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Our ref:12528177-64267-3
Your ref:

Dear Rod

Mackas Sand
Groundwater Model Update

1 Background

GHD Pty Ltd (GHD) was engaged by Umwelt (Australia) Pty Ltd (Umwelt) to update the groundwater model for Mackas Sand, located in Salt Ash NSW, using meteorological data for the period 2011 to 2019. The sand quarry operates under Project Approval MP 08_0142 within Lots 218 and 220 (the site).

A transient groundwater flow model of the site was first developed by Umwelt in 2009 using Visual MODFLOW Pro Version 4.2 (Umwelt, 2009). A single sand layer model extending from bedrock at -23 m AHD to the ground surface was created for a 22.4 square kilometre area, which extends from the Pacific Ocean in the south-east to Tilligerry Creek in the north-west.

The groundwater model was updated in 2011 by Umwelt using Visual MODFLOW Pro Version 2009.1. The update included extending the model domain to the east and west to reduce edge effects, resulting in a larger model area of 32.5 km^2, refinement of the model ground surface, and inclusion of drain cells to represent the drainage system within the Tilligerry Creek catchment. Details regarding the calibration of this model and model predictions are outlined in Umwelt (2011). A figure showing the model domain, boundary conditions and groundwater monitoring bores used in model calibration is shown in Appendix A.

The NSW Department of Planning, Industry and Environment (DPIE) has requested Mackas Sand undertake a further update to the groundwater model and report on:

- How closely the groundwater model predictions align with groundwater levels measured from 2011 until the present, as part of a recalibration of the model.
- The impact of sand removal by the Mackas Sand operation on predicted groundwater levels. The removal of sand has changed the topographic surface in Lots 218 and 220. Is there any impact on groundwater levels caused by this change, such as an increase in groundwater levels beneath the extracted area or a change in groundwater gradients either to the Hunter Water emergency borefield or towards the Pacific Ocean?
- How any changes identified by this review may affect the maximum extraction depth map.

This letter report outlines the methodology and results of this current groundwater model update.

1.1 Limitations

A numerical groundwater model is a mathematical representation of a complex natural environment where parameters and processes can only be inferred from a finite number of measurements. Simplifications and assumptions are necessary in modelling. Efforts have been made to provide clarity on the data used to support the modelling and associated limitations. Findings presented in this report should be considered in this context.

This report has been prepared by GHD for Umwelt (Australia) Pty Ltd and may only be used and relied on by Umwelt (Australia) Pty Ltd for the purpose agreed between GHD and Umwelt (Australia) Pty Ltd as set out in Section 1 of this report.

GHD otherwise disclaims responsibility to any person other than Umwelt (Australia) Pty Ltd arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

2 Methodology

The Umwelt (2011) calibrated transient groundwater model has been used for the current update. For this assessment, MODFLOW 2005, built into the Visual MODFLOW Flex 6.1 software, was utilised. As part of this current update, no changes were made to the hydrogeological conceptualisation, model structure (i.e. surface topography or layer thickness), hydraulic parameters (i.e. hydraulic conductivity or aquifer storage) or evapotranspiration. In addition, no model calibration was undertaken or considered to be warranted.

The adopted input parameter values (from Umwelt, 2011) have been summarised in Table 1.

Table 1 Model input parameter values

Parameters	Value
Specific Yield (S_y)	0.12
Specific Storage (S_s)	1×10^{-5} 1/m
Horizontal hydraulic conductivity (K_x and K_y) of dunes (zone #1)	13 m/day
Horizontal hydraulic conductivity of (K_x and K_y) of inter-barrier depression (zone #2)	5 m/day

Parameters	Value
Vertical hydraulic conductivity (K_z) for zones 1 and 2	0.05 m/day
Effective Porosity	15%
Total Porosity	30%
Recharge	35% of rainfall (data from station 061078)
Evapotranspiration	60% of pan evaporation
Evaporation Extinction Depth	2.5 m
Drain Elevation	0 to 1 m AHD
Drain Conductance	10 m/day
Constant head at Tilligery Creek	0.4 m AHD
Constant head at Pacific Ocean	0 m AHD

2.1 Model updates

The following updates were made to the Umwelt (2011) groundwater model.

2.1.1 Stress periods and time steps

The monthly time steps were extended to the end of 2019 such that the transient model period was from January 1997 to December 2019 (276 time-steps in total). As in Umwelt (2011), the transient model was run using the monthly 'Relative Date'. The equivalent 'Real Dates' for each time-step is provided in Appendix B. Quarterly stress periods were adopted, made up of three time steps.

2.1.2 Initial head

The model was run under steady state conditions to establish initial heads for the transient model. Parameters outlined in Table 1 were adopted in the steady state run. The initial starting head for the steady state model was equal to the groundwater surface (model default).

2.1.3 Recharge

Monthly meteorological data for the extended period (from September 2011 to December 2019) was obtained from the Australian Bureau of Meteorology (BoM) Williamtown RAAF Base station (station no. 061078).

Rainfall recharge was calculated for each quarterly stress period. Since recharge is in units of mm/year, raw monthly rainfall was first converted to accumulated quarterly totals, multiplied by four to obtain the equivalent annual rainfall rate (mm/year) and then multiplied by 0.35 to obtain the representative rate of groundwater recharge. Rainfall infiltration inputs for each stress period are provided in Appendix C.

2.1.4 Boundary conditions

The Umwelt (2011) groundwater model was constructed using two constant head boundaries, one to the north-west to represent Tilligerry Creek and one to the south-east to represent the Pacific Ocean. Heads assigned to these boundaries are shown in Table 1. A series of drain cells are also included between the Holocene Dunes and Tilligerry Creek to represent the Tilligerry Creek drainage system.

In the current groundwater model update, these boundary conditions were retained and extended to December 2019 with no changes to head or conductance values.

2.1.5 Groundwater observed data

Observed groundwater monitoring data for groundwater monitoring bores SP1-SP5 and BL158 between September 2011 and December 2019 were input into the model to update the observation datasets within the existing model. This data is shown in Table 2.

Table 2 Observed groundwater levels from September 2011 to December 2019 (m AHD)

Date	SP1	SP2	SP3	SP4	SP5	BL158
23/09/2011	2.08	2.56	2.51	0.97	3.33	2.91
23/10/2011	2.1	2.41	2.39	0.8	3.27	2.72
22/11/2011	2.01	2.32	2.35	1	3.24	2.63
24/12/2011	1.85	2.1	2.11	0.84	3.19	2.5
25/01/2012	1.81	2.18	2.26	0.78	3.08	3
23/02/2012	1.98	2.45	2.38	0.93	3.23	3.09
22/05/2012	2.35	2.78	2.7	0.97	3.3	2.81
25/09/2012	1.81	2.71	2.58	0.85	3.29	2.43
4/01/2013	1.8	2.04	2.17	0.64	2.76	1.95
2/04/2013	2.05	2.94	2.5	0.94	3.12	2.46
3/09/2013	2.35	2.6	2.49	0.83	3.3	2.38
6/01/2014	2.45	2.72	2.26	0.6	2.92	2.15
15/04/2014	1.88	2.13	1.91	0.7	2.67	1.75
31/05/2014	2.1	2.26	1.86	0.64	3.1	1.8
3/10/2014	2.05	2.24	2.17	0.59	2.72	1.78
12/01/2015	2	2.19	2.07	0.41	2.57	1.77
25/02/2015	2.1	2.33	1.86	-0.03	2.57	1.81
13/05/2015	2.51	3.43	2.49	0.77	3.1	2.06
31/08/2015	2.16	3.15	2.45	0.8	3.37	2.36
18/11/2015	2.05	3.1	2.44	0.7	3.16	2.22
14/04/2016	2.36	2.9	2.31	0.6	3.49	3
30/06/2016	2.16	2.92	2.57	0.75	3.41	2.36
13/10/2016	1.9	2.6	2.32	0.9	3.05	2.18
29/12/2016	1.58	2.21	2.09	0.78	2.8	2.04
23/03/2017	1.3	2.15	1.9	-0.25	2.79	2.16
16/06/2017	-	2.33	2.12	1.11	2.99	2.06
6/09/2017	1.15	1.95	1.96	0.83	2.82	1.92
19/12/2017	0.86	1.81	1.37	0.42	2.48	1.62
23/04/2018	1.28	2.05	1.6	0.61	2.36	1.61
26/06/2018	1.69	2.54	2.53	1.14	2.98	2.1
25/09/2018	1.67	2.8	1.99	0.91	2.72	1.88
10/12/2018	1.39	2.43	1.89	0.72	2.55	1.73
14/03/2019	1.06	1.95	1.46	0.42	2.08	1.36
24/06/2019	1.29	2.41	1.64	1.01	2.32	1.53
16/09/2019	1.44	2.41	1.75	0.66	2.38	1.71
11/12/2019	1.22	2.04	1.6	0.28	2.21	1.64

3 Model results and discussion

Modelled and observed groundwater levels at each bore (SP1-SP5 and BL158) between January 1997 and December 2019 are shown in Appendix D. The green line represents the final time step of the Umwelt (2011) model (i.e. August 2011). The horizontal red line represents the maximum modelled groundwater level from Umwelt (2011).

As expected, the modelled groundwater levels up to August 2011 closely match the modelled levels from the Umwelt (2011) model with the modelled maximum generally matching the Umwelt (2011) modelled maximum. Any slight differences are attributable to the use of MODFLOW 2005 in the current update compared to MODFLOW 2000 and the use of three monthly stress periods (compared to one monthly stress periods with the previous model).

There is a reasonably close match between modelled and observed groundwater levels between September 2011 and December 2019, particularly at SP4 and BL158. Modelled levels generally over-predict observed levels at SP1 and under-predict at SP2, SP3 and SP5. There is a reasonably similar response in the modelled and observed hydrographs at each bore to wet and dry periods.

Differences between modelled and observed levels are most likely to be attributable to:

- Time resolution of the model. Stress periods are three monthly which means that the effects of high rainfall events are suppressed in the model. It was necessary to change the stress period from monthly to three monthly in the extended model due to limitations on the number of allowable stress periods in MODFLOW.
- Quarrying operations outside Lots 218 and 220 that are not considered in the model. There are a number of quarries in close proximity to Mackas Sand. In particularly, it is noted that groundwater monitoring bore SP2 is very close to an adjacent operation.
- The parameters applied to the drain cells and the degree to which they represent the Tilligerry Creek drainage system and changes over time.

Table 3 shows the maximum observed and modelled groundwater levels for each bore. Modelled levels are shown for the extended period (2011-2019) as well as for the full model period (1997-2019) and are based on the current model update.

The modelled maximum groundwater level for each bore occurred in June 1999. The modelled maximum levels predicted between 2011 and 2019 remain below the June 1999 maximums. The maximum extraction depth map in Umwelt (2011) was based on the maximums from June 1999.

Maximum observed groundwater levels for SP1, SP4, SP5 and BL158 remain below the modelled maximums. The observed maximum at SP2 occurred in May 2015 and is higher than the modelled maximum at this location by 0.61 m. The maximum observed level at SP3 occurred in May 2012 and is slightly higher than the modelled maximum (by 0.06 m).

Table 3 Maximum observed and modelled groundwater levels

Bore	Maximum Groundwater Level (m AHD)		
	Observed 1997-2019	Modelled (1997-2019)	Modelled (2011-2019)
	Time, Head	Time, Head	Time, Head
SP1	(5/2015), 2.51	(6/1999), 3.66	(6/2015), 3.13
SP2	(5/2015), 3.43	(6/1999), 2.82	(6/2015), 2.48
SP3	(5/2012), 2.7	(6/1999), 2.64	(6/2015), 2.33
SP4	(6/2018), 1.14	(6/1999), 1.33	(6/2015), 1.15
SP5	(4/2016), 3.49	(6/1999), 3.77	(6/2015), 2.88
BL158	(8/1999), 3.52	(6/1999), 3.56	(6/2015), 2.93

The observed groundwater levels at SP2 (and to a lesser extent SP3) have consistently been above the corresponding model prediction compared to other bores at Lot 220 between September 2011 and December 2019 (refer Appendix D), whereas the groundwater model predicts a higher groundwater level at SP1 relative to other bores at Lot 220 and a flow gradient across Lot 220 from SP1 to SP4. Therefore, actual groundwater contours across Lot 220 have remained consistent over this period despite the higher observed levels at SP2 and SP3 above modelled maximums.

The discrepancy between modelled and predicted levels in the vicinity of SP2 are most likely attributable to off-site activities that are unknown and cannot be replicated by the model. It is unlikely that changes in landform between 2011 and 2019 resulted in the higher levels in observed levels at SP2 and SP3 above modelled maximums since they have been consistently elevated relative to other bores at Lot 220 over this period. It is noted that there has been no interception of groundwater during sand extraction activities at Lots 218 and 220.

Further, it is noted that the depth to groundwater at SP2 and SP3 is generally greater than 4 m and therefore it is unlikely that changes to evapotranspiration is having much effect on groundwater levels at these locations.

4 Conclusion

The groundwater model for Mackas Sand has been extended to the end of December 2019. No changes have been made to the hydrogeological conceptualisation, model structure or hydraulic parameters. Modelled and observed groundwater levels for groundwater monitoring bores SP1-SP5 and BL158 have been compared over the period September 2011 to December 2019.

Overall there is a reasonable match between modelled and observed groundwater levels and there is a similar response in the modelled and observed hydrographs at each bore for wet and dry periods. Discrepancies between modelled and observed levels are attributable to the time resolution of the model, off-site activities not considered in the model and the representation of the Tilligerry Creek drainage system.

The modelled groundwater levels between September 2011 and December 2019 remain below the maximum modelled groundwater levels reported in Umwelt (2011). Maximum observed levels at SP1, SP4, SP5 and BL158 remain below the maximum modelled levels at these locations, while the observed maximums at SP2 and SP3 are higher than the modelled maximums. Review of observed groundwater level data indicates that observed groundwater levels at SP2 (and to a lesser extent SP3) have consistently been higher than other bores at Lot 220 between September 2011 and December 2019 and, as such, groundwater flow patterns across Lot 220 have not changed over this period despite the changes in landform.

Since there is a good match between modelled and observed groundwater levels across the model domain it is not considered that re-calibration of the model is required at this time. The localised higher observed levels at Lot 220, particularly at SP2, are most likely due to off-site activities that cannot be replicated in the model.

Overall, it is considered that the modelled maximum groundwater levels presented in Table 3 still provide a reasonable indication of maximum groundwater levels across the model domain and it is noted that there has been no interception of groundwater during sand extraction activities at Lots 218 and 220. Therefore it is not considered necessary to update the maximum extraction depth map at this time.

5 References

Umwelt (Australia) Pty Limited, 2009. Environmental Assessment of Sand Extraction Operation from Lot 218 DP 1044608 and Lot 220 DP 1049608, Salt Ash. Report Prepared for Mackas Sand.

Umwelt (Australia) Pty Limited, 2011. Determination of Maximum Predicted Groundwater Level and Maximum Extraction Level at Lot 2018 and 220, Salt Ash. Report Prepared for Mackas Sand.

Sincerely

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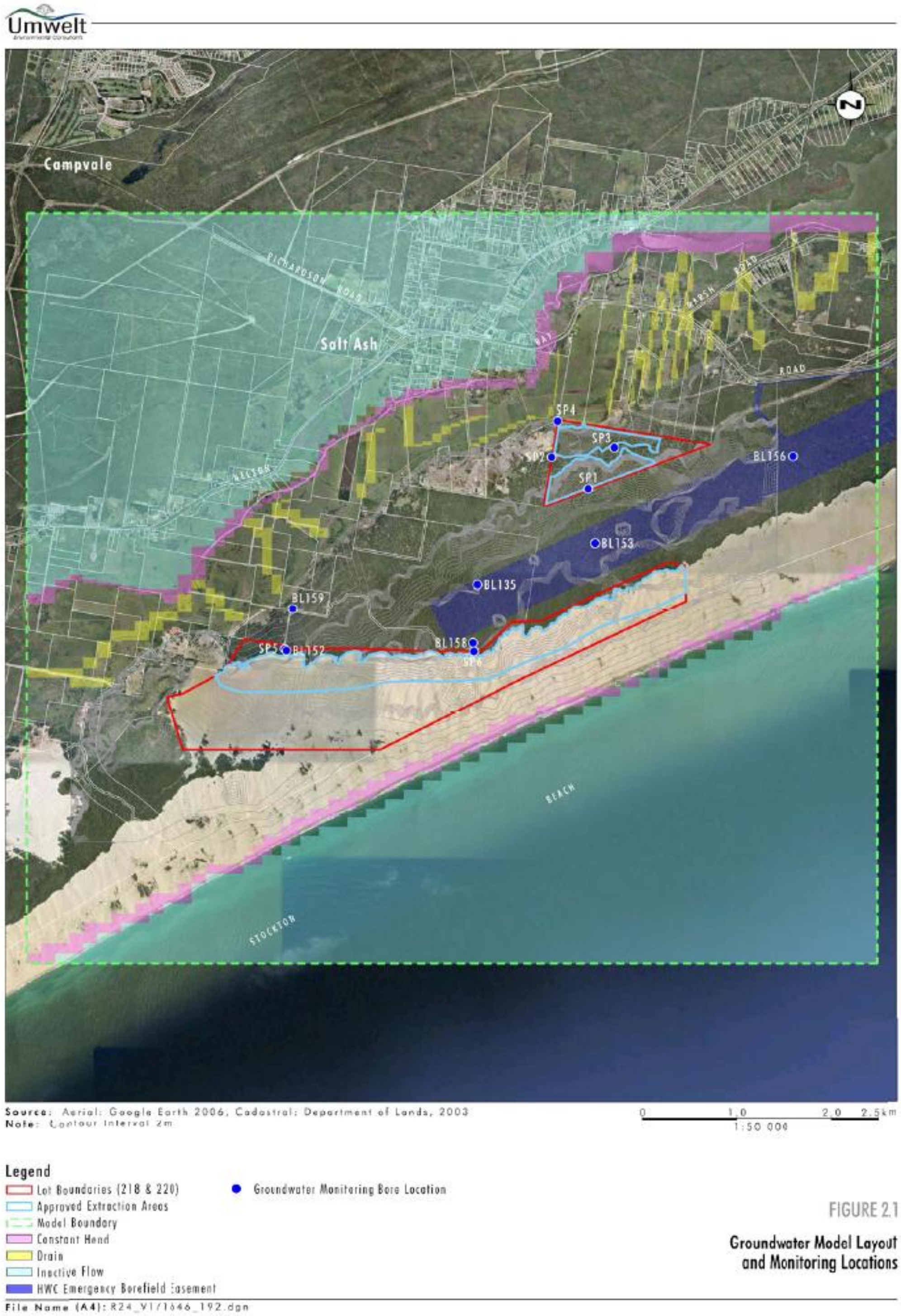
Appendix A Model domain (from Umwelt, 2011)



Appendix B Date/time classification

Time steps	Relative date	Real date	Time steps	Relative date	Real date	Time steps	Relative date	Real date
t1	31	1/01/1997	t54	1642	1/06/2001	t107	3256	1/11/2005
t2	59	1/02/1997	t55	1673	1/07/2001	t108	3287	1/12/2005
t3	90	1/03/1997	t56	1704	1/08/2001	t109	3318	1/01/2006
t4	120	1/04/1997	t57	1734	1/09/2001	t110	3346	1/02/2006
t5	151	1/05/1997	t58	1765	1/10/2001	t111	3377	1/03/2006
t6	181	1/06/1997	t59	1795	1/11/2001	t112	3407	1/04/2006
t7	212	1/07/1997	t60	1826	1/12/2001	t113	3438	1/05/2006
t8	243	1/08/1997	t61	1857	1/01/2002	t114	3468	1/06/2006
t9	273	1/09/1997	t62	1885	1/02/2002	t115	3499	1/07/2006
t10	304	1/10/1997	t63	1916	1/03/2002	t116	3530	1/08/2006
t11	334	1/11/1997	t64	1946	1/04/2002	t117	3560	1/09/2006
t12	365	1/12/1997	t65	1977	1/05/2002	t118	3591	1/10/2006
t13	396	1/01/1998	t66	2007	1/06/2002	t119	3621	1/11/2006
t14	424	1/02/1998	t67	2038	1/07/2002	t120	3652	1/12/2006
t15	455	1/03/1998	t68	2069	1/08/2002	t121	3683	1/01/2007
t16	485	1/04/1998	t69	2099	1/09/2002	t122	3711	1/02/2007
t17	516	1/05/1998	t70	2130	1/10/2002	t123	3742	1/03/2007
t18	546	1/06/1998	t71	2160	1/11/2002	t124	3772	1/04/2007
t19	577	1/07/1998	t72	2191	1/12/2002	t125	3803	1/05/2007
t20	608	1/08/1998	t73	2222	1/01/2003	t126	3833	1/06/2007
t21	638	1/09/1998	t74	2250	1/02/2003	t127	3864	1/07/2007
t22	669	1/10/1998	t75	2281	1/03/2003	t128	3895	1/08/2007
t23	699	1/11/1998	t76	2311	1/04/2003	t129	3925	1/09/2007
t24	730	1/12/1998	t77	2342	1/05/2003	t130	3956	1/10/2007
t25	761	1/01/1999	t78	2372	1/06/2003	t131	3986	1/11/2007
t26	789	1/02/1999	t79	2403	1/07/2003	t132	4017	1/12/2007
t27	820	1/03/1999	t80	2434	1/08/2003	t133	4048	1/01/2008
t28	850	1/04/1999	t81	2464	1/09/2003	t134	4077	1/02/2008
t29	881	1/05/1999	t82	2495	1/10/2003	t135	4108	1/03/2008
t30	911	1/06/1999	t83	2525	1/11/2003	t136	4138	1/04/2008
t31	942	1/07/1999	t84	2556	1/12/2003	t137	4169	1/05/2008
t32	973	1/08/1999	t85	2587	1/01/2004	t138	4199	1/06/2008
t33	1003	1/09/1999	t86	2616	1/02/2004	t139	4230	1/07/2008
t34	1034	1/10/1999	t87	2647	1/03/2004	t140	4261	1/08/2008
t35	1064	1/11/1999	t88	2677	1/04/2004	t141	4291	1/09/2008
t36	1095	1/12/1999	t89	2708	1/05/2004	t142	4322	1/10/2008
t37	1126	1/01/2000	t90	2738	1/06/2004	t143	4352	1/11/2008
t38	1155	1/02/2000	t91	2769	1/07/2004	t144	4383	1/12/2008
t39	1186	1/03/2000	t92	2800	1/08/2004	t145	4414	1/01/2009
t40	1216	1/04/2000	t93	2830	1/09/2004	t146	4442	1/02/2009
t41	1247	1/05/2000	t94	2861	1/10/2004	t147	4473	1/03/2009
t42	1277	1/06/2000	t95	2891	1/11/2004	t148	4503	1/04/2009
t43	1308	1/07/2000	t96	2922	1/12/2004	t149	4534	1/05/2009
t44	1339	1/08/2000	t97	2953	1/01/2005	t150	4564	1/06/2009
t45	1369	1/09/2000	t98	2981	1/02/2005	t151	4595	1/07/2009
t46	1400	1/10/2000	t99	3012	1/03/2005	t152	4626	1/08/2009
t47	1430	1/11/2000	t100	3042	1/04/2005	t153	4656	1/09/2009
t48	1461	1/12/2000	t101	3073	1/05/2005	t154	4687	1/10/2009
t49	1492	1/01/2001	t102	3103	1/06/2005	t155	4717	1/11/2009
t50	1520	1/02/2001	t103	3134	1/07/2005	t156	4748	1/12/2009
t51	1551	1/03/2001	t104	3165	1/08/2005	t157	4779	1/01/2010
t52	1581	1/04/2001	t105	3195	1/09/2005	t158	4807	1/02/2010
t53	1612	1/05/2001	t106	3226	1/10/2005	t159	4838	1/03/2010

Time steps	Relative date	Real date	Time steps	Relative date	Real date	Time steps	Relative date	Real date
t160	4868	1/04/2010	t208	6329	1/04/2014	t263	8003	1/11/2018
t161	4899	1/05/2010	t209	6360	1/05/2014	t264	8034	1/12/2018
t162	4929	1/06/2010	t210	6390	1/06/2014	t265	8065	1/01/2019
t163	4960	1/07/2010	t211	6421	1/07/2014	t266	8093	1/02/2019
t164	4991	1/08/2010	t212	6452	1/08/2014	t267	8124	1/03/2019
t165	5021	1/09/2010	t213	6482	1/09/2014	t268	8154	1/04/2019
t166	5052	1/10/2010	t214	6513	1/10/2014	t269	8185	1/05/2019
t167	5082	1/11/2010	t215	6543	1/11/2014	t270	8215	1/06/2019
t168	5113	1/12/2010	t216	6574	1/12/2014	t271	8246	1/07/2019
t169	5144	1/01/2011	t217	6605	1/01/2015	t272	8277	1/08/2019
t170	5172	1/02/2011	t218	6633	1/02/2015	t273	8307	1/09/2019
t171	5203	1/03/2011	t219	6664	1/03/2015	t274	8338	1/10/2019
t172	5233	1/04/2011	t220	6694	1/04/2015	t275	8368	1/11/2019
t173	5264	1/05/2011	t221	6725	1/05/2015	t276	8399	1/12/2019
t174	5294	1/06/2011	t222	6755	1/06/2015			
t175	5325	1/07/2011	t223	6786	1/07/2015			
t176	5356	1/08/2011	t224	6817	1/08/2015			
t177	5386	1/09/2011	t225	6847	1/09/2015			
t178	5417	1/10/2011	t226	6878	1/10/2015			
t179	5447	1/11/2011	t227	6908	1/11/2015			
t180	5478	1/12/2011	t228	6939	1/12/2015			
t181	5509	1/01/2012	t229	6970	1/01/2016			
t182	5537	1/02/2012	t230	6998	1/02/2016			
t183	5568	1/03/2012	t231	7029	1/03/2016			
t184	5598	1/04/2012	t232	7059	1/04/2016			
t185	5629	1/05/2012	t233	7090	1/05/2016			
t186	5659	1/06/2012	t234	7120	1/06/2016			
t187	5690	1/07/2012	t235	7151	1/07/2016			
t188	5721	1/08/2012	t236	7182	1/08/2016			
t189	5751	1/09/2012	t237	7212	1/09/2016			
t190	5782	1/10/2012	t238	7243	1/10/2016			
t191	5812	1/11/2012	t239	7273	1/11/2016			
t192	5843	1/12/2012	t240	7304	1/12/2016			
t193	5874	1/01/2013	t241	7335	1/01/2017			
t194	5902	1/02/2013	t242	7363	1/02/2017			
t195	5933	1/03/2013	t243	7394	1/03/2017			
t196	5963	1/04/2013	t244	7424	1/04/2017			
t197	5994	1/05/2013	t245	7455	1/05/2017			
t198	6024	1/06/2013	t246	7485	1/06/2017			
t199	6055	1/07/2013	t247	7516	1/07/2017			
t200	6086	1/08/2013	t248	7547	1/08/2017			
t201	6116	1/09/2013	t249	7577	1/09/2017			
t202	6147	1/10/2013	t250	7608	1/10/2017			
t203	6177	1/11/2013	t251	7638	1/11/2017			
t204	6208	1/12/2013	t252	7669	1/12/2017			
t205	6239	1/01/2014	t253	7700	1/01/2018			
t206	6268	1/02/2014	t254	7728	1/02/2018			
t207	6299	1/03/2014	t255	7759	1/03/2018			
t208	6329	1/04/2014	t256	7789	1/04/2018			
t209	6360	1/05/2014	t257	7820	1/05/2018			
t210	6390	1/06/2014	t258	7850	1/06/2018			
t204	6208	1/12/2013	t259	7881	1/07/2018			
t205	6239	1/01/2014	t260	7912	1/08/2018			
t206	6268	1/02/2014	t261	7942	1/09/2018			
t207	6299	1/03/2014	t262	7973	1/10/2018			

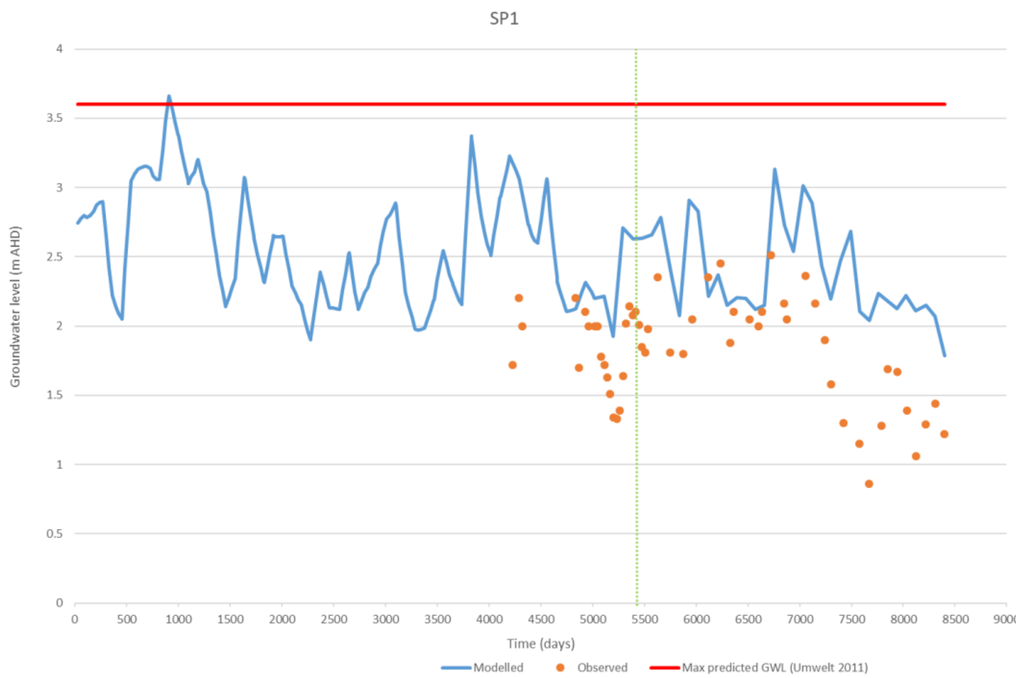
Appendix C Rainfall recharge

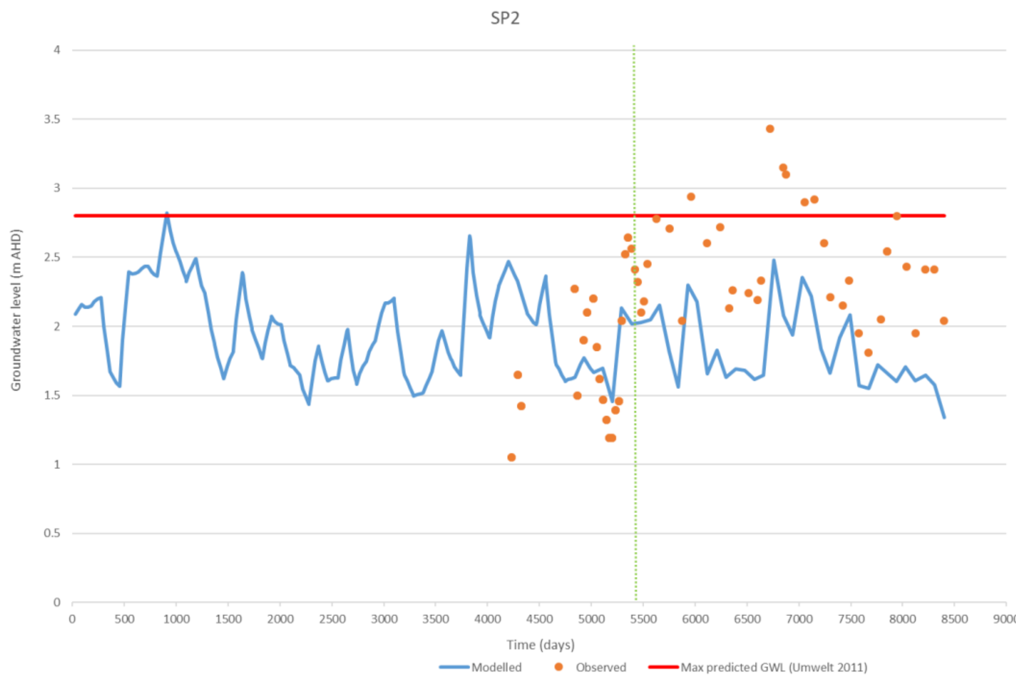
Time steps	Days	Rainfall recharge (mm/yr)
t3	9.00E+01	494.48
t6	1.81E+02	428.12
t9	2.73E+02	456.12
t12	3.65E+02	132.16
t15	4.55E+02	266.28
t18	5.46E+02	842.24
t21	6.38E+02	512.68
t24	7.30E+02	563.08
t27	8.20E+02	519.12
t30	9.11E+02	800.52
t33	1.00E+03	415.52
t36	1.10E+03	422.8
t39	1.19E+03	638.4
t42	1.28E+03	357.56
t45	1.37E+03	190.96
t48	1.46E+03	206.92
t51	1.55E+03	461.44
t54	1.64E+03	740.04
t57	1.73E+03	237.16
t60	1.83E+03	279.16
t63	1.92E+03	579.04
t66	2.01E+03	391.72
t69	2.10E+03	200.2
t72	2.19E+03	304.08
t75	2.28E+03	199.08
t78	2.37E+03	526.96
t81	2.46E+03	203
t84	2.56E+03	327.88
t87	2.65E+03	574.28
t90	2.74E+03	143.92
t93	2.83E+03	382.76
t96	2.92E+03	461.16
t99	3.01E+03	605.08
t102	3.10E+03	483.56
t105	3.20E+03	94.08
t108	3.29E+03	213.08
t111	3.38E+03	306.6
t114	3.47E+03	384.72
t117	3.56E+03	509.88
t120	3.65E+03	291.48
t123	3.74E+03	296.24

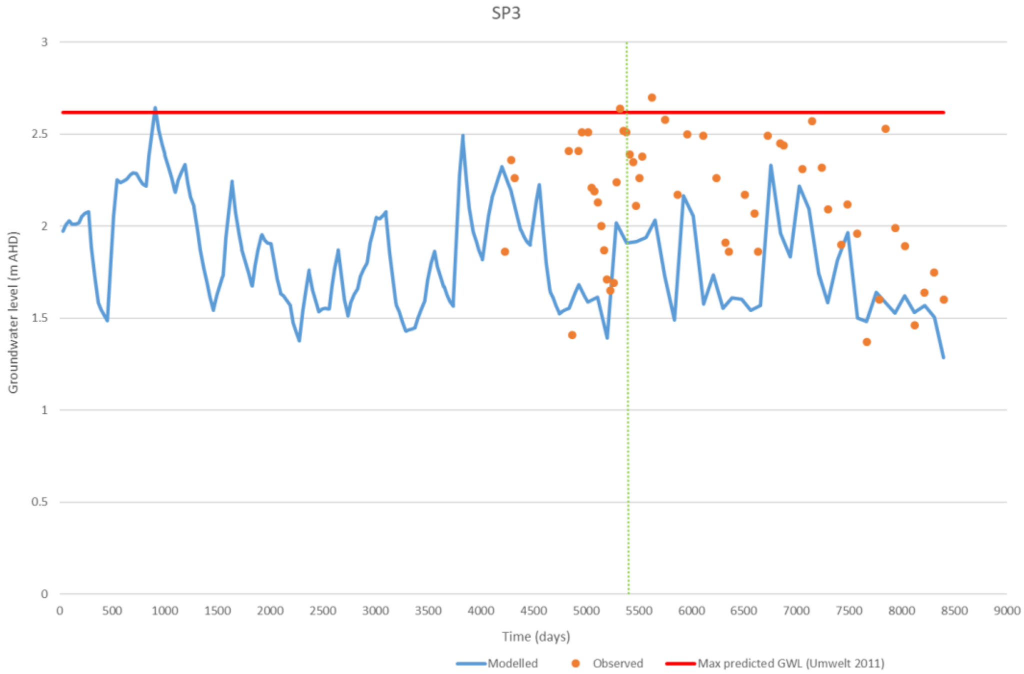
Time steps	Days	Rainfall recharge (mm/yr)
t126	3.83E+03	990.08
t129	3.93E+03	240.24
t132	4.02E+03	334.04
t135	4.11E+03	655.2
t138	4.20E+03	609
t141	4.29E+03	428.4
t144	4.38E+03	356.44
t147	4.47E+03	419.44
t150	4.56E+03	646.52
t153	4.66E+03	99.96
t156	4.75E+03	255.08
t159	4.84E+03	338.8
t162	4.93E+03	393.96
t165	5.02E+03	262.08
t168	5.11E+03	343.84
t171	5.20E+03	188.44
t174	5.29E+03	721.28
t177	5.39E+03	410.76
t180	5.48E+03	436.52
t183	5.57E+03	448.56
t186	5.66E+03	512.12
t189	5.75E+03	240.52
t192	5.84E+03	183.12
t195	5.93E+03	803.04
t198	6.02E+03	448.84
t201	6.12E+03	139.16
t204	6.21E+03	428.68
t207	6.30E+03	240.8
t210	6.39E+03	356.16
t213	6.48E+03	329.56
t216	6.57E+03	288.68
t219	6.66E+03	332.64
t222	6.76E+03	866.88
t225	6.85E+03	309.68
t228	6.94E+03	340.48
t231	7.03E+03	693.84
t234	7.12E+03	446.46
t237	7.21E+03	221.48
t240	7.30E+03	244.16
t243	7.39E+03	495.04
t246	7.49E+03	513.52
t249	7.58E+03	100.8
t252	7.67E+03	273.56

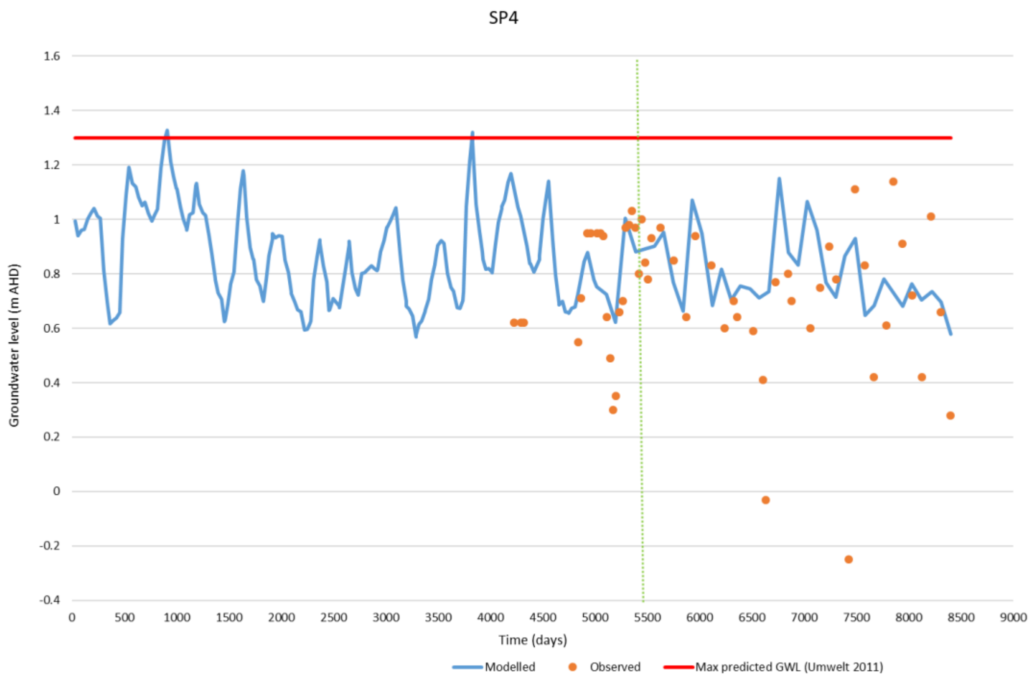
Time steps	Days	Rainfall recharge (mm/yr)
t255	7.76E+03	411.04
t258	7.85E+03	498.68
t261	7.94E+03	181.72
t264	8.03E+03	372.96
t267	8.12E+03	271.6
t270	8.22E+03	336.56
t273	8.31E+03	276.36
t276	8.40E+03	136.64

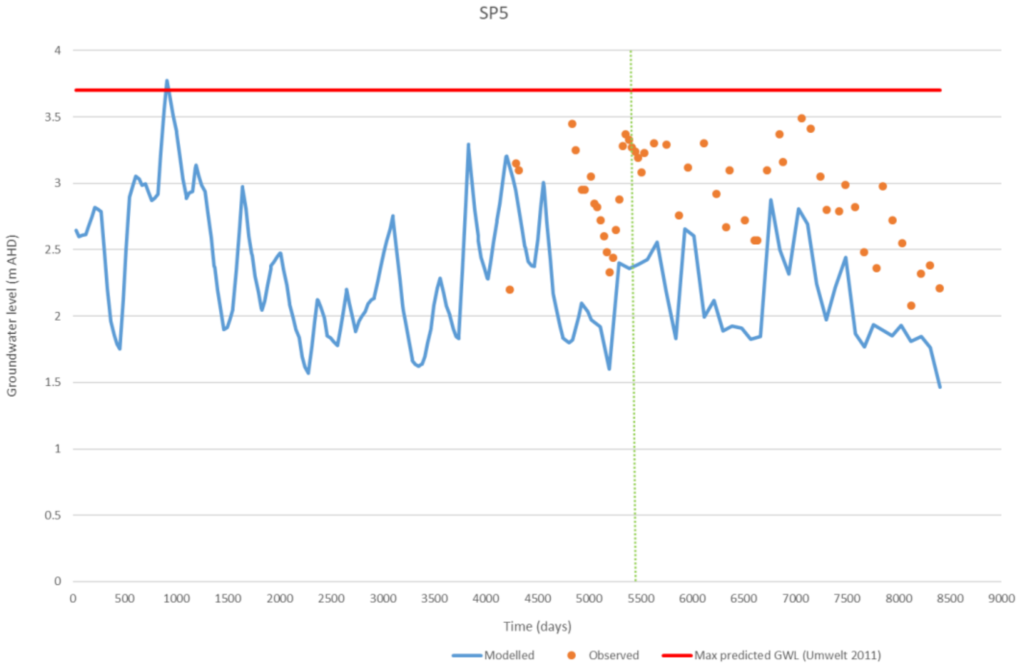
Appendix D Groundwater hydrographs

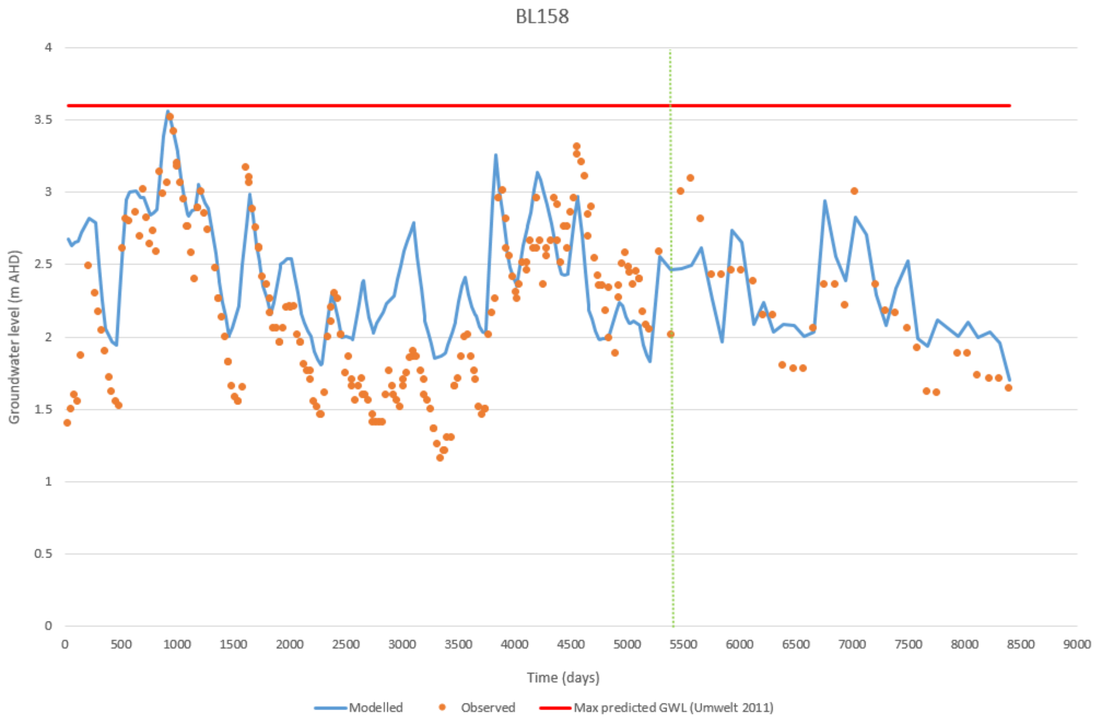





SP3
Groundwater level (m AHD)
Time (days)
Modelled
Observed
Max predicted GWL (Umwelt 2011)


SP4
Groundwater level (m AHD)
Time (days)
Modelled
Observed
Max predicted GWL (Umwelt 2011)


SP5
Groundwater level (m AHD)
Time (days)
Modelled
Observed
Max predicted GWL (Umwelt 2011)


BL158
Groundwater level (m AHD)
Time (days)
Modelled
Observed
Max predicted GWL (Umwelt 2011)