REPORT

WestConnex Stage 2 New M5

24 Month Groundwater Model Review

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1.0 INTRODUCTION

1.1 Project background

Golder Associates (Golder) have prepared this report on behalf of the CPB Dragados Samsung Joint Venture (CDS-JV) who are the primary contractor constructing the project. Planning approvals for the WestConnex Stage 2 (WCX2) New M5 project include requirements relating to impacts of tunnelling including groundwater capture, drawdown and quality. As part of the approval application process, a numerical groundwater flow model was developed during detailed design and was used to estimate changes in groundwater levels and flow directions induced by tunnel construction and operation, and groundwater flow rates into the tunnels. The development of the regional model and predictive estimates from the model of groundwater drawdown and flow into the tunnels were presented in the Hydrogeological Design Report (M5N-GOL-DPK-100-200-GT-1526-R, dated 13 April 2017).

Condition B27 of the WCX New M5 Conditions of Approval (CoA) states that the groundwater model must be updated when 24 months of groundwater monitoring data becomes available. CPB Dragados Samsung Joint Venture (CDS-JV) has undertaken a project-wide groundwater monitoring program across the WCX2 Project Corridor, referred to as the Baseline Groundwater Monitoring Network. Some of the bores in this network were installed prior to project award, and thus have monitoring records which extend back to well before construction commenced. Other bores in this network were installed by CDS-JV prior to the commencement of construction. The Groundwater Baseline Report (M5N-GOL-TER-100-200-GT-1511) documented pre-construction groundwater conditions along the Project Corridor from November 2014 to August 2016. Initial construction for the project commenced in September/October 2016, including construction of adits and declines to access the mainline tunnels. Following the initial Baseline report, Groundwater Monitoring Progress Reports were issued covering the following periods:

- August 2016 to December 2016;
- December 2016 to June 2017;
- July 2017 to December 2017; and
- January 2018 and June 2018.

Installation of the groundwater monitoring bores used for these reports was substantially complete and initial monitoring results were available for the majority of these bores by the end of May 2016. Updating of the groundwater model for the current report has utilised groundwater level monitoring results from the 24 month period from 31 May 2016 to 31 May 2018.

Estimates of groundwater inflow rates into the tunnels, adits and declines excavations are available for the combined lengths of underground excavations reporting to the Bexley, Arncliffe and St Peter's Interchange (SPI) sites. Estimates of groundwater inflow rates for water collected at the Kingsgrove site is unavailable since no measurements of inflow have been made at this site.

The following report provides details of the update to the regional groundwater model for the project, and updates estimates of long-term inflow and drawdown calculated using the updated project-wide model. The revised modelling outputs have been compared to Condition B26 of the WCX New M5 Conditions of Approval (CoA) which states that the Proponent must "take all feasible and reasonable measured to limit operational groundwater inflows into tunnel to no greater than one litre per second across any given kilometre"

1.2 Objective and scope

The objective of the work presented in this report is to update the regional groundwater model based on the data available from measured inflows and drawdown response and to provide confidence that the predictions of likely long-term impact on the regional groundwater system made using the original model remain valid.

Two models were developed for the Hydrogeological Design Report (M5N-GOL-DPK-100-200-GT-1526-R) – a regional scale model and a local scale model for the Arncliffe area. Only the regional scale model was run as a transient simulation for M5N-GOL-DRT-100-200-GT-1526-R, taking into account the anticipated construction sequence at the time. This regional model has been used as the basis for the 24 Month model update, to allow an assessment of regional scale impacts and to allow an assessment of the transient conditions as impacted by the construction sequence to date. The original regional scale model presented in M5N-GOL-DRT-100-200-GT-1526-R is referred to herein as the 2017 model.

Updating of the regional scale model involved the following:

- Collating updated groundwater monitoring data (based on information from the SOLDATA online instrumentation and monitoring portal).
- Estimating net tunnel groundwater inflow rates by comparing measurements of water inflows to the tunnel (measured usage of water for drilling and other construction related activities on site) with measured volumes of water treated in water treatment plants (WTPs). The difference between volume of water treated at the WTPs over a period of time, and the volume of water used in construction over the same period of time provides an estimation of average groundwater inflows for each site. Measurements of water usage and treatment volumes are available as monthly totals for Bexley, Arncliffe and SPI. Data for Kingsgrove is not available.
- Updating the original (anticipated) tunnel excavation schedule in the project-wide model with the actual excavation schedule achieved in the field. Tunnel excavation progress has been sourced from Golder weekly reports provided to CDS-JV which include an estimate of tunnel excavation meterage. Details of the single Arncliffe decline that was included in the original model is different to the twin declines that have been constructed. A greater length of decline tunnels has been constructed than was originally planned, with a tunnel extending to the north and joining the mainline tunnels beneath the Cooks River, and another tunnel turning back to the south to join the mainline tunnels further south.
- Re-running the model with the above modifications to simulate groundwater response using the updated (actual) excavation schedule, and updated geometry of temporary tunnels at Arncliffe. The updated model with these modifications is referred to herein as the 'modified original model (2018-A model)'.
- Comparing 2016-2018 monitoring data to the simulation results produced by the 2018-A model for the same period.
- Identifying areas of deviation between modelled simulation results and monitoring data. Minor modifications were made to the model to improve the match between observed inflow and drawdown and the modelled values. The model with the adjusted parameters is referred to herein as the 2018-B model.

After updating the groundwater numerical model, predictive simulations have been undertaken to update estimates of long-term groundwater drawdown and groundwater inflow to the tunnels.

The development of the model including the choice of grid, layer, and hydraulic parameters, and original predictive estimates from the model of groundwater drawdown and flow into the tunnel are not described in this report but were presented in M5N-GOL-DRT-100-200-GT-1526-R. This report only presents the update and changes made to the 2017 regional scale model and the updated predictive simulations obtained by running model 2018-A and model 2018-B. This report should be read in conjunction with M5N-GOL-DRT-100-200-GT-1526-R.

As noted above, the local scale model for the Arncliffe area was not updated as part of the current report. In the original Hydrogeological Design Report this model was formulated and run as a steady-state model, representing the condition after proposed grouting in the area (including in-tunnel grouting) is completed; tunnelling in this area is completed; temporary access tunnels have been sealed; and the hydrogeological system has reached a steady-state condition in response to the stress imposed on the system by the permanent configuration of underground drainage. The steady state condition will not be reached until some time after the completion of construction works. This model is therefore inherently unsuited to use for assessing the transient conditions that exist while grouting and tunnelling activities continue, and thus can not be updated based on the 2 years of monitoring data considered in this report. Furthermore, measurement of inflow is only practically possible for substantial lengths of tunnel from which inflow is amalgamated at sumps. Revising the local-scale model for the Arncliffe area based on transient drawdown data available to date would represent a substantial revision to the model requiring a much finer resolution of inflow measurements than is practically possible, combined with detailed observations of structural geological features during tunneling.

It is noted that while updating of the local-scale model has not been undertaken for the current report, monitoring results and observations for groundwater inflow, groundwater level monitoring data, and settlement monitoring data are all considered on a regular basis and are taken into account in the decision making regarding ongoing grouting that is being undertaken to limit groundwater inflow to the extent that is reasonable and feasible to achieve.

2.0 FIELD DATA UPDATE

2.1 Groundwater monitoring data

As noted in Section 1.1, updating of the groundwater model for the current report has utilised groundwater level monitoring results from the 24 month period from 31 May 2016 to 31 May 2018. For the 41 locations in the Baseline Groundwater Network, monitoring commenced at dates between 18 November 2014 and 18 August 2016, with monitoring for the majority of locations commencing before 31 May 2016. Hydrographs of the Baseline Groundwater Network for this period to 31 May 2018 are appended to this report in Appendix A.

Monitoring started between one and four months after 31 May 2016 for ten locations (i.e. LDS-BH-1019, LDS-BH-1021, LDS-BH-1032, LDS-BH-1066, LDS-BH-2011A, LDS-BH-2011B, LDS-BH-2015, LDS-BH-3045, LDS-BH-3045A, LDS-BH-5007) and started in April and May 2017 for two monitoring locations (i.e. LDS-BH-3089 and LDS-BH-3907 which are located within the St Peters Interchange site). Hydrographs for these locations are presented in Appendix A.

2.2 Tunnel excavation update and groundwater inflow data

The tunnel excavation progress applied in the groundwater model has been updated to reflect changes in the excavation schedule achieved in the field, and changes in temporary tunnel geometry. The updated excavation schedule is applied in the groundwater model as simplified monthly excavation blocks based on construction records as summarised in Golder weekly reports provided to CDS-JV.

Water Treatment Plant (WTP) data is sourced from CDS-JV weekly WTP reports. Groundwater inflow to the tunnels is not measured directly and is therefore estimated as the difference in metered tunnel water inflows and metered WTP outflows. Estimated groundwater inflows from the decline at Arncliffe were provided directly by CDS-JV (Table 3) (i.e. metered inflows and WTP outflows were not provided). Tables 1 to 4 (below) present the excavation progress and corresponding estimated groundwater inflow rates at Bexley, Arncliffe shaft, Arncliffe decline and St Peter's Interchange, respectively. Data regarding excavation progress and water usage/treatment is not available for Kingsgrove. Excavation was assumed to progress at the same rate as in the originally planned schedule, with a later start date.

Table 1: Tunnel Excavation Schedule and Groundwater Inflows – Bexley

		Tunnel excavation				Water Volumes/Flow Rates		
Date Ending	Period	Extent westbound excavation (Chainage)	Extent eastbound excavation (Chainage)	Length of excavated tunnel[1] (km)	Length of Twin Tunnels (km)	Water usage[2] (m^3)	WTP Treated Water[3] (m^3)	Estimated GW inflow[4] (m^3/d)
2/06/2017	May 2017	Excavating Shaft		0	0	-	-	-
30/06/2017	June 2017	3665	3711	0.05	-	-	-	-
28/07/2017	July 2017	3645	3738	0.09	0.18	1696	3468	63
25/08/2017	Aug 2017	3543	3819	0.28	0.56	4080	4685	22
29/09/2017	Sept 2017	3425	3976	0.55	1.10	3472	4306	24
3/11/2017	Oct 2017	3274	4106	0.83	1.66	6202	6501	9
1/12/2017	Nov 2017	3143	4253	1.11	2.22	4720	8811	146
5/01/2018	Dec 2017	3028	4356	1.33	2.66	2293	6969	134
2/02/2018	Jan 2018	2918	4445	1.53	3.06	5836	11941	218
2/03/2018	Feb 2018	2814	4564	1.75	3.50	5626	7391	63
30/03/2018	Mar 2018	2750	4648	1.90	3.80	5023	7427	86
27/04/2018	April 2018	2750	4800	2.05	4.10	4780	10452	203
25/05/2018	May 2018	2750	-	-	-	5289	8819	126

'-' Not Available

[1]- length of one excavated tunnel, calculated as distance between the extent of eastbound excavation and extent of westbound excavation

[2]- estimated as metered inflow of construction water

[3]- estimated as metered outflow measured at the water treatment plant

[4]- Groundwater (GW) inflow estimated as the difference between metered inflow and outflow

Table 2: Tunnel Excavation Schedule and Groundwater Inflows – Arncliffe Shaft (West)

		Tunnel excavation				Water Volumes/Flow Rates		
Date Ending	Period	Extent westbound excavation (Chainage)	Extent eastbound excavation (Chainage)	Length of excavated tunnel[1] (km)	Length of Twin Tunnels (km)	Water usage[2] (m^3)	WTP Treated Water[3] (m^3)	Estimated GW inflow[4] (m^3/d)
2/06/2017	May 2017	Excavating Shaft		-	-	1342	5298	128
30/06/2017	June 2017	7573	7600	0.10[5]	0.20	1341	5694	155
28/07/2017	July 2017	7461	7597	0.14	0.28	1953	5586	130
25/08/2017	Aug 2017	7362	7625	0.26	0.52	2982	6278	118
29/09/2017	Sept 2017	7207	7681	0.47	0.94	3607	6464	82
3/11/2017	Oct 2017	7056	7719	0.66	1.32	4121	7487	96
1/12/2017	Nov 2017	6998	7722	0.72	1.44	2326	5102	99
5/01/2018	Dec 2017	6882	7725	0.84	1.68	2759	6118	96
2/02/2018	Jan 2018	6777	7748	0.97	1.94	3135	5202	74
2/03/2018	Feb 2018	6677	7781	1.10	2.20	2399	4167	63
30/03/2018	Mar 2018	6505	7841	1.34	2.68	7009	10838	137
27/04/2018	April 2018	6379	7904	1.53	3.06	3858	6791	105
25/05/2018	May 2018	6253	7965	1.71	3.42	-	-	-

'-' Not Available

[1]- length of one excavated tunnel, calculated as distance between the extent of eastbound excavation and extent of westbound excavation

[2]- estimated as metered inflow of construction water

[3]- estimated as metered outflow measured at the water treatment plant

[4]- Groundwater (GW) inflow estimated as the difference between metered inflow and outflow

[5]- approximate adit length

Table 3: Tunnel Excavation Schedule and Groundwater Inflows – Arncliffe Declines (East)

		Tunnel excavation				Water Volumes/Flow Rates		
Date Ending	Period	Extent westbound excavation (Chainage)	Extent eastbound excavation (Chainage)	Length of excavated tunnel[1] (km)	Length of Twin Tunnels (km)	Water usage (m^3)	WTP Treated Water (m^3)	Estimated GW inflow[2] (m^3/d)
2/02/2018	Jan 2018	8435	8478	0.04	0.09	-	-	118
2/03/2018	Feb 2018	8426	8485	0.06	0.12	-	-	303
30/03/2018	Mar 2018	7923	8528	0.61	1.21	-	-	602
27/04/2018	April 2018	7911	8568	0.66	1.31	-	-	511
25/05/2018	May 2018	7883	8607	0.72	1.45	-	-	-

'-' Not Available

[1]- length of one excavated tunnel, calculated as distance between the extent of eastbound excavation and extent of westbound excavation

[2]- estimated groundwater inflows provided by CDS-JV.

Table 4: Tunnel Excavation Schedule and Groundwater Inflows – St Peter's Interchange

		Tunnel excavation				Water Treatment		
Date Ending	Period	Extent westbound excavation (Chainage)	Extent eastbound excavation (Chainage)	Length of excavated tunnel[1] (km)	Length of Twin Tunnels (km)	Water usage[2] (m^3)	WTP Treated Water[3] (m^3)	Estimated GW inflow[4] (m^3/d)
8/05/2017	April 2017	10884	10873	0.01	0.02	316	-	-11[5]
1/06/2017	May 2017	10836	10871	0.05	0.09	385	-	-16[5]
1/07/2017	June 2017	10749	10797	0.13	0.27	563	1414	28
1/08/2017	July 2017	10648	10692	0.24	0.47	1466	889	-19[5]
1/09/2017	Aug 2017	10533	10592	0.35	0.70	1731	6475	153
1/10/2017	Sept 2017	10439	10483	0.44	0.89	1680	1865	6
1/11/2017	Oct 2017	10281	10360	0.60	1.20	1529	4625	100
1/12/2017	Nov 2017	10155	10242	0.73	1.46	2272	5367	103
1/01/2018	Dec 2017	10090	10174	0.79	1.59	1698	8261	212
1/02/2018	Jan 2018	9990	10074	0.89	1.79	2255	7664	174
1/03/2018	Feb 2018	9882	9979	1.00	2.00	2718	20890	649
1/04/2018	Mar 2018	9777	9875	1.11	2.21	2708	36053	1076
1/05/2018	April 2018	9705	9778	1.18	2.36	4035	28531	817
28/05/2018	May 2018	9641	9736	1.24	2.48	-	-	-

'-' Not Available;

[1]- length of one excavated tunnel, calculated as distance between the extent of eastbound excavation and extent of westbound excavation

[2]- estimated as metered inflow of construction water

[3]- estimated as metered outflow measured at the water treatment plant

[4]- Groundwater (GW) inflow estimated as the difference between metered inflow and outflow

[5]- negative values due to water being used for surface works

3.0 COMPARISON OF MODIFIED ORIGINAL MODEL RESULTS AND FIELD DATA

3.1 Modified original model (2018-A) simulation results

The modified original regional scale model (2018-A) incorporates the updated excavation schedule presented in Tables 1 to 4 and geometric adjustments for the decline at Arncliffe. All other model parameters and boundary conditions remained unchanged from those presented for the regional scale model in the Hydrogeological Design Report (M5N-GOL-DPK-100-200-GT-1526-R, dated 02 May 2017). Note that the original regional scale model and the 2018-A model both did not include any modifications to hydraulic conductivity in the Arncliffe area to account for pre and post excavation grouting.

Figures 2 to 4 compare modelled tunnel inflows (blue) to observed net tunnel inflows calculated from WTP data (orange) at Kingsgrove, Bexley, Arncliffe and SPI, respectively. Figure 1 only presents the modelled groundwater inflow rate as there is no WTP data for Kingsgrove. Figures B1 to B6 in Appendix B compare modelled groundwater drawdown (blue) to observed groundwater drawdown (orange) at a selection of groundwater monitoring wells along the project alignment. Section 4.0 presents the results for the complete list of active monitoring wells included in the latest Groundwater Monitoring Progress Report (M5N-GOL-TER-100-200-GT-1518-0, dated 13 September 2018).

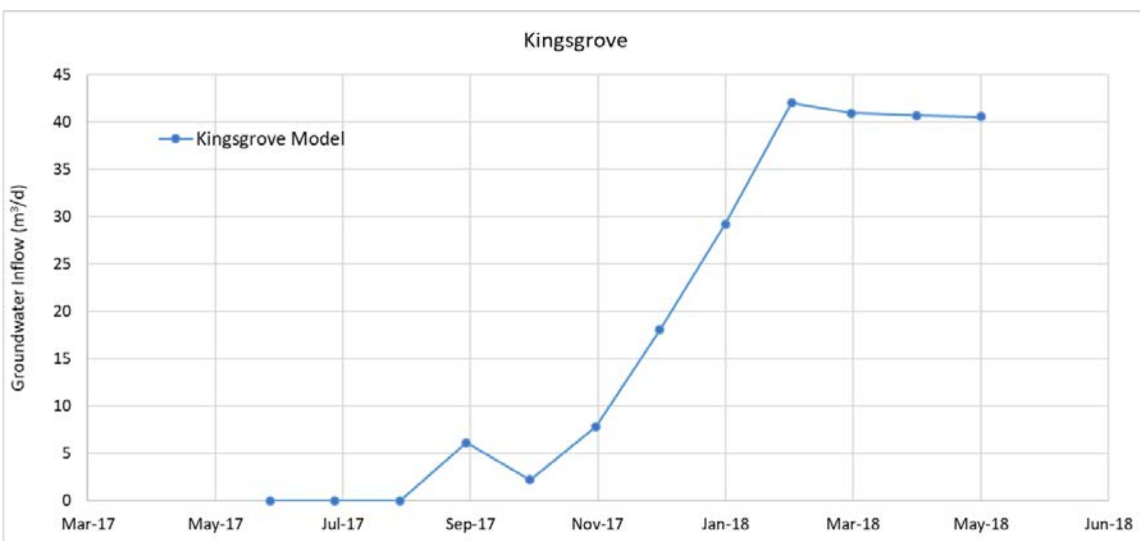

Figure 1: Modelled groundwater inflow rate at Kingsgrove (2018-A Model).

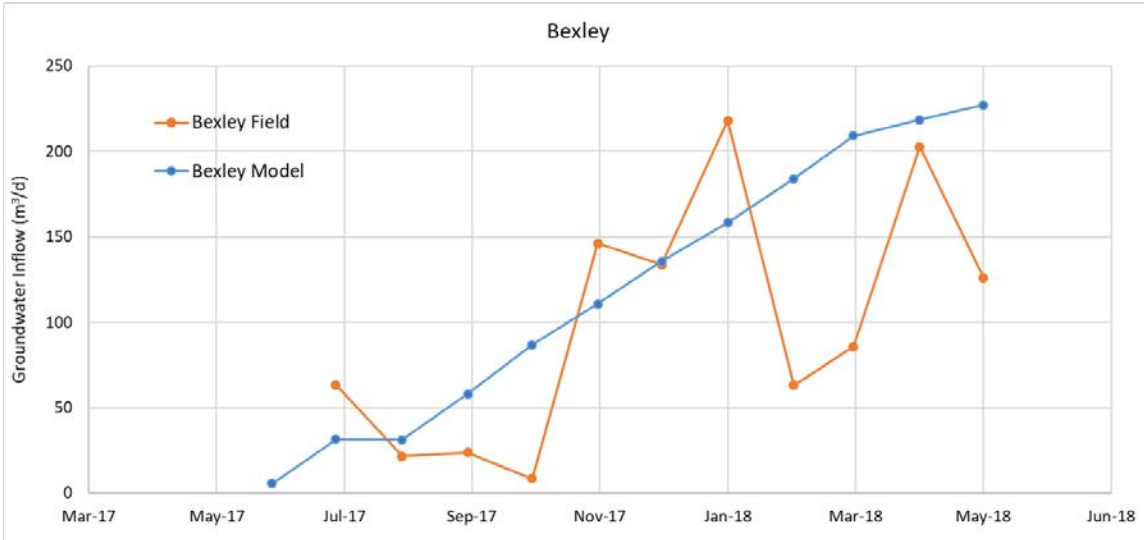

Figure 2: Modelled and observed groundwater inflow rate at Bexley (2018-A Model).

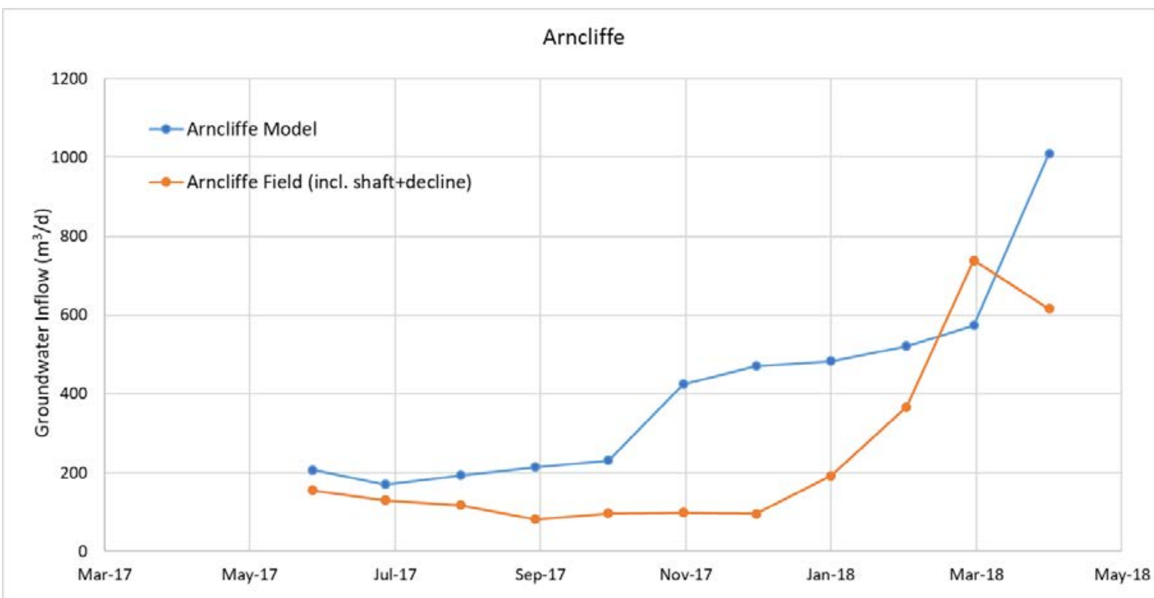

Figure 3: Modelled and observed groundwater inflow rate at Arncliffe (shaft + decline), (2018-A Model).

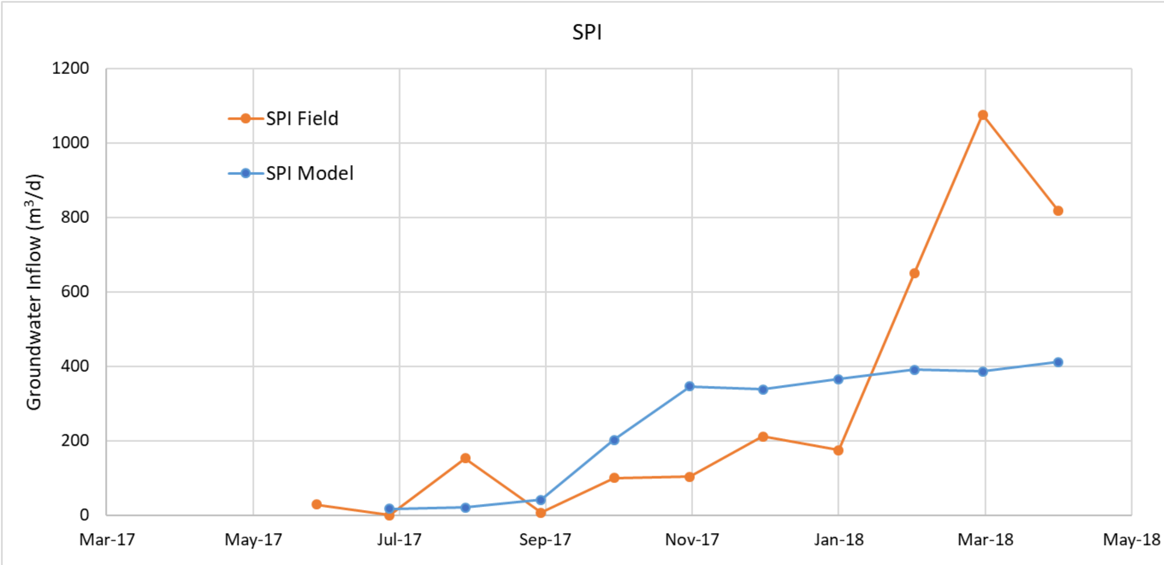

Figure 4: Modelled and observed groundwater inflow rate at St Peter's Interchange (2018-A Model).

3.2 Discussion

In general, the 2018-A groundwater model tends to predict groundwater drawdown that is less than observed and is interpreted to extend further from the tunnel than actual conditions (i.e. drawdown that is too shallow, and too broad). Groundwater inflows to tunnels are over-predicted at Arncliffe and SPI. Correcting for tunnel excavation sequence and temporary tunnel geometry at Arncliffe in the 2018-A model, the following discussion points are relevant, noting that drawdown refers to that occurring in the Hawkesbury Sandstone unless otherwise specified.

At Kingsgrove (refer to Figure B1 in Appendix B), predicted drawdown in the 2018-A Model is 5 to 8 m, whilst observed drawdown ranges from 1.5 m at LDS-BH-1027 (south of the tunnels) to 25 m at LDS-BH-1026 (north of the tunnels). Note that these two bores are approximately 120 m apart, both screened in the Hawkesbury Sandstone and yet exhibit considerably different groundwater drawdown. WTP data is unavailable for estimating groundwater inflow. Modelled inflows (Figure 1) rise steadily to 40 m^3/d (combined for two tunnels).

At Bexley (refer to Figure to B2 in Appendix B), rapid groundwater drawdowns are observed at the monitoring locations. At LDS-BH-1030 and LDS-BH-1066, Modelled drawdown in the 2018-A simulation is significantly less (approximately a third of the observed value), with a slower response. The subdued modelled response at these bores is primarily due to the modelled observation points representing these bores being located within two structures with higher hydraulic conductivity (0.6 m/d) that act as conduits for groundwater flow. The rapid observed response indicates that monitoring wells are likely connected to higher permeability zones associated with structures, however the storage of these features is interpreted to be less than is represented in the model, and/or the connectivity of these features to ongoing sources of water is greater in the model than in reality. Field estimates of groundwater inflow to the tunnels at Bexley (Figure 2) are quite variable, ranging between 10 and 200 m^3/d. Modelled inflows rise steadily and lay within that range. In April 2018, field estimates and modelled values have 95% agreement.

At Arncliffe (refer to Figures B3, B4 and B5 in Appendix B), observed groundwater drawdowns are significant in VWPs screened in the Hawkesbury Sandstone, with observed values of 46 m at LDS-BH-1038, 36 m at WCX-BH168, 27 m at LDS-BH2007A, and 39 m at LDS-BH-1041. Monitoring results in WCX-BH039 and WCX-BH070 indicate that drawdown decreases with distance, with observed drawdowns of less than 3 m at these locations. Drawdown in the alluvium is significantly less than in the Hawkesbury Sandstone (refer to LDS-BH-2003, LDS-BH-2001 and the three VWPs which are screened in alluvium in LDS-BH-1041). Modelled drawdowns for the 2018-A simulations are a reasonable match observed drawdowns in the alluvium. Field estimates of tunnel inflows at Arncliffe (including shaft and decline) were relatively steady at 100 to 150 m^3/d for the first seven months of excavation before rising to a peak of 740 m^3/d in March 2018 (Figure 3). It is possible that surface water may have entered the decline and contributed to the large outflow volumes. Modelled inflows are approximately two to three times higher than estimated inflows until February/March 2018.

At SPI, observed groundwater drawdown (Figure B6 in Appendix B) is also quite variable. Drawdowns of 25 m to 40 m are observed on both sides of the tunnel, however, a drawdown of only 6 m is observed at the bore closest to the tunnel (LDS-BH-2018). Modelled (2018-A) groundwater drawdown matches this bore quite well but is two to three times smaller than the other locations. Modelled (2018-A) tunnel inflows at SPI (Figure 4) rise steadily to 400 m^3/d by November 2017 and remain there through to May 2018. Field estimates of tunnel inflows are approximately half of modelled values until January 2018, after which there is a sudden increase in inflows from 200 m^3/d to 1100 m^3/d. Field reports state that a dyke was encountered on 19 February 2018 at CH9915 and large amounts of groundwater (150 L/min) were pumped out of the excavation over the next 20 m (approximately). The dyke, and particularly the sandstone around the dyke, are interpreted to have acted as a hydraulic conduit that generated drawdowns in the monitoring wells screened in the sandstone at that depth. The dyke is not included in the groundwater model because its alignment and inclination are unknown at this time.

4.0 GROUNDWATER MODEL UPDATE (2018-B MODEL)

4.1 Modifications to model parameters

Modifications were made to the 2018-A model, with a focus on better matching the observed groundwater drawdowns in the area close to the tunnel and tunnel inflows, and also to make allowance for the impacts of grouting at Arncliffe. As discussed above, the 2018-A model generally tended to underpredict groundwater drawdown response in the Hawkesbury Sandstone and overpredict tunnel inflows[1]. To improve the model simulation results required reducing the amount of water removed from the aquifer whilst simultaneously increasing the drawdown response to removing less water. The modelling approach was to adjust storage, hydraulic conductivity and conductance values to increase groundwater drawdown response but reduce volume of water removed from aquifer.

The following changes were made to the 2018-A model. The model with these modifications is referred to herein as the 2018-B model.

- Reducing hydraulic conductivity of the Hawkesbury Sandstone in general;
- Reducing fault zone hydraulic conductivity in areas where fault conductivity would have been reduced by surface grouting operations at Arncliffe;
- Increasing specific storage Hawkesbury Sandstone in general; and
- Reducing drain cell conductance values.

Table 5 summarised the changes to parameters in the updated (2018-B) groundwater model. Hydraulic conductivity of the Hawkesbury Sandstone has been reduced to 0.0025 m/d, which is slightly below the geometric mean (0.0036 m/d) and median (0.004 m/d) values derived from WCX2 water pressure test results.

The impact of grouting in the 2018-B was represented by reducing the hydraulic conductivity in sub-vertical fault zones and sub-horizontal shear zones where these zones are intersected by the tunnel. Reductions were applied only in the model cells which are located immediately adjacent to the drain cells representing the tunnels. A hydraulic conductivity of 0.004 m/d (i.e. $5x10^{-8}$ m/s) has been applied for the grouted high permeability structural features immediately adjacent to the tunnels. In reality, reductions in permeability as a result of grouting will apply much more extensively throughout the subsurface as a result of the surface grouting that has been undertaken in combination with in-tunnel grouting in the immediate vicinity of the tunnel. The hydraulic conductivity that has been applied in the model only to cells that are located immediately adjacent to the tunnel is thus a surrogate value representing the effect of a much larger zone of grouting.

[1] While the tendency of the model to underpredict groundwater drawdown response in the Hawkesbury Sandstone and overpredict tunnel inflows is generally the case, there are exceptions to this generalisation. For example, drawdown in bores WCX-BH070, WCX-BH088 and LDS-BH1027; inflows in March 2018 at Arncliffe; and inflows at SPI from February 2018 onwards. Refer to discussion in Section 3.1 for more detail.

Table 5: Changes to hydraulic parameters values (2018-B Model)

Model parameter	2017 Model[1]	2018-B Model
Hawkesbury Sandstone Horizontal Hydraulic Conductivity K_h	0.01 m/d	0.0025 m/d
Hawkesbury Sandstone Vertical Hydraulic Conductivity K_v (m/d)	0.001 m/d	0.0002 m/d
Hawkesbury Sandstone Specific Storage S_s	$1x10^{-7}$ m^{-1}	$2x10^{-6}$ m^{-1}
M5 Tunnel Conductance	0.4 m^2/d	0.04 m^2/d
Grouting	No grouting was represented in the 2017 regional scale model	0.004 m/d, applied to cells immediately adjacent to tunnel drain cells where tunnels intersect sub-vertical faults and sub-horizontal shear zones.

1: This refers to the regional scale model presented in in the Hydrogeological Design Report (M5N-GOL-DPK-100-200-GT-1526-R, dated 02 May 2017).

Comparisons of modelled and observed drawdowns and tunnel inflows for the 2018-B model are presented in Figures B1 to B6 in Appendix B. In Figures B1 to B6, calculated drawdowns for the 2018-A model are shown in blue, the revised calculated drawdowns for the 2018-B model are shown in purple and the field monitoring data is shown in orange.

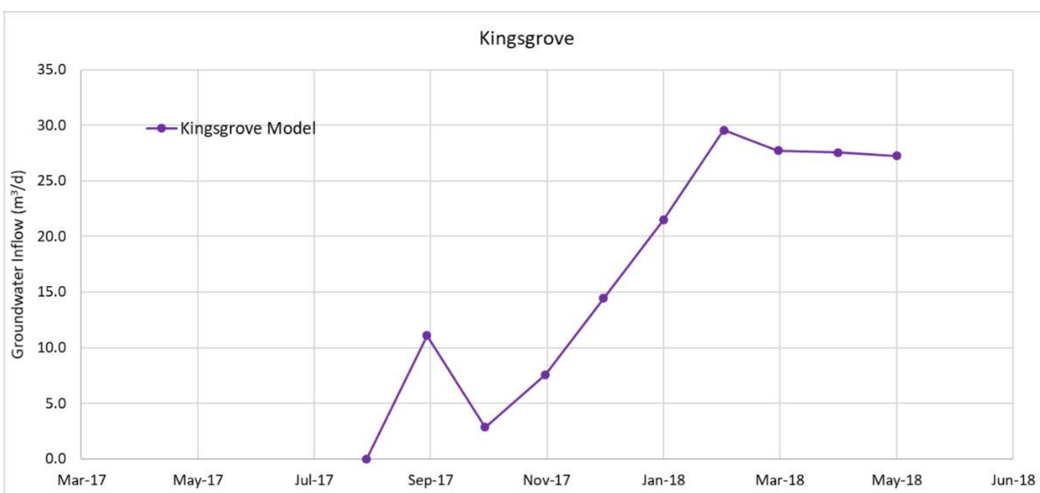

Figure 5: Updated modelled groundwater inflow rate at Kingsgrove (2018-B Model).

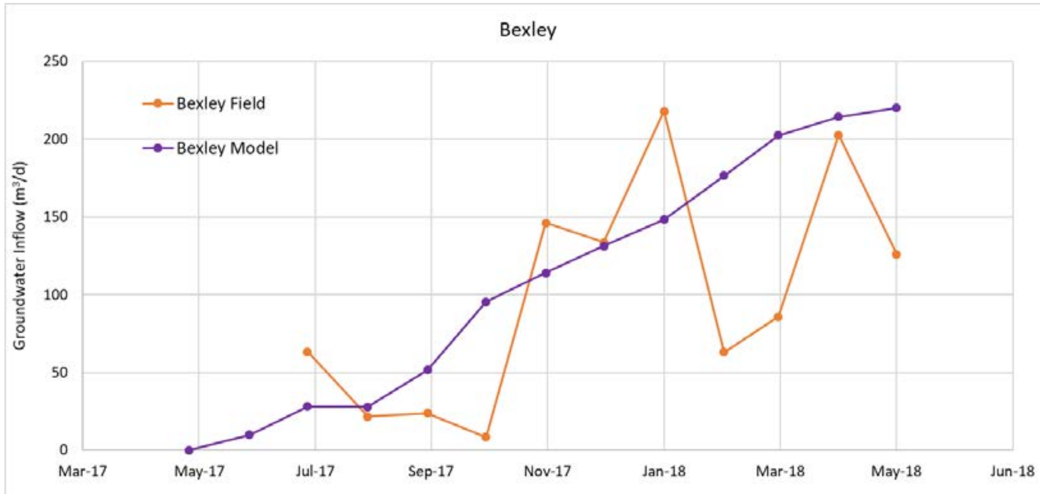

Figure 6: Updated modelled and observed groundwater inflow rate at Bexley (2018-B Model).

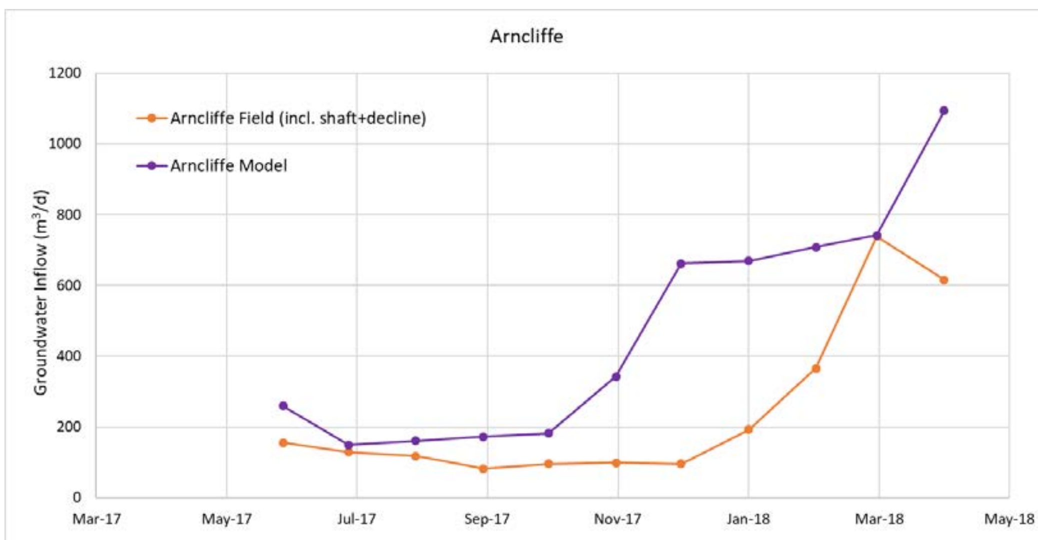

Figure 7: Updated modelled and observed groundwater inflow rate at Arncliffe (2018-B Model).

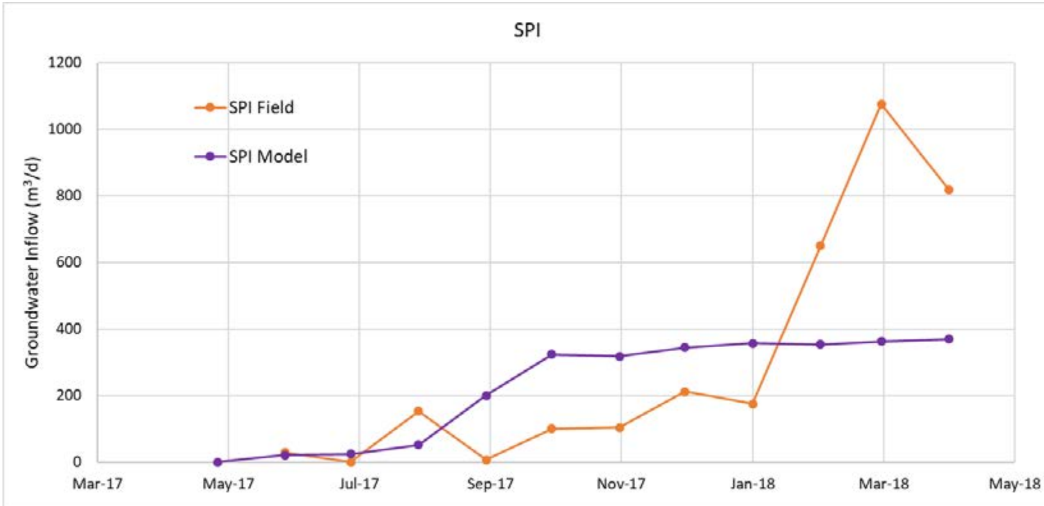

Figure 8: Updated modelled and observed groundwater inflow rate at SPI (2018-B Model).

4.2 Discussion

In general, groundwater drawdowns produced by the 2018-B groundwater model have improved agreement with observed drawdown and marginally improved agreement with tunnel inflows compared to the 2018-A model. The 2018-B model still tends to underpredict groundwater drawdown and overpredict groundwater inflows to tunnels.

In the following discussion, drawdown refers to the drawdown occurring in the Hawkesbury Sandstone unless otherwise specified.

At Kingsgrove, modelled drawdown has increased by 5 to 12 m (refer to Figure B1 in Appendix B), resulting in a better match with observed drawdown at LDS-BH-1026 and WCX-BH-137. Consequentially, modelled drawdown are still higher than observed drawdown at LDS-BH-1027. Modelled at inflows (Figure 5) rise steadily to a lower peak of 30 m^3/d.

At Bexley modelled tunnel inflows (Figure 6) remain essentially unchanged from the previous model. However, the match between modelled groundwater drawdown and observed drawdown have improved (refer to Figure B2 in Appendix B), particularly at LDS-BH-1031 and LDS-BH-1032.

At Arncliffe, modelled groundwater drawdowns in the Hawkesbury Sandstone are improved at LDS-BH-1038, LDS-BH-2007A, WCX-BH039 and (to a lesser extent) at WCX-BH168 and LDS-BH-2008, whereas the match at LDS-BH-1041 is not improved. The match between modelled and observed drawdown in the alluvium is relatively unchanged (refer to Figure B3, B4 and B5 in Appendix B). Some drawdown is observed before the start of the modelled drawdown for each sensor that may be due to dewatering associated with other projects or may reflect a requirement to more accurately model the actual tunnel construction sequence. Modelled tunnel inflows at Arncliffe (Figure 7, including shaft and decline) have a closer match to estimates through to October 2017, but then exceed field estimates of tunnel inflow until March 2018, at which point both modelled and estimated values match.

At SPI, modelled groundwater drawdown increases and has marginally improved agreement with observed drawdown at WCX-BH103 and WCX-BH109 and still matches well at LDS-BH-2018 (refer to Figures B5 and B6 in Appendix B). Modelled tunnel inflows at SPI (Figure 8) have a slightly improved agreement with estimated inflows through to January 2018 but are unable to capture the sudden increase in inflows in February 2018 because the dyke which caused this inflow is not represented in the model.

4.3 Long-term groundwater drawdown and tunnel inflows

Long-term groundwater drawdown and inflows to the tunnels were estimated using the 2018-B groundwater model to conduct a steady-state simulation. Temporary adit and decline structures were removed from the model for the long-term prediction.

Figure 9 presents the long-term groundwater inflows to the tunnel. Modelled inflows peak at 0.44 L/s/km/tunnel at Kingsgrove, 0.64 L/s/km/tunnel at Bexley, 0.82 L/s/km/tunnel at Arncliffe, and 0.98 L/s/km/tunnel at SPI (note that the chainage from 9900 m to 10900 m at SPI includes two main tunnels and two stub-tunnels, the total length of which has been included in the calculation of the running average inflow rate shown in Figure 9).

Figure 10 presents the long-term groundwater drawdown in the Hawkesbury Sandstone. Maximum drawdowns between 62 to 65 m were calculated, with these maxima occurring at Arncliffe, and to the north of Cooks River. Note that these calculated drawdowns indicate the potential for reduction in deeper groundwater levels. The model does not allow for the representation of the potential development of perched shallow groundwater systems isolated from the deeper, lowered groundwater level.

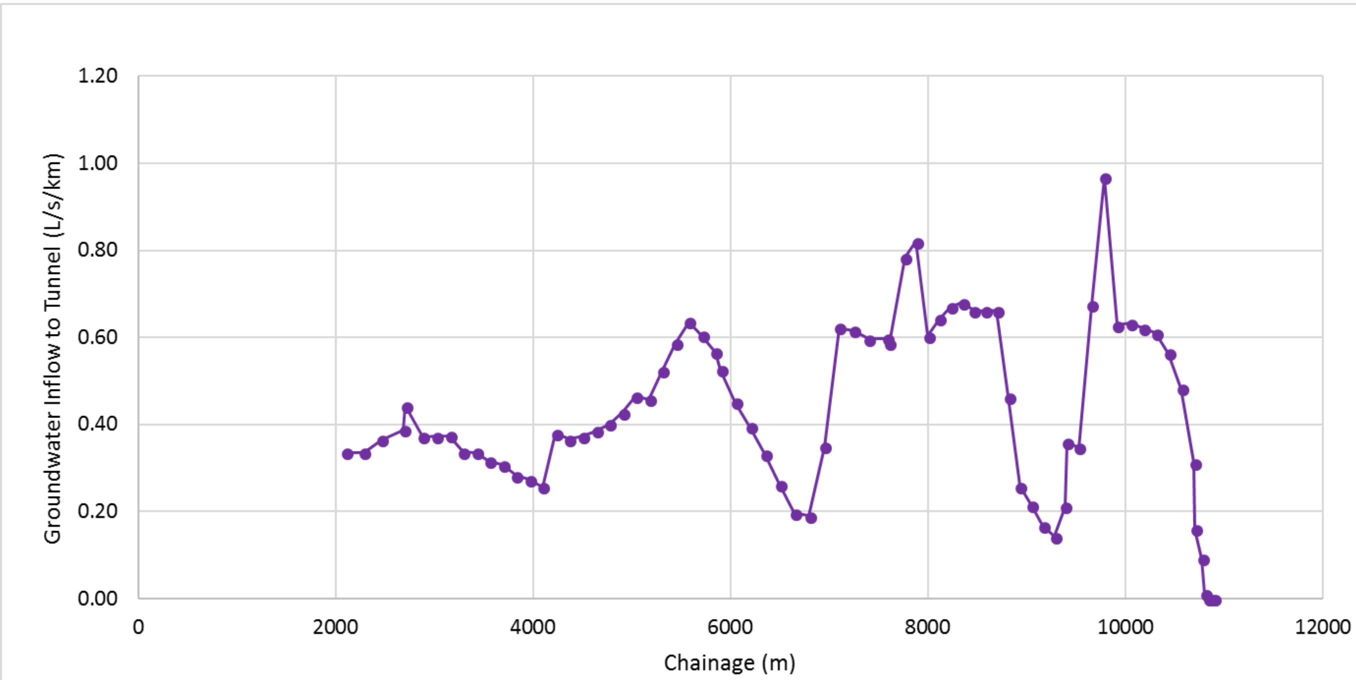

Figure 9: Long-term groundwater tunnel inflows (L/s/km) (2018-B model minus temporary adits).

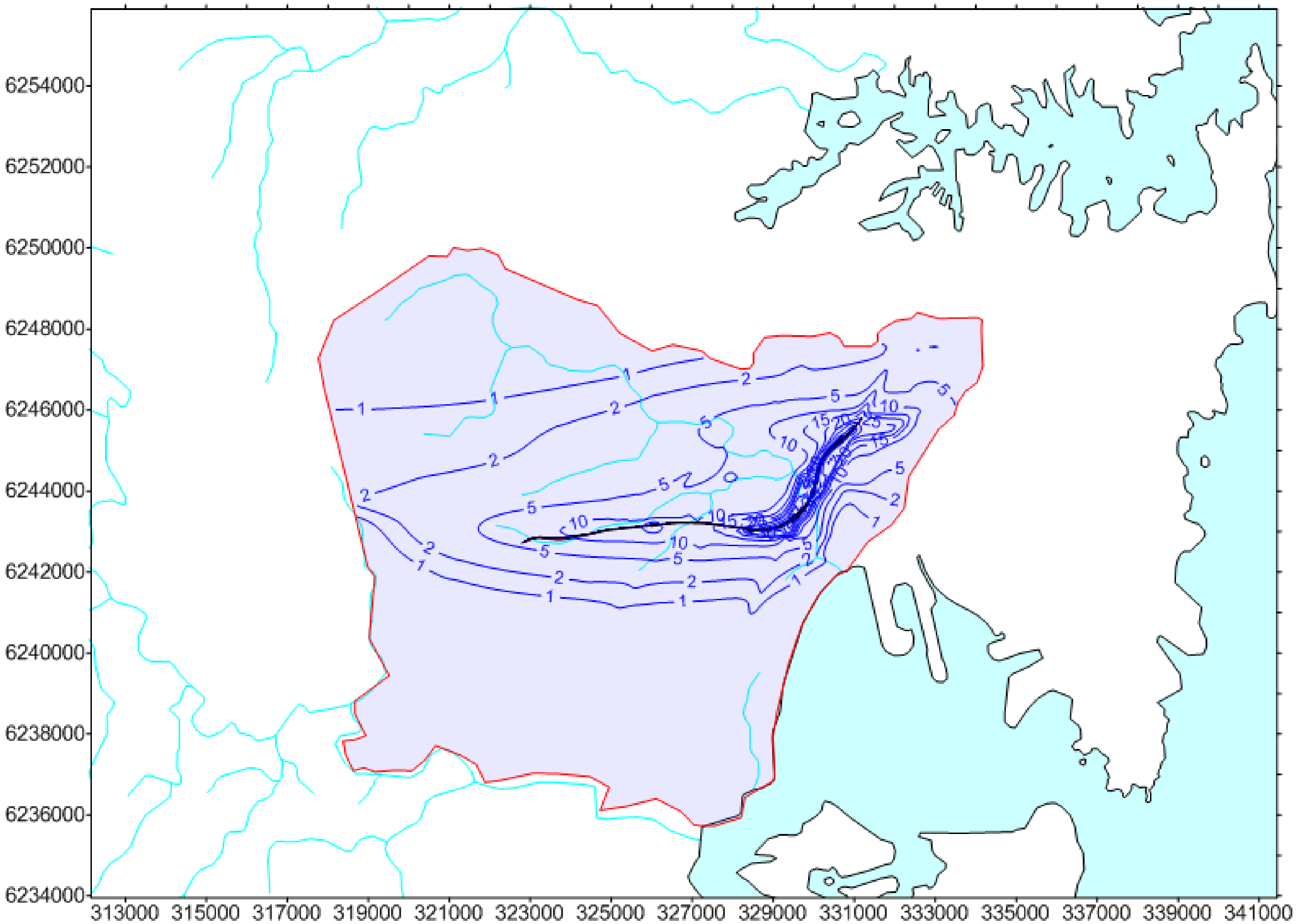

Figure 10: Long-term groundwater drawdown (m)
(2018-B model excluding temporary adits temporary adits).

5.0 SUMMARY AND LIMITATIONS

The 2018-B groundwater model retains the assumptions and limitations of the 2017 groundwater model which are presented in Section 2.3.4 of the Hydrogeological Design Report (M5N-GOL-DPK-100-200-GT-1526-R, May 2017). Updating the 2017 groundwater model to the 2018-B groundwater model includes:

- Updating tunnel excavation schedule (which is modelled as monthly steps), and geometry of temporary tunnels at Arncliffe.
- Modification of model parameters to improve the match between modelled and observed groundwater drawdown and tunnel inflow data. Modifications were made to:
  - Hawkesbury Sandstone hydraulic parameters (hydraulic conductivity and specific storage)
  - M5 tunnel conductance
  - Hydraulic conductivity of the fault zone at Arncliffe where high permeability structures intersect the tunnels in the model, to represent the impact of grouting.

The revised long-term groundwater inflows to the tunnels are estimated to be less than 1 L/s/km on average, following sealing of temporary works. At locations where observations indicate that inflows are likely to locally exceed 1 L/s/km, ongoing in-tunnel grouting works are being undertaken to limit groundwater inflow. Planning and implementation of ongoing grouting works are based on results of monitoring, rather than model updates.

Signature Page

Golder Associates Pty Ltd

[redacted] [redacted]

[redacted] [redacted]

Senior Geotechnical Engineer *Principal*

[redacted]

A.B.N. 64 006 107 857

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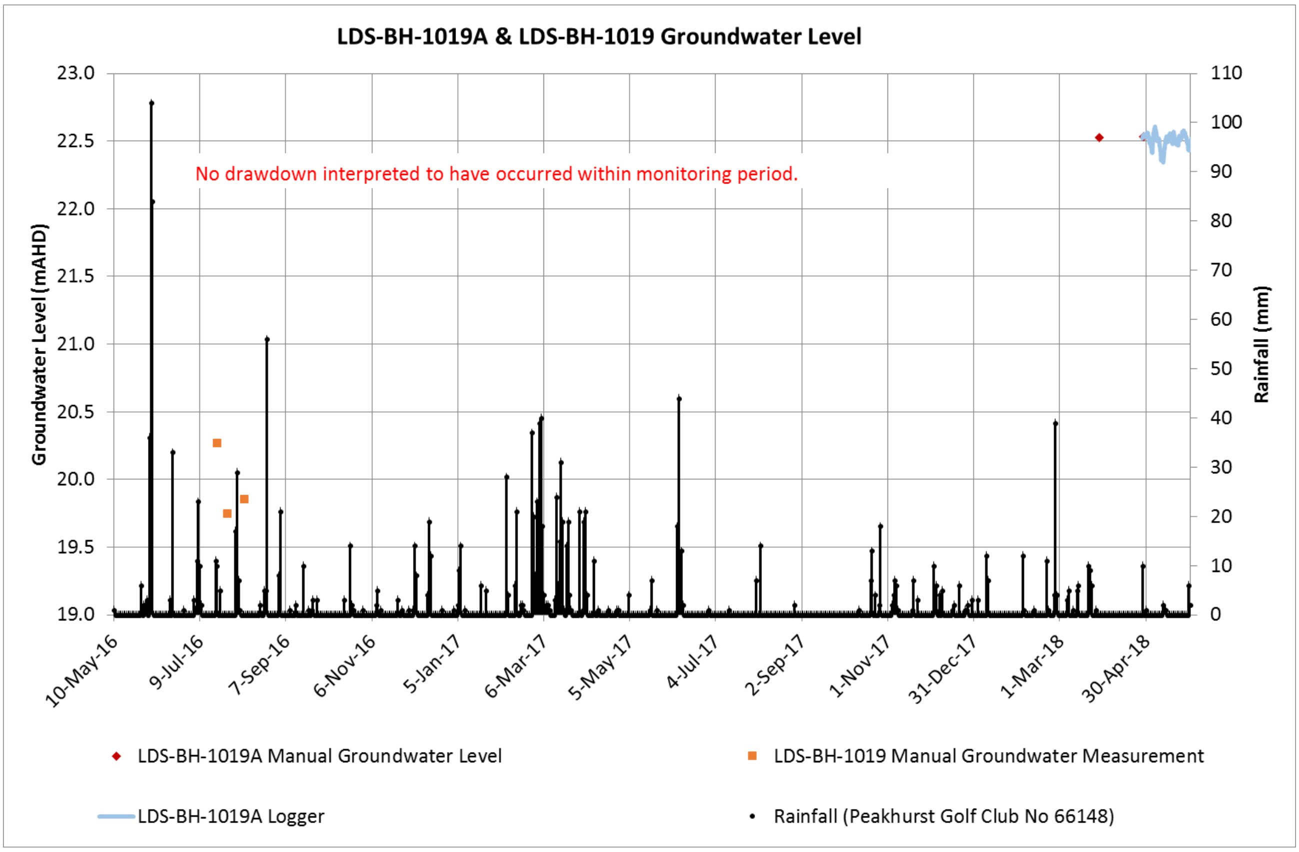
APPENDIX A

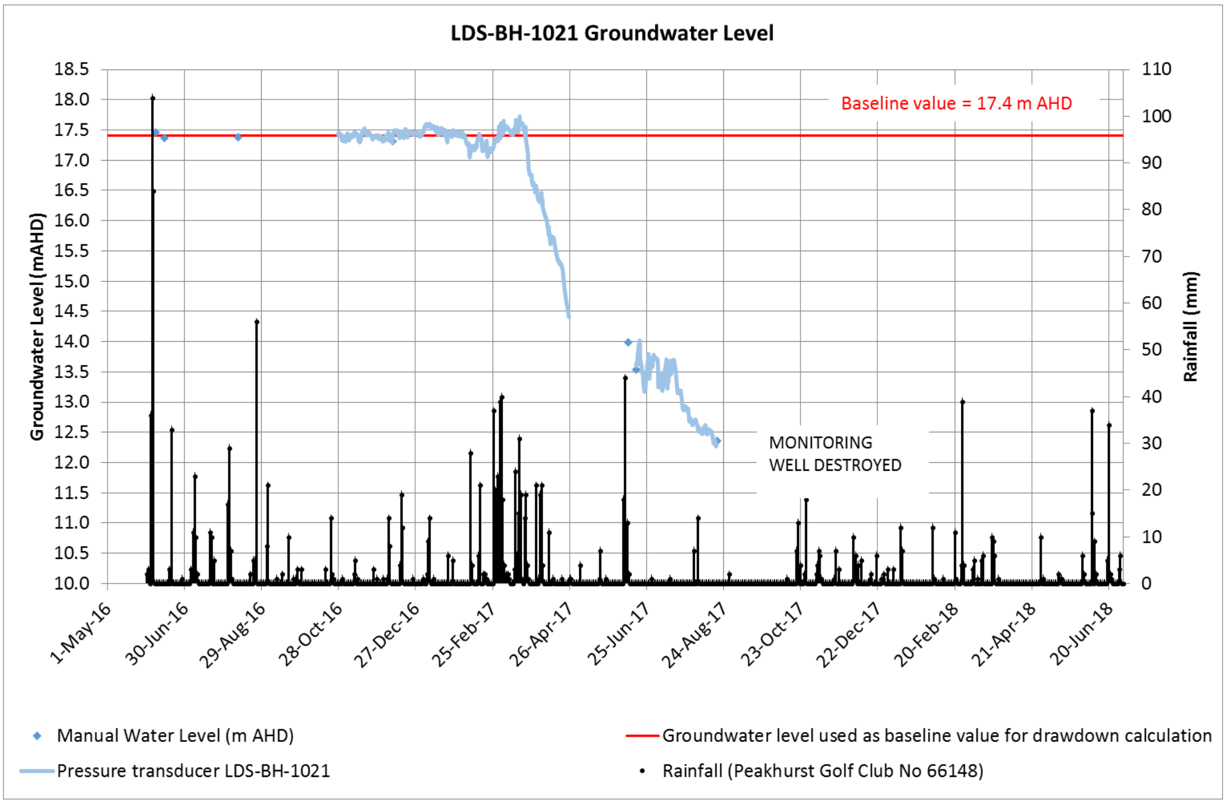
Baseline Groundwater Monitoring Network Hydrographs

WCX-BH006 – This location was not included as it was destroyed before construction activities started.

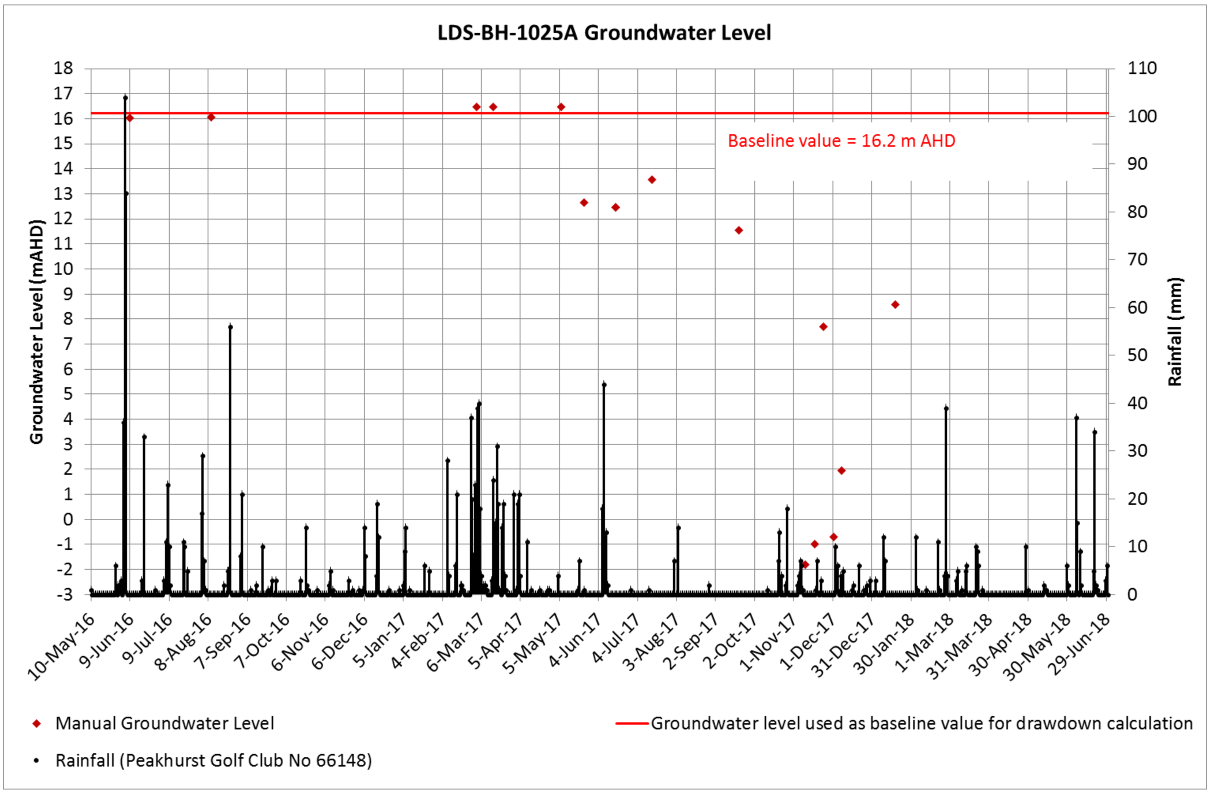
LDS-BH-1019 and LDS-BH-1019A – LDS-BH-1019A was installed as replacement for LDS-BH-1019 after this well was destroyed.



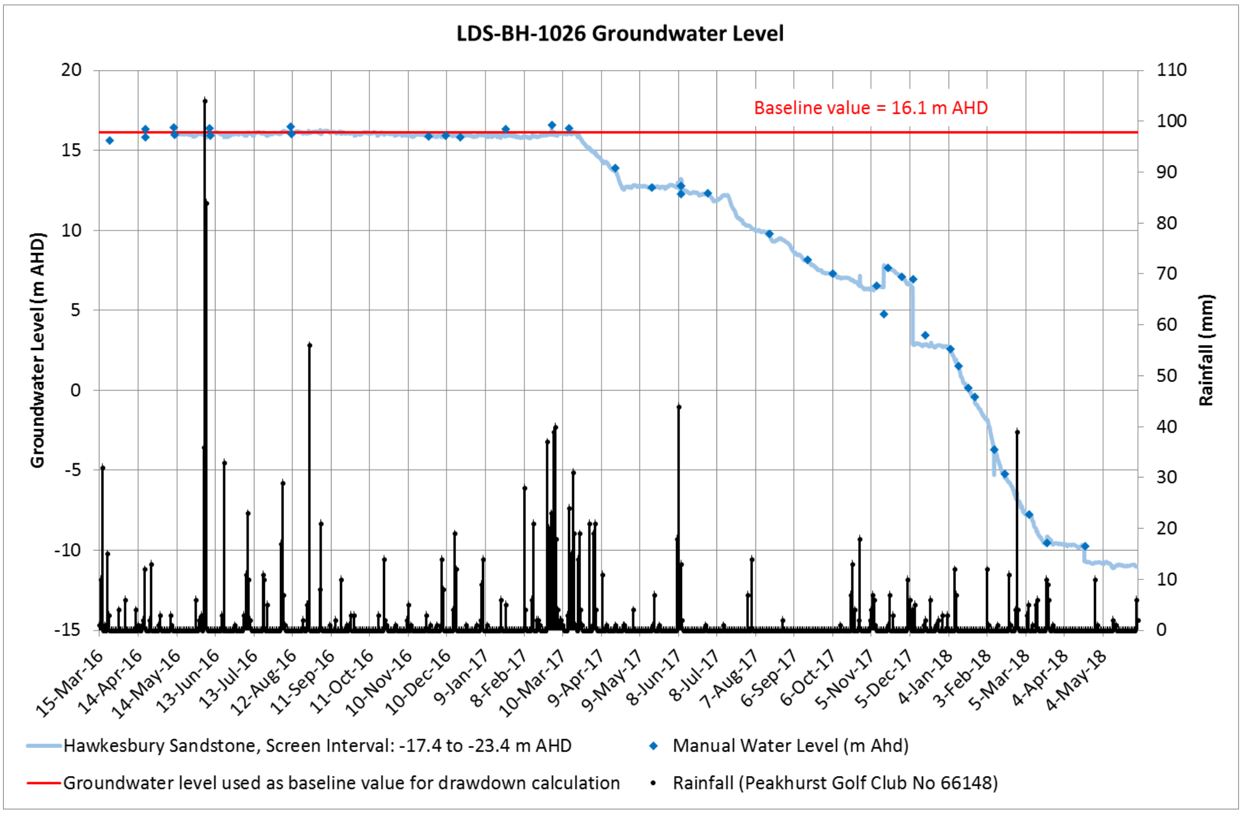
LDS-BH-1021 – Monitoring well is destroyed



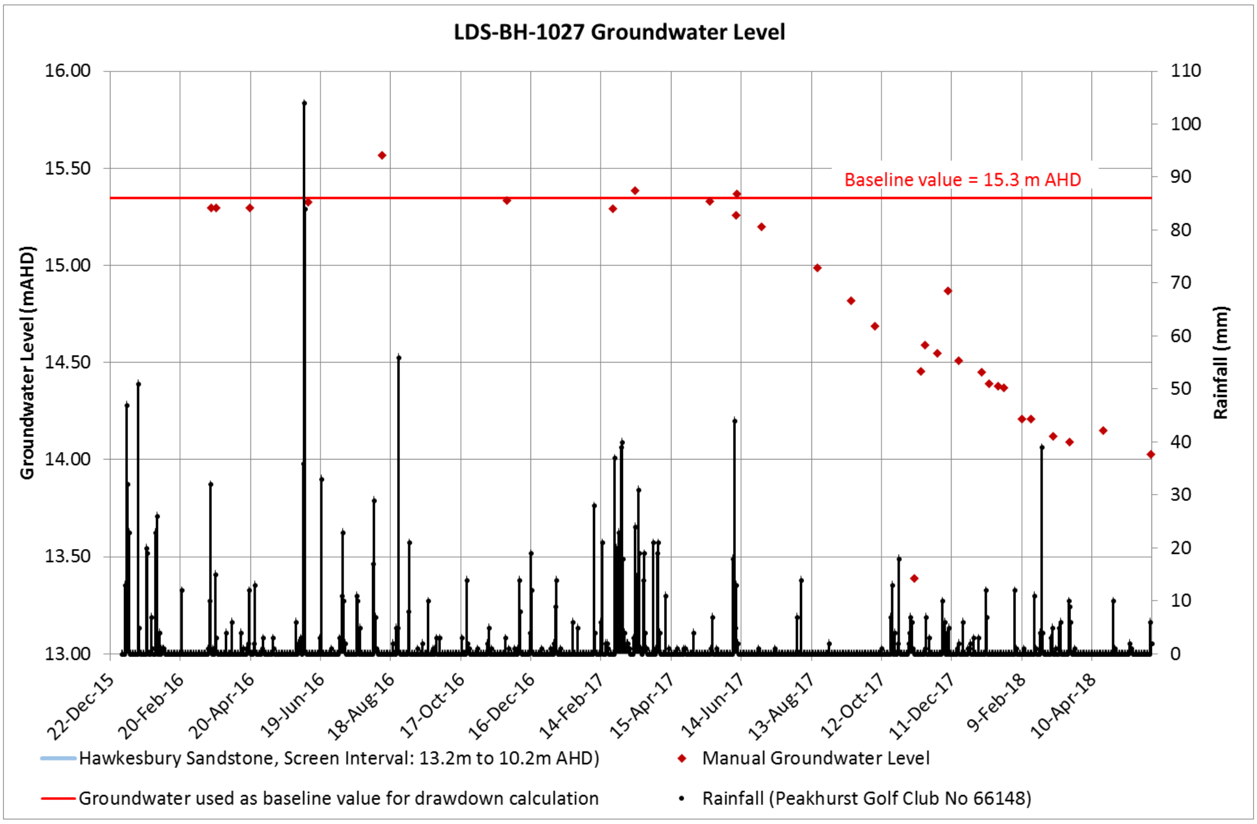
LDS-BH-1025A – Monitoring well has not been accessible since January 2018.



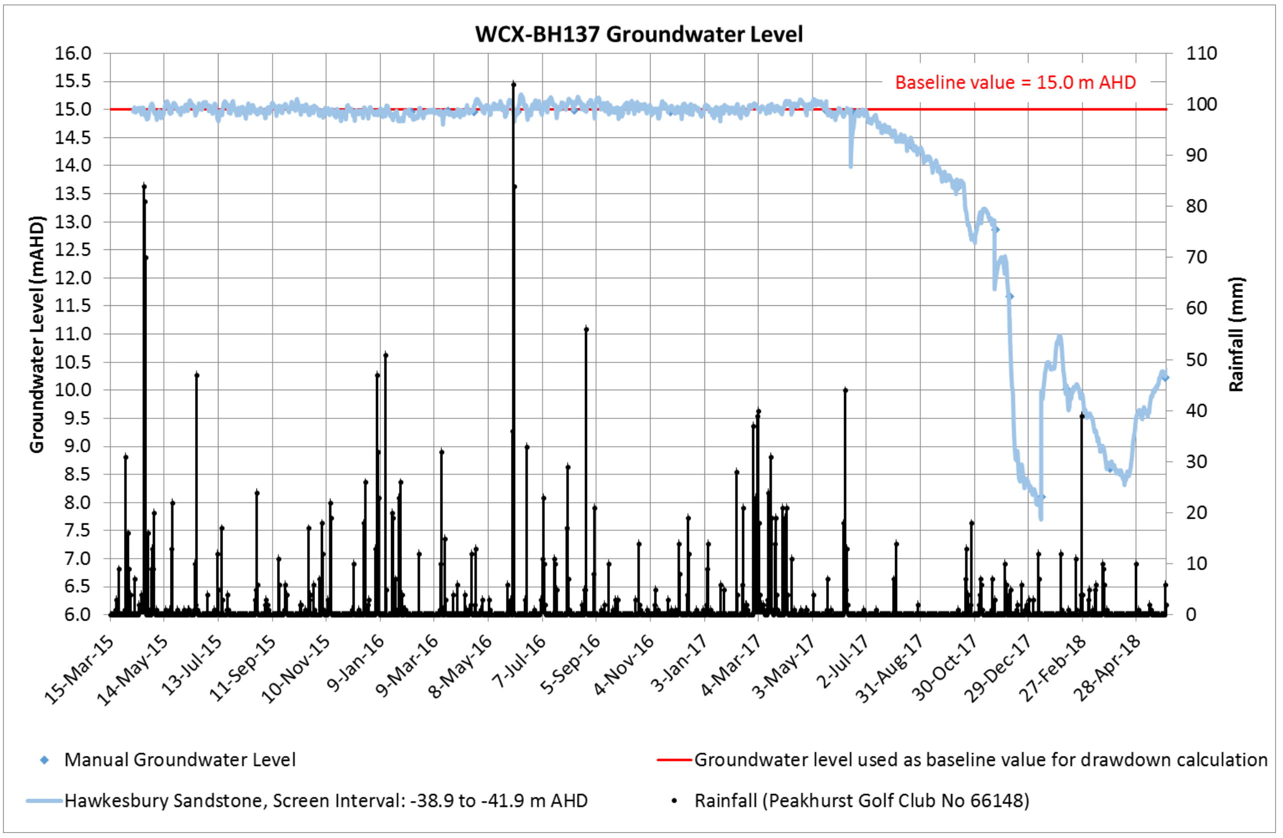
LDS-BH-1026



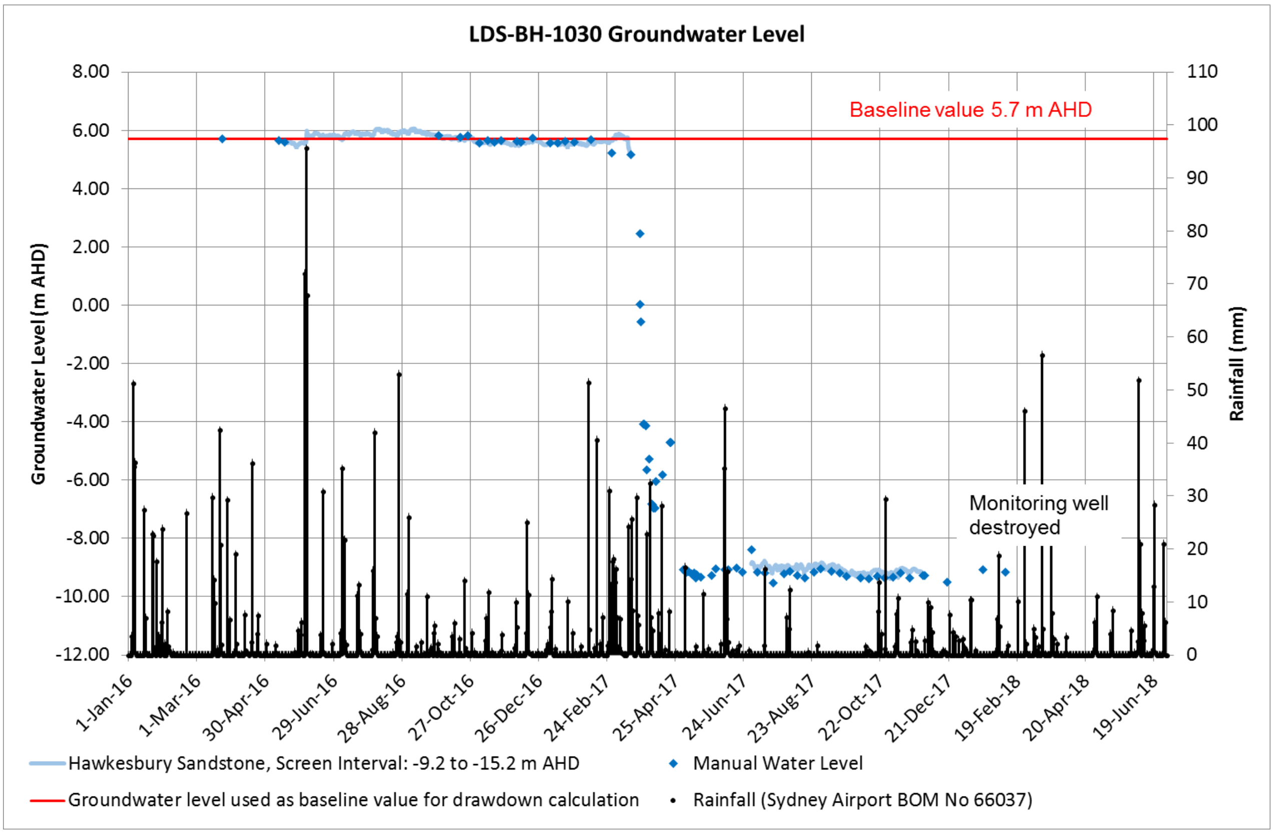
LDS-BH-1027



WCX-BH137

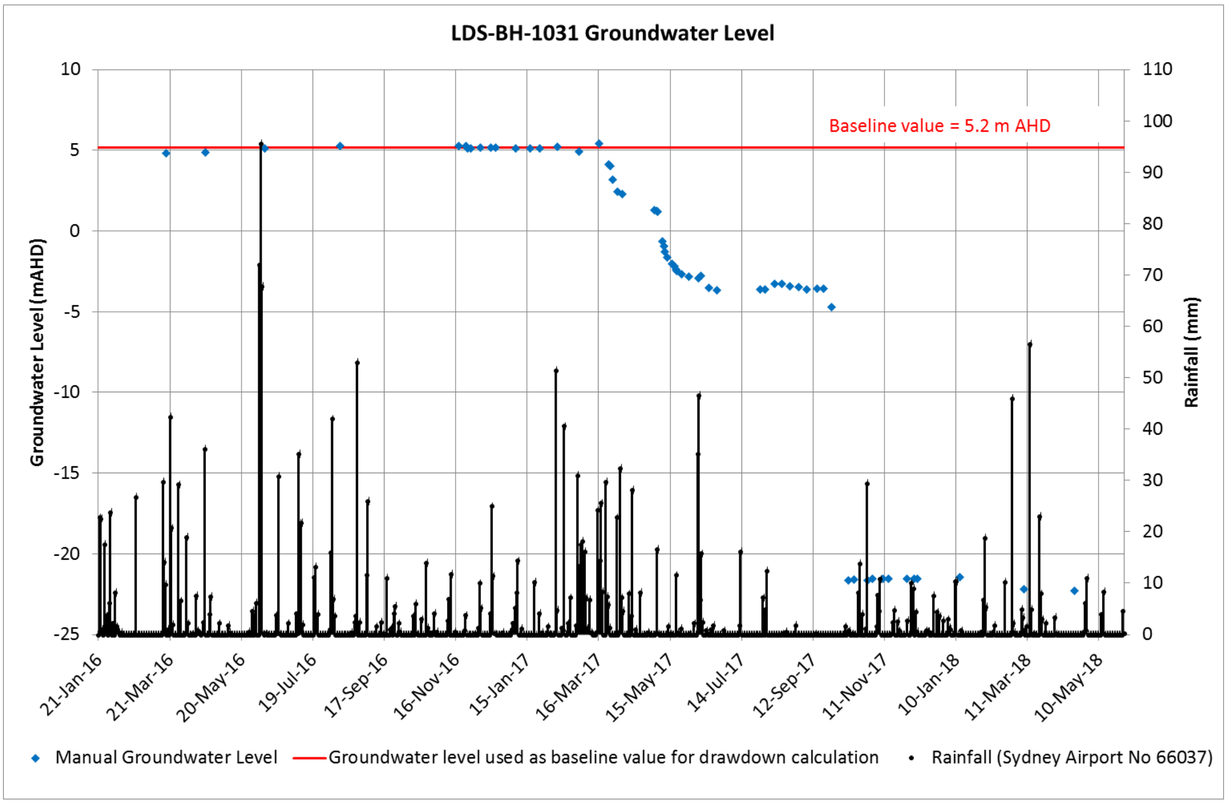


LDS-BH-1030 – Monitoring well destroyed after February 2018

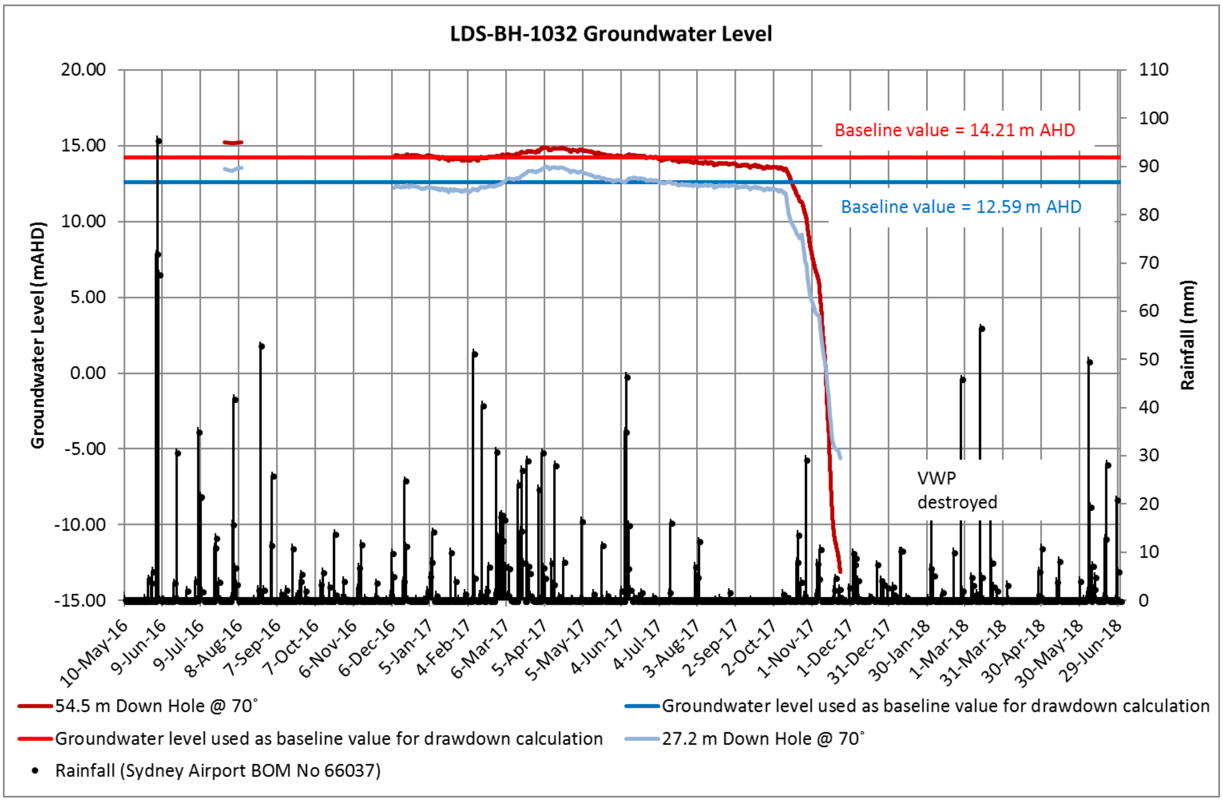


WCX-BH072 – This location was not included as it was destroyed before construction activities started.

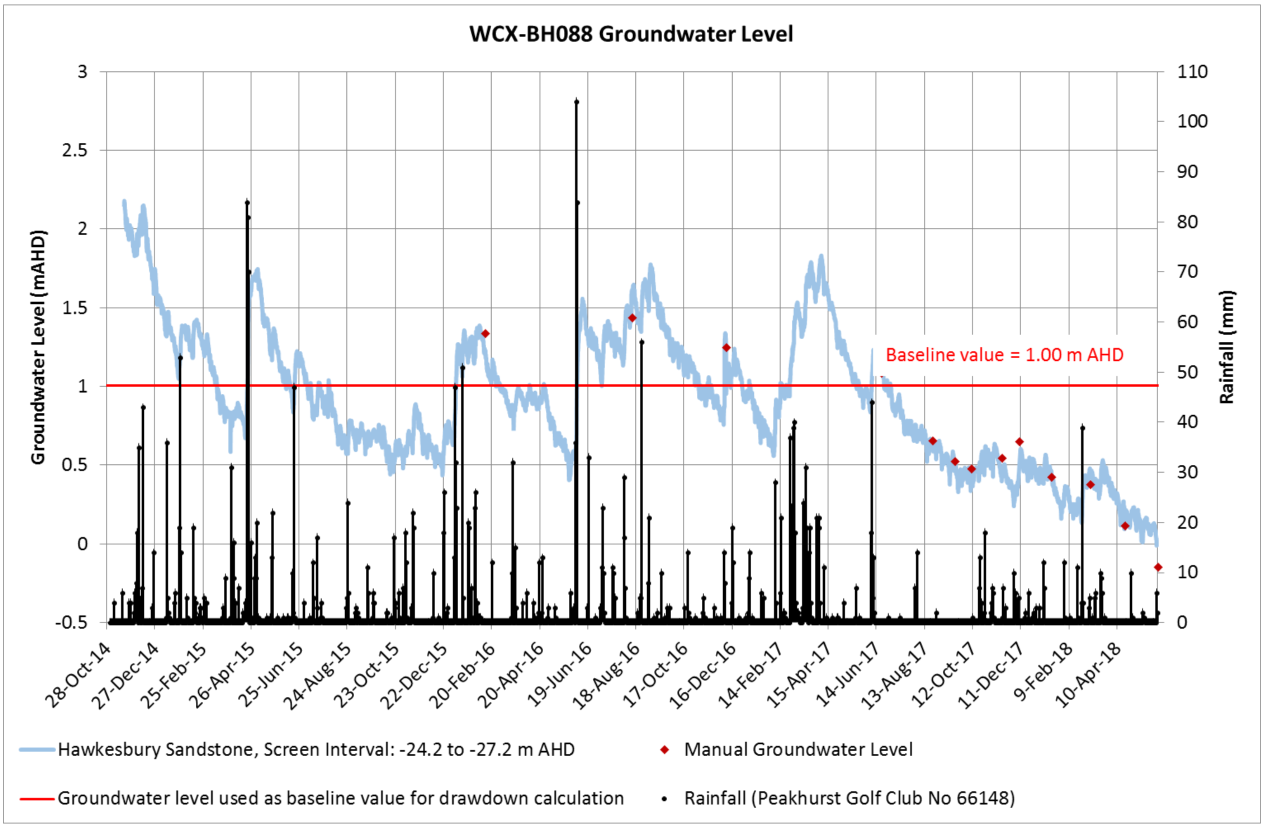
LDS-BH-1031



LDS-BH-1032 – VWP is destroyed

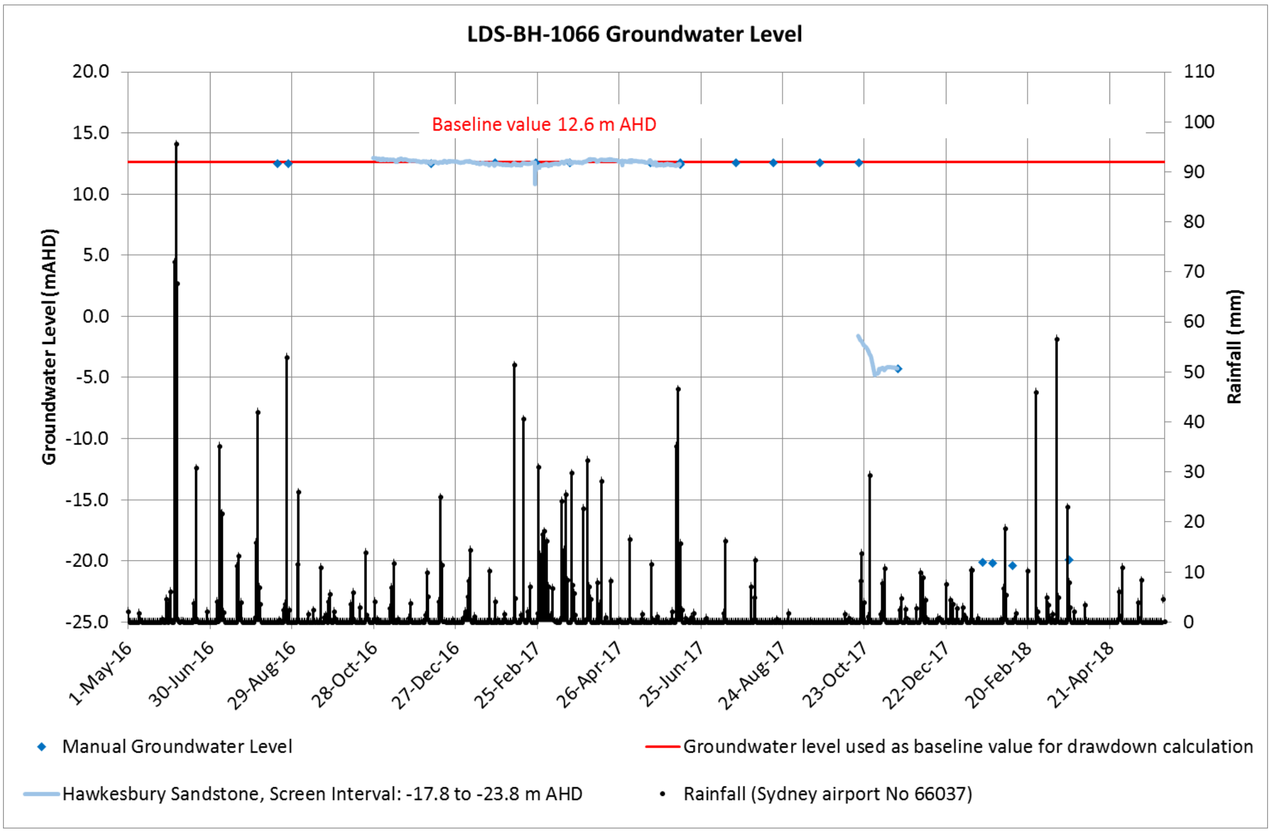


WCX-BH088

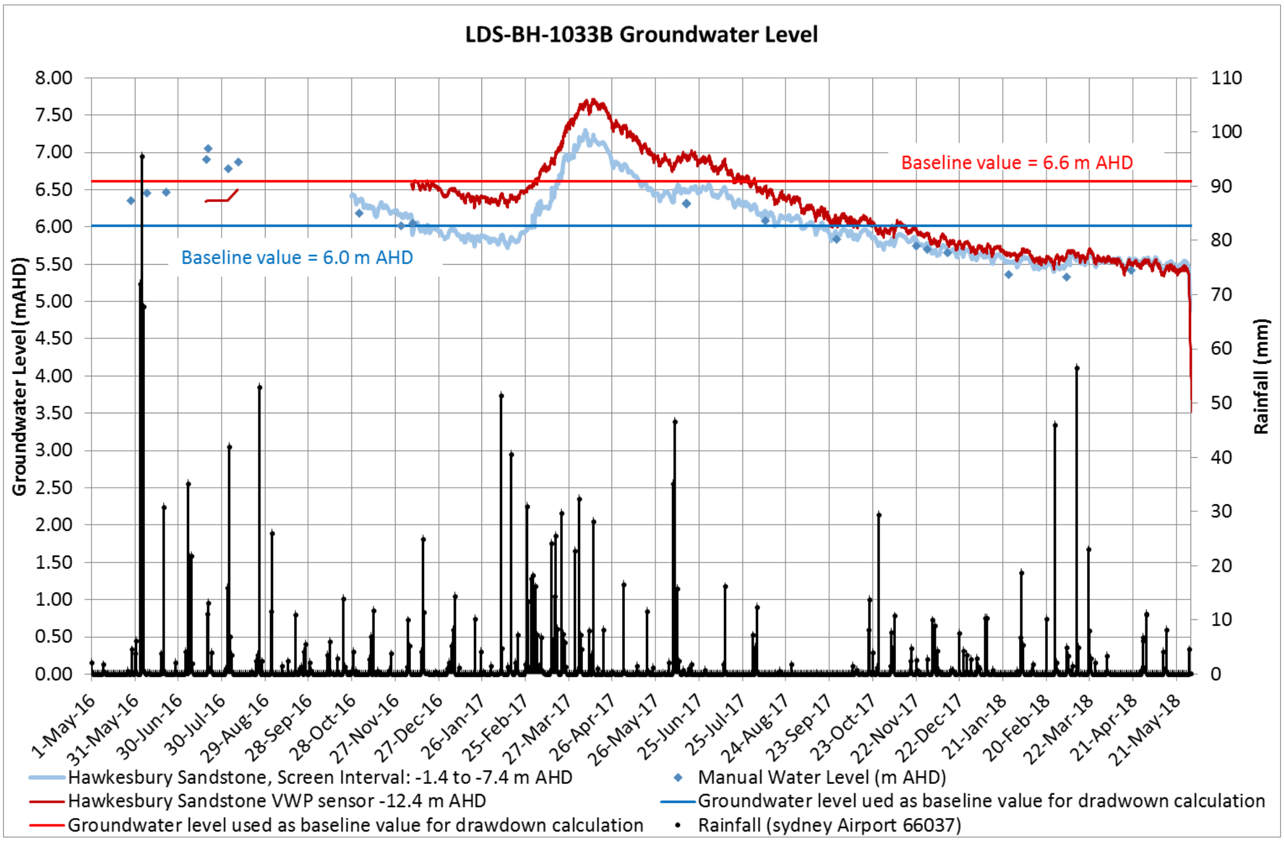


LDS-BH-1044 – This monitoring well has been dry since installation (08/02/2016)

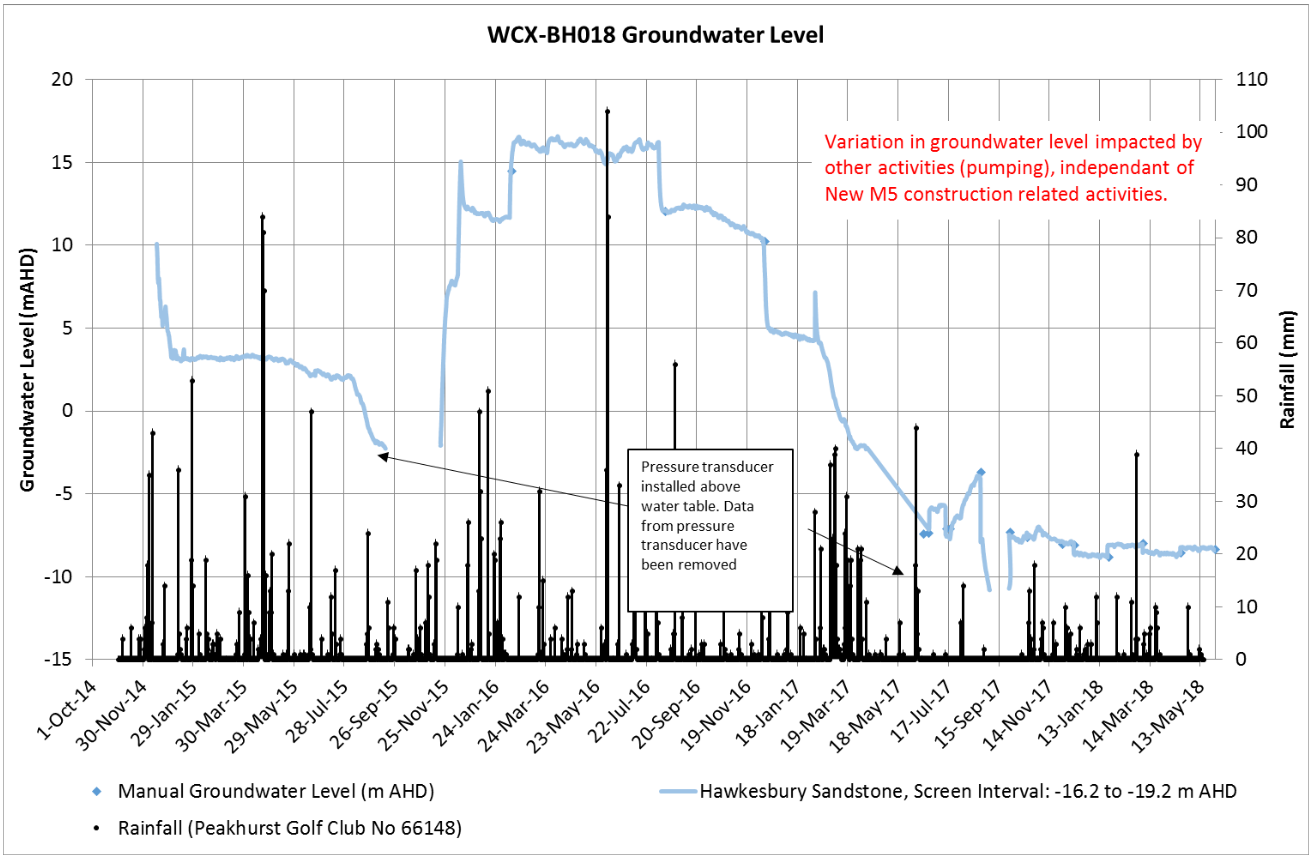
LDS-BH-1066



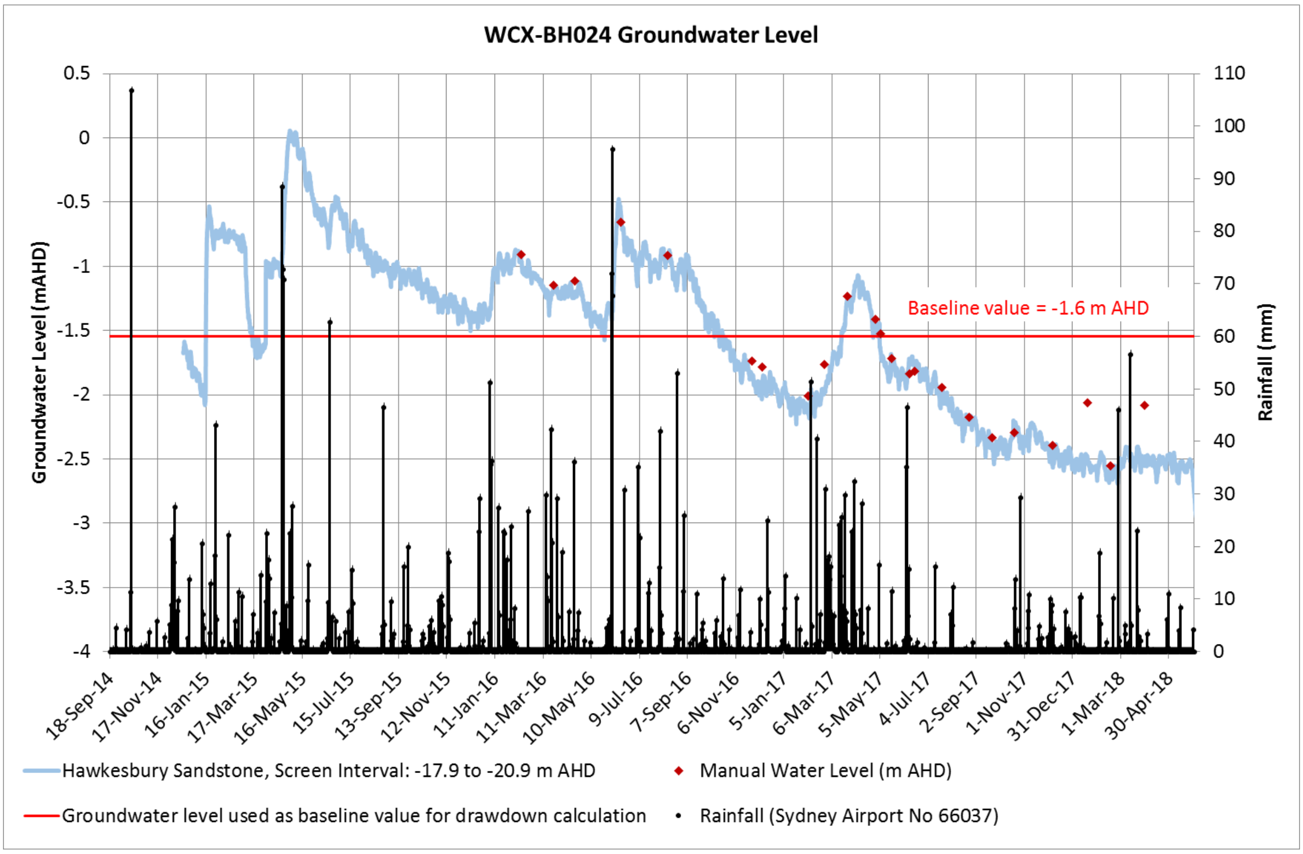
LDS-BH-1033B



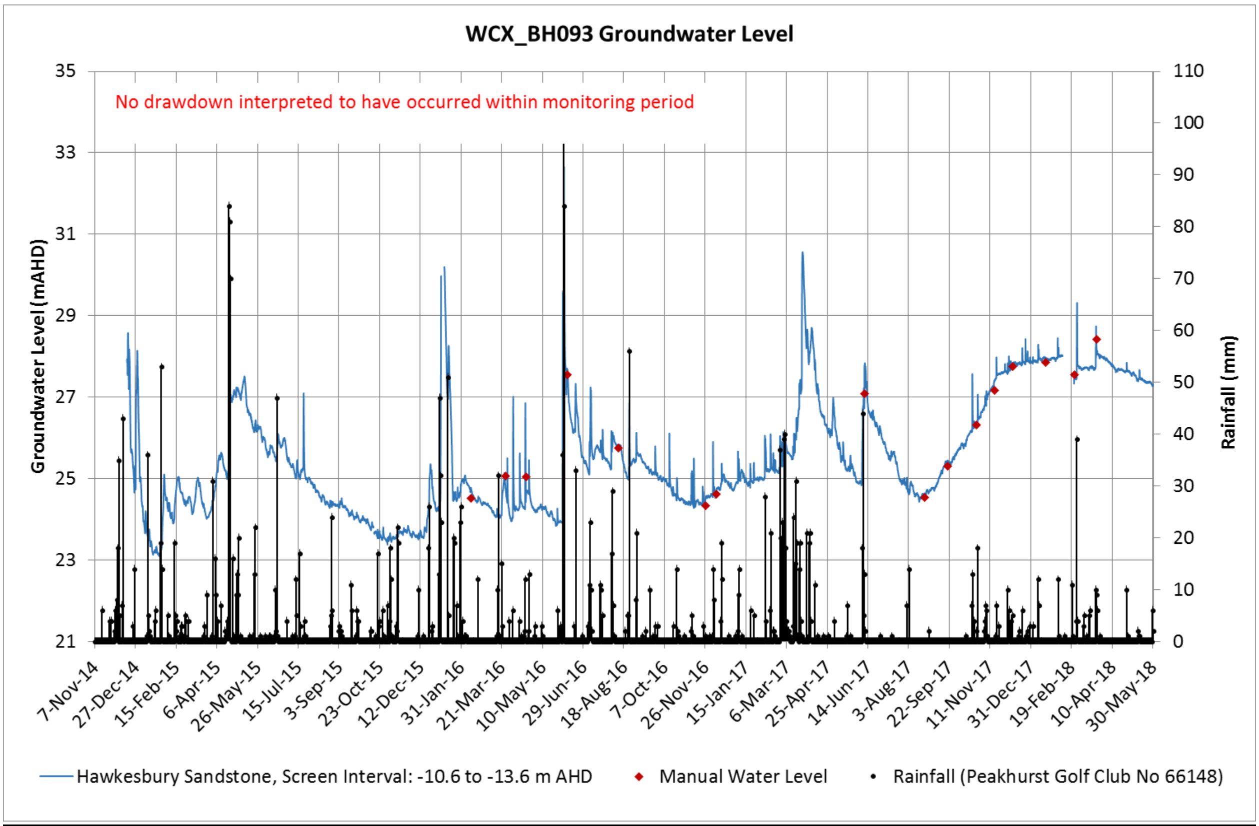
WCX-BH018



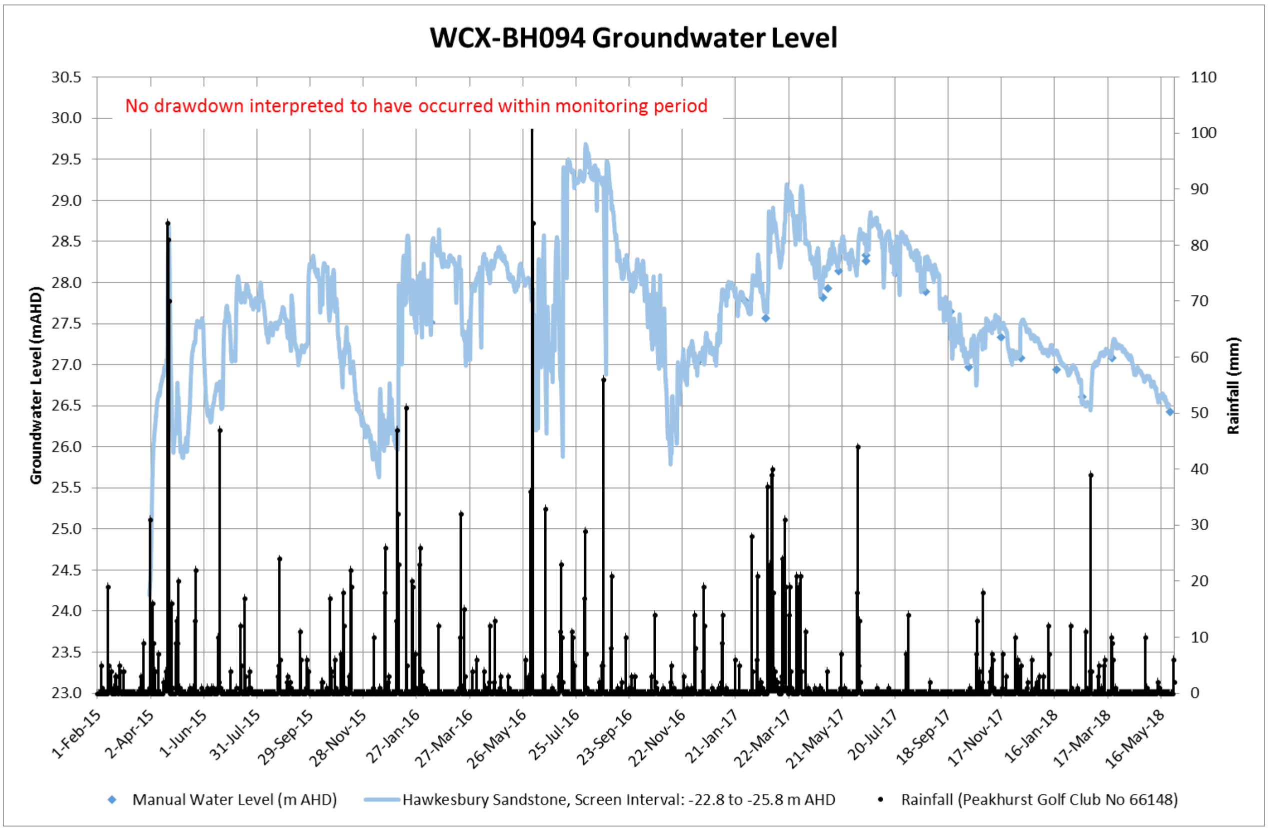
WCX-BH024



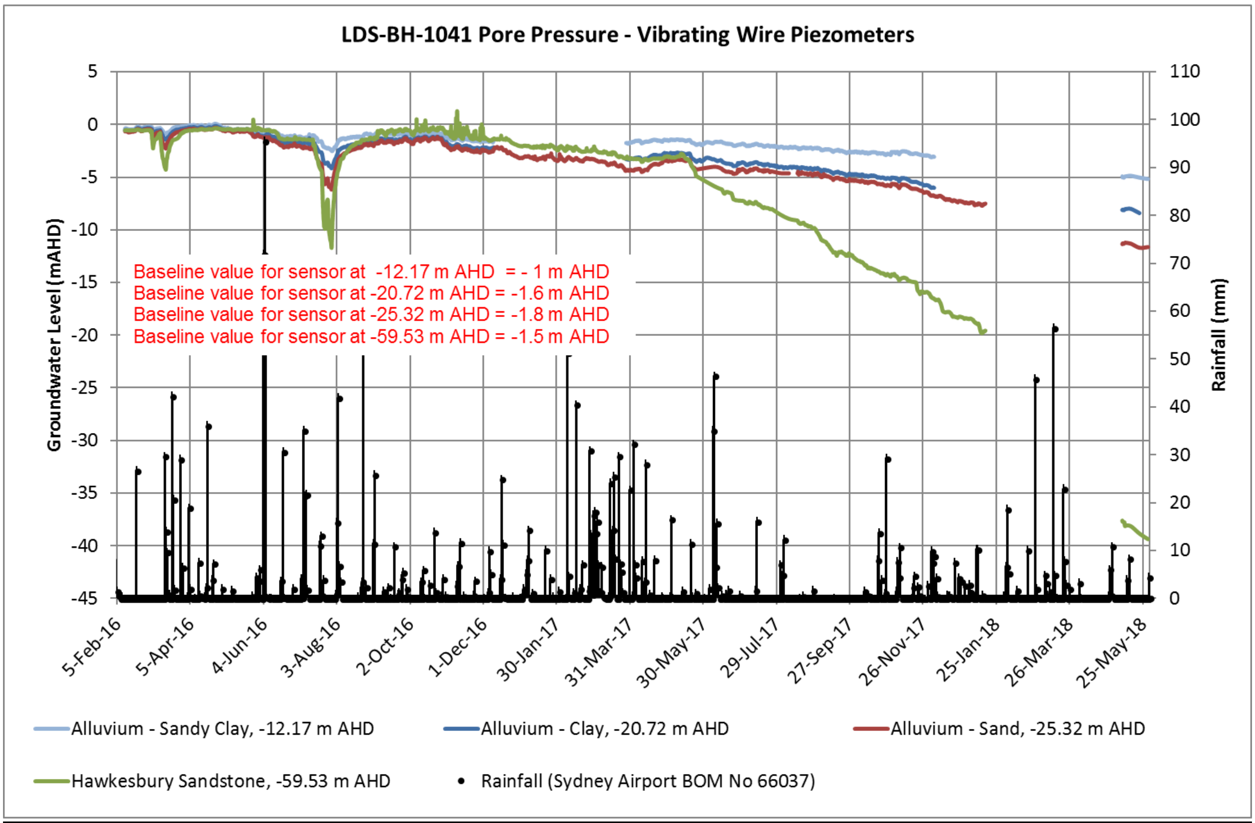
WCX-BH093



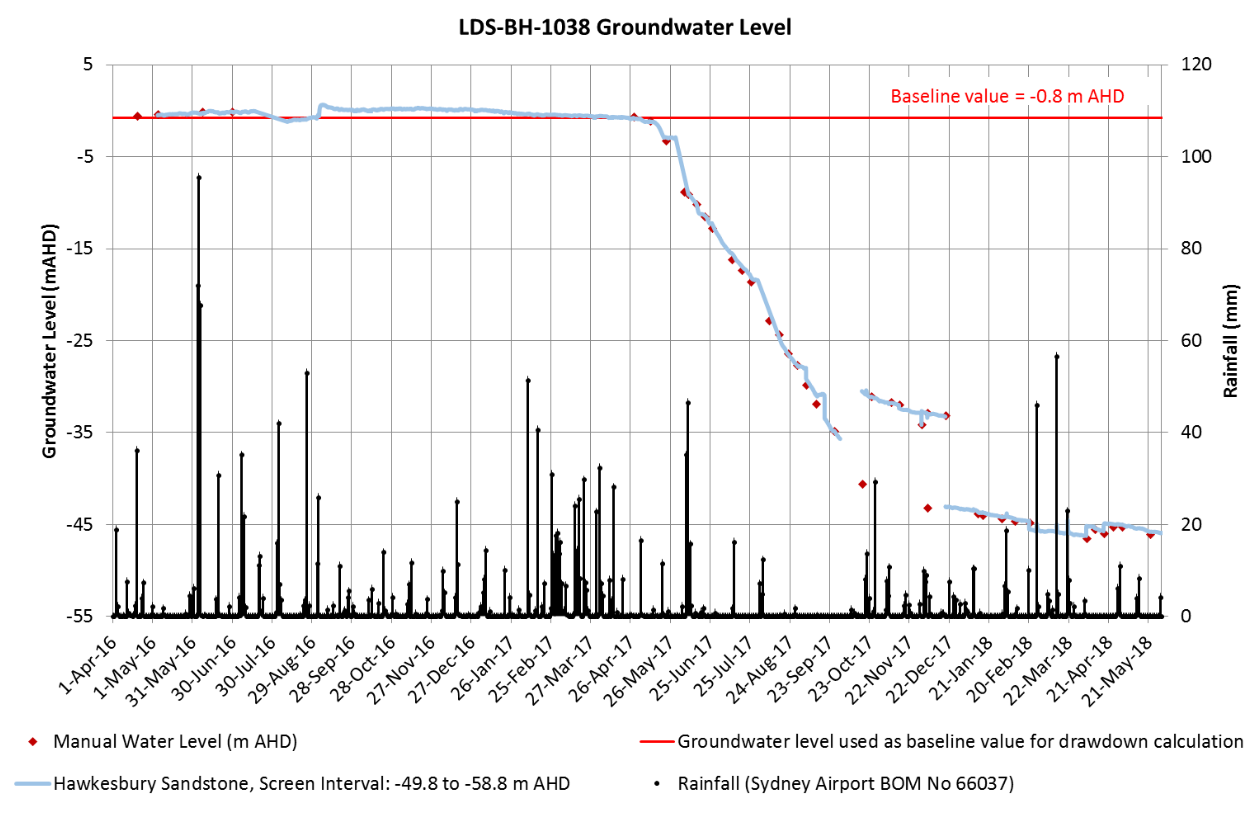
WCX-BH094



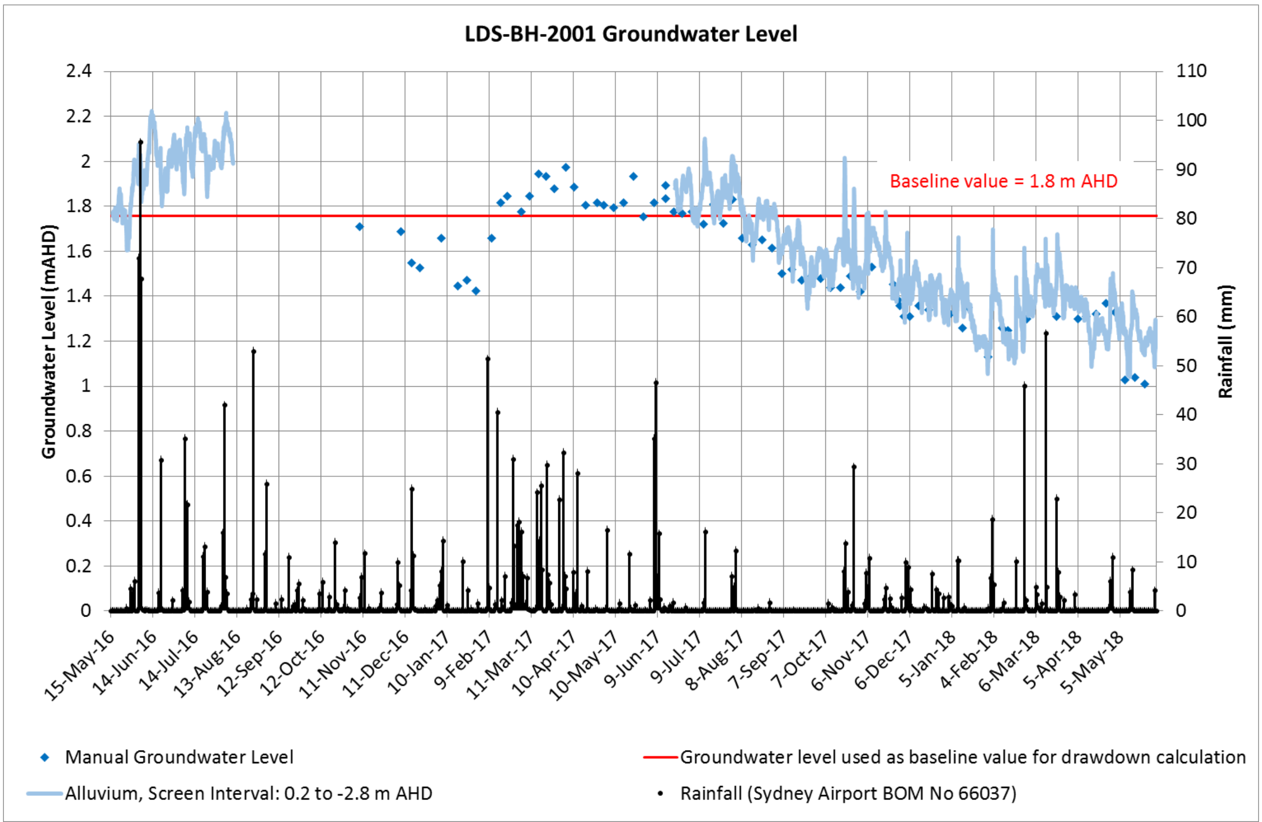
LDS-BH-1041



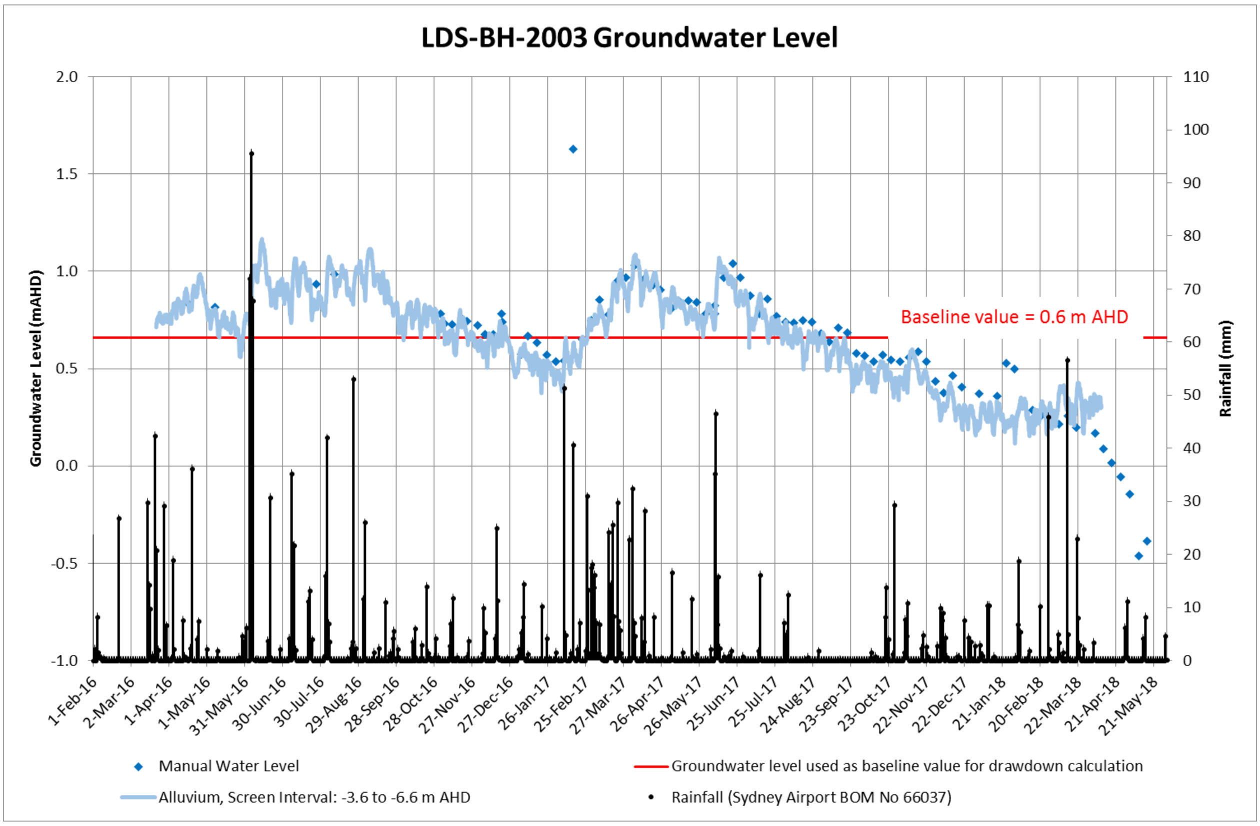
LDS-BH-1038



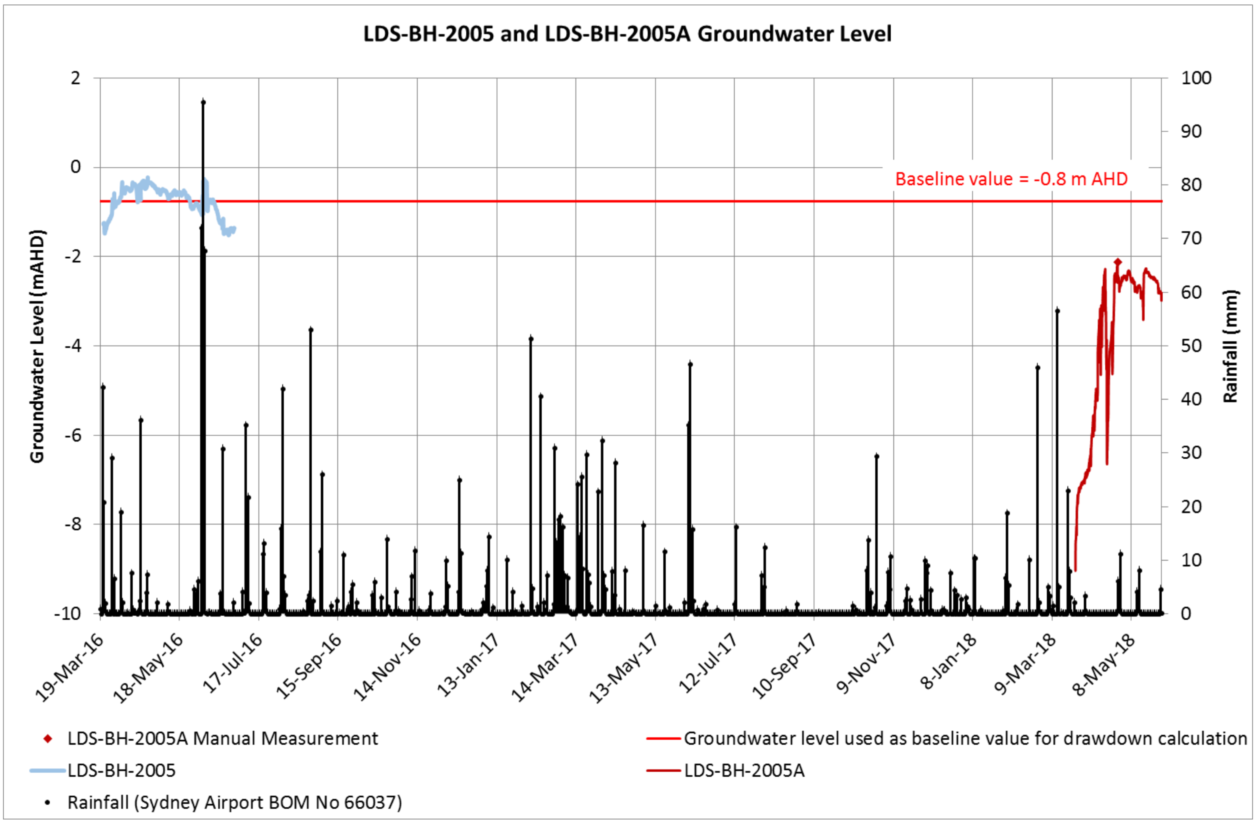
LDS-BH-2001



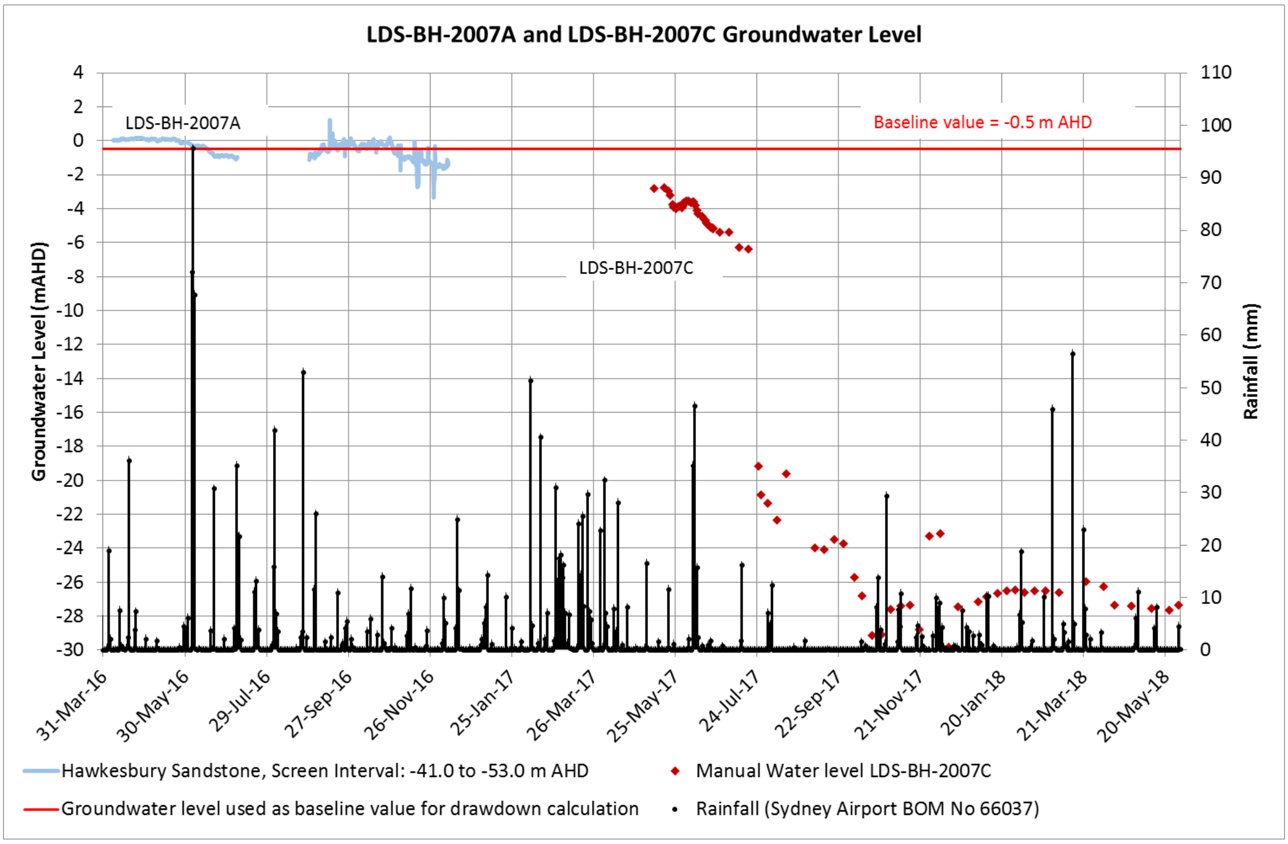
LDS-BH-2003



LDS-BH-2005 and LDS-BH-2005A (installed after LDS-BH-2005 was destroyed)



LDS-BH-2007A and LDS-BH-2007C (installed after LDS-BH-2007A was destroyed)

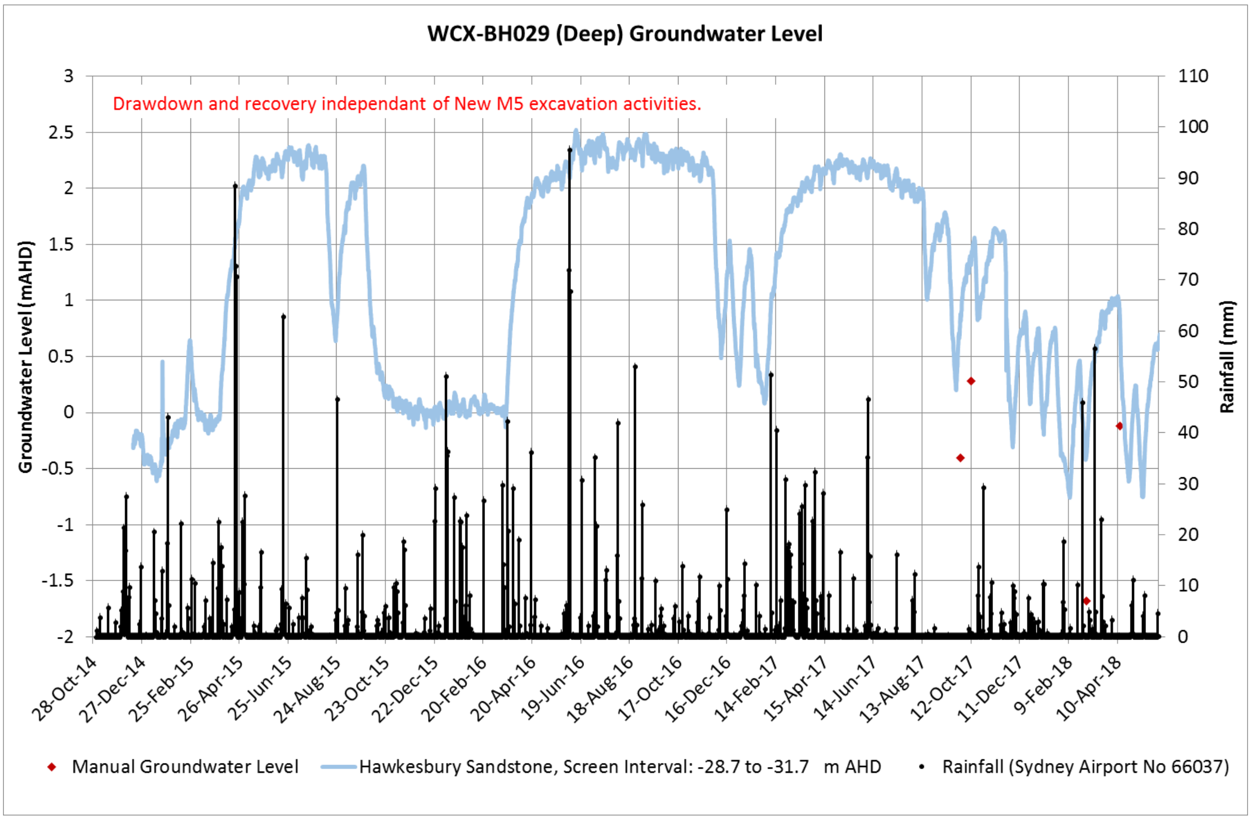


LDS-BH-2029 – Monitoring well was destroyed before construction related activities started.

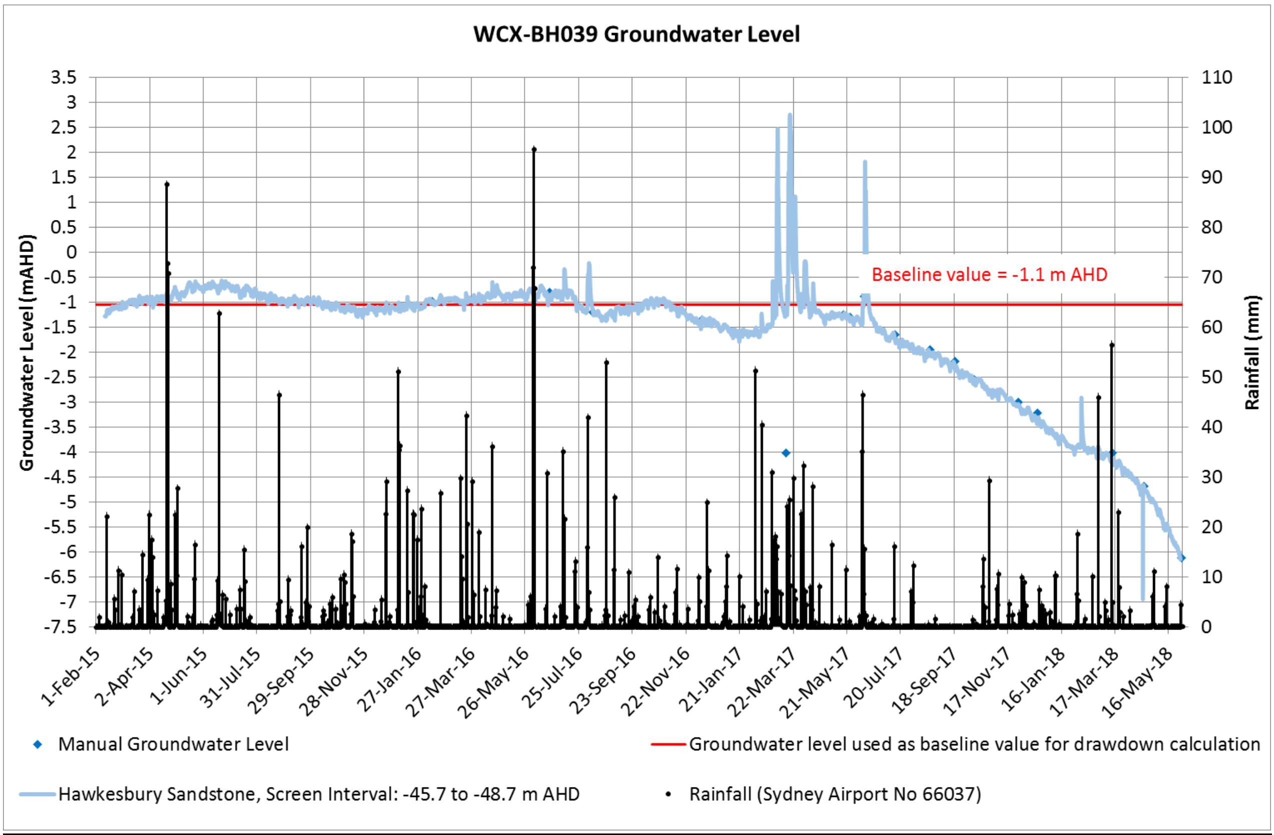
LDS-BH-2029A – Monitoring well was destroyed before construction related activities started.

WCX-BH025 – No data available during construction phase due to limited access to well.

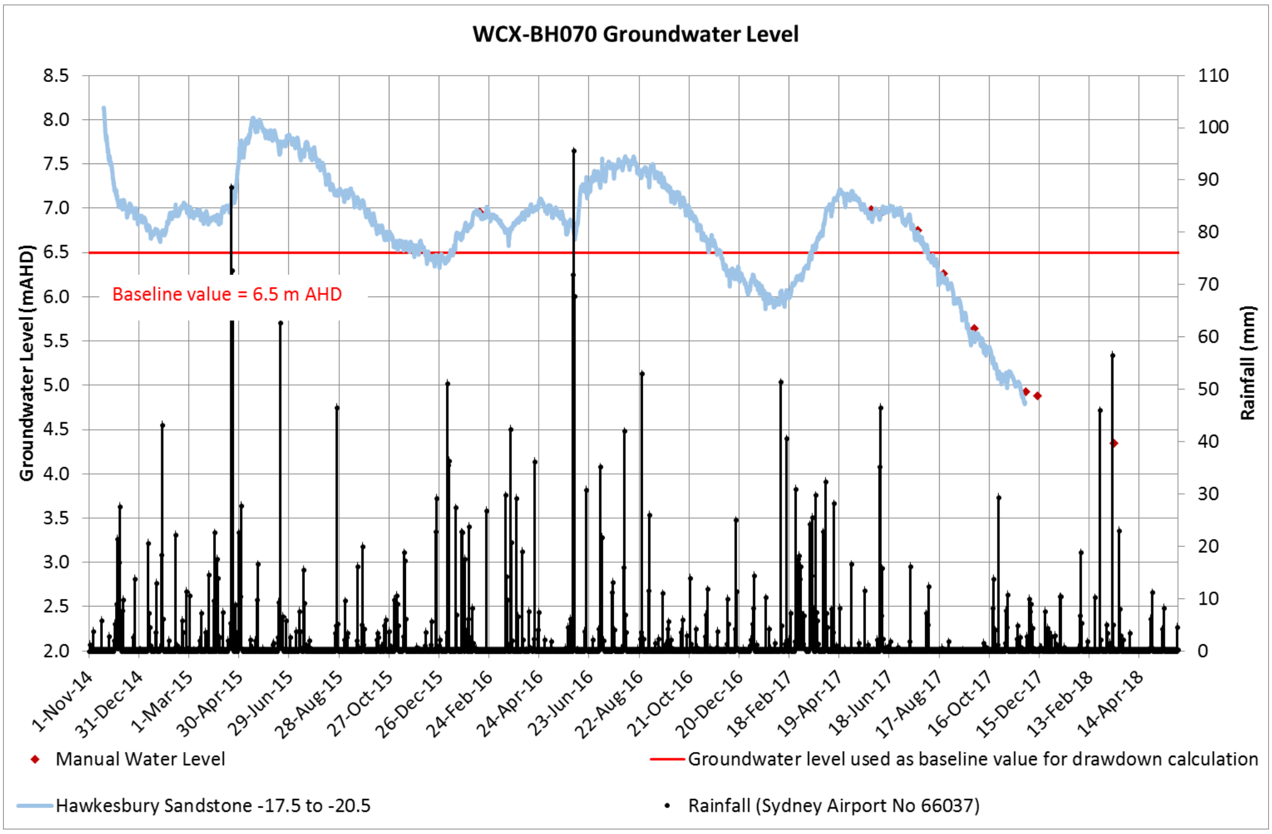
WCX-BH029



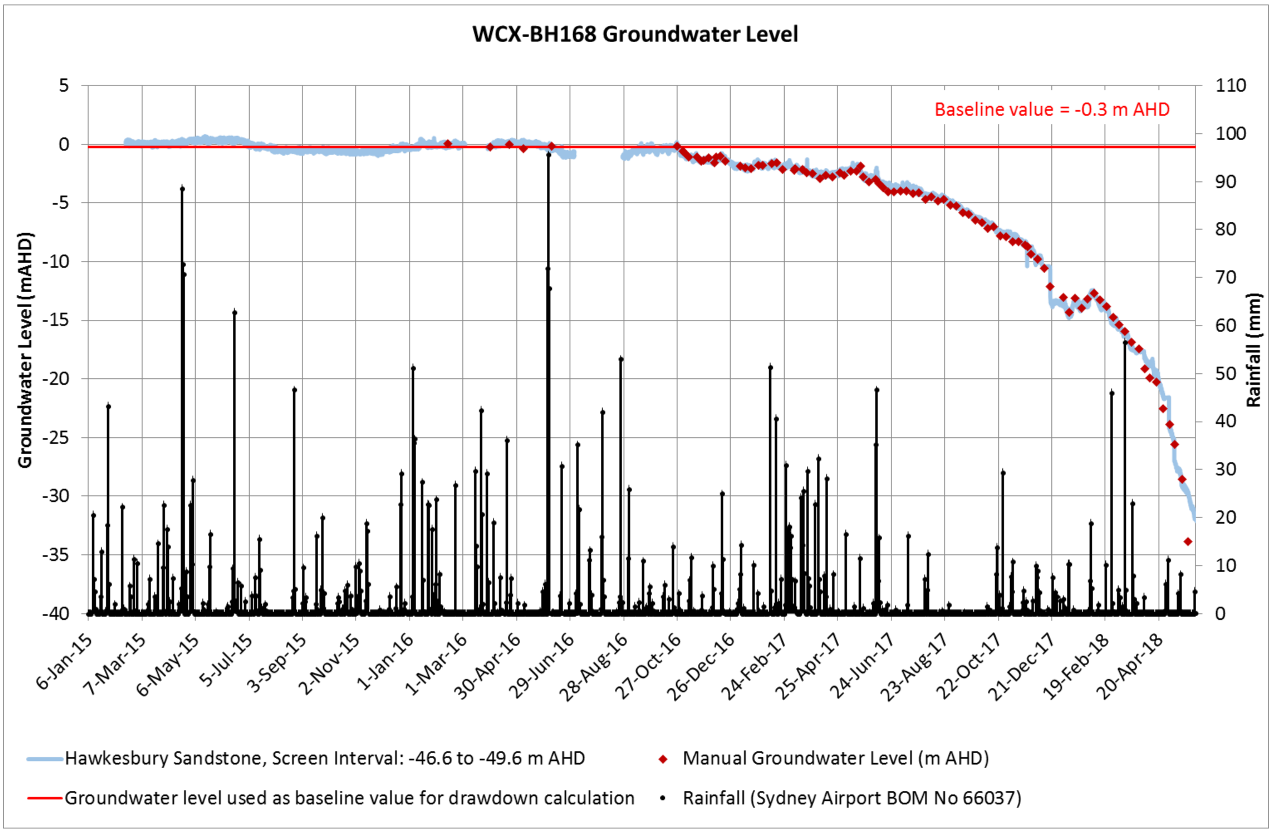
WCX-BH039



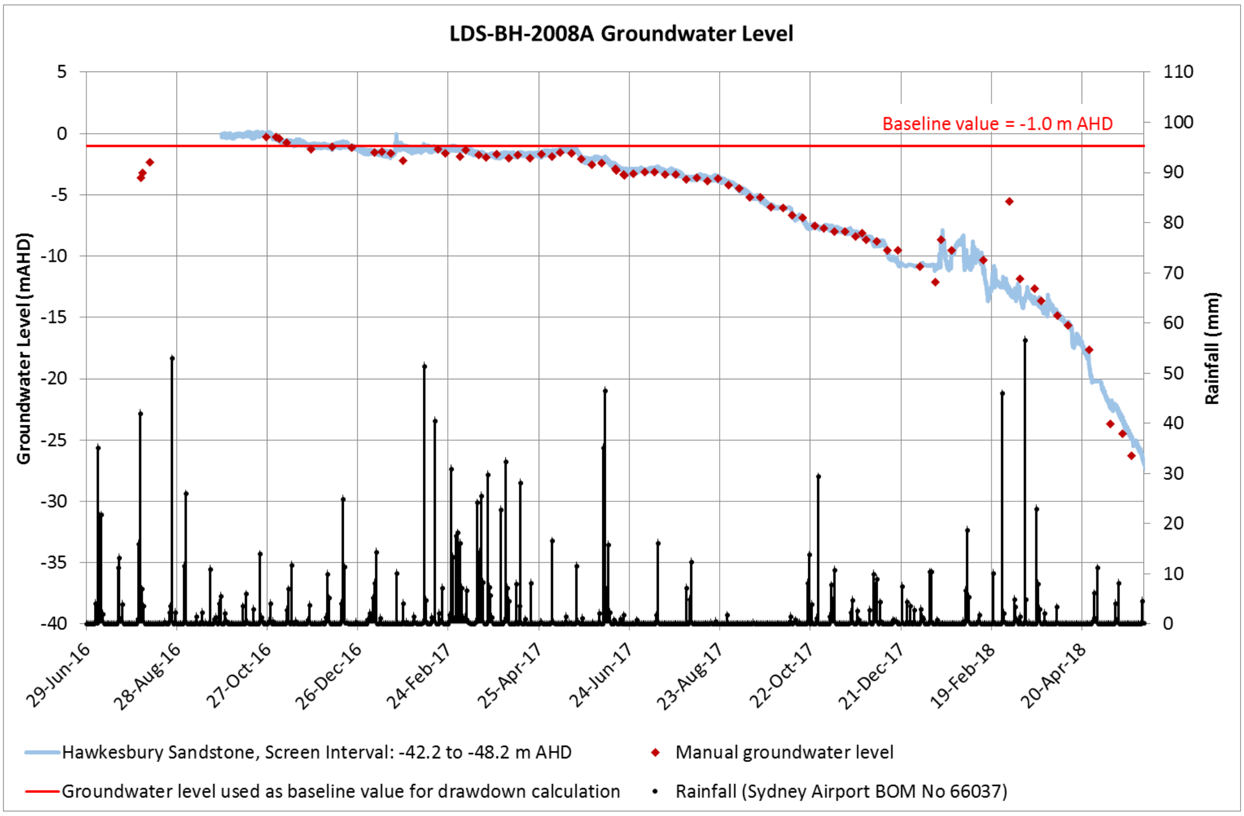
WCX-BH070


WCX-BH070 Groundwater Level
Groundwater Level (mAHD)
Rainfall (mm)
Baseline value = 6.5 m AHD
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
110
100
90
80
70
60
50
40
30
20
10
0
1-Nov-14
31-Dec-14
1-Mar-15
30-Apr-15
29-Jun-15
28-Aug-15
27-Oct-15
26-Dec-15
24-Feb-16
24-Apr-16
23-Jun-16
22-Aug-16
21-Oct-16
20-Dec-16
18-Feb-17
19-Apr-17
18-Jun-17
17-Aug-17
16-Oct-17
15-Dec-17
13-Feb-18
14-Apr-18
Manual Water Level
Groundwater level used as baseline value for drawdown calculation
Hawkesbury Sandstone -17.5 to -20.5
Rainfall (Sydney Airport No 66037)

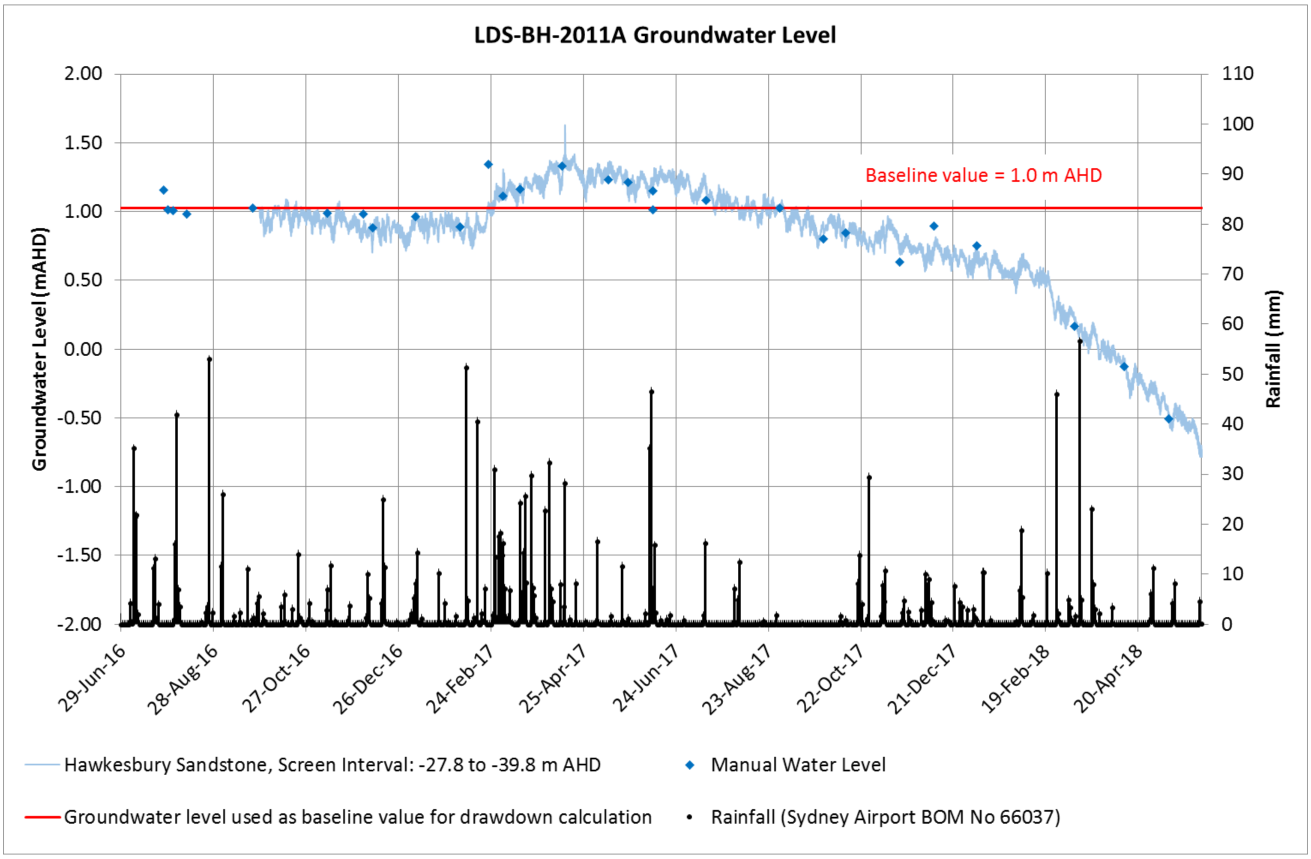
WCX-BH168



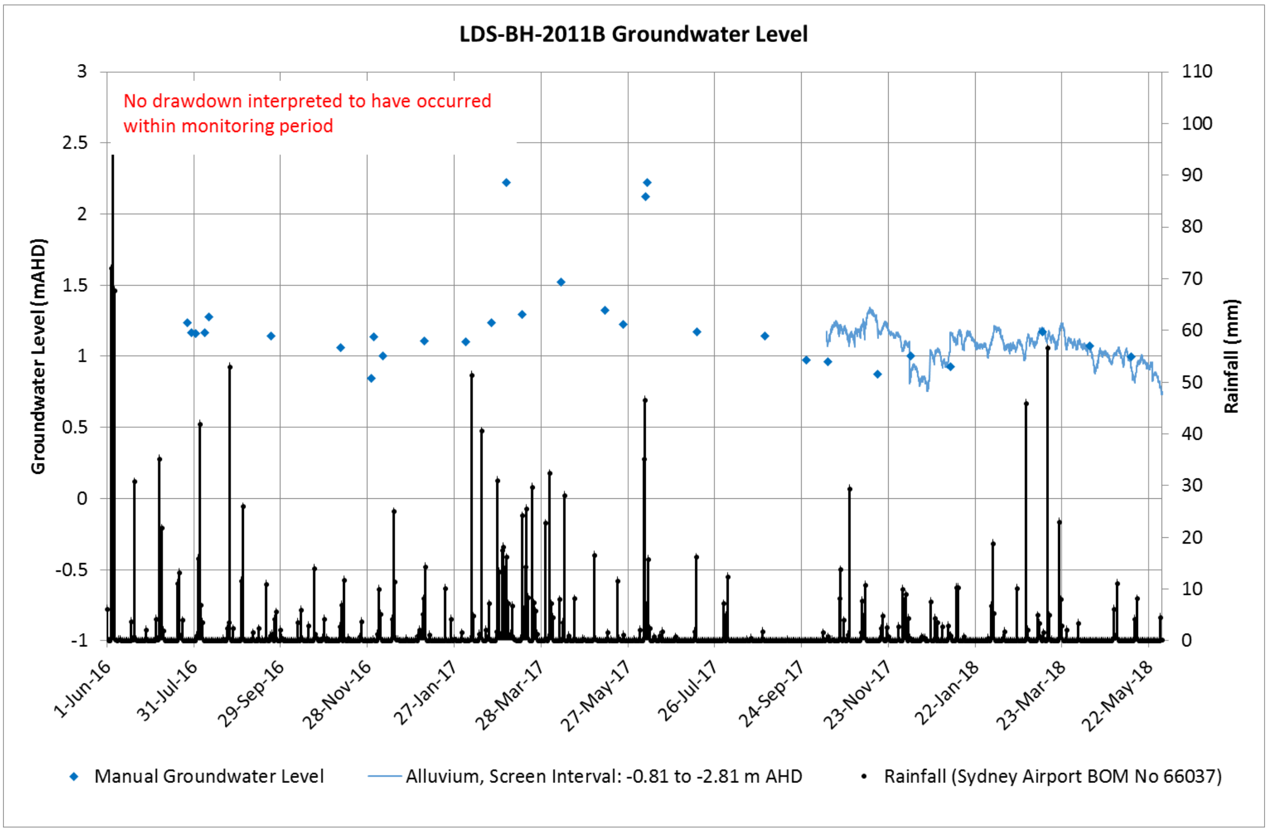
LDS-BH-2008A



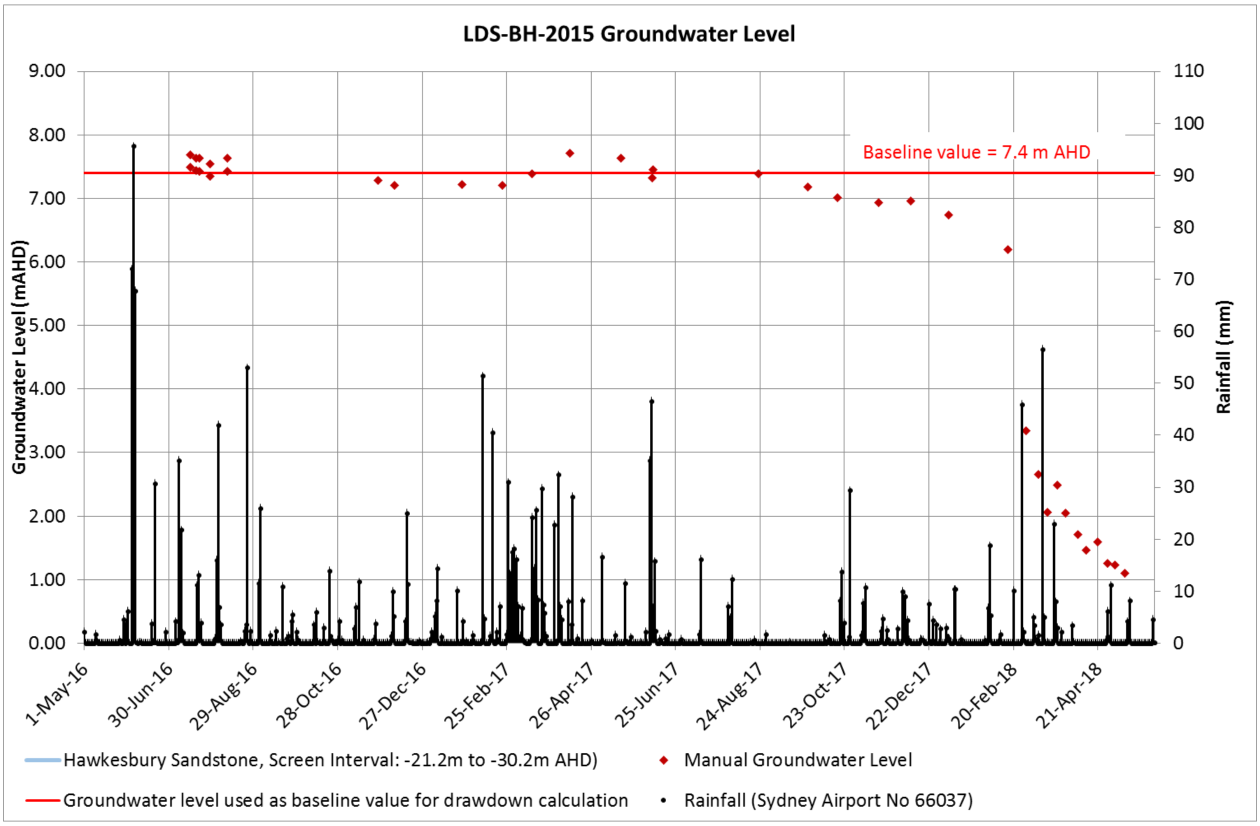
LDS-BH-2011A



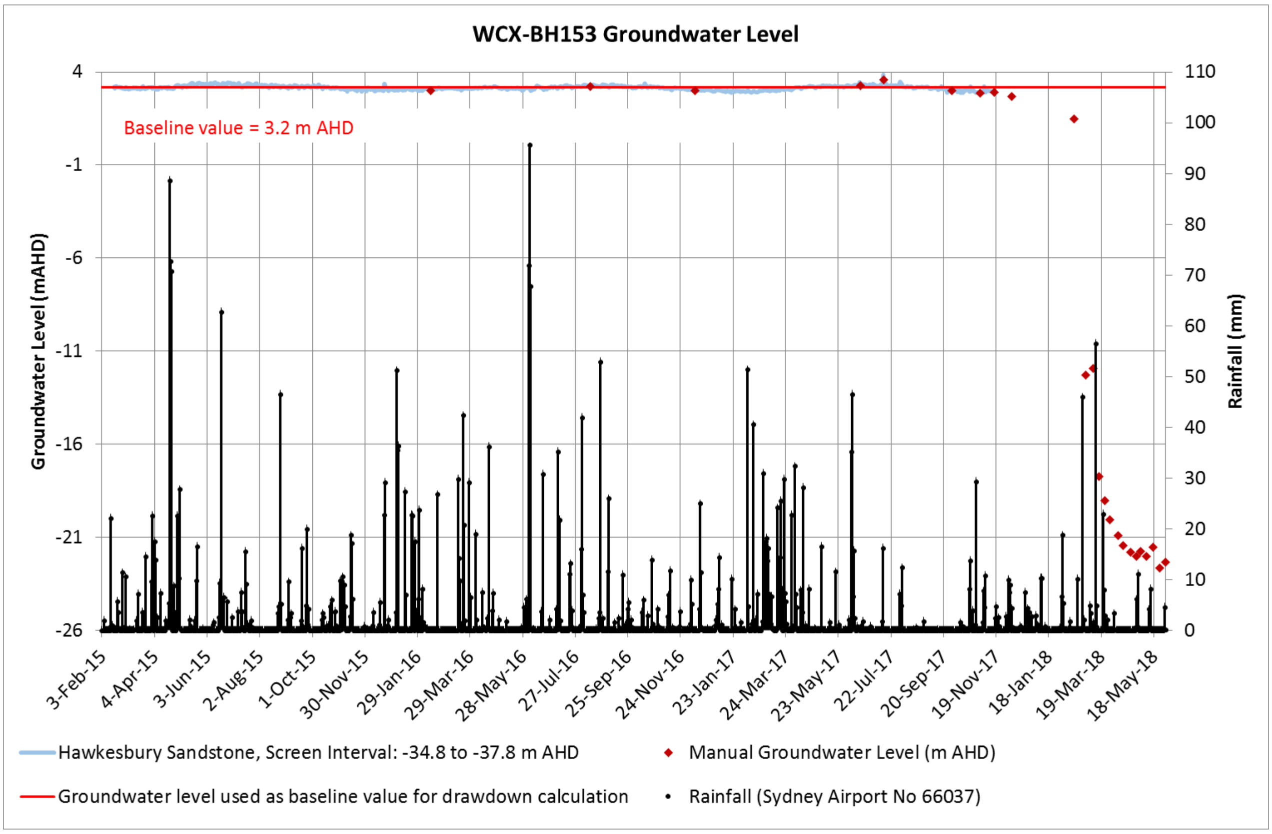
LDS-BH-2011B



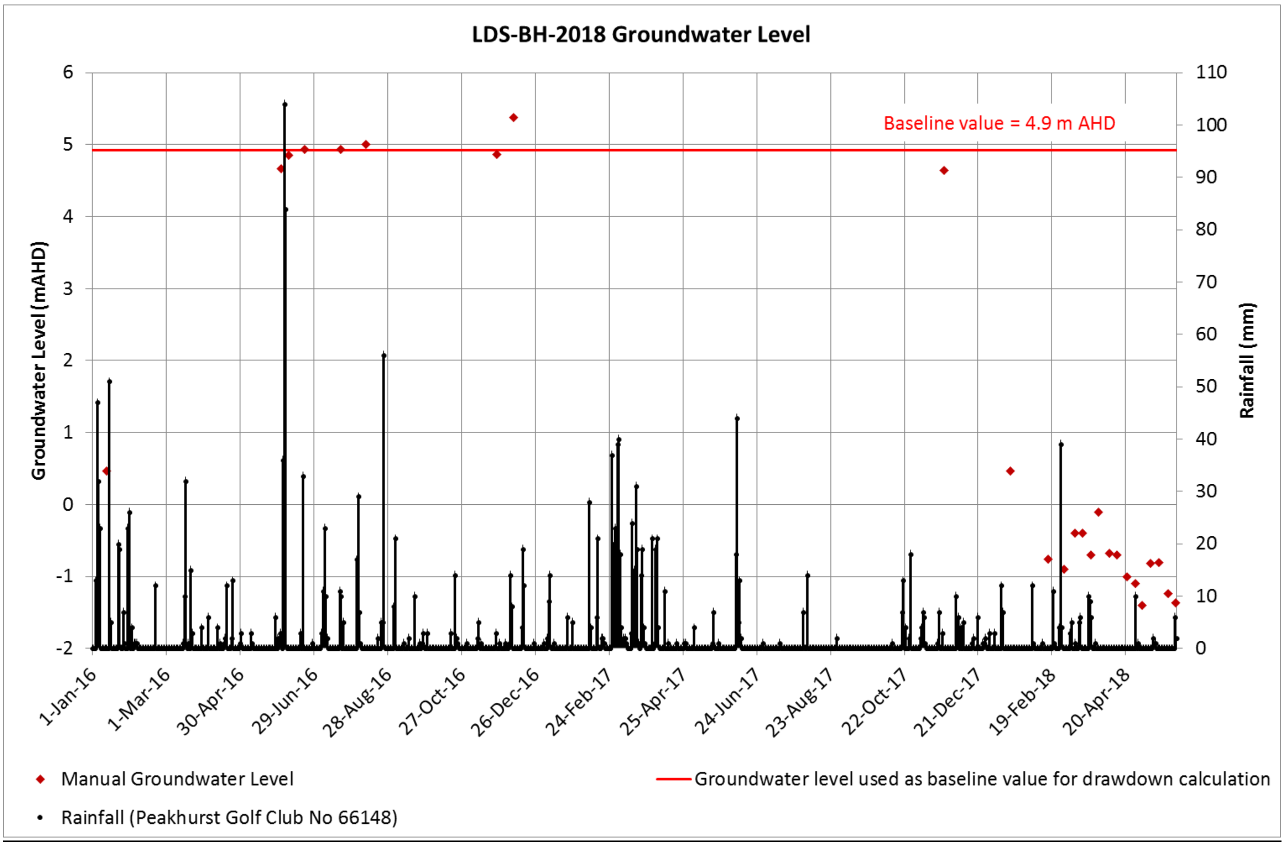
LDS-BH-2015



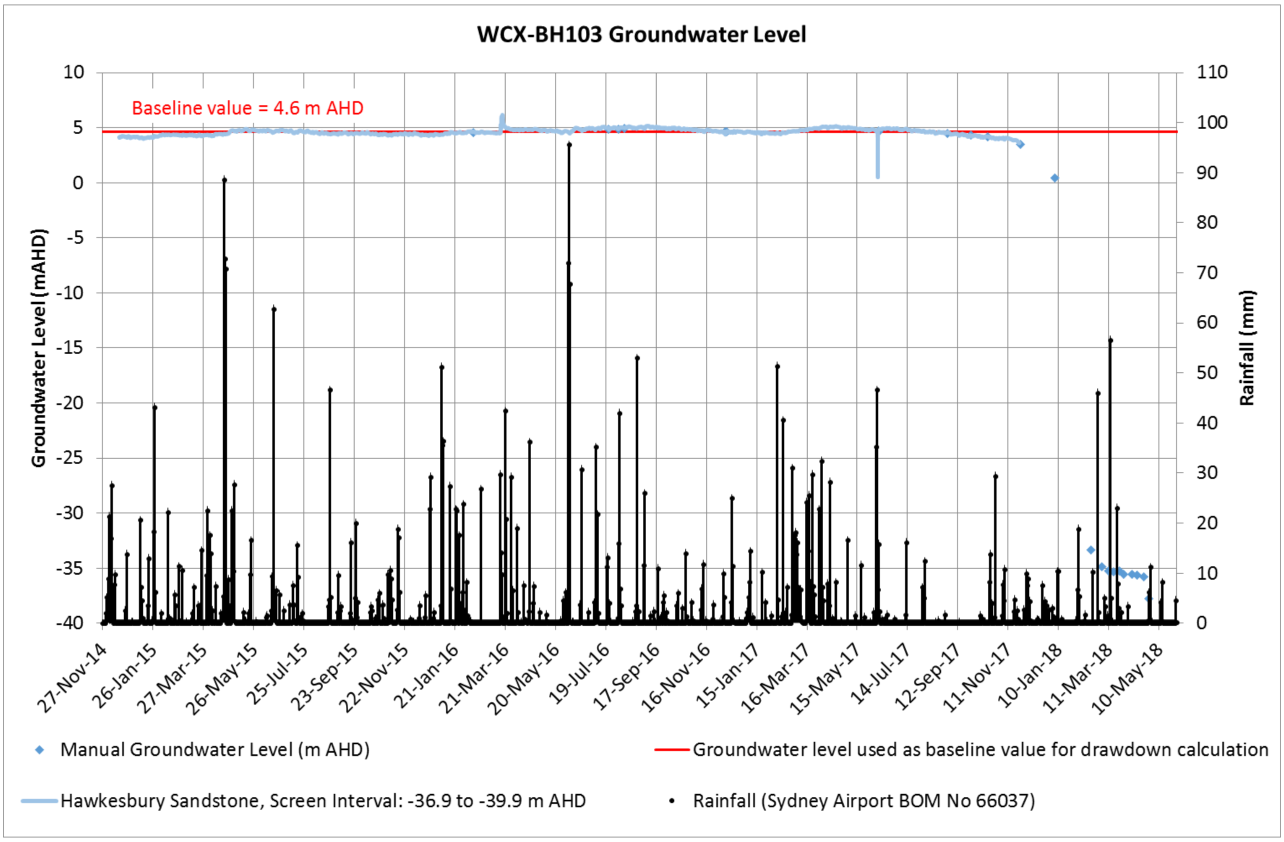
WCX-BH153



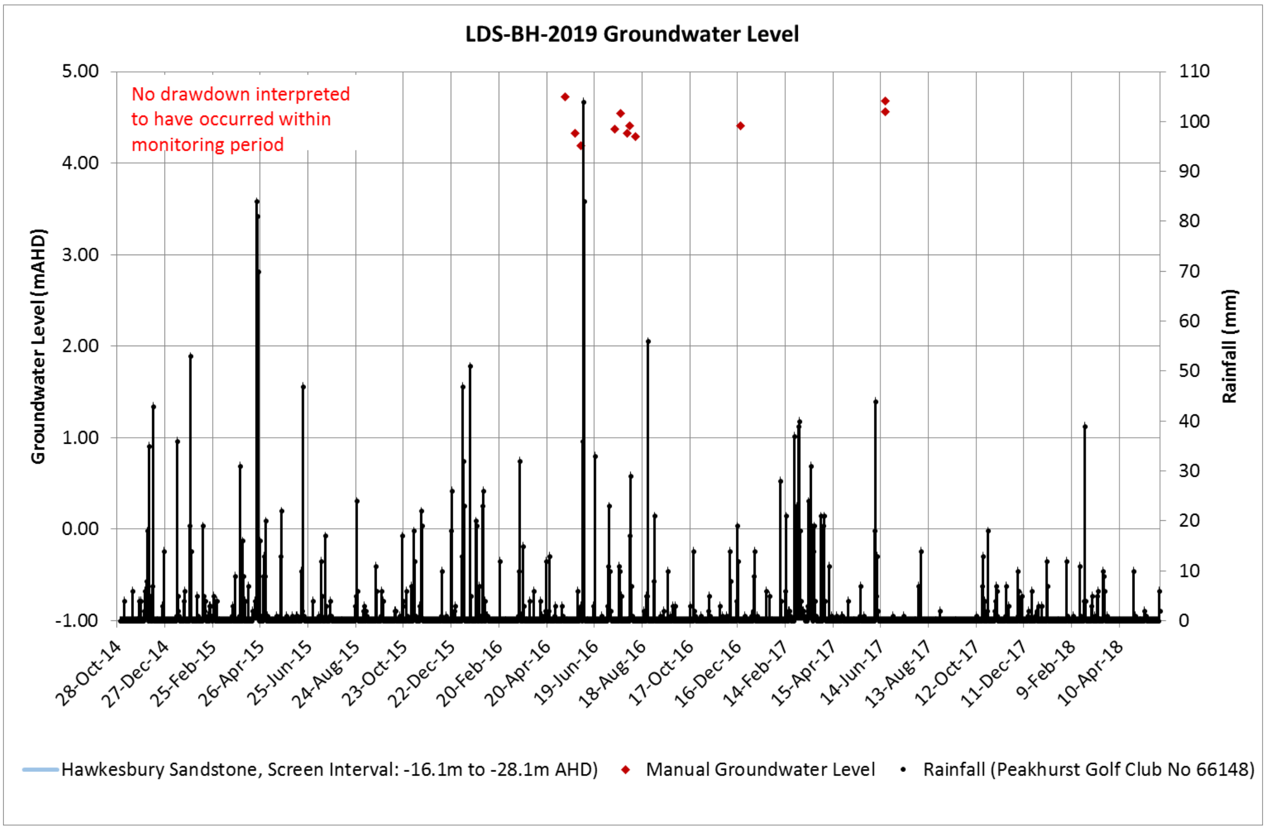
LDS-BH-2018



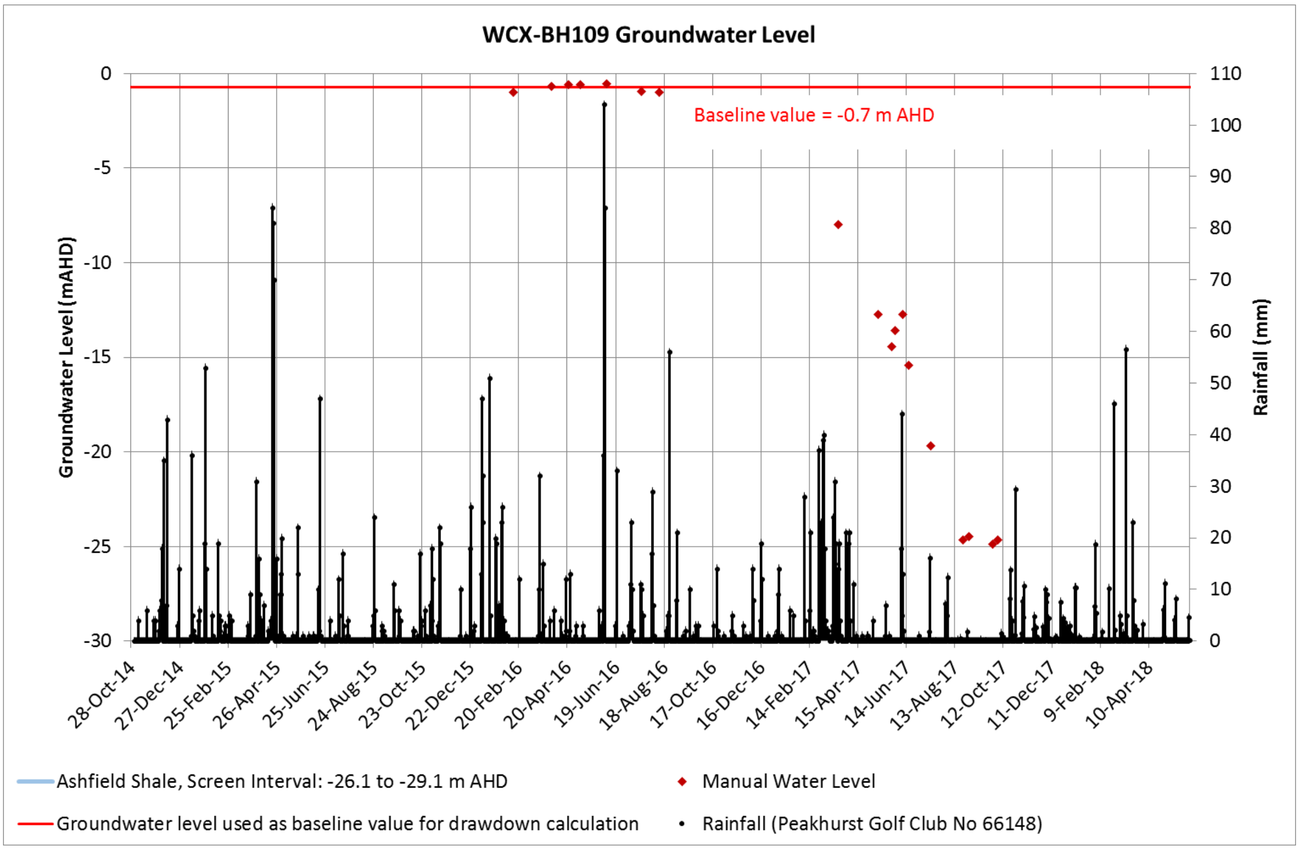
WCX-BH103



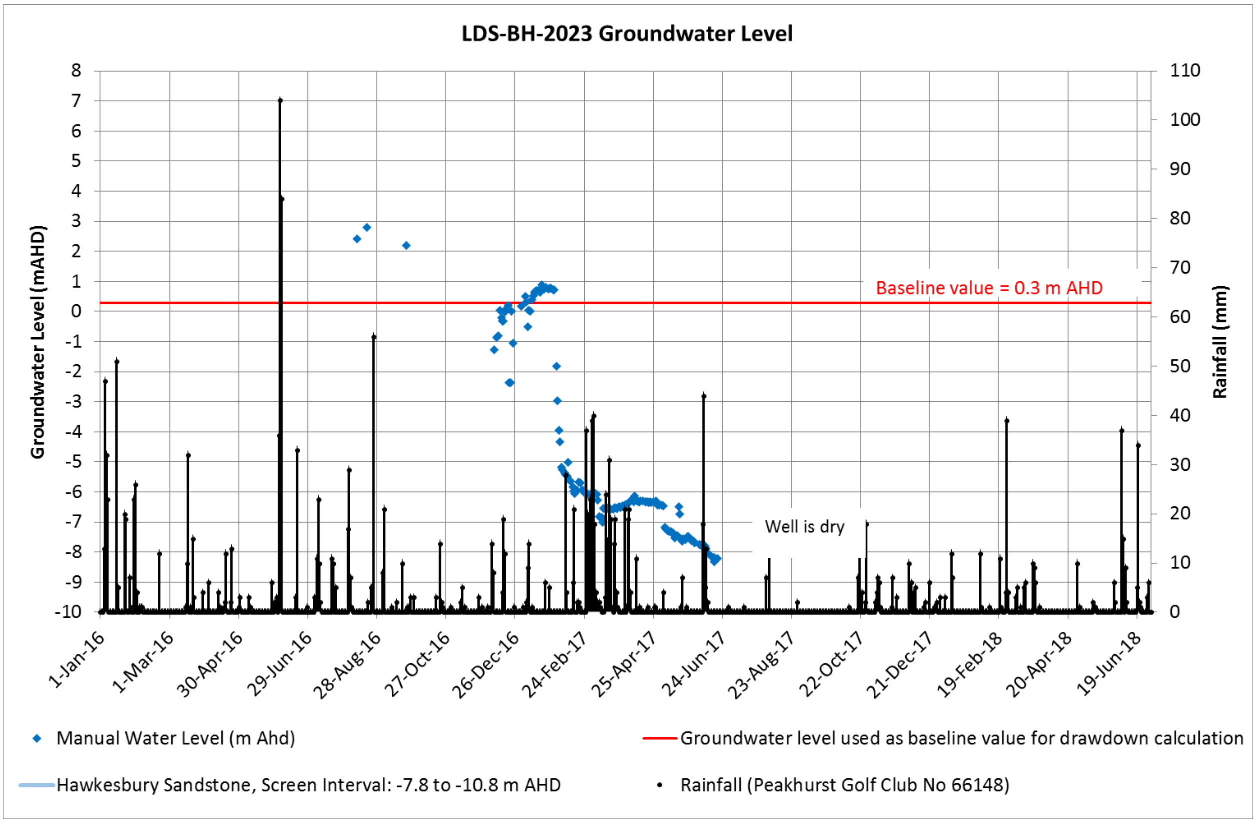
LDS-BH-2019


LDS-BH-2019 Groundwater Level
No drawdown interpreted to have occurred within monitoring period
Groundwater Level (mAHD)
Rainfall (mm)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
110
100
90
80
70
60
50
40
30
20
10
0
28-Oct-14
27-Dec-14
25-Feb-15
26-Apr-15
25-Jun-15
24-Aug-15
23-Oct-15
22-Dec-15
20-Feb-16
20-Apr-16
19-Jun-16
18-Aug-16
17-Oct-16
16-Dec-16
14-Feb-17
15-Apr-17
14-Jun-17
13-Aug-17
12-Oct-17
11-Dec-17
9-Feb-18
10-Apr-18
Hawkesbury Sandstone, Screen Interval: -16.1m to -28.1m AHD)
Manual Groundwater Level
Rainfall (Peakhurst Golf Club No 66148)

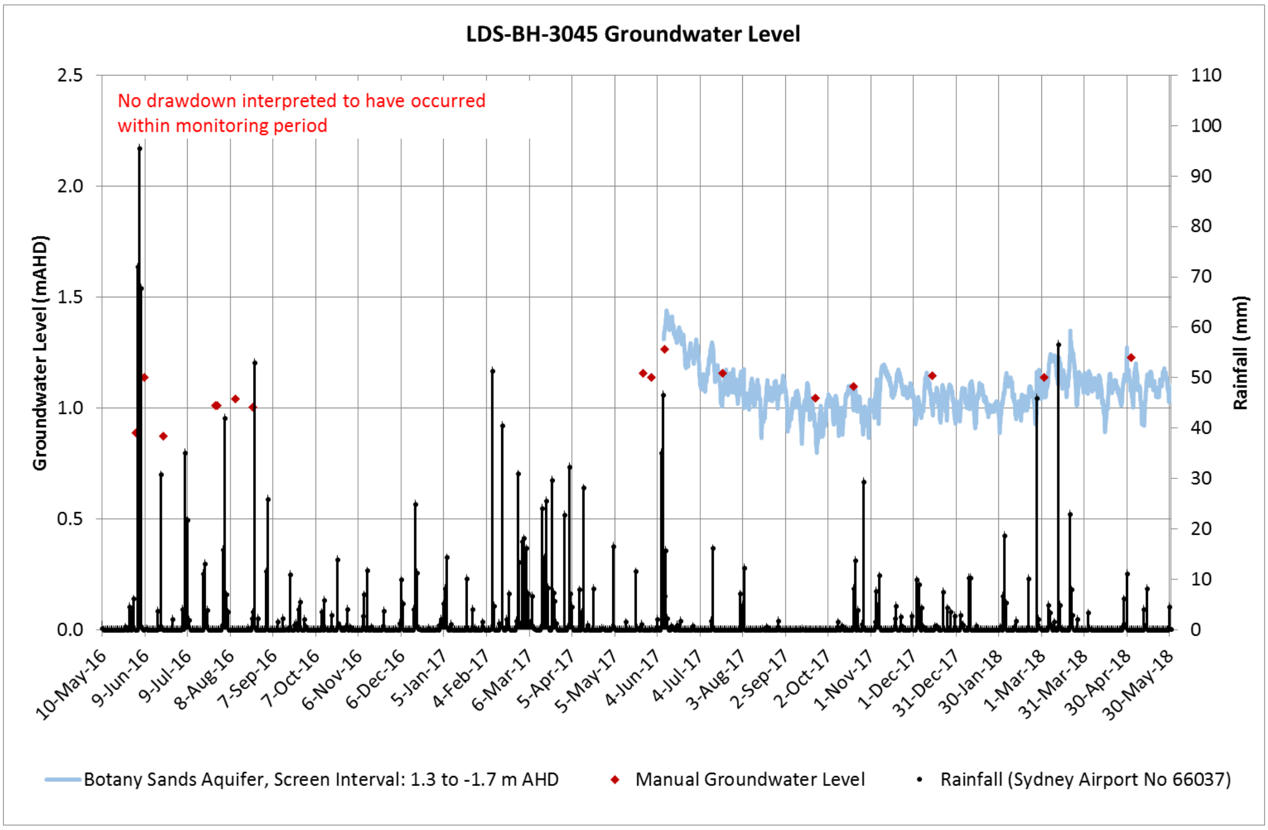
WCX-BH109



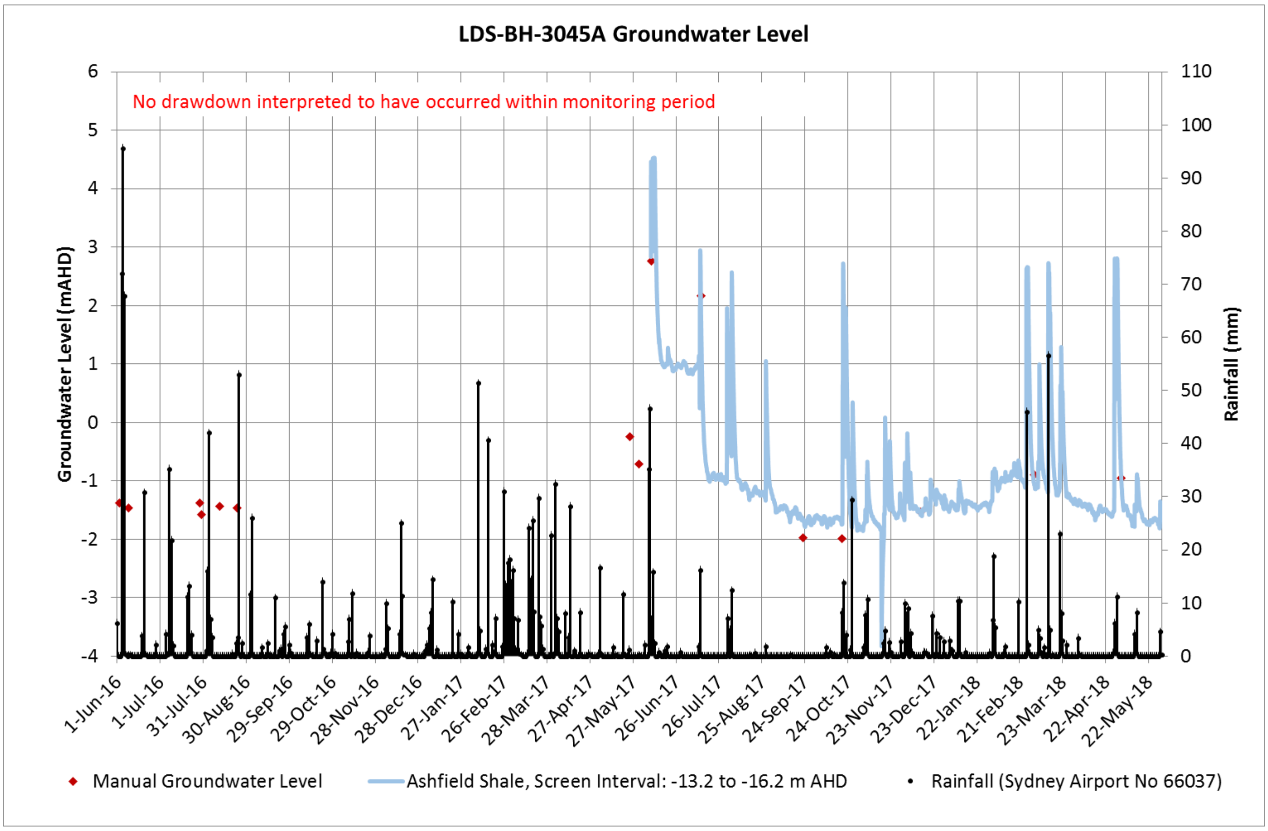
LDS-BH-2023



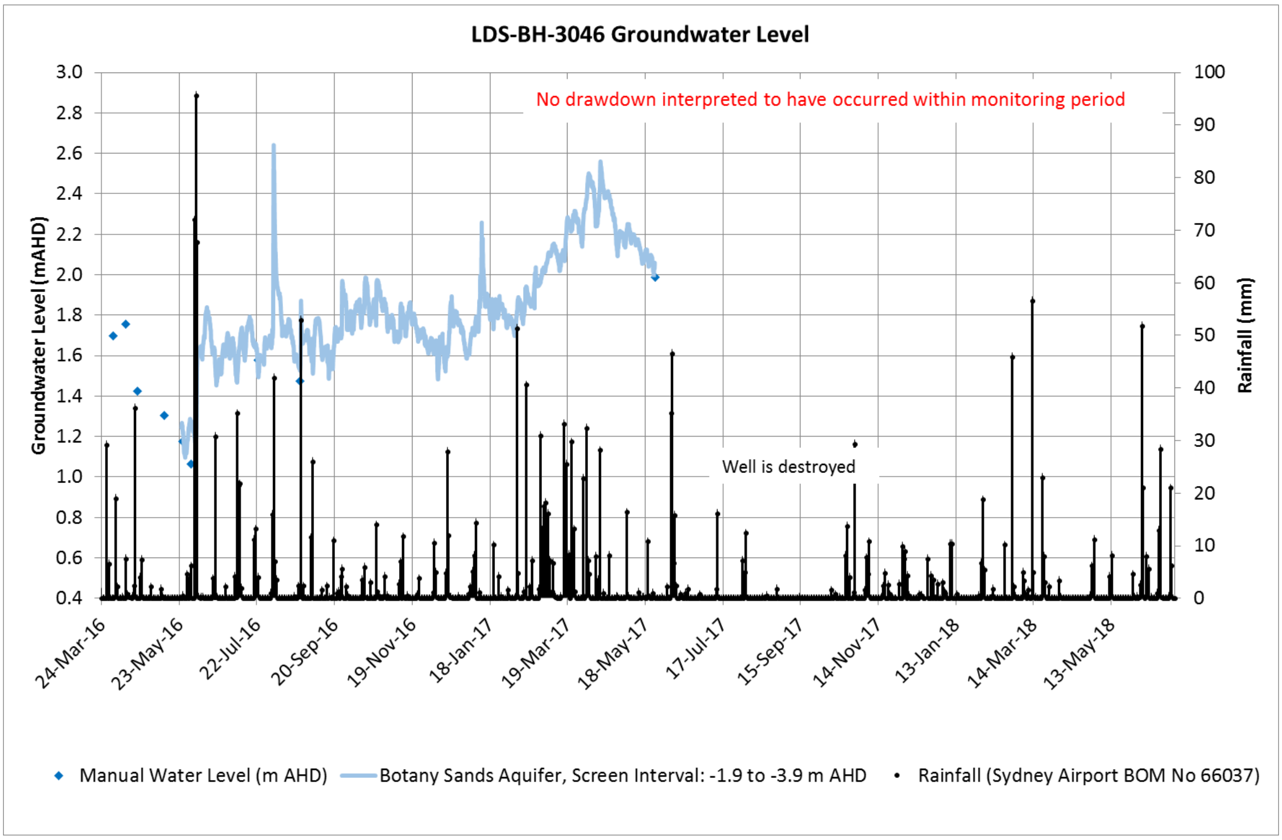
LDS-BH-3045



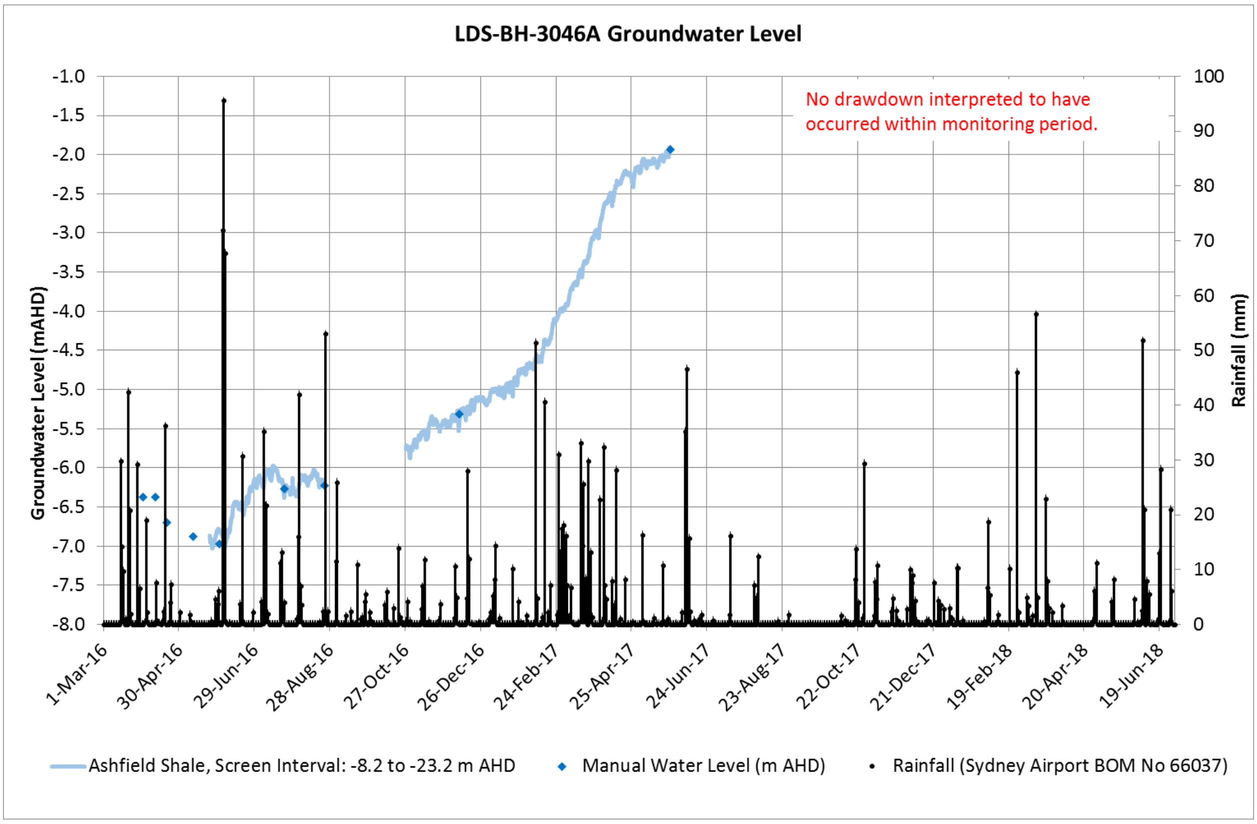
LDS-BH-3045A



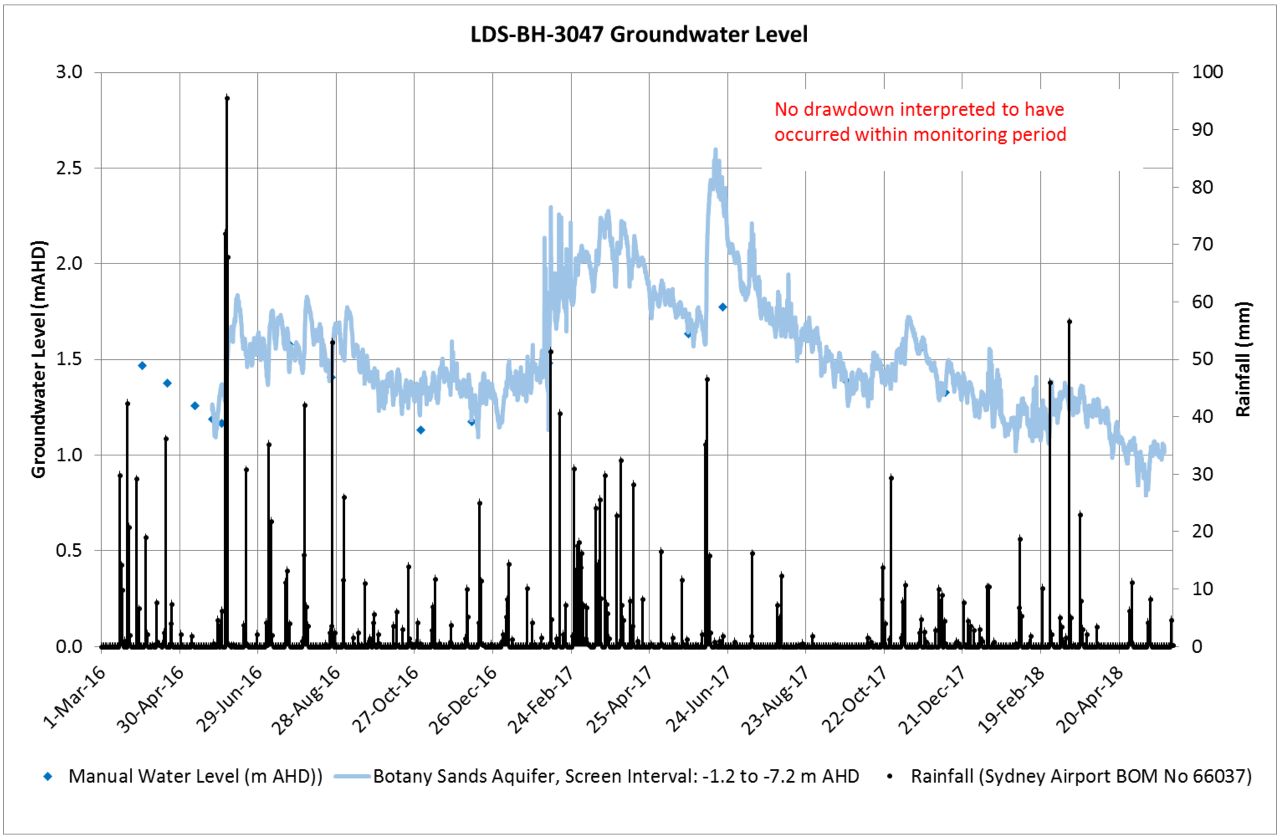
LDS-BH-3046 – Monitoring well is destroyed



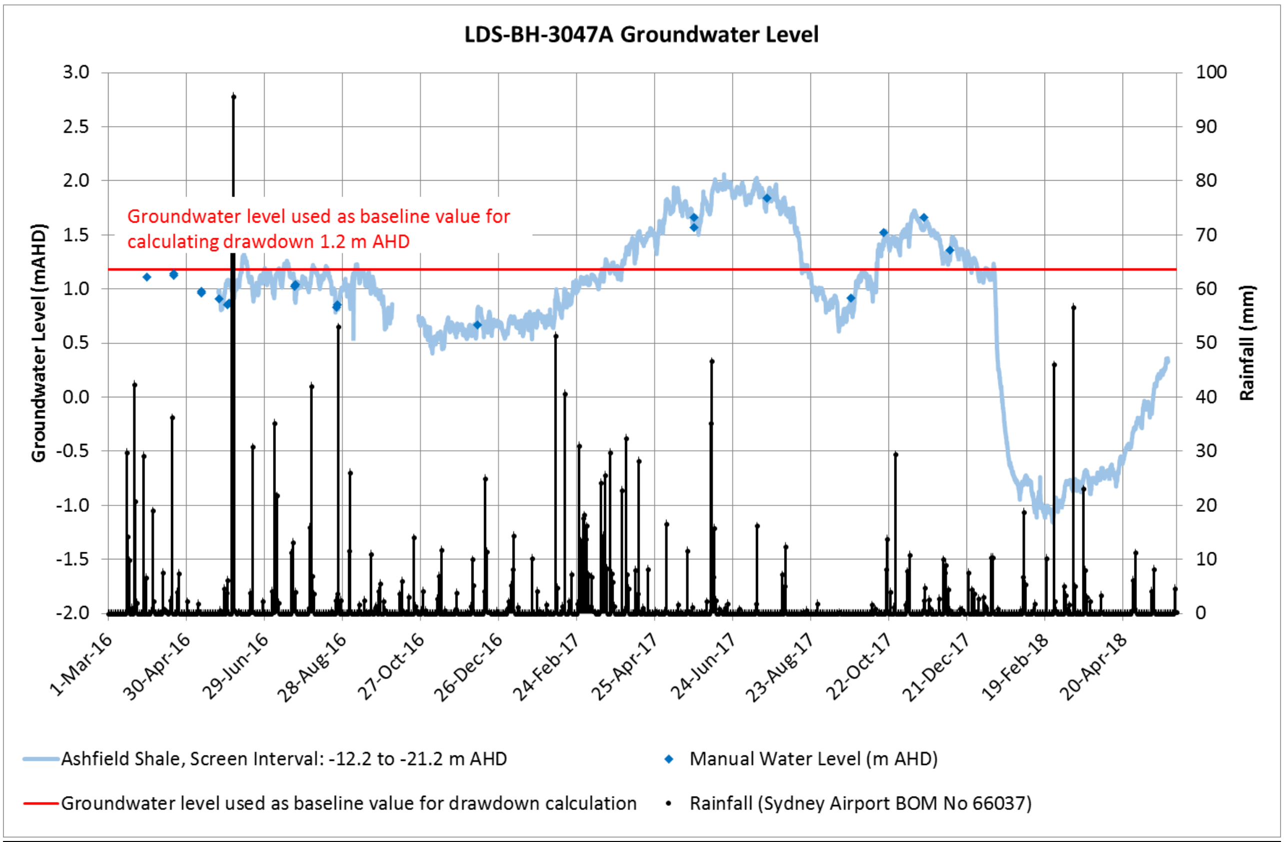
LDS-BH-3046A – Monitoring well is destroyed



LDS-BH-3047



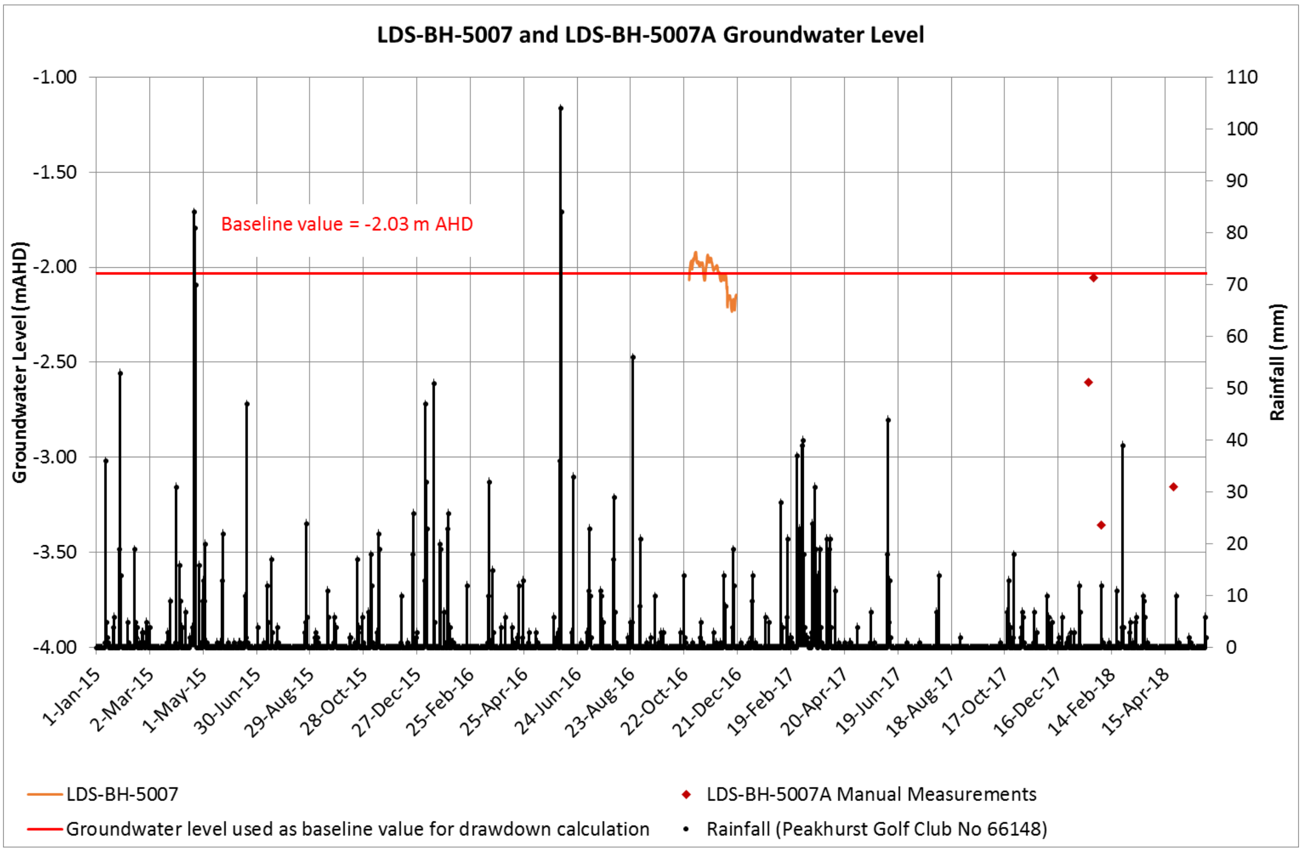
LDS-BH-3047A



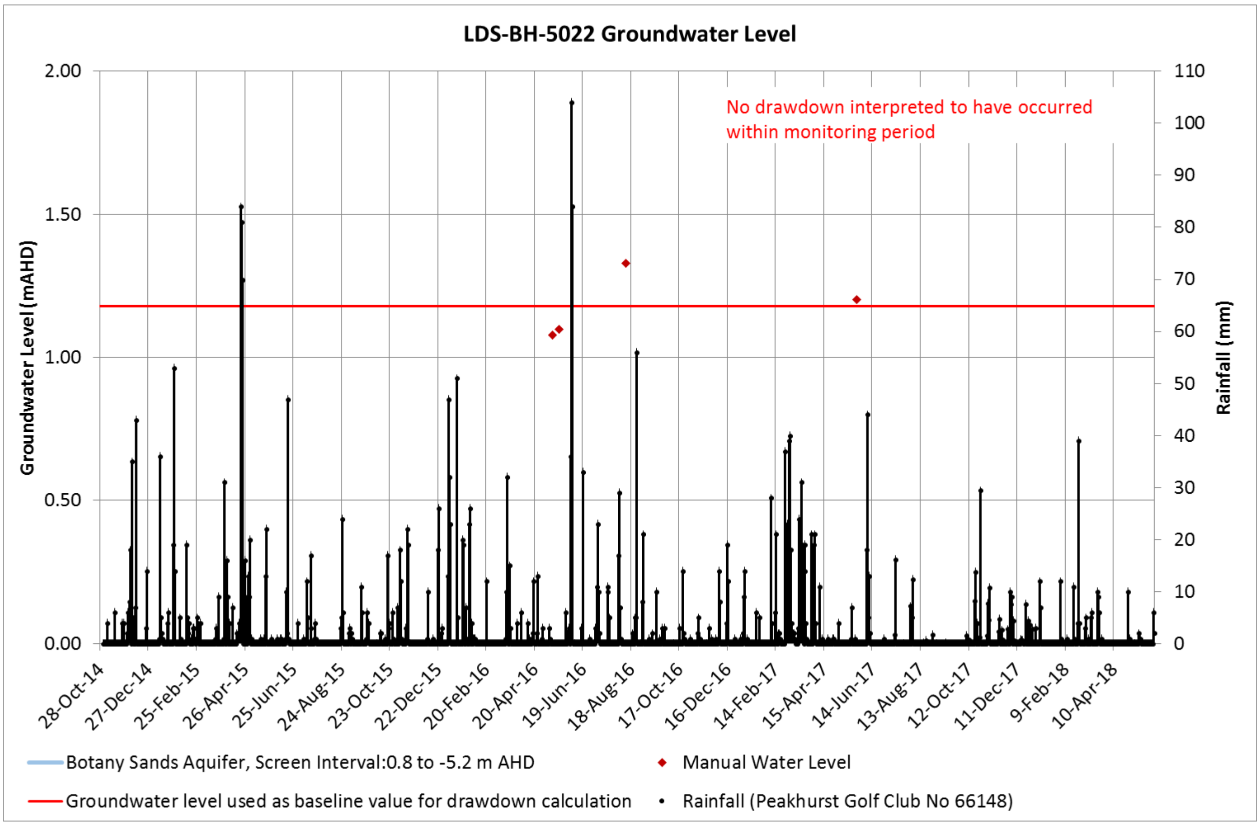
LDS-BH-3089 – Well destroyed before sufficient reliable data was collected.

LDS-BH-3907– Well destroyed before sufficient reliable data was collected

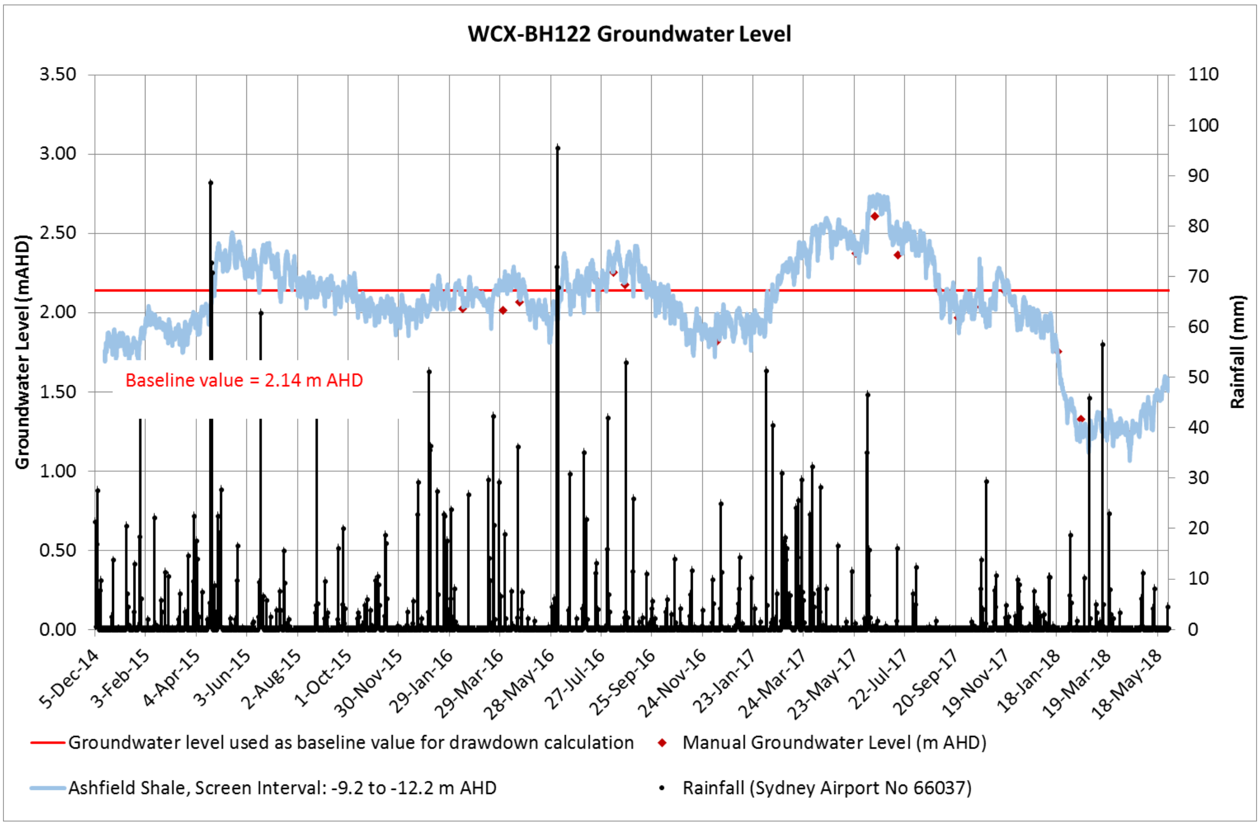
LDS-BH-5007 and LDS-BH-5007A



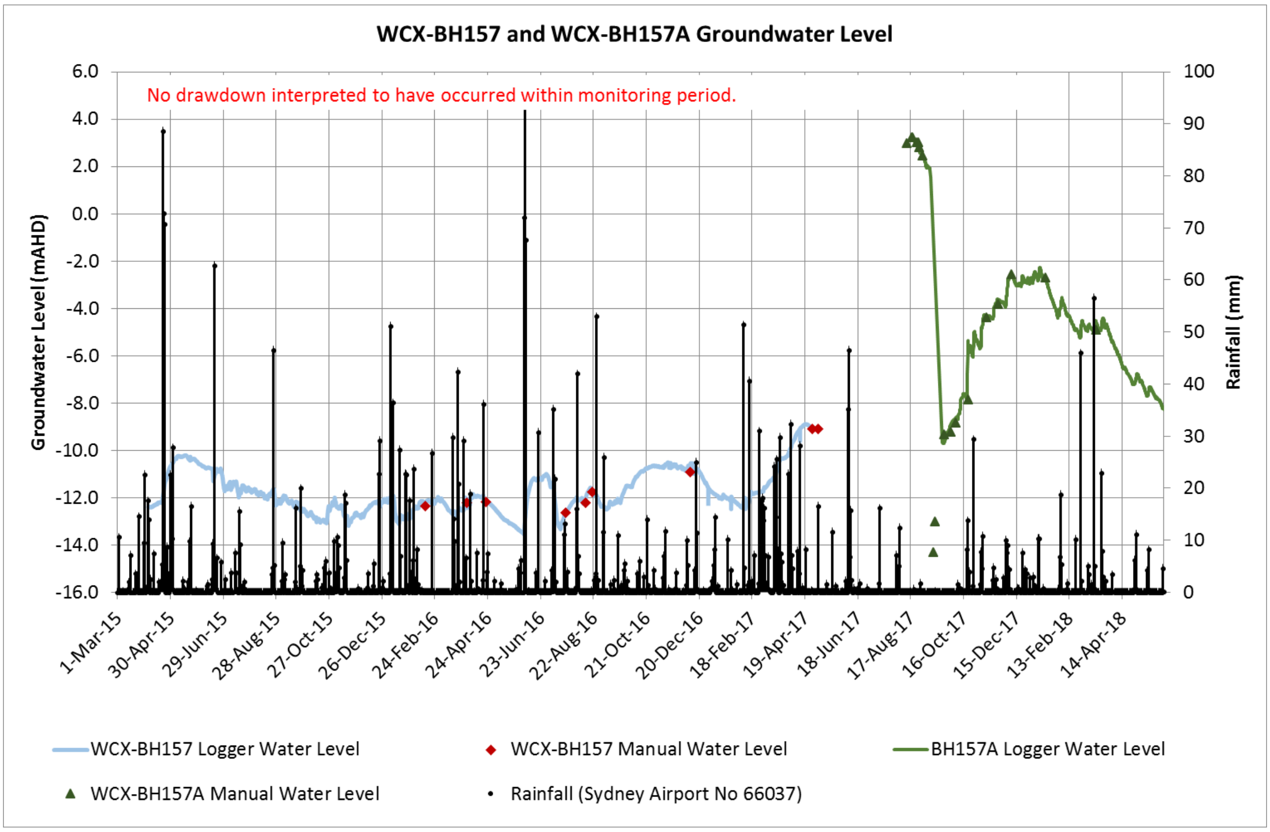
LDS-BH-5022



WCX-BH122

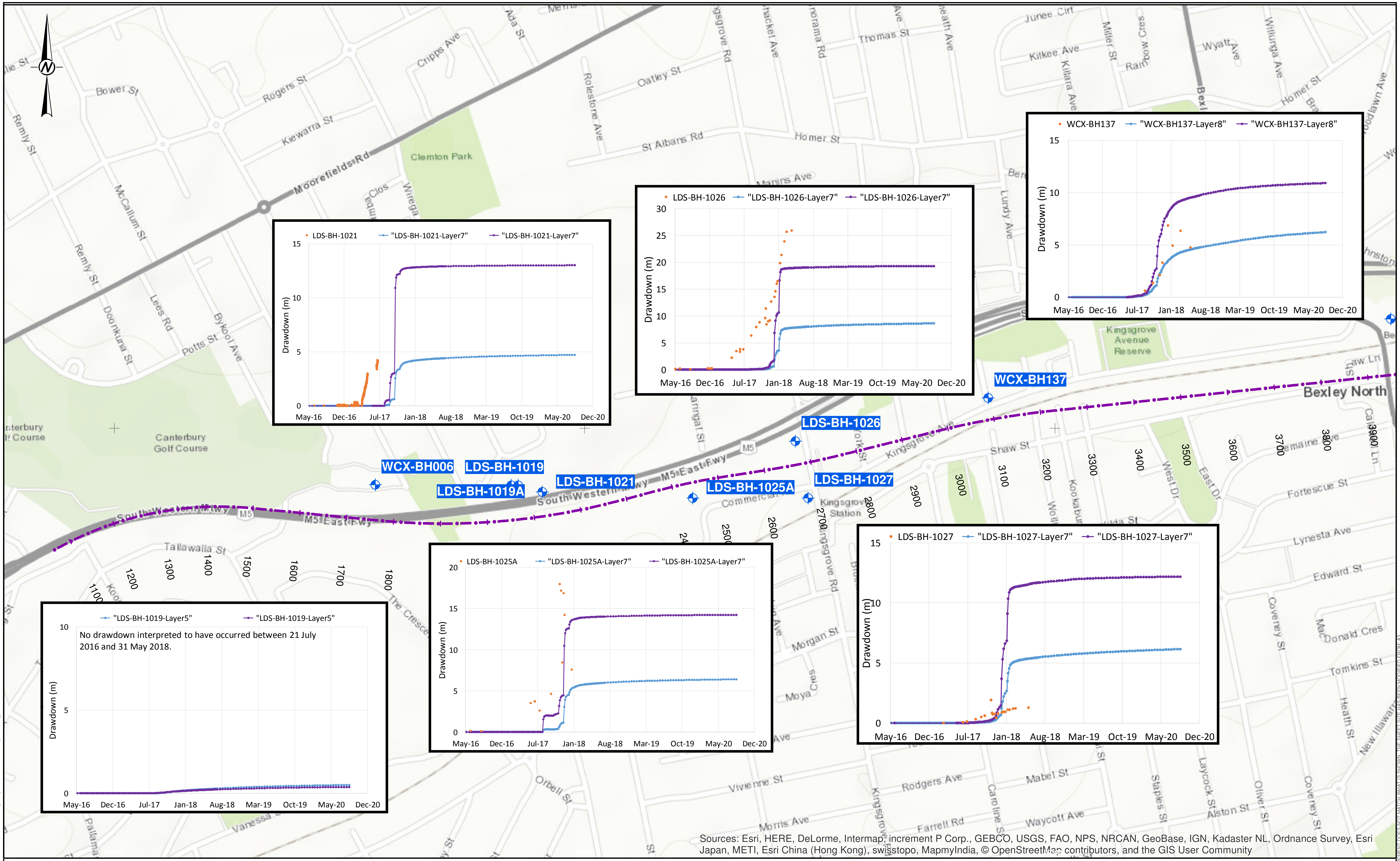


WCX-BH157 and WCX-BH157A - (installed after WCX-BH157 was destroyed)



APPENDIX B

2018-A and 2018-B Model Plans



LEGEND

New M5 Alignement

Baseline Groundwater Monitoring Network

- Monitoring bores
- Vibrating Wire Piezometers

LEGEND DRAWDOWN PLOTS

- observed monitoring data
- modelled drawdown (2018-A model)
- modelled drawdown (2018-B model)

Notes:
1. Drawdown plot for WCX-BH006 not shown as this monitoring well was destroyed before construction activities started.
2. Refer to Appendix A for observed groundwater monitoring data.
3. LDS-BH-1019 destroyed and replaced by LDS-BH-1019A.

CLIENT
WEST CONNEX DELIVERY AUTHORITY

PROJECT
WESTCONNEX STAGE 2 M5 EAST

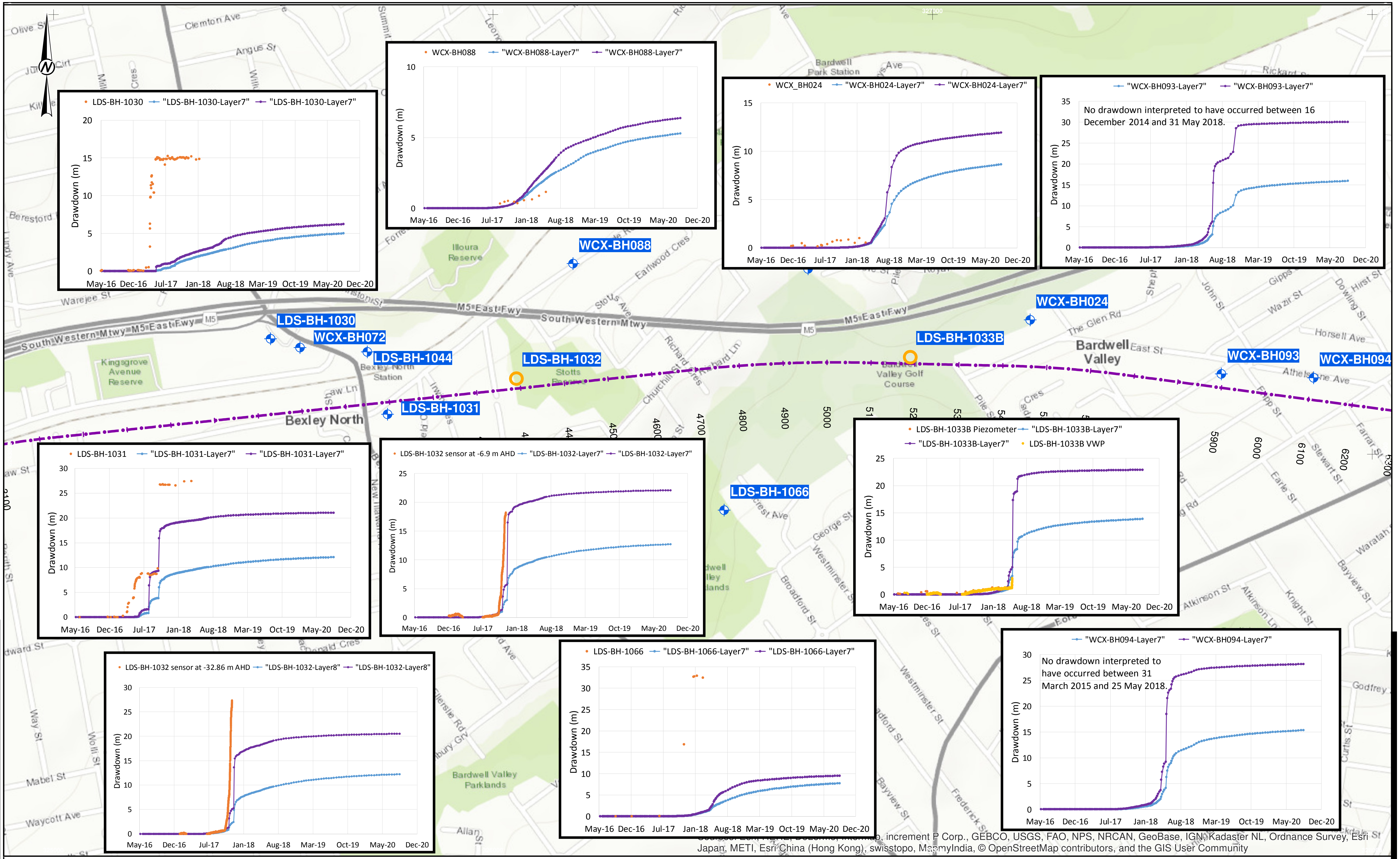
0 80 160 240 320 400
METRES

Control Line: control_line_option_h2
REFERENCE SCALE: 1:7,500 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
DRAWDOWN HYDROGRAPHS KINGSGROVE (OBSERVED, 2018-A MODEL AND 2018-B MODEL)

YYYY-MM-DD	2019-05-16
PREPARED	[redacted]
DESIGN	[redacted]
REVIEW	[redacted]
APPROVED	[redacted]

DRAWING No. M5N-GOL-DAN-100-200-HG-0290 | Rev. D | FIGURE B01



LEGEND

- New M5 Alignement

Baseline Groundwater Monitoring Network

- Monitoring bores
- Vibrating Wire Piezometers

DRAWDOWN HYDROGRAPH LEGEND

- observed monitoring data (manual measurement)
- modelled drawdown (2018-A model)
- modelled drawdown (2018-B model)

Notes:
1. Refer to Appendix A for observed groundwater monitoring data.
3. No drawdown interpreted to have occurred within monitoring period at WCX-BH093 and WCX-BH094.
2. No drawdown plots shown for LDS-BH-1044 (dry since beginning of monitoring), WCX-BH072 (destroyed before construction related activities started), WCX-BH018 (presents variation in groundwater level impacted by other activities independant of New M5 excavation related activities).

CLIENT
WEST CONNEX DELIVERY AUTHORITY

PROJECT
WESTCONNEX STAGE 2 M5 EAST

0 90 180 270 360 450
METRES

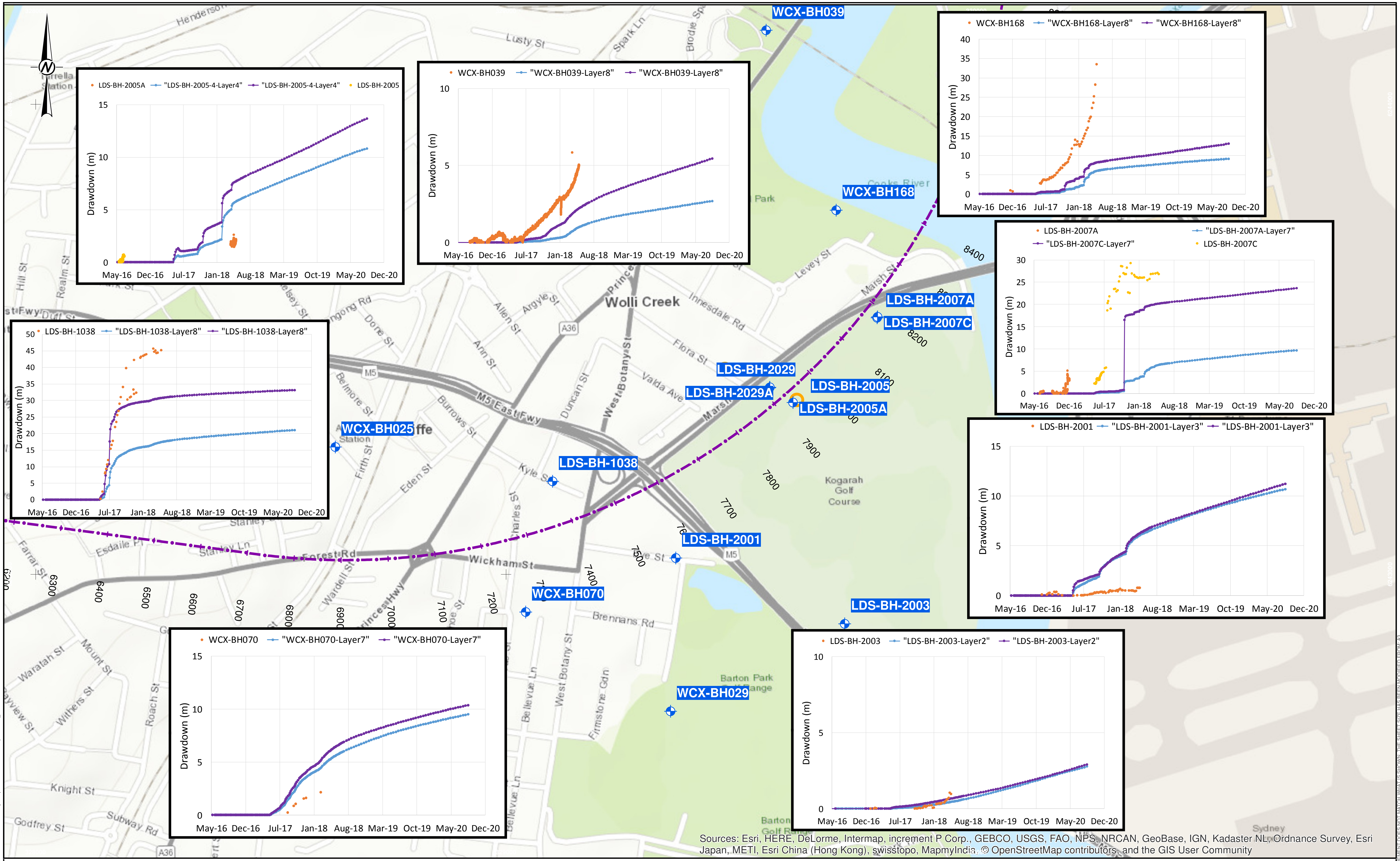
Control Line: control_line_option_h2
REFERENCE SCALE: 1:8,000 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
DRAWDOWN HYDROGRAPHS BEXLEY (2018-A AND 2018-B MODEL)

CPB CONTRACTORS | DRAGADOS | SAMSUNG C&T | WestConnex Stage 2 M5 | GOLDER

YYYY-MM-DD	2019-05-16
PREPARED	[redacted]
DESIGN	[redacted]
REVIEW	[redacted]
APPROVED	[redacted]

[redacted]
M5N-GOL-TER-100-200-HG-0290 | [redacted] D | FIGURE B02



LEGEND

New M5 Alignement

Baseline Groundwater Monitoring Network

Monitoring bores

Vibrating Wire Piezometers

DRAWDOWN HYDROGRAPH LEGEND

observed monitoring data (manual measurement)
modelled drawdown (2018-A model)
modelled drawdown (2018-B model)

Note:
1. Refer to Appendix A for observed groundwater monitoring data.
2. WCX-BH025 not presented as there is no available data since construction activities started.
3. Variation in groundwater level at WCX-BH029 impacted by other activities independant of New M5 construction related activities .
4. LDS-BH-2029 and LDS-BH-2029A not shown as wells were destroyed before construction activities started.

Sydney
Liverpool
Sources: Esri, HERE, DeLorme, Intermap,

CLIENT
WEST CONNEX DELIVERY AUTHORITY

PROJECT
WESTCONNEX STAGE 2 M5 EAST

0 80 160 240 320 400
METRES

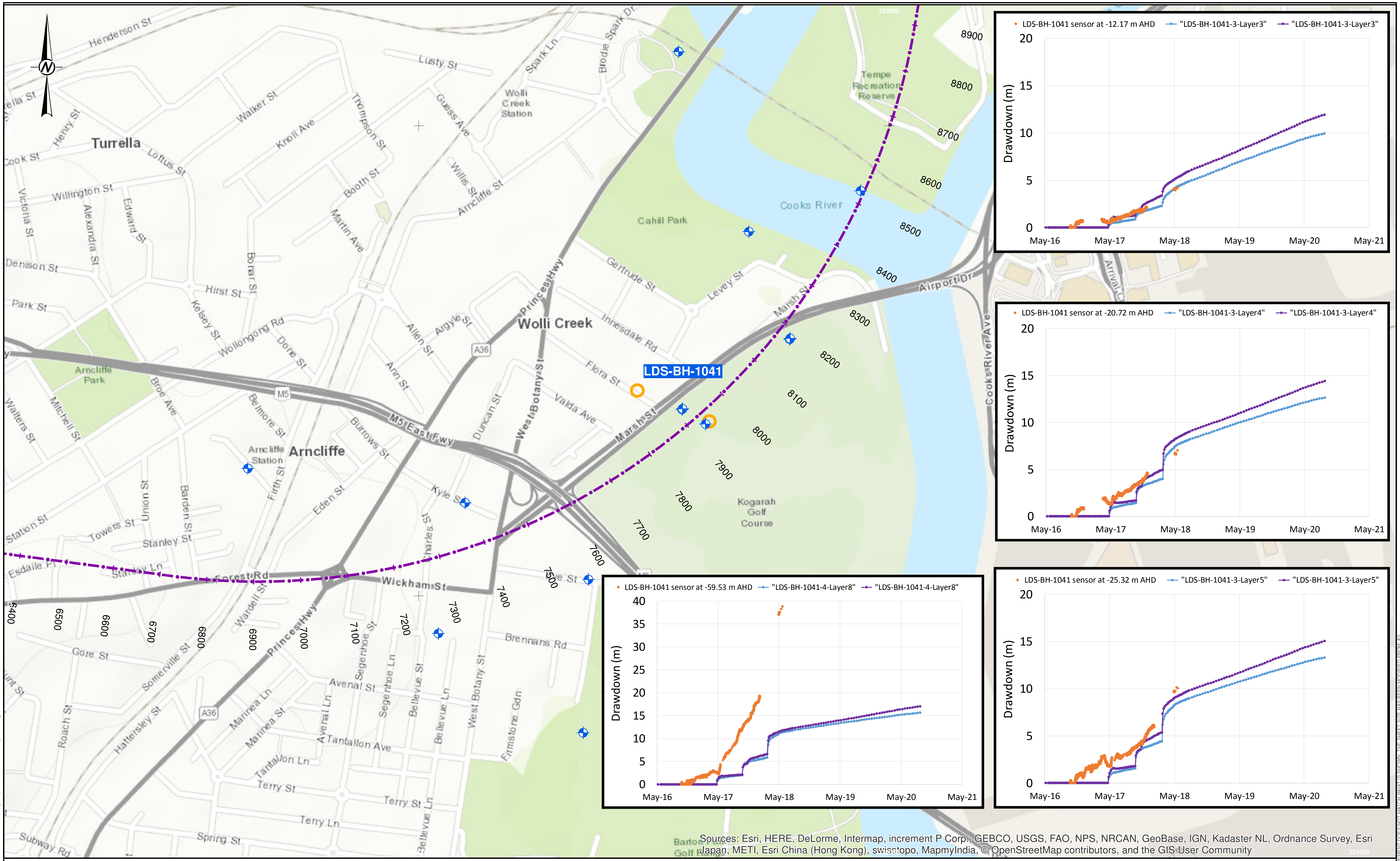
Control Line: control_line_option_h2
REFERENCE SCALE: 1:7,500 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
DRAWDOWN HYDROGRAPHS ARNCLIFFE (2018-A IN BLUE AND 2018-B MODEL IN PURPLE)

CPB CONTRACTORS DRAGADOS SAMSUNG C&T
WestConnex Stage 2 M5
GOLDER

YYYY-MM-DD	2019-05-16
PREPARED	[redacted]
DESIGN	[redacted]
REVIEW	[redacted]
APPROVED	[redacted]

DRAWING No. M5N-GOL-TER-100-200-HG-0290 Rev. D FIGURE B03



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

LEGEND

- New M5 Alignement

Baseline Groundwater Monitoring Network

- Monitoring bores
- Vibrating Wire Piezometers

DRAWDOWN HYDROGRAPH LEGEND

- observed monitoring data (manual measurement)
- modelled drawdown (2018-A model)
- modelled drawdown (2018-B model)

Note:
1. Refer to Appendix A for observed groundwater monitoring data.

Sources: Esri, HERE, DeLorme, Intermap,

CLIENT
WEST CONNEX DELIVERY AUTHORITY

PROJECT
WESTCONNEX STAGE 2 M5 EAST

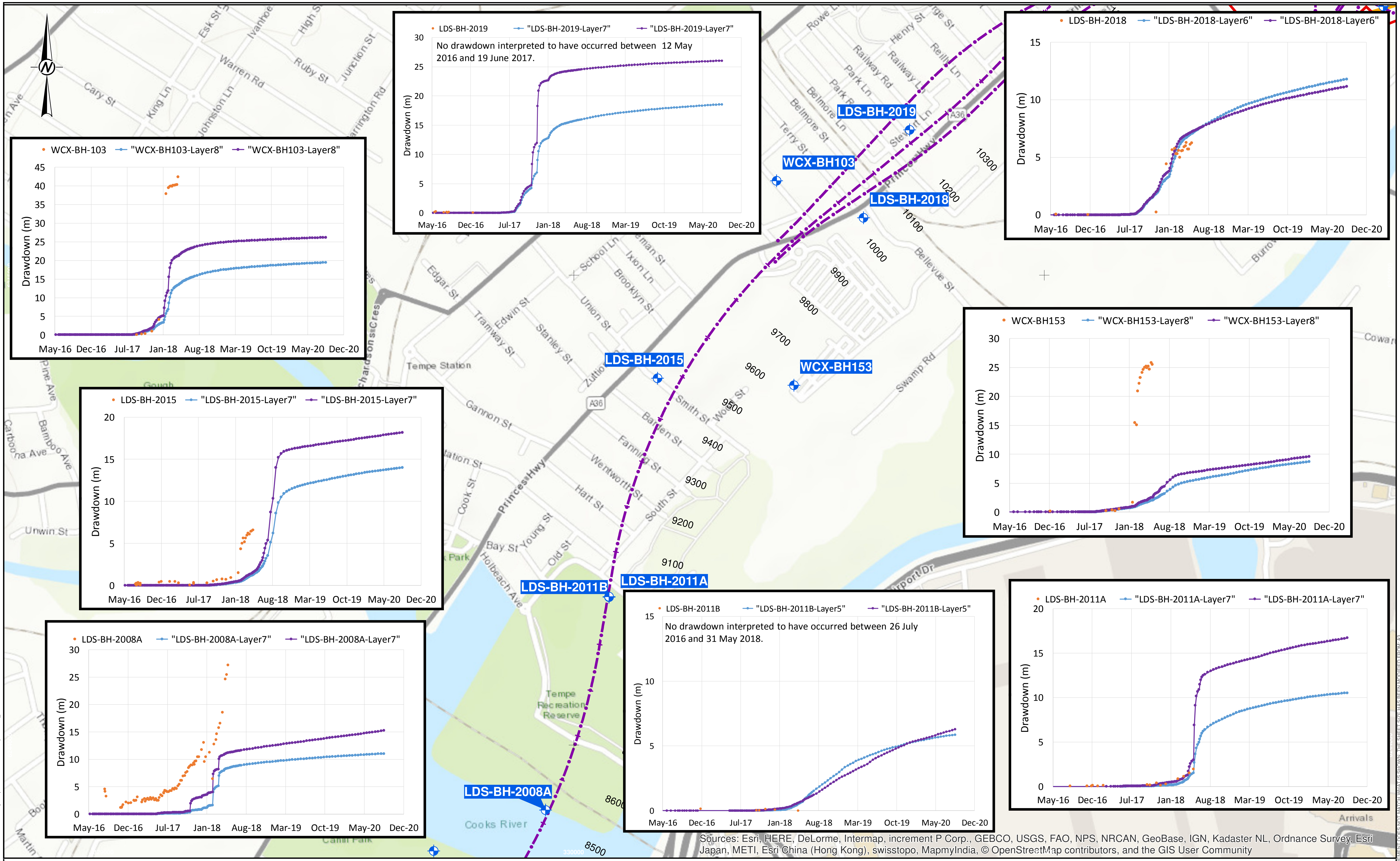
0 80 160 240 320 400 METRES

Control Line: control_line_option_h2
REFERENCE SCALE: 1:7,500 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
DRAWDOWN HYDROGRAPHS LDS-BH-1041 AT ARNCLIFFE (2018-A IN BLUE AND 2018-B MODEL IN PURPLE)

YYYY-MM-DD	2019-05-16
PREPARED	TM
DESIGN	TM
REVIEW	SF
APPROVED	SF

DRAWING No. M5N-GOL-DAN-100-200-HG-0290 Rev. D FIGURE B04



LEGEND

- St Peters Interchange Site Boundary
- Barrier Wall
- New M5 Alignement

Baseline Groundwater Monitoring Network

- Monitoring bores
- Vibrating Wire Piezometers

DRAWDOWN HYDROGRAPH LEGEND

- observed monitoring data (manual measurement)
- modelled drawdown (2018-A model)
- modelled drawdown (2018-B model)

Note:
1. Refer to Appendix A for observed groundwater monitoring data.

Sources: Esri, HERE, DeLorme, Intermap,

CLIENT
WEST CONNEX DELIVERY AUTHORITY

PROJECT
WESTCONNEX STAGE 2 M5 EAST

0 80 160 240 320 400
METRES

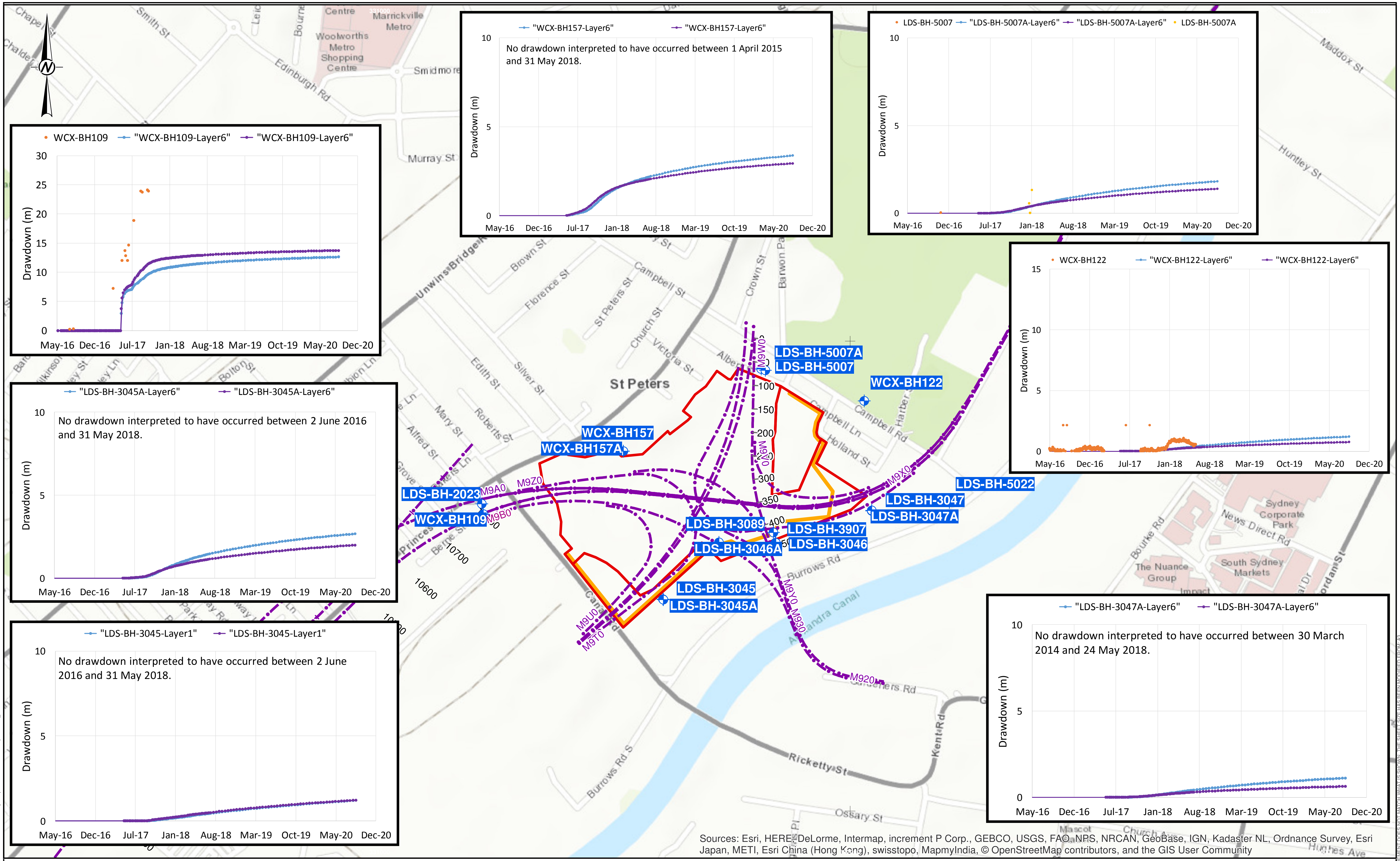
Control Line: control_line_option_h2
REFERENCE SCALE: 1:7,500 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
DRAWDOWN HYDROGRAPHS TEMPE (2018-A IN BLUE AND 2018-B MODEL IN PURPLE)

YYYY-MM-DD	2019-05-16
PREPARED	
DESIGN	
REVIEW	
APPROVED	

GOLDER

DRAWING No.	Rev.	FIGURE
M5N-GOL-TER-100-200-HG-0290	D	B05



LEGEND

- St Peters Interchange Site Boundary
- Barrier Wall
- New M5 Alignment

Baseline Groundwater Monitoring Network

- Monitoring bores
- Vibrating Wire Piezometers

DRAWDOWN HYDROGRAPH LEGEND

- observed monitoring data (manual measurement)
- modelled drawdown (2018-A model)
- modelled drawdown (2018-B model)

Notes:
1. Refer to Appendix A for observed groundwater monitoring data.
2. WCX-BH157 destroyed and replaced by WCX-BH157A. WCX-BH109 destroyed and replaced by LDS-BH-2023
3. Simulated drawdown smaller than 0.15 m in September 2020 for LDS-BH-3047 (2018-A and 2018-B models). Drawdown plot is not shown.
4. LDS-BH-3046, LDS-BH3046A, LDS-BH3089 and LDS-BH-3907 destroyed before significant construction activities started.

Sources: Esri, HERE, DeLorme, Intermap,

CLIENT
WEST CONNEX DELIVERY AUTHORITY

PROJECT
WESTCONNEX STAGE 2 M5 EAST

0 80 160 240 320 400 METRES

Control Line: control_line_option_h2
REFERENCE SCALE: 1:7,500 (at A3)
PROJECTION: GDA 1994 MGA Zone 56

TITLE
DRAWDOWN HYDROGRAPHS SPI (2018-A IN BLUE AND 2018-B MODEL IN PURPLE)

CPB CONTRACTORS · DRAGADOS · SAMSUNG C&T · WestConnex Stage 2 M5 · GOLDER

YYYY-MM-DD	2019-05-16
PREPARED	[redacted]
DESIGN	[redacted]
REVIEW	[redacted]
APPROVED	[redacted]

DRAWING No. M5N-GOL-TER-100-200-HG-0290 Rev. D FIGURE B06

GOLDER

golder.com