_O_1**	**Medium. 45% 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)	0 – 3,100 mg/L	Moderate Based on CDM Smith (2022)
Groundwater yield	Variable	Low Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1970-2021**	**High**
Spatial clustering of licensed bores in relation to Suites	Yes, outside lower Suite area	Based on DEECA density mapping and licenced bore data.
Groundwater use		
Licensed groundwater use	**22,625 for all of Stratford GMA**	**Low – insufficient data to split by zone (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	17,225 ML for all of Stratford GMA	Low - insufficient data to split by zone (Based on historical VWA data, year 2011/12)
Maximum historic groundwater use	**27,897 ML for all of Stratford GMA**	Low - **insufficient data to split by zone (Based on historical VWA data, year 2016/17)**
Entitlement (Groundwater allocation)	**37,434 ML for all of Stratford GMA**	**Low – insufficient data to split by zone (Based on licenced volumes in 2020/21)**
Significant drivers of groundwater level variability (primary)	**Commercial/industrial. Irrigation**	**Moderate**
Secondary drivers of groundwater level variability	**Off-shore oil and gas extraction**	**Moderate**
Groundwater use profile	Variable -driven by mining activities	Low

External Influence	**Off-shore oil and gas extraction (Latrobe valley mines included in Stratford extraction)**	
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 1.5 3 4.5 6

Kilometers

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

N

DEECA
Sustainable yield review - confined aquifers

Stratford GMA: Zone 1
Site location and key features

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

Figure 352a

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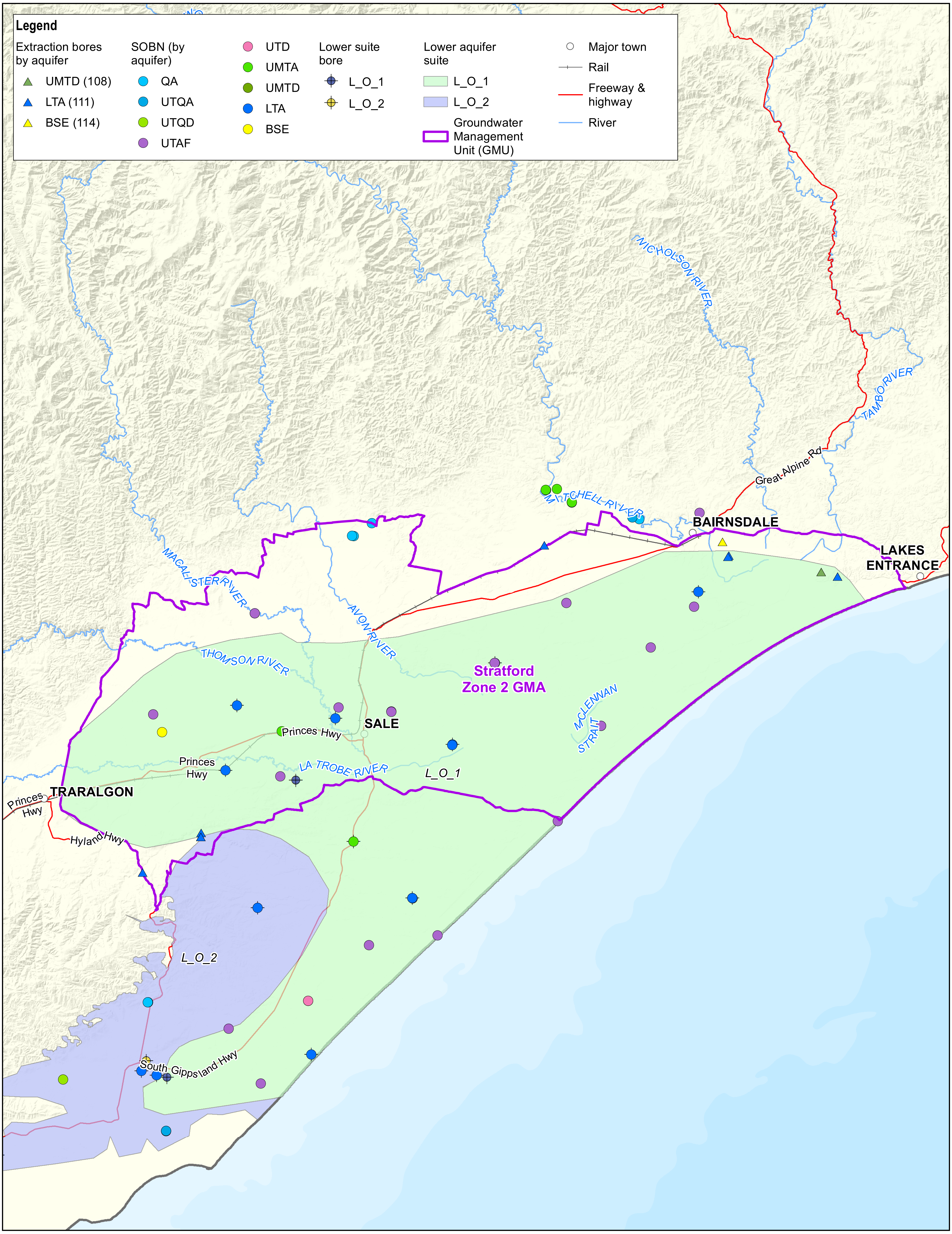
Print date: 16 Jan 2024 - 12:47

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

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Grid: GDA 1994 VICGRID94

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DEECA
Sustainable yield review - confined aquifers

Stratford GMA: Zone 2
Site location and key features

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

Figure 352b

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Print date: 16 Jan 2024 - 12:48

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

22.2 Technical analysis

22.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs generated for the relevant Suites for Stratford GMA are shown in Figure 353 and Figure 354. The Suite hydrographs show the seasonal fluctuations for Suites L_O_1 and L_O_2 and hence recovered water levels; which both exhibit a decreasing trend. Suite L_O_1 shows a displacement in the hydrograph between 1982 and 1986. This data was corrected before undertaking the collation of annual recovered levels, to better align with adjacent data. It is noted that Suites L_PP_88, L_P_1 and B_S_1 do not show a decreasing trend with time.

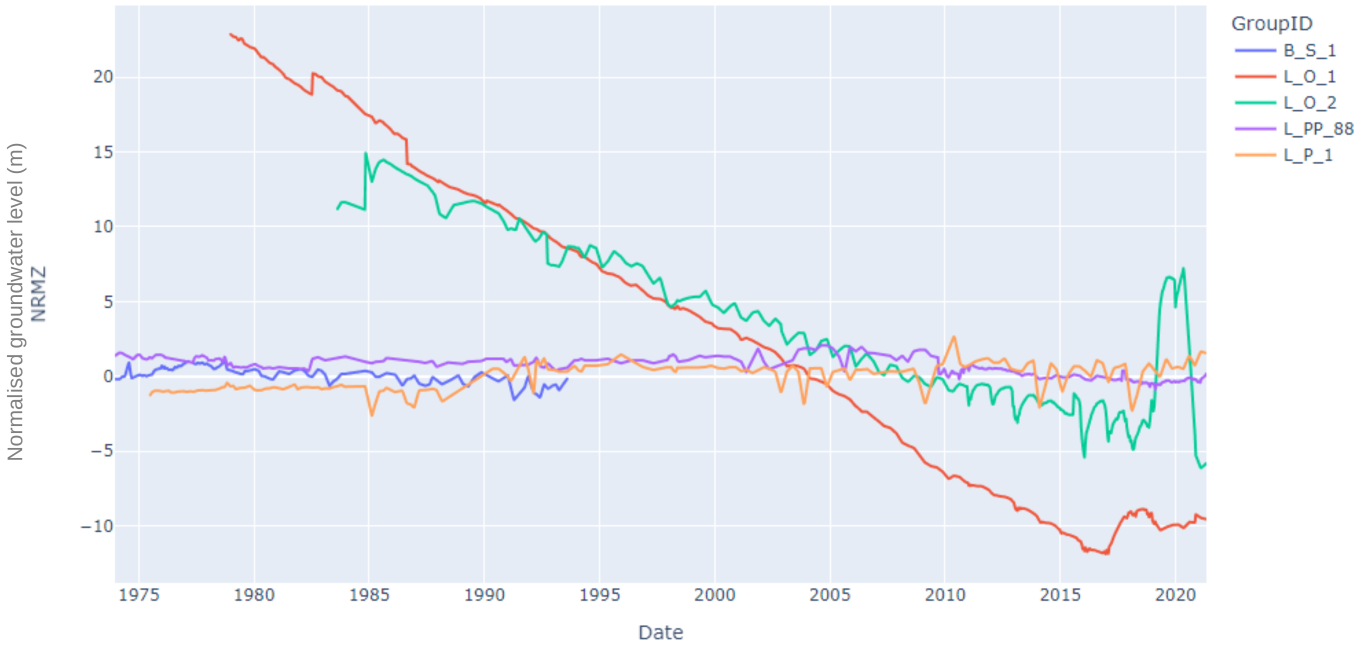


Figure 353 Stratford GMA Zone 1 Suite Hydrographs for all confined aquifers

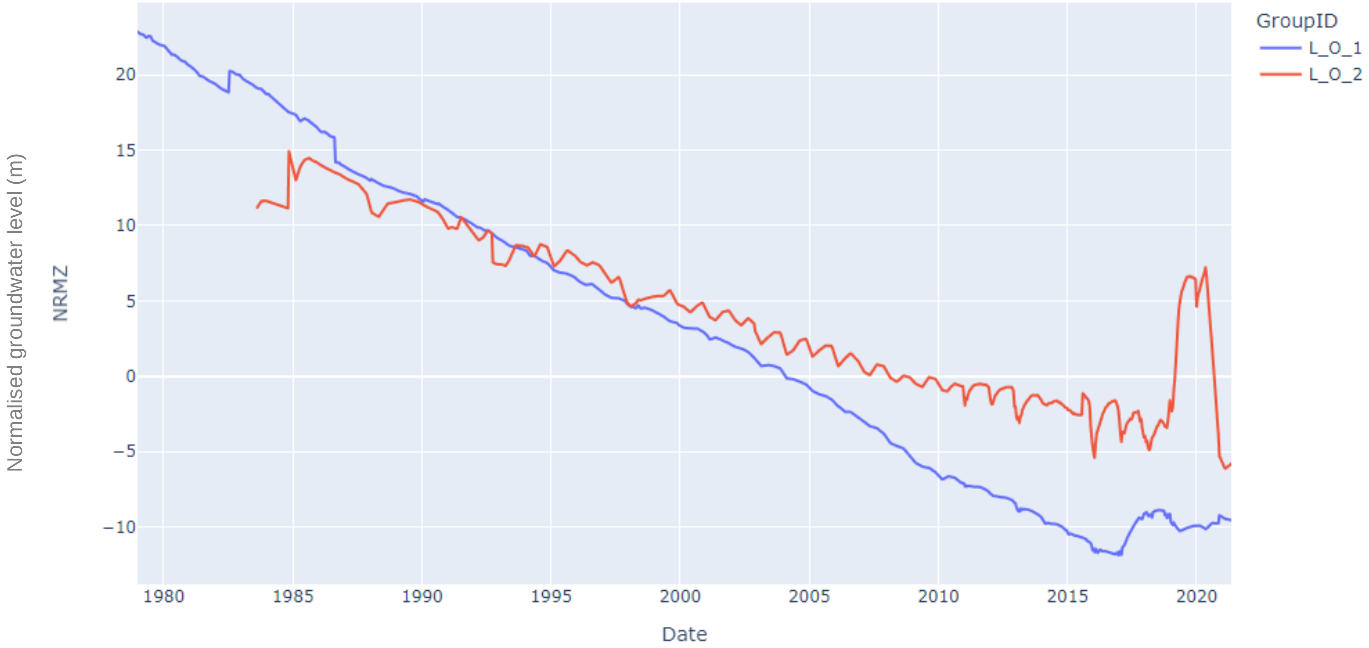


Figure 354 Stratford GMA Zone 2 Suite Hydrographs for all confined aquifers

The representative Suite analysed for this GMU was Suite L_O_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 Lower Aquifer with much of the other extraction occurring outside of Suite areas within the GMU
- The greatest volume of extraction occurs within zone 2 of Stratford GMA
- The Lower Aquifer pertains to the LTA, which is the intended aquifer of the GMU
- Suite L_O_1 covers 72% of the GMU
- Suite L_O_1 has six active SOBN bores within the GMU
- Suite L_O_1 is not close to extraction points (nor are any other Suites for Stratford GMA)

The annual recovered Suite hydrographs for the representative Suite L_O_1 for Stratford GMA, is shown in Figure 355.

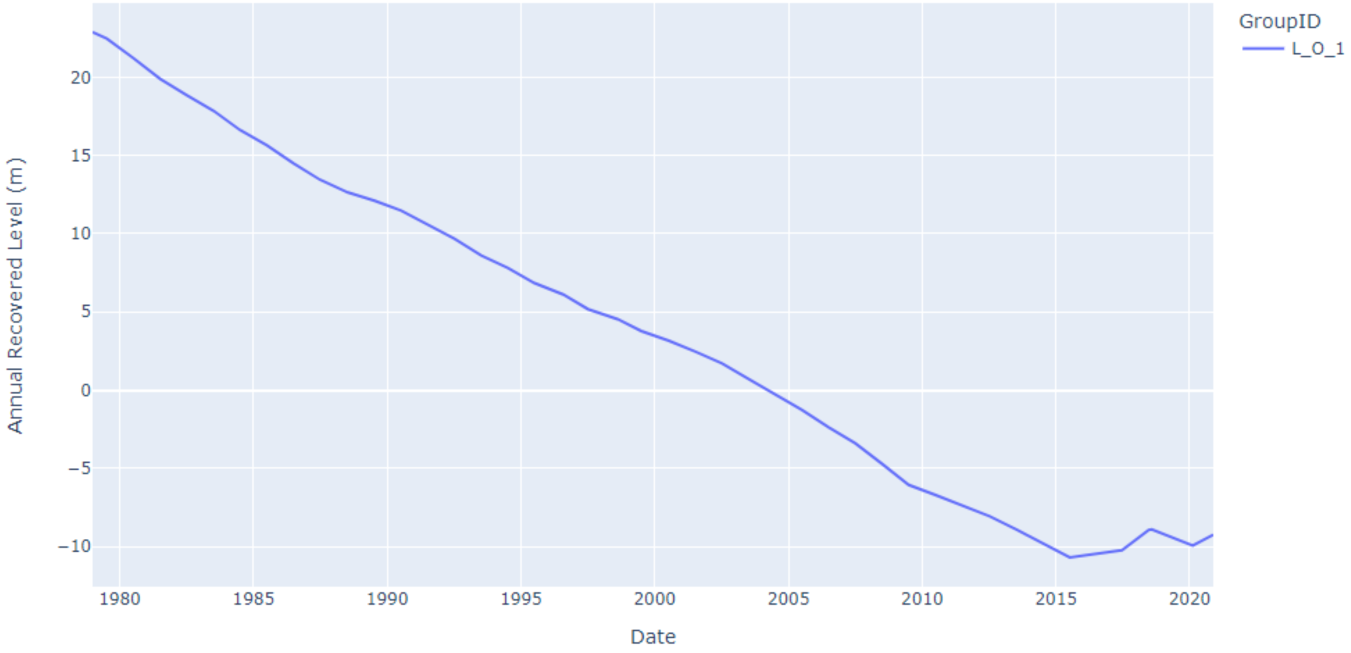


Figure 355 Stratford GMA Annual Recovered Level Suite Hydrographs for representative Suites

22.2.2 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 Stratford for Suite L_O_1.

The pre-development annual recovered levels was taken to be the first level of the time series data, this occurred in the year 1978/1979 for Suite L_O_1 which equated to 22.87 m.

22.2.3 Externalities

As identified through the conceptualisation, Stratford GMA extraction includes that occurring within the Latrobe Valley Mines. However, Stratford GMA, particularly zone 2, may be influenced by extraction occurring offshore. To test the influence of this extraction, data was sourced from DEECA to incorporate in the model.

Figure 377 shows the Stratford GMA annual groundwater extraction volumes, the offshore extraction volumes and the combined volumes. Note that where extraction does not occur in both Stratford GMA and offshore extractions, that year of data cannot be incorporated into the model without hindcasting. It is noted that the Stratford GMA extractions are typically only 19% of the offshore extraction volumes.

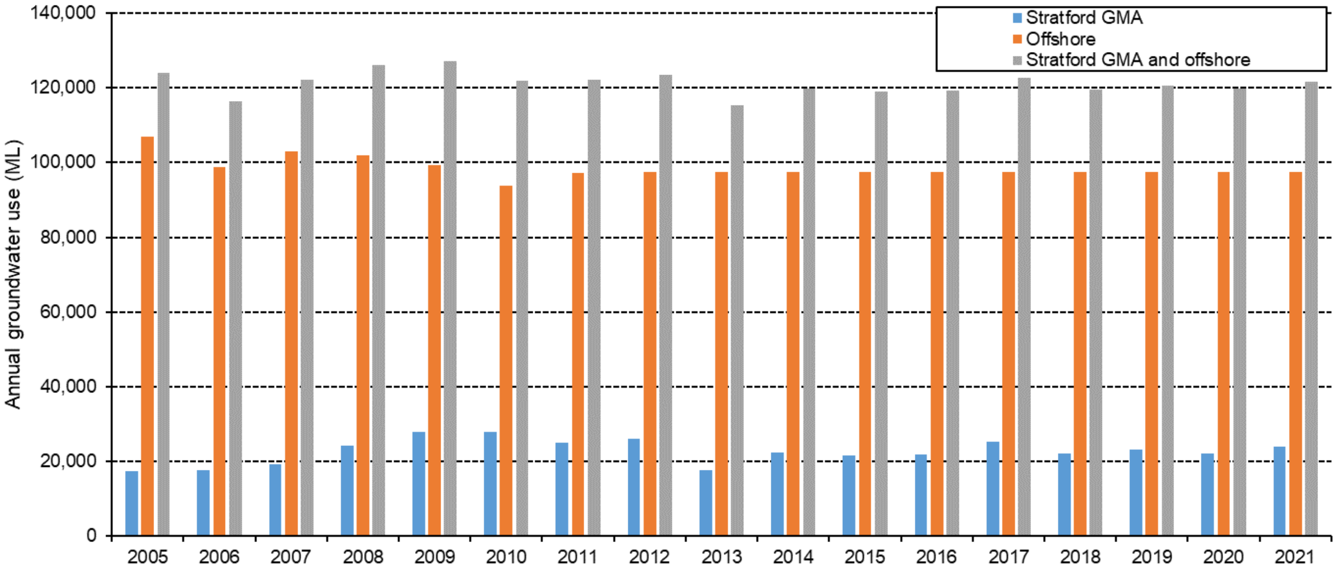


Figure 356 Stratford GMA and Offshore extractions – groundwater use

22.2.4 Hindcasting

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

22.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, eight different correlations were developed using the annual groundwater extraction as described below.

Figure 357:

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

Figure 358:

- Annual rainfall vs annual combined extraction at Stratford GMA and Offshore extractions (external influence)
- Two yearly average annual rainfall vs annual combined extraction at Stratford GMA and Offshore extractions (external influence)
- Annual summer period rainfall vs annual combined extraction at Stratford GMA and Offshore extractions (external influence)
- Annual irrigation period rainfall vs annual combined extraction at Stratford GMA and Offshore extractions (external influence)

As shown in Figure 357, the goodness-of-fit represented by the R^2 is low across all four correlations developed using just Stratford GMA extraction. The correlation with annual irrigation rainfall shows the highest R^2; this was adopted with method H1 without externalities. When externalities in the form of offshore extraction was included, the R^2 was highest for the correlation using annual rainfall. Generally, the R^2 was lower when incorporating externalities than without.

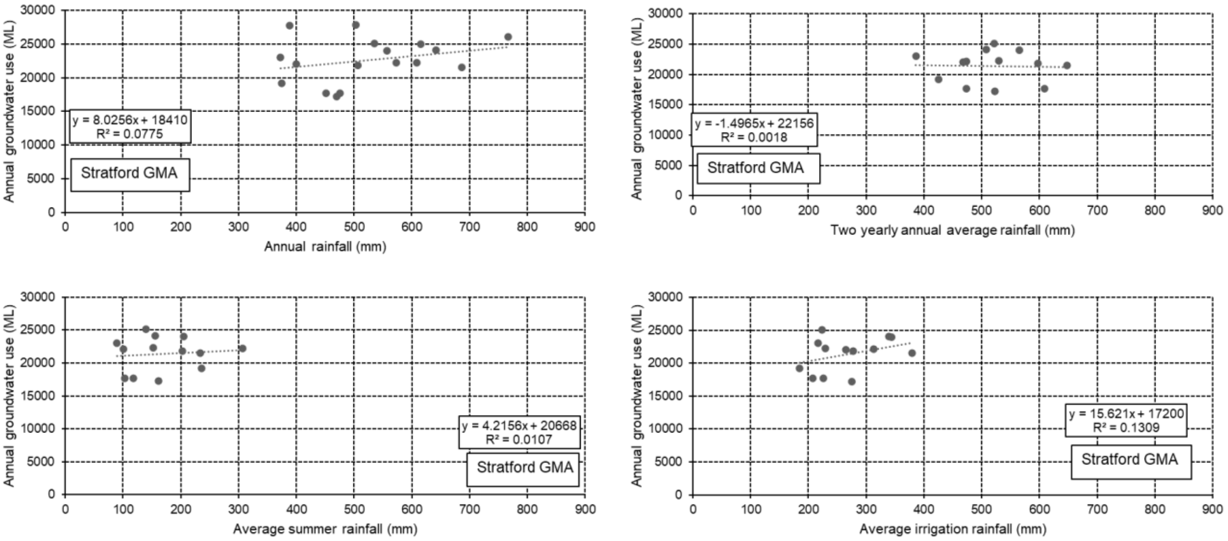


Figure 357 Stratford GMA: Hindcast method 1 correlations (Stratford GMA annual extraction)

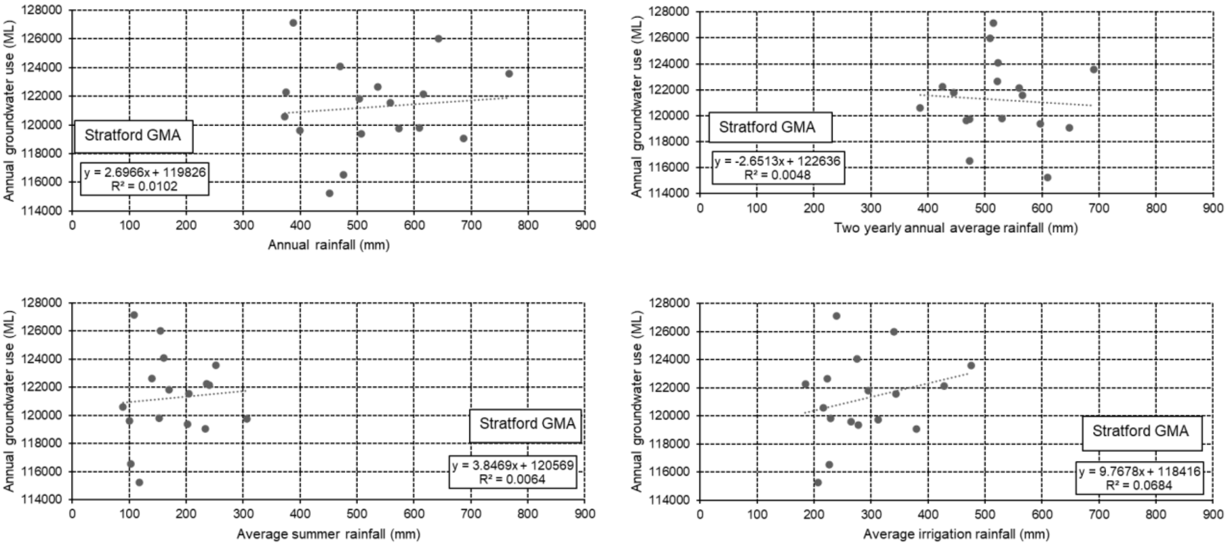


Figure 358 Stratford GMA: Hindcast method 1 correlations (Stratford GMA and offshore annual extraction)

22.2.4.2 Hindcasting Method 2 (H2)

Eight correlations were developed using method H2 as described below.

Figure 359:

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

Figure 360:

- Stratford GMA and Offshore extractions (external influence) use per Stratford GMA bore vs annual rainfall
- Stratford GMA and Offshore extractions (external influence) use per Stratford GMA bore vs two yearly average annual rainfall
- Stratford GMA and Offshore extractions (external influence) use per Stratford GMA bore vs annual summer period rainfall

- Stratford GMA and Offshore extractions (external influence) use per Stratford GMA bore vs annual irrigation period rainfall

As shown in Figure 359 and Figure 360, the goodness-of-fit represented by the R^2 is low across all eight correlations. The highest R^2 for using only Stratford GMA extraction is the correlation with annual irrigation rainfall and when both Stratford GMA and offshore extraction is combined, the highest R2 is with summer rainfall. Thus, the correlation with annual irrigation rainfall has been adopted for hindcast method H2 when using only Stratford GMA extraction data and the correlation with annual summer rainfall was adopted for hindcast method H2 when using the combined Stratford GMA and offshore extraction.

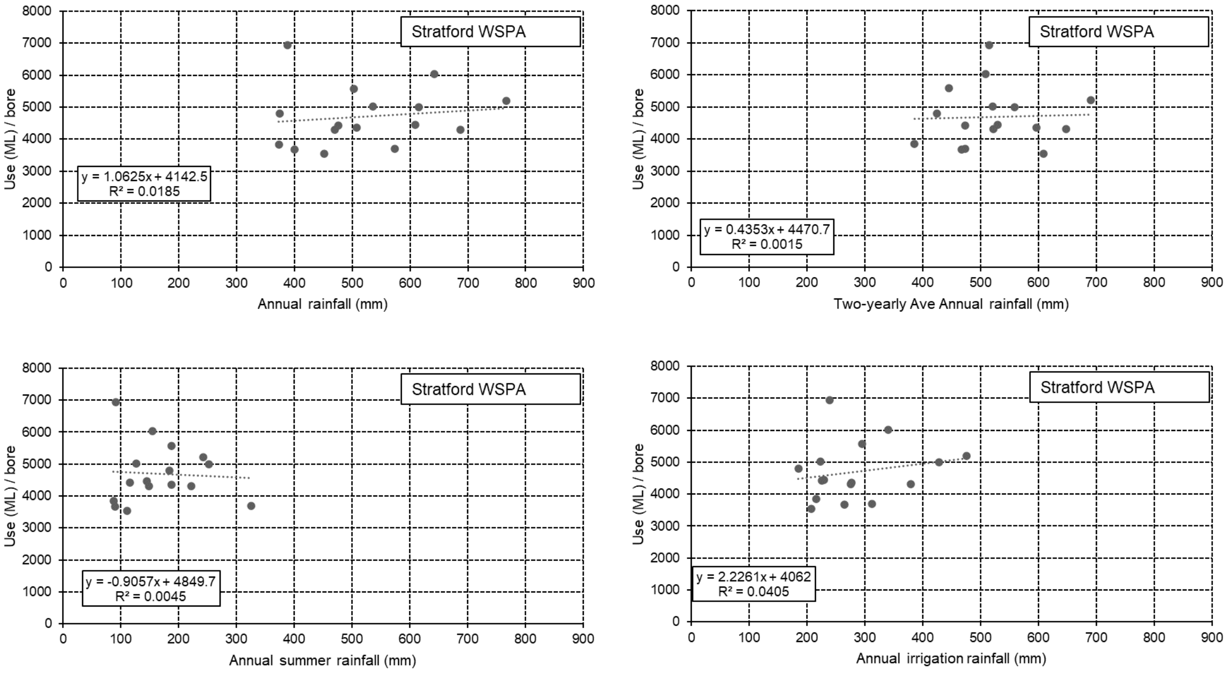


Figure 359 Stratford GMA: Hindcast method 2 correlations (Stratford GMA only extraction)

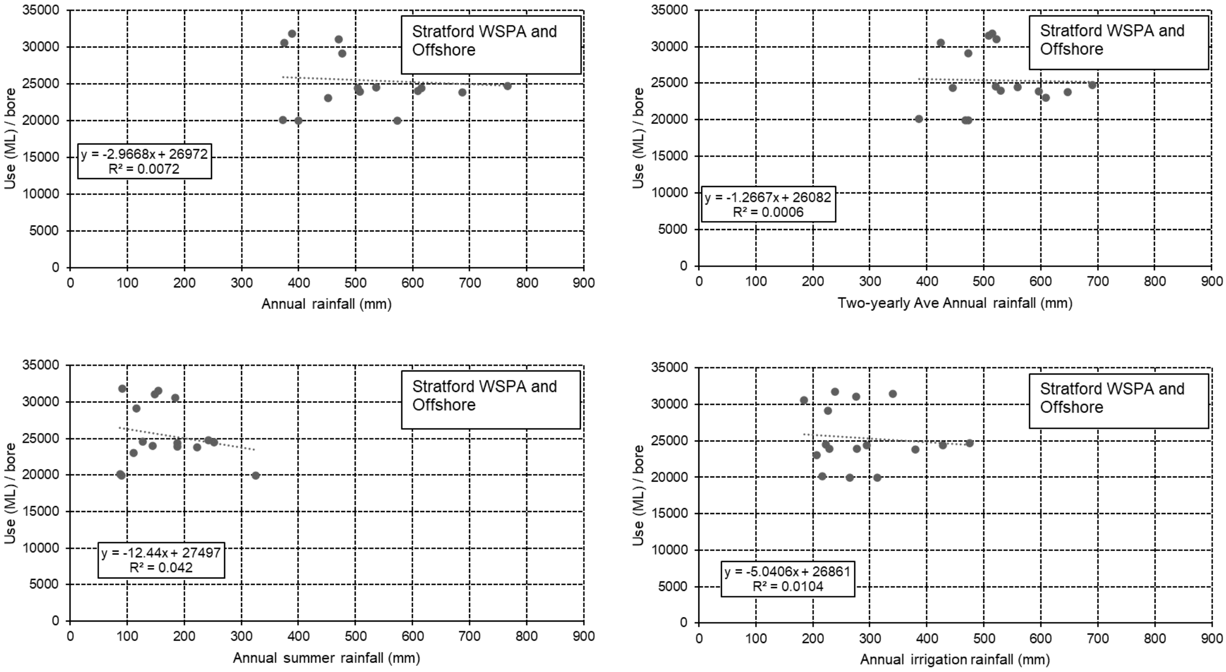


Figure 360 Stratford GMA: Hindcast method 2 correlations (Stratford GMA and offshore extraction)

22.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below.

Figure 361:

- 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

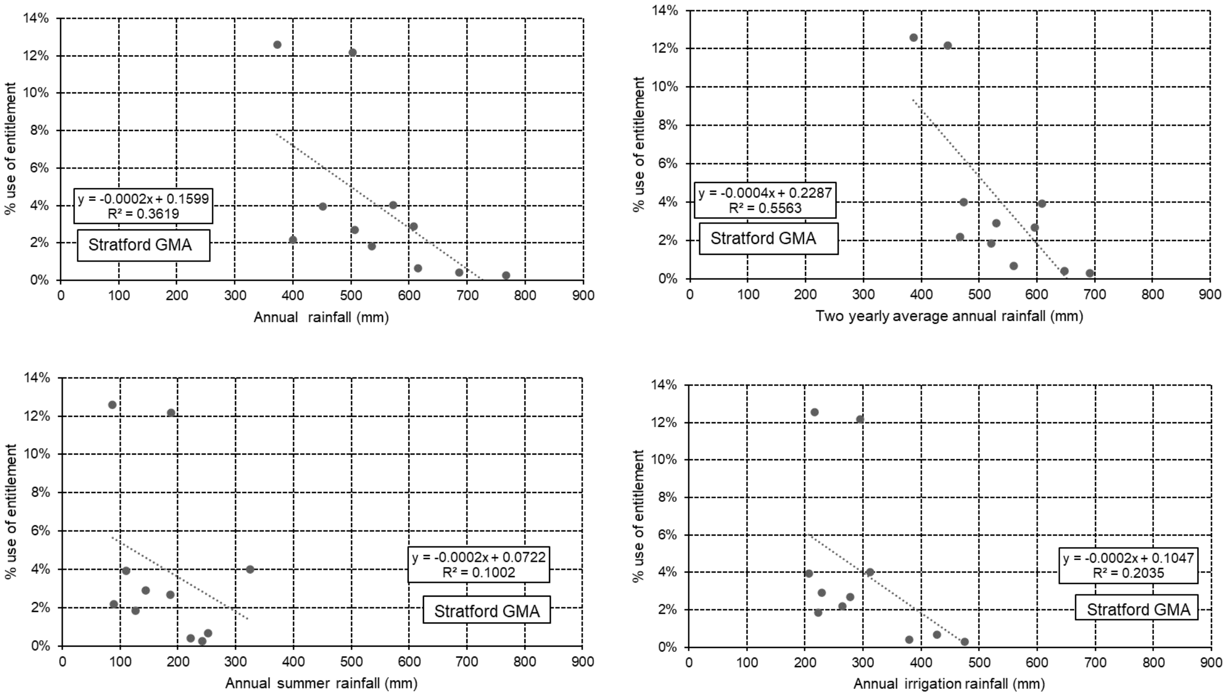


Figure 361 Stratford GMA: Hindcast method 3 correlations (Stratford GMA only extraction)

As shown in Figure 361, the goodness-of-fit represented by the R^2 is generally higher than the other two methods. The highest R^2 was the correlation with two yearly average annual rainfall, which was adopted for hindcast method H3.

22.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 362 and Figure 363 for the hindcasting based Stratford GMA groundwater use. Figure 362 shows a comparison of the three hindcasting methods against the recorded use only (over the recorded use dates) and Figure 363 shows the hindcasted data back to 1973/1974. A comparison of the three input datasets is shown in Figure 364 and Figure 365 for the hindcasting based Stratford GMA groundwater use. Figure 364 shows a comparison of the three hindcasting methods against the recorded use only (over the recorded use dates) and Figure 365shows the hindcasted data back to 1973/1974.

As shown in Figure 363 and Figure 365, groundwater use using method H1 does not decrease historically as there is no factor to account for the changing number of bores extracting over time and thus provides a higher groundwater extraction estimate than the other two methods.

In Figure 363, Method H3 provides an underestimate due to the spatial dataset being incomplete; that is, when the data is summed by year it is significantly less than the Victorian Water Accounts Data (for example, the 2019/20 in the VWA data is 22,198 ML and in the spatial dataset this is 35 ML). Hindcasting results show that the smallest average variation of recorded use to estimated use occurs for method H1.

In Figure 365, the hindcasting results show that the smallest average variation of recorded use to estimated use occurs for method H1.

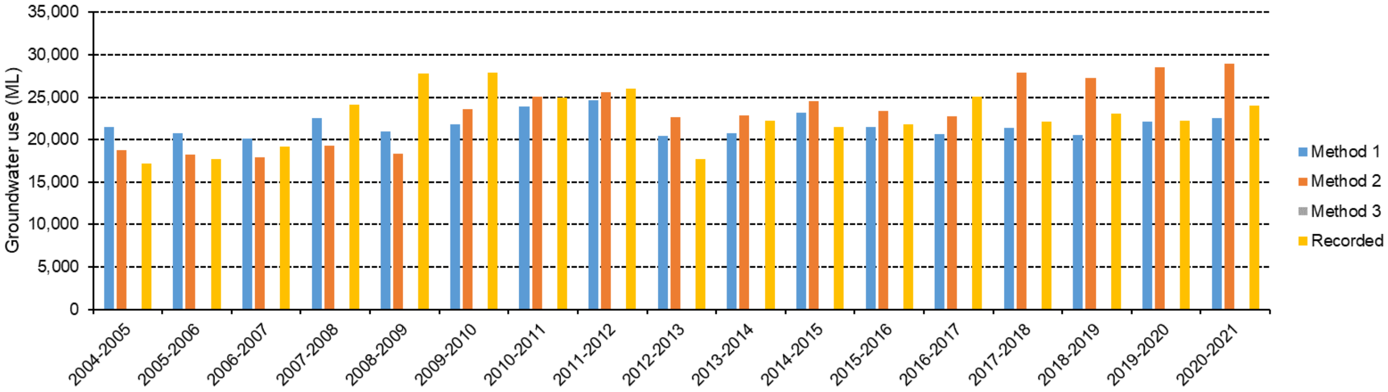


Figure 362 *Stratford GMA: Comparison of hindcasting over recorded use period – Stratford GMA only extraction*

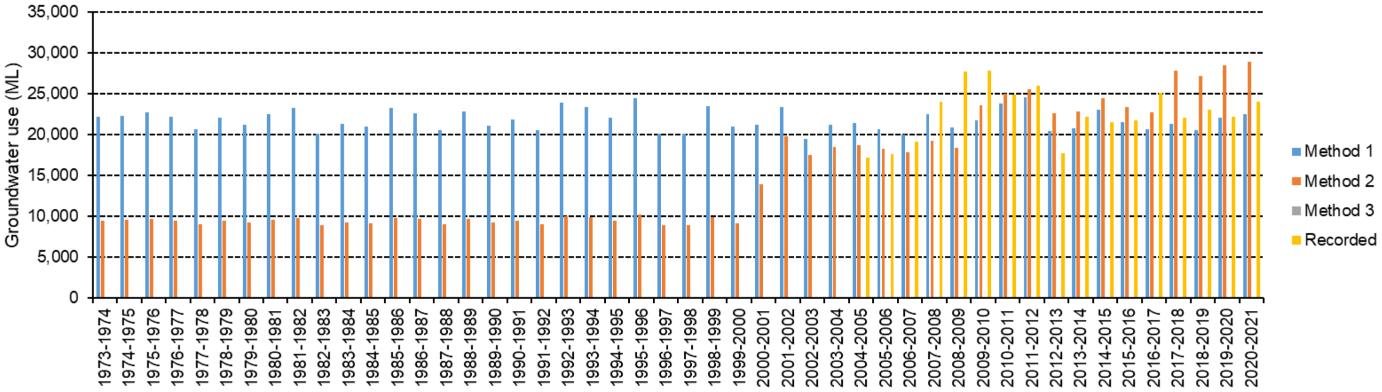


Figure 363 *Stratford GMA: Comparison of hindcasting – Stratford GMA only extraction*

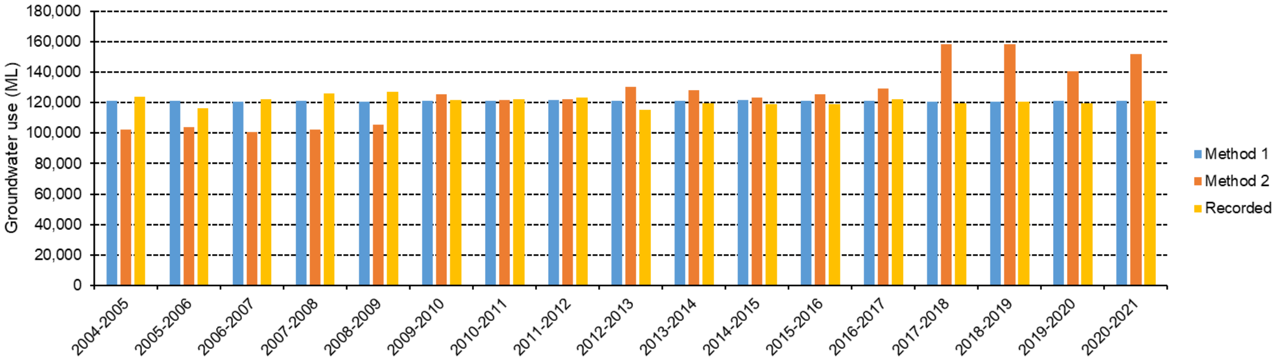


Figure 364 *Stratford GMA: Comparison of hindcasting over recorded use period – Stratford GMA and offshore extraction*

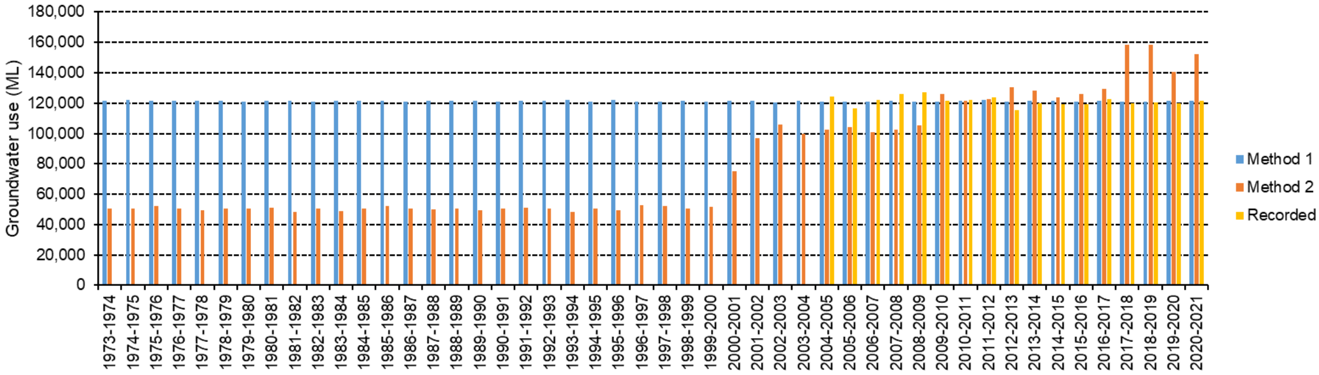


Figure 365 *Stratford GMA: Comparison of hindcasting – Stratford GMA only extraction and offshore extraction*

22.3 Modelling

22.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 131 summarises the combinations of model inputs run for Stratford GMA. Model runs highlighted blue indicate they were run with annual extraction and grey indicates they were run using two yearly average annual extraction. Due to issues with the spatial datasets, related model runs were not run for Stratford GMA.

Table 131 Stratford 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_O_1)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Stratford GMA only	✓																		
Two yearly average annual extraction – Stratford GMA only		✓																	
Annual extraction – Stratford GMA and Externalities			✓																
Two yearly average annual extraction – Stratford GMA and Externalities				✓															
H1 annual extraction – Stratford GMA only					✓														
H1 annual extraction – Stratford GMA and Externalities						✓													
H2 annual extraction – Stratford GMA only							✓												
H2 annual extraction – Stratford GMA and Externalities								✓											
H3 annual extraction – Stratford GMA only									✓										
H1 two yearly average annual extraction – Stratford GMA only										✓									
H1 two yearly average annual extraction – Stratford 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 – Stratford GMA only												✓							
H2 two yearly average annual extraction – Stratford GMA and Externalities													✓						
S1 annual extraction – Stratford GMA only														✓					
S2 annual extraction – Stratford GMA only															✓				
S3 annual extraction – Stratford GMA only																✓			
S1 annual extraction and H1 annual extraction – Stratford GMA only																	✓		
S2 annual extraction and H2 annual extraction – Stratford GMA only																		✓	
S3 annual extraction and H3 annual extraction – Stratford GMA only																			✓

22.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 131 is presented in Table 132 for the selection of potential representative Suites for Stratford GMA using the process outlined in section 22.2.1. 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_O_1

A review of the results and statistical summary for Suite L_O_1 shows that model runs 1,2 and 4 (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 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. Based on the hindcasted models, model run 6 (highlighted green) was found to have the best statistical results with the longest dataset, having the lowest 95PPU thickness and RMSE, and the highest R^2 values. The graphical model output for this model run is shown in Figure 366.

Given the results, model run 6 has been adopted to progress to predictive modelling for Suite L_O_1.

Table 132 Stratford GMA: summary of model outputs

Suite	Statistic	Model run											
		1	2	3	4	5	6	7	8	10	11	12	13
L_O_1	95PPU TH	3.87	3.16	4.2	3.75	13.08	12.54	17.16	17.09	16.22	15.53	17.41	17.47
	%Obs in 95 PPU	100	100	100	93.75	90.7	93.02	81.4	93.72	88.37	86.05	83.72	72.09
	R^2	96.0	97.3	96.0	96.1	97.7	97.9	52.2	76.0	97.9	98.1	52.8	64.2
	RMSE	0.57	0.47	0.57	0.56	1.58	1.51	7.21	5.1	1.5	1.43	7.17	6.24
	No obs data points	16	16	16	16	43	43	43	43	43	43	43	43
	Range of observed levels	9.4	9.4	9.4	9.4	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6

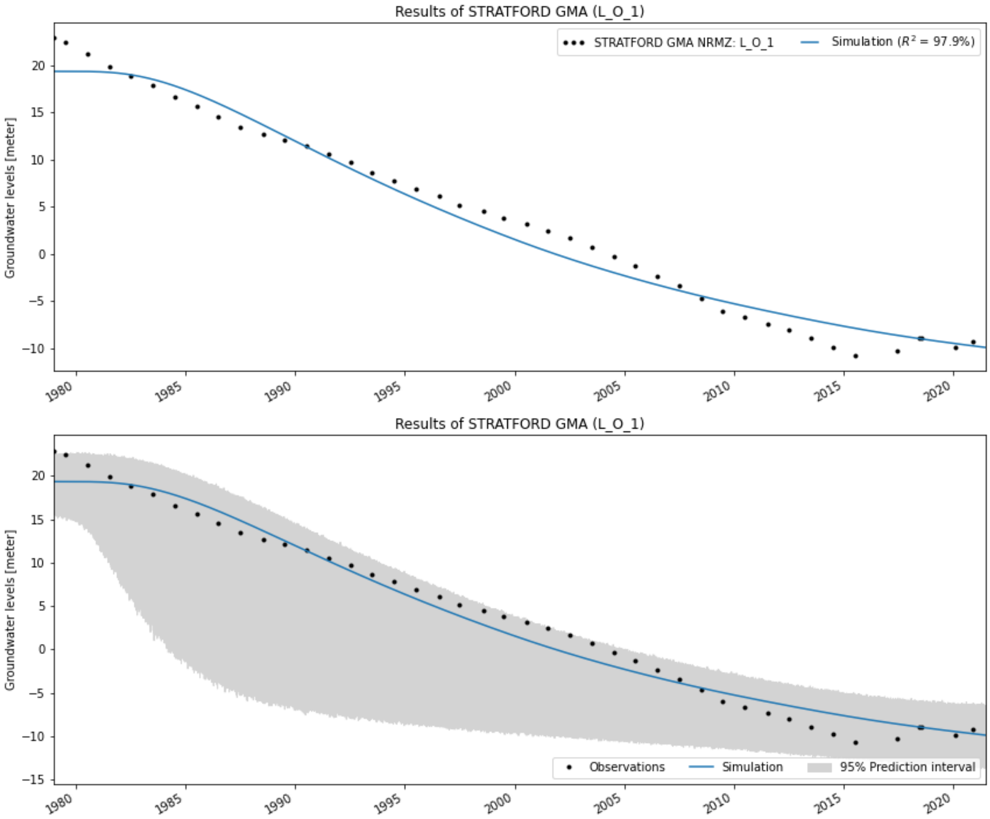


***Figure** 366 Stratford GMA Suite L_O_1: model run 6 (Stratford GMA and offshore annual extraction with hindcast method H1) output hydrographs*

22.4 Predictive modelling

22.4.1 Model inputs

The preferred model to run the predictive modelling for Stratford GMA was model run 6 for the selected representative Suite. 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 133.

***Table 133** Stratford 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 2016/17)
Combined Stratford GMA and Offshore volumes (ML/year)	164,562*	164,562	121,556	121,242	127,128

**Note no licenced entitlement or PCV could be identified for Offshore and thus the PCV and licenced entitlement for Stratford GMA and Offshore volumes was taken to be the combined max historic use with the licenced entitlement.*

22.4.2 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 367 for scenario 4. As shown in Figure 367, 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 368.

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.

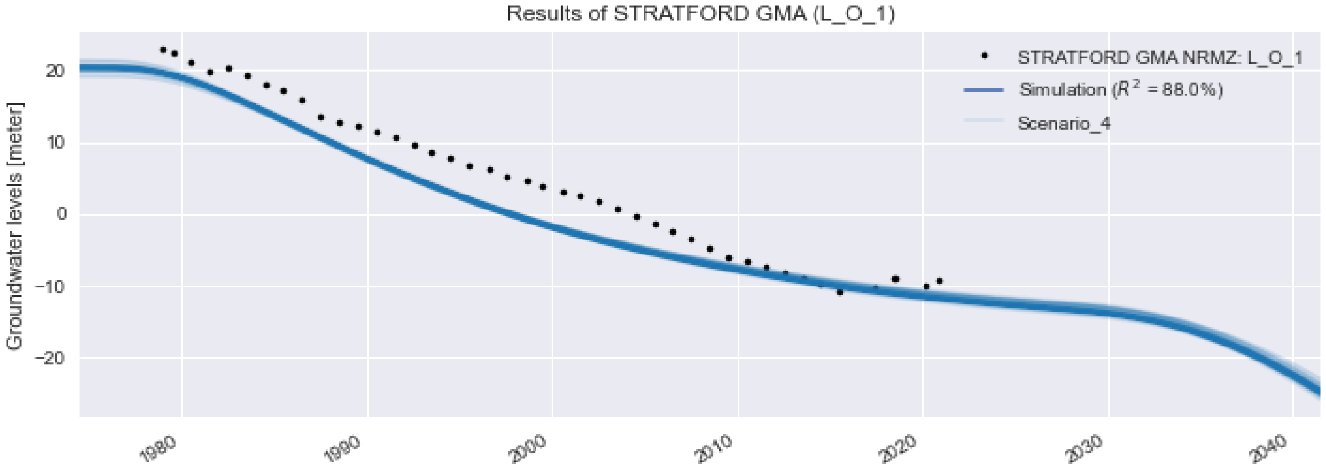


Figure 367 Stratford GMA: Suite L_O_1 MCMC analysis for Forecast Scenario 4

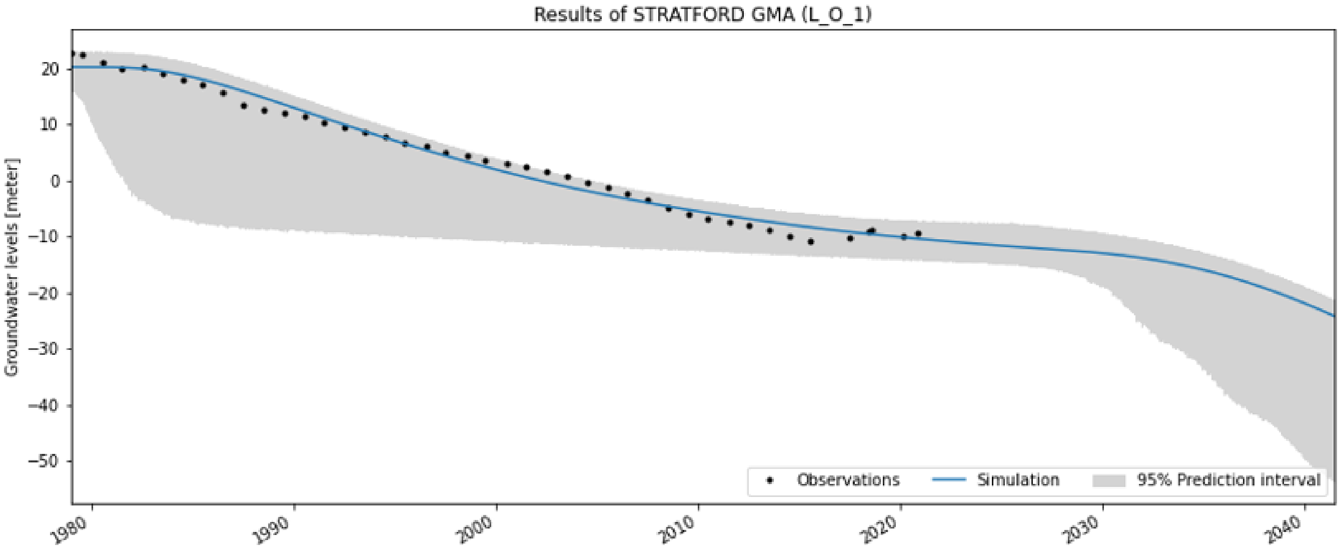


Figure 368 Stratford GMA: Suite L_O_1 Forecast Scenario 4 with 95% prediction bands

22.4.3 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 Stratford 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 22.2.2, 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 369 for the Suite L_O_1 hydrograph of annual recovered levels. In Figure 369:

- Actual annual groundwater use (Stratford GMA and Offshore) is represented by the blue column graph between 2005/2006 and 2020/2021
- Hindcasted annual groundwater use (Stratford GMA and Offshore) is represented by the orange columns between 1974/1975 to 2005/2006
- Forecasted annual groundwater use (Stratford GMA and Offshore) is represented by the grey columns after 2021/2022
- The annual recovered water level behaviour based on recorded data is represented by the red line graph
- The pre-development annual recovered levels are taken to be the first measurement which equates to 22.87 m

The modelled forecasted annual recovered levels are represented by the purple line in Figure 369.

The calibration annual recovered levels are represented by the black line in Figure 369.

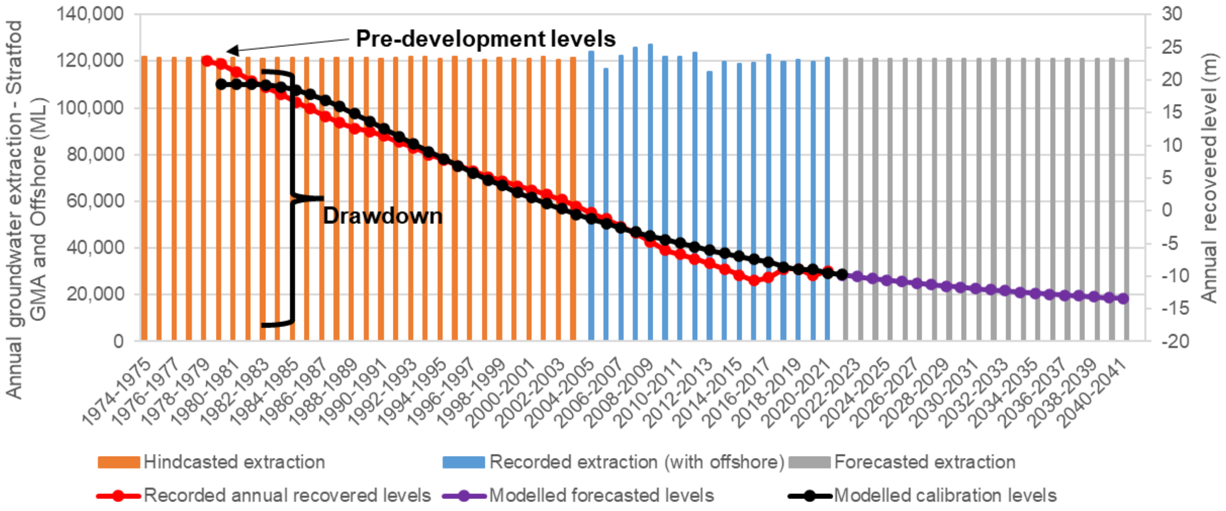


Figure 369 *Estimating pre-pumping water levels (example from Suite L_O_1)*

For Suite L_O_1, the volumes needed to be converted from a combined volume of Stratford GMA and Offshore to just a volume that represents Stratford GMA. On average, Stratford GMA extraction makes up 19% of the combined volume based on the recorded datasets. As such 19% of the combined volume has been used in the use-drawdown relationships for Suite L_O_1.

For Suite L_O_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 370) and a graph of the scenarios for specific time periods (Figure 371) to develop the volume to drawdown relationship. For each scenario, a linear regression was applied and the coefficient of determination (R^2) was calculated. A comparison of each of these graphs shows variations in the coefficient of determination. Its noted that in Figure 370, there is a large array of drawdowns for the same volume at around 23,000 ML (the average use), this can also be seen in Figure 369 where drawdown continues when extraction is occurring at the same volume year on year. This could be the effects of the offshore extraction or potentially other external sources. Its noted that if you exclude this series of drawdowns at 23,000 ML, the correlation in Figure 370 would become very similar to that in Figure 371. Given that for the other GMUs, the correlation developed based on all scenarios has been adopted (Figure 370), the same has been applied to this GMU.

The use-drawdown for all the 19 forecast scenario drawdowns and volumes (both the recorded and forecasted volumes) over each year modelled (1979 to 2041) is shown in Figure 370 for Suite L_O_1. 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. It is noted that there is a difference of 3.5 m between the selected pre-development level of the recorded data compared to the modelled level at the same time; this difference contributes to the intercept value.
- Average use is around 23,000 ML. Figure 370 indicates a large spread in drawdown values around this usage.
- For the same annual use, different drawdowns can be obtained as Pastas predicts a water level for each year. For example, Figure 369 shows a scenario where groundwater use remains constant at around 121,200 ML/year over the next 20 years.

The correlation for groundwater use and drawdown for Suite L_O_1 is poor as shown by the R^2 in Figure 370.

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.

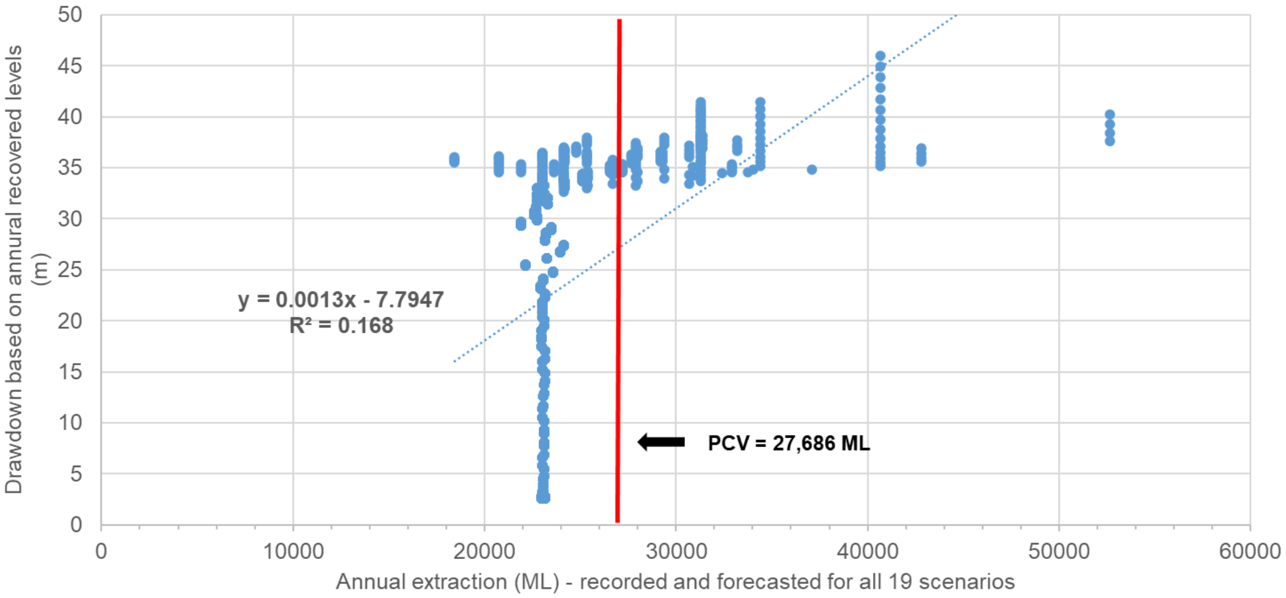


Figure 370 *Stratford GMA Suite L_O_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <60,000 ML) for all data between 1979 to 2041 and all forecasted scenarios*

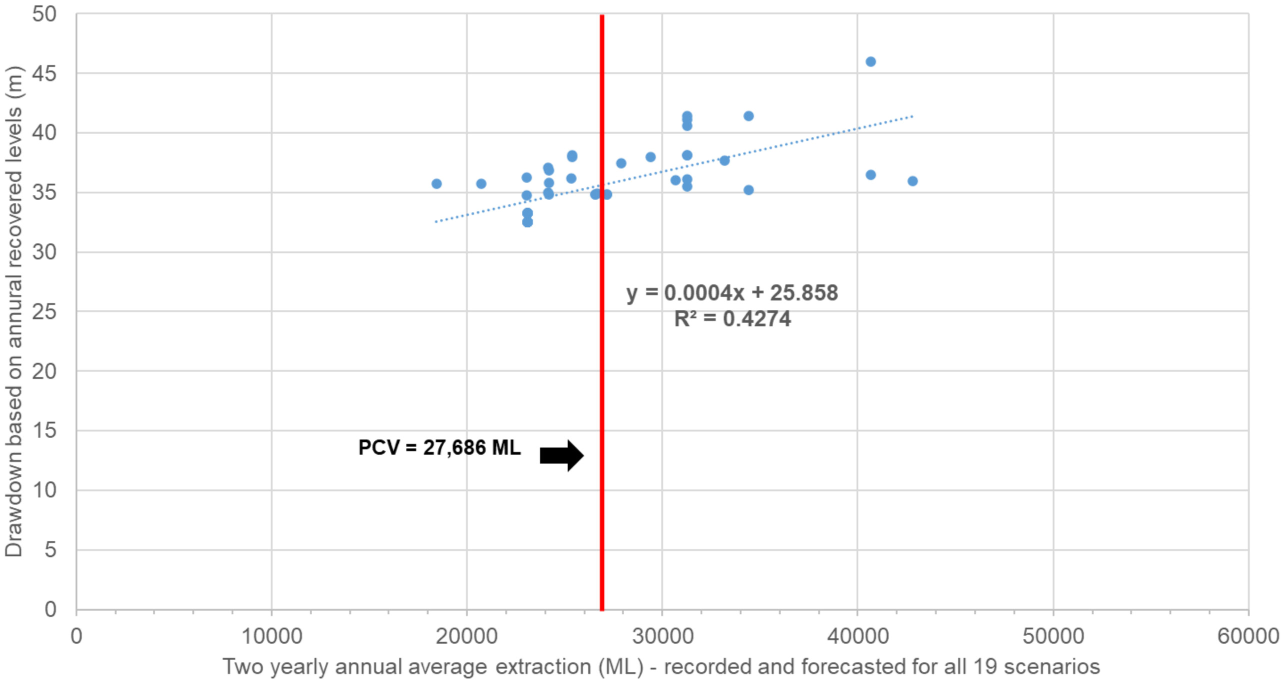


Figure 371 *Stratford GMA Suite L_O_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <60,000 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

22.5 Sustainability metrics

22.5.1 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 134 for Stratford GMA Suite L_O_1 (noting Stratford GMA has a current PCV of 27,686 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 134 and Figure 372 for Suite L_O_1. It is noted that the predicted model does not lie within the lower and upper bands of the 95% prediction interval.

As previously discussed, for Suite L_O_1, the predicted model adopted was based on the combined extraction from Stratford GMA and Offshore extractions This was brought back to a Stratford GMA only extraction for plotting the drawdown with extraction by taking 19% of the combined extraction (19% is the average portion of Stratford GMA to the combined extraction based on recorded data). Table 134 shows the volume for Stratford GMA to a given drawdown; the same table has been replicated for the combined use as shown in Table 135 (its noted that this is the actual usage used in the predictive model).

A comparison of volumes at drawdown intervals provided by DEECA is shown in Table 136 for Suite L_O_1. Based on the correlations, it is predicted that 5 m of drawdown could occur for an annual groundwater usage of 9,800 ML and 10 m of drawdown could occur for an annual groundwater usage of 13,700 ML.

Table 134 Relationship of Suite drawdown to GMU extraction for Stratford GMA Suite L_O_1

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_O_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
70,000	83.2 (66.2 - 68.7)
65,000	76.7 (61.2 - 64.7)
60,000	70.2 (56.2 - 60.7)
55,000	63.7 (51.2 - 56.7)
50,000	57.2 (46.2 - 52.7)
45,000	50.7 (41.2 - 48.7)
40,000	44.2 (36.2 - 44.7)
35,000	37.7 (31.2 - 40.7)
30,000	31.2 (26.2 - 36.7)
25,000	24.7 (21.2 - 32.7)
20,000	18.2 (16.2 - 28.7)
15,000	11.7 (11.2 - 24.7)
10,000	5.2 (6.2 - 20.7)
5,000	-1.3 (1.2 - 16.7)
0	-7.8 (-3.8 - 12.7)

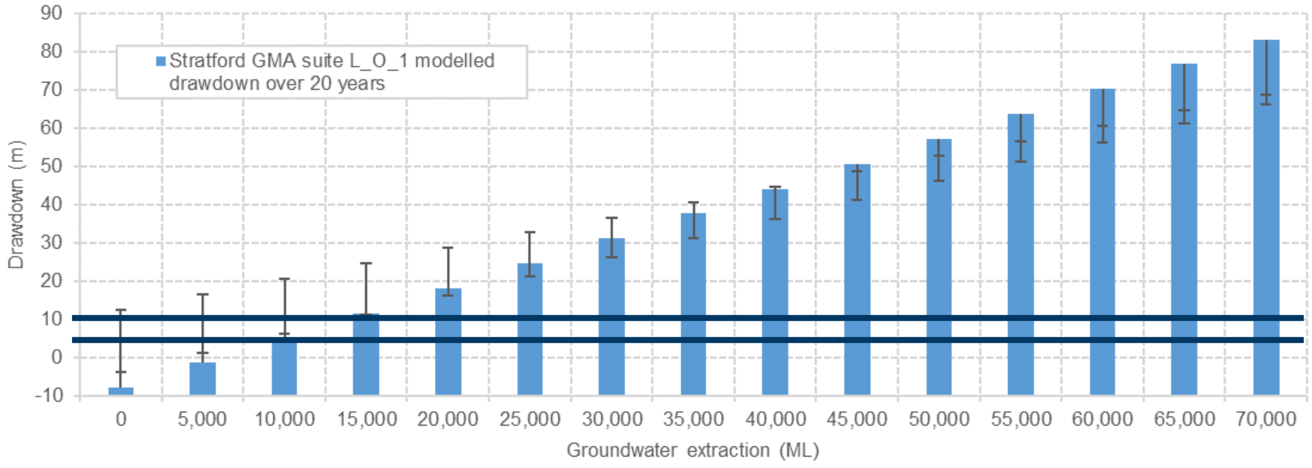


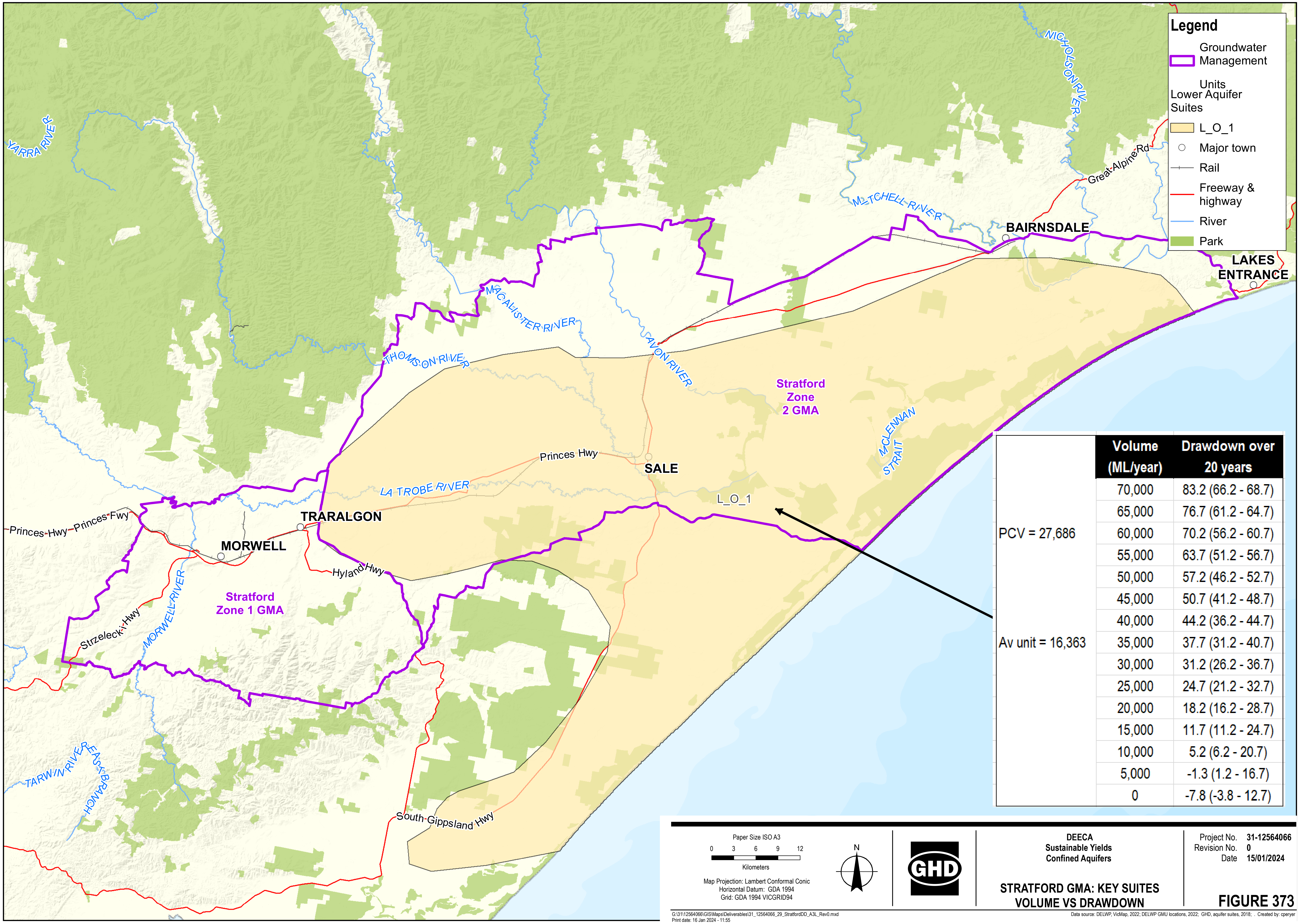
Figure 372 Stratford GMA Suite L_O_1: Relationship of Suite drawdown to two yearly annual average GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 135 Relationship of Suite drawdown to combined Stratford GMA and offshore extraction for Stratford GMA Suite L_O_1

Volume (ML/year) for combined Stratford GMA and Offshore extraction	Based on model prediction of Suite L_O_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
70,000	11 (12.9 - 26)
65,000	10 (11.9 - 25)
60,000	9 (10.9 - 24)
55,000	8 (9.9 - 23)
50,000	7 (8.9 - 22)
45,000	6 (7.9 - 21)
40,000	5 (6.9 - 20)
35,000	4 (5.9 - 19)
30,000	3 (4.9 - 18)
25,000	2 (3.9 - 17)
20,000	1 (2.9 - 16)
15,000	0 (1.9 - 15)
10,000	-1 (0.9 - 14)
5,000	-2 (-0.1 - 13)
0	-3 (-1.1 - 12)

Table 136 Predicted GMU volumes for drawdown metrics

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite L_O_1 drawdowns (lower limit to upper limit)
5	9,800 (-9,700 – 8,800)
10	13,700 (-3,400 – 13,800)



	Volume (ML/year)	Drawdown over 20 years
	70,000	83.2 (66.2 - 68.7)
	65,000	76.7 (61.2 - 64.7)
PCV = 27,686	60,000	70.2 (56.2 - 60.7)
	55,000	63.7 (51.2 - 56.7)
	50,000	57.2 (46.2 - 52.7)
	45,000	50.7 (41.2 - 48.7)
	40,000	44.2 (36.2 - 44.7)
Av unit = 16,363	35,000	37.7 (31.2 - 40.7)
	30,000	31.2 (26.2 - 36.7)
	25,000	24.7 (21.2 - 32.7)
	20,000	18.2 (16.2 - 28.7)
	15,000	11.7 (11.2 - 24.7)
	10,000	5.2 (6.2 - 20.7)
	5,000	-1.3 (1.2 - 16.7)
	0	-7.8 (-3.8 - 12.7)

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

GHD

DEECA
Sustainable Yields
Confined Aquifers

STRATFORD GMA: KEY SUITES VOLUME VS DRAWDOWN

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

FIGURE 373

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Print date: 16 Jan 2024 - 11:55

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

22.6 GMU summary

22.6.1 Findings

Stratford GMA primarily relates to the Traralgon seams and aquifers (LTA) where groundwater is predominately extracted for power generation in the Latrobe Valley. The LTA falls within the Lower Aquifer Suites, which at Stratford GMA comprise L_O_1 (72%), L_O_2 (<1%), L_PP_88 (<1%) and L_P_1 (<1%). The identified representative Suite is L_O_1. The Suite hydrographs for the representative Suites show an overall decreasing trend along with minor 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 (without hindcasting) showed a better model fit based on the statistical analysis. When hindcasting was also considered, the results were poorer using two yearly average annual extraction with hindcast method H1 but improved when using hindcast method H2.

The application of spatial distribution method could not be completed as the spatial datasets did not reflect actual usage, i.e., there is a significant disparity with the Victorian Water Accounts Data.

As identified through the conceptualisation, Stratford GMA may be influenced by extraction occurring from Offshore, which is significantly greater than the extraction that occurs within the GMU. Of the two hindcasting methods that consider both extraction datasets, hindcast method H1 produced the best result.

Based on an assessment of all model runs, the model run 6 of annual extraction from both Stratford GMA and offshore with hindcast method H1 applies was adopted to undertake the predictive modelling for Suite L_O_1. 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-developments levels of 22.87 m for Suite L_O_1, from which drawdowns have been calculated.

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

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite L_O_1 drawdowns (lower limit to upper limit)
5	9,800 (-9,700 – 8,800)
10	13,700 (-3,400 – 13,800)

The model for Suite L_O_1 was assessed as having a “Poor” model applicability rating using the criteria outlined in section 5.2. It’s noted that there is still significant extraction at the time of pre-development level in the model selected, it’s likely the pre-development level is incorrect. This provides a poor R^2 and intercept of -8 m and nothing to calibrate on <18,000 ML/year for extraction.

22.6.2 Limitations

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

- The licenced bore spatial dataset is incomplete for Stratford GMA, providing a much lower estimate than the Victorian Water Accounts dataset. As a result, spatial distribution methodologies could not be applied to this GMU
- The results use modelled levels using Stratford GMA and Offshore extractions, but the volumes stated are Stratford only in the use-drawdown graphs. The logic for deriving Stratford GMA extraction from the combined source is that when extraction of Stratford GMA and Offshore extraction are combined annually, on average, Stratford GMA extraction makes up 19% of this thus 19% of the combined volume has been used in the final relationship.
- Suite L_O_1 mainly applied to Stratford GMA Zone 2

As there is still significant extraction at the time of pre-development level in the model selected, it is likely the pre-development level is incorrect. This provides a poor R2 and intercept of -8m and nothing to calibrate on <18,000 ML/year.

The use-drawdown relationship was influenced by different drawdowns occurring at the same volume. Consideration should be made as to whether the simplified version of the graph (showing data from each of the 19 scenarios at intervals of 2020/2021, 2030/2031 and 2040/2041) should be adopted.

22.6.3 Recommendations

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

- The licenced bore dataset provided by DEECA is incomplete for Stratford GMA. This dataset should be updated to reflect licenced bores and their usage for the GMU.

23. Yarram WSPA

23.1 Conceptualisation

The hydrogeological conceptualisation elements relevant to this study are summarised in Table 137 and Table 138, a map of the GMU is presented in Figure 374. 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 137 Yarram WSPA Zone 1– Tabulated conceptualisation

GMU summary
Yarram WSPA is situated in eastern Victoria (as shown in Figure 374) and stretches along part of the Bass Coast from Yarram to Bairnsdale. Yarram WSPA covers an area of 2,595 km^2 and pertains to formations 200 m below the surface in zone 1, and to all formations below the surface in zone 2, with a combined PCV of 25,690 ML/year. Yarram WSPA is managed by SRW and occurs within the Gippsland Groundwater Basin.

Hydrostratigraphy summary

Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Approx. use volumes ML (2019/20)	Approx entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Undifferentiated sediments (QA)	-	-	0	NA	0	0	Low
	Haunted Hills Gravels (UTQA)	U_AB_1 (5%)	5%	0	NA	0	0	Low
	Nuntin clay (UTQD)	-	-	0	NA	0	0	Low
Middle	Boisdale Formation (UTAF)	U_AG_1 (42%) U_AF_1 (32%)	74%	0	NA	0	0	Low
	Jemmy's Point Formation (UTD)	-	-	0	NA	0	0	Low
	Balook Formation (UMTA)	-	-	0	NA	0	0	Low
	Gippsland Limestone/Lakes Entrance Formation (UMTD)	-	-	1	NA	0	0	Low
Lower	M2C aquifer/Seaspray Sands (LMTA)	-	-	0	NA	0	0	Low
	Latrobe Group (LTA)	L_O_1 (22%), L_O_2 (54%)	100%	2	NA	0	0	Low
	Carrajung Volcanics (LTB)	-	-	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 366 ML of unassigned use to Yarram WSPA due to unknown depths (1,754 ML of entitlement).

Characteristic and importance	Description	Degree of understanding
Intended aquifer		
Aquifer thickness (range, based on VAF)	Max: 795 m, Average: 558 m	High
Aquifer extent	Regional, extensive	High
Likelihood of inter-aquifer flow	High	Moderate
Likelihood of groundwater – surface water interaction	Low	Moderate. Zone 1 pertains to aquifer >200 m below surface, thereffor interaction not llikely.
Representative Suite	**L_O_2**	**Low. No extraction recorded from licenced bore data for past 5 years.**
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)	311 mg/L (WMIS) 0 – 600 mg/L (CDM Smith 2022)	Moderate Based on WMIS and CDM Smith (2022)
Groundwater yield	5 – 50 L/s	Low Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1978 to 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	**11,481 ML (for all of Yarram WSPA)**	**High (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	6,470 ML (for all of Yarram WSPA)	Low - insufficient data to split by zone (Based on historical VWA data, year 2011/12)
Maximum historic groundwater use	**16,557 ML (for all of Yarram WSPA)**	**Low - insufficient data to split by zone (Based on historical VWA data, year 2018/19)**
Entitlement (Groundwater allocation) (ML)	**25,688 ML (for all of Yarram WSPA)**	**High (Based on licenced volumes in 2020/21)**
Significant drivers of groundwater level variability (primary)	**Pumping for irrigation & dairy**	**High**
Secondary drivers of groundwater level variability	Off-shore oil and gas extraction	High
Groundwater use profile	Influenced by seasonality	Moderate

Characteristic and importance	Description	Degree of understanding
External influence	**Offshore extraction**	
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 138 Yarram WSPA Zone 2– Tabulated conceptualisation

GMU summary

Yarram WSPA is situated in eastern Victoria (as shown in Figure 374) and stretches along part of the Bass Coast from Yarram to Bairnsdale. Yarram WSPA covers an area of 2,595 km^2 and pertains to formations 200 m below the surface in zone 1, and to all formations below the surface in zone 2, with a combined PCV of 25,690 ML/year.

Yarram WSPA is managed by SRW and occurs within the Gippsland Groundwater Basin.

Hydrostratigraphy summary

Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Approx. use volumes ML (2019/20)	Approx entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Undifferentiated sediments (QA)	-	-	2		1	4	Low
	Haunted Hills Gravels (UTQA)	U_AH_1 (25%)	-	2		7	314	Low
	Nuntin clay (UTQD)	-	-	1		0	6	Low
Middle	Boisdale Formation (UTAF)	U_AG_1 (9%)	75%	1		143	833	Low
	Jemmy’s Point Formation (UTD)	-	-	0		539	1,294	Low
	Balook Formation (UMTA)	-	-	2		755	3,275	Low
	Gippsland Limestone/Lakes Entrance Formation (UMTD)	-	-	0		601	2,230	Low

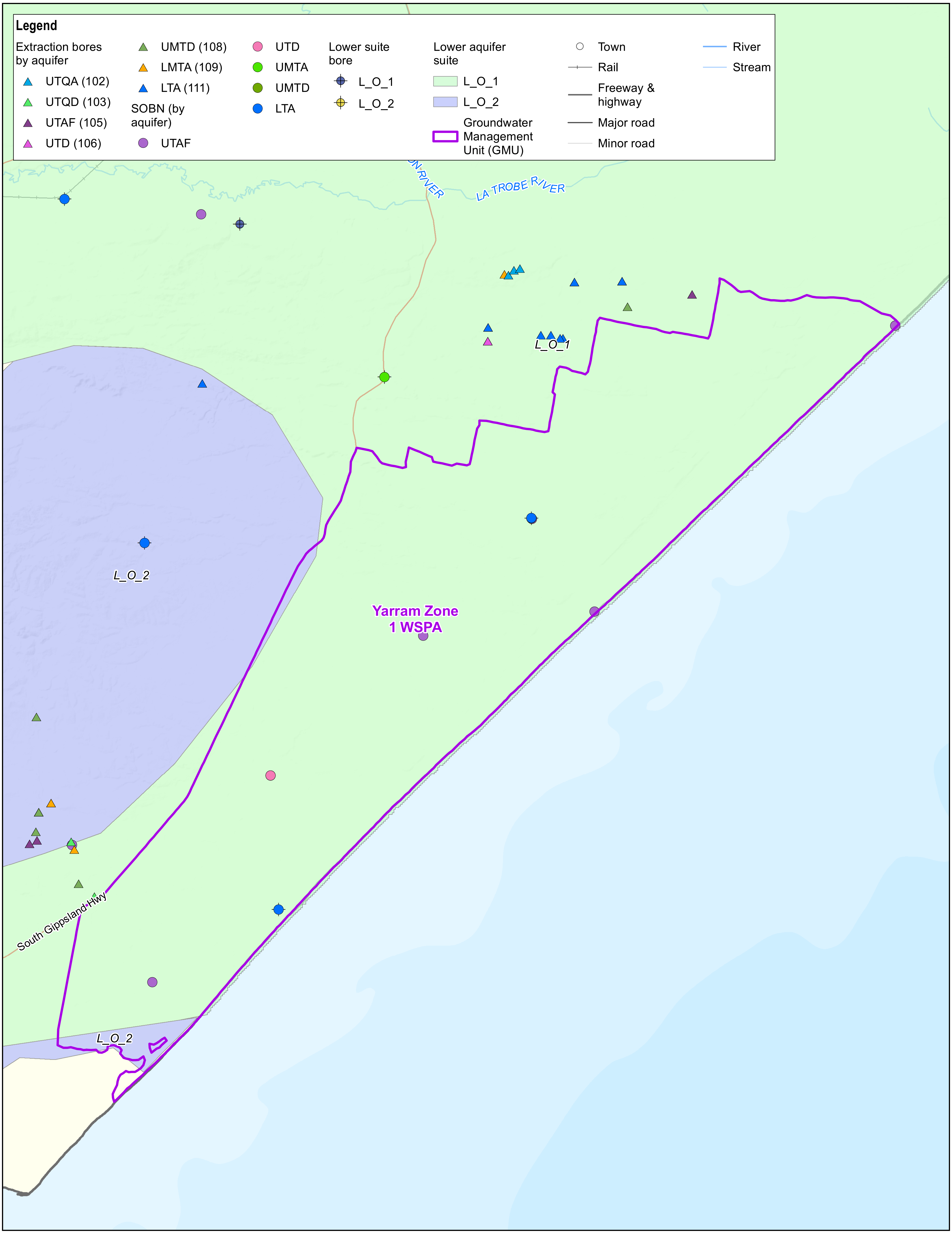
Lower	M2C aquifer/Seaspray Sands (LMTA)	-	-	0		402	1,430	Low
	Latrobe Group (LTA)	L_O_1 (22%), L_O_2 (54%)	100%	5		4,462	11,346	Medium
	Carrajung Volcanics (LTB)	-	-	0		0	1	Low
Basement	Basement rocks (BSE)	-	-	0		354	2,775	Low

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 366 ML of unassigned use to Yarram WSPA due to unknown depths (1,754 ML of entitlement).

Characteristic and importance	Description	Degree of understanding
Intended aquifer		
Aquifer thickness (range, based on VAF)	Max: 788 m, Average: 273 m	High
Aquifer extent	Regional, extensive	High
Likelihood of inter-aquifer flow	High	Moderate
Likelihood of groundwater – surface water interaction	Moderate	Moderate – GMU pertains to all formations below the surface, there does appear to be some outcropping of lower aquifers on the northern margins of GMU.
Representative Suite	**L_O_2**	**Low. 31% 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)	0 – 600 mg/L (CDM Smith 2022)	Low Based on WMIS and CDM Smith (2022)
Groundwater yield	5 – 50 L/s	Low Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1978 to 2021**	**High**
Spatial clustering of licensed bores in relation to Suites	**Yes, L_O_2**	**Based on DEECA density mapping and licenced bore data.**
Groundwater use		

Licensed groundwater use	**11,481 ML (for all of Yarram WSPA)**	**High (Based on average historical VWA data over 17 years)**
Minimum historic groundwater use	6,470 ML(for all of Yarram WSPA)	Low - insufficient data to split by zone (Based on historical VWA data, year 2011/12)
Maximum historic groundwater use	**16,557 ML(for all of Yarram WSPA)**	**Low - insufficient data to split by zone (Based on historical VWA data, year 2018/19)**
Entitlement (Groundwater allocation) (ML)	**25,688 ML (for all of Yarram WSPA)**	**High (Based on licenced volumes in 2020/21)**
Significant drivers of groundwater level variability (primary)	Pumping for irrigation & dairy	High
Secondary drivers of groundwater level variability	Off-shore oil and gas extraction	Low
Groundwater use profile	Influenced by seasonality	Moderate
External influence	**Offshore extraction**	
Groundwater values and risks		
Existing Environmental Values to be protected, relevant to this GMU	Potable water supply Licensed non-potable supply (irrigation, commercial, industrial) Unlicensed non-potable supply (domestic and stock)	
Risks to groundwater values	Direct risks: - Drawdown which may affect access to groundwater by existing users - Drawdown which may affect groundwater – surface water connectivity	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 1.5 3 4.5 6

Kilometers

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

N

DEECA
Sustainable yield review - confined aquifers

Yarram WSPA: Zone 1
Site location and key features

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

Figure 374a

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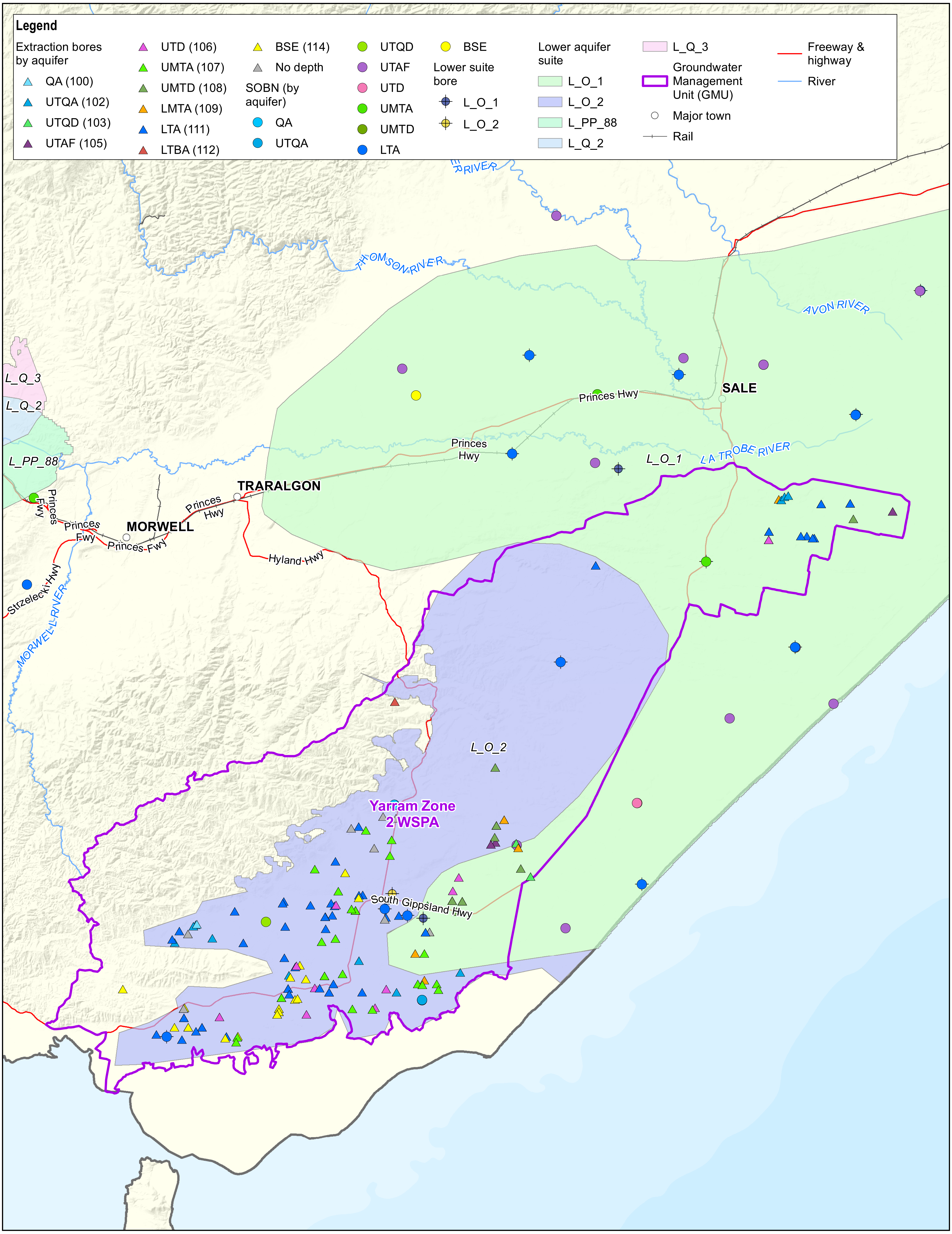
Print date: 16 Jan 2024 - 12:55

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

0 2.5 5 7.5 10

Kilometers

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

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DEECA
Sustainable yield review - confined aquifers

Yarram WSPA: Zone 2
Site location and key features

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

Figure 374b

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Print date: 16 Jan 2024 - 12:56

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

23.2 Technical analysis

23.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the confined Suites for Yarram WSPA as shown in Figure 375. The Suite hydrographs show the seasonal fluctuations for Suites L_O_1 and L_O_2 and hence recovered water levels. Both Suite hydrographs shown in Figure 375 exhibit a decreasing trend. Suite L_O_1 shows a displacement in the hydrograph between 1982 and 1986. This data was corrected before undertaking the collation of annual recovered levels, to better align with adjacent data.

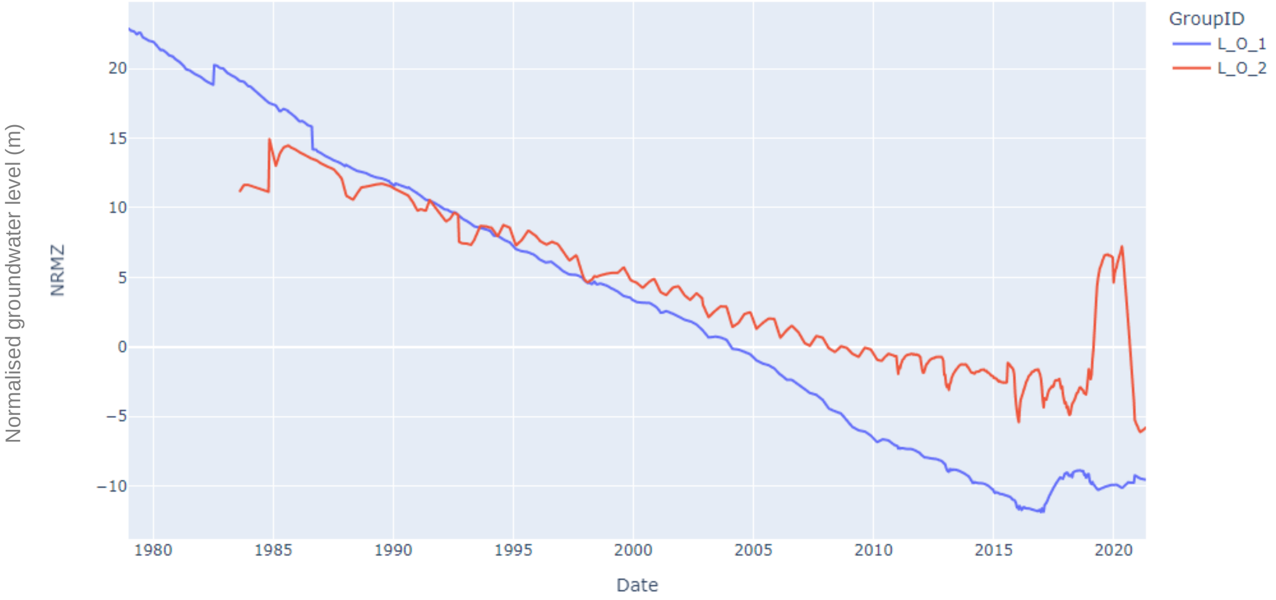


Figure 375 Yarram WSPA Suite Hydrographs for all confined aquifers

The representative Suites analysed for this GMU were Suites L_O_1 and L_O_2. The Representative Suites were selected based on the methodology outlined in section 2.6.4 which identified Suite L_O_2 as the most representative followed by L_O_1. The process is summarised as follows:

- The greatest volume of extraction occurring within the Lower Aquifer
- The Lower Aquifer pertains to the Lower Tertiary Aquifer (LTA), which is the intended aquifer for this GMU
- Suite L_O_1 covers 22% of the GMU and Suite L_O_2 covers 54%
- Suite L_O_1 has three active SOBN bores and Suite L_O_2 has three SOBN bores
- Three of the four Suite bores for L_O_2 are close to extraction points

It is noted that the only active extraction has occurred from extraction bores located in Yarram WSPA zone 2 for the past 5 years based on the spatial licenced bore dataset provided.

The annual recovered Suite hydrographs for the representative Suites for Yarram WSPA L_O_1 and L_O_2 are shown in Figure 376.

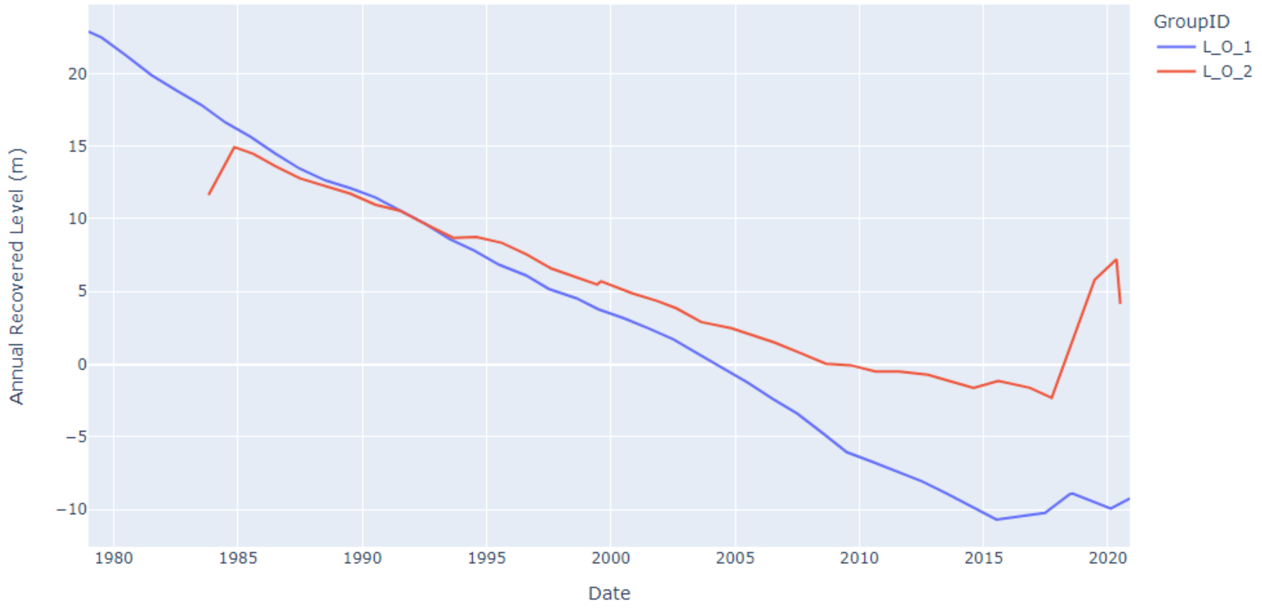


Figure 376 Yarram WSPA Annual Recovered Level Suite Hydrographs for representative Suites

23.2.2 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 Stratford for Suite L_O_1 and L_O_2.

The pre-development annual recovered level was taken to be the first level of the time series data, this occurred in the year 1978/1979 for Suite L_O_1 which equated to 22.87 m. The pre-development annual recovered level was taken to be the second level which is the maximum level of the time series data, this occurred in the year 1984/1985 for Suite L_O_2 which equated to 14.93 m.

23.2.3 Externalities

As identified through the conceptualisation, Yarram WSPA may be influenced by extraction occurring offshore. To test the influence of this extraction, data was sourced from DEECA to incorporate in the model.

Figure 377 shows the Yarram WSPA annual groundwater extraction volumes, the offshore extraction volumes and the combined volumes. Note that where extraction does not occur in both Yarram WSPA and offshore extractions, that year of data cannot be incorporated into the model without hindcasting. It is noted that the Yarram WSPA extractions are typically only 12% of the offshore extraction volumes.

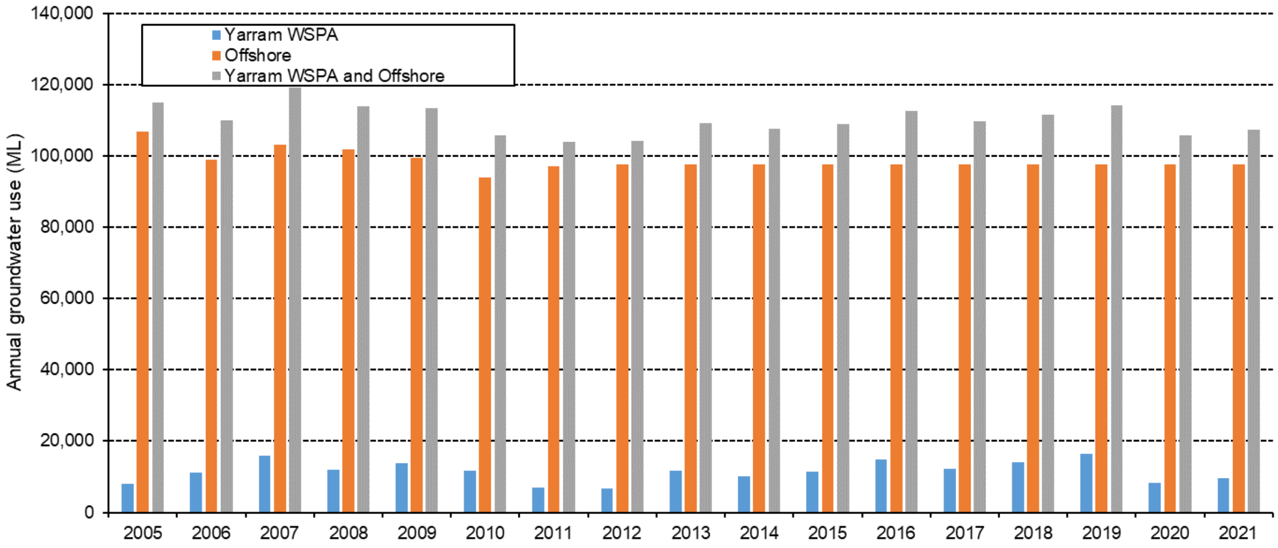


Figure 377 Yarram WSPA and Offshore extractions – groundwater use

23.2.4 Hindcasting

Groundwater use data for Yarram WSPA and combined groundwater use for Yarram WSPA and Offshore extractions is available from 2004/2005 to 2020/2021. The hindcasting methodologies outlined in section 3.3.4.5 were applied to Yarram WSPA, with results summarised below.

23.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, 12 different correlations were developed as described below.

Figure 378:

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

Figure 379:

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

Figure 380:

- Annual rainfall vs annual combined extraction at Yarram WSPA and Offshore extractions (external influence)
- Two yearly average annual rainfall vs annual combined extraction at Yarram WSPA and Offshore extractions (external influence)
- Annual summer period rainfall vs annual combined extraction at Yarram WSPA and Offshore extractions (external influence)
- Annual irrigation period rainfall vs annual combined extraction at Yarram WSPA and Offshore extractions (external influence)

Figure 378, Figure 379 and Figure 380 show the goodness-of-fit (represented by the R^2) when the Offshore extractions (external influence) was included in the analysis. The best goodness-of-fit result was represented by the correlation of the annual rainfall with annual irrigation groundwater extraction from Yarram WSPA. However, the percentage of irrigation extraction was quite variable (58 to 70%), thus the correlation adopted from this method for Yarram WSPA only extraction was 'annual rainfall with annual groundwater extraction'. The best R^2 including the external influence of the Offshore extractions was annual groundwater use and annual rainfall as shown in Figure 380. Both these correlations (Yarram WSPA only and combined Yarram WSPA and offshore extraction) were modelled.

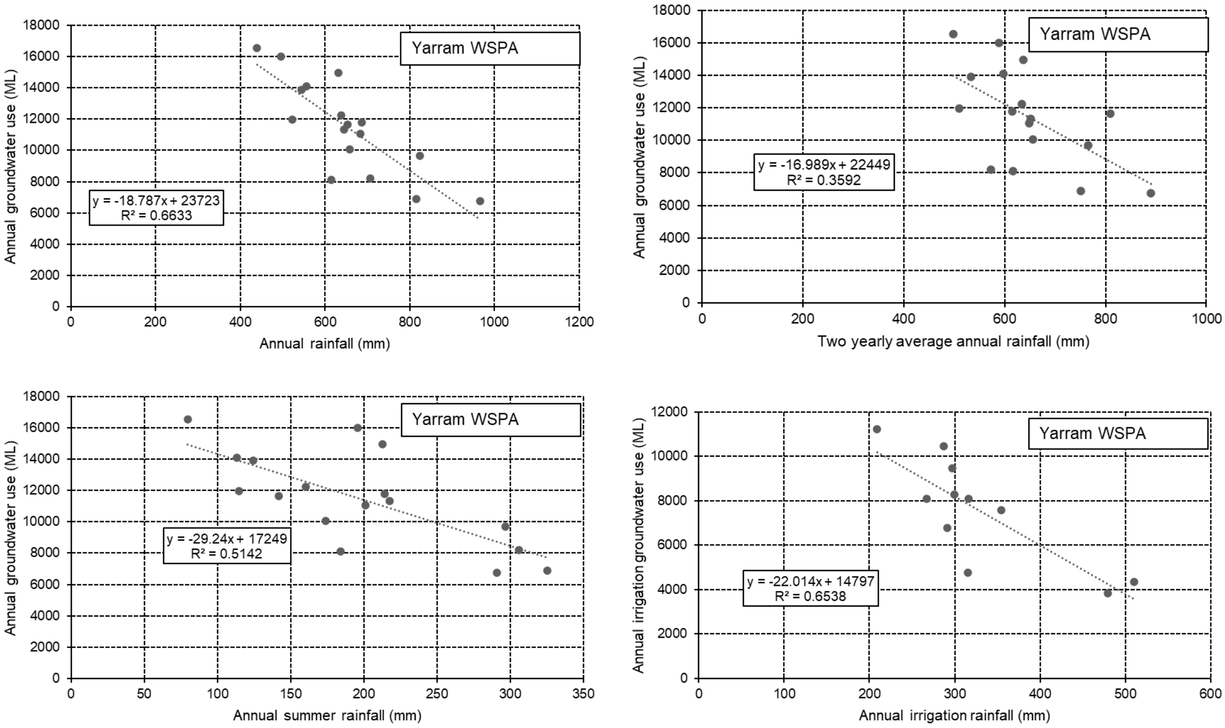


Figure 378 *Yarram WSPA: Hindcast method 1 correlations (Yarram WSPA and annual groundwater use)*

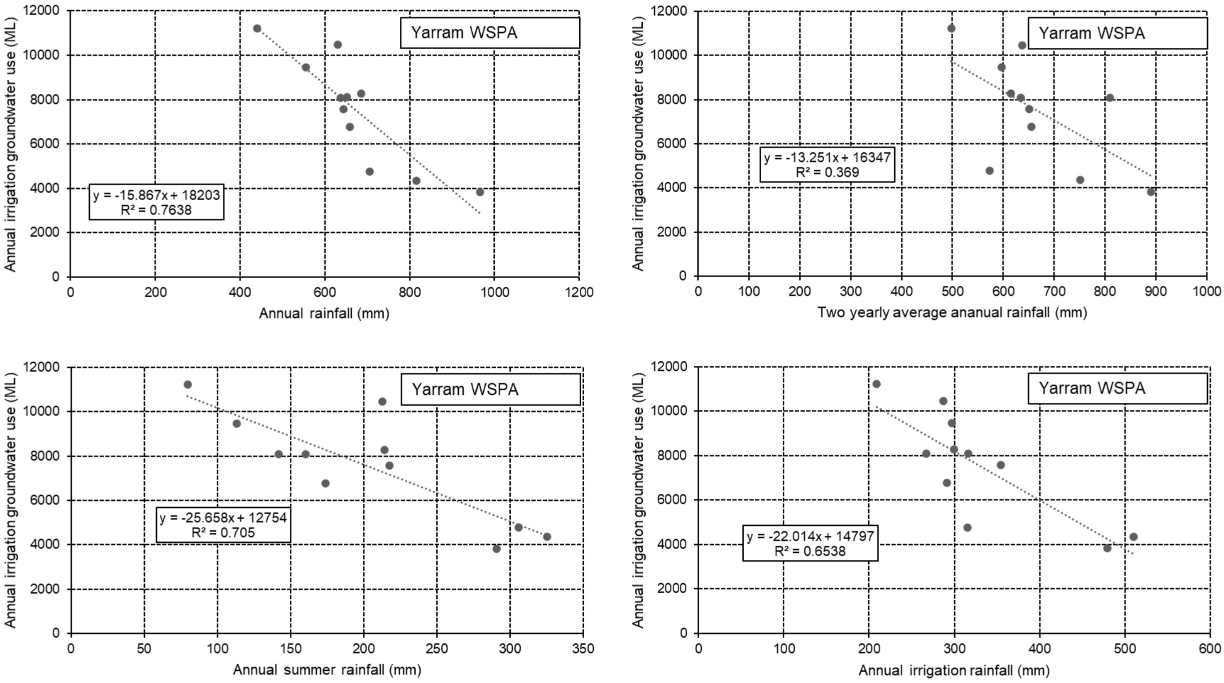


Figure 379 *Yarram WSPA: Hindcast method 1 correlations (Yarram WSPA and annual irrigation groundwater use)*

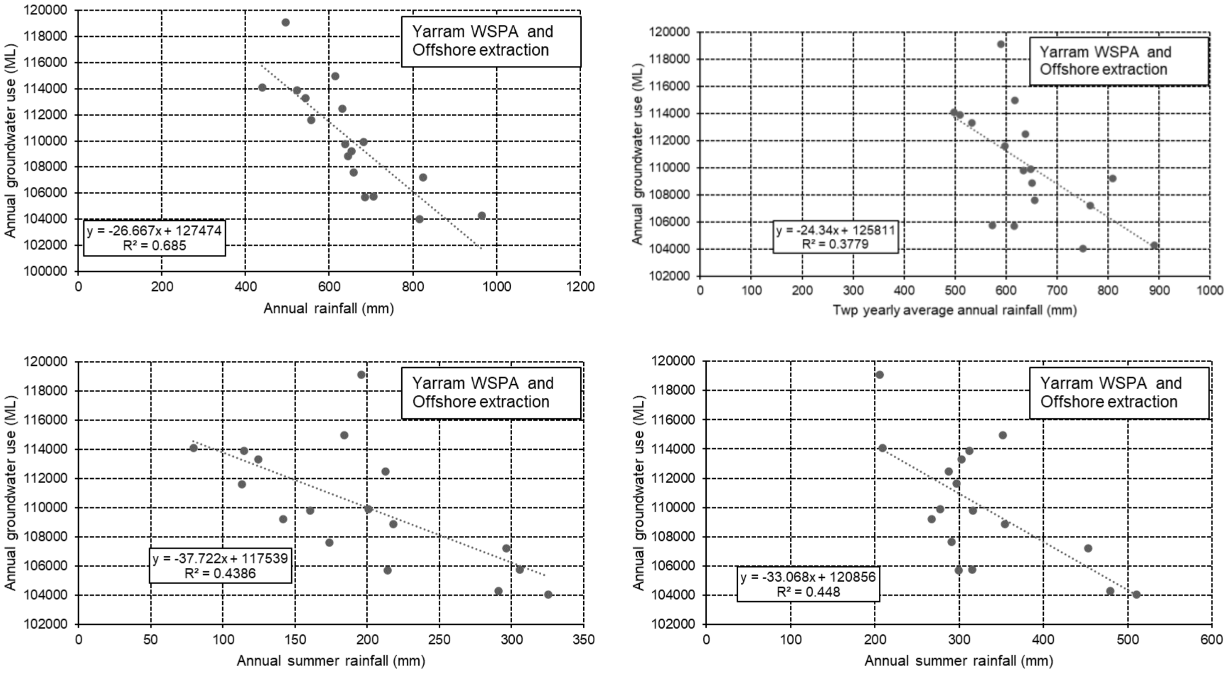


Figure 380 *Yarram WSPA: Hindcast method 1 correlations (Yarram WSPA and Offshore extractions and annual groundwater use)*

23.2.4.2 Hindcasting Method 2 (H2)

Eight correlations were developed using method H2 as described below.

Figure 381:

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

Figure 382

- Yarram WSPA and Offshore extraction use per Yarram WSPA bore vs annual rainfall
- Yarram WSPA and Offshore extraction use per Yarram WSPA bore vs two yearly average annual rainfall
- Yarram WSPA and Offshore extraction use per Yarram WSPA bore vs annual summer period rainfall
- Yarram WSPA and Offshore extraction use per Yarram WSPA bore vs annual irrigation period rainfall

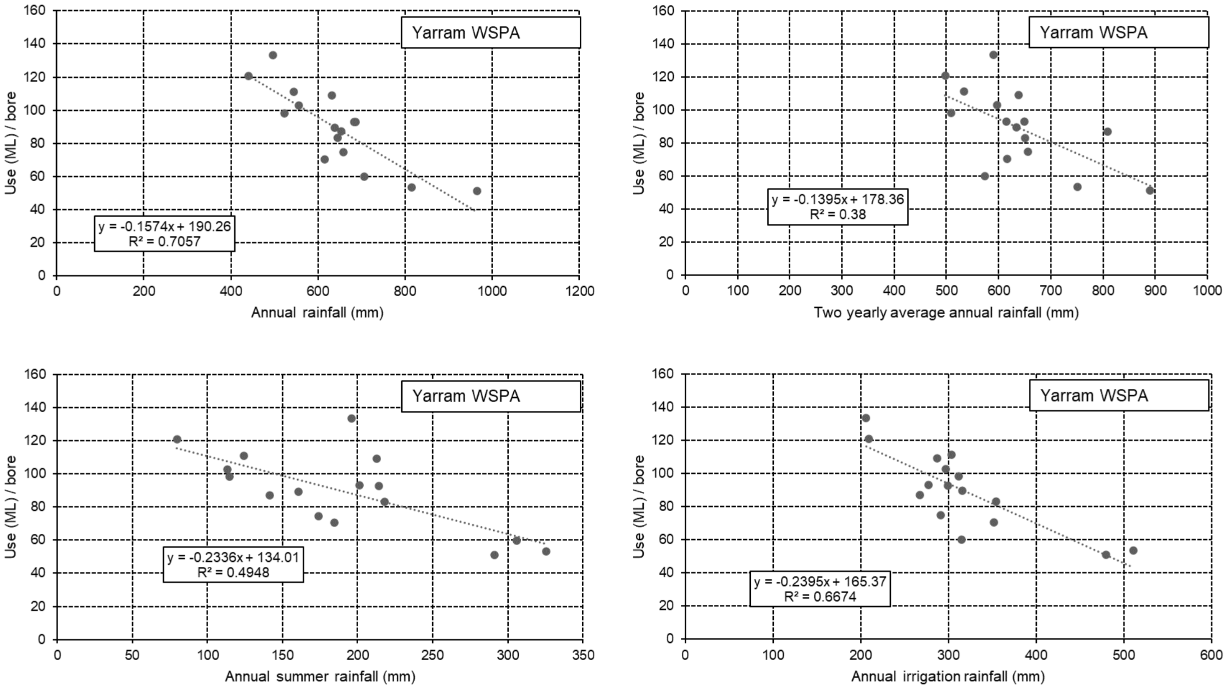


Figure 381 Yarram WSPA: Hindcast method 2 correlations (Yarram WSPA only)

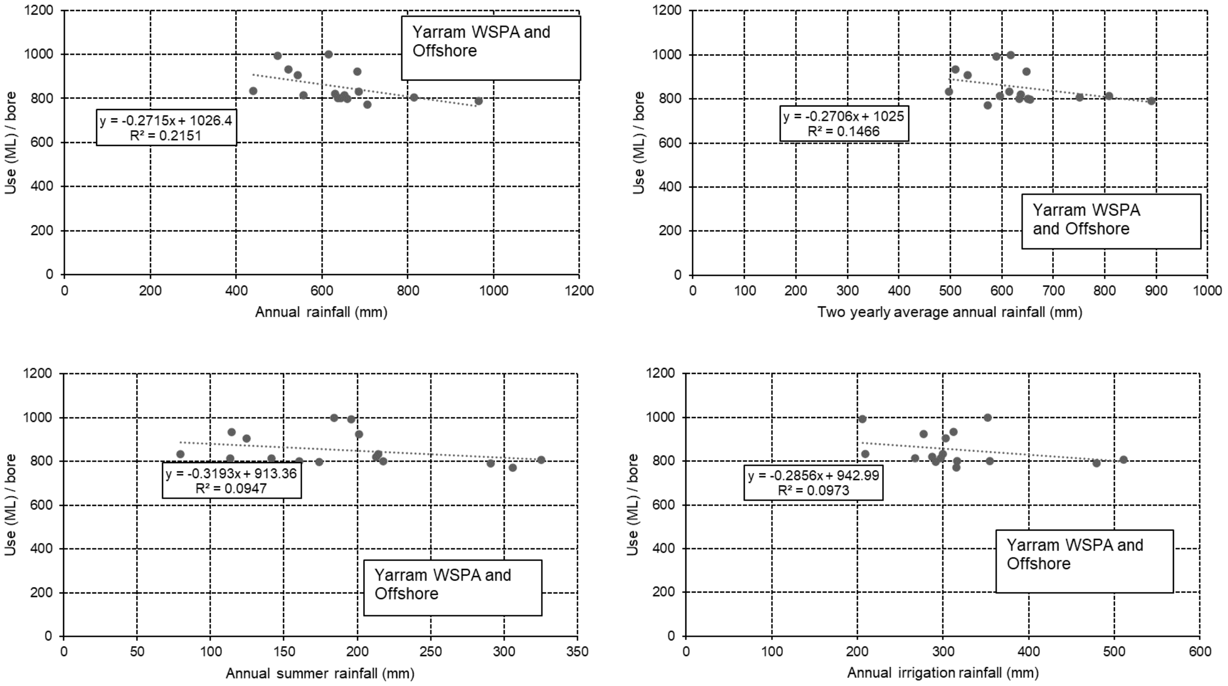


Figure 382 Yarram WSPA: Hindcast method 2 correlations (Yarram WSPA and Offshore extractions)

As shown in Figure 381 and similar to method H1, the R^2 decreased in both instances where the extraction from the Offshore extractions (external influence) was included. The best R^2 was shown to be the correlation of the annual rainfall and Yarram WSPA use per bore. This and the Yarram WSPA and Offshore extraction per bore (with annual rainfall) were modelled; albeit the latter had a very poor fit.

23.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 383:

- 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

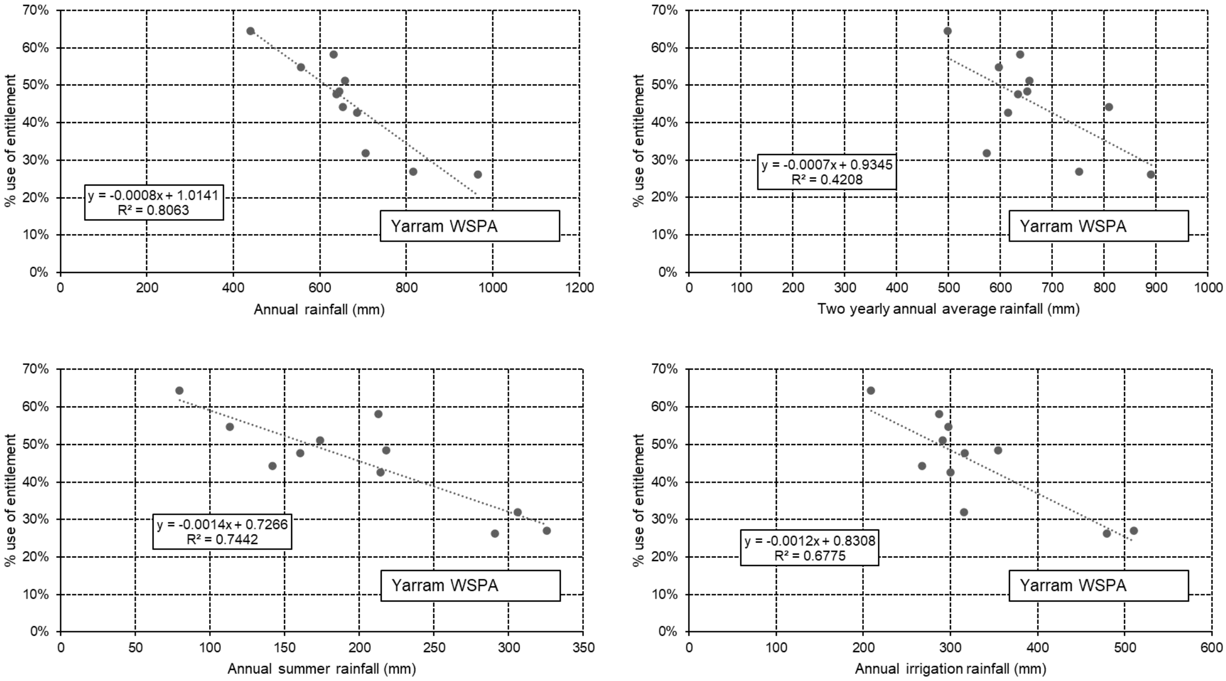


Figure 383 Yarram WSPA: Hindcast method 3 correlations

As shown in Figure 383 and similar to method H1 and H2, the best R^2 was shown to be the correlation of the annual rainfall; this correlation was used for the H3 modelling.

23.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 384 and Figure 385 for the hindcasting based on only Yarram WSPA groundwater use.

Figure 384 shows a comparison of the three hindcasting methods against the recorded use only, over the recorded use date. Figure 385 shows the hindcasted data back to 1978/1979. A comparison of the three input datasets for hindcasting based on the combined Yarram WSPA and Offshore extractions groundwater use is shown in Figure 386 and Figure 387. Figure 386 shows a comparison of the three hindcasting methods against the recorded use only over the recorded use date. Figure 387 shows the hindcasted data back to 1978/1979.

As shown in Figure 385 and Figure 387, 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. The hindcasting results show that the smallest average variation of recorded use to estimate use occurs for method 2 for Yarram WSPA only extraction and method 1 for the combined Yarram WSPA and Offshore.

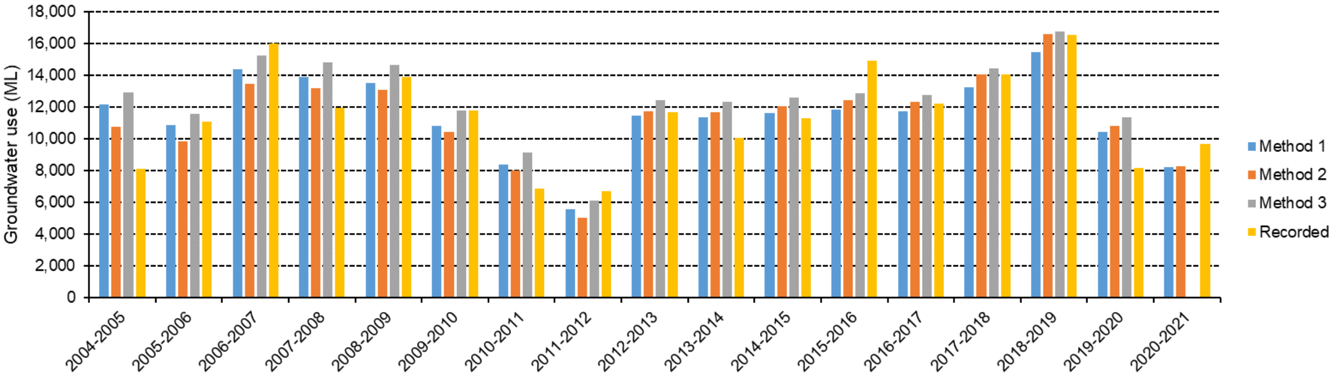


Figure 384 *Yarram WSPA: Comparison of hindcasting over recorded use period – Yarram WSPA only extraction*

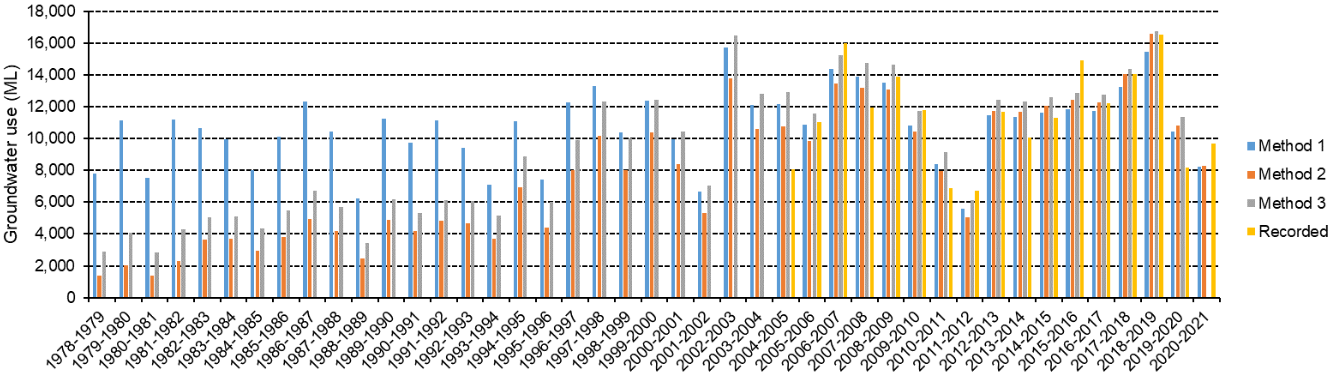


Figure 385 *Yarram WSPA: Comparison of hindcasting – Yarram WSPA only extraction*

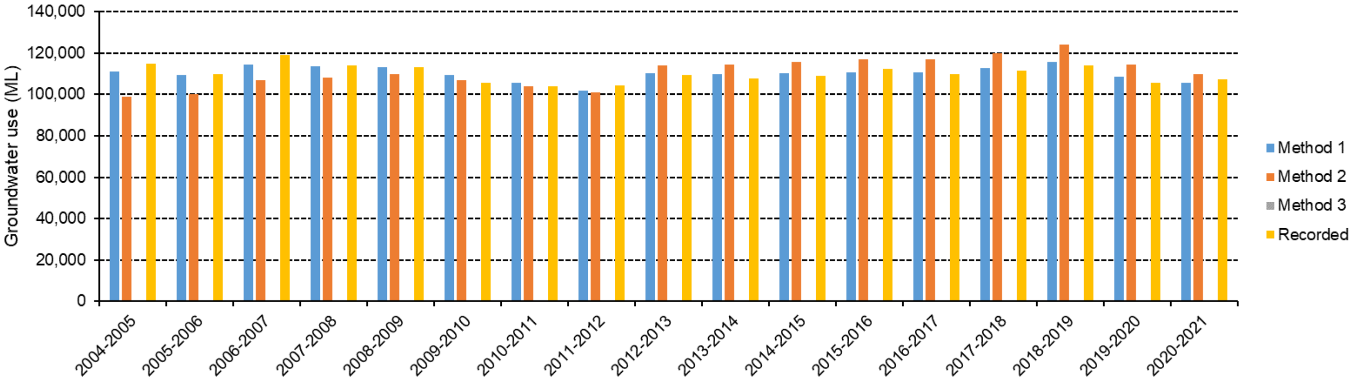


Figure 386 *Yarram WSPA: Comparison of hindcasting over recorded use period – Yarram WSPA and Offshore extractions*

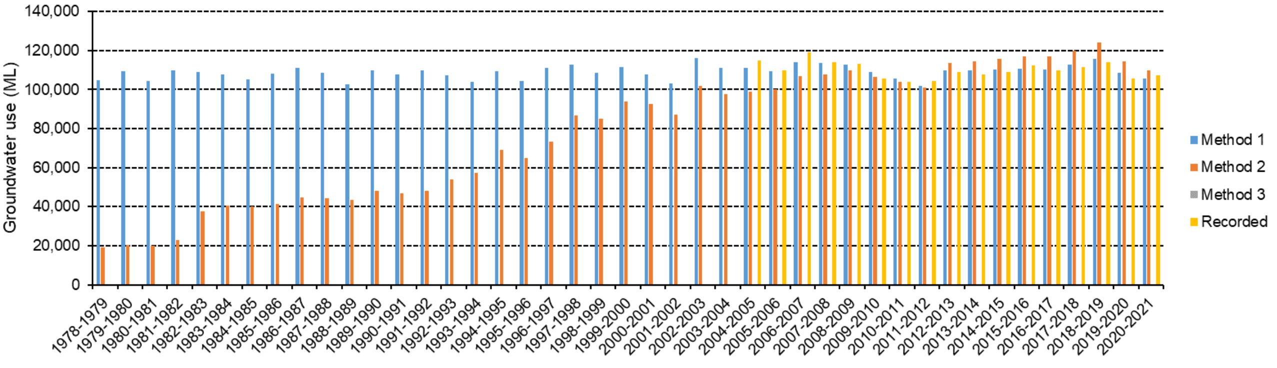


Figure 387 *Yarram WSPA: Comparison of hindcasting – Yarram WSPA and Offshore extractions*

23.3 Modelling

23.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 139 summarises the combinations of model inputs run for Yarram 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 139 Yarram 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 (L_O_1 and L_O_2)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Yarram WSPA only	✓																		
Two yearly average annual extraction – Yarram WSPA only		✓																	
Annual extraction – Yarram WSPA and Offshore extractions			✓																
Two yearly average annual extraction – Yarram WSPA and Offshore extractions				✓															
H1 annual extraction – Yarram WSPA only					✓														
H1 annual extraction – Yarram WSPA and Offshore extractions						✓													
H2 annual extraction – Yarram WSPA only							✓												
H2 annual extraction – Yarram WSPA and Offshore extractions								✓											
H3 annual extraction – Yarram WSPA only									✓										
H1 two yearly average annual extraction – Yarram WSPA only										✓									
H1 two yearly average annual extraction – Yarram WSPA and Offshore extractions											✓								
H2 two yearly average annual extraction – Yarram WSPA only												✓							
H2 two yearly average annual extraction – Yarram WSPA and Offshore extractions													✓						
S1 annual extraction – Yarram WSPA only														✓					
S2 annual extraction – Yarram 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 – Yarram WSPA only																✓			
S1 annual extraction and H1 annual extraction – Yarram WSPA only																	✓		
S2 annual extraction and H2 annual extraction – Yarram WSPA only																		✓	
S3 annual extraction and H3 annual extraction – Yarram WSPA only																			✓

23.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 139 is presented in Table 140 for the selection of potential representative Suites for Yarram WSPA. The column heading for L_O_2 is highlighted blue to indicate that this Suite was selected as the most representative Suite based on the process outlined in section 23.2.1. 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_O_1

A review of the results and statistical summary for Suite L_O_1 shows that model runs 3 and 4 (highlighted orange) show the best results when considering the 95PPU TH first and then the combination of all four of the statistical measures of the 19 different model input combinations. However, these models only include 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. Based on the hindcasted models, model run 8 (highlighted green) was found to have the best statistical results with the longest dataset, having one of the the lowest 95PPU thickness and RMSE, and one of the highest R^2 values of all the hindcasted results. Thus model run 8 has been selected as the preferred model to progress to predictive modelling for Suite L_O_1. The graphical model output for this run is shown in Figure 388.

Suite L_O_2

A review of the results and statistical summary for Suite L_O_2 shows that model runs 9 and 17 (highlighted green) show the best results when considering the 95PPU TH first and then the combination of all four of the statistical measures of the 19 different model input combinations. The graphical model output for model runs 9 and 17 are shown in Figure 389 and Figure 390 respectively. These two model results show relatively good R^2 and percentage of observations within the 95PPU but poorer RMSE and 95PPU thickness. Comparing the statistical measures of both model runs, they are very similar. Model run 9 has been adopted as the preferred model to undertake the predictive modelling, based on the complexity in model run 17 and because the result is similar to that of model run 9.

Modelling was progressed on the basis of adopting model run 8 for Suite L_O_1 and model run 9 for Suite L_O_2.

Table 140 Yarram WSPA: summary of model outputs

Suite	Statistic	Model run																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
L_O_1	95PPU TH	7.59	6.96	4.57	4.55	10.92	15.05	10.63	6.79	16.98	13.11	12.57	10.7	6.66	4.42	3.35	63.37	9.97	15.37	nan
	%Obs in 95 PPU	100	100	100	100	97.62	90.48	42.86	100	71.43	95.24	90.48	45.24	100	100	90	100	75.61	12.2	0
	R^2	84.5	90.1	95.2	95.4	98.4	98.3	62.9	98.3	78.1	98.7	98	64.6	98.2	55.8	44.9	90.6	70.4	28.3	-328.3
	RMSE	1.12	0.9	0.62	0.61	1.27	1.34	6.17	1.33	4.74	1.17	1.43	6.03	1.35	0.81	0.9	0.37	5.47	8.52	20.81
	No obs data points	16	16	16	16	42	42	42	42	42	42	42	42	42	10	10	10	41	41	41
	Range of observed levels	9.4	9.4	9.4	9.4	33.2	33.2	33.2	33.2	33.2	33.2	33.2	33.2	33.2	4.0	4.0	4.0	33.2	33.2	33.2
L_O_2	95PPU TH	11.81	11.72	10.79	10.31	11.79	10.68	8.54	8.57	6.69	14.88	10.7	11.44	8.59	10.71	9.41	9.41	5.24	7.57	15.82
	%Obs in 95 PPU	86.67	86.67	86.67	86.67	100	100	94.59	94.59	94.59	100	97.3	94.59	94.59	80	80	80	91.89	91.89	100
	R^2	0	0	2.9	2.3	74.1	83.1	87.5	86	92.1	52.1	83	70.5	85.8	-5.8	-5.9	-5.9	93.5	81.4	38.2
	RMSE	2.63	2.63	2.59	2.59	2.66	2.15	1.85	1.96	1.47	3.61	2.15	2.84	1.97	3.24	3.24	3.24	1.33	2.25	4.11
	No obs data points	15	15	15	15	37	37	37	37	37	37	37	37	37	10	10	10	37	37	37
	Range of observed levels	9.5	9.5	9.5	9.5	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	9.5	9.5	9.5	17.2	17.2	17.2

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

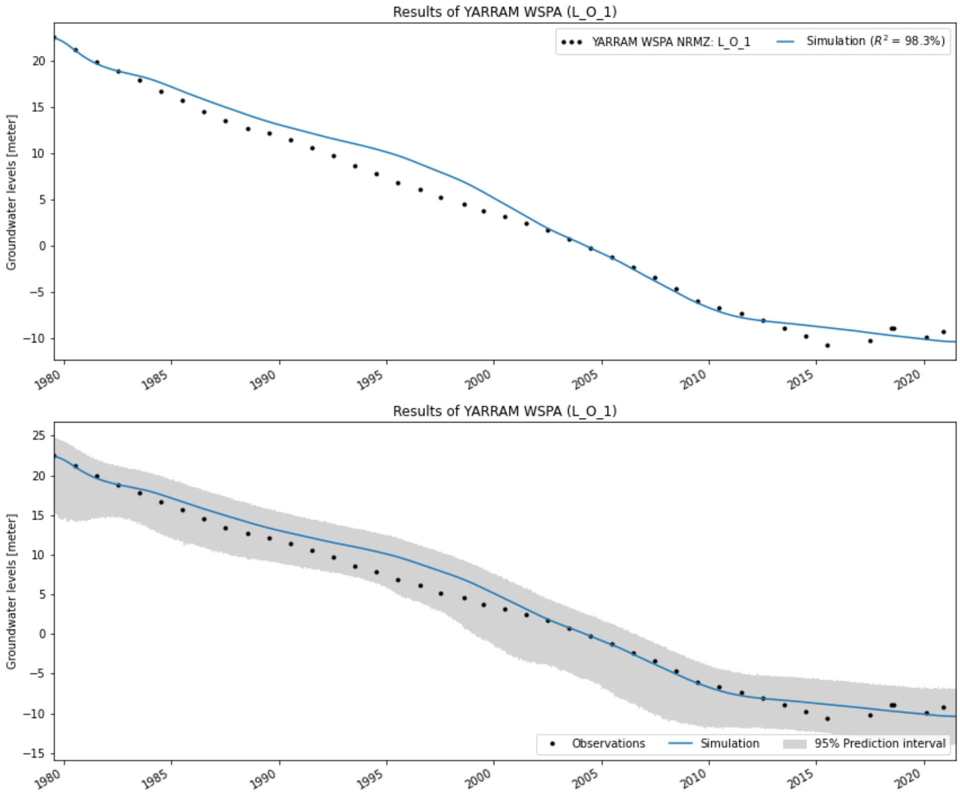


Figure 388 *Yarram WSPA Suite L_O_1: model run 8 (Yarram WSPA and Offshore annual extraction with hindcast method H2) output hydrographs*

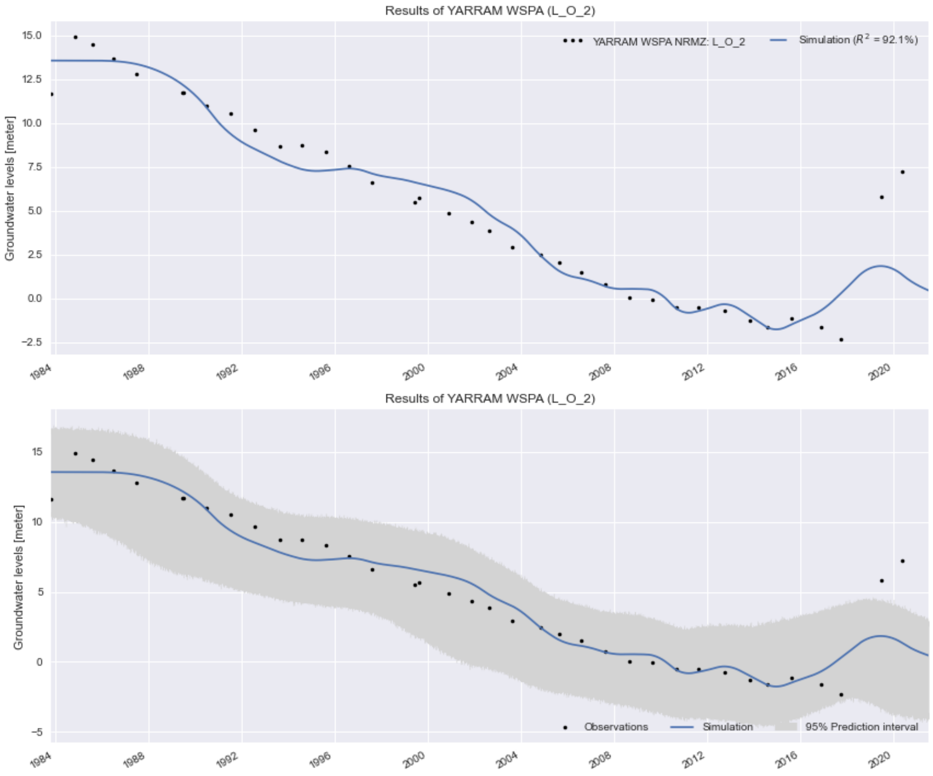


Figure 389 *Yarram WSPA Suite L_O_2: model run 9 (Yarram WSPA annual extraction with hindcast method 3) output hydrographs*

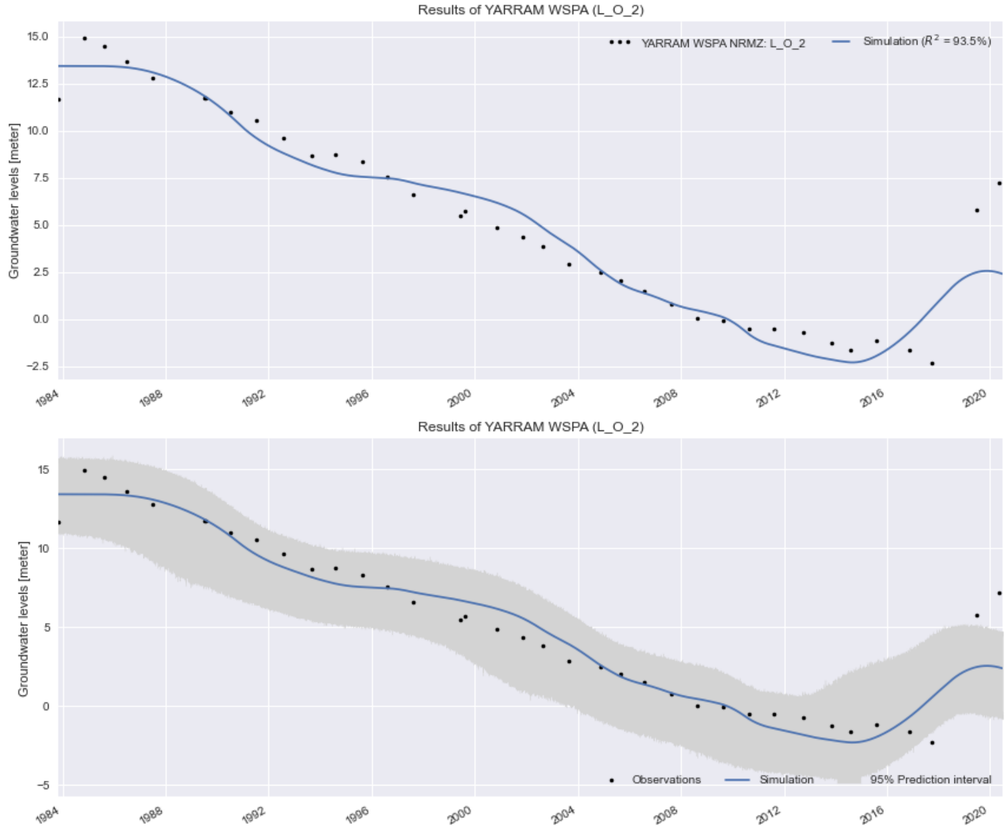


Figure 390 *Yarram WSPA Suite L_O_2 model run 17 (Yarram WSPA annual extraction with hindcast method 3 and spatial distribution 1) output hydrographs*

23.4 Predictive modelling

23.4.1 Model inputs

The preferred model to run the predictive modelling for Yarram WSPA was model run 8 for Suite L_O_1 and model run 9 for Suite L_O_2. The key inputs for the model were the annual recovered levels and either the annual hindcasted extraction in Yarram WSPA or the annual extraction in Yarram WSPA and Offshore. 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 141.

Table 141 *Yarram 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)
Yarram WSPA only volumes (ML/year)	25,690	25,688	9,677	11,482	16,557
Yarram WSPA and Offshore volumes (ML/year)	144,778*	144,778*	107,214	110,098	119,090

**Note no licenced entitlement or PCV could be identified and thus the PCV and licenced entitlement for Yarram WSPA and Offshore volumes was taken to be the combined max historic use with the licenced entitlement.*

23.4.2 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 output is presented for scenario 16 in Figure 391 which shows that uncertainty in model prediction increases as the model predicts further into the future. Compared with the graphical output for the same scenario, the MCMC realisations show a greater spread than the 95% prediction interval bands shown in Figure 392.

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.

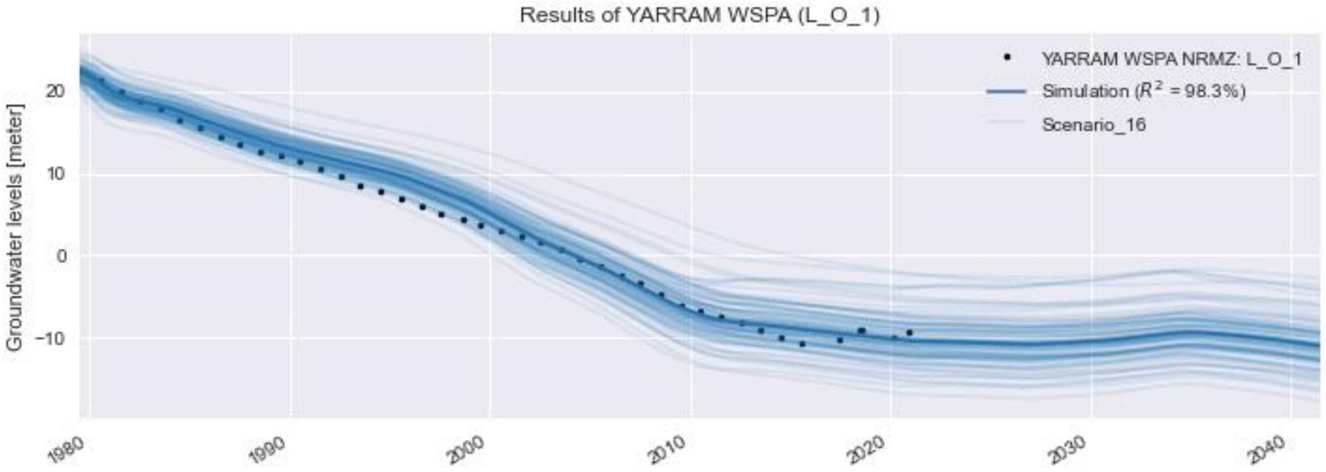


Figure 391 *Yarram WSPA: Suite L_O_1 MCMC analysis for Forecast Scenario 16*

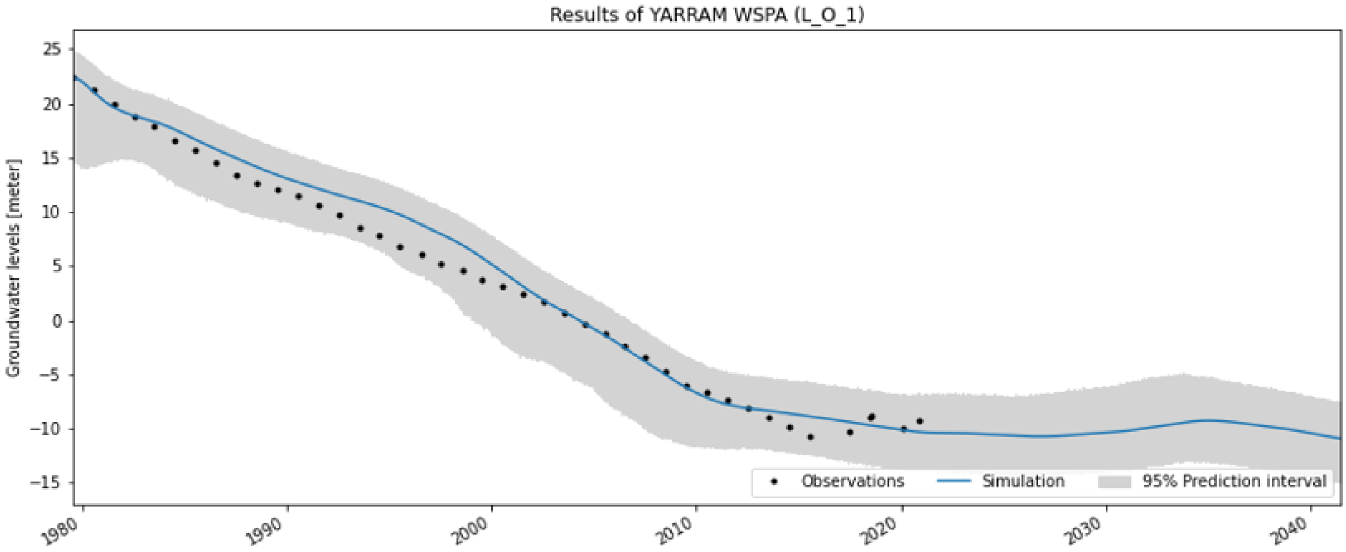


Figure 392 *Yarram WSPA: Suite L_O_1 Forecast Scenario 16 with 95% prediction bands*

23.4.3 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 in the GMU
- Initiation of groundwater development preceded SOBN installation and temporal groundwater monitoring

Using the pre-development levels defined in section 23.2.2, 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 393 for Suite L_O_1 hydrograph of annual recovered levels. In Figure 393:

- Recorded annual groundwater use for Yarram WSPA and Offshore is represented by the blue column graph between 2004/2005 and 2020/2021
- Hindcasted groundwater use is represented by the orange columns between 1978/1979 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
- The pre-development annual recovered level is taken to be the first reading which equates to 22.87 m
- The modelled forecasted annual recovered levels are represented by the purple line in Figure 393
- The calibration annual recovered levels are represented by the black line in Figure 393

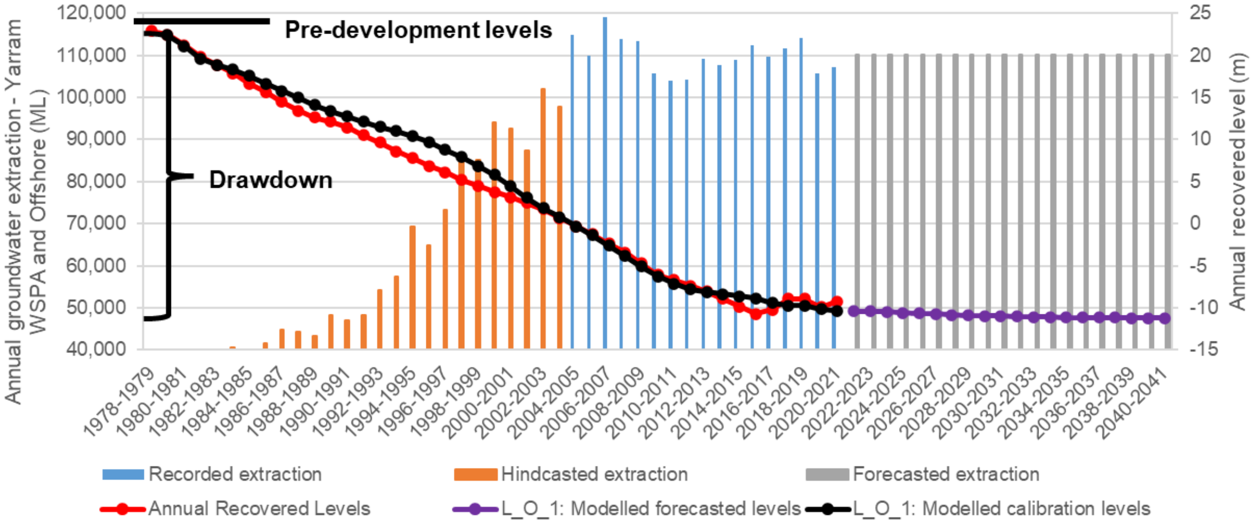


Figure 393 Estimating pre-pumping water levels (example from Suite L_O_1)

For Suite L_O_1, the volumes needed to be converted from a combined volume of Yarram WSPA and Offshore to just a volume that represents Yarram WSPA. On average, Yarram WSPA extraction makes up 12% of the combined volume based on the recorded datasets. As such 12% of the combined volume has been used in the use-drawdown relationships for Suite L_O_1.

For Suite L_O_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 394) and a graph of the scenarios for specific time periods (Figure 395) 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 changes in R^2. The same process was applied for Suite L_O_2, however, there variations in the R^2 between the graphs. As these last two graphs were similar with the same linear equation, and keeping in line with the assessments conducted at other GMUs, the correlation from all scenarios was adopted. 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 394 for Suite L_O_1 and Figure 396 for L_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). 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 11,500 ML for Yarram WSPA. Figure 394 indicates that at use around this volume the model forecast drawdown occurs above the predicted line of best fit for Suite L_O_1. Figure 396 indicates that at use of around 11,500 ML the model forecast drawdown occurs above the predicted line of best fit for Suite L_O_2.
- For the same annual use, different drawdowns can be obtained as Pastas predicts a water level for each year. For example, Figure 393 shows a scenario where groundwater use remains constant at around 110,000 ML/year for the combined Yarram WSPA and Offshore over the next 20 years.
- 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.

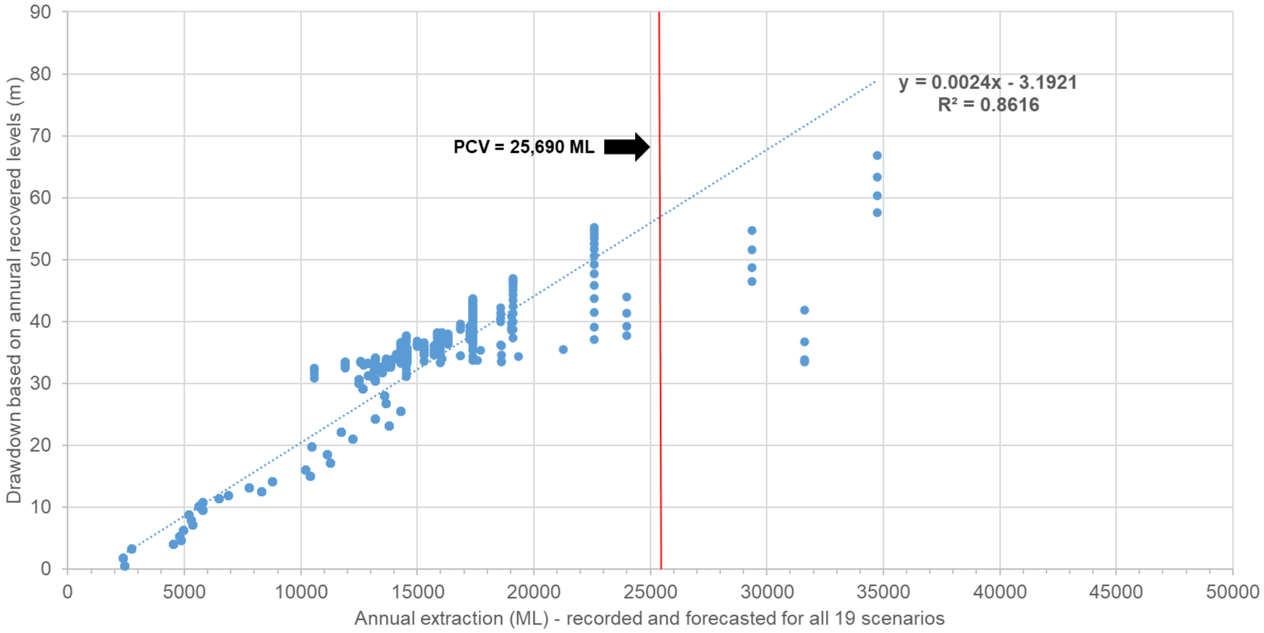


Figure 394 Yarram WSPA Suite L_O_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <50,000 ML for Yarram WSPA) for all data between 1980 to 2041 and all forecasted scenarios

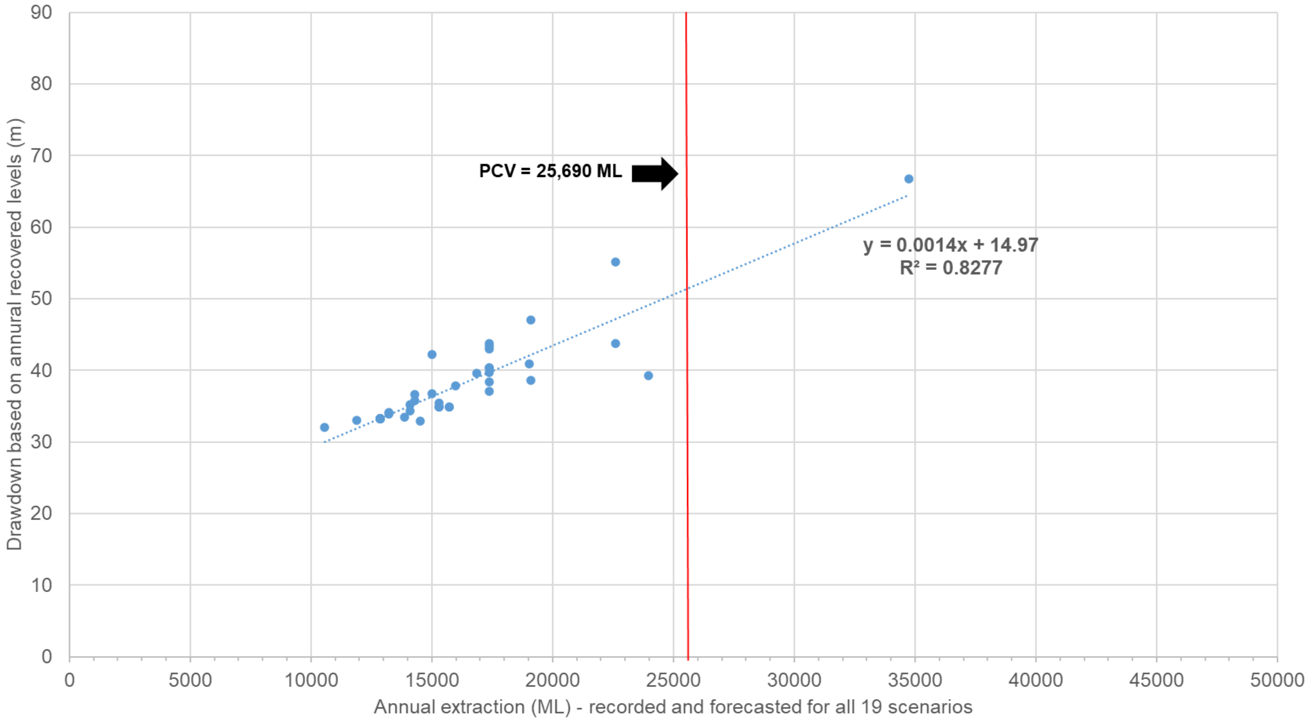


Figure 395 *Yarram WSPA Suite L_O_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <50,000 ML for Yarram WSPA) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

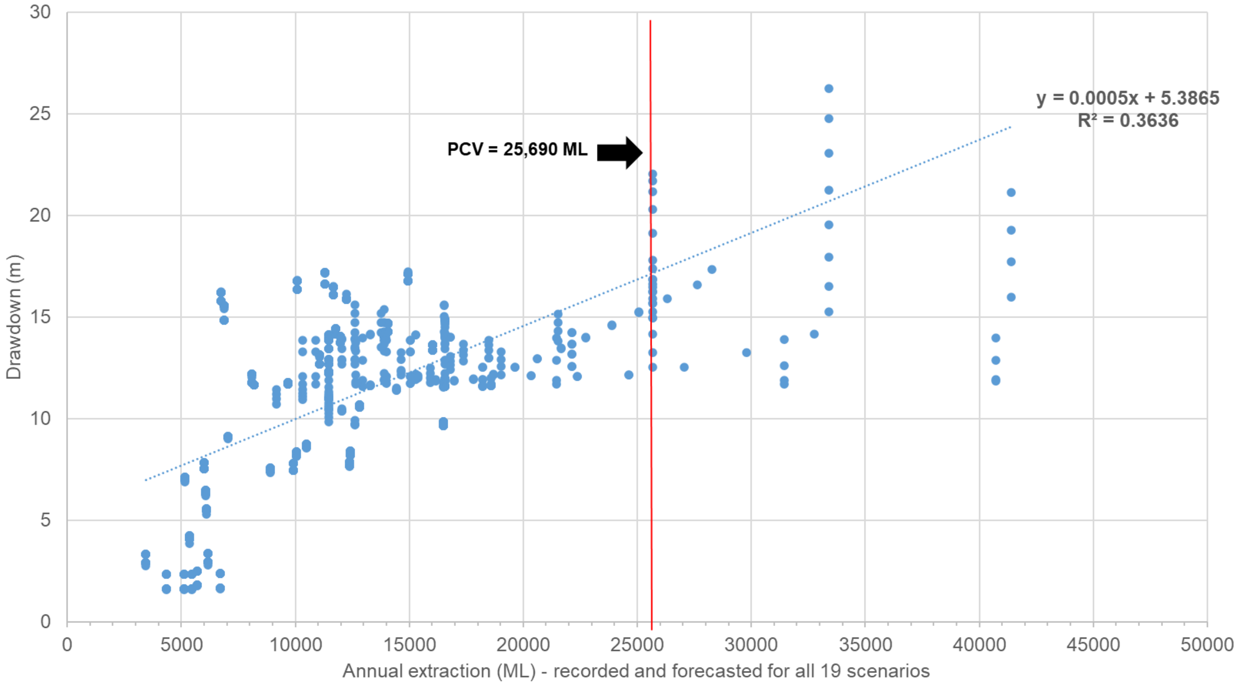


Figure 396 *Yarram WSPA Suite L_O_2: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <50,000 ML for Yarram WSPA) for all data between 1984 to 2041 and all forecasted scenarios*

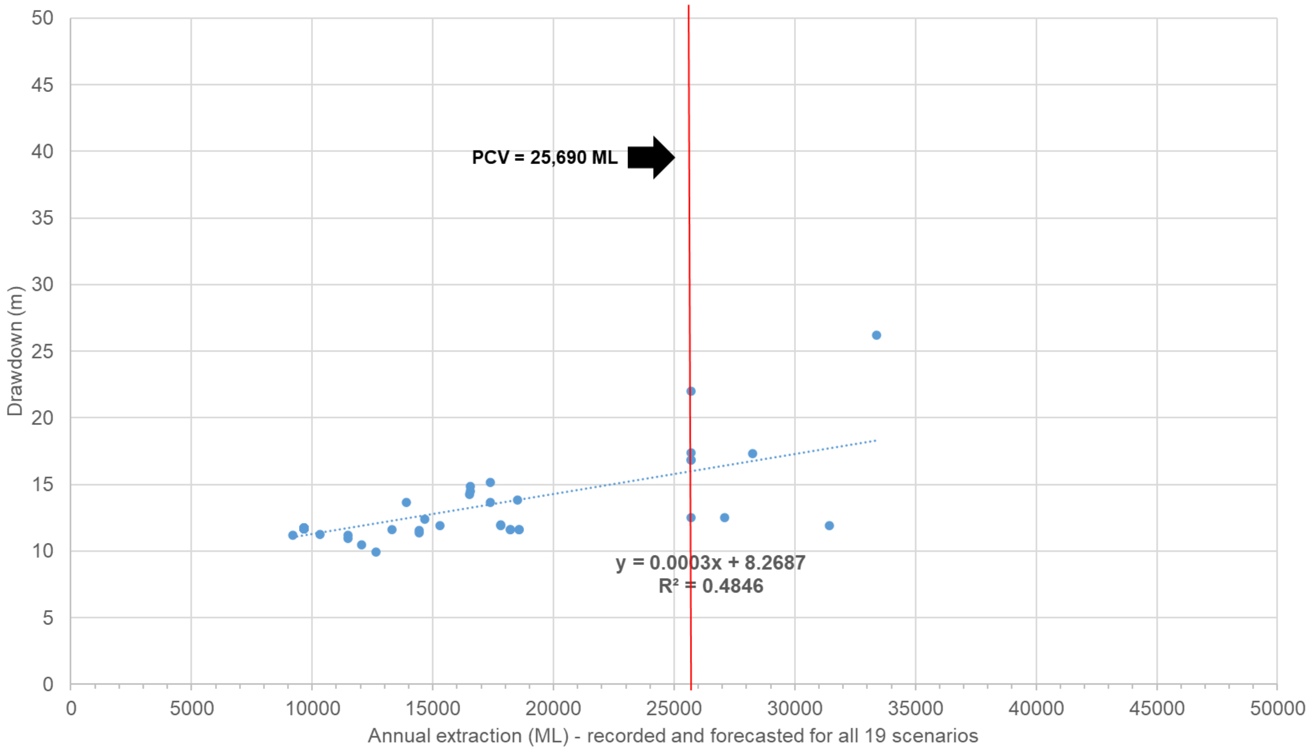


Figure 397 *Yarram WSPA Suite L_O_2: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <50,000 ML for Yarram WSPA) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

23.5 Sustainability metrics

23.5.1 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 142 and Figure 398 for Yarram WSPA Suite L_O_1. Noting that Yarram WSPA has a current PCV of 25,690 ML and combined with Offshore, the cap was estimated to be 144,778 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 142 and Figure 398 for Suite L_O_1, and Table 143 and Figure 399 for Suite L_O_2. Figure 400 shows graphically and spatially by Suite the drawdowns associated with extraction rates.

As previously discussed, for Suite L_O_1, the predicted model adopted was based on the combined extraction from Yarram WSPA and offshore extraction). This was brought back to a Yarram WSPA only extraction for plotting the drawdown with extraction by taking 12% of the combined extraction (12% is the average portion of Yarram WSPA to the combined extraction based on recorded data). Table 142 shows the volume for Yarram WSPA to a given drawdown; the same table has been replicated for the combined use as shown in Table 144 (its noted that this is the actually usage used in the predictive model).

A comparison of volumes at drawdown intervals provided by DEECA is shown in Table 145 for Suite L_O_1 and L_O_2. Based on the correlations, it is predicted that 5 m of drawdown could occur for an annual groundwater usage of 3,400 ML (which could vary from 1,900 to 4,300 ML) for Suite L_O_1 and -800 ML (which could vary from -6,600 to 5,500 ML) for Suite L_O_2. Whereas, it is predicted that 10 m of drawdown could occur for an annual groundwater usage of 5,500 ML (which could vary from 4,000 to 6,500 ML) for Suite L_O_1 and 9,200 ML (which could vary from 3,400 to 17,900 ML) for Suite L_O_2.

Table 142 Relationship of Suite drawdown to GMU extraction for Yarram WSPA Suite L_O_1

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_O_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
14,000	30.4 (27.2 - 34)
13,000	28 (24.9 - 31.6)
12,000	25.6 (22.6 - 29.2)
11,000	23.2 (20.3 - 26.8)
10,000	20.8 (18 - 24.4)
9,000	18.4 (15.7 - 22)
8,000	16 (13.4 - 19.6)
7,000	13.6 (11.1 - 17.2)
6,000	11.2 (8.8 - 14.8)
5,000	8.8 (6.5 - 12.4)
4,000	6.4 (4.2 - 10)
3,000	4 (1.9 - 7.6)
2,000	1.6 (-0.4 - 5.2)
1,000	-0.8 (-2.7 - 2.8)
0	-3.2 (-5 - 0.4)

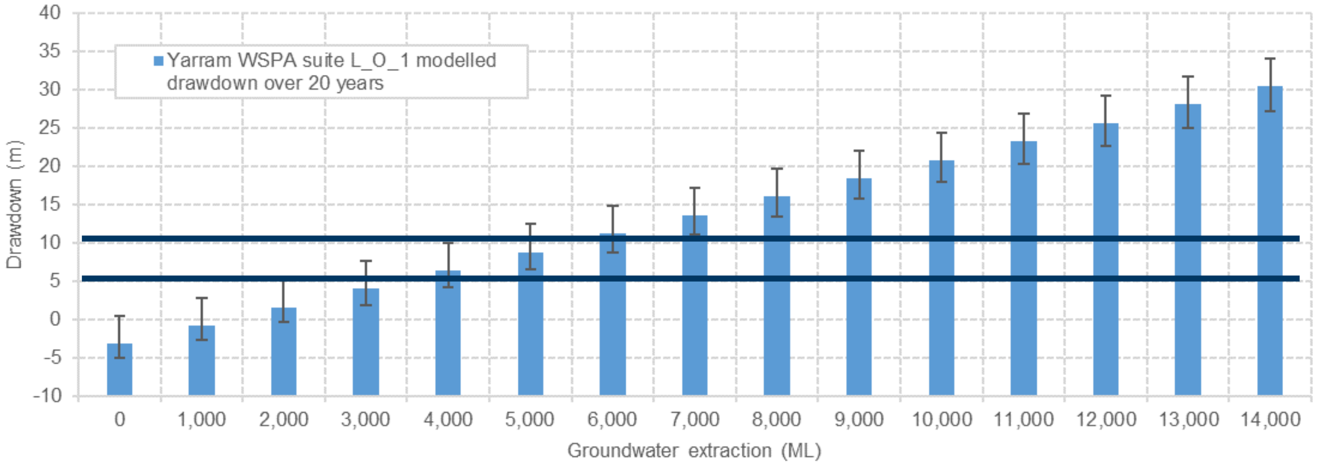


Figure 398 *Yarram WSPA Suite L_O_1: Relationship of Suite drawdown to whole of Yarram WSPA (with error bars showing results of drawdown using levels from model's 95% prediction intervals)*

Table 143 *Relationship of Suite drawdown to GMU extraction for Yarram WSPA Suite L_O_2*

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_O_2 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
30,000	20.4 (14.8 - 23.3)
28,000	19.4 (14 - 22.3)
26,000	18.4 (13.2 - 21.3)
24,000	17.4 (12.4 - 20.3)
22,000	16.4 (11.6 - 19.3)
20,000	15.4 (10.8 - 18.3)
18,000	14.4 (10 - 17.3)
16,000	13.4 (9.2 - 16.3)
14,000	12.4 (8.4 - 15.3)
12,000	11.4 (7.6 - 14.3)
10,000	10.4 (6.8 - 13.3)
8,000	9.4 (6 - 12.3)
6,000	8.4 (5.2 - 11.3)
4,000	7.4 (4.4 - 10.3)
2,000	6.4 (3.6 - 9.3)
0	5.4 (2.8 - 8.3)

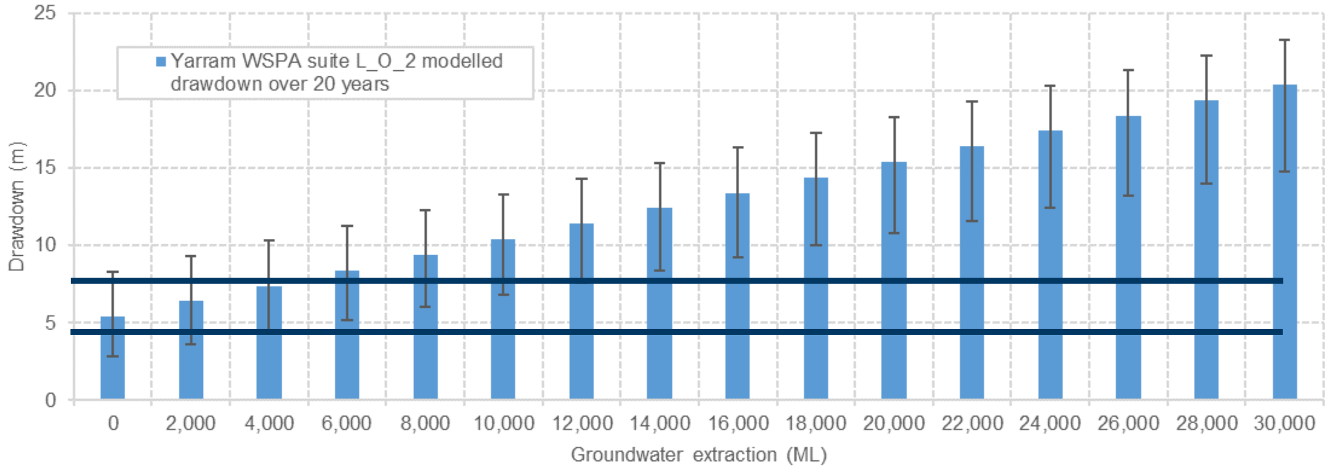


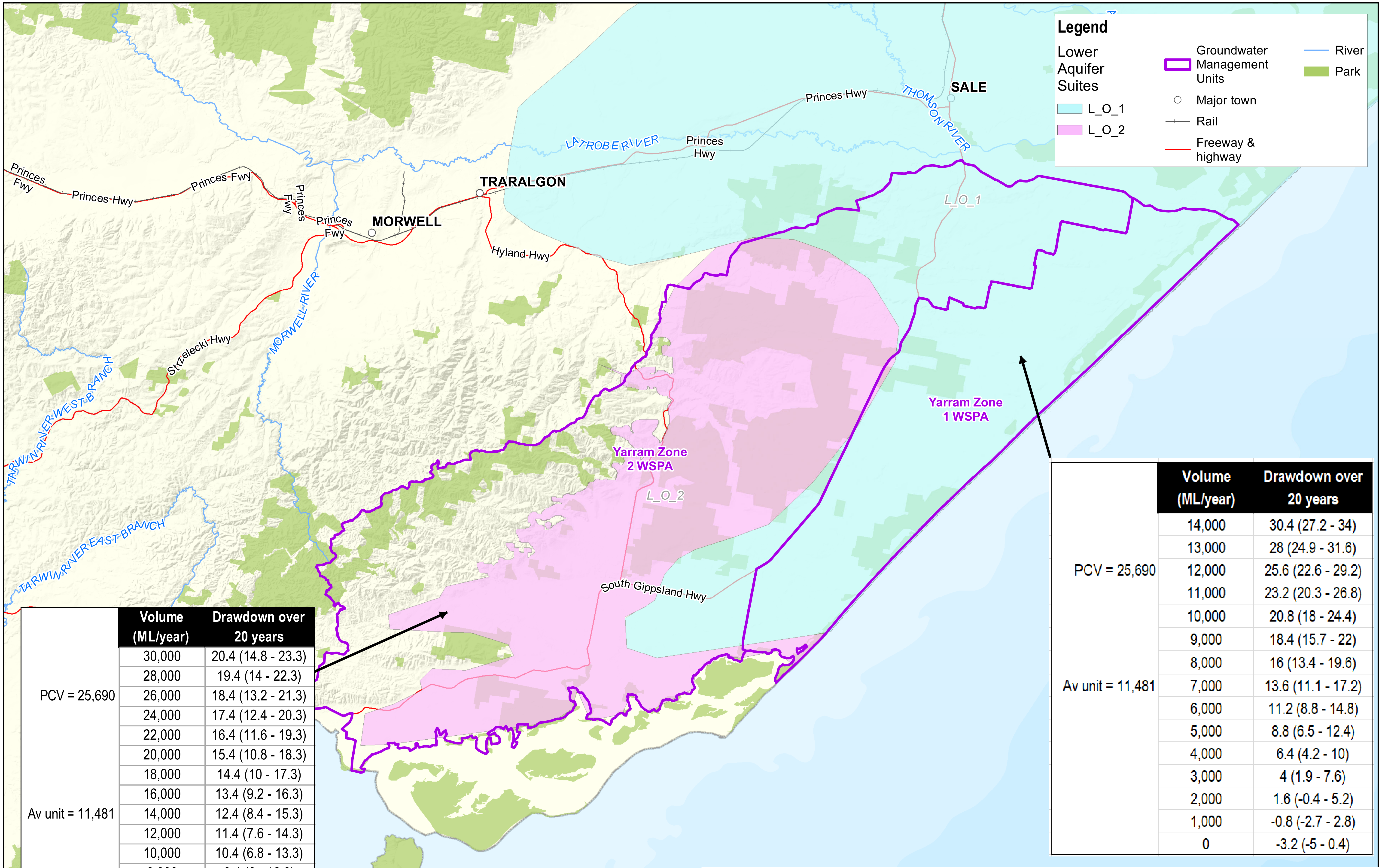
Figure 399 *Yarram WSPA Suite L_O_2: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)*

Table 144 *Relationship of Suite drawdown to GMU extraction for combined Yarram WSPA and offshore Suite L_O_1*

Volume (ML/year) for combined Yarram WSPA and offshore extraction	Based on model prediction of Suite L_O_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
50,000	11.8 (10 - 15.4)
45,000	10.3 (8.5 - 13.9)
40,000	8.8 (7 - 12.4)
35,000	7.3 (5.5 - 10.9)
30,000	5.8 (4 - 9.4)
25,000	4.3 (2.5 - 7.9)
20,000	2.8 (1 - 6.4)
15,000	1.3 (-0.5 - 4.9)
10,000	-0.2 (-2 - 3.4)
5,000	-1.7 (-3.5 - 1.9)
0	-3.2 (-5 - 0.4)

Table 145 *Predicted GMU volumes for drawdown metrics*

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite L_O_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite L_O_2 drawdowns (lower limit to upper limit)
5	3,400 (1,900 – 4,300)	-800 (-6,600 – 5,500)
10	5,500 (4,000 – 6,500)	9,200 (3,400 – 17,900)



	Volume (ML/year)	Drawdown over 20 years
	30,000	20.4 (14.8 - 23.3)
	28,000	19.4 (14 - 22.3)
PCV = 25,690	26,000	18.4 (13.2 - 21.3)
	24,000	17.4 (12.4 - 20.3)
	22,000	16.4 (11.6 - 19.3)
	20,000	15.4 (10.8 - 18.3)
	18,000	14.4 (10 - 17.3)
	16,000	13.4 (9.2 - 16.3)
Av unit = 11,481	14,000	12.4 (8.4 - 15.3)
	12,000	11.4 (7.6 - 14.3)
	10,000	10.4 (6.8 - 13.3)
	8,000	9.4 (6 - 12.3)
	6,000	8.4 (5.2 - 11.3)
	4,000	7.4 (4.4 - 10.3)
	2,000	6.4 (3.6 - 9.3)
	0	5.4 (2.8 - 8.3)

	Volume (ML/year)	Drawdown over 20 years
	14,000	30.4 (27.2 - 34)
	13,000	28 (24.9 - 31.6)
PCV = 25,690	12,000	25.6 (22.6 - 29.2)
	11,000	23.2 (20.3 - 26.8)
	10,000	20.8 (18 - 24.4)
	9,000	18.4 (15.7 - 22)
	8,000	16 (13.4 - 19.6)
Av unit = 11,481	7,000	13.6 (11.1 - 17.2)
	6,000	11.2 (8.8 - 14.8)
	5,000	8.8 (6.5 - 12.4)
	4,000	6.4 (4.2 - 10)
	3,000	4 (1.9 - 7.6)
	2,000	1.6 (-0.4 - 5.2)
	1,000	-0.8 (-2.7 - 2.8)
	0	-3.2 (-5 - 0.4)

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 Yields
Confined Aquifers

YARRAM WSPA: KEY SUITES VOLUME VS DRAWDOWN

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

FIGURE 400

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Print date: 16 Jan 2024 - 08:56

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

23.6 GMU summary

23.6.1 Findings

Yarram WSPA primarily relates to the Latrobe Group Aquifer (LTA) where groundwater is predominately extracted for irrigation and dairy purposes. The LTA falls within the Lower Aquifer Suites, which at Yarram WSPA include L_O_1 (22%) and L_O_2 (54%), providing a total coverage of 76%. The identified representative Suites are L_O_2 (most preferred) and L_O_1. The Suite hydrographs for the representative Suites show an overall decreasing trend along with seasonal fluctuation and thus recovered water levels, which were adopted for the assessment.

As identified through the conceptualisation, Yarram WSPA may be influenced by extraction occurring offshore from oil and gas development. Extraction occurring from the Offshore extractions makes up around 90% of the total extraction when the two datasets are combined. Of the two hindcasting methods that look at both extraction datasets, the correlations developed to apply the hindcasting were improved when only the Yarram WSPA extraction datasets were considered rather than the combined dataset. However, for method 1 using the annual rainfall, the correlations developed were similar for both the Yarram WSPA only and Yarram WSPA plus offshore. Given this, it was considered that including this external influence within the Yarram WSPA predictive modelling should be tested.

Application of two yearly annual average extraction, instead of annual average, generally showed a variable result, sometimes improving the model fit and sometimes producing a poorer model fit, based on the statistical analysis. All the model runs using the hindcast method for Yarram WSPA only extraction showed a poor model fit whether annual extraction or two yearly average extraction was utilised. The best match using the two yearly average annual extraction was model run 4 (two yearly average annual extraction for Yarram WSPA and Offshore extractions with annual recovered levels) for Suite L_O_1 and model run 13 for Suite L_O_2 (two yearly average annual extraction hindcasted using method 2 for Yarram WSPA and offshore with annual recovered levels).

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 for Suite L_O_1 but a better model fit for L_O_2. The quality of the result increased when spatial distribution methodology 1 and 2 were combined with hindcasting methodology 3 for L_O_2.

Based on an assessment of all model runs, the model run 8 of Yarram WSPA and Offshore annual extraction with hindcasted method H2 applies and the annual recovered levels was adopted to undertake the predictive modelling for Suite L_O_1 and model 9 with hindcasting method 3 was adopted for L_O_2.

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 22.87 m for Suite L_O_1 and 14.93 m for Suite L_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 L_O_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite L_O_2 drawdowns (lower limit to upper limit)
5	3,400 (1,900 – 4,300)	-800 (-6,600 – 5,500)
10	5,500 (4,000 – 6,500)	9,200 (3,400 – 17,900)

The model for Suite L_O_2 was assessed as having a “Poor” model applicability rating and the model for Suite L_O_1 was assessed as having a “Good” rating using the criteria outlined in section 5.2. For Suite L_O_2, the model did not match the pre-development level well and thus there is an offset in the results. There is also an underestimate of annual recovered levels at some flow rates which may be associated by offshore extraction influence. It is noted that Suite L_O_1 incorporated offshore extraction.

Suite L_O_2 was selected as the most likely representative Suite for Yarram WSPA based on its coverage and the location of Suite bores to extraction points. However, further work is needed to improve the model fit.

23.6.2 Limitations

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

- Groundwater use for Offshore extractions has not been incorporated into the spatial distribution modelling methodology
- Groundwater use for Offshore extractions is only available until 2012, after this time the same extraction rate has been adopted until 2020/2021 as per previous modelling in the area
- The licenced bore dataset provided by DEECA has 10% of bores assigned to Yarram WSPA with no depth data. These were 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 primary aquifer that extraction occurs from for this GMU.
- 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.
- For Suite L_O_2, there is an underestimate of annual recovered levels at some flow rates which may be associated by offshore extraction influence
- For Suite L_O_2, the model did not match the pre-development level well and thus there is an offset in the results
- The results for Suite L_O_1 have the modelled levels using Yarram WSPA and offshore extractions, but the volumes stated are Yarram WSPA only in the use-drawdown graphs. The logic for deriving Yarram WSPA extraction from the combined source is that when extraction of Yarram WSPA and Offshore are combined annually, on average, Yarram WSPA extraction makes up 12% of this thus 12% of the combined volume has been used in the final relationship.

23.6.3 Recommendations

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

- To address the above bore depth data limitation, it is recommended that DEECA obtains the relevant depth and aquifer monitored data for licenced bores within this GMU
- DEECA to reconsider applicability of GHD’s method to Yarram WSPA, given the low and variable model results and correlation developed for use to drawdown. If the above mentioned limitations can be addressed and the method reapplied, an evaluation of method suitability could be undertaken. If the reapplied method continues to show poor correlation, other methods (e.g., numerical groundwater modelling) could be explored for application.

24. Condah WSPA

24.1 Conceptualisation

The hydrogeological conceptualisation elements relevant to this study are summarised in Table 146 and a map of the GMU is presented in Figure 401. It is noted that a significant volume of information was collated to provide hydrogeological conceptual understanding of the GMU. The information that is directly relevant to the modelling are in bold or colour coded within Table 146.

Table 146 Condah WSPA – Tabulated conceptualisation

GMU summary
Condah WSPA is situated in western Victoria north of Portland and Heywood and covers an area of 975 km^2. The northern and western boundaries coincide with Clifton Formation outcrops along the Crawford River and an associated elevation high. The eastern boundary occurs near to the Port Fairy-Hamilton and Branxholme-Brisbane Hill Roads and Miakite Creek. The southern boundary correlates with a point where aquifer depth is greater than 200 m, roughly corresponding with the nearby Princess Highway, Carters, Loftus, Anya Creek and Mt Eccles Roads. Condah WSPA pertains to all formations between 70 m to 200 m below ground surface, and was intended to manage groundwater resources of the Clifton Formation (Lower-Mid Tertiary Aquifer, LMTA) which are predominantly developed for irrigation of pasture for the dairy industry. The Clifton Formation is largely confined by the overlying Gellibrand Marl throughout much of the GMU. The intake zone for the aquifer is interpreted around the Crawford River, however, recharge processes are poorly understood. Condah WSPA underlies the South West Limestone GMA and is underlain by Portland GMA (Condah WSPA Local Management Plan 2017). The PCV is 7,475 ML/year. It is noted that Condah Swamp located within the geographical boundary of Condah WSPA, incorporates the cultural site Budj Bim, which is a UNESCO World Heritage Site (GHD 2020).

Hydrostratigraphy summary

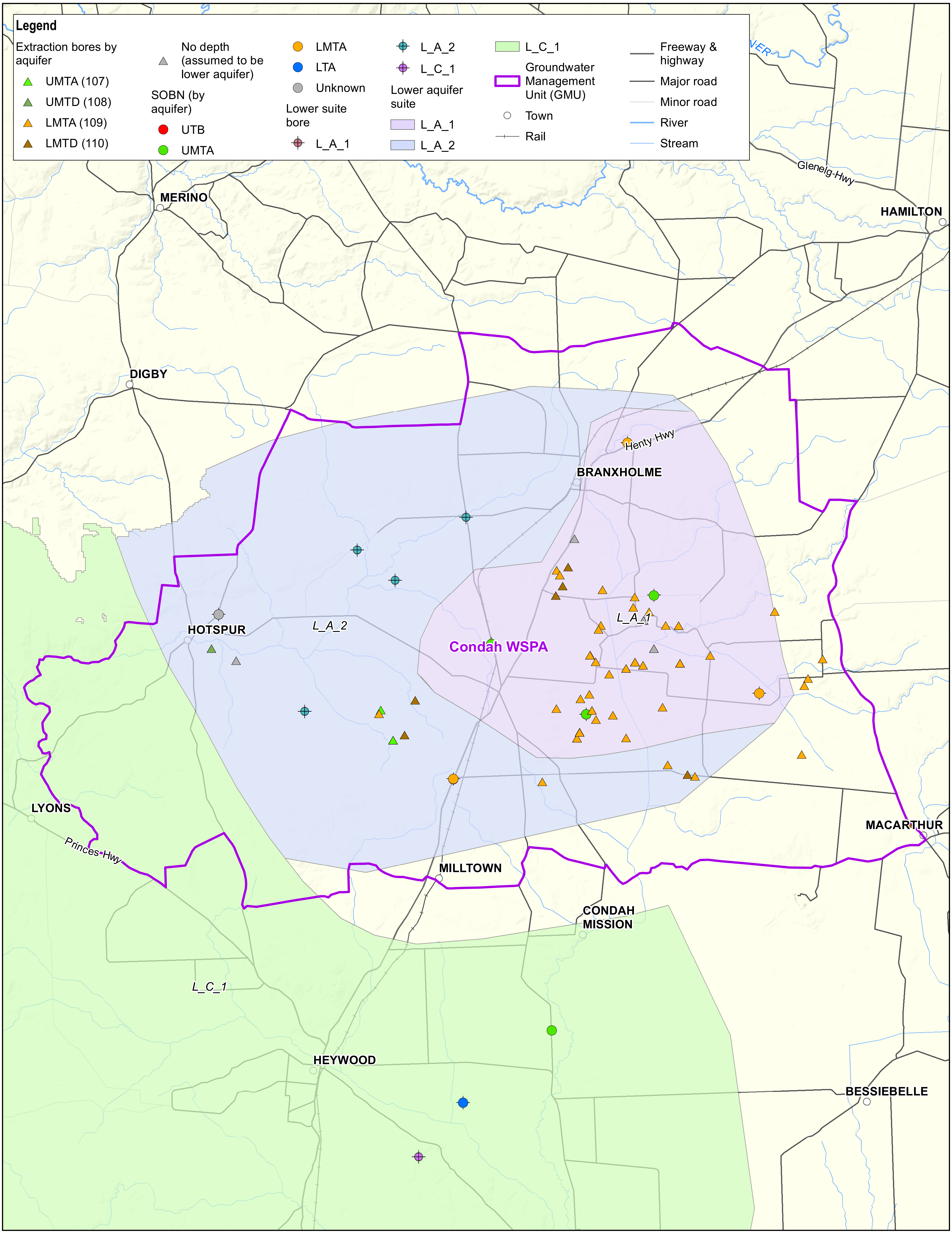
Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Use volumes ML (2019/20)	Entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Newer Volcanics (UTB)	-	-	0	NA	0	0	Low
	Hanson Plain Sand (UTAM)	U_A_2 (76%), U_D_8 (7%)	82%	0	NA	0	0	Low
Middle	Port Campbell Limestone (UMTA)	M_B_1 (16%)	16%	0	Dairy, stock, irrigation	191	466	Low
	Gellibrand Marl (UMTD)	-	-	0	NA	0	0	Low
Lower	Clifton Formation (LMTA)	L_A_1 (24%), L_A_2 (42%), L_C_1 (11%)	77%	5	Urban, irrigation, dairy, stock, domestic	2,135 (119)	7,004 (283)	Medium
	Narrawaturk Marl (LMTD)	-	-	0	NA	0	0	Low
	Dilwyn Formation (LTA)	-	-	0	NA	0	0	Low
Basement	-	-	-	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. In some instances, bore depth is not available and has been reallocated where possible; the reassigned volumes are indicated within the brackets.

119 ML did not have an assignment due to no depth data being available; this has been re-allocated to the LMTA.

Characteristic and importance	Description	Degree of understanding
Intended aquifer (LMTA highlighted blue above)		
Aquifer thickness within GMU (range, based on VAF)	Max: 59 m, Average: 40 m	High
Aquifer extent	Regional, extensive	High
Likelihood of inter-aquifer flow	Potentially inter aquifer flow on margins of basin (outside of the WSPA boundary) Inter aquifer flow between Clifton Formation and Port Campbell Limestone also possible	Low
Likelihood of groundwater – surface water interaction	Possibly - vertical leakage upwards to the Condah Swamp.	Low GHD (2020) Nolan (2002)
Representative Suite	**L_A_1**	**High. 80% of GMU extraction occurs within this Suite, which relates to the most relevant GMU aquifer**
Current hydrological condition of intended aquifer		
Representative Suite trend	Decreasing	High
Groundwater quality (average salinity based on WMIS and CDM Smith spatial segment(s) with highest coverage)	1,418 mg/L (WMIS) 1,200 – 5,400 mg/L (CDM Smith 2022)	High Based on WMIS Based on CDM Smith (2022)
Groundwater yield	Up to 50 L/sec	High based on Condah PAV by SKM (1998)
Groundwater levels of intended aquifer		
Temporal groundwater level data range	**1974 to 2021**	**Based on Suite data**
Spatial clustering of licensed bores in relation to Suites	**Yes, L_A_1**	**Based on DEECA density mapping and licenced bore data.**
Groundwater use within GMU		
Licensed groundwater use	**2,782 ML**	**High (Based on average historical VWA data over 16 years)**
Minimum historic groundwater use	1,115 ML	High (Based on historical VWA data, year 2010/11)
Maximum historic groundwater use	3,912 ML	**High (Based on historical VWA data, year 2006/07)**
Entitlement (Groundwater allocation)	**7,470 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 stock or domestic use	Moderate
Groundwater use profile	Influenced by seasonality	Moderate
External Influence	**None identified**	
Groundwater values and risks to intended aquifer		
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 1 2 3 4

Kilometers

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

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DEECA
Sustainable yield review - confined aquifers

Condah WSPA
Site location and key features

Project No. **12564066**
Revision No. **0**
Date **15/01/2024**

Figure 401

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Print date: 15 Jan 2024 - 13:09

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

24.2 Technical analysis

24.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the confined Suites for Condah WSPA as shown in Figure 402. Generally, the Suite hydrographs show the seasonal fluctuations and hence recovered water levels.

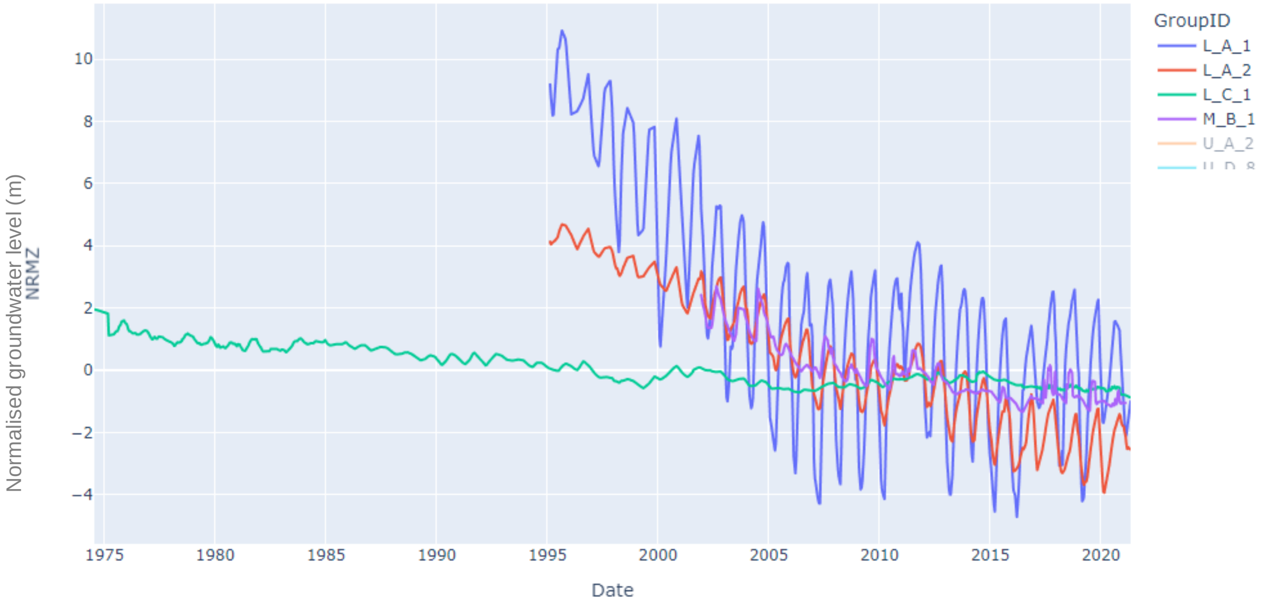


Figure 402 Condah WSPA Suite Hydrographs for all confined aquifers

The representative Suites analysed for this GMU are Suites L_A_1 and L_A_2. The Representative Suites were selected based on the methodology outlined in section 2.6.4 which identified Suite L_A_1 as the most representative followed by L_A_2. The process is summarised as follows:

- The greatest volume of extraction occurs within the Lower Aquifer
- The greatest volume of extraction occurs within Suite L_A_1 (80%)
- The Lower Aquifer pertains to the LMTA which is the intended aquifer for this GMU
- Suite L_A_1 covers 24% of the GMU, while L_A_2 covers 42% and L_C_1 covers 11%
- Suite L_A_1 has three active SOBN bores within the Suite area
- Suite bores for L_A_1 are close to extraction points, there are no extraction points located within Suite L_C_1
- The annual recovered Suite hydrographs for the representative Suites for Condah WSPA, L_A_1 and L_A_2 are shown in Figure 403

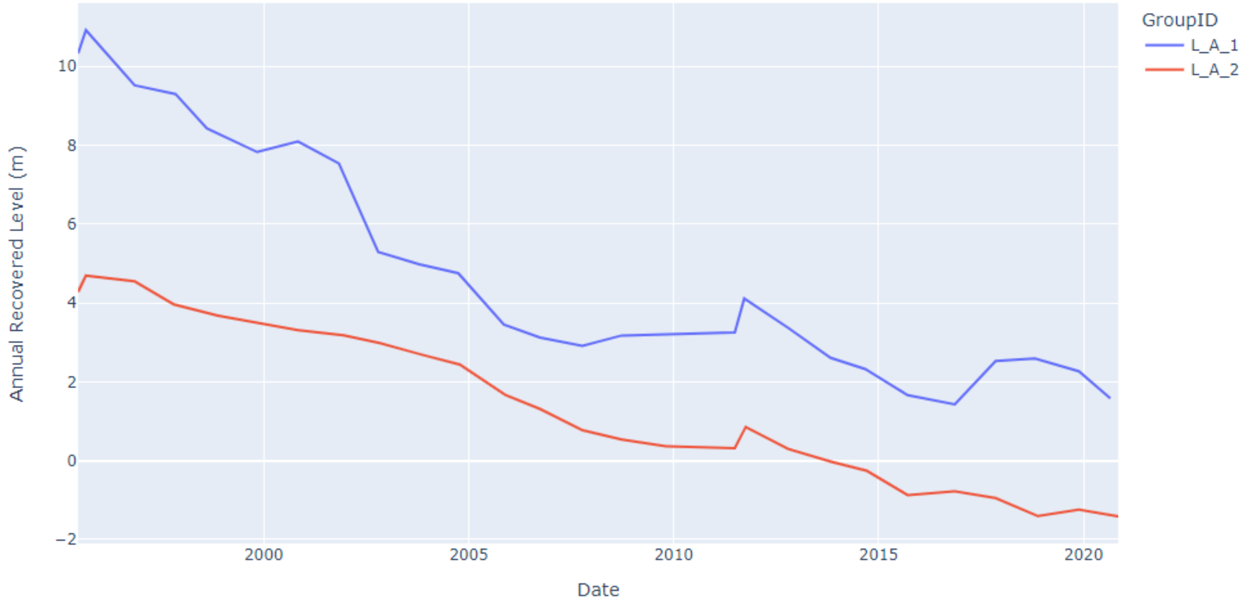


Figure 403 Condah WSPA Annual Recovered Level Suite Hydrographs for representative Suites

24.2.2 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 Condah WSPA for Suite L_A_1 and L_A_2.

The pre-development annual recovered level was taken to be the second level and maximum level of the time series data, this occurred in the year 1995/1996 for Suite L_A_1 and L_A_2 which equated to 10.91 m and 4.69 m respectively (refer further details in section 24.4.3).

24.2.3 Externalities

Through the conceptualisation, no external influence was inferred for Condah WSPA.

24.2.4 Hindcasting

Groundwater use data for Condah WSPA is available from 1989/1990 to 1999/2000 and from 2004/2005 to 2020/2021. The hindcasting methodologies outlined in section 3.3.4.5 were applied to Condah WSPA. A summary of the hindcasting results is shown below.

24.2.4.1 Hindcasting Method 1 (H1)

Applying method H1, eight different correlations were developed as described below.

Figure 404:

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

Figure 405:

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

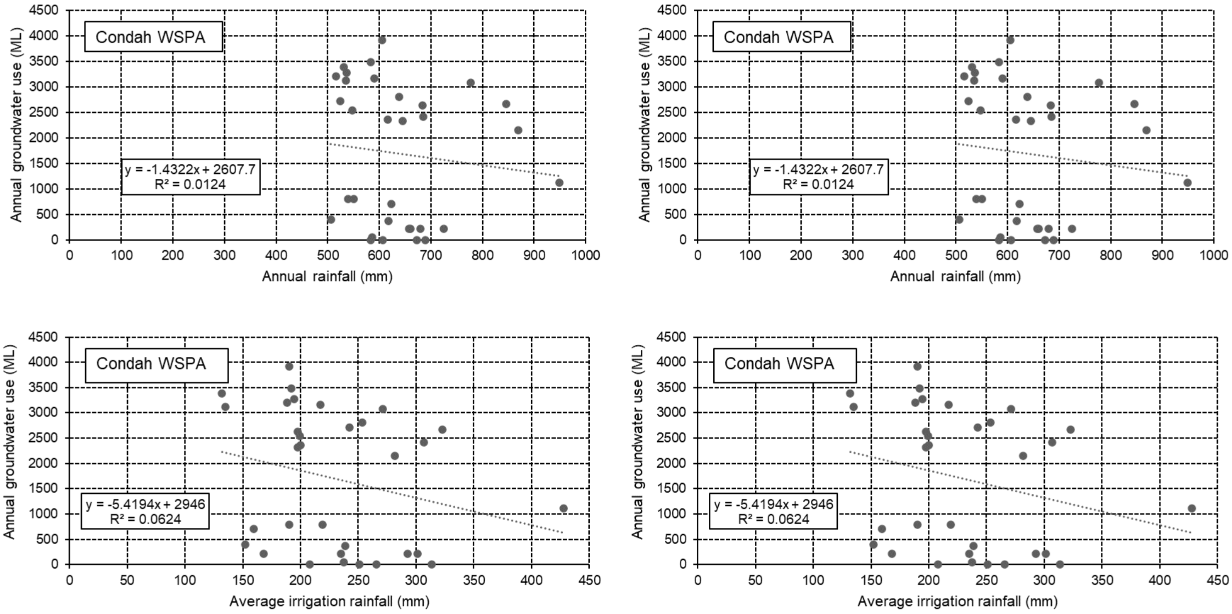


Figure 404 Condah WSPA: Hindcast method 1 correlations (annual extraction)

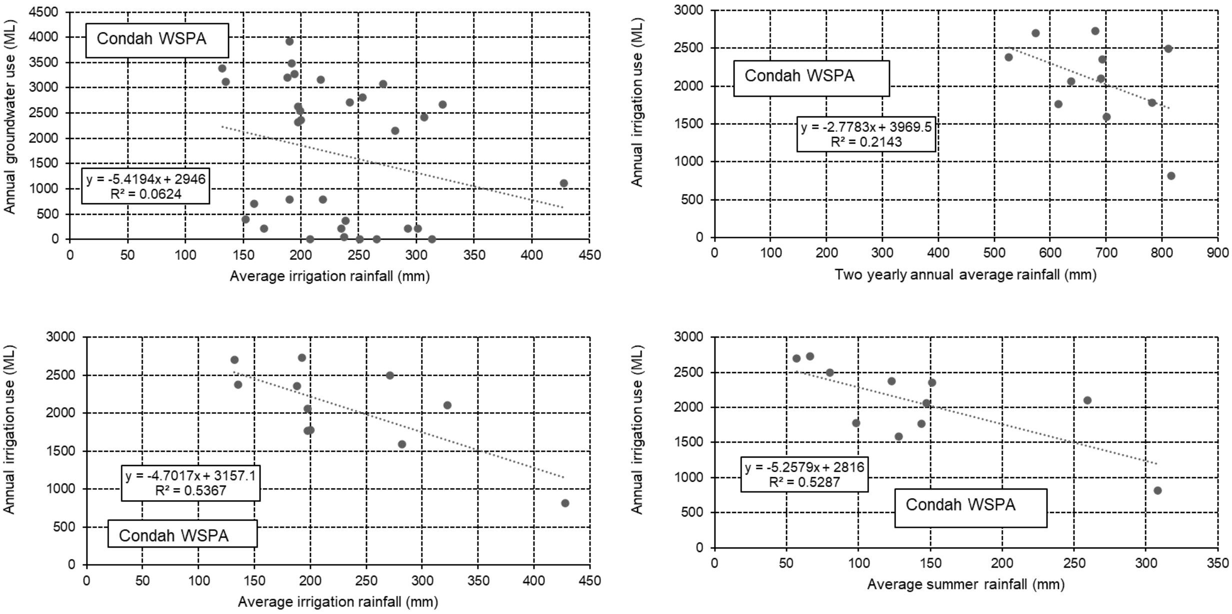


Figure 405 Condah WSPA: Hindcast method 1 correlations (annual irrigation extraction)

As shown in Figure 404 and Figure 405, when only groundwater extraction over the irrigation period is considered, the goodness of fit indicated by the R^2 increases. The best goodness-of-fit was shown to be the correlation of the annual irrigation rainfall with annual irrigation groundwater extraction; this was the correlation modelled for this method.

24.2.4.2 Hindcasting Method 2 (H2)

Four correlations were developed using method H2 for as described below and shown in Figure 406:

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

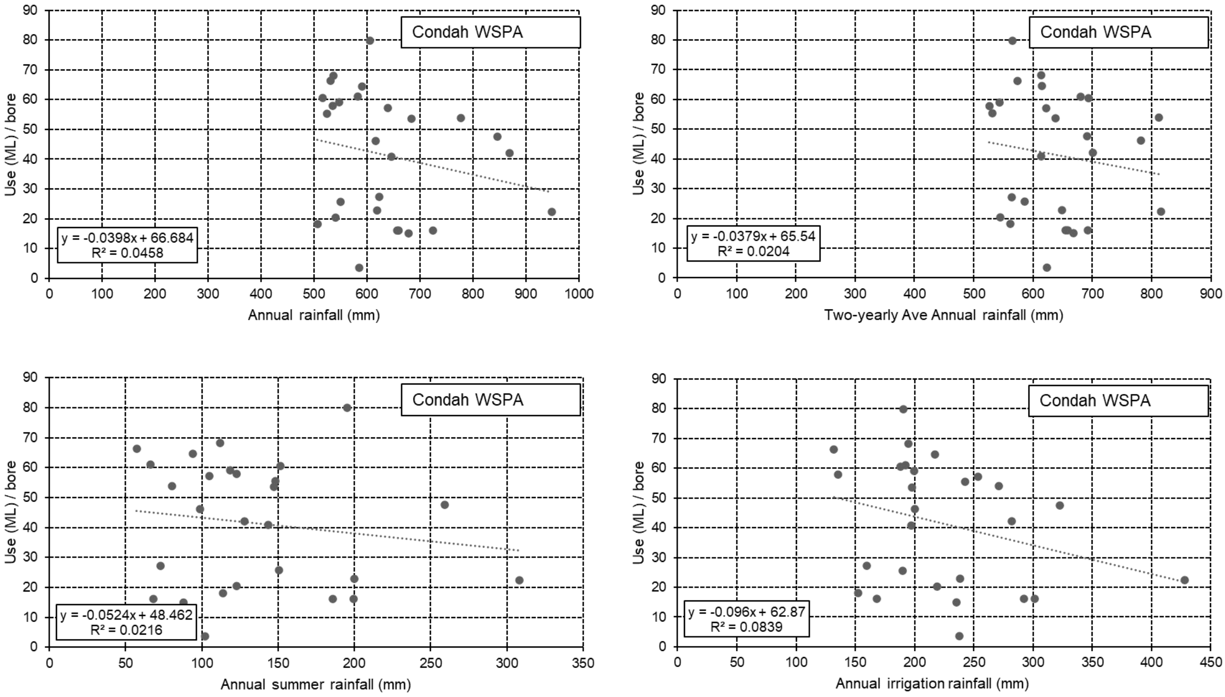


Figure 406 *Condah WSPA: Hindcast method 2 correlations (Condah WSPA only)*

As shown in Figure 406 and similar to method H1, the goodness-of-fit increased slightly when annual irrigation rainfall was adopted. It is noted that the goodness-of-fit is quite poor for Condah WSPA using this method. The Condah WSPA only extraction per bore (with annual irrigation rainfall) was modelled. For hindcast method H2.

24.2.4.3 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 407:

- 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

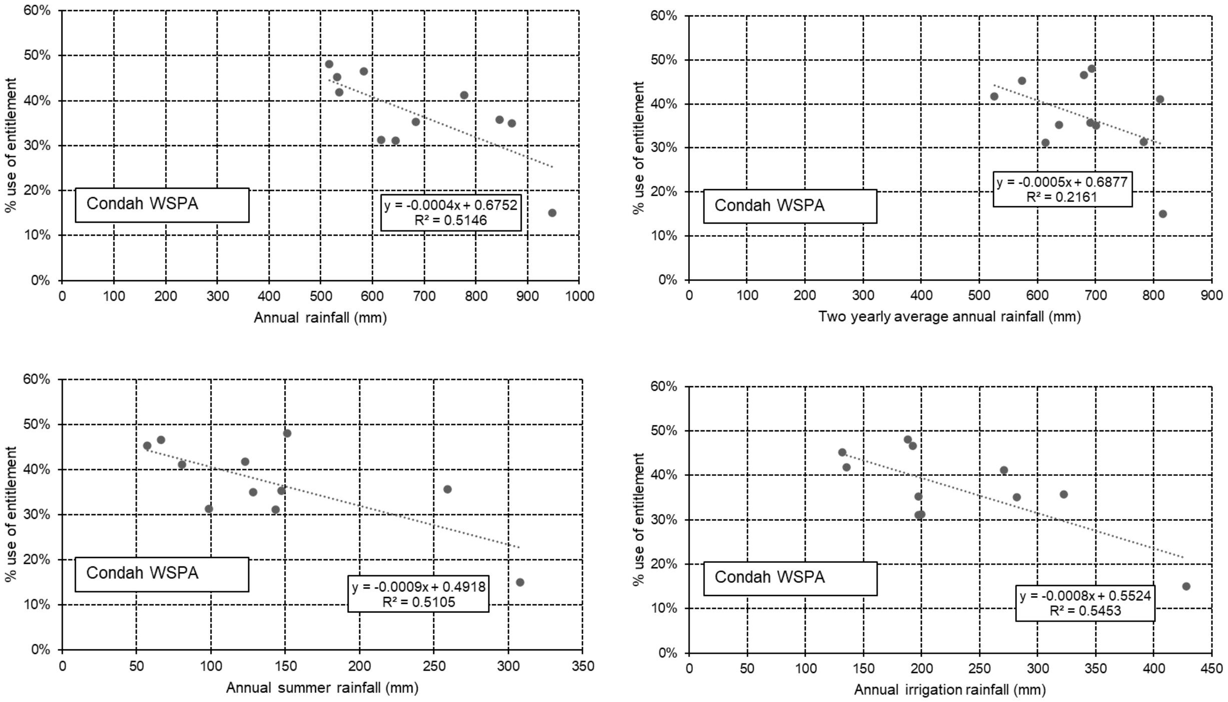


Figure 407 *Condah WSPA: Hindcast method 3 correlations*

As shown in Figure 407 and similar to method H1 and H2, the best goodness-of-fit was shown through the correlation of the annual irrigation rainfall, which is the correlation that was modelled for hindcast method 3. It is noted that there is only minor variation in the correlations between using irrigation annual rainfall, annual rainfall and annual summer rainfall.

24.2.4.4 Comparison

A comparison of the three input datasets is shown in Figure 408 for the hindcasting based on Condah WSPA groundwater use. Figure 408 shows a comparison of the three hindcasting methods against the recorded use only, over the recorded use date.

As shown in Figure 408, 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, resulting 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 Condah WSPA. It is noted that hindcasting was only needed to infill groundwater use data between years 2000/01 and 2003/04 for Condah WSPA.

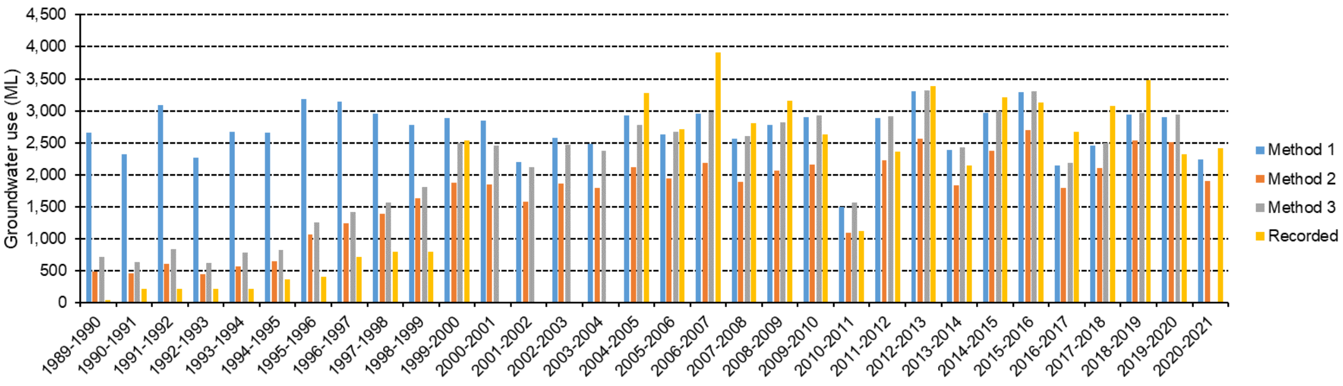


Figure 408 *Condah WSPA: Comparison of hindcasting over recorded use period – Condah WSPA only extraction*

24.3 Modelling

24.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 147 summarises the combinations of model inputs run for Condah WSPA. Model runs highlighted blue were run with annual extraction and those highlighted grey were run using two yearly average annual extraction. It is noted that none of the spatial distribution methods could be run for Condah WSPA as no Suite bores were identified for Condah WSPA.

Table 147 Condah 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 (L_A_1 and L_A_2)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Condah WSPA only	✓																		
Two yearly average annual extraction – Condah WSPA only		✓																	
Annual extraction – Condah WSPA and Externalities			✓																
Two yearly average annual extraction – Condah WSPA and Externalities				✓															
H1 annual extraction – Condah WSPA only					✓														
H1 annual extraction – Condah WSPA and Externalities						✓													
H2 annual extraction – Condah WSPA only							✓												
H2 annual extraction – Condah WSPA and Externalities								✓											
H3 annual extraction – Condah WSPA only									✓										
H1 two yearly average annual extraction – Condah WSPA only										✓									
H1 two yearly average annual extraction – Condah WSPA and Externalities											✓								
H2 two yearly average annual extraction – Condah WSPA only												✓							
H2 two yearly average annual extraction – Condah WSPA and Externalities													✓						
S1 annual extraction – Condah WSPA only														✓					
S2 annual extraction – Condah WSPA only															✓				
S3 annual extraction – Condah 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
S1 annual extraction and H1 annual extraction – Condah WSPA only			■	■		■		■			■		■	■	■	■	✓	■	■
S2 annual extraction and H2 annual extraction – Condah WSPA only			■	■		■		■			■		■	■	■	■	■	✓	■
S3 annual extraction and H3 annual extraction – Condah WSPA only			■	■		■		■			■		■	■	■	■	■	■	✓

24.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 147 is presented in Table 148 for the selection of potential representative Suites for Condah WSPA. The column heading for L_A_1 is highlighted blue to indicate that this Suite was selected as the most likely representative Suite based on the process outlined in section 24.2.1. The statistics summarised include four key statistical measures pf the average 95 PPU thickness (95PPU TH), percentage of observed levels within 95 PPU (%Obs in 95 PPU), R^2 and root mean square error (RMSE) as well as the number of annual recovered level observation points (No obs data points) and the range of observed annual recovered levels.

Suite L_A_1

A review of the results and statistical summary for Suite L_A_1 shows that model runs 5, 9 and 10 (highlighted green) had the best results (by considering all four of the statistical measures) of the 19 different model input combinations. The graphical model output for these runs is shown in Figure 409, Figure 410 and Figure 411 respectively. It is noted that the difference between the three models is not significant and visually, the results look very similar. As the model already considers the previous year's extraction, model run 10 was not progressed to the next stage. Reviewing the hindcasting application in section 24.2.4, hindcast method 9 produced a closer estimate to the measured data than hindcast method 5. Given this, model run 9 was selected as the preferred model to undertake the predictive modelling.

Suite L_A_2

A review of the results and statistical summary for Suite L_A_2 shows that model run 7 (highlighted green) had the best results (when considering the four statistical measures) of the 19 different model input combinations. The graphical model output for model run 7 is shown in Figure 412 and was adopted as the preferred model to undertake the predictive modelling for this Suite.

A comparison was undertaken against model run 7 which uses the annual groundwater extraction hindcasted with method H2 and model run 9 which uses the annual groundwater extraction with hindcast method H3. The simulated levels and 95% prediction band limits were plotted for model run 7 along with the simulated levels for model run 9 as shown in Figure 413. This shows that there is very little difference in the estimated simulated levels (with model run 9 falling well within the 95% prediction interval) and that whichever model is used is not likely to have a significant impact on the results.

Modelling was progressed on the basis of adopting model run 9 for Suite L_A_1 and model run 7 for L_A_2.

Table 148 Condah WSPA: summary of model outputs

Suite	Statistic	Model run						
		1	2	5	7	9	10	12
L_A_1	95PPU TH	2.87	2.77	3.44	3.87	3.43	3.37	4.05
	%Obs in 95 PPU	93.75	93.75	96.3	100	96.3	96.3	96.3
	R^2	33.7	33.4	94.5	92.3	94.4	94.5	90.6
	RMSE	0.59	0.59	0.68	0.81	0.69	0.68	0.89
	No obs data points	16	16	27	27	27	27	27
	Range of observed levels	2.7	2.7	9.5	9.5	9.5	9.5	9.5
L_A_2	95PPU TH	2.63	4.65	3.17	2.5	3.04	2.61	2.4
	%Obs in 95 PPU	93.75	93.75	96.3	100	96.3	96.3	96.3
	R^2	87.7	90.4	97.2	97.9	97.3	97.2	97.6
	RMSE	0.33	0.29	0.33	0.28	0.32	0.33	0.3
	No obs data points	16	16	27	27	27	27	27
	Range of observed levels	3.1	3.1	6.1	6.1	6.1	6.1	6.1

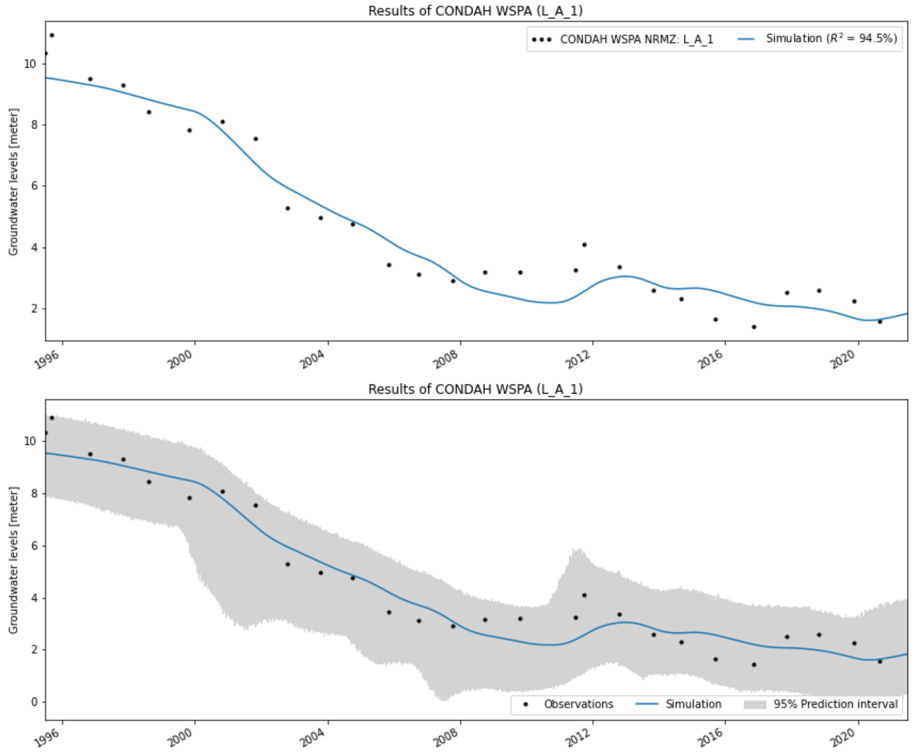


Figure 409 *Condah WSPA Suite L_A_1: model run 5 (Condah WSPA annual extraction with hindcast method 1) output hydrographs*

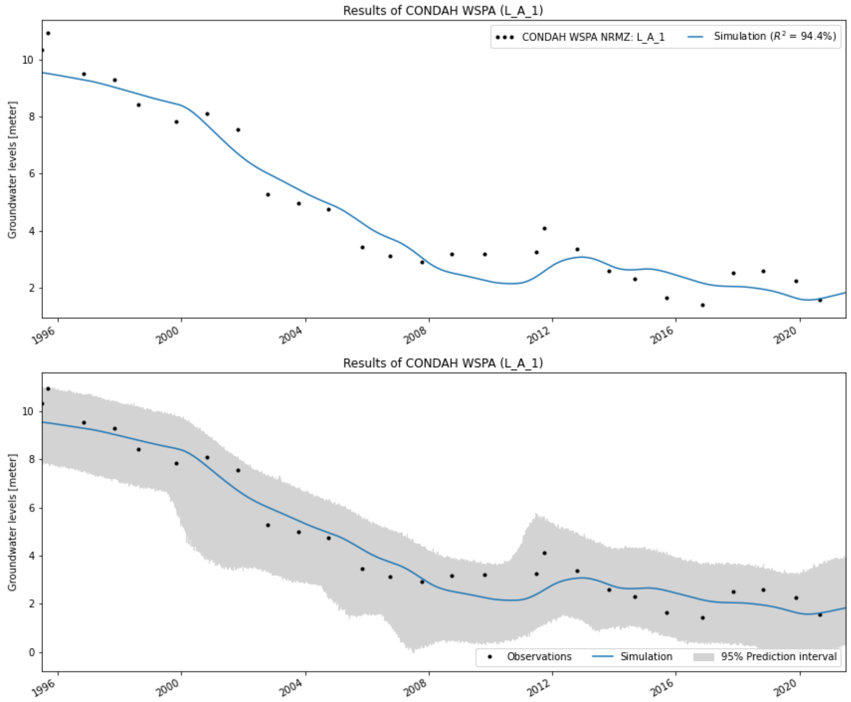


Figure 410 *Condah WSPA Suite L_A_1: model run 9 (Condah WSPA annual extraction with hindcast method 3) output hydrographs*

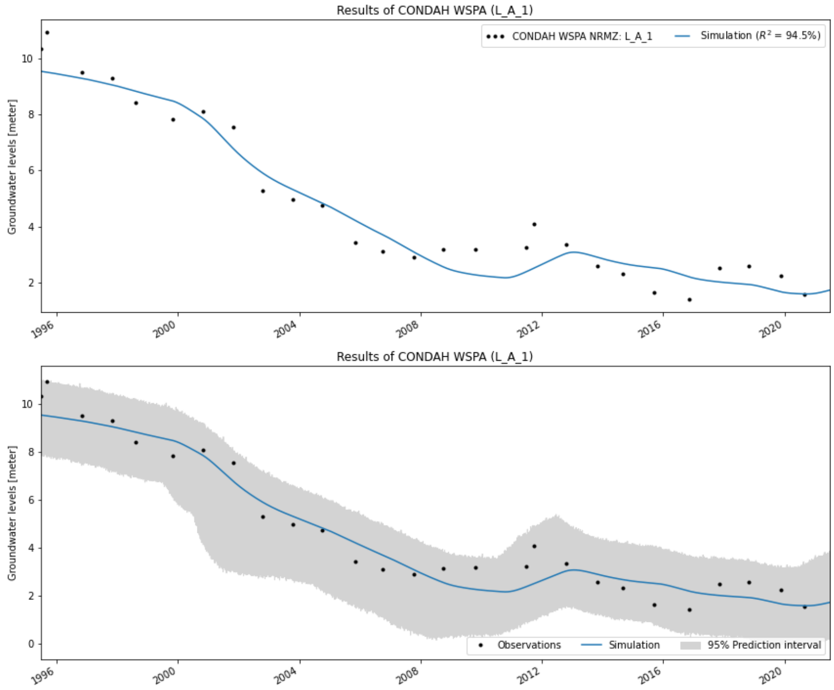


Figure 411 *Condah WSPA Suite L_A_1: model run 10 (Condah WSPA two yearly average annual extraction with hindcast method 1) output hydrographs*

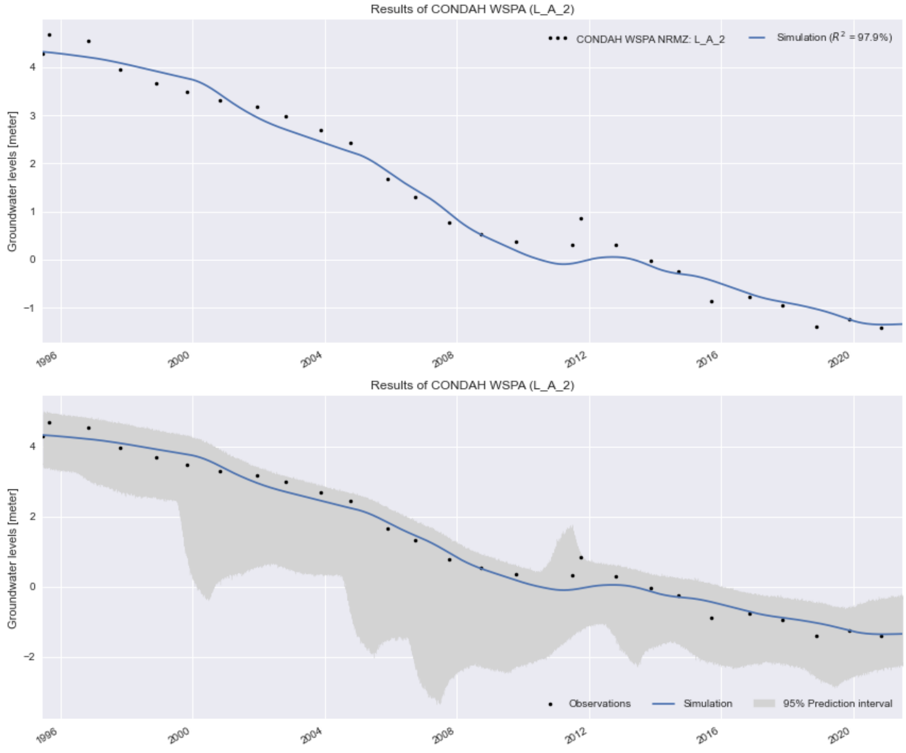


Figure 412 *Condah WSPA Suite L_A_2: model run 7 (Condah WSPA annual extraction hindcast method 2) output hydrographs*

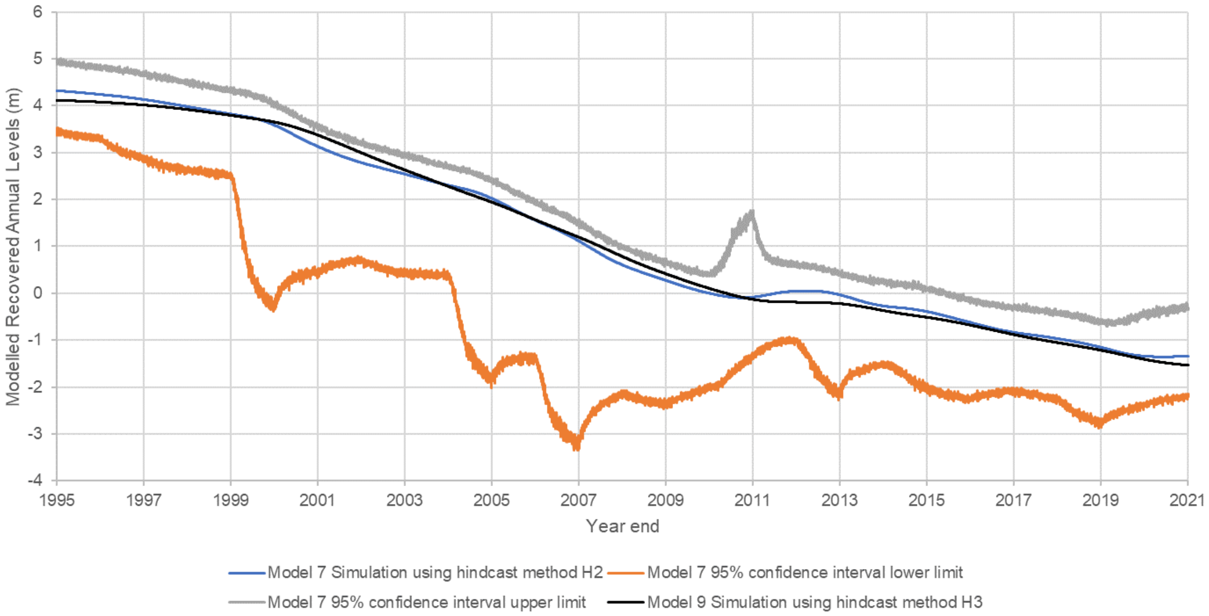


Figure 413 Condah WSPA Suite L_A_2: comparison of model run 7 and model run 9 simulations

24.4 Predictive modelling

24.4.1 Model inputs

The preferred model to run the predictive modelling for Condah WSPA was model run 7 for Suite L_A_2 and model run 9 for Suite L_A_1, thus the key inputs for the model were the annual recovered levels and the annual extraction hindcasted (either method H2 or H3) in Condah WSPA. 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 149.

Table 149 Condah 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 2006/07)
Value (ML/year)	7,475	7,470	2,413	2,782	3,912

24.4.2 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 414 for scenario 4. As shown in Figure 414, 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 415. It is noted that some realisations fall outside of the upper 95% prediction interval band.

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.

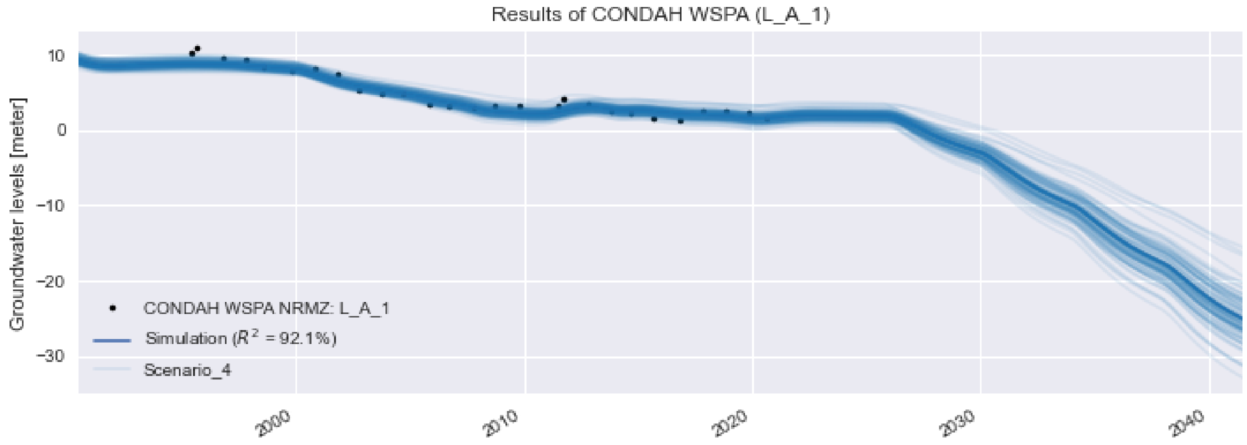


Figure 414 Condah WSPA: Suite L_A_1 MCMC analysis for Forecast Scenario 4

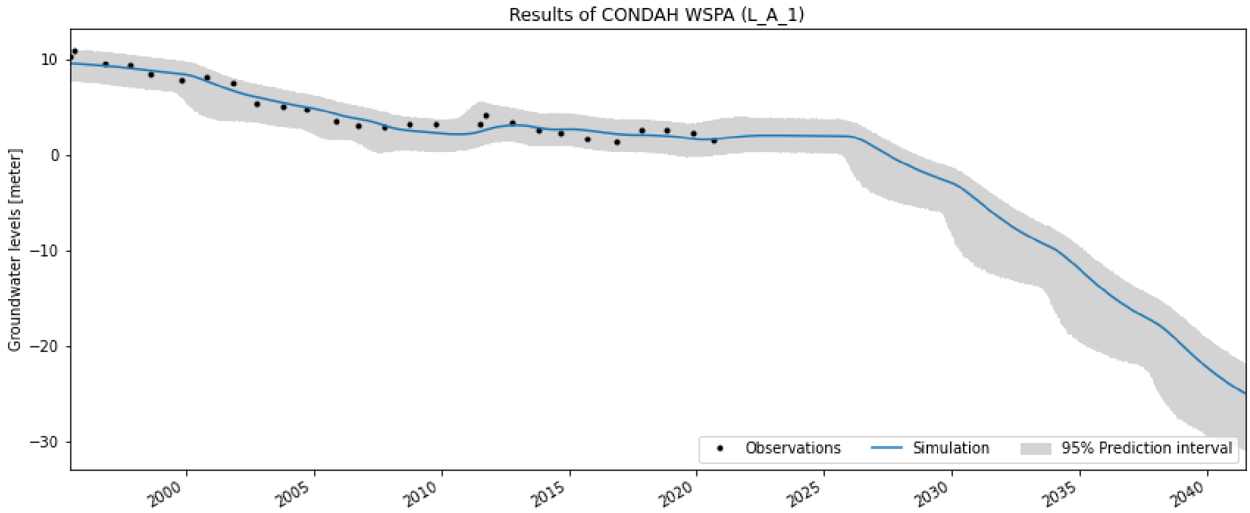


Figure 415 Condah WSPA: Suite L_A_1 Forecast Scenario 4 with 95% prediction bands

24.4.3 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 Condah WSPA, 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 24.2.2, 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 416 for the Suite L_A_1 hydrograph of annual recovered levels. In Figure 416:

- Actual annual groundwater use is represented by the blue column graph between 1989/1990 to 1999/2000 and 2004/2005 to 2020/2021
- Hindcasted groundwater use is represented by the orange columns between 2000/2001 and 2003/2004
- Forecasted use is represented by the grey columns after 2021/2022
- The annual recovered water level behaviour based on recorded data, this is represented by the red line graph, whereby the earliest data is taken to best reflect the pre-development levels
- The pre-development annual recovered level is taken to be the second reading which equates to 10.91 m

- The modelled forecasted annual recovered levels are represented by the purple line in Figure 416
- The calibration annual recovered levels are represented by the black line in Figure 416

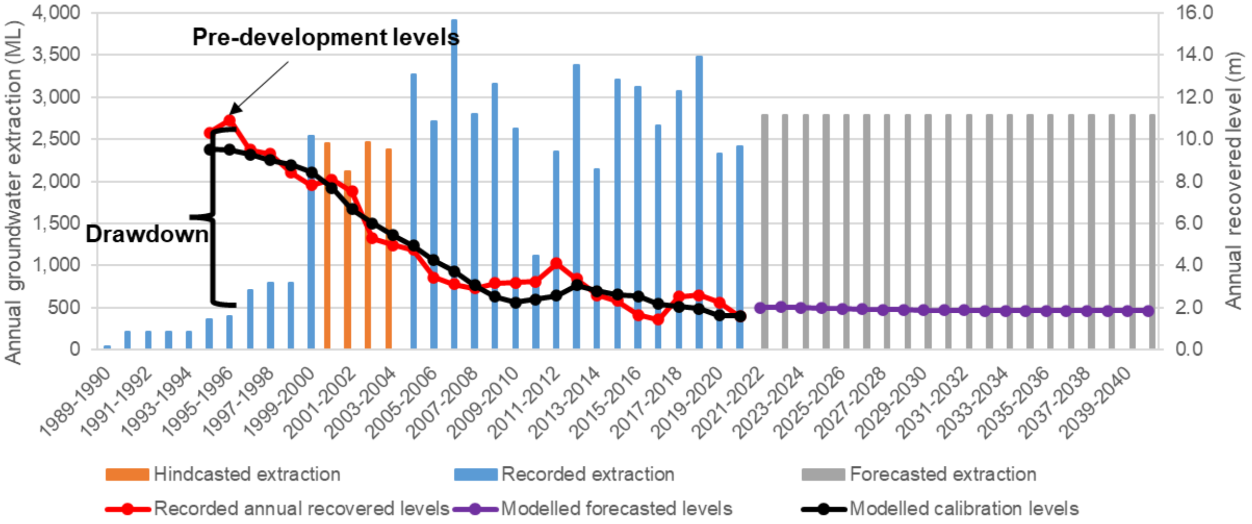


Figure 416 Estimating pre-pumping water levels (example from Suite L_A_1)

For Suite L_A_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 417) and a graph of the scenarios for specific time periods (Figure 418) to develop the volume to drawdown relationship. For each scenario, a linear regression was applied and the coefficient of determination (R^2) was calculated. A comparison of each of these graphs shows variations in the coefficient of determination and slope of the line. The same process was applied for Suite L_A_2 and again, there was variations 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 (1995 to 2041) is shown in Figure 417 for Suite L_A_1 and Figure 419 for L_A_2. Note the abscissa range of the chart has been clipped and does not show forecast drawdowns for the higher use scenarios (more improbable use of greater than 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)
- Average use is around 3,000 ML. Figure 417 indicates at this usage the model forecast drawdown is above the predicted line of best fit for Suite L_A_1 and L_A_2.
- For the same annual use, different drawdowns can be obtained as PASTAS predicts a water level for each year. For example, Figure 416 shows a scenario where groundwater use remains constant at around 3,000 ML/year over the next 20 years.
- The correlation for groundwater use and drawdown for Suite L_A_1 is excellent and is good for Suite L_A_2 as shown in Figure 417 and Figure 419 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.

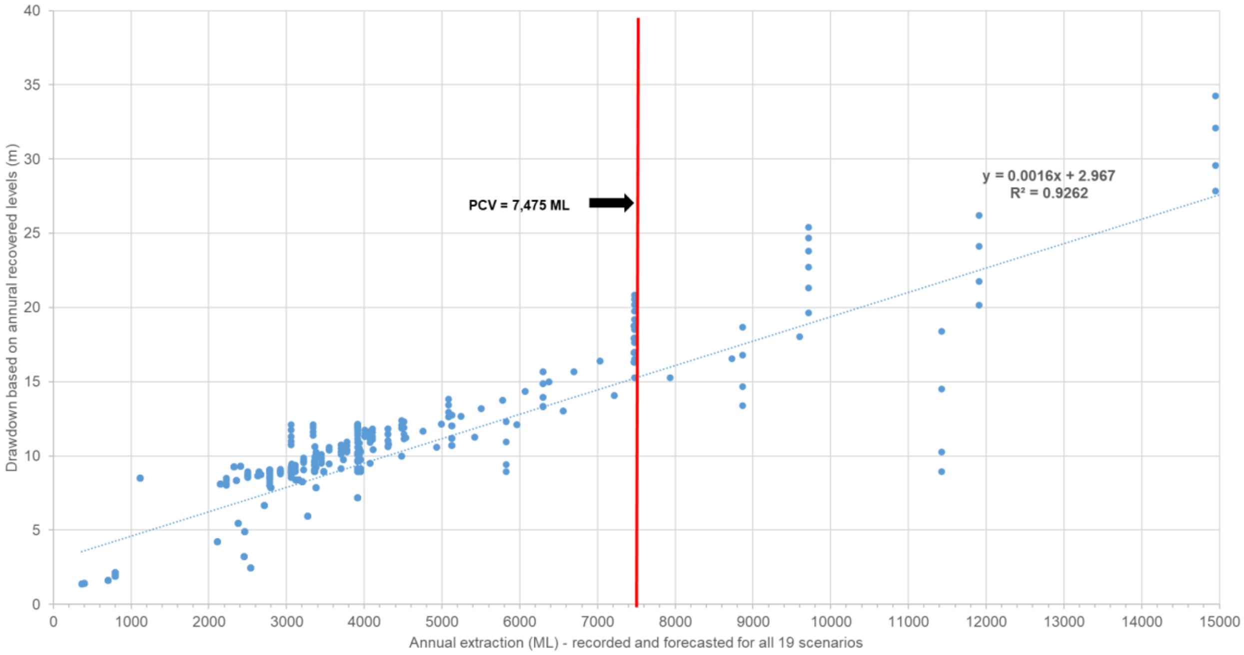


Figure 417 *Condah WSPA Suite L_A_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <15,000 ML) for all data between 1995 to 2041 and all forecasted scenarios*

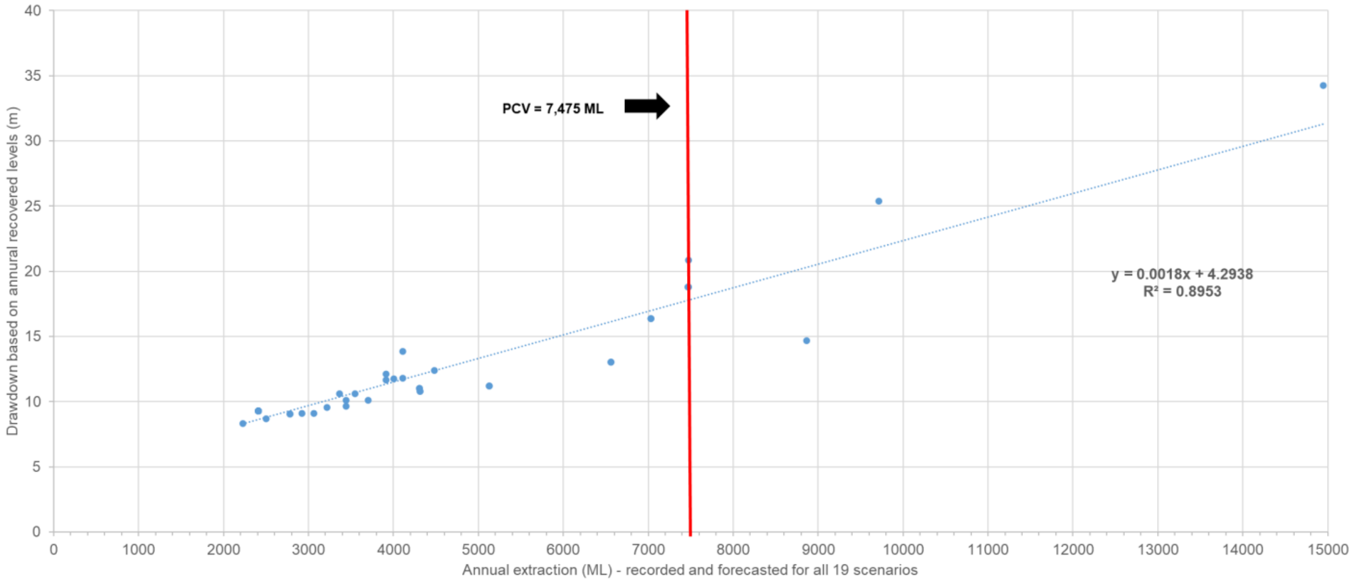


Figure 418 *Condah WSPA Suite L_A_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <15,000 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

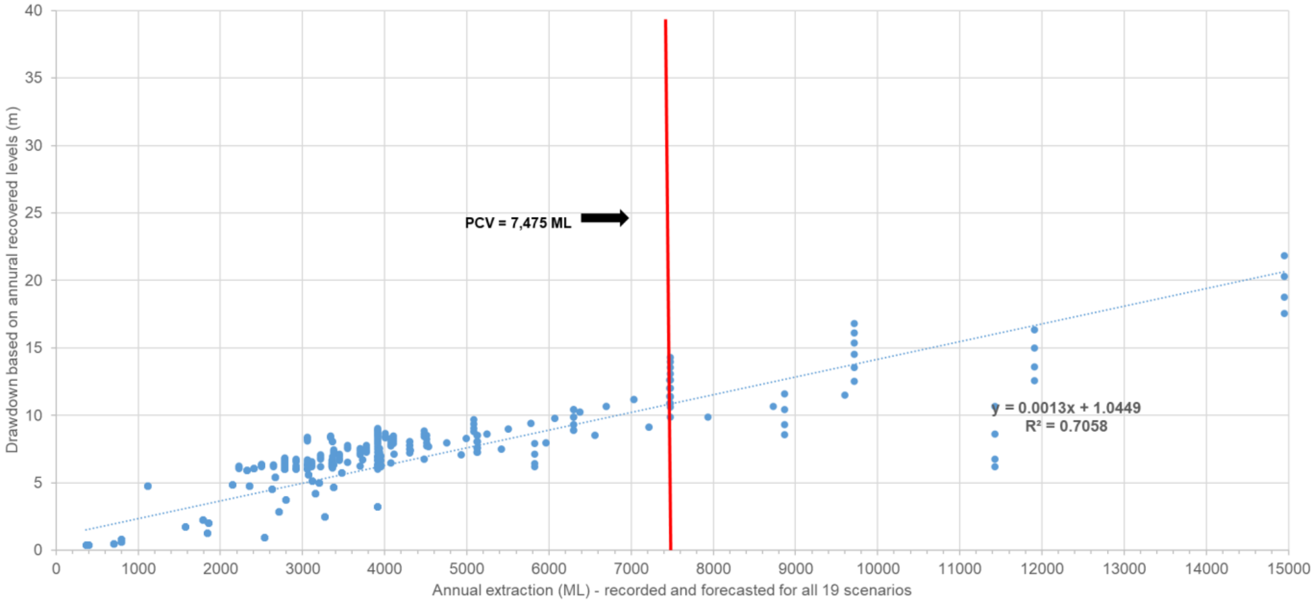


Figure 419 Condah WSPA Suite L_A_2: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <15,000 ML) for all data between 1995 to 2041 and all forecasted scenarios

24.5 Sustainability metrics

24.5.1 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 metrics that define groundwater resource sustainability.

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 150 for Condah WSPA Suite L_A_1 and Table 151 for Condah WSPA Suite L_A_2 (noting Condah WSPA has a current PCV of 7,475 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 150 and Figure 420 for Suite L_A_1, and Table 151 and Figure 421 for Suite L_A_2.

In comparing the two Condah WSPA Suites L_A_1 and L_A_2, Suite L_A_1 shows greater variability and uncertainty when comparing the drawdown to use relationships based on the 95% prediction interval bands. A comparison of volumes at drawdown intervals provided by DEECA is shown in Table 152 for Suite L_A_1 and L_A_2. Based on this, a 5 m of drawdown is predicted to occur at a groundwater extraction volume of 1,300 ML (which could range from 800 ML to 2,500 ML) for Suite L_A_1 and 3,000 ML (which could range from 2,000 ML to 3,600 ML) for Suite L_A_2. Whereas, a 10 m of drawdown is predicted to occur at a groundwater extraction volume of 4,400 ML (which could range from 3,000 ML to 5,000 ML) for Suite L_A_1 and 6,900 ML (which could range from 4,800 ML to 7,400 ML) for Suite L_A_2.

Table 150 Relationship of Suite drawdown to GMU extraction for Condah WSPA Suite L_A_1

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_A_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
15,000	27 (27.9 - 36.3)
14,000	25.4 (26.1 - 34.1)
13,000	23.8 (24.3 - 31.9)
12,000	22.2 (22.5 - 29.7)
11,000	20.6 (20.7 - 27.5)
10,000	19 (18.9 - 25.3)
9,000	17.4 (17.1 - 23.1)
8,000	15.8 (15.3 - 20.9)
7,000	14.2 (13.5 - 18.7)
6,000	12.6 (11.7 - 16.5)
5,000	11 (9.9 - 14.3)
4,000	9.4 (8.1 - 12.1)
3,000	7.8 (6.3 - 9.9)
2,000	6.2 (4.5 - 7.7)
1,000	4.6 (2.7 - 5.5)
0	3 (0.9 - 3.3)

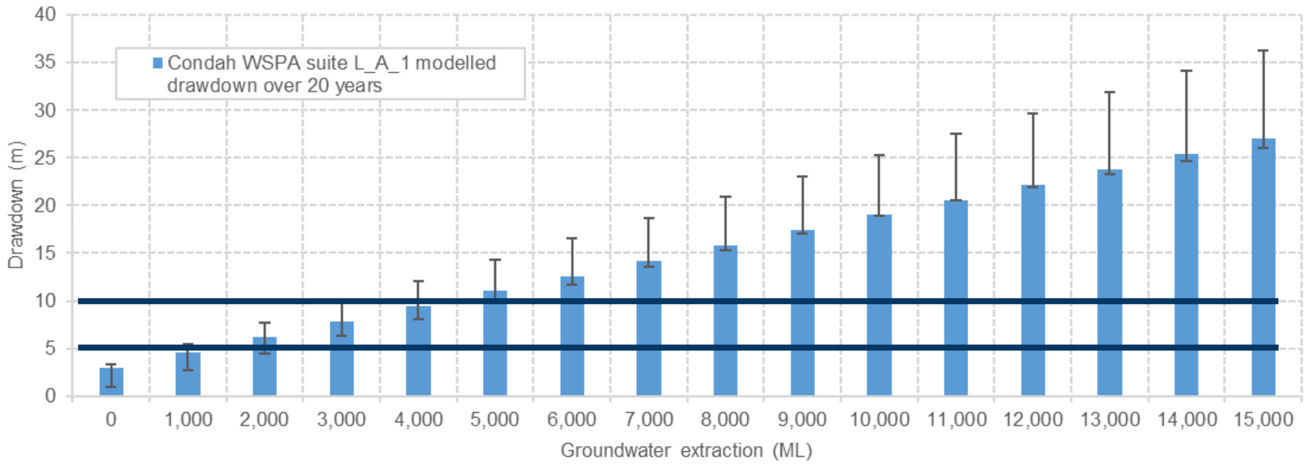


Figure 420 Condah WSPA Suite L_A_1: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 151 Relationship of Suite drawdown to GMU extraction for Condah WSPA Suite L_A_2

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_A_2 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
15,000	20.5 (19.9 - 28.4)
14,000	19.2 (18.6 - 26.6)
13,000	17.9 (17.3 - 24.8)
12,000	16.6 (16 - 23)
11,000	15.3 (14.7 - 21.2)
10,000	14 (13.4 - 19.4)
9,000	12.7 (12.1 - 17.6)
8,000	11.4 (10.8 - 15.8)
7,000	10.1 (9.5 - 14)
6,000	8.8 (8.2 - 12.2)
5,000	7.5 (6.9 - 10.4)
4,000	6.2 (5.6 - 8.6)
3,000	4.9 (4.3 - 6.8)
2,000	3.6 (3 - 5)
1,000	2.3 (1.7 - 3.2)
0	1 (0.4 - 1.4)

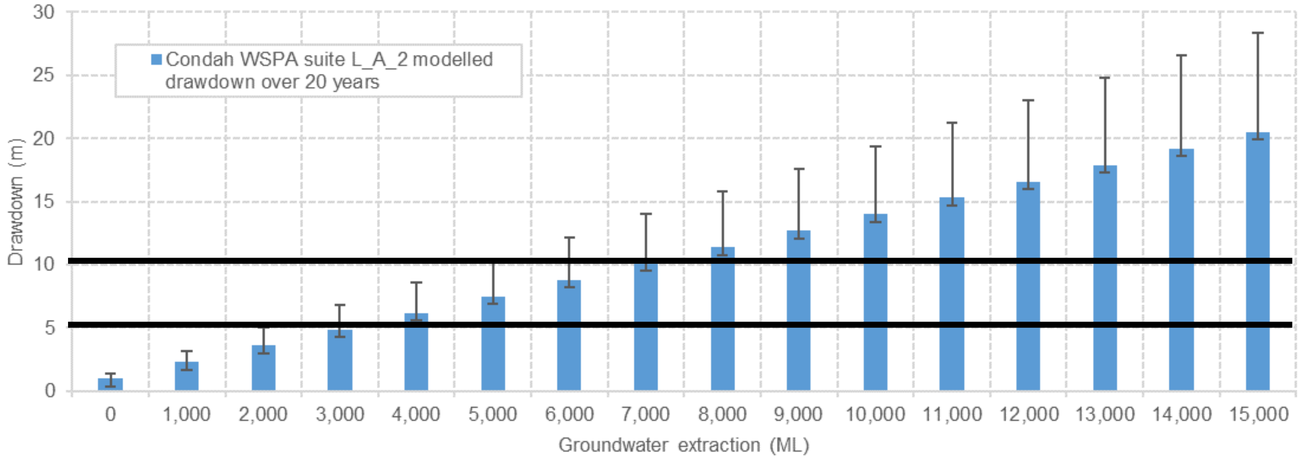
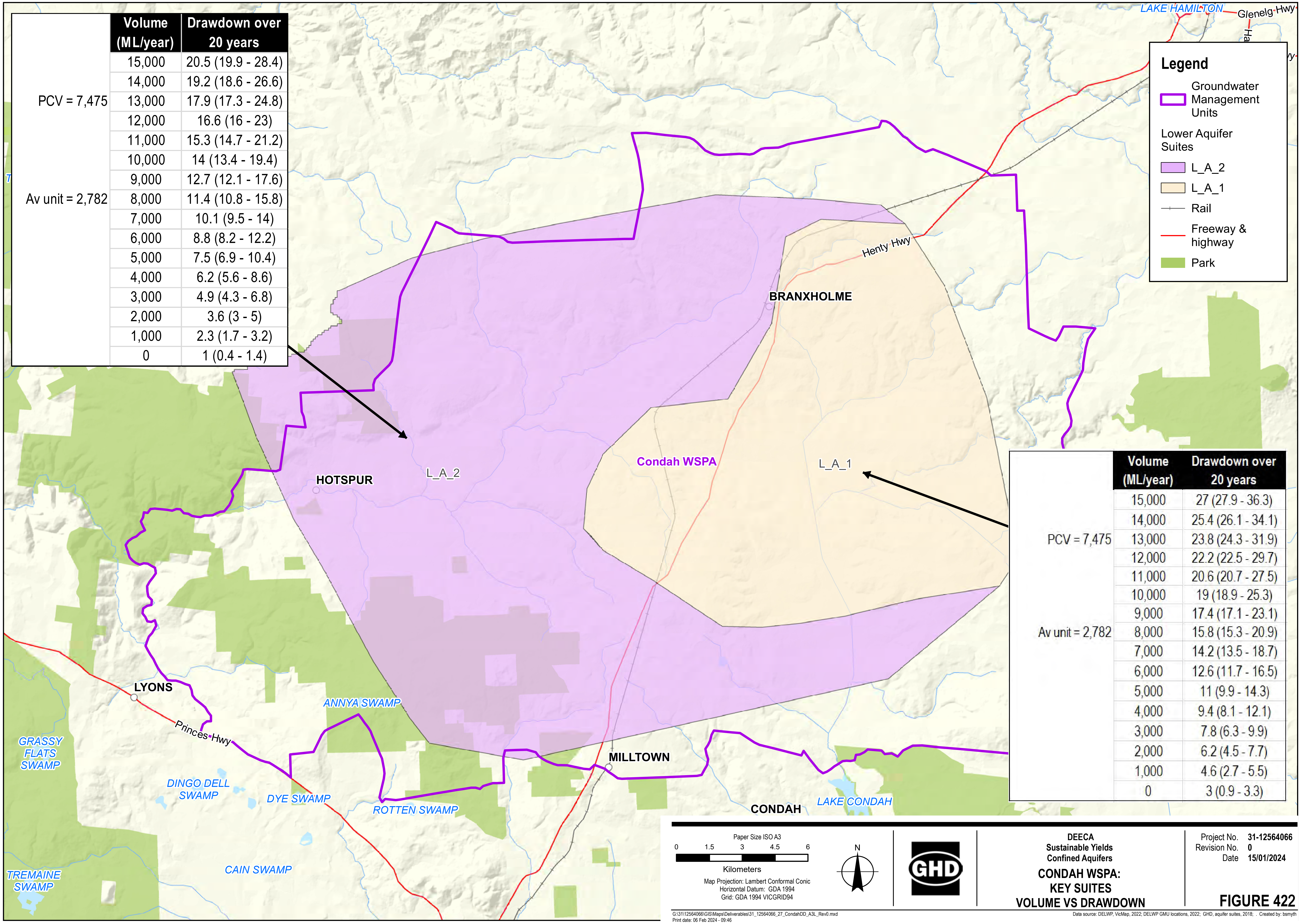


Figure 421 Condah WSPA Suite L_A_2: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 152 Predicted GMU volumes for drawdown metrics

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite L_A_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite L_A_2 drawdowns (lower limit to upper limit)
5	1,300 (800 – 2,300)	3,000 (2,000 – 3,600)
10	4,400 (3,000 – 5,000)	6,900 (4,800 – 7,400)



L_A_2

	Volume (ML/year)	Drawdown over 20 years
	15,000	20.5 (19.9 - 28.4)
	14,000	19.2 (18.6 - 26.6)
PCV = 7,475	13,000	17.9 (17.3 - 24.8)
	12,000	16.6 (16 - 23)
	11,000	15.3 (14.7 - 21.2)
	10,000	14 (13.4 - 19.4)
	9,000	12.7 (12.1 - 17.6)
Av unit = 2,782	8,000	11.4 (10.8 - 15.8)
	7,000	10.1 (9.5 - 14)
	6,000	8.8 (8.2 - 12.2)
	5,000	7.5 (6.9 - 10.4)
	4,000	6.2 (5.6 - 8.6)
	3,000	4.9 (4.3 - 6.8)
	2,000	3.6 (3 - 5)
	1,000	2.3 (1.7 - 3.2)
	0	1 (0.4 - 1.4)

L_A_1

	Volume (ML/year)	Drawdown over 20 years
	15,000	27 (27.9 - 36.3)
	14,000	25.4 (26.1 - 34.1)
PCV = 7,475	13,000	23.8 (24.3 - 31.9)
	12,000	22.2 (22.5 - 29.7)
	11,000	20.6 (20.7 - 27.5)
	10,000	19 (18.9 - 25.3)
	9,000	17.4 (17.1 - 23.1)
Av unit = 2,782	8,000	15.8 (15.3 - 20.9)
	7,000	14.2 (13.5 - 18.7)
	6,000	12.6 (11.7 - 16.5)
	5,000	11 (9.9 - 14.3)
	4,000	9.4 (8.1 - 12.1)
	3,000	7.8 (6.3 - 9.9)
	2,000	6.2 (4.5 - 7.7)
	1,000	4.6 (2.7 - 5.5)
	0	3 (0.9 - 3.3)

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

GHD

DEECA
Sustainable Yields
Confined Aquifers

CONDAH WSPA: KEY SUITES VOLUME VS DRAWDOWN

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

FIGURE 422

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Print date: 06 Feb 2024 - 09:46

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

24.6 GMU summary

24.6.1 Findings

Condah WSPA primarily relates to the Clifton Formation aquifer (LMTA) where groundwater is predominately extracted for irrigation purposes. The LMTA falls within the Lower Aquifer Suites, the Lower Aquifer Suites that cover Condah WSPA are L_A_1 (24%), L_A_2 (42%) and L_C_1 (11%), providing a total coverage of 66%. The identified potential representative Suites are L_A_1 (most preferred, with 80% of extraction occurring within this Suite) and L_A_2. The Suite hydrographs for these 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 very similar model fits compared to the annual, based on the statistical analysis across the model runs. The best model result using the two yearly average annual extraction was the model that included hindcast method H1 to extrapolate extraction between two sets of recorded extraction data.

No spatial distribution methods were applied since no Suite bores were identified for Condah WSPA.

Based on an assessment of all model runs, model run 9 for Suite L_A_1 of annual extraction hindcasted using method H3 and model run 7 for Suite L_A_2 of annual extraction hindcasted using method H2 was adopted to undertake the predictive modelling.

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 10.91 m for Suite L_A_1 and 4.69 m for Suite L_A_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 L_A_1 drawdowns (lower limit to upper limit)	Predicted volumes (ML) for GMU based on Suite L_A_2 drawdowns (lower limit to upper limit)
5	1,300 (800 – 2,300)	3,000 (2,000 – 3,600)
10	4,400 (3,000 – 5,000)	6,900 (4,800 – 7,400)

The models for Suites L_A_1 and L_A_2 were assessed as having an “Excellent” model applicability rating using the criteria outlined in section 5.2. It’s noted that there is drawdown at 0 ML/year of around 3 m for Suite L_A_1, as the model underestimates the groundwater at the lower flow rates, thus providing conservative results.

Suite L_A_1 was considered the most representations for Condah WSPA and thus it’s recommended the results be utilised from this Suite.

24.6.2 Limitations

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

- The licenced bore dataset provided by DEECA has 4% of bores assigned to Condah WSPA 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 in order to assist with the determination of the representative Suite. However, this data was not used in the model analysis.
- No Suite bores identified for Condah WSPA
- Drawdown at 0 ML/year is around 3 m for Suite L_A_1, as the model underestimates the groundwater at the lower flow rates

24.6.3 Recommendations

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

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

25. Gellibrand GMA

25.1 Conceptualisation

The hydrogeological conceptualisation elements relevant to this study are summarised in Table 153 and a map of the GMU is presented in Figure 423. 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 153.

Table 153 Gellibrand GMA – Tabulated conceptualisation

GMU summary
Gellibrand GMA is located in south western Victoria, south of Colac and covers an area of approximately 83 km^2. The Gellibrand GMA borders are shared with the Gerangamete GMA to the north and east, while the Newlingrook GMA occurs nearby to the southwest. The Gellibrand GMA is located within the Kawarren groundwater sub-basin, which is bordered by the Barongarook High to the north west, Bambra Fault to the south east and the Gellibrand Saddle to the south west. The Gellibrand River partly aligns with the southern boundary of the GMA, has significant environmental value, and provides a water source to the population centres in the Western Districts. Loves Creek is also thought to be of environmental value to the GMA, interacting with groundwater. Gellibrand GMA pertains to all formations below the ground surface but was intended to primarily manage the groundwater resource of the Dilwyn Formation (Lower Tertiary Aquifer, LTA). The PCV (0 ML/year[9]) relates to confined and unconfined aquifers.

Hydrostratigraphy summary

Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Approx. use volumes ML (2019/20)	Approx entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Bridgewater Formation (QA)	-	-	0	NA	0	0	Low
Middle	Port Campbell Limestone (UMTA)	-	-	0	NA	0	0	Low
	Gellibrand Marl (UMTD)	-	-	0	NA	0	0	Low
Lower	Clifton Formation (LMTA)	M_Y_5 (60%)	-	0	NA	0	0	Low
	Narrawaturk Marl (LMTD)	-	-	0	NA	0	0	Low
	Dilwyn Formation (LTA)	L_Y_3 (72%), L_AA_99 (2%), L_AC_2 (4%), L_AD_1 (1%), L_Y_2 (0.2%), L_Y_4 (1%), L_Y_5 (16%)	97%	12	NA	0	0	High
	Older Volcanics (LTB)	-	-	0	NA	0	0	Low
Basement	Basement rocks	B_X_1 (15%), B_X_3 (81%)	-	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.								

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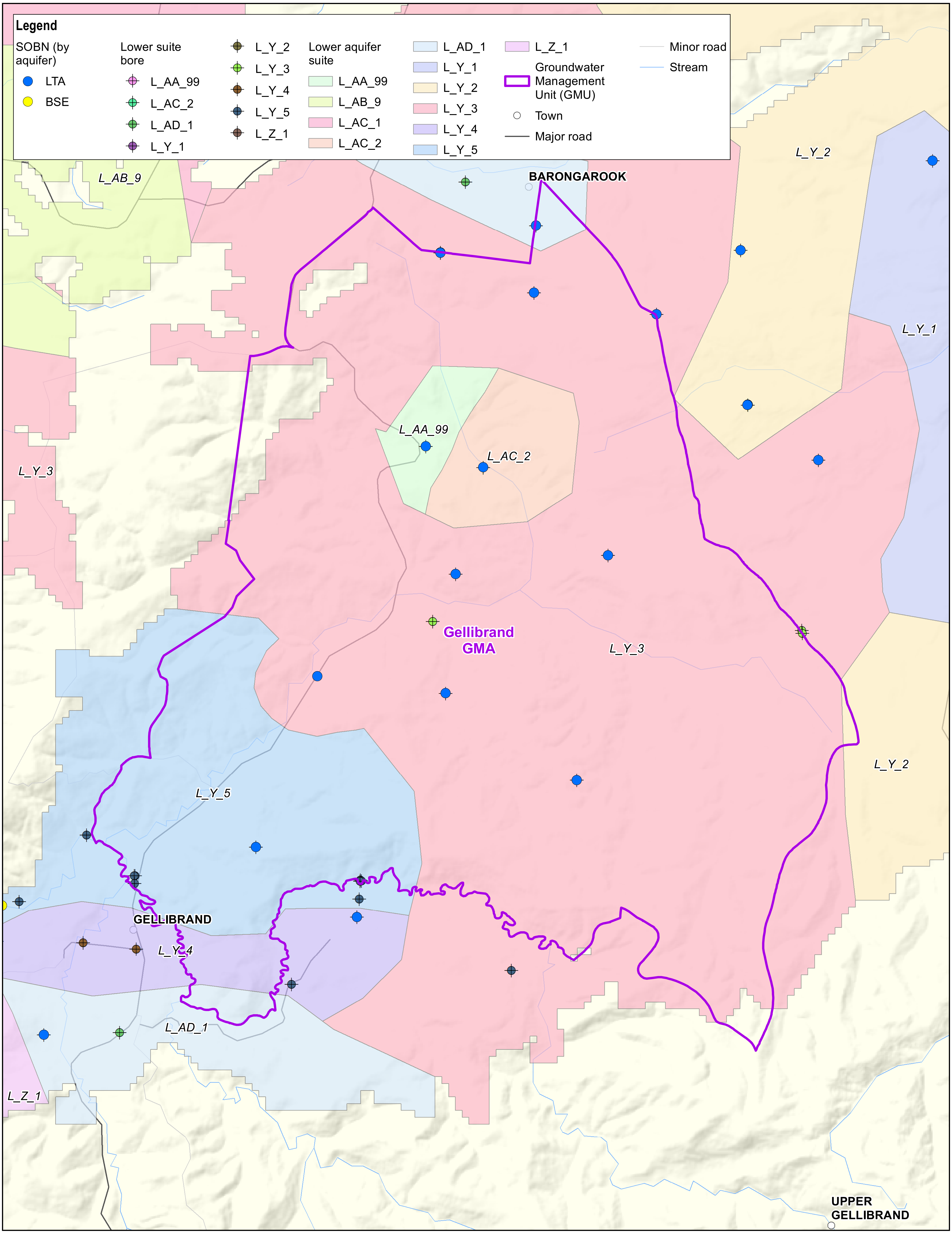
[9] The PCV for Gellibrand GMA is currently set to 0 ML/year as it is under investigation to understand the extent of interaction with surface water

Characteristic and importance	Description	Degree of understanding
Intended aquifer		
Aquifer thickness within GMU (range, based on VAF)	Max: 296 m, Average: 103 m	High
Aquifer extent	Small, local	High
Likelihood of inter-aquifer flow	Medium	Low
Likelihood of groundwater – surface water interaction	High	Low (No recent modelling undertaken)
Representative Suite	**L_Y_3**	**Medium. No extraction within this GMU. Representative Suite selected on basis of most relevant aquifer and spatial coverage of GMU**
Current hydrological condition of representative aquifer		
Representative Suite trend	Declining	Low – declining trend since 1990, even with no use. No discernible correlation to climate trend
Groundwater quality (average salinity based on WMIS and CDM Smith spatial segment(s) with highest coverage)	379 mg/L (WMIS) 0 – 600 mg/L (CDM Smith 2022)	High Based on WMIS and CDM Smith (2022)
Groundwater yield	5 – 50 L/s	Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1974-2021**	**N/A**
Spatial clustering of licensed bores in relation to Suites	**No (no licenced bores)**	**High**
Groundwater use		
Licensed groundwater use (ML, based on average of last 5 years)	**No allocations have been issued and PCV of zero is declared**	**High (Based on historical VWA data)**
Minimum historic groundwater use (ML)		**High (Based on historical VWA data)**
Maximum historic groundwater use (ML)		**High (Based on historical VWA data)**
Entitlement (Groundwater allocation) (ML)		**High (Based on licenced volumes in 2020/21)**
Significant drivers of groundwater level variability (primary)	**Groundwater recharge (rainfall, surface water interactions, inter-aquifer flow)**	Low
Secondary drivers of groundwater level variability	Groundwater extraction (based on historic data); deep groundwater is currently recovering.	Low
Groundwater use profile	N/A - no extraction	Low

Characteristic and importance	Description	Degree of understanding
External influences	**Barwon Downs Borefield**	
Groundwater values and risks		
Existing Environmental Values to be protected, relevant to this GMU	Unlicensed non-potable supply (domestic and stock)	



Paper Size ISO A3

0 0.35 0.7 1.05 1.4

Kilometers

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

N

DEECA
Sustainable yield review - confined aquifers

Gellibrand GMA
Site location and key features

Project No. **12564066**
Revision No. **0**
Date **15/01/2024**

Figure 423

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Print date: 15 Jan 2024 - 14:26

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

25.2 Technical analysis

25.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the confined Suites for Gellibrand GMA as shown in Figure 424. Generally, the Suite hydrographs show the seasonal fluctuations and hence recovered water levels. The exception to this is Suite L_Y_2 and L_Y_3 which show large variations pre-1990 that are not analogous to trends from seasonal variation. It is expected that there may be an issue with this Suite data prior to this date and hence would be excluded from the assessment.

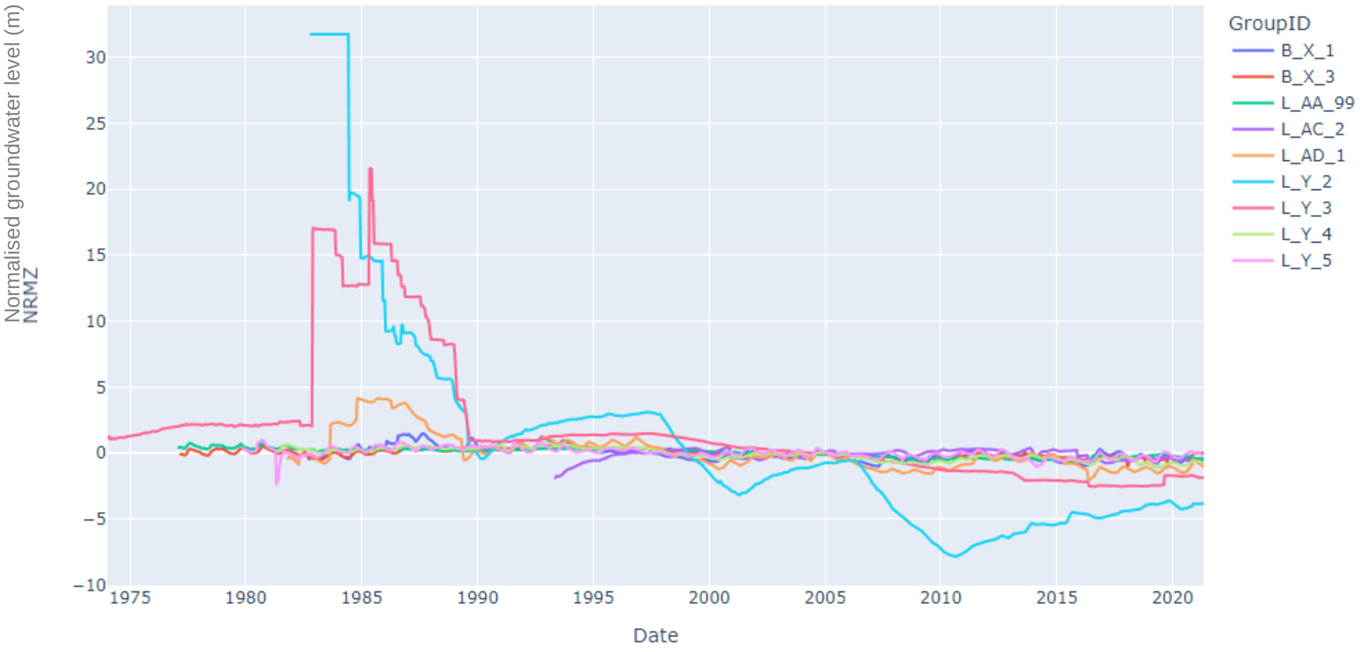

Figure 424 Gellibrand GMA Suite Hydrographs for all confined aquifers

The representative Suite analysed for this GMU was Suite L_Y_3. This representative Suite was selected following the methodology outlined in section 2.6.4 and summarised as follows:

- The Lower Aquifer pertains to the LTA which is the intended aquifer for this GMU
- The Lower Aquifer and Suite L_Y_3 was the only Suite which had extraction bores
- Suite L_Y_3 covers 72% of the GMU
- Suite L_Y_3 has 7 active SOBN bores within the Suite area

The normalised annual recovered Suite hydrograph for the representative Suite for Gellibrand GMA, L_Y_3 is shown in Figure 425.

Figure 425 ***Gellibrand GMA Annual Recovered Level Suite Hydrographs for representative Suites***

25.2.2 Externalities

Through the conceptualisation, the Barwon Downs Borefield was inferred as an external influence for Gellibrand GMA, although no extraction data was available for Gelibrand and thus external influence has not been considered further in this assessment.

25.2.3 Hindcasting

No groundwater use information is available for Gellibrand GMA as groundwater extraction within this GMU has ceased due to environmental impacts which are being investigated. Therefore, hindcasting could not be undertaken.

25.3 Modelling

Without groundwater extraction information, the assessment approach cannot be applied to Gellibrand GMA.

25.4 Predictive modelling

Without groundwater extraction information, the assessment approach cannot be applied to Gellibrand GMA.

25.1 Sustainability metrics

Without groundwater extraction information, the assessment approach cannot be applied to Gellibrand GMA.

25.2 GMU summary

25.2.1 Findings

Gellibrand GMA primarily relates to the Dilwyn Formation (LTA) and groundwater extraction currently no longer occurs. The LTA falls within the Lower Aquifer Suites, which at Gellibrand GMA include L_Y_1 (72%), L_AA_99 (2%), L_AC_2 (4%), L_AD_1 (1%), L_Y_2 (0.2%), L_Y_4 (1%) and L_Y_5 (16%) providing a total coverage of 96%. The identified representative Suite is L_Y_3. The Suite hydrographs for the representative Suites show an overall decreasing trend with very little observed seasonal fluctuations.

As no groundwater extraction information could be provided, and no allocations issued, for the assessment, the methodology developed for the project could not be applied.

25.2.2 Limitations

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

- No groundwater extraction information is available for Gellibrand GMA
- The representative Suite identified does not show seasonal fluctuations and thus the annual recovered levels calculated are unlikely to be representative of recovered levels
- As no groundwater extraction information could be provided for the assessment, the methodology developed for the project could not be applied to Gellibrand GMA

25.2.3 Recommendations

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

- DEECA to review if future development of the GMA is likely
- If future development is likely:
  - DEECA could review available data to determine if historical datasets are available for Gellibrand GMA prior to cessation of extraction
  - If historical data is unavailable, it is recommended that DEECA identifies other methods that could be used to inform sustainable extraction estimates for Gellibrand GMA. This could include the use of externalities (i.e., Gerangamete GMU extraction) to assess the potential for influence of groundwater trends.

26. Gerangamete GMA

26.1 Conceptualisation

The hydrogeological conceptualisation elements relevant to this study are summarised in Table 154 and a map of the GMU is presented in Figure 426. It is noted that a significant volume of information was collated to provide hydrogeological conceptual understanding of the GMU. The information that is directly relevant to the modelling are shown in bold or colour coded within Table 154.

Table 154 Gerangamete GMA – Tabulated conceptualisation

GMU summary

Gerangamete GMA is located south east of Colac in the Otway Basin, adjacent to the Gellibrand GMA and covers an area of approximately 484 km^2.

The Gerangamete GMA pertains to all formations greater than 60 m below the ground surface, but was intended to primarily manage the groundwater resource of the Pebble Point Formation (Lower Tertiary Aquifer, LTA). The PCV (239 ML/year) relates primarily to confined aquifers.

Barwon Water's Barwon Downs borefield is located within the Gerangamete GMA and was previously used for urban water supply. The licence for the borefield was withdrawn on 14 March 2019 (Barwon Water 2019[10]) until remediation of historical impacts of groundwater pumping was completed. The borefield is located in an area with identified groundwater dependent ecosystems.

The Barwon Downs borefield was one of the few licenced groundwater extractors in the Gerangamete GMA and thus, limited licenced extraction currently occurs from this GMA.

Hydrostratigraphy summary

Aquifer	Formation	Relevant Suites (% coverage of GMU)	% of GMU covered by Suites	Number of SON bores	Groundwater use	Use volumes ML (2019/20)	Entitlement volumes ML (2019/20)	Understanding (Low, Medium, High)
Upper	Bridgewater Formation (QA)	U_AS_1 (39%)	39%	0	NA	0	0	Low
Middle	Gellibrand Marl (UMTD)	M_Z_8 (14%) M_Y_1 (7%)	21%	0	Urban	0	0	Low
Lower	Clifton Formation (LMTA)	M_X_1 (26%), M_Y_5 (14%)	40%	2	NA	0	0	Low
	Narrawaturk Marl (LMTD)	-	-	0	NA	0	0	Low
	Pebble Point Formation/Eastern View Formation (LTA)	L_AB_9 (0.2%), L_AC_1 (0.5%), L_AC_2 (2%), L_AD_1 (1%), L_Y_1 (21%), L_Y_2 (47%), L_Y_3 (23%), L_Y_5 (0.1%), L_Z_1 (0.3%)	95%	39	Dairy, irrigation	112 (112)	238 (220)	High
	Older Volcanics (LTB)	-	-	0	NA	0	0	Low
Basement	Basement rocks	B_X_3 (25%)	25%	0	Irrigation, urban	0	0	Low

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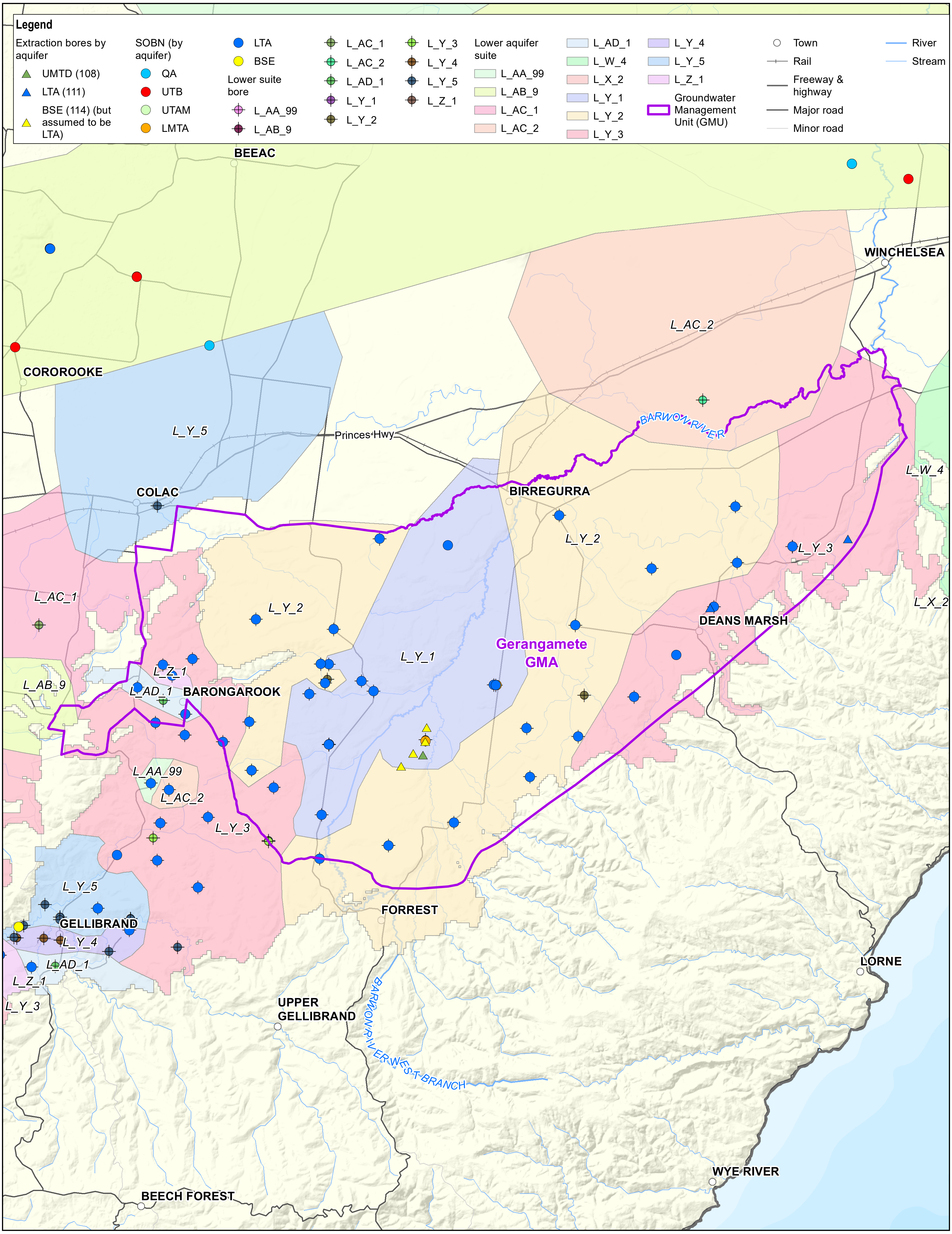
[10] Barwon Water 2019, Gerangamete GMA, Groundwater licence:BEE032496, 2018/2019 report

GMU summary		
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 112 ML of usage has been reassigned from BSE to LTA based on lithology logs.		
Characteristic & importance	**Description**	**Degree of understanding**
Intended aquifer		
Aquifer thickness within GMU (range, based on VAF)	Max: 296 m, Average: 103 m	High
Aquifer extent	Small, local	High
Likelihood of inter-aquifer flow	Medium	Low
Likelihood of groundwater – surface water interaction	High	High – interaction with Big Swamp and Boundary Creek
Representative Suite	**L_Y_1**	**Low. No extraction but Suite represents the most relevant GMU aquifer. Likely issue with bore data since 86% 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)	1,000 mg/L (WMIS) 0 – 600 mg/L (CDM Smith 2022)	Low – data from WMIS variable Based on WMIS and CDM Smith (2022)
Groundwater yield	5 – 50 L/s	Low Based on CDM Smith (2022)
Groundwater levels		
Temporal groundwater level data range	**1974-2021**	
Spatial clustering of licensed bores in relation to Suites	**Yes, no Suite**	**Based on DEECA density mapping and licenced bore data.**
Groundwater use		
Licensed groundwater use	**3,524 ML**	**High (Based on average historical VWA data over 16 years, this includes Barwon Downs usage)**
Minimum historic groundwater use	3 ML	High (Based on historical VWA data, year 2017/18, this includes Barwon Downs usage)
Maximum historic groundwater use	**12,692 ML**	**High (Based on historical VWA data, year 2009/10, this includes Barwon Downs usage)**

<table>
<tr><th colspan="3">GMU summary</th></tr>
<tr><td>Entitlement (Groundwater allocation)</td><td>238 ML</td><td>High (Based on licenced volumes in 2020/21, this doesn’t includes Barwon Downs usage)</td></tr>
<tr><td>Significant drivers of groundwater level variability (primary)</td><td>Pumping for irrigation</td><td>Low</td></tr>
<tr><td>Secondary drivers of groundwater level variability</td><td>Hydraulic connection with adjacent Gellibrand GMA</td><td>Low</td></tr>
<tr><td>Groundwater use profile</td><td>Extraction no longer occurring from Barwon Downs Borefield</td><td>Moderate</td></tr>
<tr><td>Licensed groundwater use</td><td>None identified</td><td></td></tr>
<tr><td colspan="3">Groundwater values and risks</td></tr>
<tr><td>Existing Environmental Values to be protected, relevant to this GMU</td><td colspan="2">Potable water supply
Licensed non-potable supply (irrigation, commercial, industrial)
Unlicensed non-potable supply (domestic and stock)</td></tr>
<tr><td>Risks to groundwater values</td><td>Direct risks:
– Drawdown which may affect access to groundwater by existing users</td><td>High</td></tr>
<tr><td>Indicators used to assess impacts to groundwater</td><td>– Measured drawdown using pre-determined metrics measured from a pre-determined level for the purpose of this modelling</td><td>High</td></tr>
</table>



Paper Size ISO A3

0 1 2 3 4

Kilometers

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

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GHD

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Sustainable yield review - confined aquifers

Gerangamete GMA
Site location and key features

Project No.	**12564066**
Revision No.	**0**
Date	**15/01/2024**

Figure 426

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Print date: 15 Jan 2024 - 14:32

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

26.2 Technical analysis

26.2.1 Hydrograph review and selection of representative Suites for further analysis

Suite hydrographs were generated for the confined Suites for Gerangamete GMA as shown in Figure 427. A number of different trends can be seen across the Suites within Gerangamete GMA. Suites L_Y_1 and L_Y_2 show periods of drawdown and recovery, likely influenced by periods of groundwater extraction. Many of the other Suites show periodic fluctuations in levels, consistent with seasonal extraction.

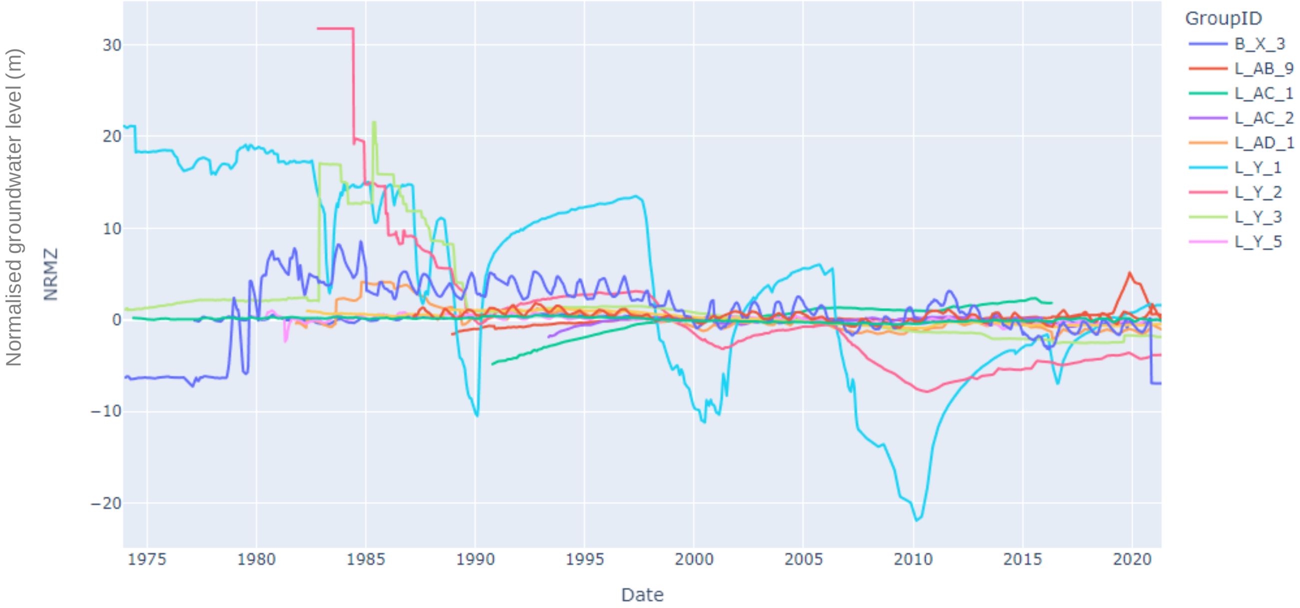


Figure 427 Gerangamete GMA Suite Hydrographs for all confined aquifers

The potential representative Suites analysed for this GMU were Suites L_Y_1 and L_Y_3 (it is noted that Suite M_Y_5 was a potential representative Suite but was not included since there is no Suite hydrograph available for this Suite). The Representative Suites were selected based on the methodology outlined in section 2.6.4 which identified Suite L_Y_1 as the most representative followed by Suite L_Y_3. The process is summarised as follows:

- The greatest volume of extraction occurs within the Lower Aquifer
- Suite L_Y_1 is taken as having the highest extraction based on 5 years of data (2015/16 to 2019/2020)
- No extraction bores were found to be located within Suite L_Y_2
- The Lower Aquifer pertains to the LTA which is the intended aquifer for this GMU
- Suite L_Y_1 covers 21% of the GMU, while Suite L_Y_3 covers 23% and M_Y_5 covers 14%
- Suite L_Y_3 has nine active SOBN bores within the Suite area
- One Suite bore for L_Y_3 within the GMU is close to an extraction point and one Suite bore for L_Y_1 within the GMU is close to an extraction point

The annual recovered Suite hydrograph for the representative Suite and second most likely representative Suite for Gerangamete GMA, L_Y_1 and L_Y_3 is shown in Figure 428. The hydrograph for L_Y_3 in Figure 428 appears to be erroneous data pre-1990; due to low confidence in the data, it has not been included in the assessment.

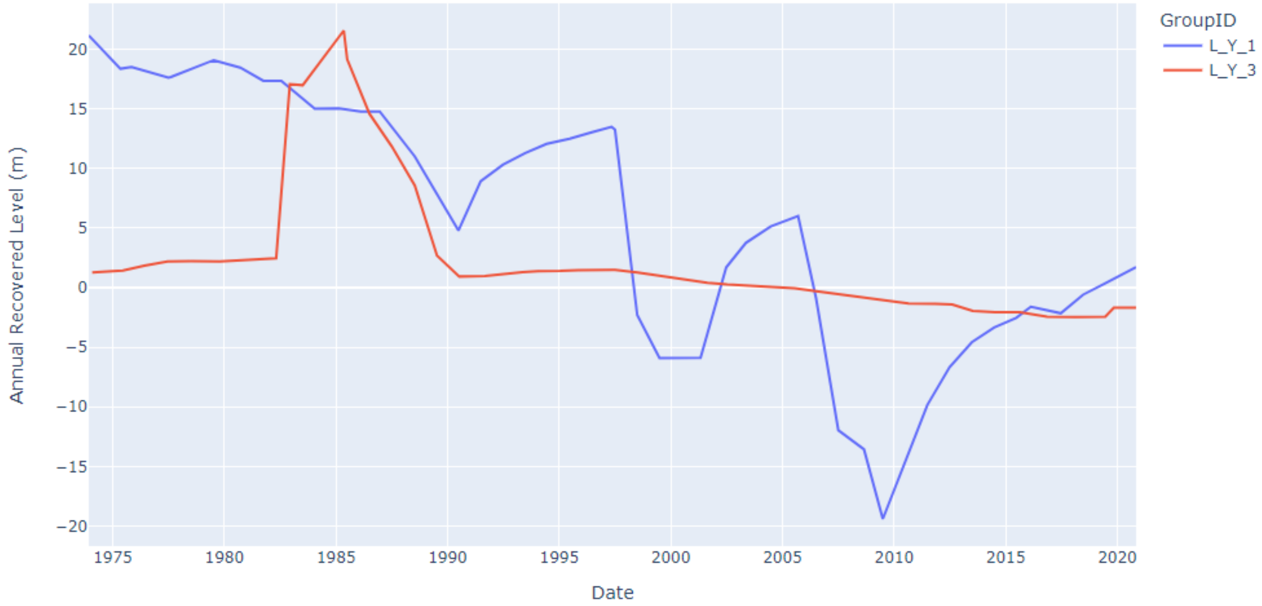


Figure 428 ***Gerangamete GMA Annual Recovered Level Suite Hydrographs for the representative Suites***

26.2.2 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 Gerangamete GMA for Suite L_Y_1.

The pre-development annual recovered level was taken to be the first and maximum level of the time series data, this occurred in the year 1973/1974 for Suite L_Y_1 which equated to 21.16m (refer further details in section 26.4.3).

26.2.3 Externalities

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

26.2.4 Hindcasting

Groundwater use data for Gerangamete GMA is available for the period 1982/1983 to 2020/2021 on an annual GMU basis. As groundwater data is available for the extraction period, no hindcasting is needed when running models without spatial distribution. However, as the spatial distribution extraction dataset only dates back to 2009/2010 this needs to be hindcasted back to 1982/1983 for model runs incorporating both spatial distribution and hindcasting. As hindcasting methods H1 and H2 are not applicable to spatial distribution methods, only hindcasting method H3 was applied for Koo Wee Rup WSPA. The hindcasting methodology for method H3 outlined in section 3.3.4.5 was applied to Gerangamete GMA. A summary of the hindcasting results is shown below.

26.2.4.1 Hindcasting Method 3 (H3)

Four correlations were developed using method H3 as described below and shown in Figure 429:

- 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

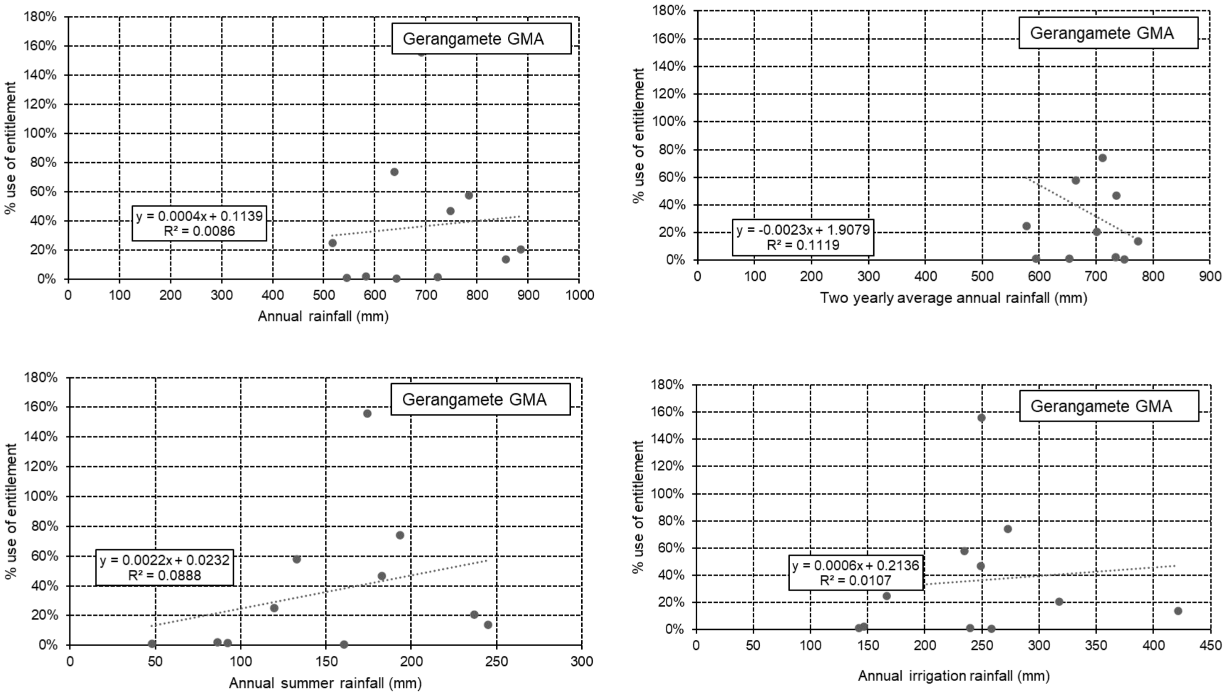


Figure 429 Gerangamete GMA: Hindcast method 3 correlations

As shown in Figure 429, the best goodness-of-fit was shown through the correlation with the two yearly average annual rainfall. This is the correlation that was modelled for hindcast method H3. It is noted that in all correlations tested, the goodness-of-fit was relatively poor.

26.2.4.2 Comparison

A comparison of the hindcast method H3 input dataset with recorded use is shown in Figure 430. Figure 430 shows a comparison of the one hindcasting method against the recorded use only over the recorded use date back to 1982/1983.

As you can see from Figure 430, groundwater use using method H3 has a mixture of under estimating and over estimating, typically underestimating in years where extraction was recorded.

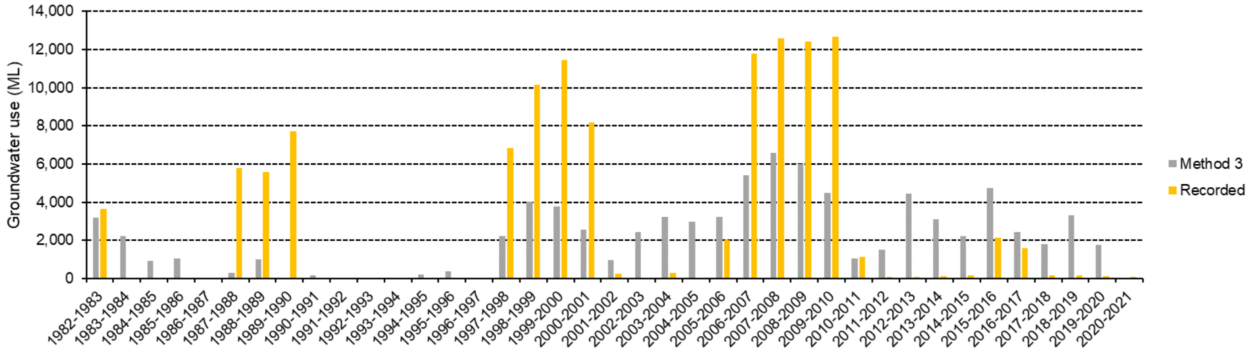


Figure 430 Gerangamete GMA: Comparison of hindcasting over recorded use period – Gerangamete GMA only extraction

26.3 Modelling

26.3.1 Model inputs

A number of different models were run based on the various model inputs developed and combinations of these. Table 155 summarises the combinations of model inputs run for Gerangamete GMA. Model runs highlighted blue were run with annual extraction while those highlighted grey were run using two yearly average annual extraction. As mentioned previously, none of the hindcasting models were run, as historic extraction data was available on an annual basis except for the spatial distribution methods.

Table 155 Gerangamete 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_Y_1)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual extraction – Gerangamete GMA only	✓																		
Two yearly average annual extraction – Gerangamete GMA only		✓																	
Annual extraction – Gerangamete GMA and Externalities			✓																
Two yearly average annual extraction – Gerangamete GMA and Externalities				✓															
H1 annual extraction – Gerangamete GMA only					✓														
H1 annual extraction – Gerangamete GMA and Externalities						✓													
H2 annual extraction – Gerangamete GMA only							✓												
H2 annual extraction – Gerangamete GMA and Externalities								✓											
H3 annual extraction – Gerangamete GMA only									✓										
H1 two yearly average annual extraction – Gerangamete GMA only										✓									
H1 two yearly average annual extraction – Gerangamete GMA and Externalities											✓								
H2 two yearly average annual extraction – Gerangamete GMA only												✓							
H2 two yearly average annual extraction – Gerangamete GMA and Externalities													✓						
S1 annual extraction – Gerangamete GMA only														✓					

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

26.3.2 Model calibration and uncertainty analysis

A statistical summary of the model output results for the runs described in Table 155 is presented in Table 156 for the selection of potential representative Suites for Gerangamete GMA. The column heading for L_Y_1 is highlighted blue to indicate that this Suite was selected as the most likely representative Suite based on the process outlined in section 26.2.1. 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_Y_1

A review of the results and statistical summary for Suite L_Y_1 shows that model run 17 (highlighted orange) initially provided the best results of the eight different model input combinations when considering a balance of small RMSE value, high R^2 value and small 95PPU thickness. However, this model did not cover the period of pre-development. Considering the need to include a longer historic record and this period in the calibration model but knowing that there was unlikely no licenced extraction prior to 1982/1983, the annual data for model run 1 was extended back to the pre-development period using 0 ML as the input volume. This created model run 1a as shown in Table 156 which has the highest R^2 and greatest number of observation points included of the calibration model runs. The graphical model output for model run 1a is shown in Figure 431.

Model run 1a is the preferred model to undertake predictive modelling for Suite L_Y_1.

Table 156 Gerangamete GMA: summary of model outputs

Suite	Statistic	Model run								
		1	1a	2	14	15	16	17	18	19
L_Y_1	95PPU TH	23.58	20.81	26.01	13.85	12.43	12.44	21.97	28.6	28.6
	%Obs in 95 PPU	71.05	93.75	65.79	100	90	90	100	94.59	94.59
	R^2	12.0	84.6	-49.9	0.0	0.0	0.0	74.5	74.9	74.9
	RMSE	8.38	3.98	10.93	3.22	3.22	3.22	4.63	4.59	4.59
	No obs data points	38	48	38	10	10	10	37	37	37
	Range of observed levels	34.5	40.6	34.5	11.1	11.1	11.1	34.5	34.5	34.5

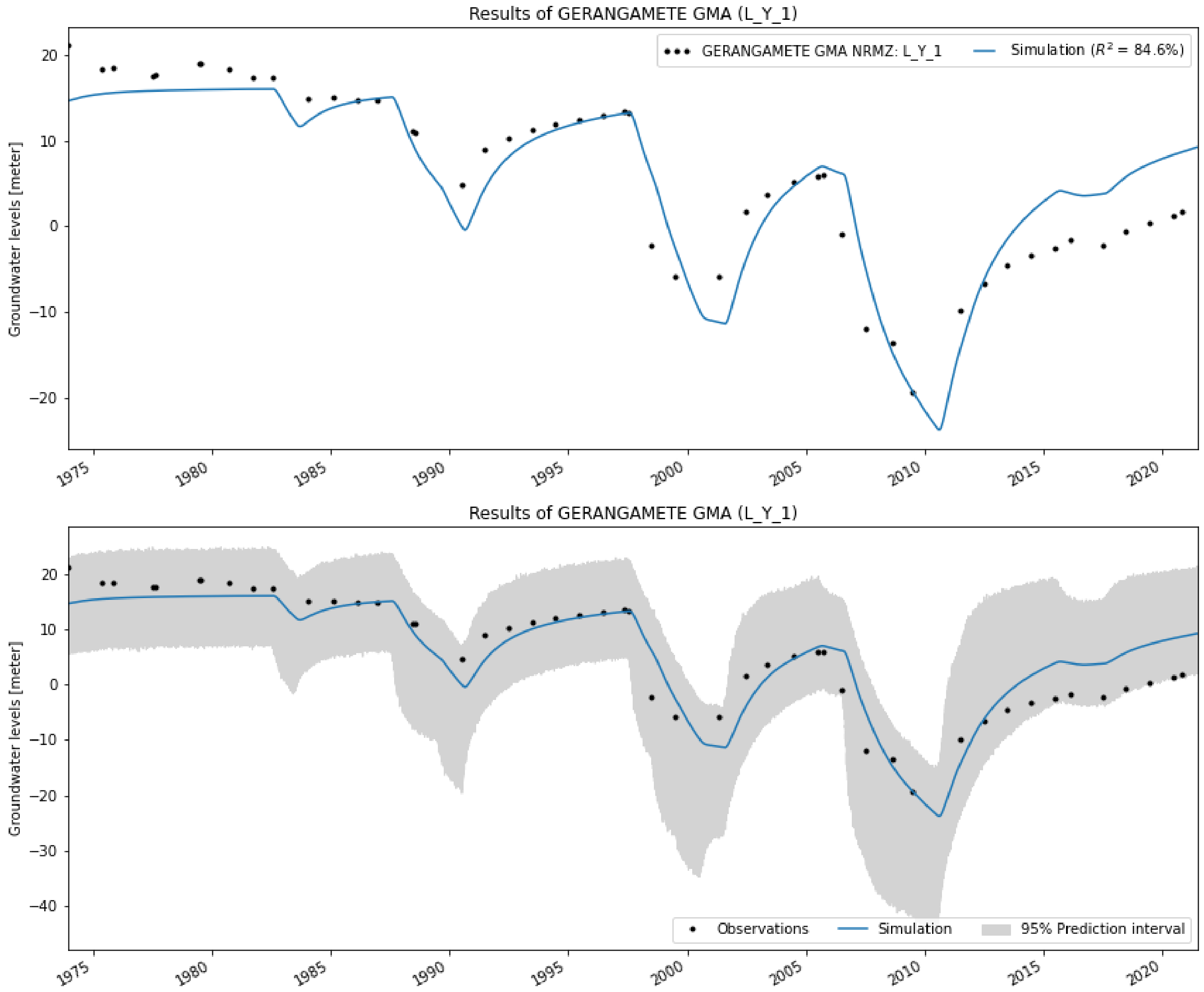


Figure 431 *Gerangamete GMA Suite L_Y_1: model run 1a (Gerangamete GMA annual extraction with extraction hindcasted back using 0 ML) output hydrographs*

26.4 Predictive modelling

26.4.1 Model inputs

The preferred model to run the predictive modelling for Gerangamete GMA was model run 1a for Suite L_Y_1.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 157.

As licences have not been renewed for the Barwon Downs borefield, and this borefield was activated as drought relief, the average use used in the predictive scenarios is higher than existing use which will likely impact the results.

Table 157 *Gerangamete 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 2009/10)
Value (ML/year)	239	238	65	3,524	12,692

26.4.2 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 432 for scenario 4 for Suite L_Y_1. As shown in Figure 432, the uncertainty of the model prediction does not significantly increase 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 433.

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.

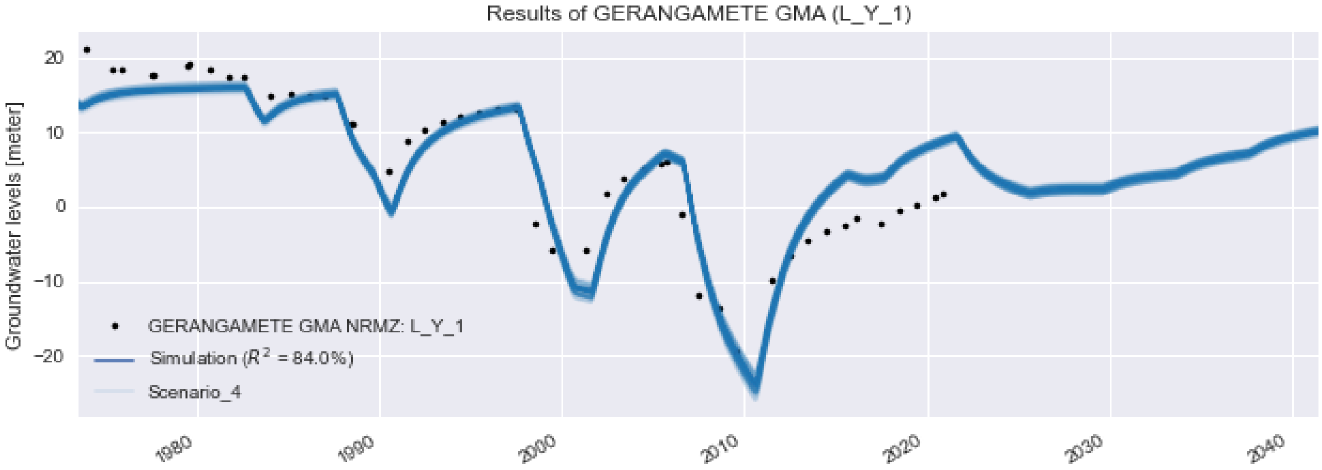


Figure 432 ***Gerangamete GMA: Suite L_Y_1 MCMC analysis for Forecast Scenario 4***

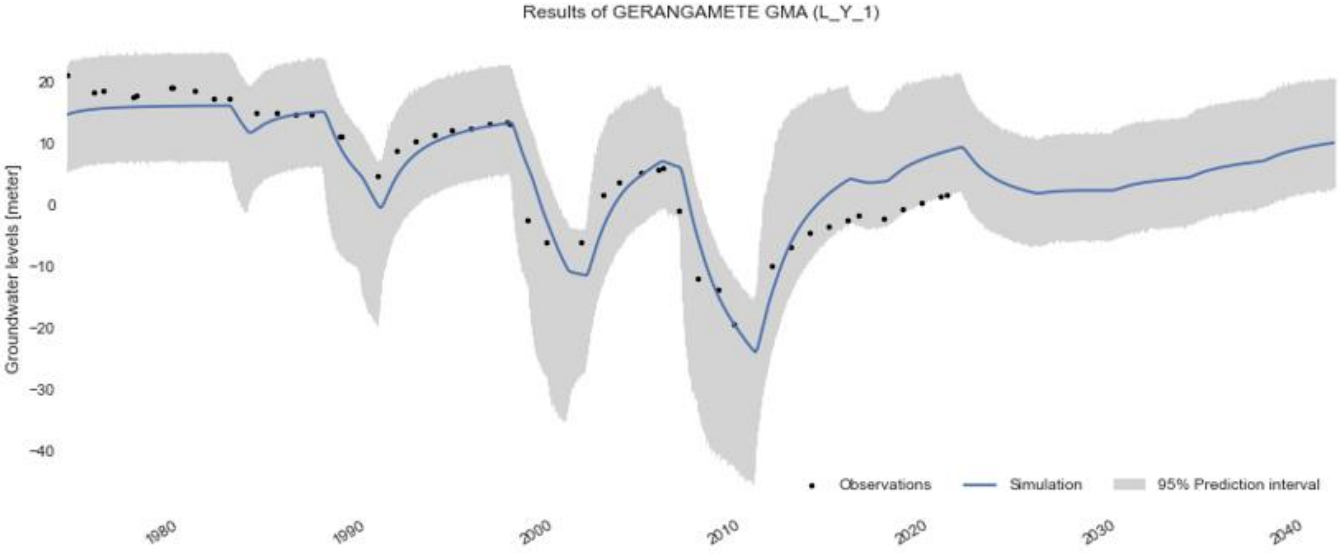


Figure 433 ***Gerangamete GMA: Suite L_Y_1 Forecast Scenario 4 with 95% prediction bands***

26.4.3 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 Gerangamete GMA, development is estimated to have commenced around 1983.

Using the pre-development levels defined in section 26.2.2, 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 434 for Suite L_Y_1 hydrograph of annual recovered levels. In Figure 434:

- Actual annual groundwater use is represented by the blue column graph in 1982/1983, 1987/1988 to 1989/1990 and between 1997/1998 and 2020/2021
- 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, whereby the earliest data is taken to best reflect the pre-development levels
- In the case of Figure 434, the pre-development annual recovered level is taken to be the first reading which is 21.16 m
- The modelled forecasted annual recovered levels are represented by the purple line in Figure 434
- The calibration annual recovered levels are represented by the black line in Figure 434

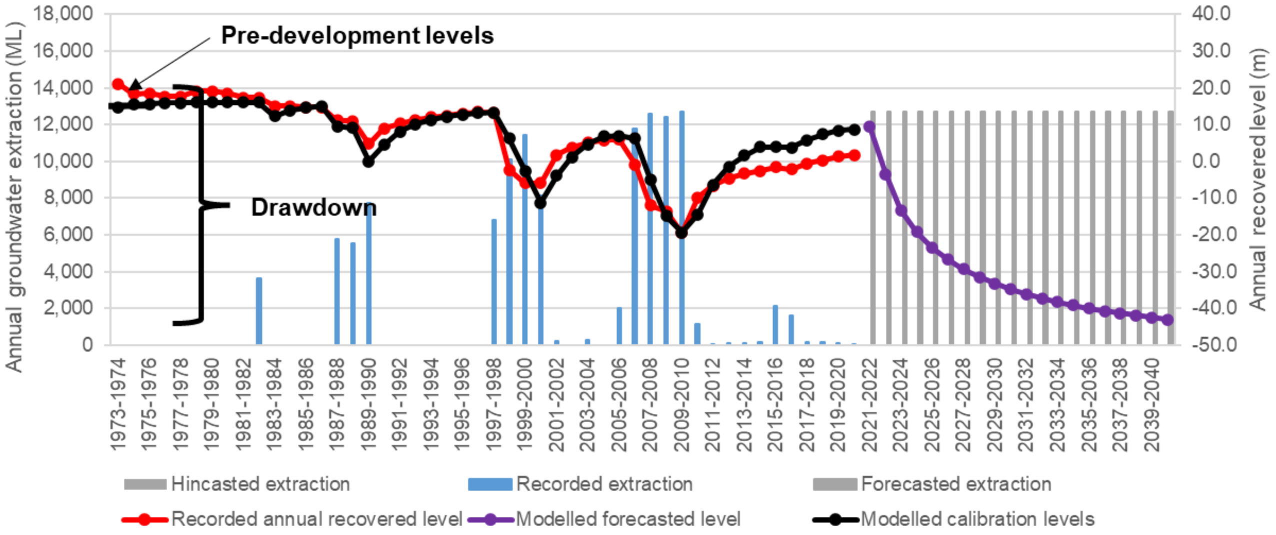


Figure 434 Estimating pre-pumping water levels (example from Suite L_Y_1)

For Suite L_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 435) and a graph of the scenarios for specific time periods (Figure 436) to develop the volume to drawdown relationship. It is noted that unlike the other GMUs, the graphs for Gerangamete only include the forecasted data (data post 2020/2021) as the data prior to this includes recovery data which skews the graphs. For each scenario, a linear regression was applied and the coefficient of determination (R^2) was calculated. A comparison of each of these graphs shows variations in the coefficient of determination and the slope of the line of best fit. Given this, the drawdown-use plot of all scenarios was adopted to capture these variations.

The use-drawdown for all the 19 forecast scenario drawdowns and volumes (both the recorded and forecasted volumes) over each year modelled is shown in Figure 435 for Suite L_Y_1 (1984 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 uses that are two times the average historic use).

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. There is a 6.5 m different between the recorded annual recovered level and the modelled annual recovered level at the taken pre-development date; this contributed to the y-intercept value.
- Average use is around 3,500 ML. Figure 435 for Suite L_Y_1 indicates that at this use the model forecast drawdown tends to occur below to the predicted line of best fit.
- For the same annual use, different drawdowns can be obtained as Pastas predicts a water level for each year. For example, Figure 434 shows a scenario where groundwater use remains constant at around 12,700 ML/year over the next 20 years
- The correlation (R^2) for groundwater use and drawdown for Suite L_Y_1 is poor as shown in Figure 435.
- 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.

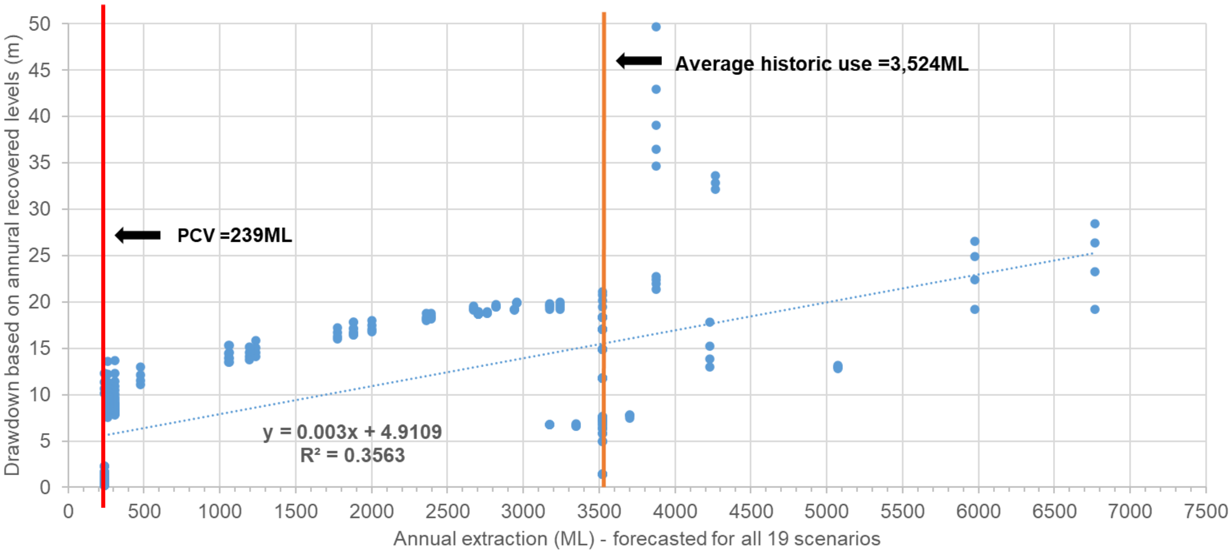


Figure 435 *Gerangamete GMA Suite L_Y_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <7,000 ML) for all data between 2021 to 2041 and all forecasted scenarios*

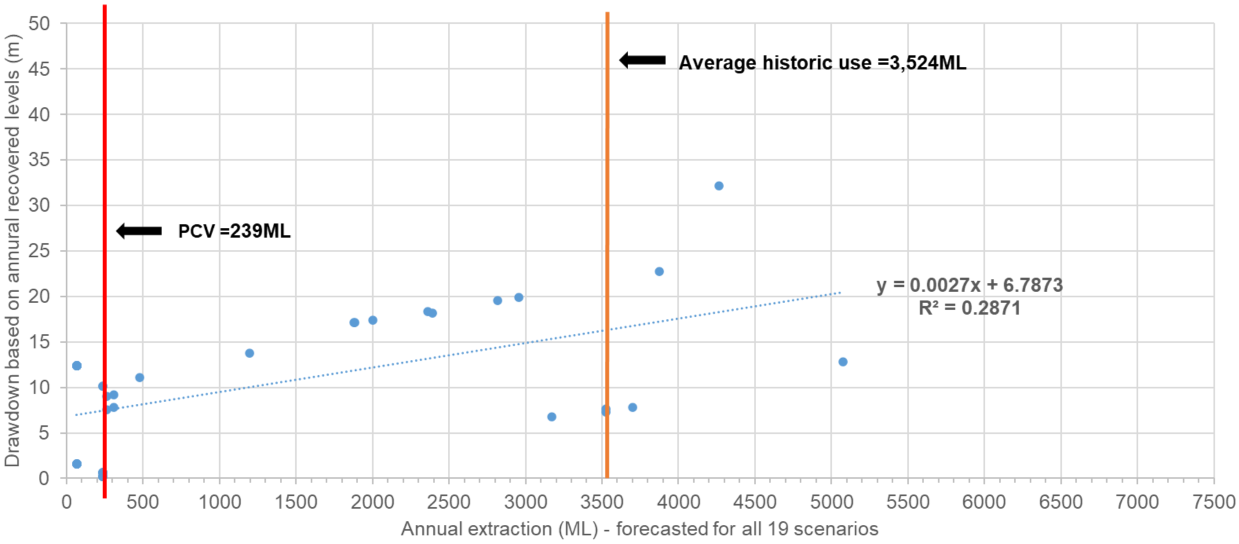


Figure 436 *Gerangamete GMA Suite L_Y_1: Drawdown (on annual recovered levels) and extraction volumes (recorded and forecasted <7,000 ML) for years 2020/2021, 2030/2031 and 2040/2041 for all forecasted scenarios*

26.5 Sustainability metrics

26.5.1 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 metrics that define groundwater resource sustainability.

The application of these metrics and the relationship between drawdown based on the Suite annual recovered levels and extraction volume for the whole GMU, which is shown in Table 158 for Gerangamete GMA Suite L_Y_1 (noting Gerangamete GMA has a current PCV of 239 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 158 and Figure ***437*** for Suite L_Y_1.

A comparison of volumes at drawdown intervals provided by DEECA is shown in Table 159 for Suites L_Y_1. Based on the relationships developed, it is predicted that 5 m of drawdown could occur for a groundwater use of 30 ML (could vary from -2,700 ML to 4,100 ML) based on Suite L_Y_1 and 10 m of drawdown could occcur for a groundwater use of 1,700 ML (could vary from -1,100 ML to 5,600 ML) based on Suite L_Y_1.

Table 158 Relationship of Suite drawdown to GMU extraction for Gerangamete GMA Suite L_Y_1

Volume (ML/year) for whole of GMU	Based on model prediction of Suite L_Y_1 annual recovered levels
	Drawdown over 20 years (m) (lower limit to upper limit based on 95% prediction interval band)
7,500	27.4 (16.3 - 35.7)
7,000	25.9 (14.7 - 34.2)
6,500	24.4 (13 - 32.7)
6,000	22.9 (11.4 - 31.2)
5,500	21.4 (9.7 - 29.7)
5,000	19.9 (8.1 - 28.2)
4,500	18.4 (6.4 - 26.7)
4,000	16.9 (4.8 - 25.2)
3,500	15.4 (3.1 - 23.7)
3,000	13.9 (1.5 - 22.2)
2,500	12.4 (-0.2 - 20.7)
2,000	10.9 (-1.8 - 19.2)
1,500	9.4 (-3.5 - 17.7)
1,000	7.9 (-5.1 - 16.2)
500	6.4 (-6.8 - 14.7)
0	4.9 (-8.4 - 13.2)

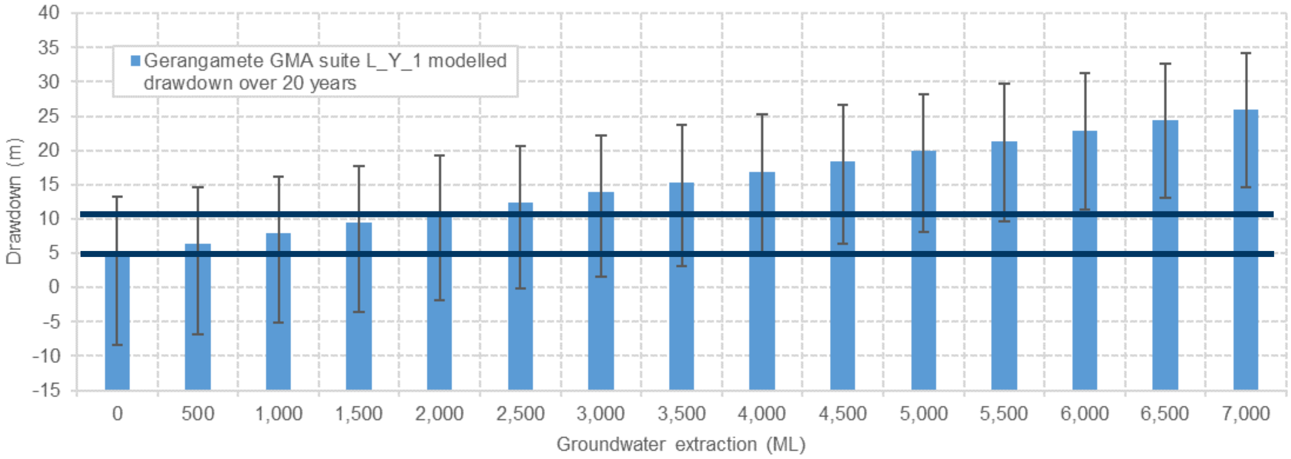
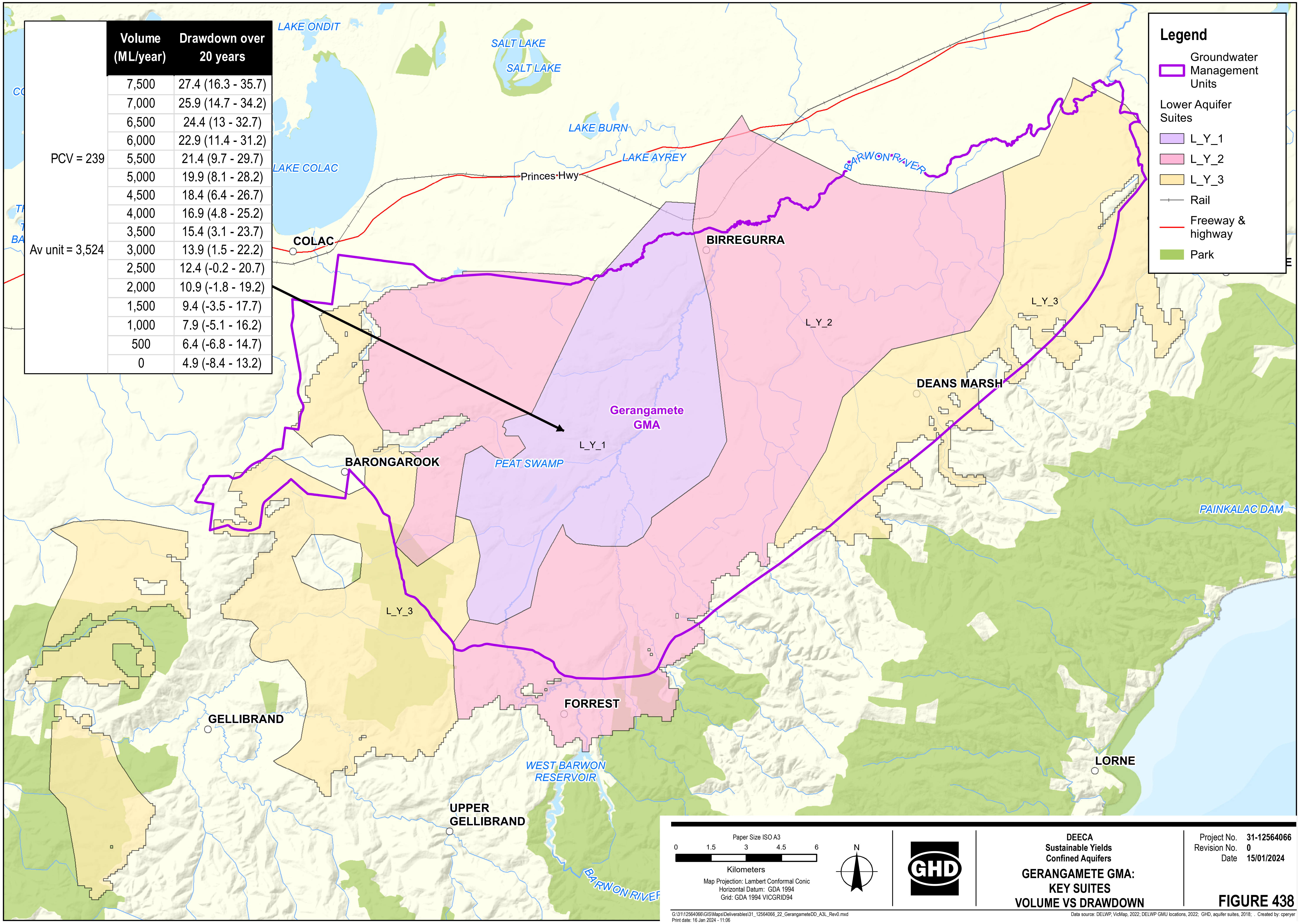


Figure** 437* ***Gerangamete GMA Suite L_Y_1: Relationship of Suite drawdown to GMU extraction (with error bars showing results of drawdown using levels from model's 95% prediction intervals)

Table 159 ***Predicted volumes for drawdown metrics***

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite L_Y_1 drawdowns (lower limit to upper limit)
5	30 (-2,700 – 4,100)
10	1,700 (-1,100 – 5,600)



	Volume (ML/year)	Drawdown over 20 years
PCV = 239	7,500	27.4 (16.3 - 35.7)
	7,000	25.9 (14.7 - 34.2)
	6,500	24.4 (13 - 32.7)
	6,000	22.9 (11.4 - 31.2)
	5,500	21.4 (9.7 - 29.7)
	5,000	19.9 (8.1 - 28.2)
	4,500	18.4 (6.4 - 26.7)
	4,000	16.9 (4.8 - 25.2)
	3,500	15.4 (3.1 - 23.7)
Av unit = 3,524	3,000	13.9 (1.5 - 22.2)
	2,500	12.4 (-0.2 - 20.7)
	2,000	10.9 (-1.8 - 19.2)
	1,500	9.4 (-3.5 - 17.7)
	1,000	7.9 (-5.1 - 16.2)
	500	6.4 (-6.8 - 14.7)
	0	4.9 (-8.4 - 13.2)

Legend

- Groundwater Management Units
- Lower Aquifer Suites
  - L_Y_1
  - L_Y_2
  - L_Y_3
- Rail
- Freeway & highway
- Park

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

GHD

DEECA
Sustainable Yields
Confined Aquifers

**GERANGAMETE GMA:
KEY SUITES
VOLUME VS DRAWDOWN**

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

FIGURE 438

G:\31\12564066\GIS\Maps\Deliverables\31_12564066_22_GerangameteDD_A3L_Rev0.mxd
Print date: 16 Jan 2024 - 11:06

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

26.6 GMU summary

26.6.1 Findings

Gerangamete GMA primarily relates to the Pebble Point Formation/Eastern View Formation aquifer (LTA). Groundwater was historically extracted through the Barwon Downs borefield for urban supply purposes but currently, limited extraction occurs from this GMA. The LTA falls within the Lower Aquifer Suites, which comprise L_AB_9 (0.2%), L_AC_1 (0.5%), L_AC_2 (2%), L_AD_1 (1%), L_Y_1 (21%), L_Y_2 (47%), L_Y_3 (23%), L_Y_5 (0.1%) and L_Z_1 (0.3%) in Gerangamete GMA, providing a total coverage of 95%. The identified representative Suites are L_Y_1 (most preferred) and L_Y_3. However, the hydrograph for L_Y_3 appeared to have erroneous data pre-1990; due to low confidence in the data, it has not been included in the assessment. The Suite hydrographs for the representative Suites L_Y_1 show an overall decreasing trend with periods of drawdown and recovery, likely influenced by periods of groundwater extraction.

The application of spatial distribution produced an improved model fit compared to the model run using just the annual recorded groundwater usage for the whole GMU. The quality of the result did increase when spatial distribution methodology was combined with hindcasting methodology for Suite L_Y_1 but decreased for Suite L_Y_3. The decrease in model statistics was expected for Suite L_Y_3 given the period of increased annual recovered levels near the commencement of pumping which does not align to the rest of the dataset.

Based on an assessment of all original model runs, none went back far enough to capture the pre-development level. Considering the need to include a longer historic record and this period in the calibration model but knowing that there was unlikely no licenced extraction prior to 1982/1983, the annual data for model run 1 was extended back to the pre-development period using 0 ML as the input volume forming model run 1a. This model had the highest R^2 and greatest number of observation points included of the calibration model runs and was adopted to undertake the predicative modelling for Suite L_Y_1. It’s noted that licences have not been renewed for the Barwon Downs borefield, thus the average use used in the predictive scenarios is higher than existing use which has likely impact the results.

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-developments level of 21.16 m for Suite L_Y_1. The drawdowns were calculated based on these pre-development levels and the simulated levels from each of the 19 forecast scenarios but only including data post 2020/2021 (inclusively) due to the amount of recovery data in the recorded dataset.

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

Drawdown (m)	Predicted volumes (ML) for GMU based on Suite L_Y_1 drawdowns (lower limit to upper limit)
5	30 (-2,700 – 4,100)
10	1,700 (-1,100 – 5,600)

The model for Suite L_Y_1 was assessed as having a “Poor” model applicability rating using the criteria outlined in section 5.2. There is a 6.5 m different between the recorded annual recovered level and the modelled annual recovered level at the taken pre-development date; this contributed to the y-intercept value. The issue around the differences in historical use versus what was used in the predictive scenarios has also probably contributed to this poor result.

26.6.2 Limitations

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

- The licenced bore dataset provided by DEECA has most extraction assigned to the Basement Aquifer, however, this was taken to be incorrectly assigned and thus was reassigned to the Lower Aquifer
- The hydrograph for L_Y_3 has what appears to be erroneous data pre-1990 (see graph below). Due to low confidence in the data, it has not been included in the assessment.

- 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.
- In order for the model to capture the pre-development period, the extraction input dataset needed to be extended back in time. This was done by adopted 0 ML/year extraction back to this time.
- There is a very low R^2 for the use-drawdown relationship developed using Suite L_Y_1
- A slightly different method in terms of the use-drawdown relationship had to be employed. This involved removing the recovery data from the graph which was affecting the use-drawdown relationship; this meant only data post calibration is included in the use-drawdown graph.

26.6.3 Recommendations

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

- The licenced bore dataset provided by DEECA appears to have VAF layers incorrectly assigned based on the bore information. It is recommended that DEECA obtains the relevant depth and aquifer monitored data for licenced bores within this GMU.
- It is recommended that DEECA review the water level data used to construct the Suite hydrograph for L_Y_3 and amend the dataset as needed