PROPOSED VANCOUVER BEACH RESORT, ALBANY

RESULTS OF HYDROGEOLOGICAL INVESTIGATIONS AND NUMERICAL MODELLING

REPORT FOR AURORA ENVIRONMENTAL

Report No 101-0/19/01

Rockwater
HYDROGEOLOGICAL AND ENVIRONMENTAL CONSULTANTS

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REVISION	AUTHOR	REVIEW	AUTHORISED	ISSUED
0	PHW	JRP		19/8/19

1. INTRODUCTION

A resort development is planned for a site between Frenchman Bay and Lake Vancouver (Fig. 1), in the Albany area. Aurora Environmental is conducting environmental investigations for the project, including an assessment of potential changes in groundwater quality and directions of groundwater flow. Rockwater was engaged by Aurora Environmental on behalf of the developer to contribute to groundwater aspects of the continuing environmental assessment. Rockwater has previously completed hydrogeological test works in the project area (Rockwater, 1986, 1989 and 1992).

This report presents the results of recent hydrogeological investigations in the area, which were used with data from the previous investigations to prepare a conceptual hydrogeological model for the site. That model was used as the basis for numerical hydrogeological modelling to assess the potential impacts of the planned development on groundwater at the site, and Lake Vancouver.

1.1. TOPOGRAPHY

The project area lies near the southern end of Vancouver Peninsula in a relatively flat-lying area with elevations generally below 5 m AHD. To the south, ground surface rises to about 15 m AHD, and further south granite hills reach an elevation of 70 m AHD.

The peninsula is about 1,500 m wide in the project area.

1.2. CLIMATE

The area has a mild temperate climate – the proximity of the ocean has a strong moderating influence on temperatures.

The nearest climate station is Little Grove (BoM Station 009766), located 6 km west of the project site. Average rainfalls (1968 to 2019) and dam evaporation at Albany (Luke, Burke and O'Brien, 1988) are given in Table 1.

Table 1: Average Rainfall Little Grove, and Dam Evaporation, Albany (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rainfall	25.8	21.4	34.9	66.6	108.3	131.7	144.4	132.1	106.6	77.2	52.1	27.3	931.2
Dam Evap.	213	165	145	88	61	45	47	64	81	102	145	193	1349

Rainfall averages 931 mm per year; and dam evaporation 1,349 mm. On average, evaporation exceeds rainfall from October to April, and by a factor of 1.45 overall.

Temperatures have been recorded at Albany BoM Station 009500, 6 km to the north, from 1880 to 1965 and from 2003 to 2019. Mean monthly minimum temperatures range from 8.2 ^{o}C (July) to 15.6 ^{o}C (February); and mean monthly maximum temperatures from 15.8 ^{o}C (July) to 22.9 ^{o}C (February).

1.3. PREVIOUS WORK

Rockwater first investigated the area in 1986, when 20 bores were constructed within the project area and across the peninsula to the west. The drilling indicated that top of the granitic bedrock was above ground level south of the site, sloping down to -28 m AHD near the northern site boundary. The bedrock is overlain by sand, silt and clay up to about -15 m AHD, above which there is mainly silty, very fine to medium-grained sand.

Summer and winter groundwater levels were measured, and groundwater salinity measurements were made through the sedimentary sequence.

In 1989 Rockwater assessed directions of groundwater flow between Frenchman Bay and Lake Vancouver; and in 1992 made an assessment of the possibility of septic tank effluent impacting Lake Vancouver, and changes to groundwater levels that would occur around water-supply bores which were planned at the time.

2. HYDROGEOLOGICAL SETTING

The site is underlain by basal estuarine sediments of generally fine grain size, overlain by mainly aeolian and paralic sand of silt to medium sand grain size. Most of the groundwater flow would be in the upper sands (from 0 to -15 m AHD) although this material was indicated to be of low permeability: holes drilled using cable-tool methods and sludge pumps made little water during drilling. This low permeability is supported by the results of falling-head permeability tests (Section 3.4 below).

The sand aquifer thins and is bounded to the south by outcropping granite; and to the east, west and distant north by the ocean. There is a steep saltwater interface in the east with salinities of 1,500 to 5,000 mg/L TDS measured below 17 m below ground surface near the base of bore FB2 (Rockwater, 1986). The upper part of a saltwater wedge was also intersected in the base of a bore near the coast in the west (Shoal Bay).

Most of the groundwater in the aquifer is fresh to slightly brackish, with salinities of 500 to 1,000 mg/L TDS.

The groundwater is recharged by the direct infiltration of rainfall, and discharges to the coast to the east and west. Lake Vancouver is a surface expression of the water table, and water is lost from the lake – and to a lesser degree from swampy areas west of the lake – by evaporation and transpiration.

3. RECENT HYDROGEOLOGICAL INVESTIGATIONS

3.1. BORE CONSTRUCTION

Aurora Environmental constructed some additional shallow bores (CHE001A to CHE010) to supplement or replace those drilled in 1986 (FB series) within the project area. Bore details are summarised in Table 2. Bore locations are shown in Figure 3.

The bores provide a good spread over the project area, although CHE001/FB2 appears to have silted up to above the slotted interval.

3.2. GROUNDWATER-LEVEL MONITORING

Aurora Environmental has monitored groundwater levels in the bores since November 2016.

Pressure transducers with data loggers were used to provide a continuous record of groundwater levels from December 2017 to May 2019, with manual measurements made approximately monthly from August 2018 as a check on the automatic measurements (Figs. 4 to 7).

Table 2: Monitoring Bore Details

Bore	mE	mN	Top of Casing		Depth	Slots	Static Water Level			Hyd. Cond.	Remarks
	(MGA94)	(MGA94)	(m agl)	(m AHD)	(mbtc)	(m btc)	(mbtc)	(m AHD)	Date	(m/d)	
CHE001/FB2	585339.5	6117351.8	0.47	2.88	14.65	14.73-16.73	2.36	0.52	23/05/2019	0.14	Screens Blocked?
CHE001A			1.25		2.64	0-2.64	2.45		23/05/2019	3.5	Shallow Bore
CHE002	585040.4	6117278		1.76							Standpipe in lake
CHE002A	585039.6	6117278		1.72							Stake in lake
CHE003	585263.3	6117316.3	0.61	2.64	2.5	0-2.5	2.23	0.41	23/05/2019	1.4	
CHE004	585258.8	6117251.7	1.44	2.85	2.61	0-2.61	2.49	0.36	24/05/2019	0.3	
CHE005	585414.1	6117170.2	0.42	2.12	2.69	0-2.69	1.65	0.47	24/05/2019	5.3	
CHE006	585288.8	6117244.7	0.33	2.07	2.39	0-2.39	1.66	0.41	24/05/2019	1.8	
CHE007	585241.9	6117349.3	0.565	3.38	3.19	0-3.19	2.96	0.42	23/05/2019	1.6	
CHE008	585278.1	6117351.2	1.135	4.96	4.72	0-4.72	4.52	0.44	23/05/2019	1.1	
CHE010	585329.5	6117258.1	0.26	2.31	2.84	1.7-2.75	1.87	0.44	24/05/2019	2.3	
FB3	585051.7	6117399.1	0.34	2.03	18.04	16.6-18.6	1.70	0.33	23/05/2019	5.0	
FBe	585012.6	6117282.3	1.06	2.31	2.465	0-2.47	2.06	0.25	23/05/2019	1.0	
FBi	584999.9	6117105.9	0.29	1.62	2.28	0.6-3.0	1.32	0.30	23/05/2019	1.1	

mbtc = metres below collar

Although the pressure transducer values drifted at times, had some gaps in the record, and were impacted by tidal changes (particularly CHE001/FB2), together with the manual measurements they provide a good record of seasonal groundwater-level changes over two summer minima and one winter maximum. They show that groundwater levels vary seasonally by 0.6 m to 1.2 m; and the lake level by 1.0 m.

3.3. GROUNDWATER QUALITY

Field measurements of groundwater quality were made on several occasions. The results are given in Table 3.

Table 3: Field Measurements of Groundwater Quality

Bore	pH				EC (mS/cm)				Temp (°C)				TDS (mg/L)			
	28/11/16	06/12/16	06/12/17	21/01/18	28/11/16	06/12/16	06/12/17	21/01/18	28/11/16	06/12/16	06/12/17	21/01/18	28/11/16	06/12/16	06/12/17	21/01/18
CHE001/FB2		7.34	7.71	7.84	1.20		1.17	1.13	18.3		17.6	16.0	600		580	570
CHE002A	7.09	7.42	7.87	8.44	2.38	3.01	2.00	1.99	22.2	19.6	19.8	13.9	1,190	1,410	1,100	990
CHE003			7.75				1.61				16.7				810	
CHE004																
CHE005		7.30			1.59				17.1				790			
CHE006		7.65	7.43	8.00	2.31		1.74	1.87	17.9		17.4	15.8	1,160		870	940
CHE007		7.05	7.27		2.71		3.00		18.0		17.7		1,340		1,500	
CHE008																
CHE010		7.52	7.30		1.87		1.89		16.3		16.3		930		950	

They show that the groundwater (including lake water) is slightly alkaline and fresh to brackish with salinities ranging from 570 to 1,500 mg/L TDS.

Water samples have been collected on four occasions from four bores (CHE001, CHE003, CHE006 and CHE009) and the lake (CHE002) and analysed in a NATA-accredited Analytical Reference Laboratory for baseline physiochemical parameters, nutrients and metals. The results are tabulated in Appendix I.

The water from all bores except CHE009 and the lake is slightly alkaline, with a maximum pH of 8.3 for the lake on 16 April 2019. CHE009, a drainage sump on La Perouse Road, had water that was slightly acidic with pH 6.5 to 6.9. CHE009 also has very low salinity, ranging from 48 to 230 mg/L TDS, reflecting the presence of surface runoff. Salinities in the bores and lake range from 450 (CHE001, 21/1/19) to 2,400 mg/L TDS (CHE003, 20/11/18).

There was elevated nitrogen in all bores and the lake, with total nitrogen ranging from 1.1 to 65 mg/L – much of that is in the form of TKN. Ammonia-N is a relatively small component of the TKN, up to 3 mg/L. Total phosphorus concentrations exceed ANZECC trigger values ranging from 0.04 to 4.9 mg/L.

Metals were analysed in one sampling round and were generally below levels of reporting. There were low levels of iron, aluminium, copper and chromium.

Pesticides and hydrocarbons were also analysed in samples from one sampling run. Pesticides were all below reporting levels. Low levels of hydrocarbons were detected in the sump CHE009, presumably originating from road drainage.

3.4. FALLING-HEAD PERMEABILITY TESTS

Falling-head permeability tests were conducted by Aurora Environmental by placing an 18 litre slug of water in each monitoring bore, and measuring the subsequent fall in groundwater levels at one-second intervals using a pressure transducer and data logger. Manual measurements were also made using an electronic dipper.

The results were analysed using the method of Bouwer and Rice (1976). The Water-level versus time graphs and the analyses are given in Appendix II. The calculated values of hydraulic conductivity are given in Table 2. Apart from a low value for CHE001/FB2 (which has silted-up screens) the values range from 0.3 to 5.3 m/d. From our experience, falling-head tests tend to under-estimate hydraulic conductivity due to factors such as skin effects, where smearing of clay on the borehole walls can reduce hydraulic connection with the aquifer. Consequently, the highest values (5.0 and 5.3 m/d) are likely to be the most representative, and are typical of silty, very fine- to medium-grained sand.

4. NUMERICAL MODELLING OF GROUNDWATER FLOW

4.1. CONCEPTUAL MODEL

The conceptual hydrogeological model on which the numerical model is based is generally as described in Section 2 above, together with the results of the groundwater-level measurements and measured hydraulic conductivity values.

Based on the 1986 bore data (Rockwater, 1986) the fine to medium sand extends down to between 0 m AHD (west) and -12 m AHD (east) in the south, to between about -16 m to -22 m AHD in the north (Fig. 2), generally deepening to the east.

Horizontal hydraulic conductivity of the sand is taken to be 5 m/d, and vertical hydraulic conductivity values to be about one tenth of this.

The ocean in the east is taken to be a constant head boundary. Granite outcrop forms a barrier boundary to the south, and the northern boundary is also set as a no-flow boundary as it is parallel to the direction of groundwater flow. Groundwater flows into the model area from the west at rates that are controlled in the numerical model by a variable head boundary (heads varying seasonally).

Rainfall recharge is assumed to all occur during the period May to September each year (153 days) and all evapotranspiration from the lake from October to April (212 days). The rates of recharge and evapotranspiration were varied in model calibration as described in Section 4.2.2 below.

4.1.1. IMPACT OF PLANNED DEVELOPMENT ON GROUNDWATER

The planned development is planned to have minimal impact on the groundwater flow regime. The potential impacts are as follows:

- All roof runoff will be stored in rainwater tanks and will be used in the residential units. Locally this will reduce groundwater recharge.
- Rainfall on paved areas will be directed to infiltration swales that will increase groundwater recharge.
- Wastewater will be treated to reduce nitrogen concentrations to less than 10 mg/L and phosphorus to less than 1 mg/L, and will then be used to irrigate vegetation in areas where groundwater is flowing towards the ocean.

4.2. NUMERICAL MODEL DESCRIPTION

The numerical model consists of a rectangular grid of 35 rows, 47 columns and two layers covering an area of 700 m east–west by 500 m north–south. Cell sizes range from 10 m by 10 m at the project site, to 20 m by 20 m in peripheral areas. Layer 1 extends down to -0.1 m AHD and is used to simulate groundwater interactions with Lake Vancouver, and to enable simulation of the vertical component of groundwater flow where groundwater discharges to the ocean in the east. Layer 2 extends down to between -0.2 m AHD (south-west) to -22 m AHD (north).

The model utilises Processing Modflow Pro version 8.0.47 which incorporates MODFLOW 2005, a recent version of the industry-standard finite difference groundwater modelling software designed by the United States Geological Survey (McDonald and Harbaugh, 1988).

4.2.1. MODEL PARAMETERS

Model parameters that were adopted in calibration of the model are listed in Table 4.

Table 4: Adopted Model Parameters

Parameter	Unit	Layer 1		Layer 2
		Aquifer	Lake	Aquifer
Horiz. Hyd. Conductivity	m/d	5, 3 (coast)	1,000	5, 3 (coast)
Vert. Hyd. Conductivity	m/d	0.1	1	0.5, 0.2 (coast)
Specific Yield	v/v	0.08-0.19	0.6	0.14
Storage Coefficient	v/v	N/A		0.001
Av. Recharge	m/yr	0.110-0.365	0	N/A
Evapotranspiration	m/yr	0	0.139	N/A

N/A = Not Applicable

Lower values of hydraulic conductivity were adopted along the coast to simulate the thinner zone of flow above the saltwater interface. High values of hydraulic conductivity and specific yield were used to simulate Lake Vancouver – the specific yield was less than unity as the lake probably does not occupy the full thickness of Layer 1 and the adopted value was necessary to simulate the magnitude of the seasonal fluctuations in lake water level.

Recharge rates for an average rainfall year are given in Table 4. An annual factor was then applied to the recharge values for each year modelled in the calibration process from 1980 to 2019, based on the rainfall each year compared to the annual average at Little Grove. The factors are a weighted percentage of rainfall above or below the average, as shown in Figure 8, that are similar to those derived to achieve calibration of models in other areas. The factors follow a curved rather than straight-line trend as there is proportionately more recharge in wet years, and less in dry years.

4.2.2. MODEL CALIBRATION

The model was first calibrated approximately to seasonal average water levels measured in monitoring bores at the site in 2018 and 2019 using steady-state runs. The main parameters varied were recharge and evapotranspiration rates, and hydraulic conductivities along the coast.

It was then calibrated in transient mode to match the water levels and the magnitude of seasonal fluctuations in the monitoring bores during 2017 to 2019. The main parameter varied was specific yield; with some changes to vertical hydraulic conductivity, and horizontal hydraulic conductivity along the coast.

There is a close correspondence between measured and model-calculated peak winter water levels in 2018 and the summer minima in 2019 (Figs 9 and 10) with a root mean square error for all the calculated values of only 0.11 m. However, the timing of these maxima and minima vary each year, depending on when major rainfall events had occurred and bore position. The modelling assumes peaks each year at the end of September and troughs at the end of April. The measured data for 2018 and 2019 indicate minima occur between early February and mid-April, and maxima between late July and early September (Figs 4 to 7).

Also, the water levels measured in September 1986 and February 1987 (Rockwater, 1986, 1989) are 0.21 m to 0.61 m below those expected based on calibration of the model to recent water-level data, and taking variations in annual rainfall into account (the 10-year moving average rainfall in 1986 was similar or slightly lower than for 2018). The reduced level of the casing for bore CHE001/FB2 is unchanged, so the higher groundwater levels now are attributed to the impacts of urbanisation at Goode Beach, immediately south of the planned development area. Based on the modelling results, recharge in 1986 is indicated to have been about seven percent of average annual rainfall compared to about 28 percent at present.

4.3. PREDICTION OF IMPACTS OF RESORT DEVELOPMENT

Development of the resort and planned water management will have the following impacts on the groundwater flow regime:

- Runoff from paved areas will flow to infiltration swales, which will increase local groundwater recharge;
- Roof water will be collected and used in the residential units, thereby reducing or stopping groundwater recharge in the footprints of buildings; and
- Wastewater will be treated to reduce nutrient concentrations, and used to irrigate entrance areas. All the treated water is likely to be consumed by vegetation and evapotranspiration in summer, but is likely to contribute to groundwater recharge in winter.

The numerical groundwater model described above was used to assess the impacts of resort development – in particular the infiltration of treated wastewater. It is important that water containing nitrogen does not flow towards Lake Vancouver.

Assumptions made in running the model to predict the impacts of the resort development include:

- There is no groundwater recharge from rainfall infiltration in roofed areas (buildings);
- Runoff from paved areas is 60 % of average annual rainfall (at the lower (conservative) end of the range of 60 to 70 % given in Xu et. al., (2008); and
- Treated wastewater at the average rates calculated for winter (May to September) by Aurora Environmental of 9.9 m^3/d all infiltrates to groundwater in the Reticulation Zone (Fig. 11), with no recharge from October to April.

The modelling results indicate that these changes to the hydrogeological environment resulting from the resort development will cause a very small rise in end-of-summer groundwater levels (less than 0.02 m, Fig. 11); rises of up to 0.1 m in end-of-winter groundwater levels (Fig. 12); and that any treated wastewater that reaches the groundwater will flow towards the ocean (Fig. 13).

The quantity of nitrogen (TN) reaching the ocean will be very small. If the treated wastewater had the maximum concentration of 10 mg/L TN, if all the winter water is infiltrated, and if there is no denitrification, the total nitrogen load would be 15 kg per annum.

4.3.1. MODEL SENSITIVITY AND UNCERTAINTY ANALYSIS

Although the model utilises measured hydraulic conductivity values and has been calibrated to observed groundwater levels, the values of parameters adopted in model calibration are not unique, and calibration could probably be achieved with a different data set.

Sensitivity analysis was carried out to determine which parameters are the most sensitive in predicting groundwater levels and seasonal changes, and are therefore important in determining groundwater flow directions. Bore CHE003 near the centre of the planned development was selected for comparing calculated groundwater levels. The results of the sensitivity analysis are given in Table 5. They show that the model is most sensitive to recharge rates, followed by lake evapotranspiration (summer groundwater levels), then specific yield, and vertical hydraulic conductivity. The model is less sensitive to horizontal hydraulic conductivity, and not sensitive to the confined storage coefficient.

The model was then run – after varying each of the sensitive model parameters by plus or minus 50 percent (the maximum likely range of uncertainty) – to see whether there is a possibility of groundwater beneath the Reticulation Zone flowing towards Lake Vancouver if parameters are different to those adopted. In all cases, the modelling results indicate that most of the groundwater flow from beneath the planned Reticulation Zone would be towards the ocean. However, if lake evapotranspiration was 50 percent higher then there could be flow towards the lake from the north-western end of the zone and from the western lobe (Fig. 14). Also, if specific yield, vertical hydraulic conductivity or horizontal hydraulic conductivity were 50 percent lower, then there could be flow towards the lake from the north-western end of the zone only.

Table 5: Results of Sensitivity Analysis

Case	Calcilated WL CHE003 (m AHD)			
	End of Summer	% Change	End of Winter	% Change
Adopted Parameters	0.36		1.32	
Recharge * 1.2	0.47	30.6	1.54	16.7
Recharge / 1.2	0.30	-16.7	1.14	-13.6
Lake ET * 1.2	0.29	-19.4	1.29	-2.3
Lake ET / 1.2	0.42	16.7	1.35	2.3
Horiz. Hyd. Cond * 1.2	0.34	-5.6	1.30	-1.5
Horiz. Hyd. Cond / 1.2	0.37	2.8	1.35	2.3
Vert. Hyd. Cond * 1.2	0.32	-11.1	1.27	-3.8
Vert. Hyd. Cond / 1.2	0.40	11.1	1.37	3.8
Specific Yield * 1.2	0.41	13.9	1.23	-6.8
Specific Yield / 1.2	0.30	-16.7	1.41	6.8
Storage Coef. * 1.2	0.36	0.0	1.32	0.0
Storage Coef. / 1.2	0.36	0.0	1.32	0.0

5. RECOMMENDATIONS FOR MONITORING GROUNDWATER IMPACTS

It is recommended that pairs of monitoring bores be installed to the west of both the north-western end and the western lobe of the Reticulation Zone (Fig. 14) for monitoring groundwater levels and nitrogen concentrations before and after development of the site. If the measured hydraulic gradients were to indicate westward groundwater flow,, or elevated nitrogen concentrations were detected, then irrigation using treated wastewater should cease in the area where either of these were detected.

6. CONCLUSIONS

The site is underlain by basal fine-grained estuarine sediments, overlain by silt to medium sand. Most of the groundwater flow would be in the upper sands which extend down to elevations ranging from about 0 m AHD in the south-west to -22 m AHD in the north-east. These sands are moderately permeable (hydraulic conductivity about 5 m/d).

Groundwater in the sand is recharged by the direct infiltration of rainfall and it flows to the east to discharge to the ocean. It is generally fresh to slightly brackish, with salinities of 500 to 1,000 mg/L TDS.

Lake Vancouver represents a window in the water table – groundwater discharges from the lake and surrounding low-lying areas by evapotranspiration, in summer.

The planned resort development will have the following impacts on the groundwater flow regime:

- Runoff from paved areas will flow to infiltration swales, which will increase local groundwater recharge;
- Roof water will be collected and used in the units, thereby reducing or preventing groundwater recharge in the footprints of buildings; and
- Wastewater will be treated to reduce nutrient concentrations, and used to irrigate entrance areas. The treated wastewater is likely to be all consumed by vegetation and evapotranspiration in summer, but is likely to contribute to groundwater recharge in winter.

A numerical groundwater model was used to assess the effects of these changes to the groundwater flow regime. The modelling results indicate that there will be only small changes in groundwater levels and hence flow as a result of the resort development. All groundwater flow from beneath the Reticulation Zone, (where treated wastewater will be used for plant irrigation) should be to the east to the ocean rather than to Lake Vancouver, and nitrogen loads will be very small.

However, uncertainty analysis indicates that if aquifer parameters are considerably different to those adopted in the model, there could possibly be a small component of groundwater flow from beneath the Reticulation Zone to Lake Vancouver.

The installation of two pairs of monitoring bores, with monitoring of groundwater levels and nitrogen concentrations before and after resort development, is recommended to indicate whether all groundwater flow is to the east.

Dated: 19 August 2019 **Rockwater Pty Ltd**

P H Wharton
Principal

REFERENCES

Bouwer, H., and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. Water Resource. Res. 12:423-248.

Luke, G.J., Burke, K.L., and O'Brien, T.M., 1988, Evaporation data for Western Australia. Tech. Report No. 65 (2nd Ed), W.A. Dept. of Agriculture.

McDonald, M.G., and A.W. Harbaugh, 1988, A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model. Book 6, Chapter A1, Techniques of Water Resources Investigations. U.S. Geol. Surv., Washington, DC. (A:3980).

Rockwater, 1986, Frenchman Bay Resort Hotel, Groundwater investigation of Lots 401 and 402 Vancouver Peninsula, Albany. Report to L'Oire Nominees.

Rockwater, 1989, Effluent movement from septic tanks, proposed subdivision, Vancouver Peninsula, Albany. Report to Trevor Saleeba & Associates.

Rockwater, 1992, Groundwater aspects of residential development, Frenchman's Bay, Albany. Report to Alan Tingay & Associates and L'Oire Investments.

Xu, C., Canci, M., Martin, M., Donnelly, M., and Stokes, R., 2008, Perth regional aquifer modelling system (PRAMS) model development: Application of the vertical flux model. Department of Water Western Australia, Hydrogeological record series HG 27.

FIGURES

FIGURE 1

locality plan.srf

CLIENT: Aurora Environmental

PROJECT: Vancouver Beach Resort

DATE: August 2019

Dwg No: 101-0/19/1-1

LOCALITY PLAN

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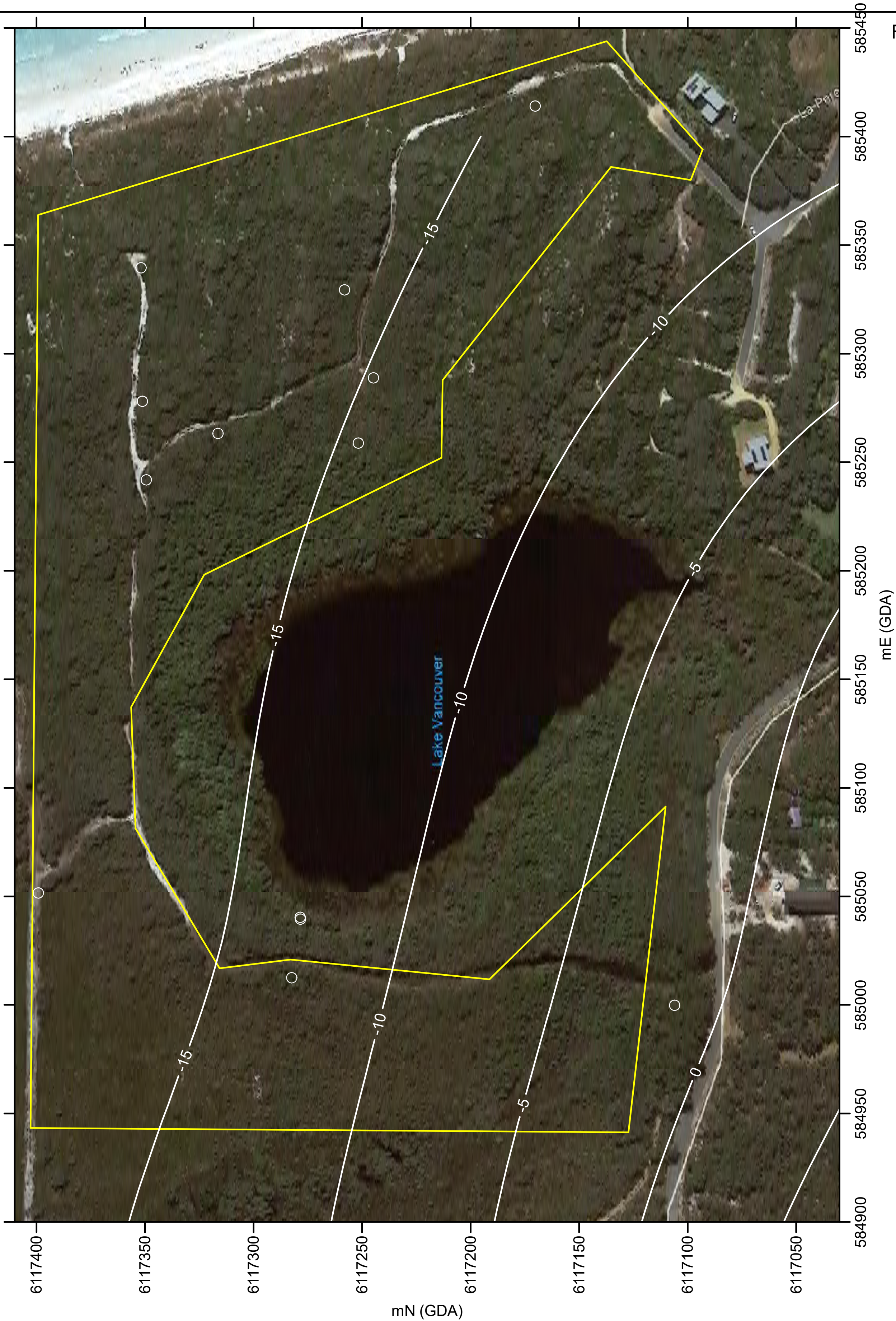
FIGURE 2



base of sand2.srf

CLIENT: Aurora Environmental

PROJECT: Vancouver Beach Resort

DATE: August 2019

Dwg No: 101-0/19/1-2

ELEVATION, BASE OF FINE TO MEDIUM SAND
(m AHD)

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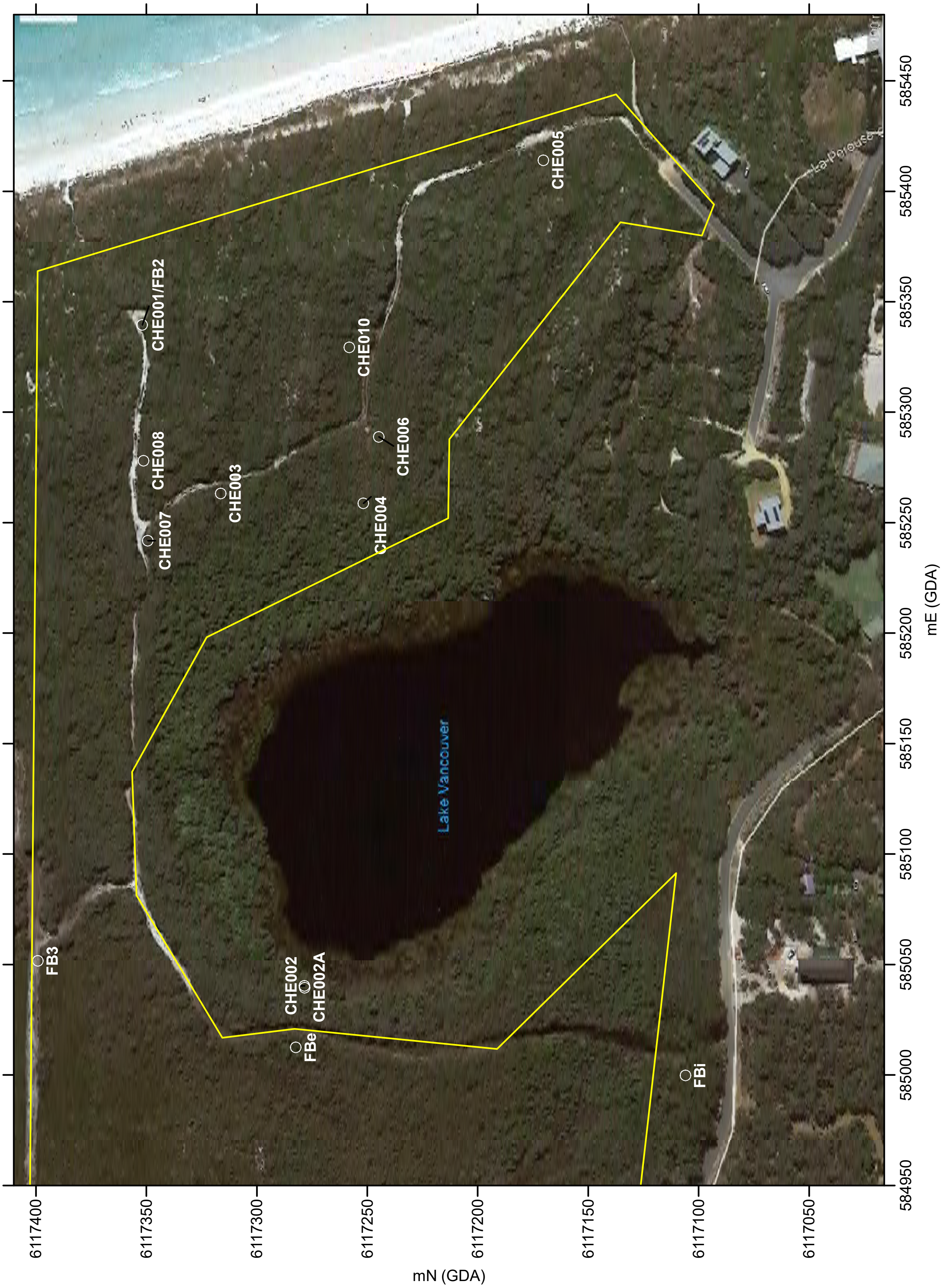
FIGURE 3



bore locations surveyed.srf

CLIENT: Aurora Environmental

PROJECT: Vancouver Beach Resort

DATE: August 2019

Dwg No: 101-0/19/1-3

MONITORING BORE LOCATIONS

Rockwater Pty Ltd

Client: Aurora Environmental

Project: Vancouver Beach Resort

Date: August 2019

Dwg. No: 101-0/19/1-4

MONITORING BORE WATER LEVELS
CHE001, CHE002 & CHE006

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groundwater levels.grf

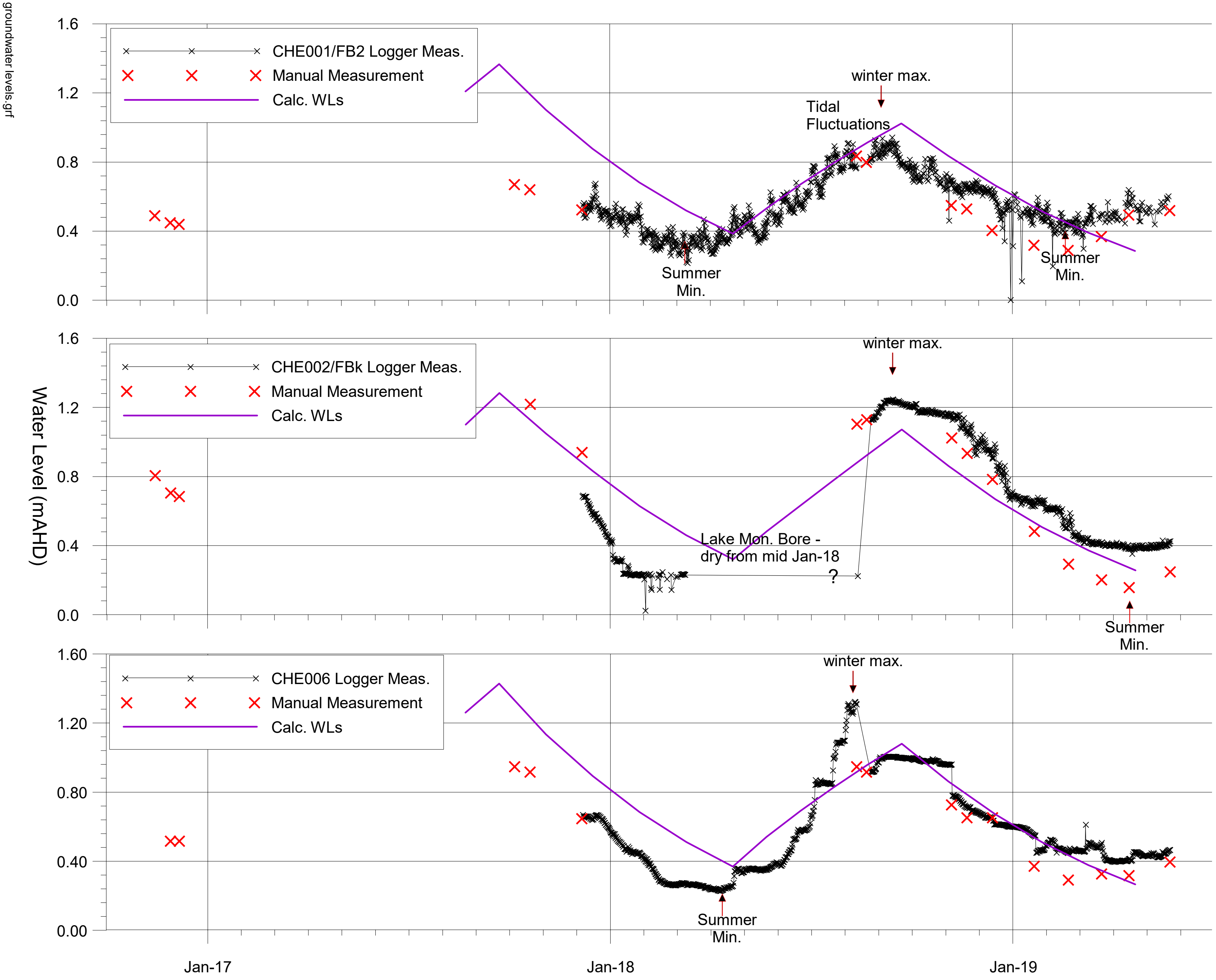
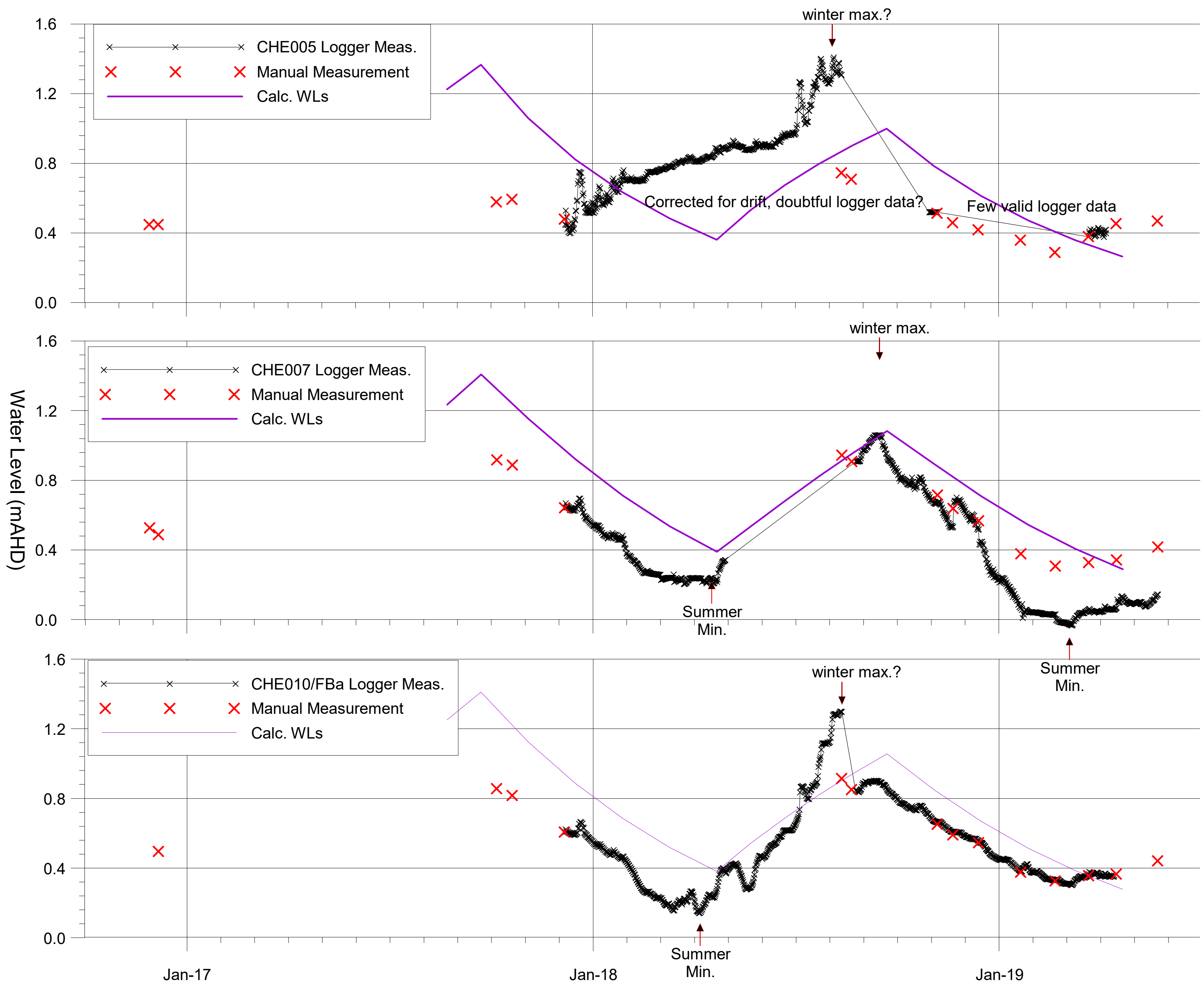


Figure 4

Client: Aurora Environmental
Project: Vancouver Beach Resort
Date: August 2019
Dwg. No: 101-0/19/1-5

groundwater levels2.grf



MONITORING BORE WATER LEVELS
CHE005, CHE007 & CHE010

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Figure 5

Client: Aurora Environmental

Project: Vancouver Beach Resort

Date: August 2019

Dwg. No: 101-0/19/1-6

MONITORING BORE WATER LEVELS CHE003, CHE004 & CHE008

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groundwater levels3.grf

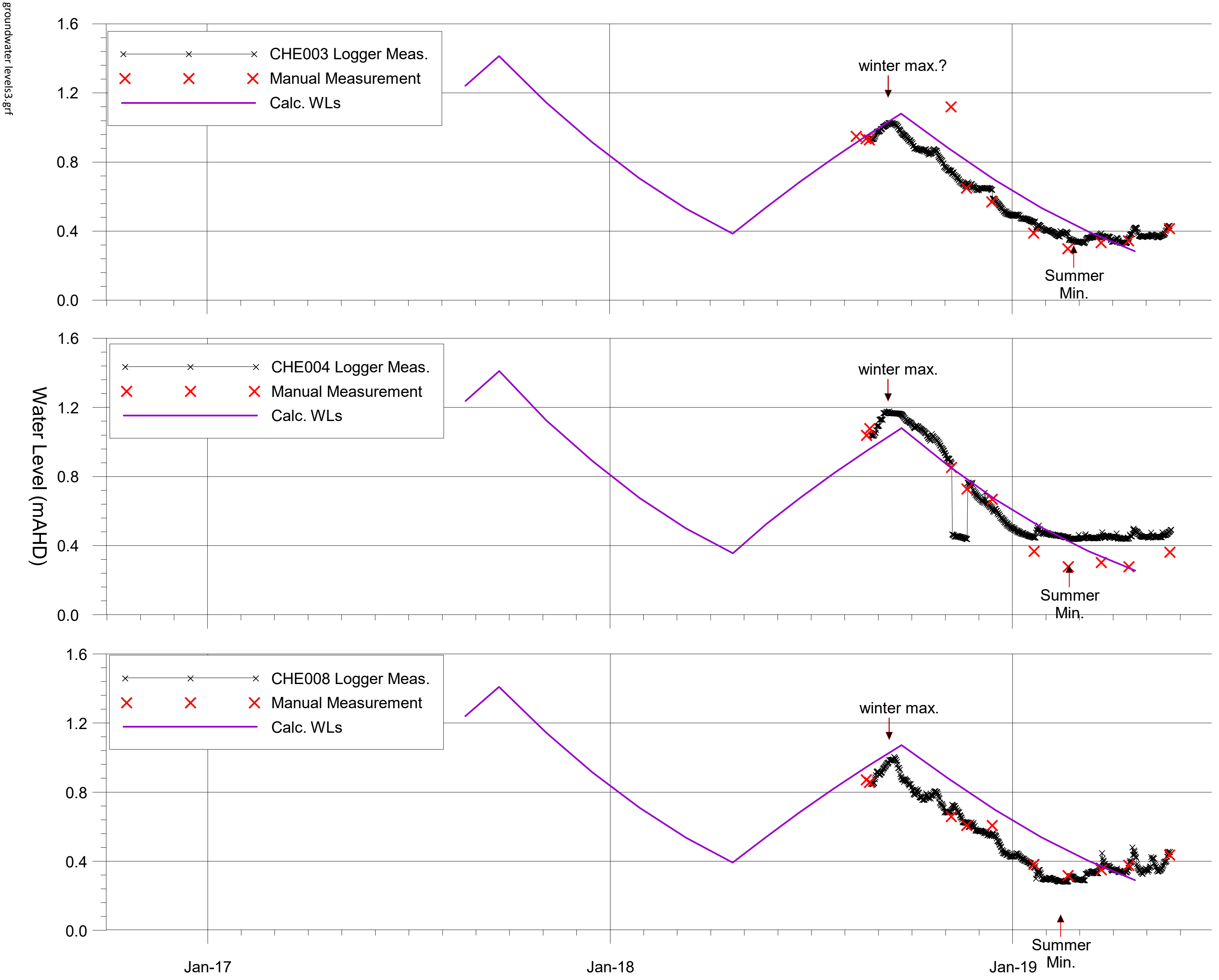


Figure 6

Client: Aurora Environmental
Project: Vancouver Beach Resort
Date: August 2019
Dwg. No: 101-0/19/1-7

groundwater levels4.grf

MONITORING BORE WATER LEVELS
FB3, FBe, & FBi

Rockwater Pty Ltd

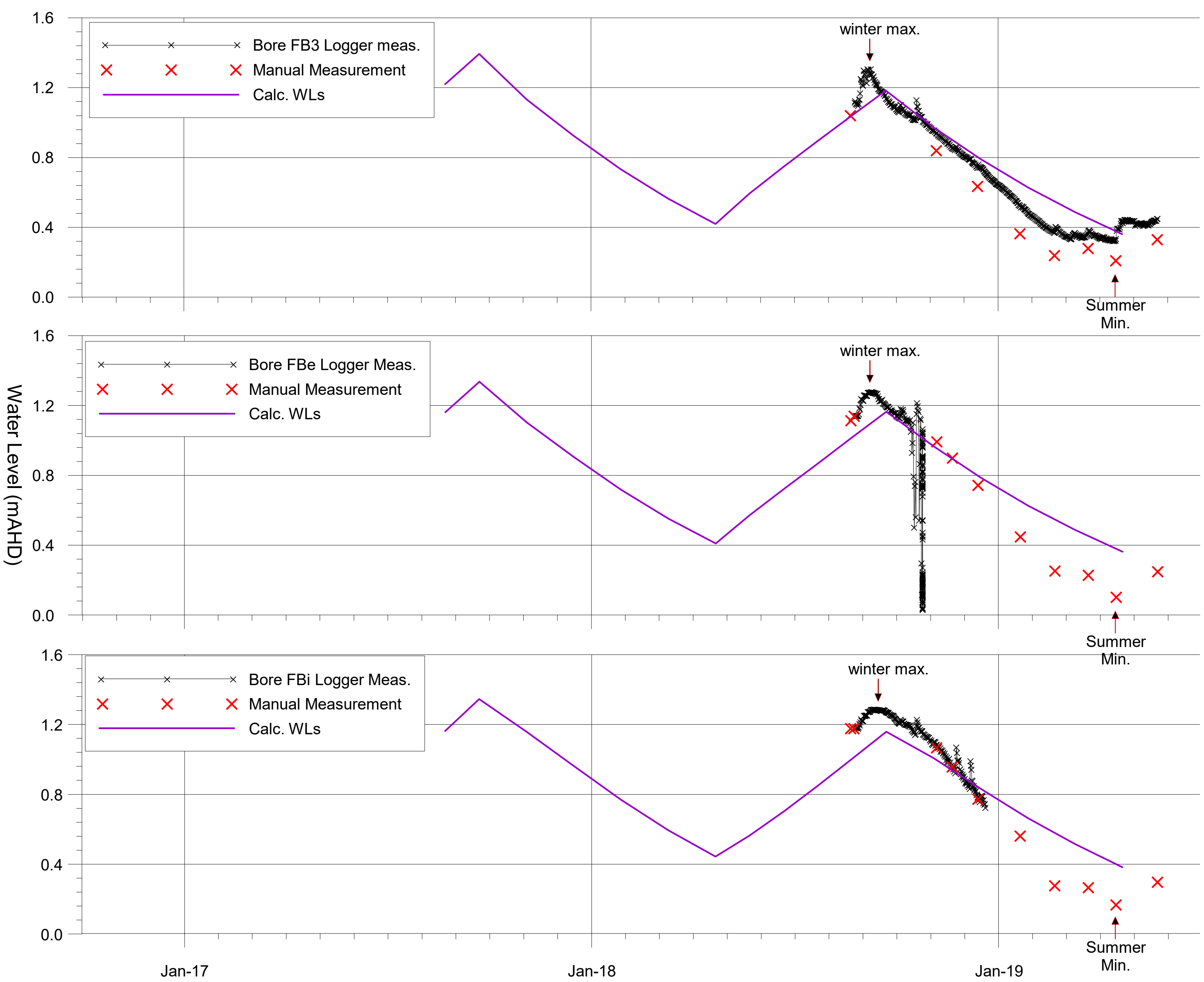


Figure 7

Client: Aurora Environmental
Project : Vancouver Beach
Date : August 2019
Dwg. No: 101-0/19/1-8

RECHARGE FACTOR, FOR ANNUAL RAINFALL

Rockwater Pty Ltd

annual recharge multiplier.grf

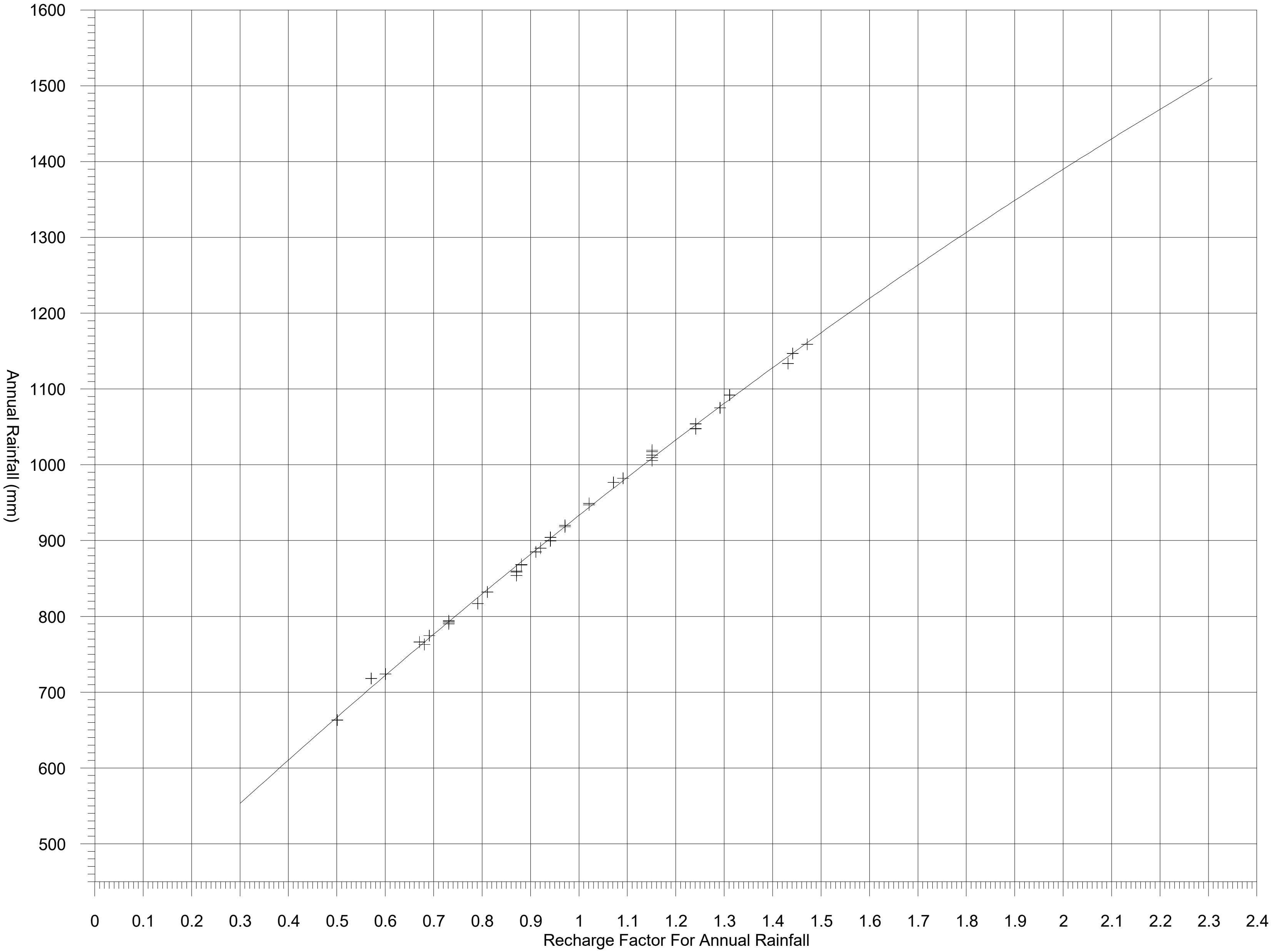
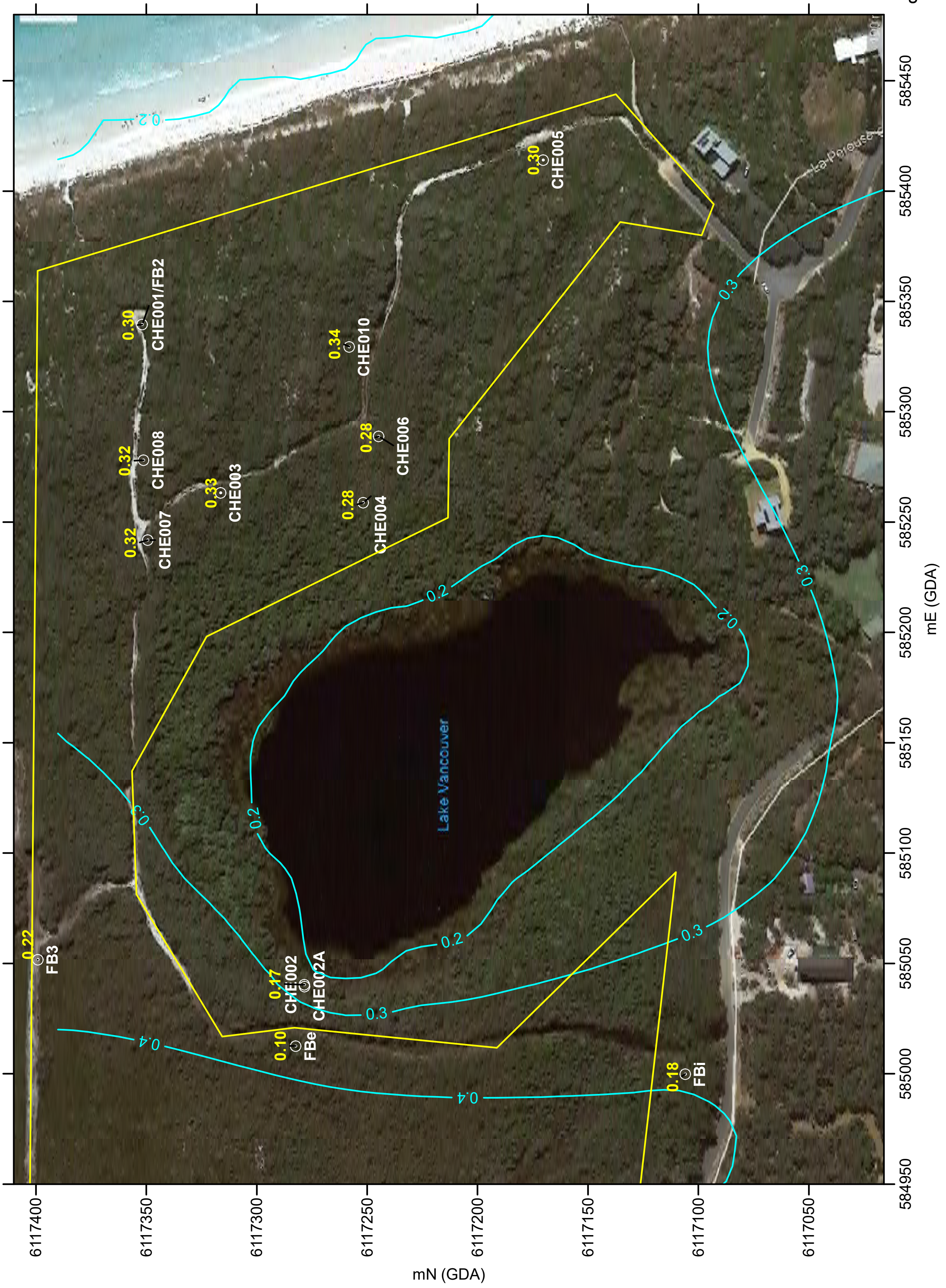


Figure 8

Figure 9



meas & calc summer min wls.srf

CLIENT: Aurora Environmental

PROJECT: Vancouver Beach Resort

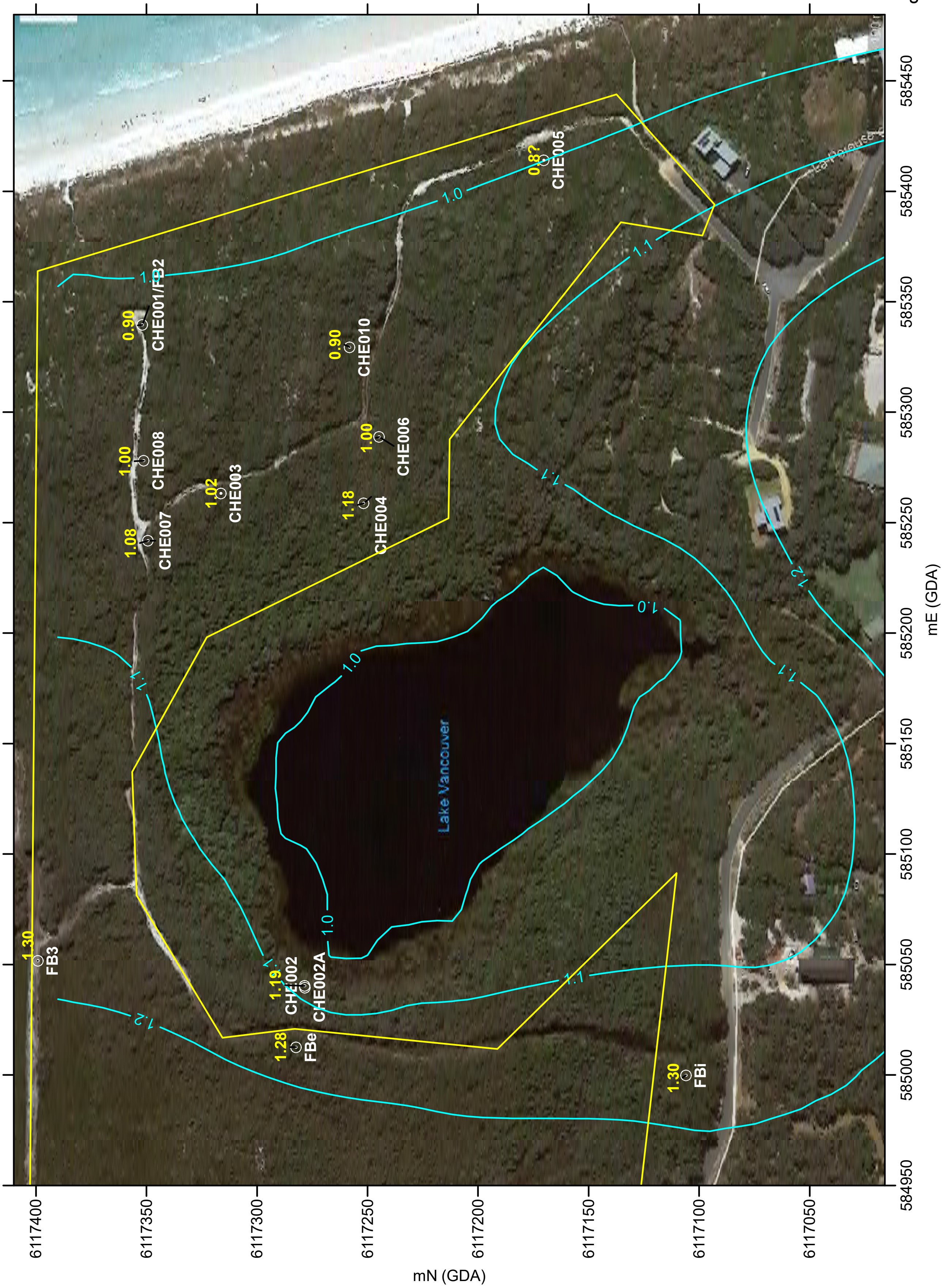
DATE: August 2019

Dwg No: 101-0/19/1-9

MEASURED (POST VALUES) & MODEL-CALCULATED (CONTOURS) SUMMER MINIMUM GROUNDWATER LEVELS (m AHD)

Rockwater Pty Ltd

Figure 10



meas & calc winter max wls2.srf

CLIENT: Aurora Environmental

PROJECT: Vancouver Beach Resort

DATE: August 2019

Dwg No: 101-0/19/1-10

MEASURED (POST VALUES) & MODEL-CALCULATED (CONTOURS) WINTER MAXIMUM GROUNDWATER LEVELS (m AHD)

Rockwater Pty Ltd

CLIENT: Aurora Environmental
PROJECT: Vancouver Beach Resort
DATE: August 2019
Dwg No: 101-0/19/1-11

MODEL-PREDICTED END-OF-SUMMER GROUNDWATER LEVEL RISE (m) WITH DEVELOPMENT

Rockwater Pty Ltd

eos wl rise.srf

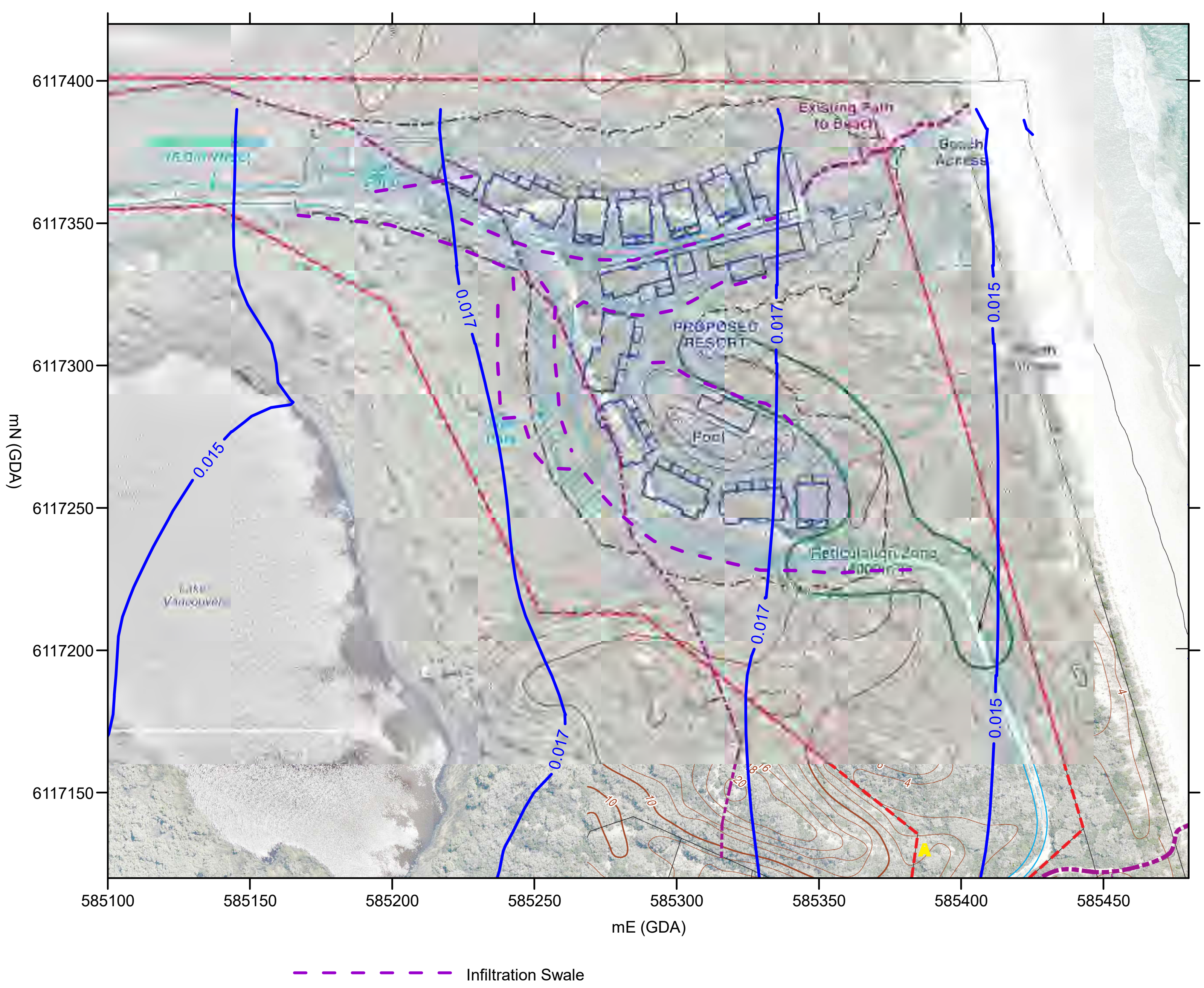


Figure 11

CLIENT: Aurora Environmental
PROJECT: Vancouver Beach Resort
DATE: August 2019
Dwg No: 101-0/19/1-12

MODEL-PREDICTED END-OF-WINTER GROUNDWATER LEVEL RISE (m) WITH DEVELOPMENT

Rockwater Pty Ltd

eow wl rise.srf

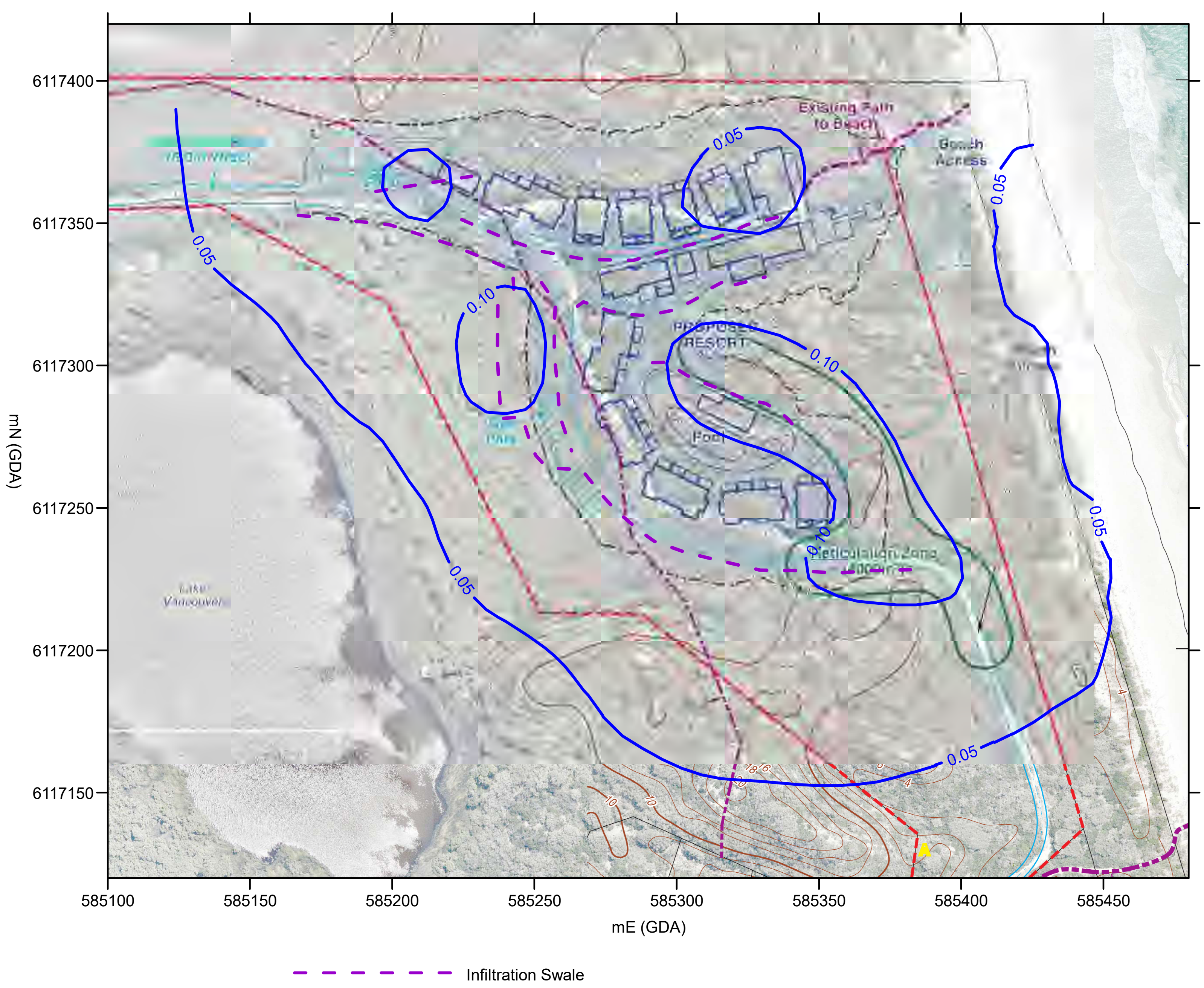


Figure 12

CLIENT: Aurora Environmental
PROJECT: Vancouver Beach Resort
DATE: August 2019
Dwg No: 101-0/19/1-13

MODEL-PREDICTED FLOW PATHS FROM RETICULATION ZONE

Rockwater Pty Ltd

flow paths.srf

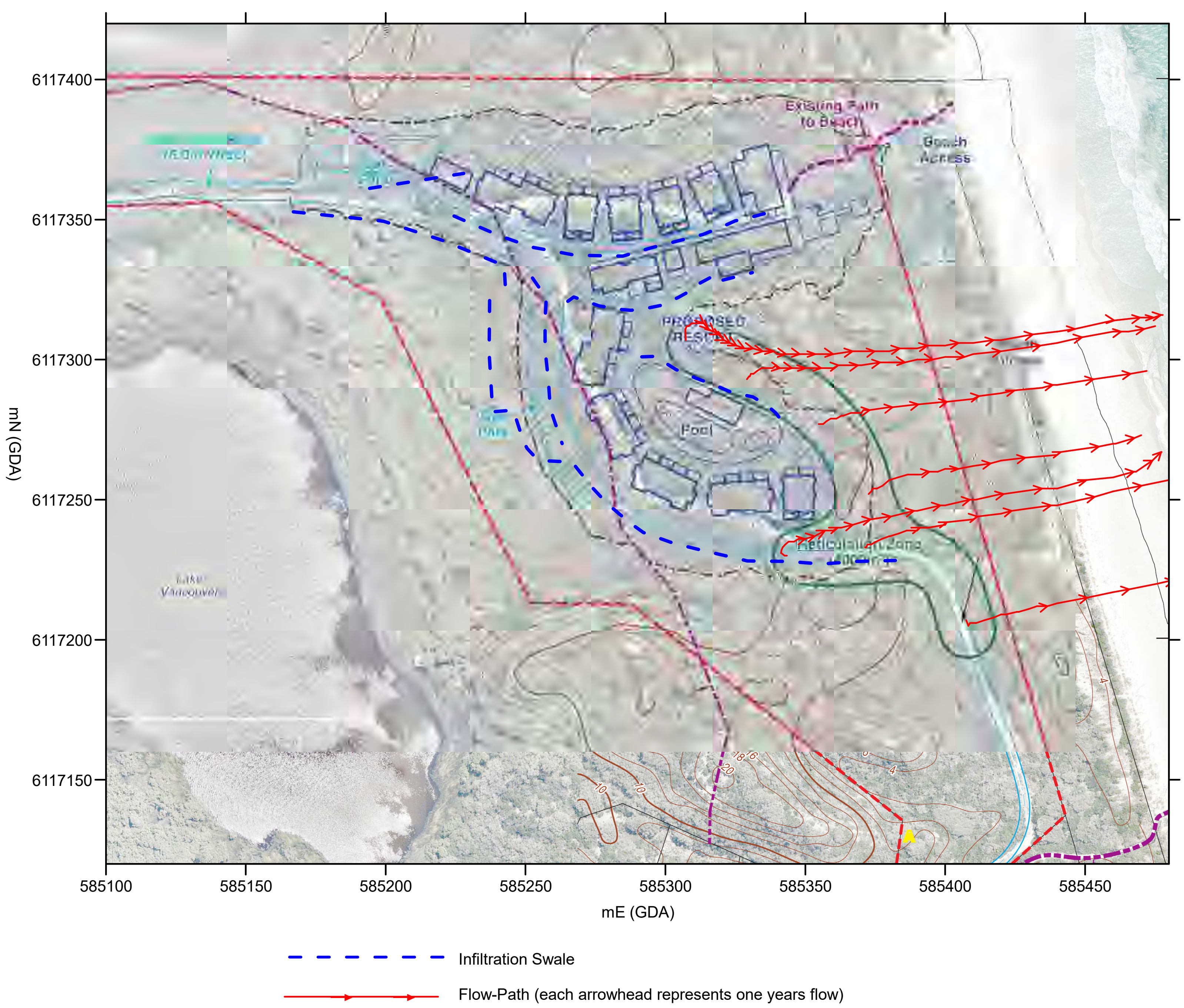


Figure 13

CLIENT: Aurora Environmental

PROJECT: Vancouver Beach Resort

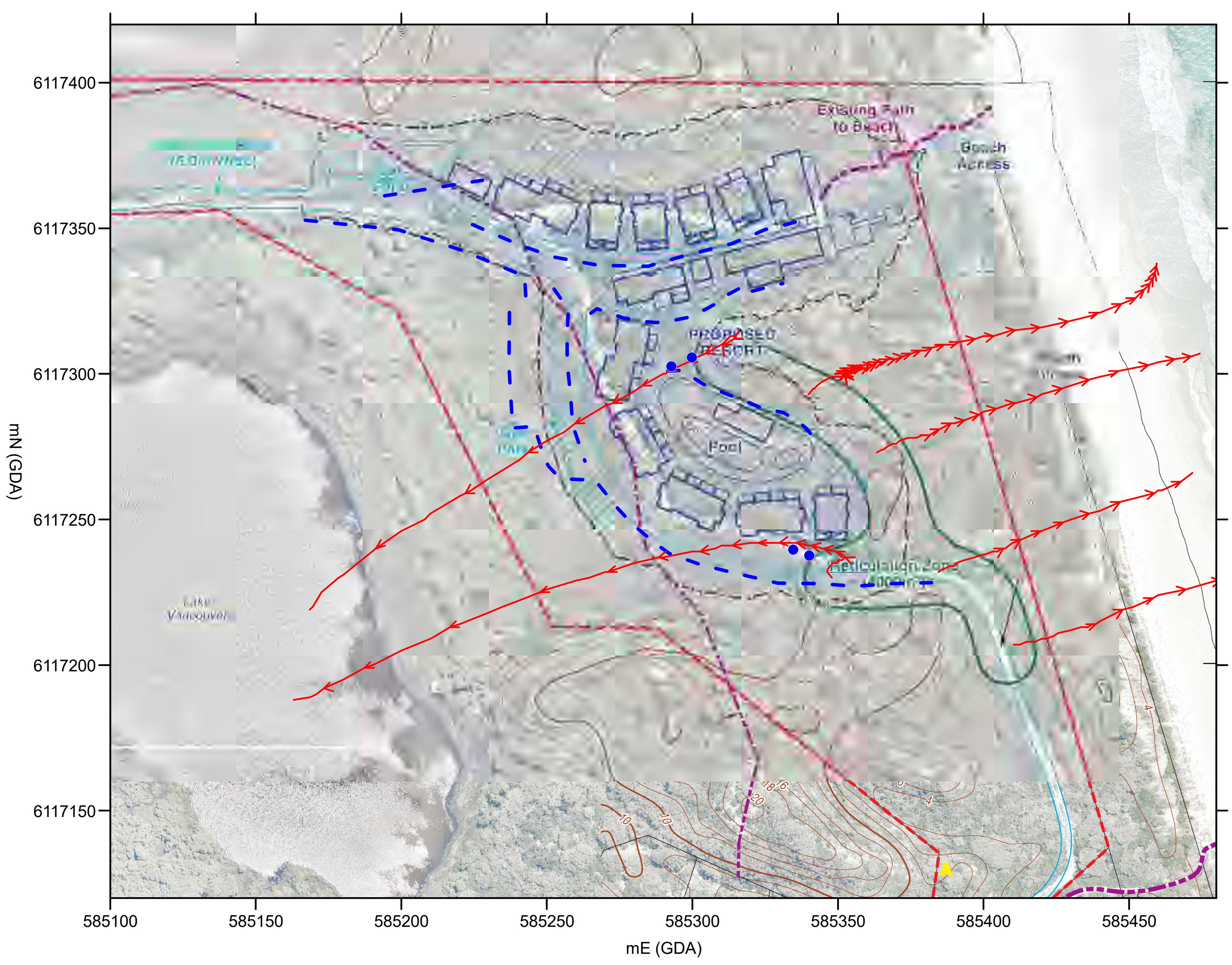
DATE: August 2019

Dwg No: 101-0/19/1-14

MODEL-PREDICTED FLOW PATHS FROM RETICULATION ZONE WITH HIGH LAKE EVAPOTRANSPIRATION

Rockwater Pty Ltd

flow paths high ET.srf



- - - - Infiltration Swale

—➤— Flow-Path (each arrowhead represents one years flow)

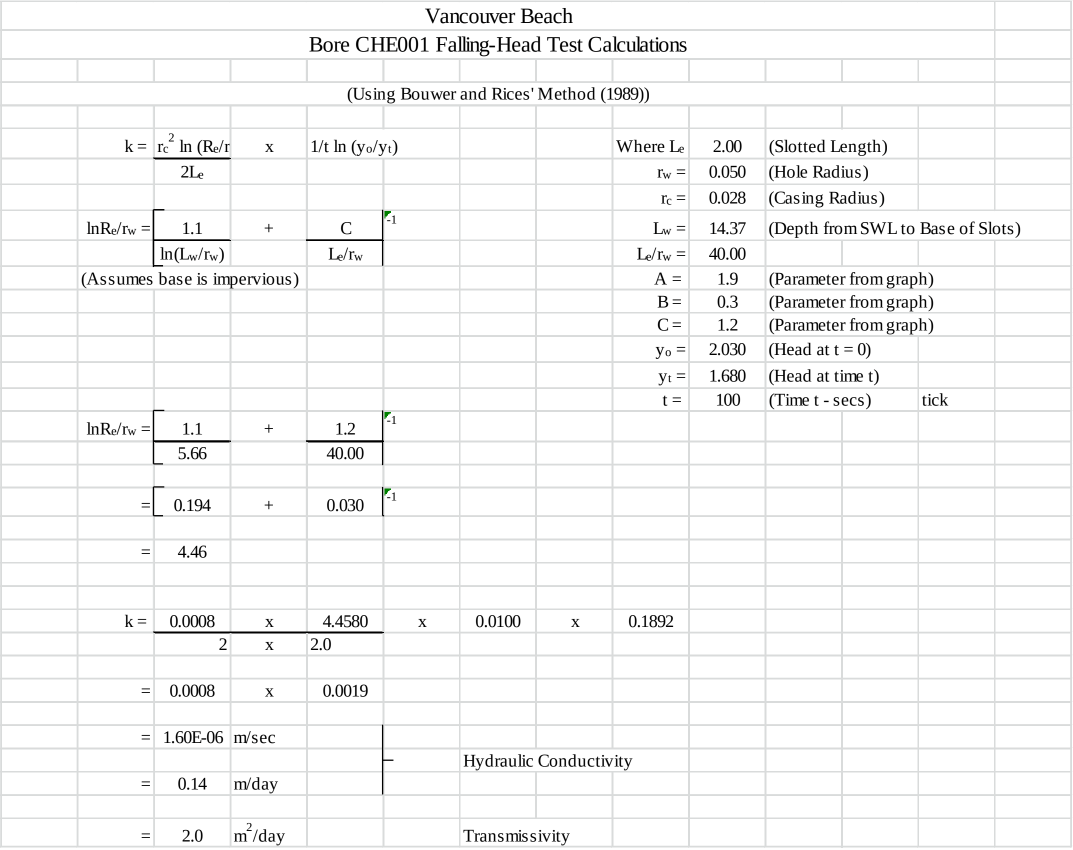
● Recommended Monitoring Bore Location

Figure 14

APPENDIX I: RESULTS OF CHEMICAL ANALYSES

		Physicochemical				Nutrients										Metals										
		pH	Conductivity (mS/cm)	TDS (mg/L)	Alkalinity (mgCaCO3/L)	Ammonia-N	Nitrite-N	Nitrate-N	NOx-N	TKN	Total Nitrogen	Filterable Reactive Phosphorus	Total Phosphorus	Total Al	Total Fe	Aluminium	Arsenic	Cadmium	Chromium	Copper	Manganese	Mercury	Iron	Nickel	Lead	Zinc
ANZECC, 2000 trigger values		**WATER ASSESSMENT CRITERIA (in mg/L unless otherwise noted)**																								
Fresh Waters - Wetlands		7.5-8.5	NV	NV	NV	0.04	NV	NV	0.1	NV	1.50	0.030	0.06	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV
Fresh Waters - Lakes & Reservoirs SW Aust		**6.5-8.0**	**NV**	**NV**	**NV**	**0.01**	**NV**	**NV**	**0.010**	**NV**	**0.35**	**0.005**	**0.01**	**NV**	**NV**	**NV**	**NV**	**NV**	**NV**	**NV**	**NV**	**NV**	**NV**	**NV**	**NV**	**NV**
Freshwater								**0.70**								0.055	0.024	0.0002	NV	0.0014	1.9	0.00006	NV	0.011	0.0034	0.008
ASS Indicators		<5	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	>1	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV
Sample ID	**Date**	**WATER ANALYTICAL RESULTS (in mg/L unless otherwise noted)**																								
		pH	Conductivity (mS/cm)	TDS (mg/L)	Alkalinity (mgCaCO3/L)	Ammonia-N	Nitrite-N	Nitrate-N	NOx-N	TKN	Total Nitrogen	Filterable Reactive Phosphorus	Total Phosphorus	Total Al	Total Fe	Aluminium	Arsenic	Cadmium	Chromium	Copper	Manganese	Mercury	Iron	Nickel	Lead	Zinc
CHE001/FB2	16 April 2019	7.4	1.1	640	190	<0.02	<0.01	**3.6**	**3.6**	0.6	**4.2**	**2.1**	**2.5**													
CHE006	16 April 2019	7.3	1.7	1,000	340	**0.1**	0.14	0.29	**0.43**	3.5	**3.9**	**0.03**	**0.19**													
CHE002/Lake	16 April 2019	**8.3**	3.3	2,000	170	**0.06**	<0.01	0.01	**0.01**	7.8	**7.8**	<0.01	**0.13**													
CHE009	16 April 2019	6.9	0.28	170	40	**0.54**	<0.01	0.04	**0.04**	1.1	**1.1**	<0.01	**0.13**													
CHE003	16 April 2019	7.3	3.3	1,900	10,000	**0.22**	0.08	0.5	**0.58**	64	65	<0.01	**4.9**													
CHE001/FB2	21 January 2019	7.3	1	450	180	**0.05**	0.02	**2.9**	**2.9**	3.4	**6.3**	**2.5**	**2.5**													
CHE006	21 January 2019	7.2	1.7	870	450	**0.52**	<0.01	**<0.01**	<0.01	19	19	**0.03**	**0.25**													
CHE002/Lake	21 January 2019	7.9	2.5	1,200	180	**0.26**	<0.01	0.01	**0.01**	3.9	**3.9**	<0.01	**0.08**													
CHE009	21 January 2019	6.6	0.39	230	170	**3**	<0.01	0.04	**0.04**	11	11	**0.01**	**0.68**													
CHE003	21 January 2019	7.3	3.9	1,800	990	**0.2**	<0.01	0.02	**0.02**	21	21	**0.1**	**1.1**													
CHE001/FB2	20 November 2018	7.4	1.1	580	200	**1.6**	0.02	**2.6**	**2.6**	3.4	**6**	**2.2**	**2.2**													
CHE006	20 November 2018	7.3	1.5	990	370	**0.12**	<0.01	<0.01	<0.01	12	12	**0.06**	**0.5**													
CHE002/Lake	20 November 2018	7.4	2	1,100	170	**0.04**	0.01	0.01	**0.02**	1.4	**1.4**	<0.01	**0.06**													
CHE009	20 November 2018	6.6	0.3	180	82	**1.4**	0.01	0.03	**0.04**	7.5	**7.5**	**0.01**	**1.5**													
CHE003	20 November 2018	7.2	4.3	2,400	670	**0.32**	0.03	0.05	**0.08**	11	11	**0.02**	**0.73**													
CHE001/FB2	21 August 2018	7.5	1	540	190	**2.1**	0.73	**2.6**	**3.3**	2.8	**6.1**	**2.3**	**2.3**	**0.06**	**0.1**	<0.01	0.001	<0.0001	0.002	0.019	<0.01	<0.0001	<0.01	0.001	0.003	0.006
CHE006	21 August 2018	7.3	1.7	1,200	510	**0.3**	<0.01	<0.01	<0.01	38	38	**0.03**	**0.89**	**3.2**	**4.1**	0.38	0.002	<0.0001	0.006	<0.001	<0.01	<0.0001	0.51	0.001	<0.001	<0.005
CHE002/Lake	21 August 2018	7.6	1.8	1,000	130	**0.02**	<0.01	<0.01	<0.01	1.4	**1.4**	<0.01	**0.04**	**0.07**	**0.28**	0.04	<0.001	<0.0001	0.002	0.002	<0.01	<0.0001	0.21	<0.001	<0.001	<0.005
CHE009	21 August 2018	**6.5**	0.08	48	17	<0.02	<0.01	<0.01	<0.01	1.1	**1.1**	<0.01	**0.06**	**2**	5.2	0.03	<0.001	<0.0001	0.002	0.001	<0.01	<0.0001	0.88	<0.001	<0.001	<0.005

APPENDIX II: FALLING-HEAD TEST DATA AND ANALYSES



Vancouver Beach
Bore CHE001 Falling-Head Test Calculations

(Using Bouwer and Rices' Method (1989))

$k = \frac{r_c^2 \ln (R_e/r}{2L_e} \times 1/t \ln (y_o/y_t)$

Where L_e	2.00	(Slotted Length)
r_w =	0.050	(Hole Radius)
r_c =	0.028	(Casing Radius)
L_w =	14.37	(Depth from SWL to Base of Slots)
L_e/r_w =	40.00	
A =	1.9	(Parameter from graph)
B =	0.3	(Parameter from graph)
C =	1.2	(Parameter from graph)
y_o =	2.030	(Head at t = 0)
y_t =	1.680	(Head at time t)
t =	100	(Time t - secs) tick

$\ln R_e/r_w = \left[\frac{1.1}{\ln(L_w/r_w)} + \frac{C}{L_e/r_w} \right]^{-1}$

(Assumes base is impervious)

$\ln R_e/r_w = \left[\frac{1.1}{5.66} + \frac{1.2}{40.00} \right]^{-1}$

$= \left[0.194 + 0.030 \right]^{-1}$

$= 4.46$

$k = \frac{0.0008 \times 4.4580}{2 \times 2.0} \times 0.0100 \times 0.1892$

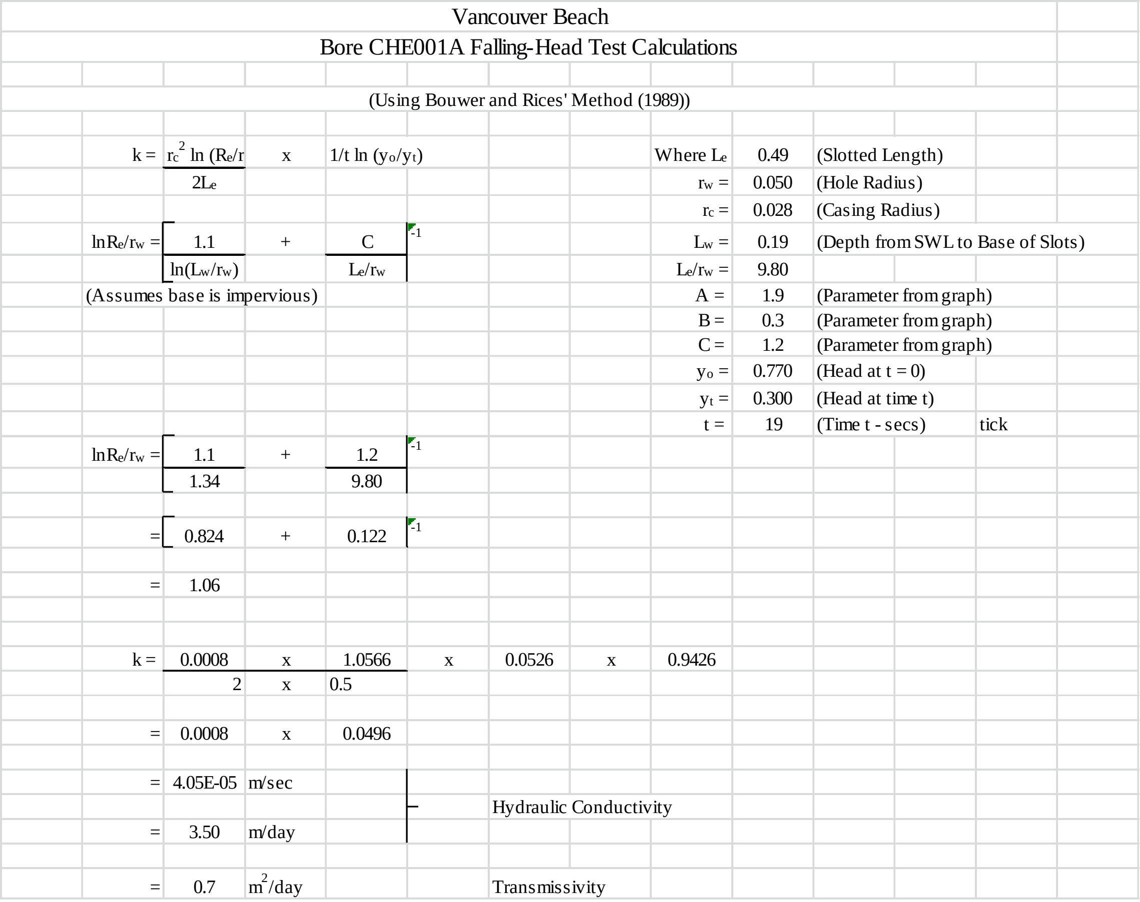
$= 0.0008 \times 0.0019$

= 1.60E-06 m/sec

= 0.14 m/day

Hydraulic Conductivity

= 2.0 m^2/day Transmissivity



Vancouver Beach
Bore CHE001A Falling-Head Test Calculations

(Using Bouwer and Rices' Method (1989))

$k = \frac{r_c^2 \ln (R_e/r}{2L_e} \times 1/t \ln (y_o/y_t)$

Where L_e	0.49	(Slotted Length)
r_w =	0.050	(Hole Radius)
r_c =	0.028	(Casing Radius)
L_w =	0.19	(Depth from SWL to Base of Slots)
L_e/r_w =	9.80	
A =	1.9	(Parameter from graph)
B =	0.3	(Parameter from graph)
C =	1.2	(Parameter from graph)
y_o =	0.770	(Head at t = 0)
y_t =	0.300	(Head at time t)
t =	19	(Time t - secs) tick

$\ln R_e/r_w = \left[\frac{1.1}{\ln(L_w/r_w)} + \frac{C}{L_e/r_w} \right]^{-1}$

(Assumes base is impervious)

$\ln R_e/r_w = \left[\frac{1.1}{1.34} + \frac{1.2}{9.80} \right]^{-1}$

$= \left[0.824 + 0.122 \right]^{-1}$

$= 1.06$

$k = \frac{0.0008 \times 1.0566}{2 \times 0.5} \times 0.0526 \times 0.9426$

$= 0.0008 \times 0.0496$

= 4.05E-05 m/sec

= 3.50 m/day

Hydraulic Conductivity

= 0.7 m^2/day Transmissivity

Vancouver Beach
Bore CHE003 Falling-Head Test Calculations

(Using Bouwer and Rices' Method (1989))

$$k = \frac{r_c^2 \ln (R_e/r}{2L_e} \times 1/t \ln (y_o/y_t)$$

$$\ln R_e/r_w = \left[\frac{1.1}{\ln(L_w/r_w)} + \frac{C}{L_e/r_w} \right]^{-1}$$

(Assumes base is impervious)

Where L_e	0.58	(Slotted Length)
r_w =	0.050	(Hole Radius)
r_c =	0.028	(Casing Radius)
L_w =	0.28	(Depth from SWL to Base of Slots)
L_e/r_w =	11.60	
A =	1.9	(Parameter from graph)
B =	0.3	(Parameter from graph)
C =	1.2	(Parameter from graph)
y_o =	0.580	(Head at t = 0)
y_t =	0.145	(Head at time t)
t =	75	(Time t - secs)

$$\ln R_e/r_w = \left[\frac{1.1}{1.70} + \frac{1.2}{11.60} \right]^{-1}$$

$$= \left[0.645 + 0.103 \right]^{-1}$$

$$= 1.34$$

$$k = \frac{0.0008 \times 1.3356}{2 \times 0.6} \times 0.0133 \times 1.3863$$

$$= 0.0009 \times 0.0185$$

= 1.61E-05 m/sec
Hydraulic Conductivity
= 1.39 m/day

= 0.4 m^2/day Transmissivity

Vancouver Beach
Bore CHE004 Falling-Head Test Calculations

(Using Bouwer and Rices' Method (1989))

$$k = \frac{r_c^2 \ln (R_e/r}{2L_e} \times 1/t \ln (y_o/y_t)$$

$$\ln R_e/r_w = \left[\frac{1.1}{\ln(L_w/r_w)} + \frac{C}{L_e/r_w} \right]^{-1}$$

(Assumes base is impervious)

Where L_e	0.93	(Slotted Length)
r_w =	0.050	(Hole Radius)
r_c =	0.028	(Casing Radius)
L_w =	0.13	(Depth from SWL to Base of Slots)
L_e/r_w =	18.60	
A =	2.1	(Parameter from graph)
B =	0.3	(Parameter from graph)
C =	1.6	(Parameter from graph)
y_o =	0.810	(Head at t = 0)
y_t =	0.330	(Head at time t)
t =	75	(Time t - secs)

$$\ln R_e/r_w = \left[\frac{1.1}{0.92} + \frac{1.6}{18.60} \right]^{-1}$$

$$= \left[1.200 + 0.086 \right]^{-1}$$

$$= 0.78$$

$$k = \frac{0.0008 \times 0.7773}{2 \times 0.9} \times 0.0133 \times 0.8979$$

$$= 0.0003 \times 0.0120$$

= 3.78E-06 m/sec
Hydraulic Conductivity
= 0.33 m/day

= 0.0 m^2/day Transmissivity

Vancouver Beach

Bore CHE005 Falling-Head Test Calculations

(Using Bouwer and Rices' Method (1989))

$$k = \frac{r_c^2 \ln (R_e/r}{2L_e} \times 1/t \ln (y_o/y_t)$$

$$\ln R_e/r_w = \left[\frac{1.1}{\ln(L_w/r_w)} + \frac{C}{L_e/r_w} \right]^{-1}$$

(Assumes base is impervious)

Where L_e	1.70	(Slotted Length)
r_w =	0.050	(Hole Radius)
r_c =	0.028	(Casing Radius)
L_w =	1.04	(Depth from SWL to Base of Slots)
L_e/r_w =	34.00	
A =	2.4	(Parameter from graph)
B =	0.4	(Parameter from graph)
C =	2.1	(Parameter from graph)
y_o =	1.300	(Head at t = 0)
y_t =	0.200	(Head at time t)
t =	16	(Time t - secs)

$$\ln R_e/r_w = \left[\frac{1.1}{3.03} + \frac{2.1}{34.00} \right]^{-1}$$

$$= \left[0.363 + 0.062 \right]^{-1}$$

$$= 2.35$$

$$k = \frac{0.0008 \times 2.3541}{2 \times 1.7} \times 0.0625 \times 1.8718$$

$$= 0.0005 \times 0.1170$$

$$\left.\begin{array}{l} = 6.13\text{E-}05 \text{ m/sec} \\ = 5.29 \text{ m/day} \end{array}\right\} \text{Hydraulic Conductivity}$$

$= 5.5$ m^2/day Transmissivity

Vancouver Beach

Bore CHE006 Falling-Head Test Calculations

(Using Bouwer and Rices' Method (1989))

$$k = \frac{r_c^2 \ln (R_e/r}{2L_e} \times 1/t \ln (y_o/y_t)$$

$$\ln R_e/r_w = \left[\frac{1.1}{\ln(L_w/r_w)} + \frac{C}{L_e/r_w} \right]^{-1}$$

(Assumes base is impervious)

Where L_e	1.00	(Slotted Length)
r_w =	0.050	(Hole Radius)
r_c =	0.028	(Casing Radius)
L_w =	0.73	(Depth from SWL to Base of Slots)
L_e/r_w =	20.00	
A =	2.2	(Parameter from graph)
B =	0.3	(Parameter from graph)
C =	1.7	(Parameter from graph)
y_o =	0.690	(Head at t = 0)
y_t =	0.120	(Head at time t)
t =	65	(Time t - secs)

$$\ln R_e/r_w = \left[\frac{1.1}{2.68} + \frac{1.7}{20.00} \right]^{-1}$$

$$= \left[0.410 + 0.085 \right]^{-1}$$

$$= 2.02$$

$$k = \frac{0.0008 \times 2.0190}{2 \times 1.0} \times 0.0154 \times 1.7492$$

$$= 0.0008 \times 0.0269$$

$$\left.\begin{array}{l} = 2.05\text{E-}05 \text{ m/sec} \\ = 1.78 \text{ m/day} \end{array}\right\} \text{Hydraulic Conductivity}$$

$= 1.3$ m^2/day Transmissivity

Vancouver Beach
Bore CHE007 Falling-Head Test Calculations

(Using Bouwer and Rices' Method (1989))

k = $\dfrac{r_c^2 \ln (R_e/r}{2L_e}$ x 1/t ln (y_o/y_t)

$\ln R_e/r_w = \left[\dfrac{1.1}{\ln(L_w/r_w)} + \dfrac{C}{L_e/r_w}\right]^{-1}$

(Assumes base is impervious)

Where L_e	0.70	(Slotted Length)
r_w =	0.050	(Hole Radius)
r_c =	0.028	(Casing Radius)
L_w =	0.23	(Depth from SWL to Base of Slots)
L_e/r_w =	14.00	
A =	1.9	(Parameter from graph)
B =	0.3	(Parameter from graph)
C =	1.2	(Parameter from graph)
y_o =	0.700	(Head at t = 0)
y_t =	0.260	(Head at time t)
t =	36.5	(Time t - secs)

$\ln R_e/r_w = \left[\dfrac{1.1}{1.53} + \dfrac{1.2}{14.00}\right]^{-1}$

$= \left[0.721 + 0.086\right]^{-1}$

= 1.24

k = $\dfrac{0.0008 \text{ x } 1.2399}{2 \text{ x } 0.7}$ x 0.0274 x 0.9904

= 0.0007 x 0.0271

= 1.82E-05 m/sec

= 1.57 m/day

Hydraulic Conductivity

= 0.4 m^2/day Transmissivity

Vancouver Beach
Bore CHE008 Falling-Head Test Calculations

(Using Bouwer and Rices' Method (1989))

k = $\dfrac{r_c^2 \ln (R_e/r}{2L_e}$ x 1/t ln (y_o/y_t)

$\ln R_e/r_w = \left[\dfrac{1.1}{\ln(L_w/r_w)} + \dfrac{C}{L_e/r_w}\right]^{-1}$

(Assumes base is impervious)

Where L_e	0.50	(Slotted Length)	
r_w =	0.050	(Hole Radius)	
r_c =	0.028	(Casing Radius)	
L_w =	0.20	(Depth from SWL to Base of Slots)	
L_e/r_w =	10.00		
A =	1.9	(Parameter from graph)	
B =	0.3	(Parameter from graph)	
C =	1.2	(Parameter from graph)	
y_o =	0.490	(Head at t = 0)	
y_t =	0.230	(Head at time t)	
t =	50	(Time t - secs)	tick

$\ln R_e/r_w = \left[\dfrac{1.1}{1.39} + \dfrac{1.2}{10.00}\right]^{-1}$

$= \left[0.793 + 0.120\right]^{-1}$

= 1.09

k = $\dfrac{0.0008 \text{ x } 1.0947}{2 \text{ x } 0.5}$ x 0.0200 x 0.7563

= 0.0008 x 0.0151

= 1.25E-05 m/sec

= 1.08 m/day

Hydraulic Conductivity

= 0.2 m^2/day Transmissivity

Vancouver Beach

Bore CHE010 Falling-Head Test Calculations

(Using Bouwer and Rices' Method (1989))

$$k = \frac{r_c^2 \ln(R_e/r_w)}{2L_e} \times 1/t \ln(y_o/y_t)$$

$$\ln R_e/r_w = \left[\frac{1.1}{\ln(L_w/r_w)} + \frac{C}{L_e/r_w}\right]^{-1}$$

(Assumes base is impervious)

Where L_e = 1.05 (Slotted Length)
r_w = 0.050 (Hole Radius)
r_c = 0.028 (Casing Radius)
L_w = 1.1 (Depth from SWL to Base of Slots)
L_e/r_w = 21.00
A = 2.1 (Parameter from graph)
B = 0.3 (Parameter from graph)
C = 1.7 (Parameter from graph)
y_o = 0.845 (Head at t = 0)
y_t = 0.315 (Head at time t)
t = 30 (Time t - secs)

$$\ln R_e/r_w = \left[\frac{1.1}{3.04} + \frac{1.7}{21.00}\right]^{-1}$$

$$= \left[0.361 + 0.081\right]^{-1}$$

$$= 2.26$$

$$k = \frac{0.0008 \times 2.2611}{2 \times 1.1} \times 0.0333 \times 0.9868$$

$$= 0.0008 \times 0.0329$$

= 2.68E-05 m/sec
= 2.31 m/day
Hydraulic Conductivity

= 2.4 m^2/day Transmissivity

Vancouver Beach

Bore FB3 Falling-Head Test Calculations

(Using Bouwer and Rices' Method (1989))

$$k = \frac{r_c^2 \ln(R_e/r}{2L_e} \times 1/t \ln(y_o/y_t)$$

$$\ln R_e/r_w = \left[\frac{1.1}{\ln(L_w/r_w)} + \frac{C}{L_e/r_w}\right]^{-1}$$

(Assumes base is impervious)

Where L_e 2.00 (Slotted Length)
r_w = 0.050 (Hole Radius)
r_c = 0.028 (Casing Radius)
L_w = 16.90 (Depth from SWL to Base of Slots)
L_e/r_w = 40.00
A = 2.7 (Parameter from graph)
B = 0.4 (Parameter from graph)
C = 2.3 (Parameter from graph)
y_o = 1.500 (Head at t = 0)
y_t = 0.610 (Head at time t)
t = 12 (Time t - secs)

$$\ln R_e/r_w = \left[\frac{1.1}{5.82} + \frac{2.3}{40.00}\right]^{-1}$$

$$= \left[0.189 + 0.058\right]^{-1}$$

$$= 4.06$$

$$k = \frac{0.0008 \times 4.0584}{2 \times 2.0} \times 0.0833 \times 0.8998$$

$$= 0.0008 \times 0.0750$$

= 5.75E-05 m/sec
= 4.97 m/day
Hydraulic Conductivity

= 84.0 m^2/day Transmissivity

Vancouver Beach
Bore FBe Falling-Head Test Calculations

(Using Bouwer and Rices' Method (1989))

$$k = \frac{r_c^2 \ln (R_e/r}{2L_e} \times 1/t \ln (y_o/y_t)$$

$$\ln R_e/r_w = \left[\frac{1.1}{\ln(L_w/r_w)} + \frac{C}{L_e/r_w} \right]^{-1}$$

(Assumes base is impervious)

Where L_e = 0.73 (Slotted Length)
r_w = 0.050 (Hole Radius)
r_c = 0.028 (Casing Radius)
L_w = 0.43 (Depth from SWL to Base of Slots)
L_e/r_w = 14.50
A = 2.0 (Parameter from graph)
B = 0.3 (Parameter from graph)
C = 1.4 (Parameter from graph)
y_o = 0.530 (Head at t = 0)
y_t = 0.190 (Head at time t)
t = 80 (Time t - secs)

$$\ln R_e/r_w = \left[\frac{1.1}{2.14} + \frac{1.4}{14.50} \right]^{-1}$$

$$= \left[0.514 + 0.097 \right]^{-1}$$

$$= 1.64$$

$$k = \frac{0.0008 \times 1.6379}{2 \times 0.7} \times 0.0125 \times 1.0259$$

$$= 0.0009 \times 0.0128$$

= 1.10E-05 m/sec
Hydraulic Conductivity
= 0.95 m/day

= 0.4 m^2/day Transmissivity

Vancouver Beach
Bore FBi Falling-Head Test Calculations

(Using Bouwer and Rices' Method (1989))

$$k = \frac{r_c^2 \ln (R_e/r}{2L_e} \times 1/t \ln (y_o/y_t)$$

$$\ln R_e/r_w = \left[\frac{1.1}{\ln(L_w/r_w)} + \frac{C}{L_e/r_w} \right]^{-1}$$

(Assumes base is impervious)

Where L_e = 2.40 (Slotted Length)
r_w = 0.050 (Hole Radius)
r_c = 0.028 (Casing Radius)
L_w = 1.68 (Depth from SWL to Base of Slots)
L_e/r_w = 48.00
A = 3.0 (Parameter from graph)
B = 0.5 (Parameter from graph)
C = 2.7 (Parameter from graph)
y_o = 0.980 (Head at t = 0)
y_t = 0.360 (Head at time t)
t = 33 (Time t - secs)

$$\ln R_e/r_w = \left[\frac{1.1}{3.51} + \frac{2.7}{48.00} \right]^{-1}$$

$$= \left[0.313 + 0.056 \right]^{-1}$$

$$= 2.71$$

$$k = \frac{0.0008 \times 2.7083}{2 \times 2.4} \times 0.0303 \times 1.0014$$

$$= 0.0004 \times 0.0303$$

= 1.29E-05 m/sec
Hydraulic Conductivity
= 1.12 m/day

= 1.9 m^2/day Transmissivity

Client: Aurora Environmental
Project : Vancouver Beach
Date : June 2019
Dwg. No: 101-0/19/1-AII-1

CHE001 FALLING HEAD TEST

Rockwater Pty Ltd

CHE001 falling head.grf

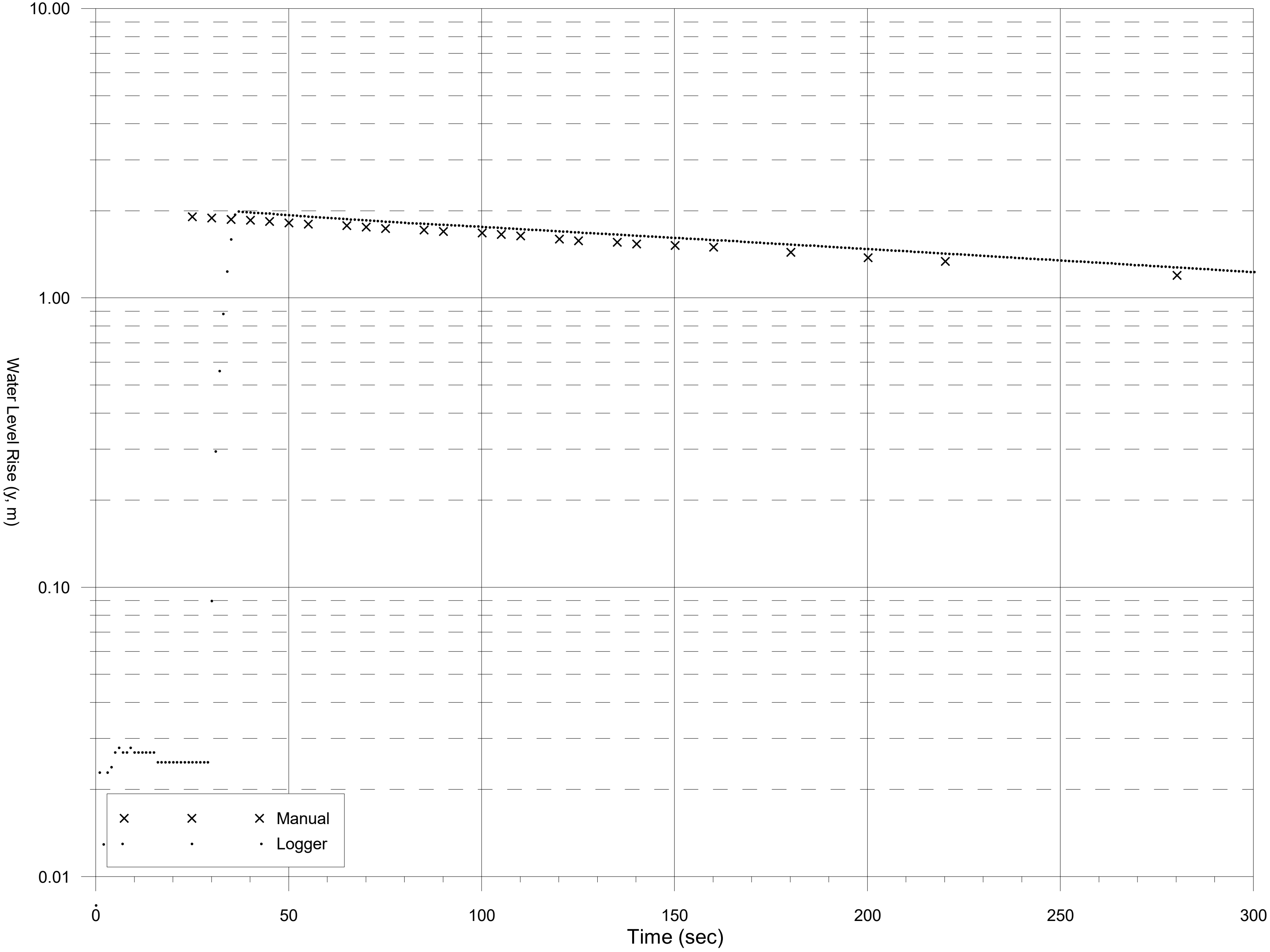


Figure AII-1

Client: Aurora Environmental
Project : Vancouver Beach
Date : June 2019
Dwg. No: 101-0/19/1-AII-2

CHE001A FALLING HEAD TEST

Rockwater Pty Ltd

CHE001A falling head.grf

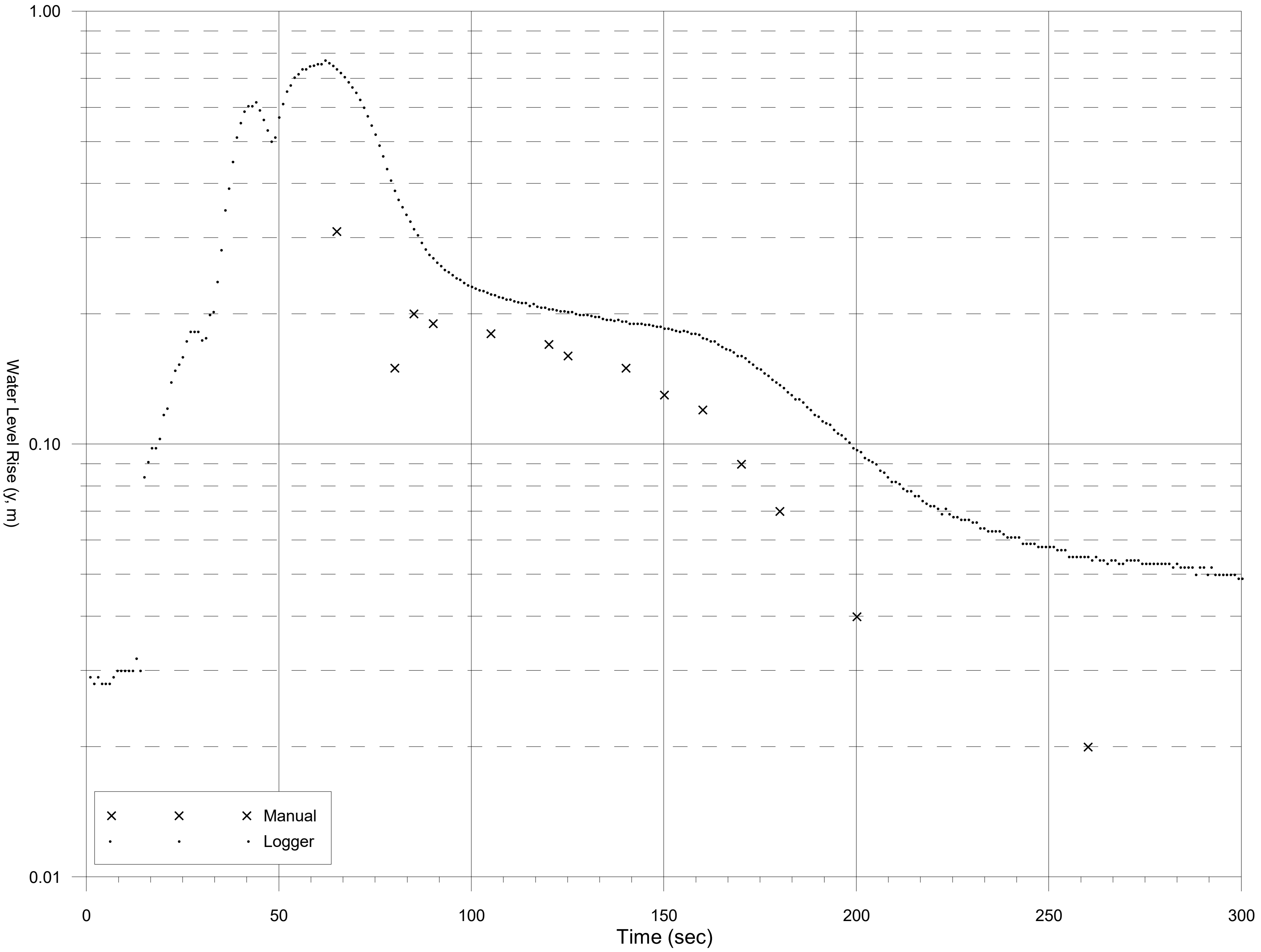


Figure AII-2

Client: Aurora Environmental
Project : Vancouver Beach
Date : June 2019
Dwg. No: 101-0/19/1-AII-3

CHE003 FALLING HEAD TEST

Rockwater Pty Ltd

CHE003 falling head.grf

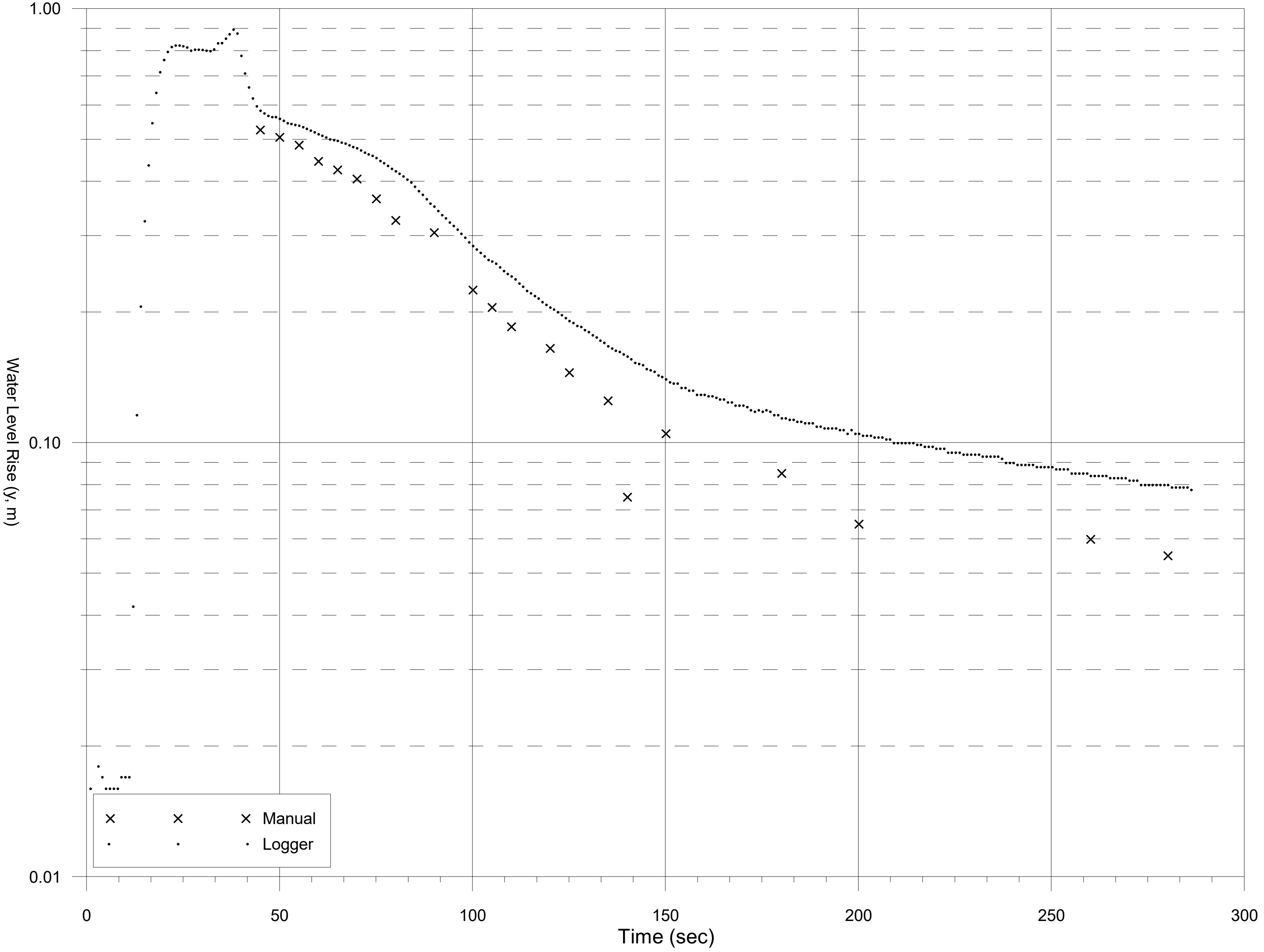


Figure AII-3

Client: Aurora Environmental
Project : Vancouver Beach
Date : June 2019
Dwg. No: 101-0/19/1-AII-4

CHE004 FALLING HEAD TEST

Rockwater Pty Ltd

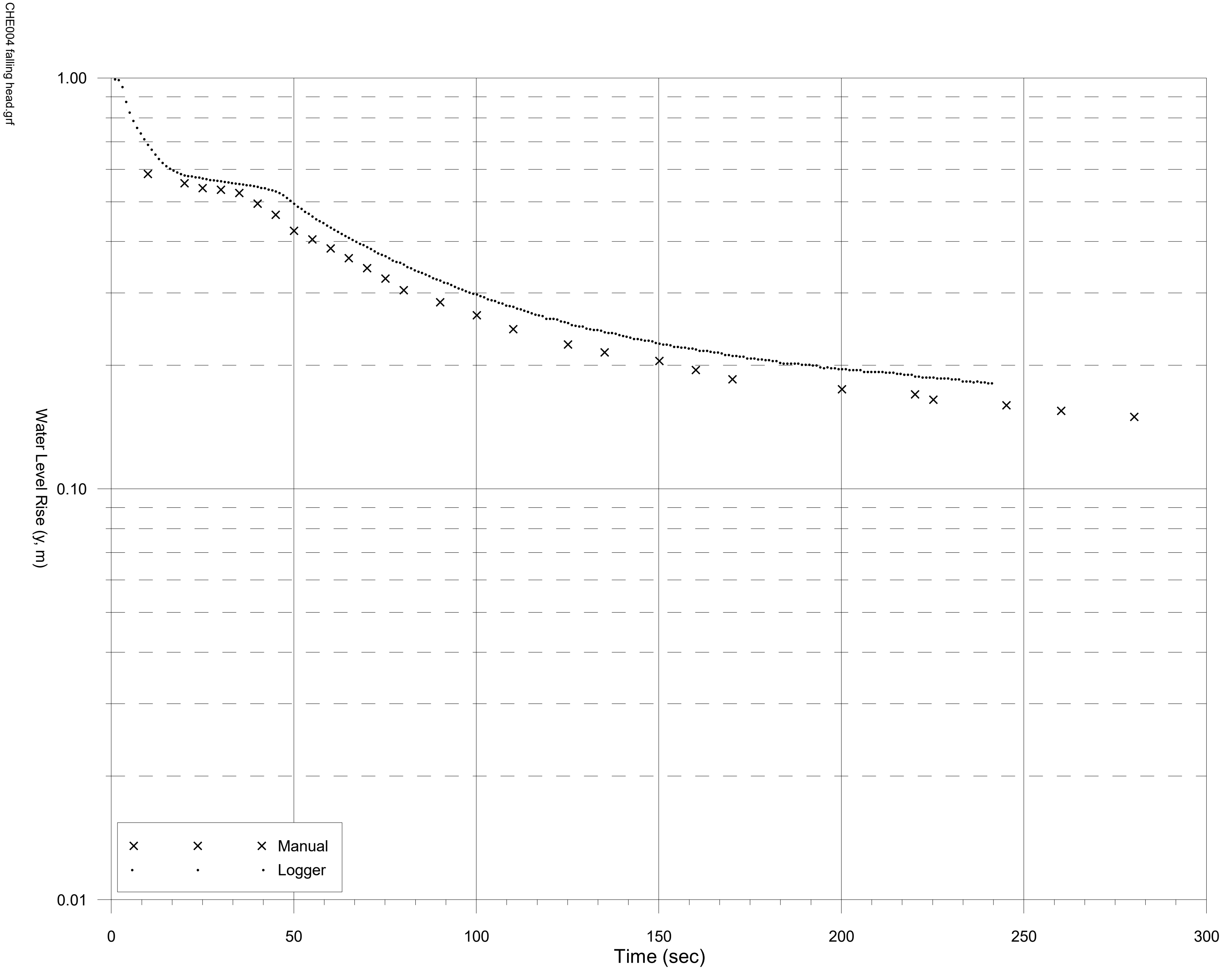


Figure AII-4

Client: Aurora Environmental
Project : Vancouver Beach
Date : June 2019
Dwg. No: 101-0/19/1-AII-5

CHE005 FALLING HEAD TEST

Rockwater Pty Ltd

CHE005 falling head.grf

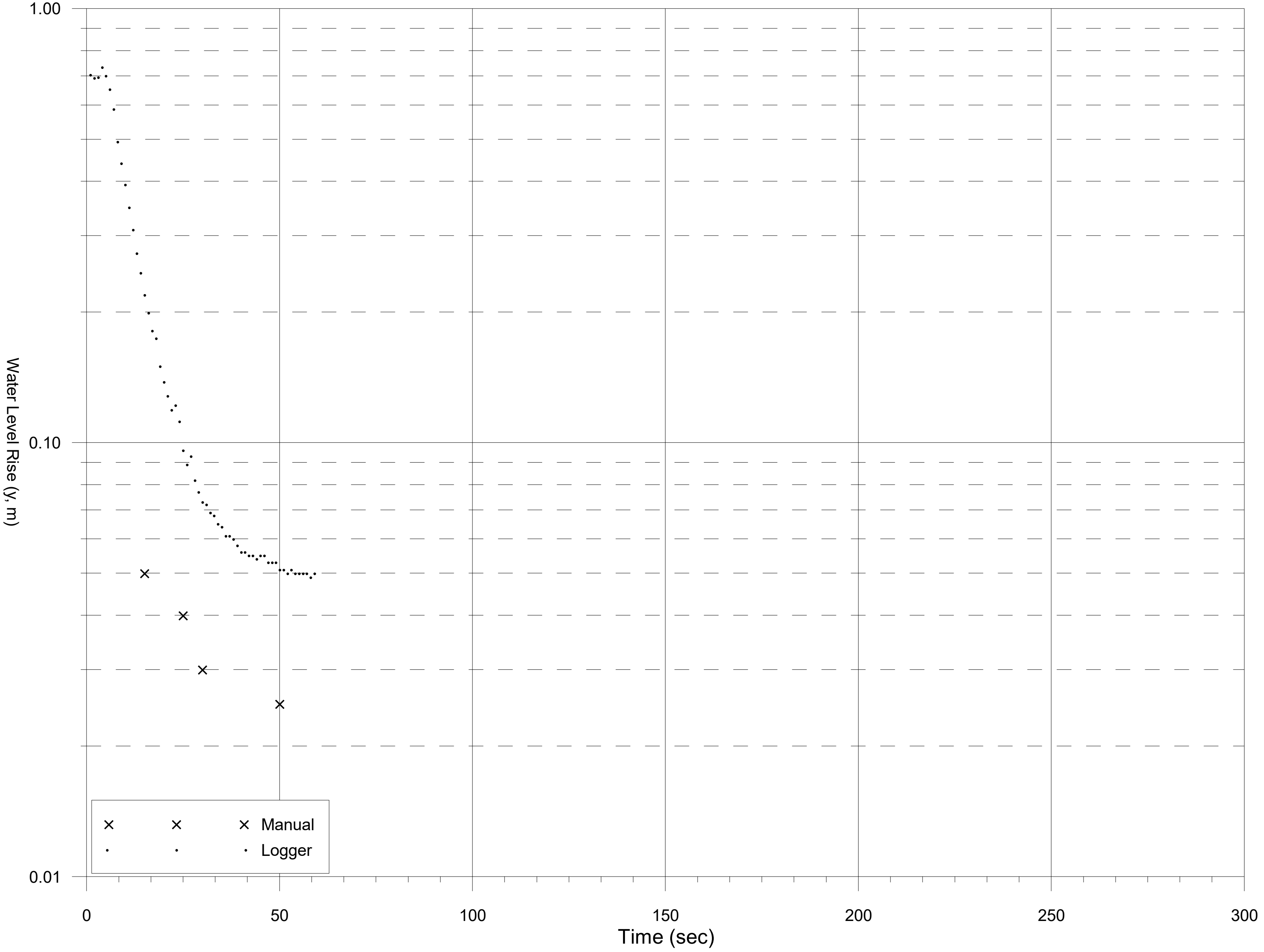
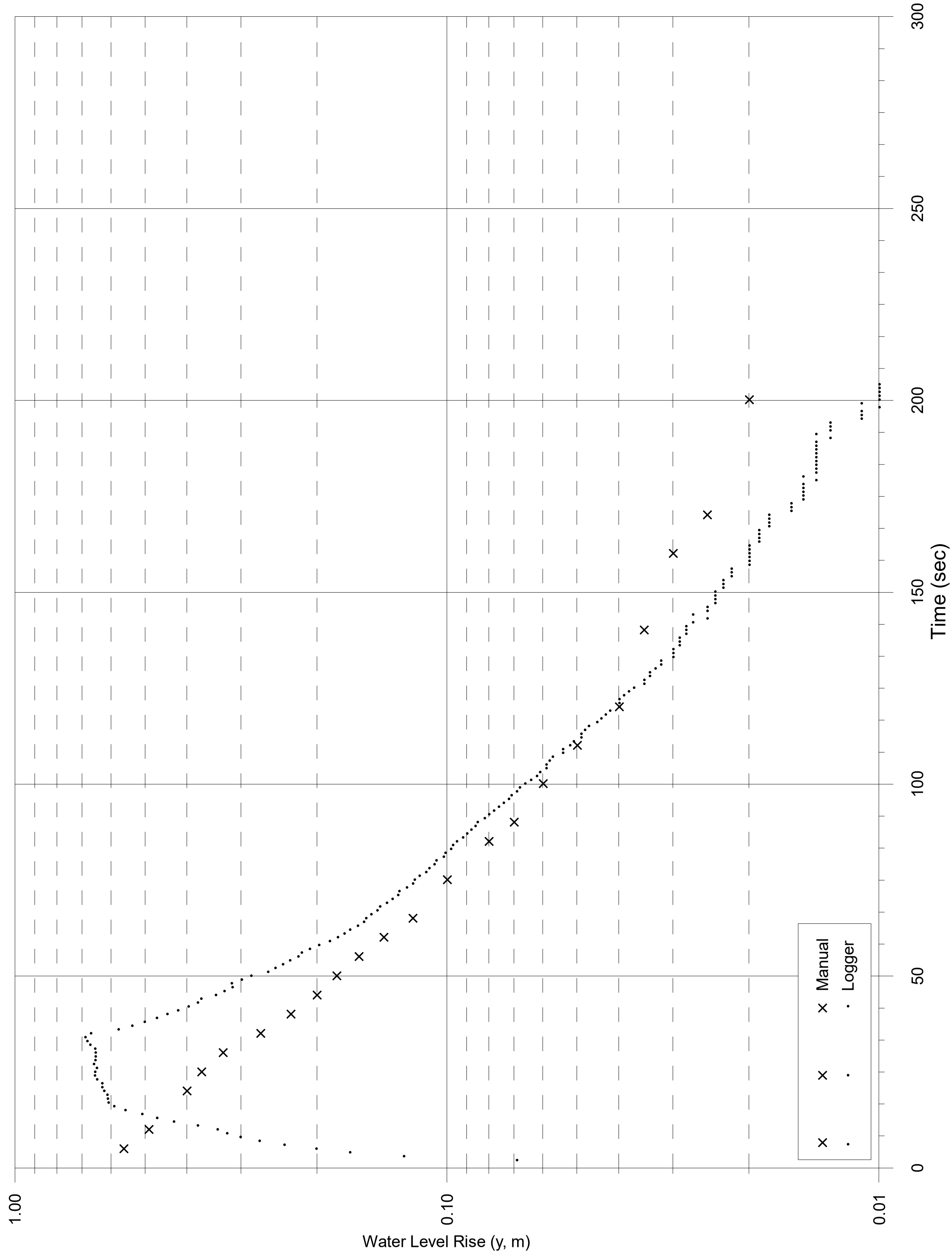


Figure AII-5

Figure AII-6



CHE006 falling head.grf

Client: Aurora Environmental
Project : Vancouver Beach
Date : June 2019
Dwg. No: 101-0/19/1-AII-6

CHE006 FALLING HEAD TEST

Rockwater Pty Ltd

Client: Aurora Environmental
Project : Vancouver Beach
Date : June 2019
Dwg. No: 101-0/19/1-AII-7

CHE007 FALLING HEAD TEST

Rockwater Pty Ltd

CHE007 falling head.grf

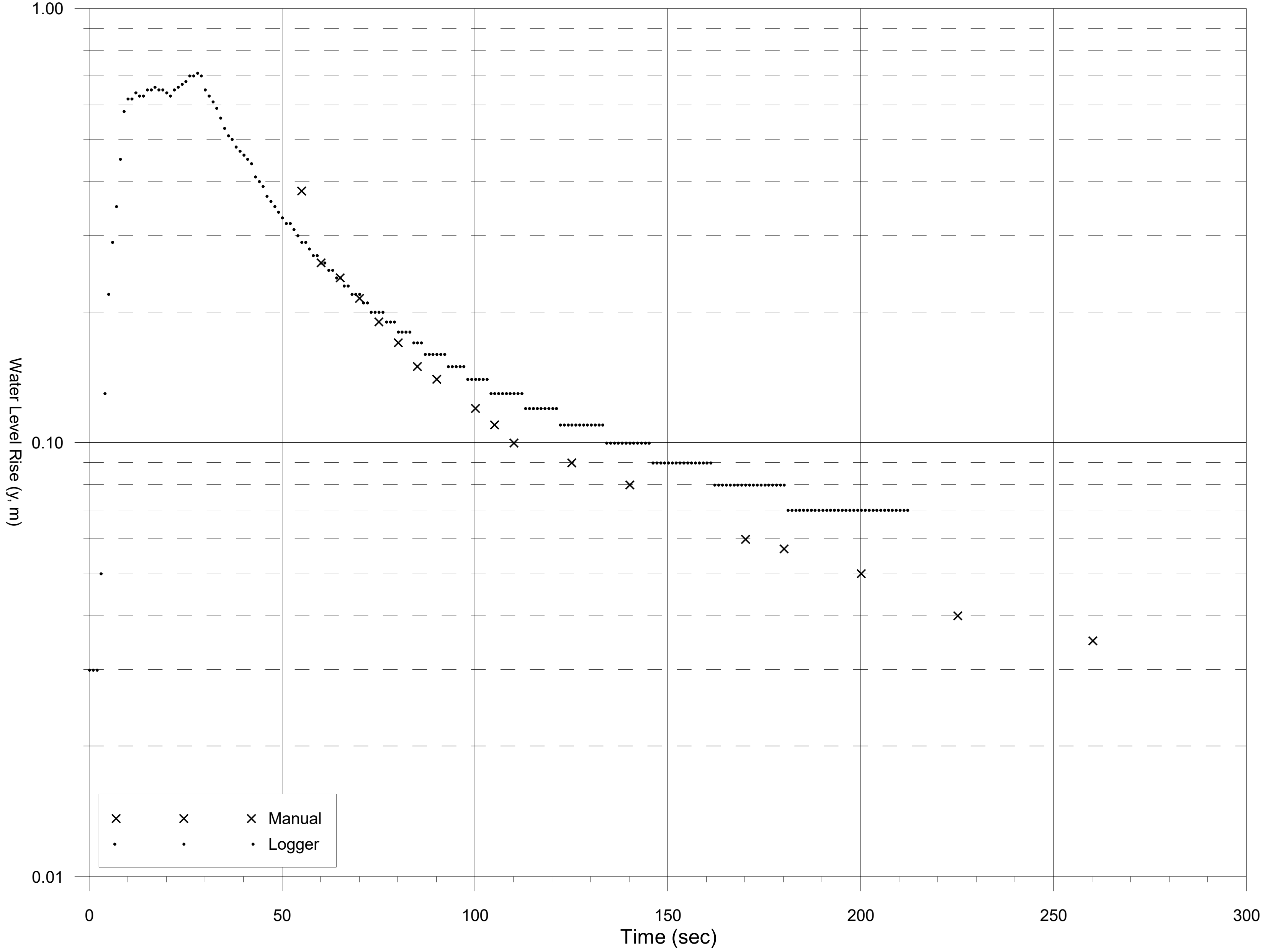


Figure AII-7

Client: Aurora Environmental
Project : Vancouver Beach
Date : June 2019
Dwg. No: 101-0/19/1-AII-8

CHE008 FALLING HEAD TEST

Rockwater Pty Ltd

CHE008 falling head.grf

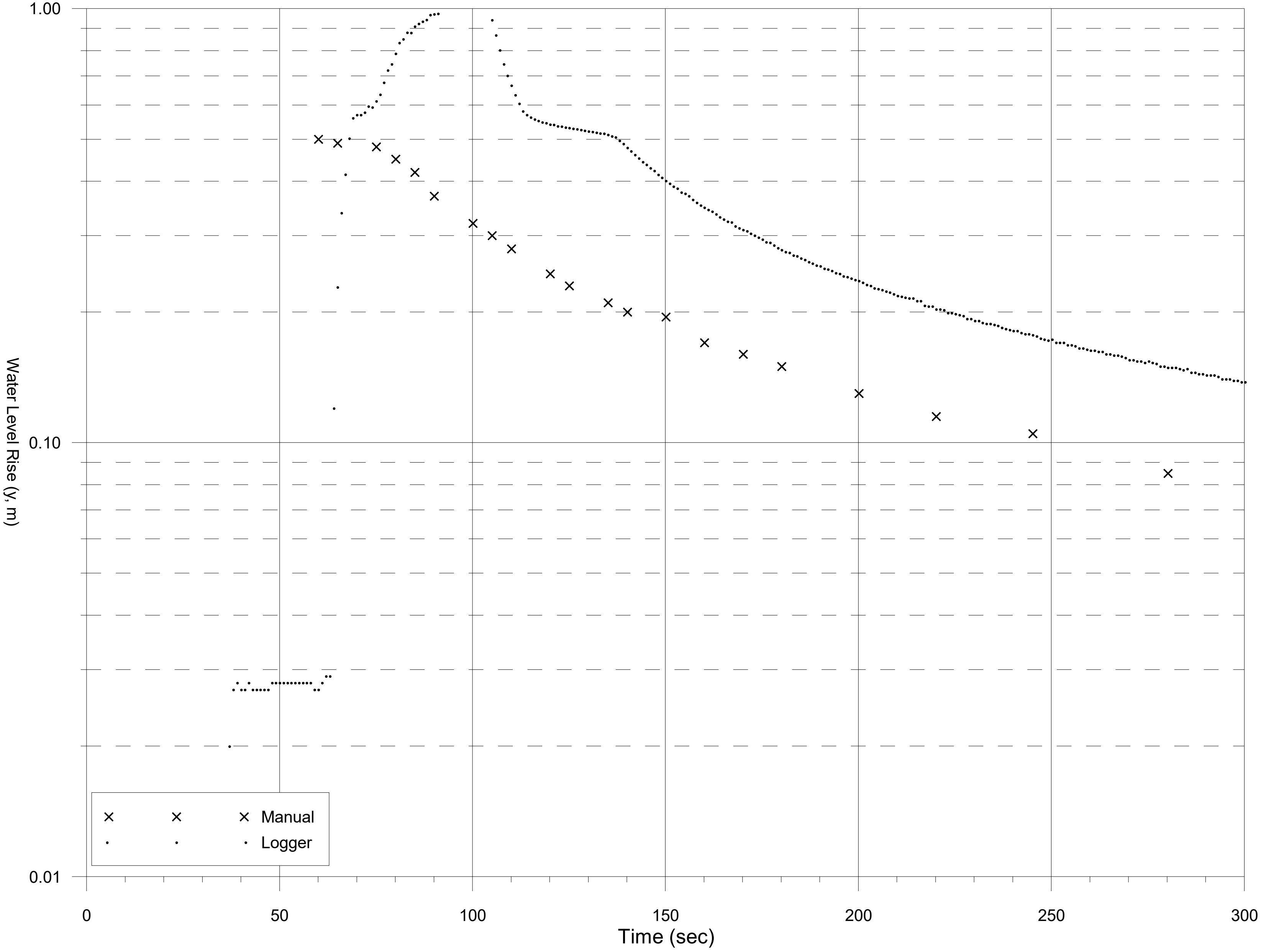
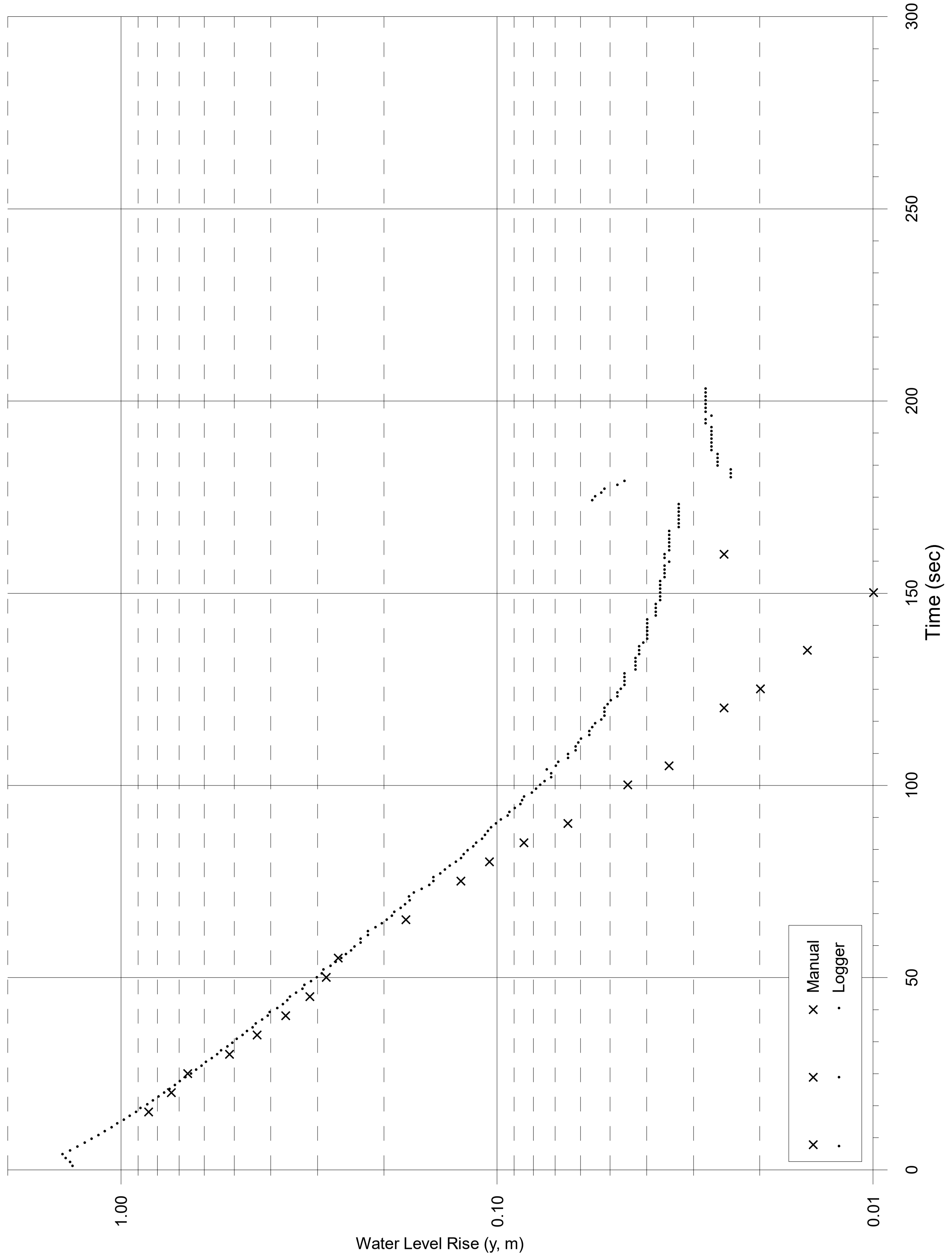


Figure AII-8

Figure AII-9



CHE010 falling head.grf

Client: Aurora Environmental
Project : Vancouver Beach
Date : June 2019
Dwg. No: 101-0/19/1-AII-9

CHE010 FALLING HEAD TEST

Rockwater Pty Ltd

Client: Aurora Environmental
Project : Vancouver Beach
Date : June 2019
Dwg. No: 101-0/19/1-AII-10

FB3 FALLING HEAD TEST

Rockwater Pty Ltd

FB3 falling head.grf

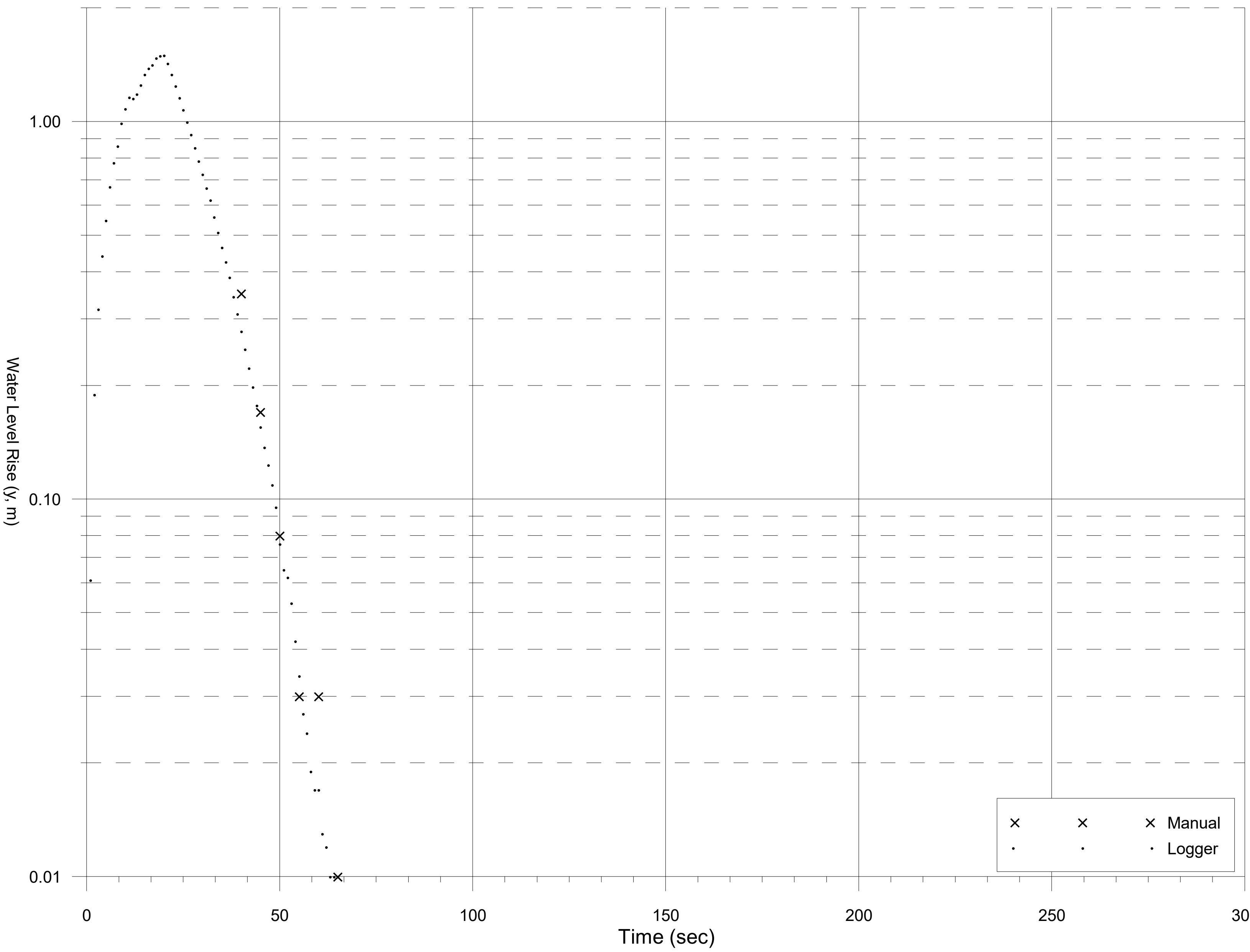


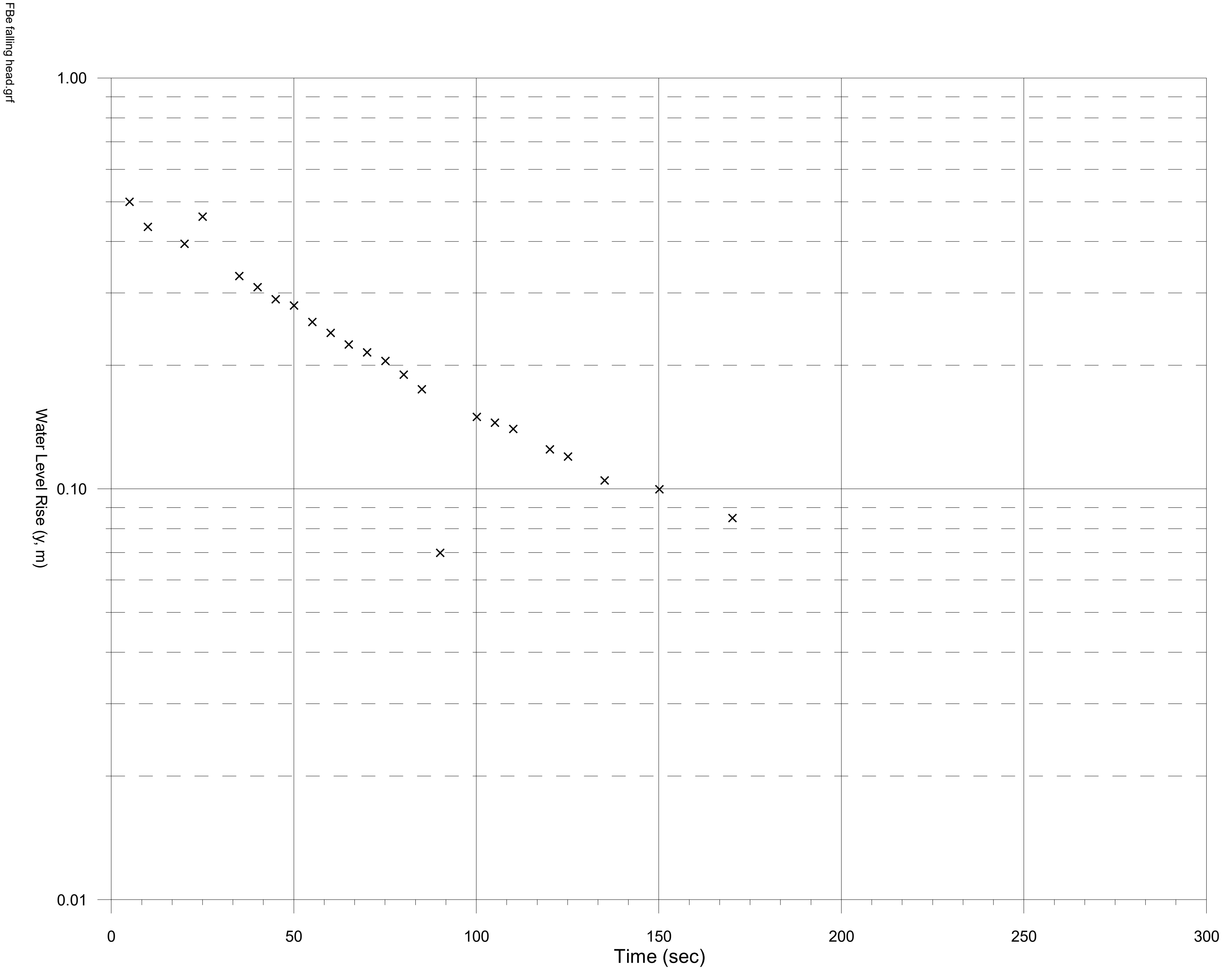
Figure AII-10

Client: Aurora Environmental
Project : Vancouver Beach
Date : June 2019
Dwg. No: 101-0/19/1-AII-11

FBe FALLING HEAD TEST

Rockwater Pty Ltd

Figure AII-11



Client: Aurora Environmental
Project : Vancouver Beach
Date : June 2019
Dwg. No: 101-0/19/1-AII-12

FBi FALLING HEAD TEST

Rockwater Pty Ltd

FBi falling head.grf

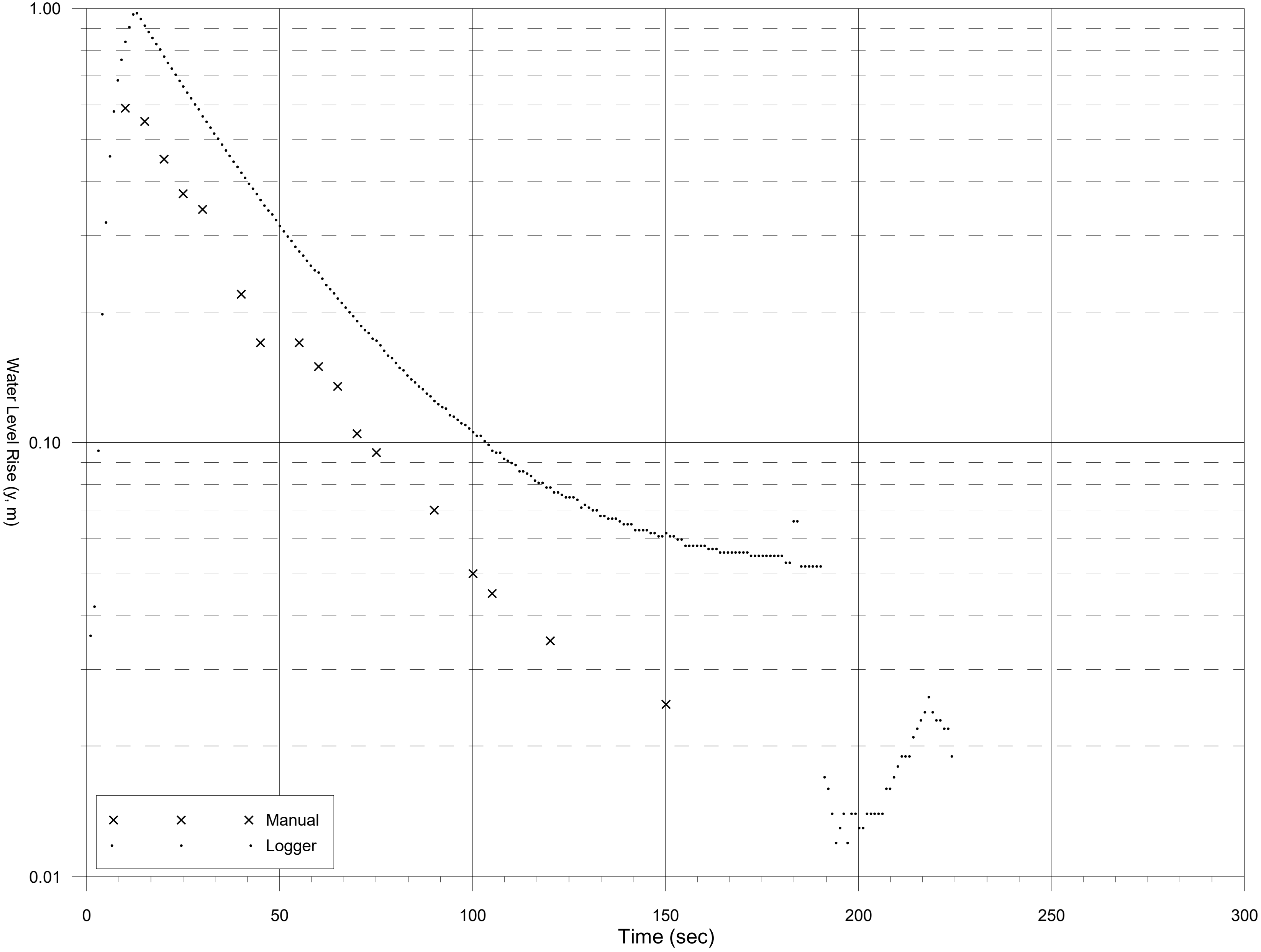


Figure AII-12