Whangamata Groundwater Monitoring Summary Report

Thames Coromandel District Council

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Contents

1 **Scope** 1

2 **Background detail** 2

3 **Monitoring Bore Data** 3
- 3.1 Bore Location 3
- 3.2 Bore Installation Data 4
  - 3.2.1 Bore 1 4
  - 3.2.2 Bores 2 and 3 4
  - 3.2.3 Bores 4 and 5 5
- 3.3 Bore Survey 6
- 3.4 Data Download 7

4 **Rainfall Data** 8

5 **Method of analysis** 9

6 **Results and Observations** 11
- 6.1 Tabulated results and observation 11
- 6.2 Seasonal Variations 12
- 6.3 Ponding 12
- 6.4 Potential Impact on Soakage Disposal 12
- 6.5 Response to Rainfall 13
- 6.6 Tidal Influence 19

7 **Implications for Whangamata Generally** 20

8 **Potential Future Initiatives** 21

9 **Recommendations** 22

Appendix A. Installation Details

Appendix B. Summary Charts

Appendix C. Year Span Charts

Appendix D. Summary Tables

Appendix E. Groundwater Level and Rainfall Relationships

Appendix F. Tidal Influence

1 Scope

Five groundwater monitoring bores were installed in Whangamata between 2008 and 2010. The main objective of the bores has been to assess the depth to groundwater below the ground surface, and the seasonal / climatic fluctuations in water level. This data is required to assess the feasibility of stormwater disposal by soakage in areas that are not reticulated. The information will also inform soakage device sizing. The effectiveness of soakage depends very much on the depth to groundwater below the ground surface.

Opus International Consultants Ltd has been assisting TCDC by monitoring groundwater levels in the bores since they were installed. Now that a substantial body of data is available, the time is right to assess and summarise the findings to date.

A secondary aim was to see if there is any evidence to indicate that flooding in the ponding areas that have been previously identified could be caused by high groundwater levels and/or groundwater breakout.

A third, future purpose might be to provide data for a groundwater modelling exercise. The groundwater monitoring was configured and conducted in a way that provides maximum usefulness in the event of future groundwater modelling, however this is not part of the current scope. Note however that the scope did not include determination of in-situ sand aquifer properties.

This report therefore addresses the first two of the above aims:

1. To assess the feasibility of more widespread use of soakage disposal of stormwater; and

2. To assess whether the flood-prone basins identified in the 2005 Catchment Management Plan[1] are due to surface accumulation, or whether they are due to groundwater mounding close to the surface.

[1] *Whangamata Stormwater Catchment Management Study – Updated Issues and Options Report*, Opus International Consultants Ltd, Draft V2, 28 September 2005

2 Background detail

The initial offer of service from Peter Ireland to Gary Deadman (TCDC) dated 21/1/2005 was to undertake groundwater level monitoring adjacent to depressions that incur the most flooding in order to establish the cause of ponding.

The scope was widened in an offer of service from Peter Ireland to Robert Paterson (TCDC) dated 8/9/2006. This noted that TCDC had identified groundwater bore sites rather than Opus. These were not necessarily in/adjacent to ponding depressions, and reflected the lack of suitable, safe, publicly-owned locations for long-term monitoring bores. TCDC determined the location of BH 1 but BH 2 and BH 3 locations were proposed by OPUS and agreed to by TCDC prior to drilling. Locations of BH 4 and 5 were proposed by TCDC and agreed upon by Opus.

3 Monitoring Bore Data

3.1 Bore Location

Groundwater monitoring bores were installed at the locations shown in Figure 1. Initially one bore was installed. Further bores were added in subsequent years as funding allowed.

Figure 1 Location of Monitoring Bores

Bore location was driven by the following factors:

- Obtaining data in areas where soil conditions and lack of stormwater infrastructure make it likely that soakage disposal will be applied
- Obtaining data in identified flood basins

- Obtaining a widely spaced dataset, representative of Whangamata generally, from which useful inferences can be made relating to specific areas of interest.
- The need to site bores in publicly-owned property (or private property with permission), clear of underground and overhead services.

3.2 Bore Installation Data

3.2.1 Bore 1

Bore 1 was drilled at 104 Winifred St on Monday the 16th October 2006. The location of the bore was chosen to reflect conditions close to the Whangamata central business area, where construction of one soakage device was underway, and others were envisaged. A pressure transducer/data-logger was installed in the bore and set to record groundwater levels at 15 minute intervals. Further details of bore installation are presented in Appendix A.

Figure 2 Groundwater monitoring bore BH 01 at 104 Winifred St

The bore-head was damaged by vehicle impact in November 2011. The data-logger was retrieved for safe-keeping, and the bore has not been reinstated at this stage.

3.2.2 Bores 2 and 3

These bores were installed on 13-14 August 2007 (refer Appendix A for details). Bore 2 was installed in the corner of the TCDC yard in Martyn Rd. Bore 3 was was drilled to the side of the car park at Williamson Golf Course, near Achilles Ave. Once again a combined pressure transducer/data-logger was installed in each bore, and set to read groundwater level every 15 minutes.

Figure 3 Groundwater monitoring bore BH 02, located in the TCDC Depot, Martyn Rd

Figure 4 Groundwater monitoring bore BH 03, located in the car park area at Williamson Golf Course, Achilles Ave

3.2.3 Bores 4 and 5

The final two bores were installed on 7-8 July 2008 (refer Appendix A for details). Bore 4 was drilled in a landscape bed along the road frontage outside the Whangamata Memorial Hall on Port Road. Bore 5 was drilled in an unformed road reserve, accessed from a right of way between Nos 219 and 221 Rangi Avenue. Once again a combined pressure transducer/data-logger was installed in each bore, and set to read groundwater level every 15 minutes.

Figure 5 Groundwater monitoring bore BH 04, located outside the Whangamata Memorial Hall on Port Road.

Figure 6 Groundwater monitoring bore BH 05 located on unformed road reserve between Nos 219 and 221 Rangi Avenue.

3.3 Bore Survey

The top level of the security standpipe of all five bores were surveyed in terms of Mean High Water Mark at the Whangamata Wharf (we were subsequently advised that this mark is 0.76 below Mean Sea Level).

We understand that survey datums in Whangamata have been subject to review over the period of the study; however no corresponding revision of groundwater levels has been made.

3.4 Data Download

All five bores were visited, checked and data downloaded approximately every three months.

4 Rainfall Data

Daily manual rain gauge data was obtained from the Whangamata Wastewater Treatment Plant on Tairua Road. It is approximately 2.5 km from the furthest groundwater monitoring bore site and is considered to be generally representative of Whangamata rainfall, being sufficiently accurate for the purposes of this study.

One significant discrepancy in the data has been identified for the month of September 2009 where there is a duplication of the August 2009 rainfall data. The correct rainfall data has not been obtained for such period hence is yet to be replaced in the Appendix B and C charts.

Historical rainfall records back to the year 1990 have also been obtained from the Golden Cross rain gauge – admittedly some 16km away and at a different elevation. It has been used to provide an indicative historical account of rainfall for the area as the WWTP rain gauge records have only been sourced back to the year 2004.

5 Method of analysis

To assess the feasibility of increased soakage disposal use, focus has been directed toward understanding any trends in maximum and minimum groundwater level depths and variability between such depths within and between each year of collected data. The trends, or lack of trends, are then used to inform the likely influence on soakage into ground from a typical soakage tank, which for the purposes of this report is assumed to have its bottom surface approximately 1.5m below ground surface.

To identify trends and variability a series of charts for each bore were produced, plotting depth to groundwater over time against underlying daily rainfall data. A typical example of a summary chart is shown as Figure 7; with summary charts for each bore included in Appendix B and Appendix C showing charts covering individual years.

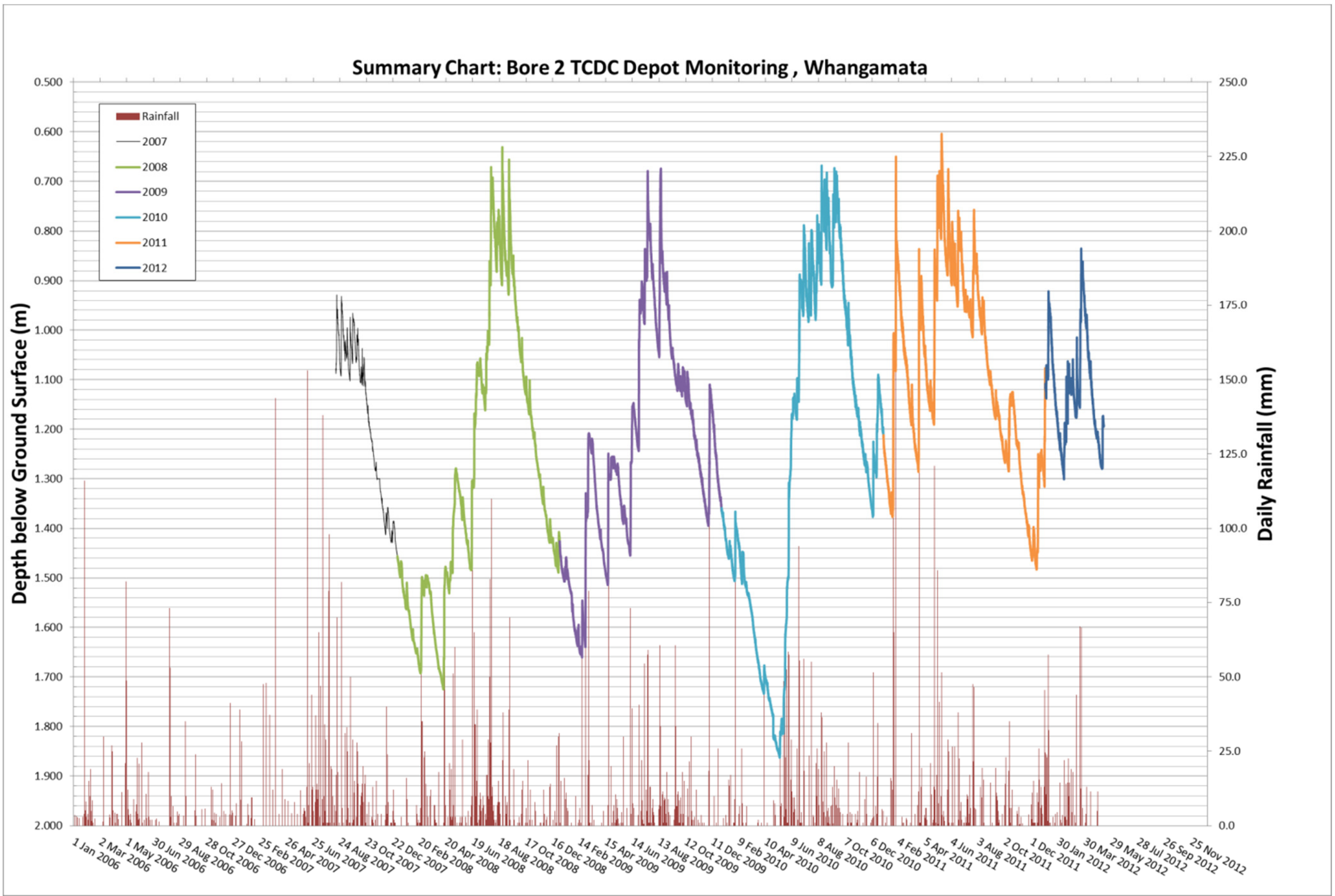

Figure 7: Typical summary chart showing all the groundwater level depths recorded by Bore 2 since its installation. Underlying daily rainfall records during this period are also shown.

At this stage the approach for identifying whether the flood-prone basins identified in the 2005 Catchment Management Plan[2] are due to groundwater mounding involves a simple check of the groundwater depths at each bore location. Zero or negative depth recordings from the bores will

[2] *Whangamata Stormwater Catchment Management Study – Updated Issues and Options Report*, Opus International Consultants Ltd, Draft V2, 28 September 2005

indicate that groundwater has breached the surface, causing ponding. Future analysis could include derivation of groundwater contours, which would give a rough indication of groundwater levels in areas more remote from the monitoring bores.

6 Results and Observations

6.1 Tabulated results and observation

Table 1 has been derived from inspection of the charts showing minimum and maximum depths to groundwater that have been maintained for at least a 4 hour period. Short duration spikes have been ignored, as they are expected to have little effect on stormwater soakage.

Table 1: Minimum, maximum, annual variation and average depths to groundwater that have been maintained for a period of at least 4 hours.

Year*	2007	2008	2009	2010	2011	Maximum variation between years.	Average of yearly min/max/variation	Clearance from soakage tank**
Bore 1								
Min depth to GW (m)	2.7	2.6	2.5	2.6	2.3	0.4	2.5	1.0
Max depth to GW (m)	3.7	3.5	3.5	3.7	3.5	0.2	3.6	2.1
Year Variation	1.0	0.9	1.0	1.1	1.2		1.1	
Bore 2								
Min depth to GW (m)	-	0.7	0.7	0.7	0.6	0.1	0.7	-0.8
Max depth to GW (m)	-	1.7	1.7	1.9	1.5	0.4	1.7	0.2
Year Variation	-	1.0	1.0	1.2	0.9		1.0	
Bore 3								
Min depth to GW (m)	-	1.9	2.2	1.8	1.7	0.5	1.9	0.4
Max depth to GW (m)	-	3.6	3.4	3.8	3.0	0.8	3.4	1.9
Year Variation	-	1.7	1.2	2.0	1.3		1.5	
Bore 4								
Min depth to GW (m)	-	-	3.3	3.2	2.9	0.3	3.1	1.6
Max depth to GW (m)	-	-	4.3	4.5	4.0	0.4	4.3	2.8
Year Variation	-	-	1.1	1.3	1.1		1.1	
Bore 5								
Min depth to GW (m)	-	-	1.3	1.3	1.1	0.3	1.2	-0.3
Max depth to GW (m)	-	-	2.5	2.8	2.3	0.4	2.5	1.0
Year Variation	-	-	1.2	1.5	1.3		1.3	

*Years 2006 and 2012 have not been included in this table as complete data sets for these years were unavailable.

** Clearance is from the bottom of an assumed typical soakage device, 1.5m below ground surface, down to the groundwater level.

The average yearly variation in minimum and maximum depths to groundwater for each of the bores ranges from 1.0 to 1.5 meters. The largest yearly variation at any bore has been at Bore 3 with a change in depth to groundwater of 2 meters in a yearly period.

From year to year the depth to groundwater maxima and minima in each bore vary relatively little (0.1 - 0.5 metres). An exception to this is Bore 3 which has 0.8m variation in the maximum depths, which is discussed in more detail in Section 6.2 below.

Bore 2 consistently has the smallest depth to groundwater, with 0.7m average minimum, which shows little variation year to year. Bore 2 has the lowest surface elevation and is the closest to the coast (in this case the estuary).

6.2 Seasonal Variations

The typical yearly variation of 1 to 1.5 metres follows a seasonal cycle. This seasonal cycle is clearly visible in Figure 7, with the greatest depths to groundwater experienced in late-summer, January to April, and the smallest depths to groundwater typically experienced in late winter, July to October.

All bore charts show an exception to this seasonal cycle in the summer of 2011 where depths to groundwater decreased to levels comparable to winter, due to a high January rainfall of 386mm. This is well above the January average of 170mm indicated by long-term rainfall data from the Golden Cross rain gauge, admittedly some 16km away.

The long-term Golden Cross gauge record also shows other above-average summer rainfalls, in the order of 400mm per month, during January, February and March 2003, February 2001 and March 1997. Such events could have also raised the summer groundwater levels in a similar way to that of January 2011, if not significantly more for the 2003 event. While the 2011 summer rainfall was unusual, it was certainly not exceptional, and can be reasonably expected to re-occur periodically; within a ten year period it would be deemed very likely.

It is also significant to note that as a result of the high summer water table in 2011, the subsequent winter levels were also the highest recorded.

6.3 Ponding

The records show the groundwater level has not reached the ground surface at any of the bore sites. No direct conclusions can be made in relation to other “basins” remote from the monitoring sites, however it appears unlikely that observed ponding in these areas is a result of groundwater mounding. It is likely that the ponding is surface accumulation rather than sub-surface break-out.

6.4 Potential Impact on Soakage Disposal

The Auckland Regional Council (ARC) TP10: *Stormwater management devices: Design guidelines manual,* second edition, May 2003 states that;

‘The invert of the infiltration practice should be at least one metre from the seasonal high water table, bedrock or relatively impermeable soil layer.’

The New Zealand Transport Agency (NZTA) is somewhat more conservative in its recommendations, stating in its ‘*Stormwater treatment standard for State Highway infrastructure,* May 2010’ that;

‘there should be at least 3 metres difference between the invert of the infiltration trench and the elevation of the seasonal groundwater table or bedrock.’

The two guidelines give an indication as to current best practice in New Zealand for soakage design for Auckland residential and national highway design respectively. Note that both guidelines are interested in stormwater treatment as well as disposal; hence the specified separation distance is intended to provide an unsaturated zone for treatment purposes in addition to the purely hydraulic functions associated with soakage.

Bore 2 consistently has the smallest depth to groundwater with annual minimum depths averaging 0.7m. Bores 5, 3, 1 and 4 follow, with 1.2m, 1.9m, 2.5m and 3.1m respectively.

For a generic soakage device, 1.5m below ground surface, Bores 2 and 5 indicate negative clearance distance would be experienced during their highest groundwater periods each year. The remaining Bores 3, 1 and 4 have average clearances of 0.4, 1.0 and 1.6m respectively with only Bore 4 consistently meeting the ARC design standard.

Having little or no clearance reduces the ability for stormwater to soak from the device into the ground. This increases the likelihood of groundwater mounding and surface breakout/flooding. Slower infiltration leads to more rapid filling of the device's storage volume, and once this is used up, surface ponding results. This may not be a significant issue if the duration of limited soakage is short and/or the storage volume large. Periods longer than one week may present more of an issue; however this is subjective, based on the community's willingness to accept ponding in their vicinity.

Table 2 is similar to Table 1 but presents yearly minimum groundwater depths that have been sustained for a duration of at least one week, as opposed to 4 hours.

Table 2: Minimum depths to groundwater that were sustained for a week long period.

Year*	2007	2008	2009	2010	2011	Maximum variation between year	Average of yearly minima	Clearance from soakage tank**
Bore 1	3.0	2.8	2.8	2.7	2.6	0.4	2.8	1.3
Bore 2	-	0.9	1.0	0.8	0.8	0.2	0.9	-0.6
Bore 3	-	2.0	2.3	2.0	1.9	0.4	2.1	0.6
Bore 4	-	3.2	3.4	3.1	3.1	0.3	3.2	1.7
Bore 5	-	1.4	1.6	1.4	1.4	0.2	1.4	-0.1

*Years 2006 and 2012 have not been included in this table as complete data sets for these years were unavailable.

** Clearance is from the bottom of an assumed typical soakage device, 1.5m below ground surface, down to the groundwater surface.

Again both Bores 2 and 5 display average minimum yearly depths to groundwater which have negative clearance for typical soakage devices. Clearances for the other three bores are low.

6.5 Response to Rainfall

An attempt has been made to derive an approximate relationship between individual rainfall events and the corresponding change in depth to groundwater. Daily rainfall was plotted against the associated change in depth, using only discrete events with no significant rainfall preceding. Small rainfalls, below 20mm per day, having no significant influence on groundwater levels were also ignored. This approach meant that only a small subset of the total data-set was used, however this subset is most relevant to soakage design, the rest arguably is not. Because of its limited size, its scientific robustness is limited; however our aim was only to obtain a preliminary, cost-effective indication of any relationship that may exist. More in-depth analysis will have to await another occasion.

The Bore 1 and Bore 2 examples are shown below in Figure 8 and Figure 9. Bores 1 and 2 show the lowest and highest R^2 values respectively of all the bore locations, which provides an indication of how strong the relationship of daily rainfall is to change in depth to groundwater. The remaining charts for the Bores 2, 3 and 4 are shown in Appendix E.

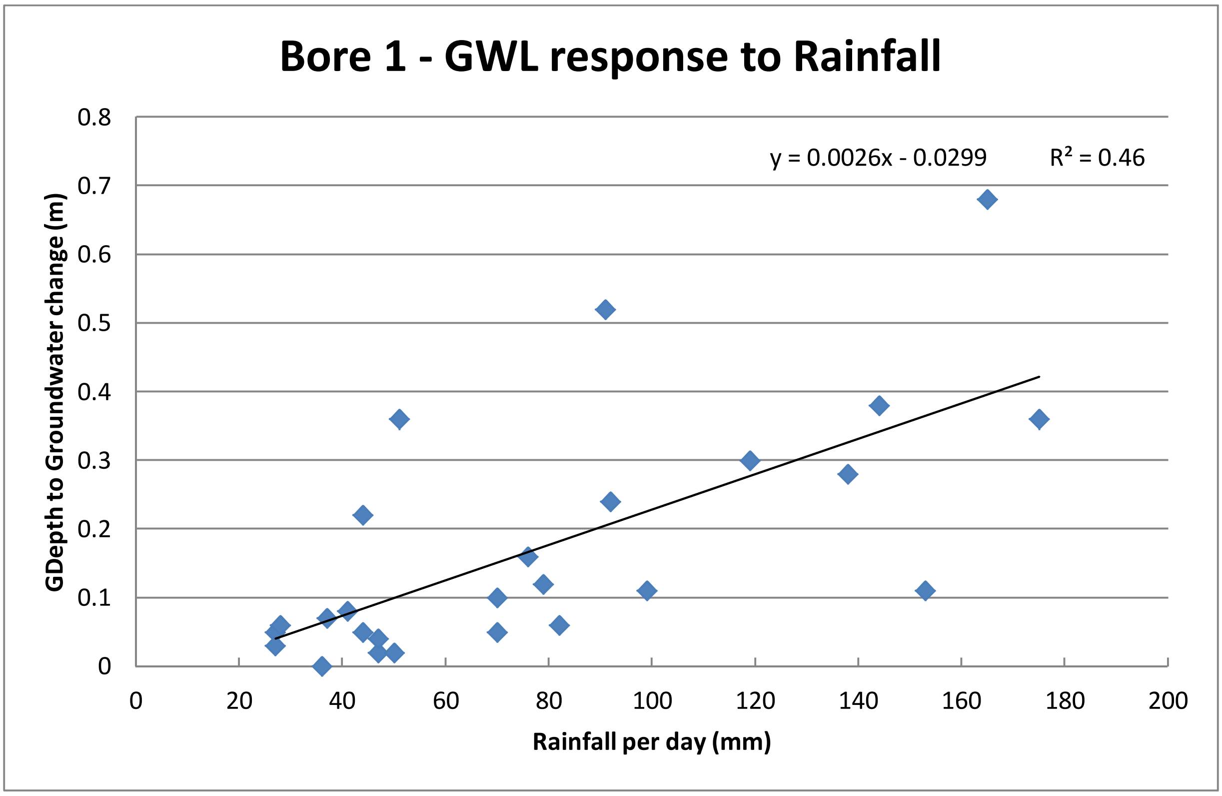

Figure 8: Bore 1 groundwater level relationship to daily rainfall.

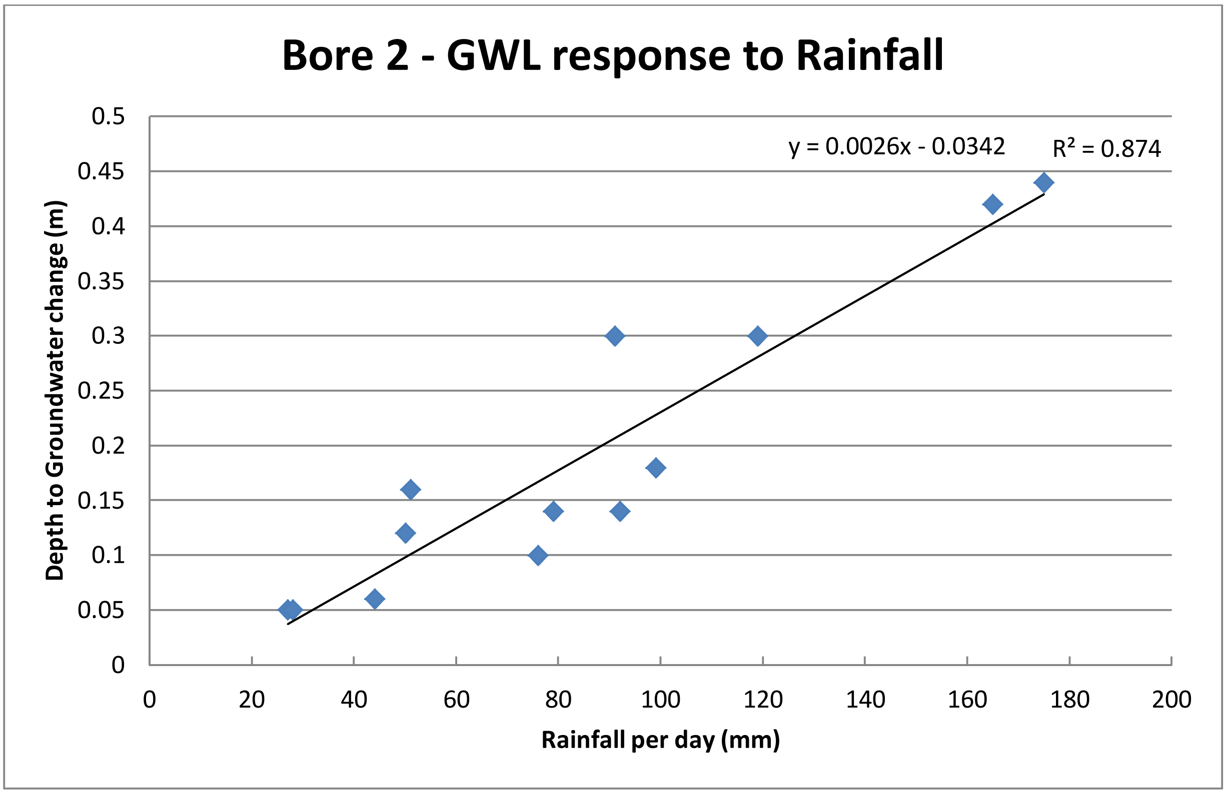

Figure 9: Bore 5 groundwater level relationship to daily rainfall.

The linear relationship equations from the above charts would suggest the following;

BORE	Example Daily Rainfall (mm)	Expected depth to GW change. (mm)	Example Daily Rainfall (mm)	Expected depth to GW change. (mm)
Bore 1	10	-4*	50	100
Bore 2	10	-8*	50	96

*The negative value indicates the line has dipped below zero on the y-axis, which suggests that 10mm rain per day at either of the bores would not be sufficient to change the groundwater level at either bore location, but instead the water levels would continue to lower as water drains through the soil layers.

Bore 1 and 2 have R^2 values of 0.46 and 0.874 respectively. Although having very similar trend line equations Bore 1, which has the larger dataset, has a lower R^2 value which means there is less confidence in the relationship between rainfall and depth to groundwater.

It may be found with more data and analysis that the R^2 value for other bores may diminish also.

Limitations to the charts are;

- The rainfall data used is a daily rainfall. There is no way to distinguish between rainfall that fell in short period of time for a given day, i.e. one or two hours as opposed to falling consistently throughout the entire 24 hour period.

- There is no clear distinction between rainfall events and corresponding effects on depth to groundwater for wet periods and dry periods (e.g. summer vs winter), however this could be further investigated within the available data.

- Typically, each of the rainfall events selected are events that had no significant rainfall within 1-7 days beforehand (note this was done by eye, looking at the charts). Therefore, it is unclear from our analysis whether a rainfall event with little preceding rainfall would influence the groundwater level at a given bore site to the same degree as one that did have significant antecedent rainfall.

Regression curves could be fitted to the data to look at the rate at which groundwater is expected to drain away after a given rainfall event. This could be looked into with the available data, but has not been undertaken for this study.

Other simpler observations can be made based on the data and charts. Some snapshots of the charts have been captured and displayed below to show these.

1) The maximum effect an individual rain event had on the depth to groundwater at each bore varied. No single rainfall event changed the depth to ground water by more than 0.68m in any bore.

BORE	Maximum rise from an individual event	Daily Rainfall mm	ARI (Based on daily rainfall)	Date
Bore 1	0.68 m	165	<1.58	28 Jan 2011
Bore 2*	0.44 m	175	<1.58	22 Mar 2011
Bore 3	0.50 m	165	<1.58	28 Jan 2011
Bore 4	0.41 m	165	<1.58	28 Jan 2011
Bore 5	0.50 m	165	<1.58	28 Jan 2011

*Bore 2 had a 28th Jan 2011 increase of 0.42 m, just below its 0.44 m increase on the 22nd Mar 2011.

2) Not all rain events increase groundwater level significantly. Days with 20mm of rainfall or less rarely of themselves change depth to groundwater by more than 50mm with examples shown in Figures 10 and 11 below.

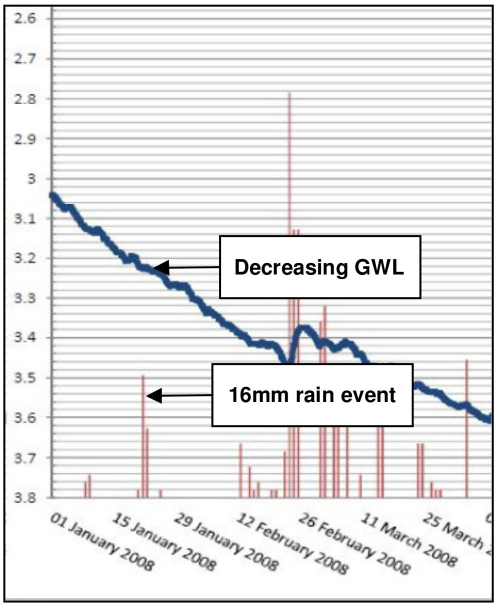

Figure 10: 16mm rainfall event not altering depth to GW in 2008 at Bore 3.

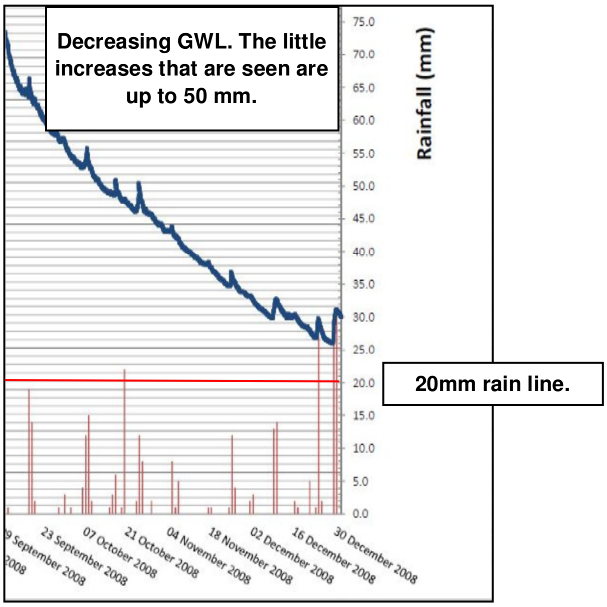

Figure 11: 20mm rainfall and below not altering depth to GW more than 50mm in 2008 at Bore 2. Each black horizontal line represents 20mm in groundwater depth.

3) The main driver for sustained high ground water levels is lots of rainfall events, whether small or large, day after day as opposed to single intense rainfall events on their own as shown in Figure 12, the Bore 2 summary chart.

For all bores, the June to September 2010 rainfall events created the largest positive increase in groundwater level. For Bore 2 such groundwater levels were consistently maintained within a 25 cm range for approximately 4 months (highlighted by Circle 1 in Figure 12). The greatest single one-day rainfall during this period was 94mm, which was only a small part of the 760mm total rainfall over the period. The regularity, not intensity, of the rainfall resulted in the large and sustained increase.

The peak groundwater level highlighted by Circle 2 was influenced by two events occurring in a short period of time with measurements approximately 100 mm and 170mm respectively. While the increase in groundwater level is significant, the corresponding time sustained does not compare with the Circle 1 period which contained significantly smaller, but more, daily rainfall events.

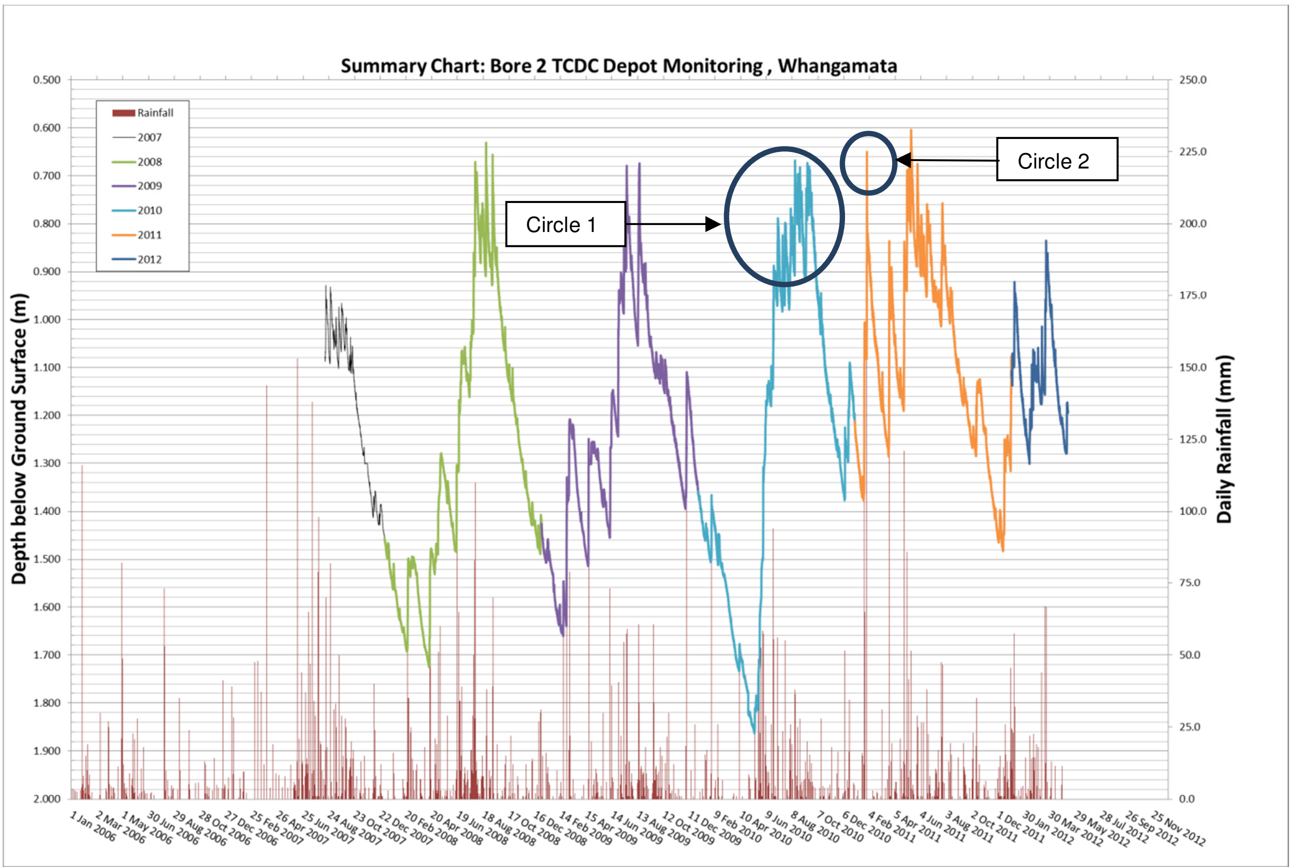

Figure 12: An example of a large increase in groundwater level, sustained over 4 months.

4) Rain events of the same size do not equally affect the groundwater level each time.

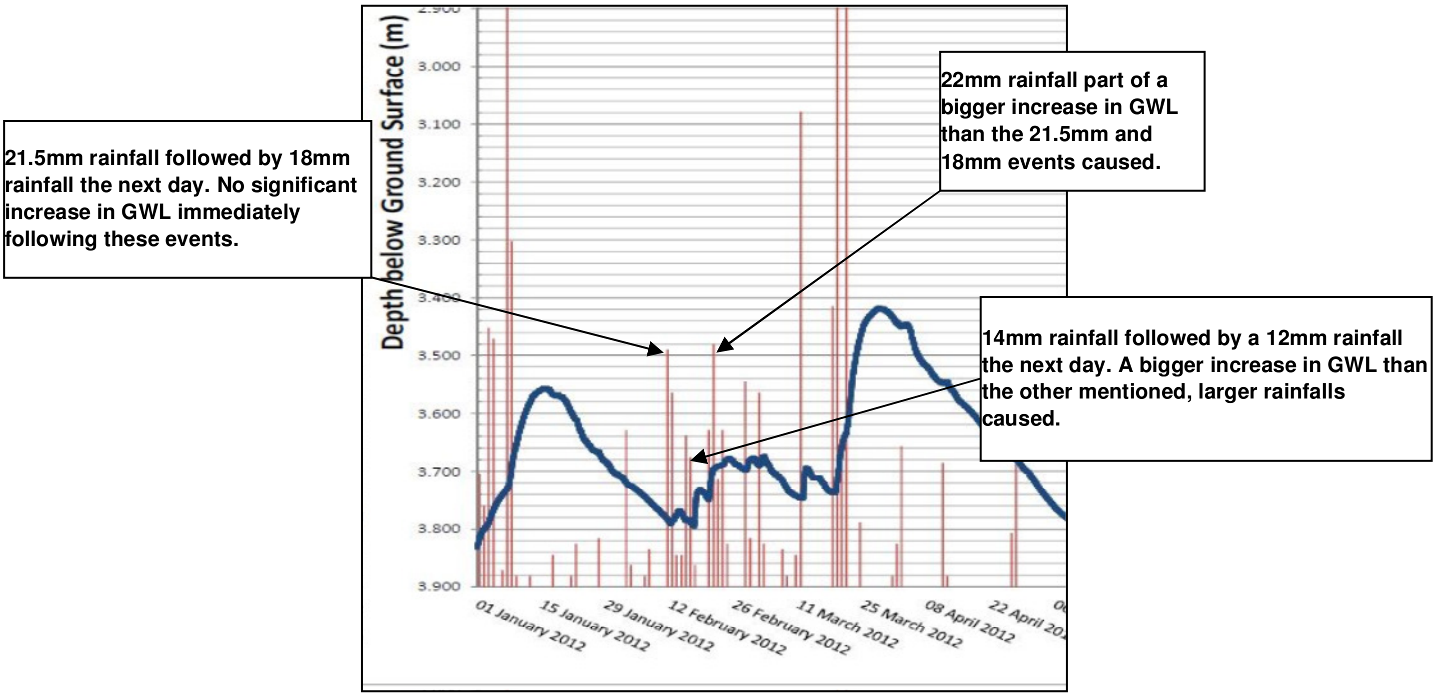

Figure 13: Bore 4 example of similar rain events not affecting GWL equally.

5) Large rainfall events can occur in winter when groundwater levels are already high, thus raising them further. However these "spikes" are generally of relatively short duration, and groundwater typically returns close to its seasonal norm after a short period. Refer to years 2008, 2009 and 2011 in Figure 12 above.

As previously mentioned, regression curves could be fitted to the data to look at the rate at which groundwater is expected to drain away after a given rainfall event. This could be looked into with the available data, but has not been for this study.

6.6 Tidal Influence

In a relatively low-lying area like Whangamata it is natural to question whether groundwater levels are significantly influenced by tide levels. Accordingly we investigated the 15 minute GWL data on non-rain days at the TCDC Depot, Bore 2 location, over two 24 hour periods, looking for any hint of the classic sinuoidal tide-cycle pattern. Bore 2 has the lowest ground elevation and closest proximity to the tidal area.

Minor daily changes were observed, generally no more than 25mm, however these did not follow any regular cyclical pattern. We consider these are more likely to be attributable to other causes, such as changes in atmospheric pressure.

We concluded that there is no discernible tidal influence at any of the monitoring sites. None of the minor perturbations observed are of engineering significance.

7 Implications for Whangamata Generally

There is no doubt that much of Whangamata is underlain by sandy soils that can in general provide excellent stormwater soakage. However the findings of this study indicate that winter groundwater levels can rise to a level where the function of a conventional soakage device could be impaired. Careful design and detailing of soakage devices will be required, including measures to keep the device shallow and maximise storage volume.

For much of Whangamata domestic soak-holes designed in accordance with standard procedures (e.g NZ Building Code, E1/VM1) are likely to be satisfactory most of the time, however due consideration should be given to the fact that the winter groundwater table is too high for successful soakage in some areas, and will cause reduced performance in many others. We recommend that TCDC commissions a specific study to develop suitable soakhole design standards for general application at single dwelling sites.

With respect to higher-intensity land-uses, such as commercial, industrial and apartments, and for communal/roading applications, we recommend that specific design is undertaken in all cases. This should include consideration of winter GWLs – as a minimum using the observations contained in this report, but preferably involving winter GWL measurements at the site itself.

8 Potential Future Initiatives

A map of Whangamata winter groundwater contours would be extremely valuable when it comes to assessing future soakage proposals, etc. However, with depth to groundwater measurements available at only five locations, an assessment based on the current data would obviously be rather coarse (and possibly even erroneous). The quality of groundwater mapping could be improved significantly by augmenting the existing long-term data with a number of instantaneous readings. For example, another dozen or so groundwater readings could be taken in mid-winter from temporary bores drilled for the purpose. (Hand-augurs will not be appropriate in the loose, sandy soils, and an alternative technique will be required.) Groundwater depths could then be read, and the bore-heads surveyed in a follow-up visit the next day. Data from these temporary bores could then be normalised against seasonal data from the long-term monitoring bores.

While we understand that Council has no immediate plans for constructing a groundwater model, the existing bore installations represent a significant investment, and for a very minor ongoing investment could yield a valuable and high quality groundwater record. Ongoing costs could be reduced by setting the data-loggers to take one reading every 6 hours, so that data downloads could be extended to six-monthly or yearly. (Less frequent downloads must be balanced against the risk of battery failure and consequent loss of data.)

Accordingly, we recommend that at least one bore is retained operational long-term. The main cost will be periodic attendance by personnel from Council or Opus to download data to a laptop computer, together with modest “house-keeping” (e.g. weedspraying) and occasional battery replacement.

Since the marginal cost of attending to the remaining four bores is small, we recommend that all five bores are retained in operation. This will provide additional data for negligible cost, and also provide insurance against data loss or damage to any single installation.

The Winifred Ave bore should be reinstated if it is practicable to do so (i.e. without the need for re-drilling).

We also recommend that standardised soakage design criteria are developed for individual dwellings, taking account of the observations contained in this study.

Furthermore, there is more potential value that could be obtained from the existing data, including:

- The determination of groundwater in terms of reduced levels (m RL) rather than depths. This will provide the opportunity to develop simple comparisons of groundwater between each bore location.

- Regression curves, evaluating the rate of groundwater level decrease after rain events.

9 Recommendations

1. That at least one, but preferably all five, monitoring bores are retained in operation to provide useful data for longer-term studies.

2. That the Winifred Ave bore be repaired and reinstated, if practicable.

3. That a selection of temporary ground-water bores are installed to provide a “snapshot” of winter groundwater levels across a wider area.

4. That TCDC develop suitable soakhole design standards for general application at individual dwelling sites.

5. That all other soakage disposal in Whangamata be subject to specific design by a competent practitioner.

Appendix A. Installation Details

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TO	Warren Bird
COPY	Greer Lees
FROM	Roger High
DATE	20 October 2006
FILE	2-67866.79
SUBJECT	**Whangamata Groundwater Monitoring Bore**

This bore was drilled at 104 Winifred St on Monday the 16th October 2006. The location of the bore was approved by Robert Paterson (TCDC Project Manager) prior to set up (Photo 1).

The bore was drilled using a hollow stem auger, as this method does not require the addition of drilling water and soil samples can be obtained from inside the hollow stem using the sampler shown on the following photo.

Hollow stem auger assembly	Cutter bit and sampling tube fit inside stem

Augering down to 3m encountered no problems, with clean fine to medium grained coastal sand returning to the ground surface via the flights. Once the groundwater level was penetrated below 3m a number of difficulties were experienced. There was no return of soils, other than the sands above the water level, and upon removing the cutter bit to obtain a sample the sandy soil flowed up the hollow rods for a least 1m above the end of the auger tip. Some of this material between 3m and 4.1m consisted of a grey muddy fine sand ie distinctly different to the clean overlying sand. Augering continued down to 7.5m, with several attempts made to obtain samples proving to be unsuccessful.

The screen assembly was then installed through the rods, but the placement took several efforts because the assembly rose as the auger rods were lifted. The installed screen assembly and backfill is as follows:

Depth	Screen details	Depth	Backfill details
-0.51 to 3.0	Unslotted 50mm	0.0 – 0.3	Concrete
3.0 to 6.0	Slotted 50mm + filter sock	0.3 – 2.0	Hydrated bentonite pellets
6.0 to 7.0	Unslotted 50mm + end cap	2.0 – 2.5	Blasting Sand
		2.5 – 3.2	Moist medium sand from hole
		3.2 – 7.5	Sand? collapsed against and beneath screen

The piezometer was lightly developed using compressed air. This was completed by 1530 hrs. A square steel casing was concreted into the ground over the piezometer. The lid of the casing is 95mm above the top of the piezometer and 605mm above the average ground surface adjacent to the bore.

A LevelTROLL 500 vented water level logger was installed into the bore to a depth of 5.468m below the top of the piezometer tube (4.863m below average ground level). At the time of installation (1720hr on 16/10/2006) the depth to groundwater was 3.985 below the top of the piezometer tube (3.380m below average ground level). The logger is set to measure the height of water above the tip of the logger at 15 minute intervals. At the time of installation the height of water above the tip of the logger was 1.483m, however the first reading was not programmed until 1800 hrs on the 16/10/2006.

Comment: The piezometer installation was eventually successfully completed, however the lack of soil samples below the groundwater level was disappointing. This information is required if the project expands into a groundwater modelling exercise. Discussions with Boart Longyear indicate that the best method of obtaining soils information and installing a piezometer may be to drill a larger diameter PQ hole (without muds), which will permit installation of the 50mm tube through the PQ barrel. The hollow stem auger method is suited to loose sands at or above the groundwater level, but when the sands run below the water level, the PQ method may be better.

R High.

Roger High
Engineering Geologist

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16 August 2007

Mr Robert Paterson
Project Engineer Service Delivery
Thames Coromandel District Council
Private Bag
Thames

2-67866.79 - 501AC

Dear Robert

Whangamata Groundwater Monitoring Bores

This letter is a brief account of the installation of the second and third groundwater monitoring bores at Whangamata.

Bore 02

This bore was drilled at the TCDC Depot on the 13th August 2007 (Photo 1). A PQ cored hole was drilled first to obtain as much core as possible in the depth interval where the well screen assembly was subsequently installed. The PQ rods were then removed from the hole and the collapsed hole then re-drilled using a PQ casing advancer. The 50mm diameter well screen assembly and gravel pack was then successfully installed within the PQ rods, which were then removed from the hole and the security standpipe concreted into the ground. A timber bollard was also installed near the bore in order to provide some protection from vehicle impact.

The materials encountered in the bore are as follows (Photos 2 and 3):

0m to 0.35m	Mixed Fill: clayey sand – bound AP20 aggregate; gravely sandy clay; clean 6mm chip
0.35 to 1.5m	dark brown becoming brown fine to medium sand, irony, trace silt
1.5m to 6.2m	light grayish brown fine to medium sand, quartzofeldspathic, loose; increase in black mafic grains 2.1m to 2.5m; 15mm x 10mm x 8mm pumice clast at 5.5m
6.2m to 6.3m	light grayish brown fine sand, silty, medium dense, nearly plastic on remould
6.3m to 7.7m	light grayish brown fine to medium sand; coarse 40mm shelly sand lens at 6.3m; trace broken shells below 6.8m
7.7m to 8.2m	gray fine sand, slightly silty, some broken shells

The well screen assembly is as follows (+ve number is below ground):

-0.680m to 0m	Security standpipe
-0.475m to 2m	Unslotted 50mm PVC pipe with end socket
2m to 8.11m	Slotted 50mm PVC pipe with filter sock and 0.11m long end cap

The well screen backfill is as follows:

0m to 0.3m	Concrete pad

0.3m to 1.5m	Hydrated bentonite pellets
1.5m to 1.8m	Blinding sand
1.8m to 8.1m	Walton Park 7/14 grade filter sand (2mm)

The details of the water level monitoring logger are as follows:

LevelTROLL 500 (11m) set at 6.504m below top of 50mm pipe and socket ≡ 6.029m below concrete pad; ≡ 4.954m below groundwater level measured at 1300 hrs on 14th August 2007. The TROLL will determine the water level every 15 minutes.

Bore 03

This bore was drilled at the side of the car park at Williamson Golf Course, near Achilles Ave, on the 14th August 2007 (Photo 4). A PQ cored hole was drilled first to obtain as much core as possible in the depth interval where the well screen assembly was subsequently installed. The PQ rods were then removed from the hole and the collapsed hole then re-drilled using a PQ casing advancer. The 50mm diameter well screen assembly and gravel pack was then successfully installed within the PQ rods, which were then removed from the hole and the security standpipe concreted into the ground.

The materials encountered in the bore are as follows (Photos 5 and 6):

0m to 0.4m	turf, dark grayish brown, clayey fine to medium sand, slightly plastic on remould
0.4m to 1.5m	dark brown becoming brown fine to medium sand, loose, slightly irony
1.5m to 3.75m	light grayish brown becoming brownish gray, fine to medium sand, quartzofeldspathic, structureless, loose
3.75 to 5.25m	grayish brown fine to medium sand, loose; 20mm thick lens of yellowish brown sandy silt at 4.35m; three 5mm to 8mm thick yellowish brown medium to coarse sand layers at 4.7m
5.25m to 8.2m	light brownish gray medium sand, medium dense, some / minor broken shells; silty matrix between 5.5-5.8m and 7.4-7.5m

The well screen assembly is as follows (+ve number is below ground):

-0.712m to 0m	Security standpipe
-0.526m to 1.7m	Unslotted 50mm PVC pipe with end socket
1.7m to 7.81m	Slotted 50mm PVC pipe with filter sock and 0.11m long end cap

The well screen backfill is as follows:

0m to 0.3m	Concrete pad
0.3m to 1.5m	Hydrated bentonite pellets
1.5m to 1.8m	Blinding sand
1.8m to 7.81m	Walton Park 7/14 grade filter sand (2mm)
7.81m to 8.2m	Collapsed natural sand

The details of the water level monitoring logger are as follows:

LevelTROLL 500 (11m) set at 6.44m below top of 50mm pipe and socket ≡ 5.914m below concrete pad; ≡ 3.40m below groundwater level measured at 1400 hrs on 14th August 2007. The water level will be determined every 15 minutes.

Survey

RMS Surveyors determined the top of the security standpipe at BH 01 at Winifred St, in terms of Mean High Water Mark at the Whangamata Wharf (we were subsequently advised that this mark is 0.76 below Mean Sea Level). The top of the standpipes at BH 02 and BH 03 should be determined to the same mark, in order to determine the RL of the groundwater level and assess other flow properties.

Niel Smith in his email to you on the 5th June 2007 advised that the piezometers were to be surveyed. I will instruct him to proceed. I understand that you are presently re-assessing survey datums at Whangamata, and that a correction to groundwater RL measured in the three bores may be required at a later date.

Yours faithfully,

Roger High
Senior Engineering Geologist
Associate

Cc Warren Bird (Opus Project Manager, Auckland)
Niel Smith (Opus Temporary Utilities Engineer, Thames)
Natalie Pullyn (Opus Engineering Cadet, Paeroa)

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Photo 1: Groundwater monitoring bore BH 02, located in the TCDC Depot

Photo 2: BH 02 PQ core from 0m to 6m depth

Photo 3: BH 02 PQ core from 6m to 8.2m depth

	**Photo 4:** Groundwater monitoring bore BH 03, located in the car park area at Williamson Golf Course, Achilles Ave.
	**Photo 5:** BH 03 PQ core from 0m to 3.75m depth
	**Photo 6:** BH 02 PQ core from 3.75m to 7.5m depth. No core recovery from 7.5m to 8.2m

14 July 2008

Mr Robert Paterson
Project Engineer Service Delivery
Thames Coromandel District Council
Private Bag
Thames

2-67866.79 - 501AC

Dear Robert

Whangamata Groundwater Monitoring Bore Nos 4 and 5 – Installation Details

This letter is a brief account of the installation of the fourth and fifth groundwater monitoring bores at Whangamata.

Bore 04

This bore was drilled outside the Whangamata Memorial Hall on Port Road on the 7th July 2008 (Photo 1). A 1.5m deep, 100mm diameter hand auger was drilled first to ensure that there were no Telecom cables beneath the flower garden adjacent to the footpath. Then a PQ cored hole was drilled first to obtain as much core as possible in the depth interval where the well screen assembly was subsequently installed. The PQ rods were then removed from the hole and the collapsed hole then re-drilled using a PQ casing advancer. The 50mm diameter well screen assembly and gravel pack was then successfully installed through the PQ rods, which were then removed from the hole and the security standpipe concreted into the ground.

The materials encountered in the bore are as follows (Photos 2 and 3):

0m to 0.2m	Topsoil
0.2m to 0.6m	Mixed Fill: road chip and dark grayish brown fine sand
0.6m to 1.0m	dark grayish brown fine sand, slightly organic
1.0m to 1.5m	dark yellowish brown (10YR 6/3) fine to medium sand, irony.
1.5m to 2.25m	pale brown (10YR 6/3) becoming light brownish gray (10YR 6/2) fine to medium sand, quartzofeldspathic, loose.
2.25m to 4.0m	light brownish gray (10YR 6/2) fine to medium sand, medium dense, trace grey rock gravel (3mm to 8mm diameter) from 3.10 to 3.15m
4.0m to 6.9m	light gray (7.5YR 7/1) fine to medium sand, some indistinct dark grey mafic – rich bands, trace of shell particles (<3mm) below 5.25m.
6.9m to 8.5m	pinkish gray (5YR 7/2) medium sand, shelly. Some shell hash layers up to 150mm thickness.

The percentage of core recovered is as follows:

0m – 1.5m	100% (hand auger, then over-drilled with PQ)
1.5m – 2.25m	87%
2.25m – 3.0m	73%
3.0m – 3.75m	66%
3.75m – 4.5m	47%

4.5m – 5.25m	33%
5.25m – 6.0m	0%
6.0m – 7.0m	90%
7.0m – 8.5m	73%

The well screen assembly is as follows (+ve number is below top of 85mm high kerb around car park):

-0.660m to 0m	Security standpipe
-0.487m to 5.2m	Unslotted 50mm PVC pipe
5.2m to 8.21m	Slotted 50mm PVC pipe with filter sock and 0.11m long end cap

The well screen backfill is as follows:

0m to 0.3m	Concrete pad
0.3m to 4.6m	Hydrated bentonite pellets
4.6m to 4.9m	Blinding sand
4.9m to 8.3m	Walton Park 7/14 grade filter sand (2mm)
8.3m to 8.5m	Collapsed natural sand

The details of the water level monitoring logger are as follows:

LevelTROLL 500 (11m) set at 6.681m below top of 50mm pipe and socket ≡ 6.194m below top of kerb; ≡ 2.374m below groundwater level measured at 1400 hrs on 8th July 2008. The TROLL will determine the water level every 15 minutes.

Bore 05

This bore was drilled in an unformed road reserve, accessed from a right of way between Nos 219 and 221 Rangi Avenue, on the 8th July 2008 (Photo 4). A 1.5m deep, 100mm diameter hand auger was drilled first to ensure that there were no Telecom cables beneath the drill site and that the trench for the adjacent 1.6m deep stormwater pipe did not extend to the drill site. Then a PQ cored hole was drilled first to obtain as much core as possible in the depth interval where the well screen assembly was subsequently installed. The PQ rods were then removed from the hole and the collapsed hole then re-drilled using a PQ casing advancer. The 50mm diameter well screen assembly and gravel pack was then successfully installed through the PQ rods, which were then removed from the hole and the security standpipe concreted into the ground.

The materials encountered in the bore are as follows (Photos 5 and 6):

0m to 0.15m	Topsoil
0.15m to 1.5m	light brownish gray (10YR 6/2) fine to slightly medium sand,
1.5m to 5.2m	light gray / gray (10YR 6/1) fine to medium sand, trace of shell particles (2mm diameter) from 2m, 20mm layer of slightly silty fine sand at about 5.0m.
5.2m to 6.0m	light brownish gray (10YR 6/2) medium to slightly coarse sand, shelly.
6.0m to 7.3m	light brownish gray (10YR 6/2) medium to coarse sand, very shelly, some whole bivalve shells (50mm x 25mm) and gastropod shells.
7.3m – 7.5m	light brownish gray fine to medium sand, with some 20mm to 40mm thick bands of slightly silty fine sand
7.5m to 8.5m	gray (2.5YR 5/1) fine sand, trace shell, dilatant, some decayed vegetation at 8.45m depth.

The percentage of core recovered is as follows:

0m – 1.5m	100% (hand auger, then over-drilled with PQ)
1.5m – 3.0m	43%
3.0m – 4.5m	43%
4.5m – 5.5m	35%
5.5m – 7.0m	60%
7.0m – 7.5m	100%
7.5m – 8.5m	85%

The well screen assembly is as follows (+ve number is below ground – assumed to be 40mm above top of concrete pad):

-0.743m to 0.040m	Security standpipe
-0.568m to 4.3m	Unslotted 50mm PVC pipe
4.3m to 7.3m	Slotted 50mm PVC pipe with filter sock and 0.11m long end cap

The well screen backfill is as follows:

0m to 0.3m	Concrete pad
0.3m to 3.6m	Hydrated bentonite pellets
3.6m to 4.0m	Blinding sand
4.0m to 7.5m	Walton Park 7/14 grade filter sand (2mm)
7.5m to 8.0m	Mixed Walton Park and collapsed natural sand.
8.0m to 8.5m	Collapsed natural sand

The details of the water level monitoring logger are as follows:

LevelTROLL 500 (11m) set at 6.107m below top of 50mm pipe and socket ≡ 5.539m below ground; ≡ 3.683m below groundwater level measured at 1342 hrs on 8th August 2008. The water level will be determined every 15 minutes.

Survey

The top of the standpipes at BH 04 and BH 05 will be levelled in terms of the same Mean Sea Level Datum used by RMS Surveyors for Bores 1 to 3 (assumed to be 0.76m below Mean High Water Mark at the Whangamata Wharf). Opus surveyors will determine these levels shortly.

Yours faithfully,

Roger High
Principal - Engineering Geology

Cc Warren Bird (Opus Project Manager, Auckland)
Peter Ireland (Opus Utilities Project Manager, Thames)
Bradley West (Opus Engineer, Paeroa)

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Photo 1:

Groundwater monitoring bore BH 04, located outside the Whangamata Memorial Hall on Port Road.

Photo 2:

BH 04 PQ core from 0m to 3.75m. Note that the first run from 0m to 1.5m is materials over-cored from the 100mm diameter hand auger hole.

Photo 3:

BH 04 PQ core from 3.75m to 8.50m depth.

Photo 4:

Groundwater monitoring bore BH 05 located on unformed road reserve between Nos 219 and 221 Rangi Avenue.

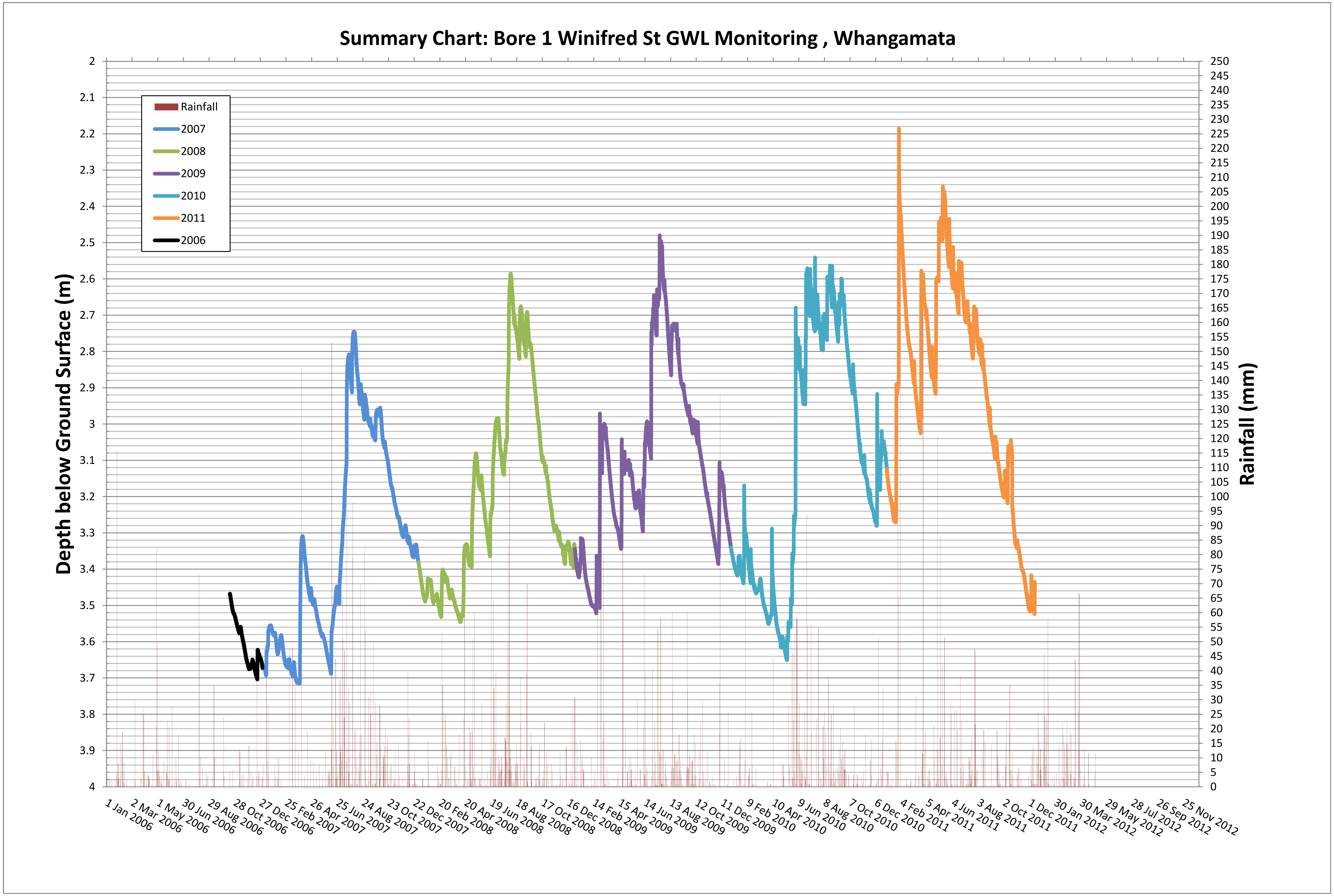
Photo 5:

BH 05 PQ core between 0m and 5.5m depth. Note that the first run from 0m to 1.5m is materials over-cored from the 100mm diameter hand auger hole.

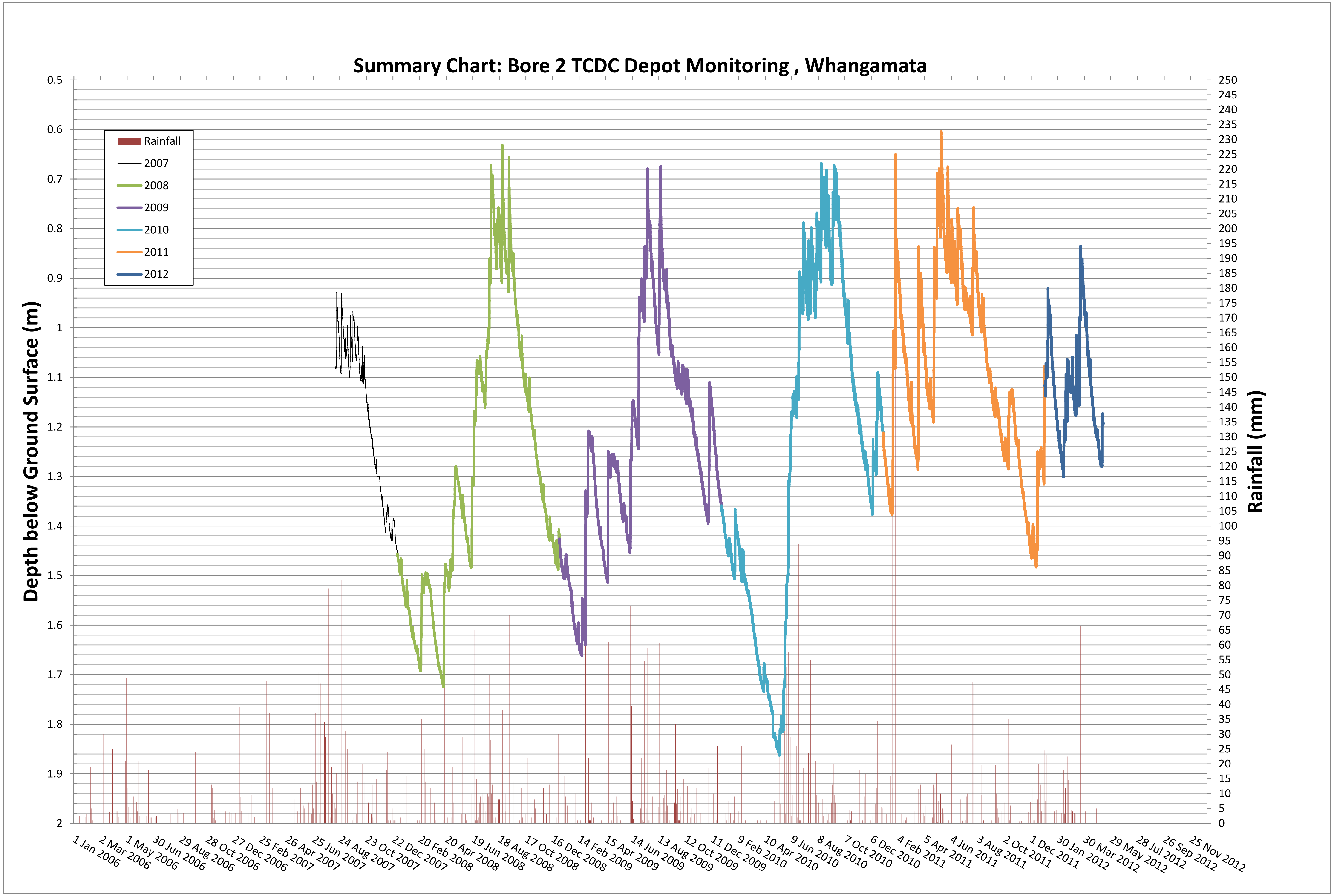
Photo 6:

BH 05 PQ core between 5.5m and 8.5m depth.

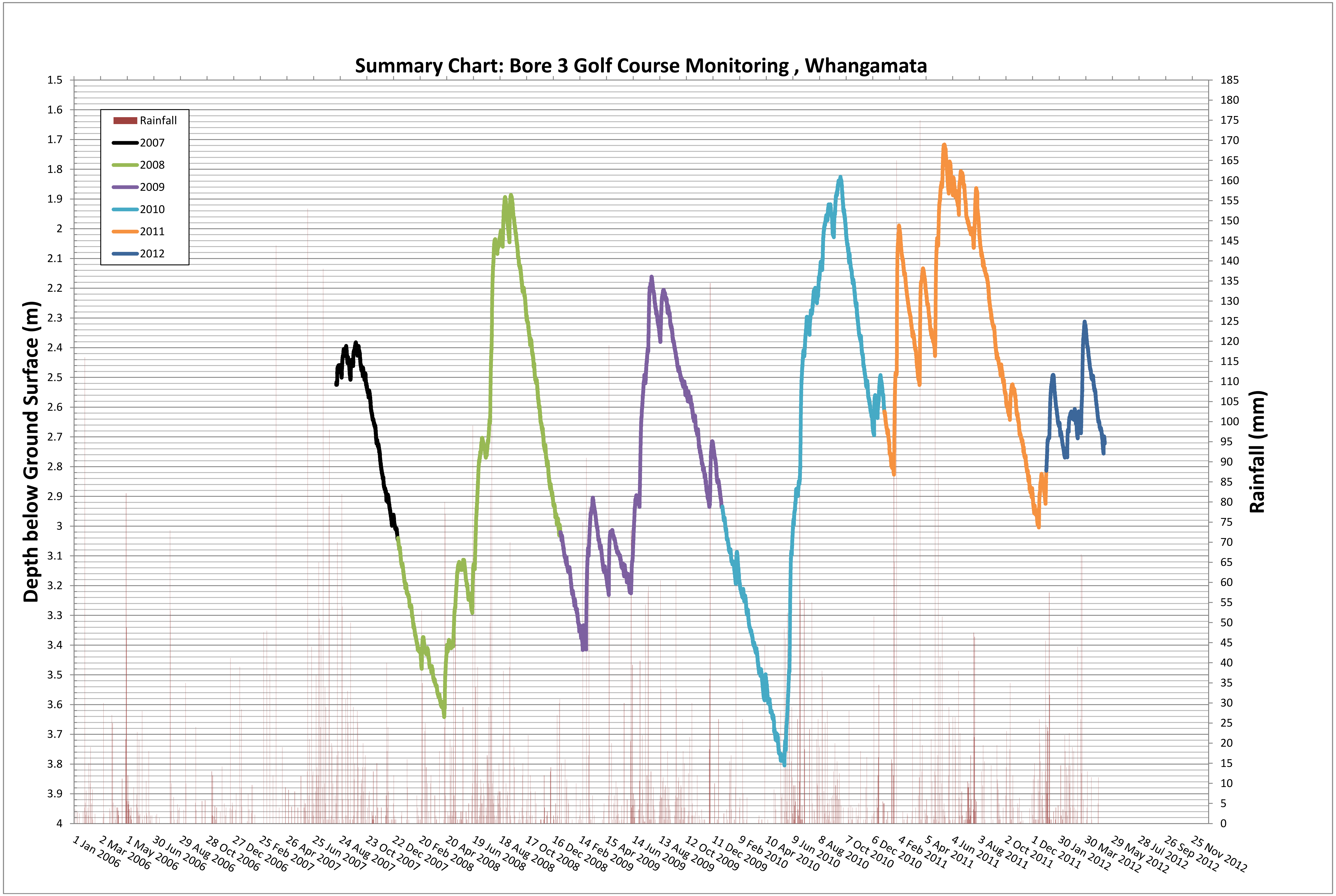
Appendix B. Summary Charts



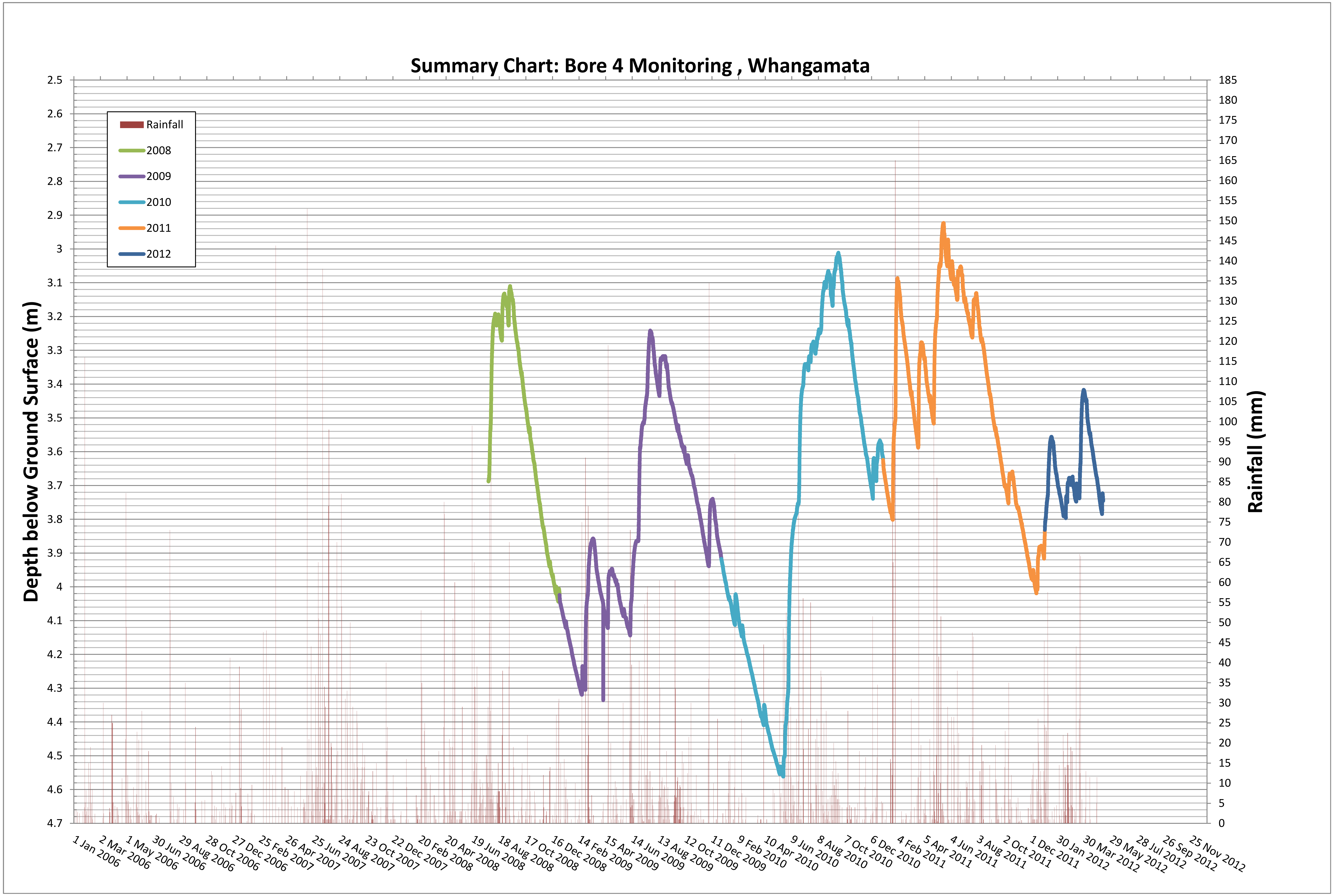
Summary Chart: Bore 1 Winifred St GWL Monitoring , Whangamata
Depth below Ground Surface (m)
Rainfall (mm)
Rainfall
2007
2008
2009
2010
2011
2006
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4
250
245
240
235
230
225
220
215
210
205
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1 Jan 2006
2 Mar 2006
1 May 2006
30 Jun 2006
29 Aug 2006
28 Oct 2006
27 Dec 2006
25 Feb 2007
26 Apr 2007
25 Jun 2007
24 Aug 2007
23 Oct 2007
22 Dec 2007
20 Feb 2008
20 Apr 2008
19 Jun 2008
18 Aug 2008
17 Oct 2008
16 Dec 2008
14 Feb 2009
15 Apr 2009
14 Jun 2009
13 Aug 2009
12 Oct 2009
11 Dec 2009
9 Feb 2010
10 Apr 2010
9 Jun 2010
8 Aug 2010
7 Oct 2010
6 Dec 2010
4 Feb 2011
5 Apr 2011
4 Jun 2011
3 Aug 2011
2 Oct 2011
1 Dec 2011
30 Jan 2012
30 Mar 2012
29 May 2012
28 Jul 2012
26 Sep 2012
25 Nov 2012



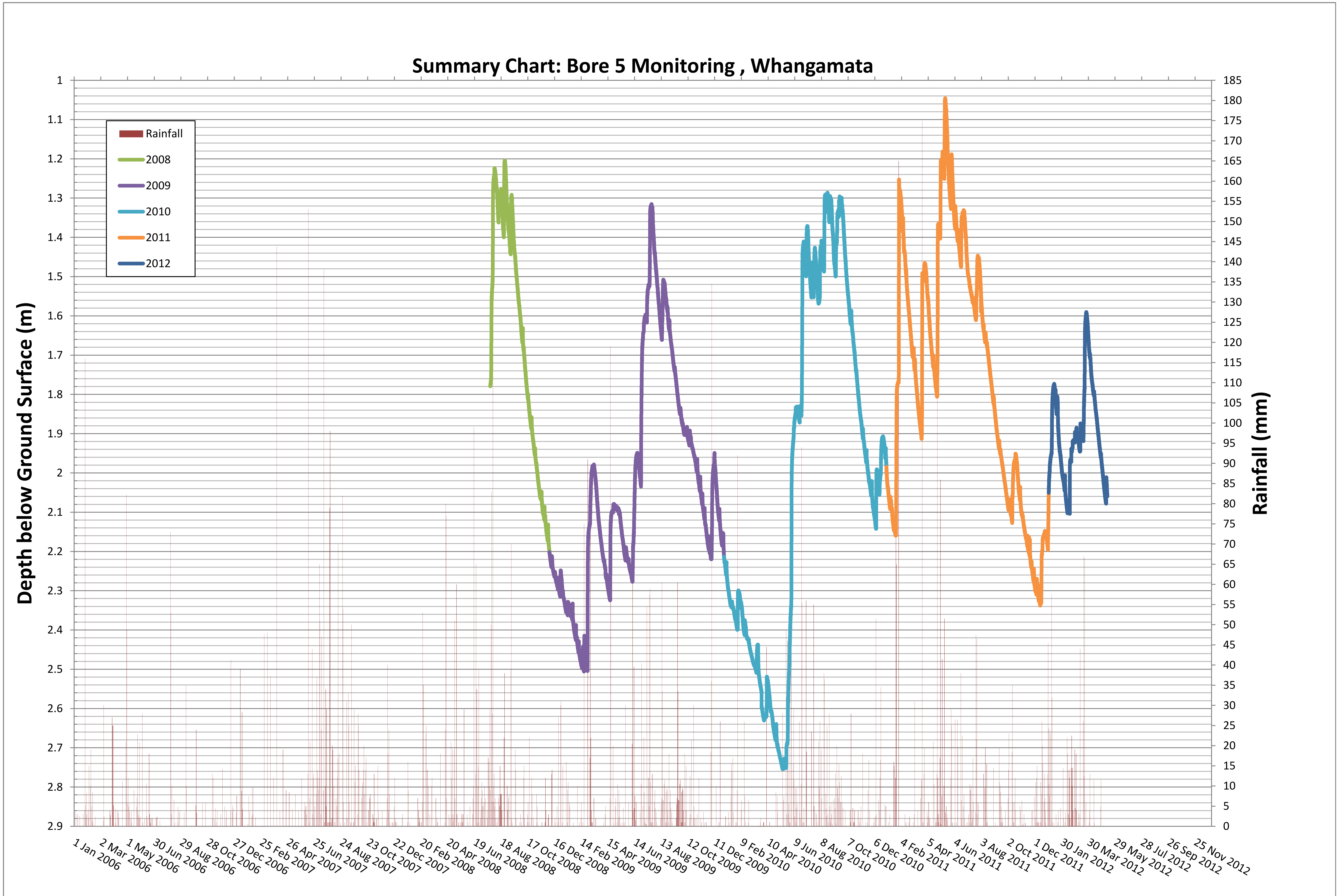
Summary Chart: Bore 2 TCDC Depot Monitoring , Whangamata
Depth below Ground Surface (m)
Rainfall (mm)
Rainfall
2007
2008
2009
2010
2011
2012



Summary Chart: Bore 3 Golf Course Monitoring , Whangamata
Depth below Ground Surface (m)
Rainfall (mm)
Rainfall
2007
2008
2009
2010
2011
2012
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1 Jan 2006
2 Mar 2006
1 May 2006
30 Jun 2006
29 Aug 2006
28 Oct 2006
27 Dec 2006
25 Feb 2007
26 Apr 2007
25 Jun 2007
24 Aug 2007
23 Oct 2007
22 Dec 2007
20 Feb 2008
20 Apr 2008
19 Jun 2008
18 Aug 2008
17 Oct 2008
16 Dec 2008
14 Feb 2009
15 Apr 2009
14 Jun 2009
13 Aug 2009
12 Oct 2009
11 Dec 2009
9 Feb 2010
10 Apr 2010
9 Jun 2010
8 Aug 2010
7 Oct 2010
6 Dec 2010
4 Feb 2011
5 Apr 2011
4 Jun 2011
3 Aug 2011
2 Oct 2011
1 Dec 2011
30 Jan 2012
30 Mar 2012
29 May 2012
28 Jul 2012
26 Sep 2012
25 Nov 2012

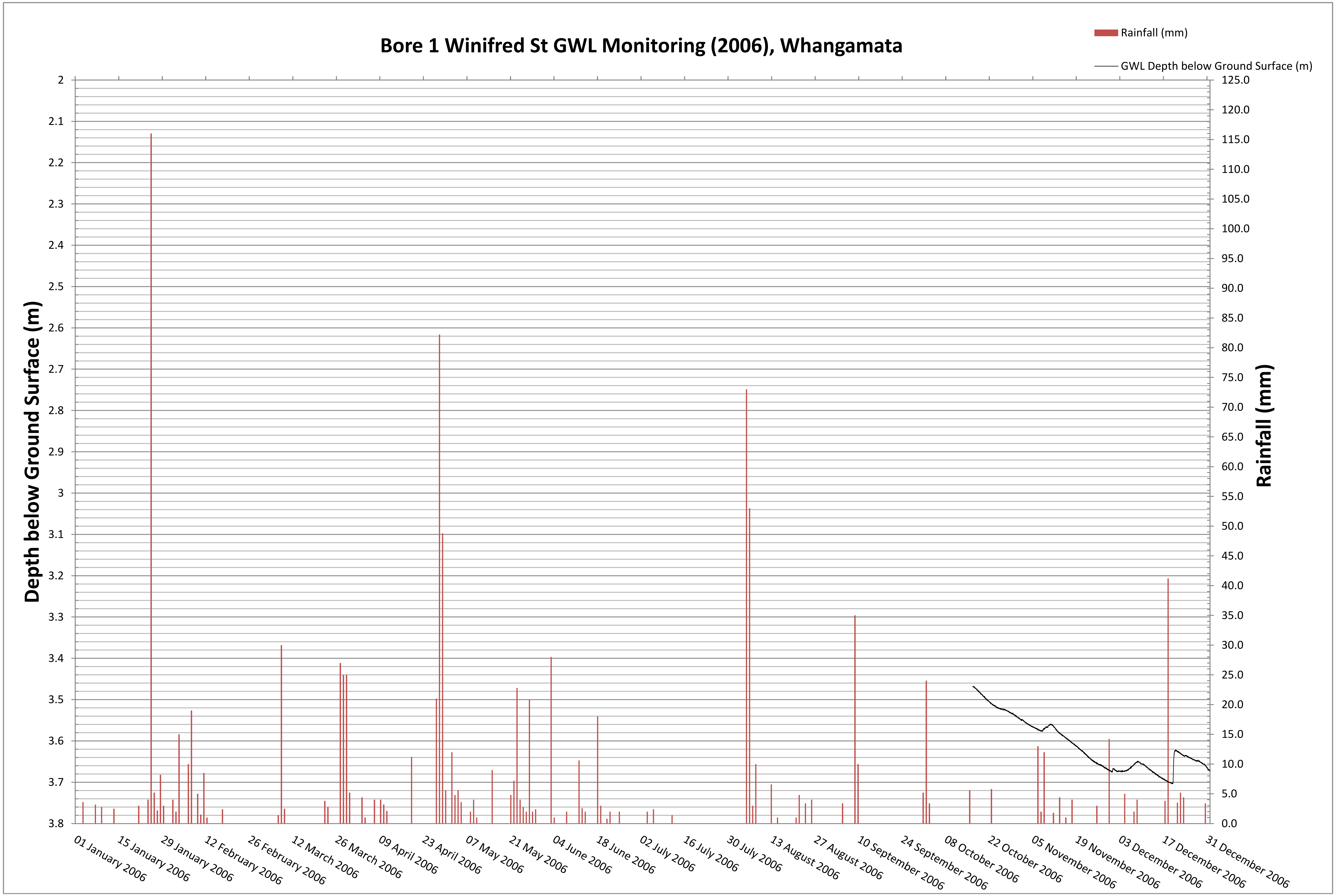


Summary Chart: Bore 4 Monitoring , Whangamata
Depth below Ground Surface (m)
Rainfall (mm)
Rainfall
2008
2009
2010
2011
2012
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
4.4
4.5
4.6
4.7
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1 Jan 2006
2 Mar 2006
1 May 2006
30 Jun 2006
29 Aug 2006
28 Oct 2006
27 Dec 2006
25 Feb 2007
26 Apr 2007
25 Jun 2007
24 Aug 2007
23 Oct 2007
22 Dec 2007
20 Feb 2008
20 Apr 2008
19 Jun 2008
18 Aug 2008
17 Oct 2008
16 Dec 2008
14 Feb 2009
15 Apr 2009
14 Jun 2009
13 Aug 2009
12 Oct 2009
11 Dec 2009
9 Feb 2010
10 Apr 2010
9 Jun 2010
8 Aug 2010
7 Oct 2010
6 Dec 2010
4 Feb 2011
5 Apr 2011
4 Jun 2011
3 Aug 2011
2 Oct 2011
1 Dec 2011
30 Jan 2012
30 Mar 2012
29 May 2012
28 Jul 2012
26 Sep 2012
25 Nov 2012



Summary Chart: Bore 5 Monitoring , Whangamata
Rainfall
2008
2009
2010
2011
2012
Depth below Ground Surface (m)
Rainfall (mm)
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1 Jan 2006
2 Mar 2006
1 May 2006
30 Jun 2006
29 Aug 2006
28 Oct 2006
27 Dec 2006
25 Feb 2007
26 Apr 2007
25 Jun 2007
24 Aug 2007
23 Oct 2007
22 Dec 2007
20 Feb 2008
20 Apr 2008
19 Jun 2008
18 Aug 2008
17 Oct 2008
16 Dec 2008
14 Feb 2009
15 Apr 2009
14 Jun 2009
13 Aug 2009
12 Oct 2009
11 Dec 2009
9 Feb 2010
10 Apr 2010
9 Jun 2010
8 Aug 2010
7 Oct 2010
6 Dec 2010
4 Feb 2011
5 Apr 2011
4 Jun 2011
3 Aug 2011
2 Oct 2011
1 Dec 2011
30 Jan 2012
30 Mar 2012
29 May 2012
28 Jul 2012
26 Sep 2012
25 Nov 2012

Appendix C. Year Span Charts



Bore 1 Winifred St GWL Monitoring (2006), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
125.0
120.0
115.0
110.0
105.0
100.0
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
01 January 2006
15 January 2006
29 January 2006
12 February 2006
26 February 2006
12 March 2006
26 March 2006
09 April 2006
23 April 2006
07 May 2006
21 May 2006
04 June 2006
18 June 2006
02 July 2006
16 July 2006
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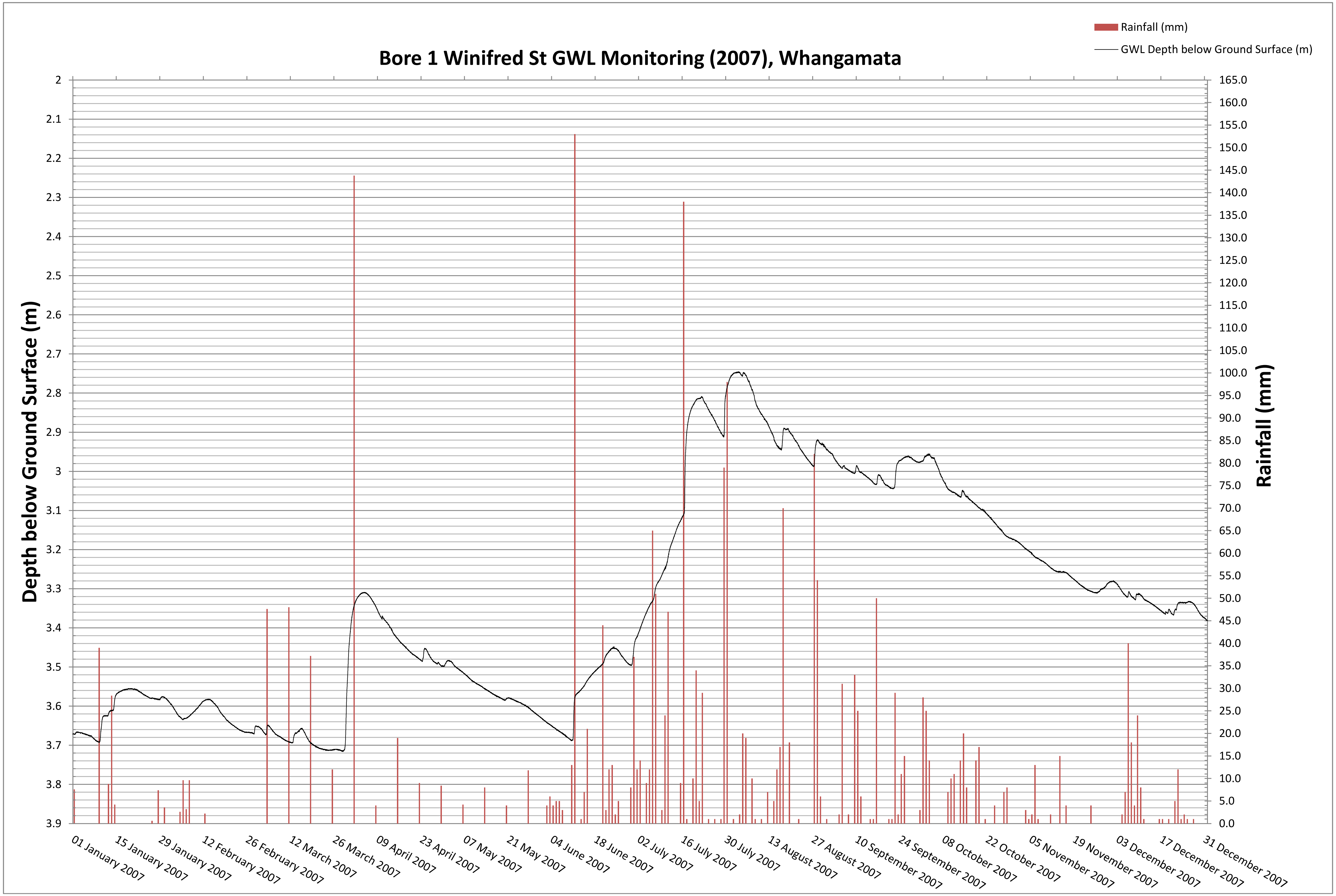
03 December 2006
17 December 2006
31 December 2006



Bore 1 Winifred St GWL Monitoring (2007), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
165.0
160.0
155.0
150.0
145.0
140.0
135.0
130.0
125.0
120.0
115.0
110.0
105.0
100.0
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
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01 January 2007
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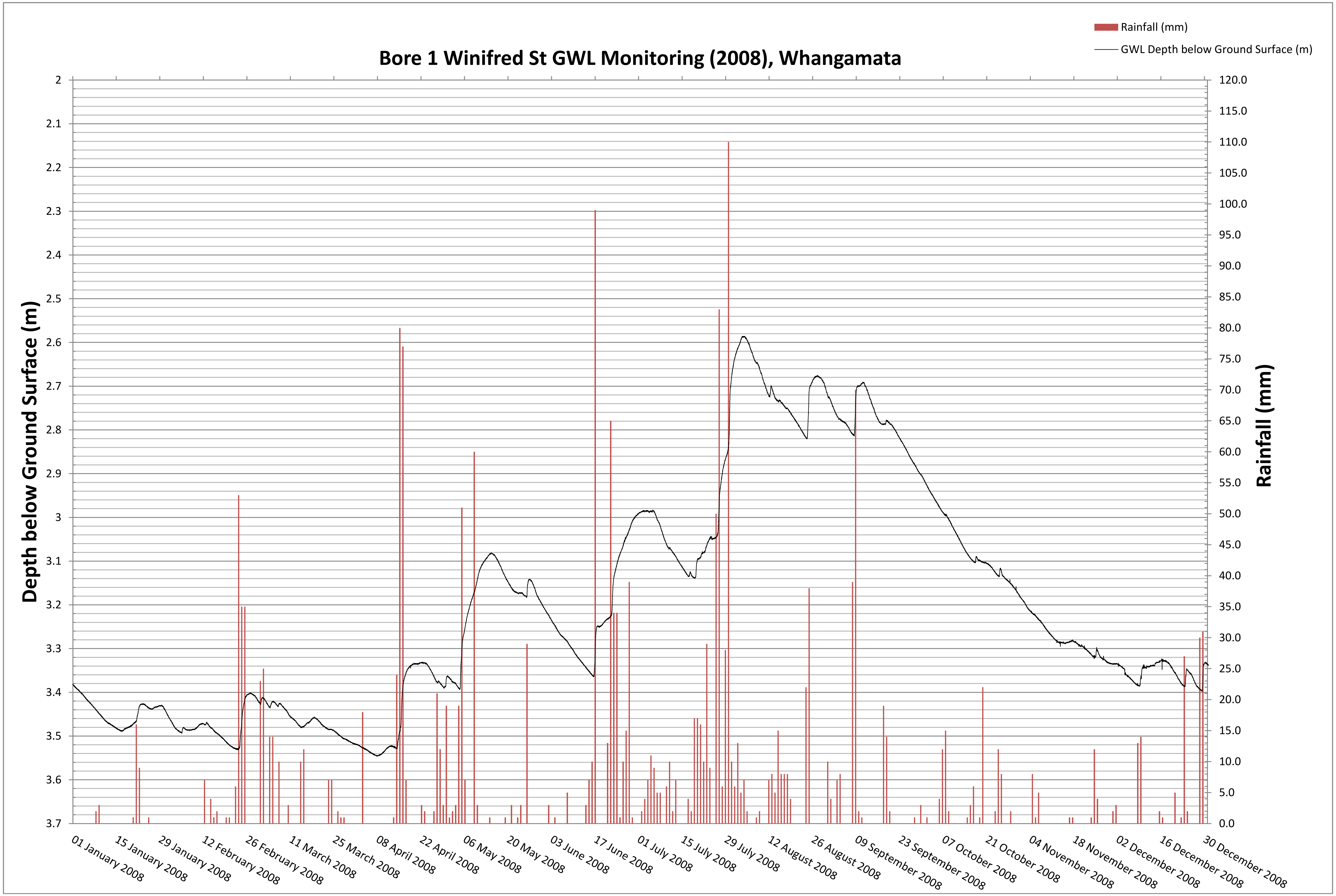
19 November 2007
03 December 2007
17 December 2007
31 December 2007


Bore 1 Winifred St GWL Monitoring (2008), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
2
2.1
2.2
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2.5
2.6
2.7
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3
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120.0
115.0
110.0
105.0
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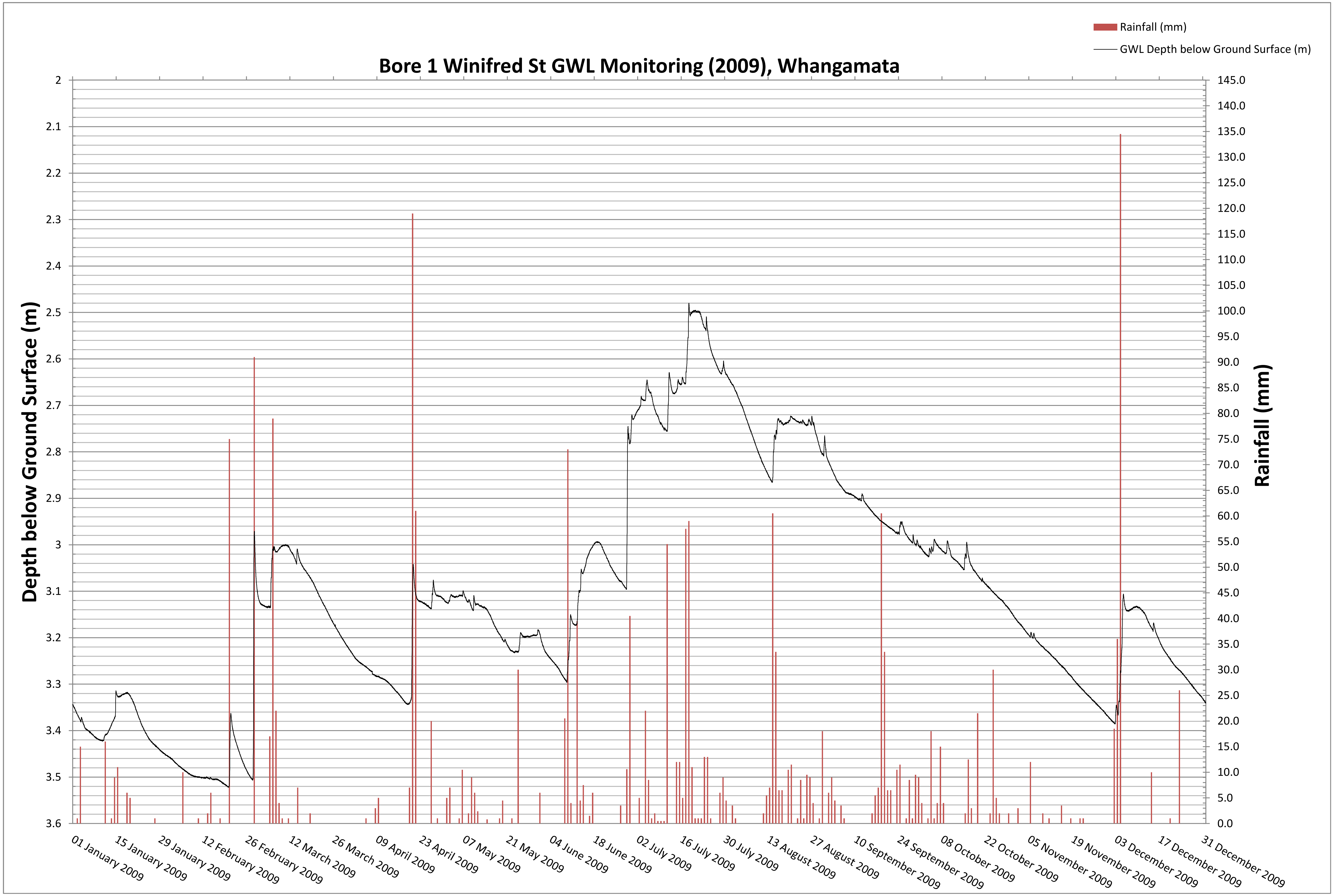

Bore 1 Winifred St GWL Monitoring (2009), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
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2.1
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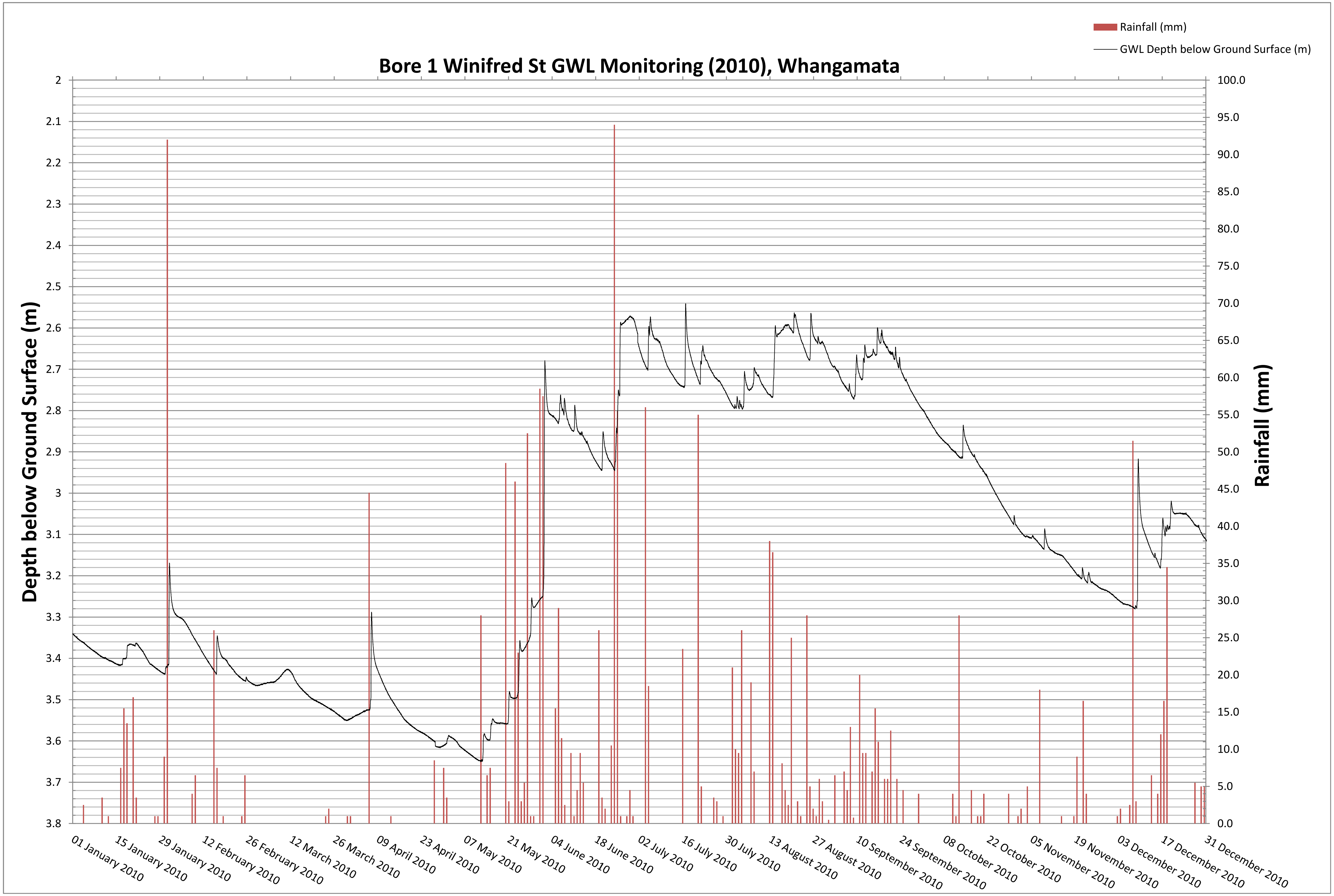

Rainfall (mm)
GWL Depth below Ground Surface (m)
Bore 1 Winifred St GWL Monitoring (2010), Whangamata
Depth below Ground Surface (m)
Rainfall (mm)
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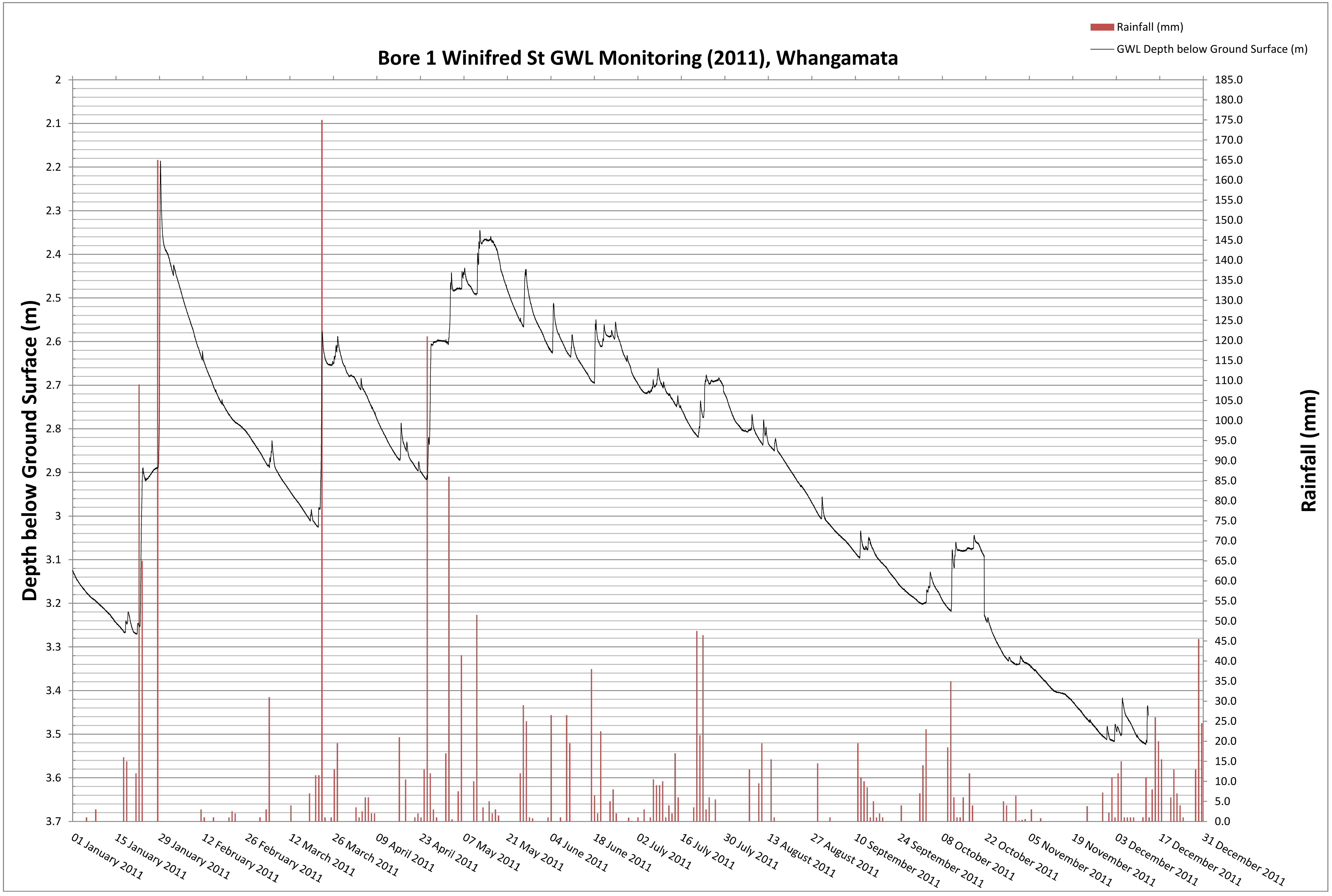

Bore 1 Winifred St GWL Monitoring (2011), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
2
2.1
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2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
3.6
3.7
185.0
180.0
175.0
170.0
165.0
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155.0
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115.0
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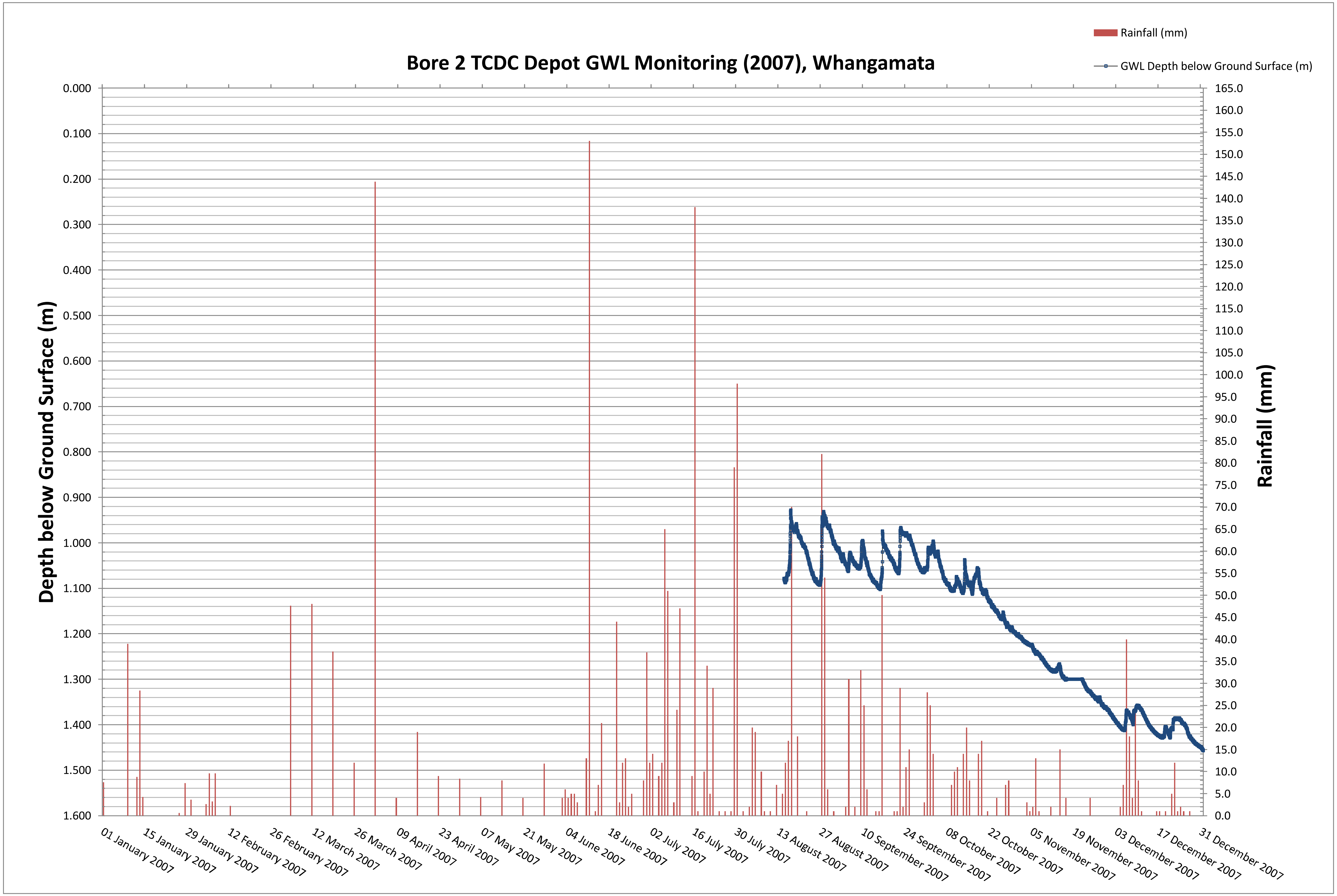
17 December 2011
31 December 2011



Bore 2 TCDC Depot GWL Monitoring (2007), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
1.600
165.0
160.0
155.0
150.0
145.0
140.0
135.0
130.0
125.0
120.0
115.0
110.0
105.0
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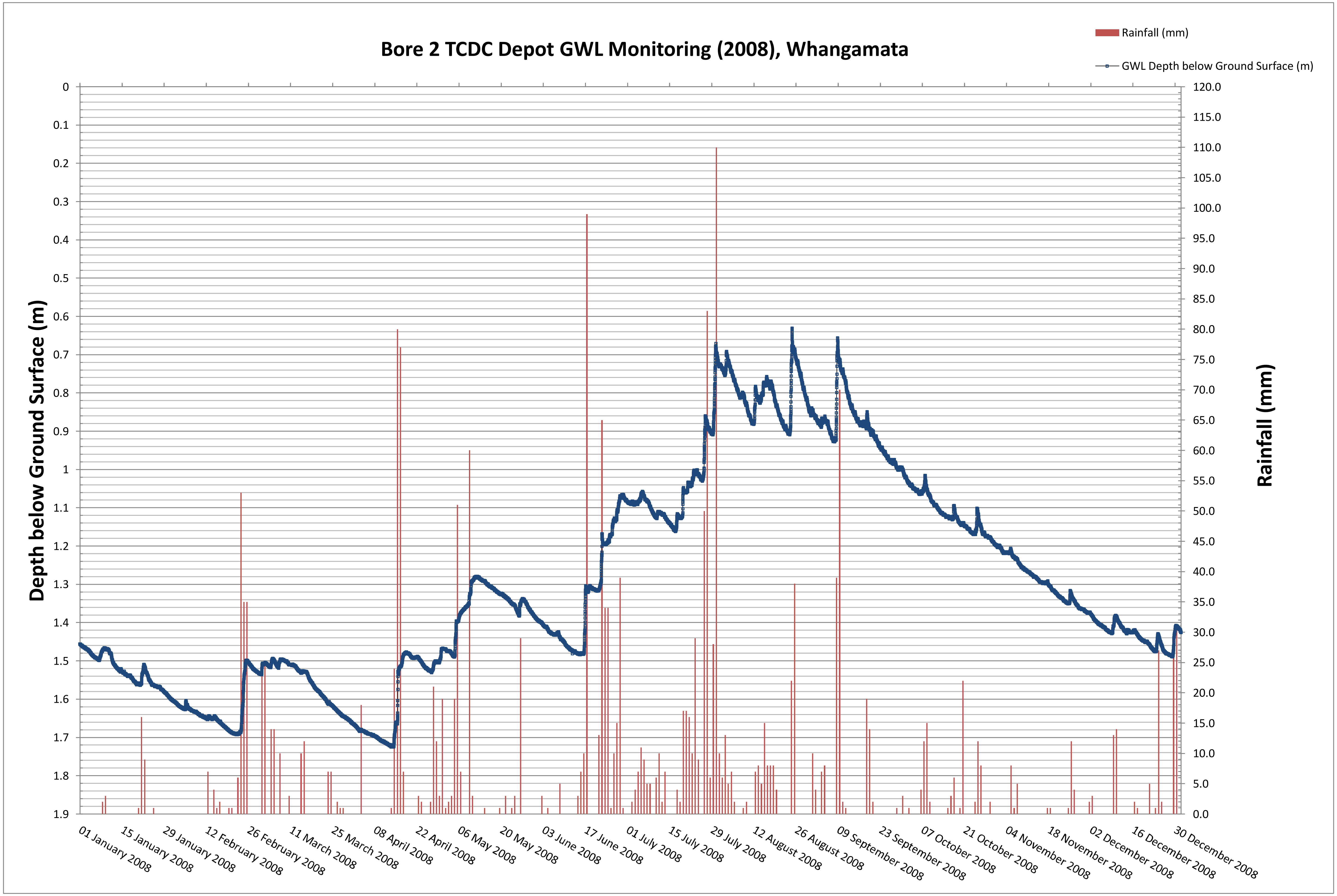
31 December 2007



Bore 2 TCDC Depot GWL Monitoring (2008), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
120.0
115.0
110.0
105.0
100.0
95.0
90.0
85.0
80.0
75.0
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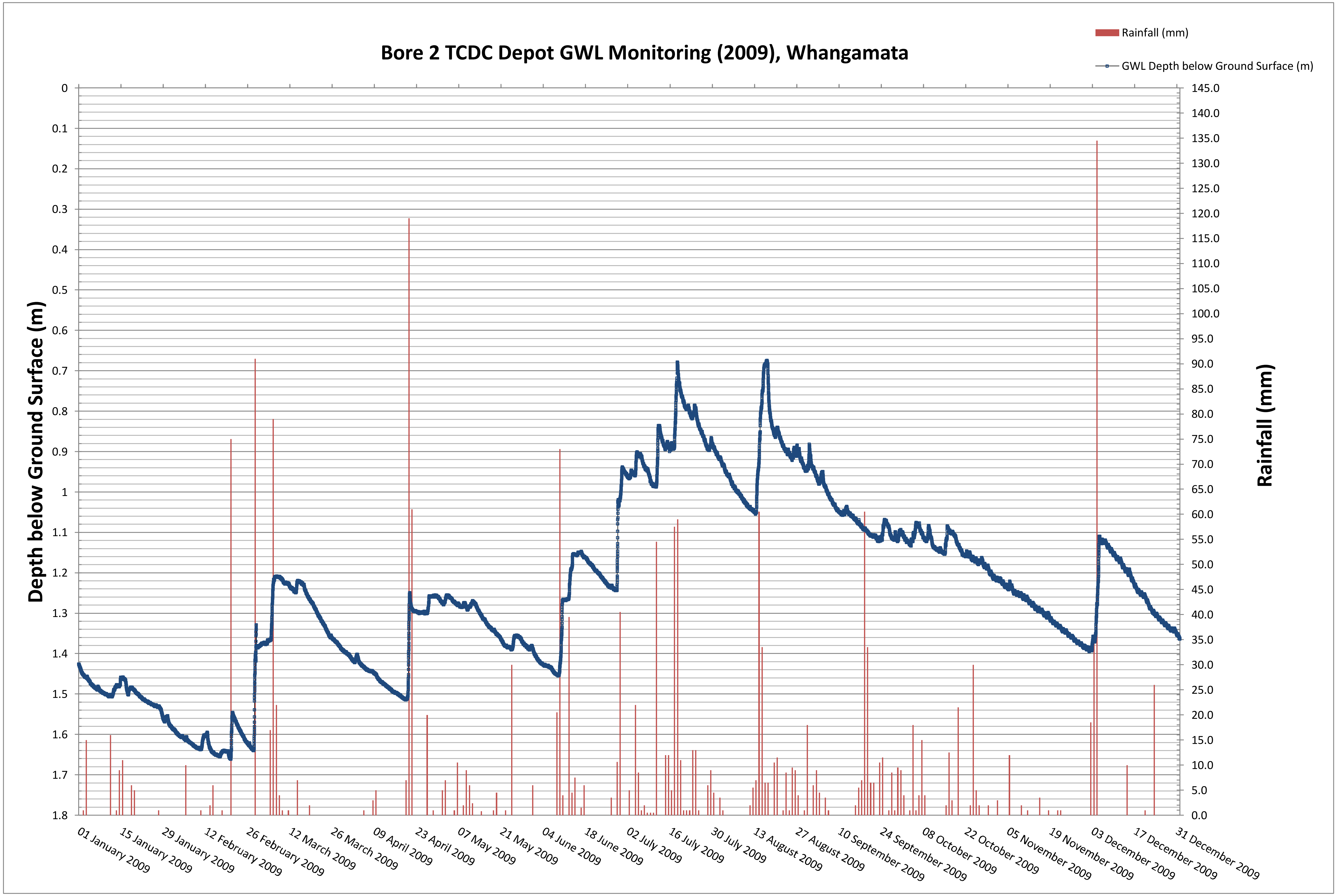
Bore 2 TCDC Depot GWL Monitoring (2009), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
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145.0
140.0
135.0
130.0
125.0
120.0
115.0
110.0
105.0
100.0
95.0
90.0
85.0
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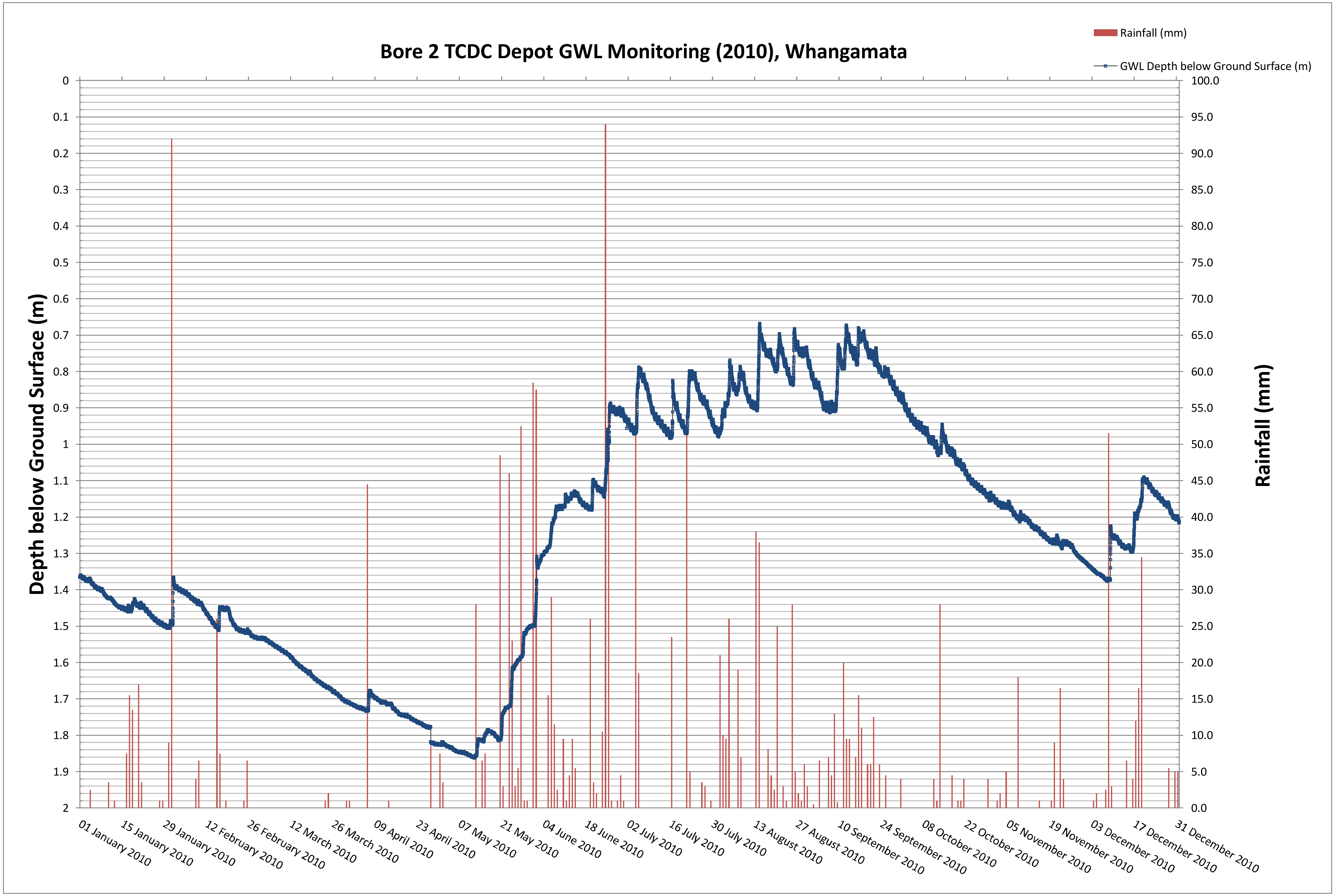
Bore 2 TCDC Depot GWL Monitoring (2010), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
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1.6
1.7
1.8
1.9
2
100.0
95.0
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85.0
80.0
75.0
70.0
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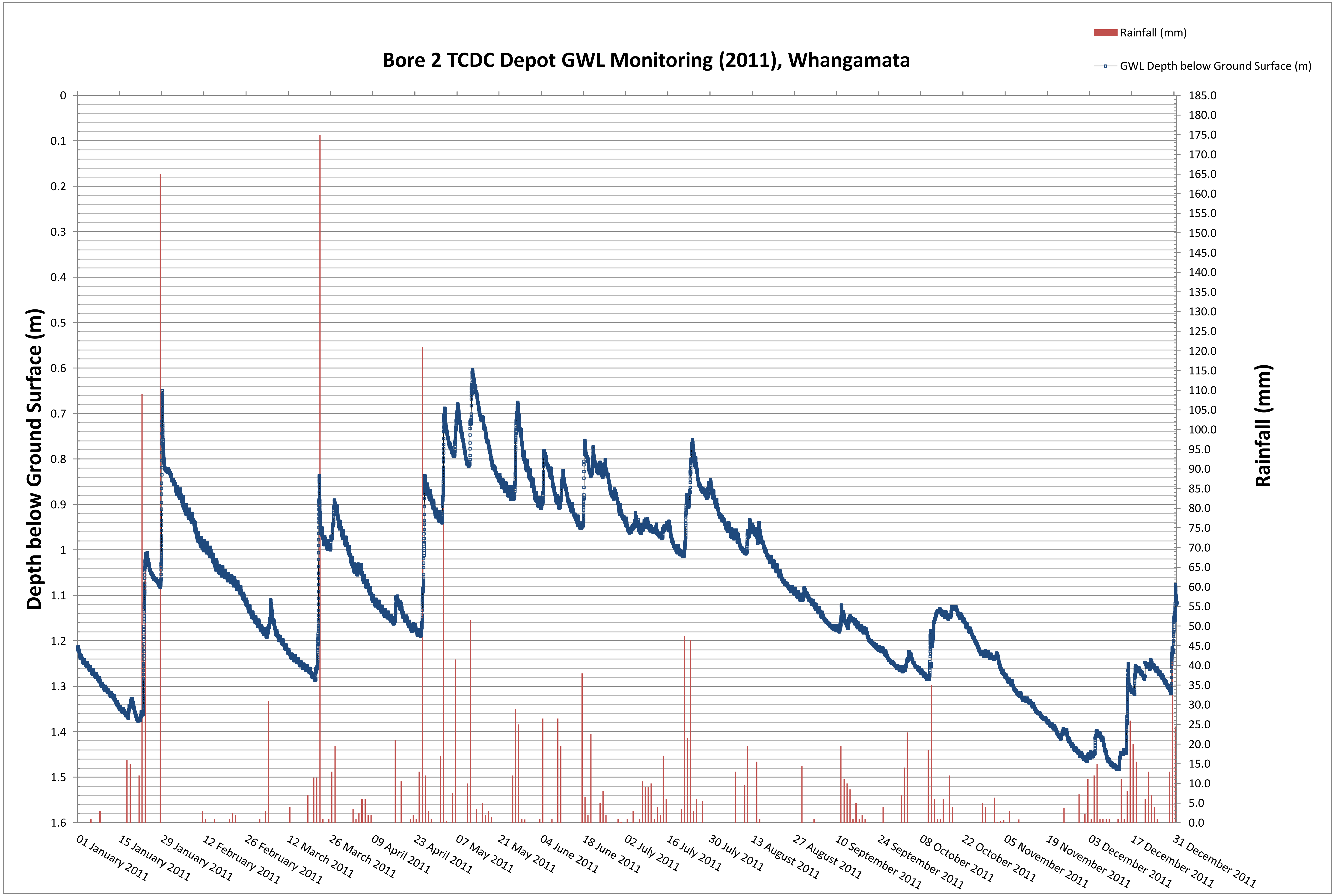

Bore 2 TCDC Depot GWL Monitoring (2011), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
185.0
180.0
175.0
170.0
165.0
160.0
155.0
150.0
145.0
140.0
135.0
130.0
125.0
120.0
115.0
110.0
105.0
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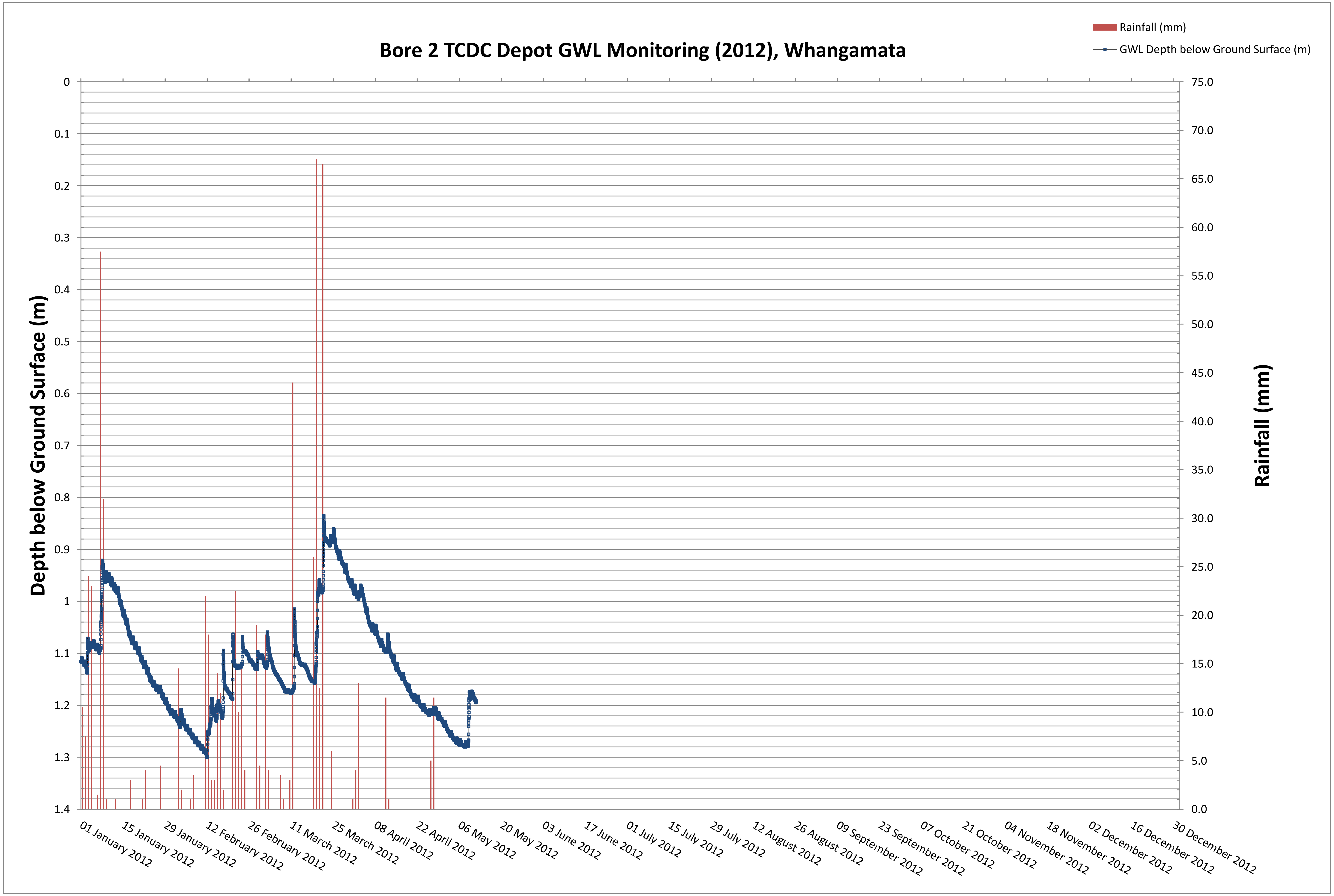

Bore 2 TCDC Depot GWL Monitoring (2012), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
75.0
70.0
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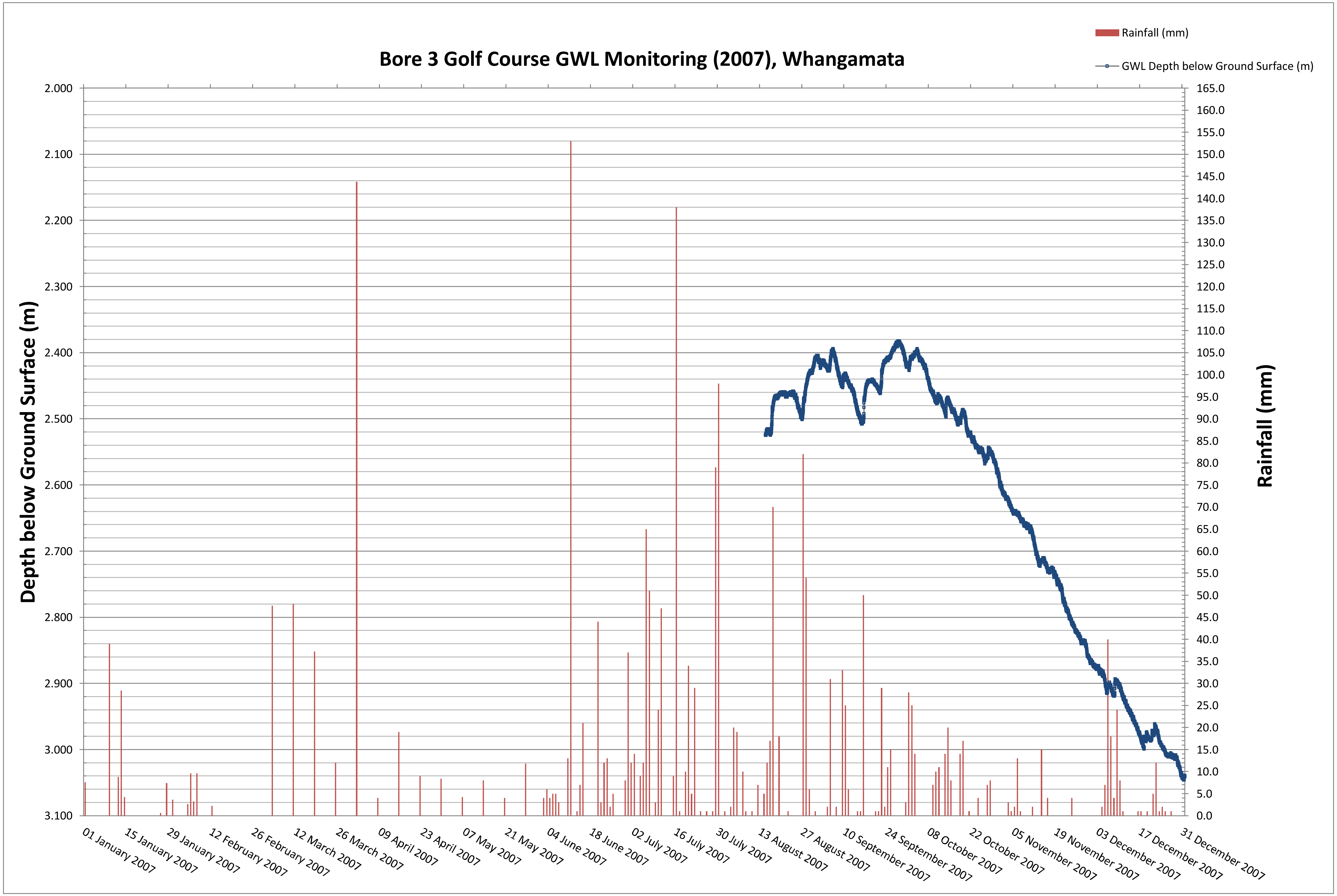

Bore 3 Golf Course GWL Monitoring (2007), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
2.000
2.100
2.200
2.300
2.400
2.500
2.600
2.700
2.800
2.900
3.000
3.100
165.0
160.0
155.0
150.0
145.0
140.0
135.0
130.0
125.0
120.0
115.0
110.0
105.0
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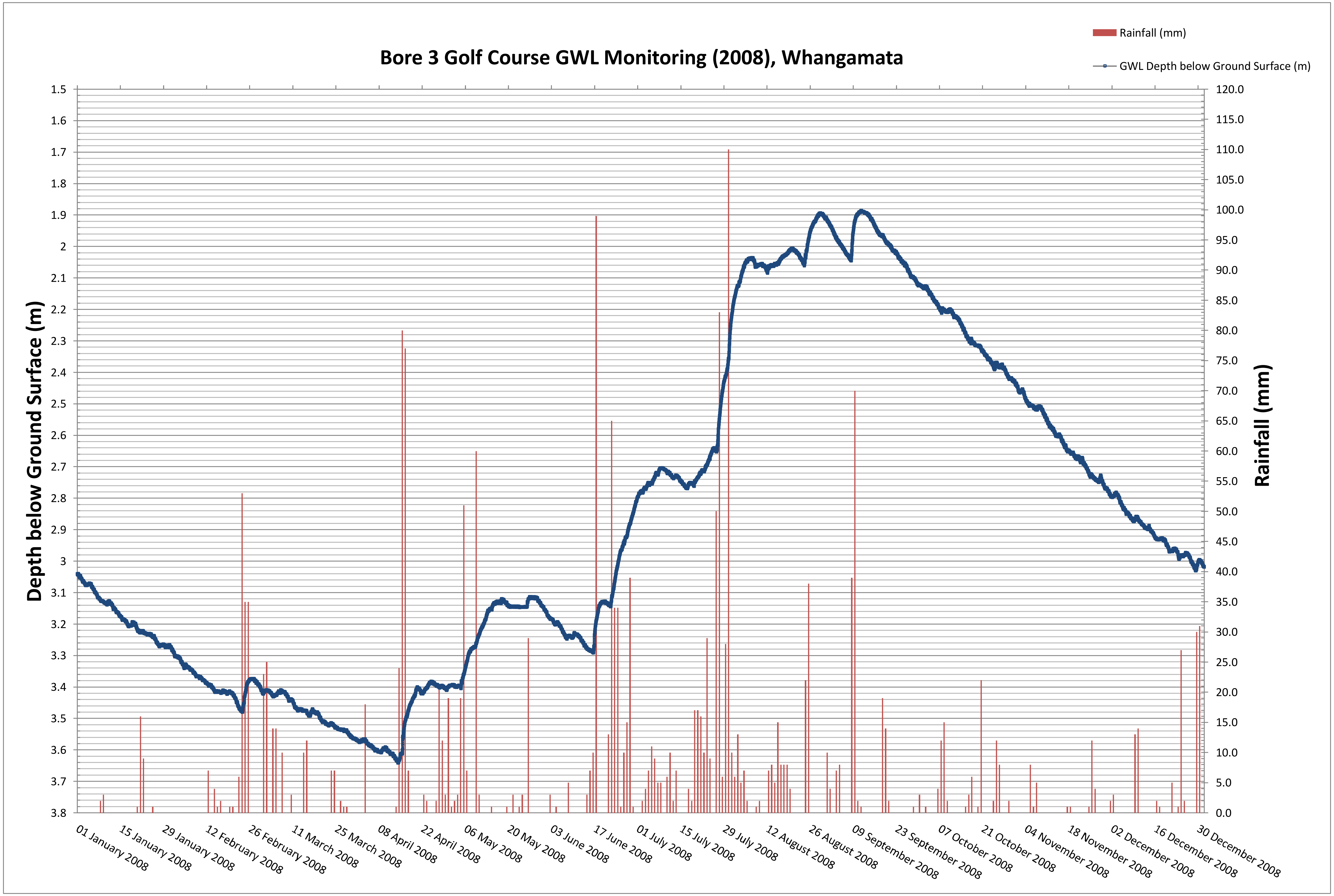

Bore 3 Golf Course GWL Monitoring (2008), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
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3.8
120.0
115.0
110.0
105.0
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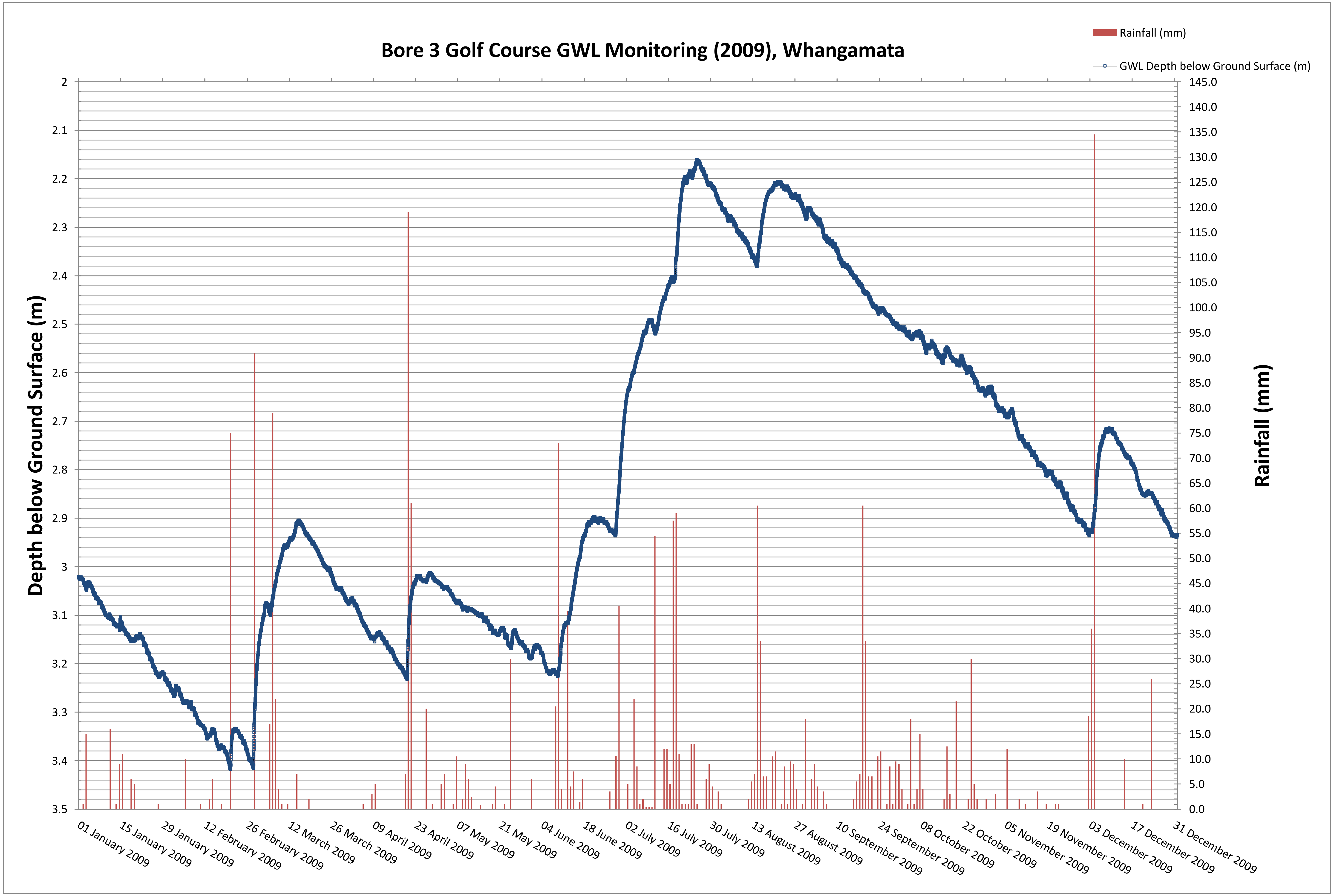

Bore 3 Golf Course GWL Monitoring (2009), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
2
2.1
2.2
2.3
2.4
2.5
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3.1
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145.0
140.0
135.0
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125.0
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115.0
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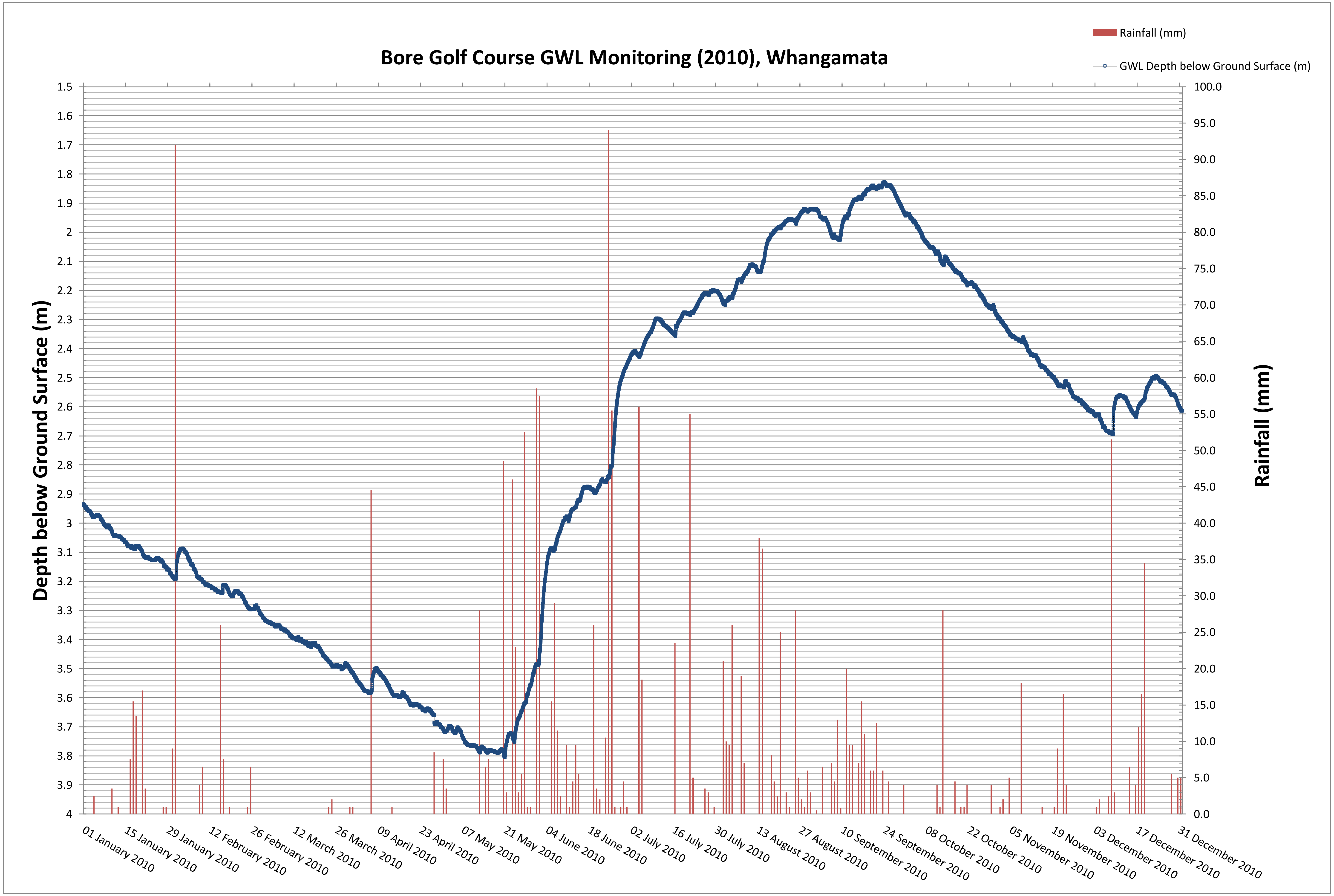
Bore Golf Course GWL Monitoring (2010), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
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2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
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3.3
3.4
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4
100.0
95.0
90.0
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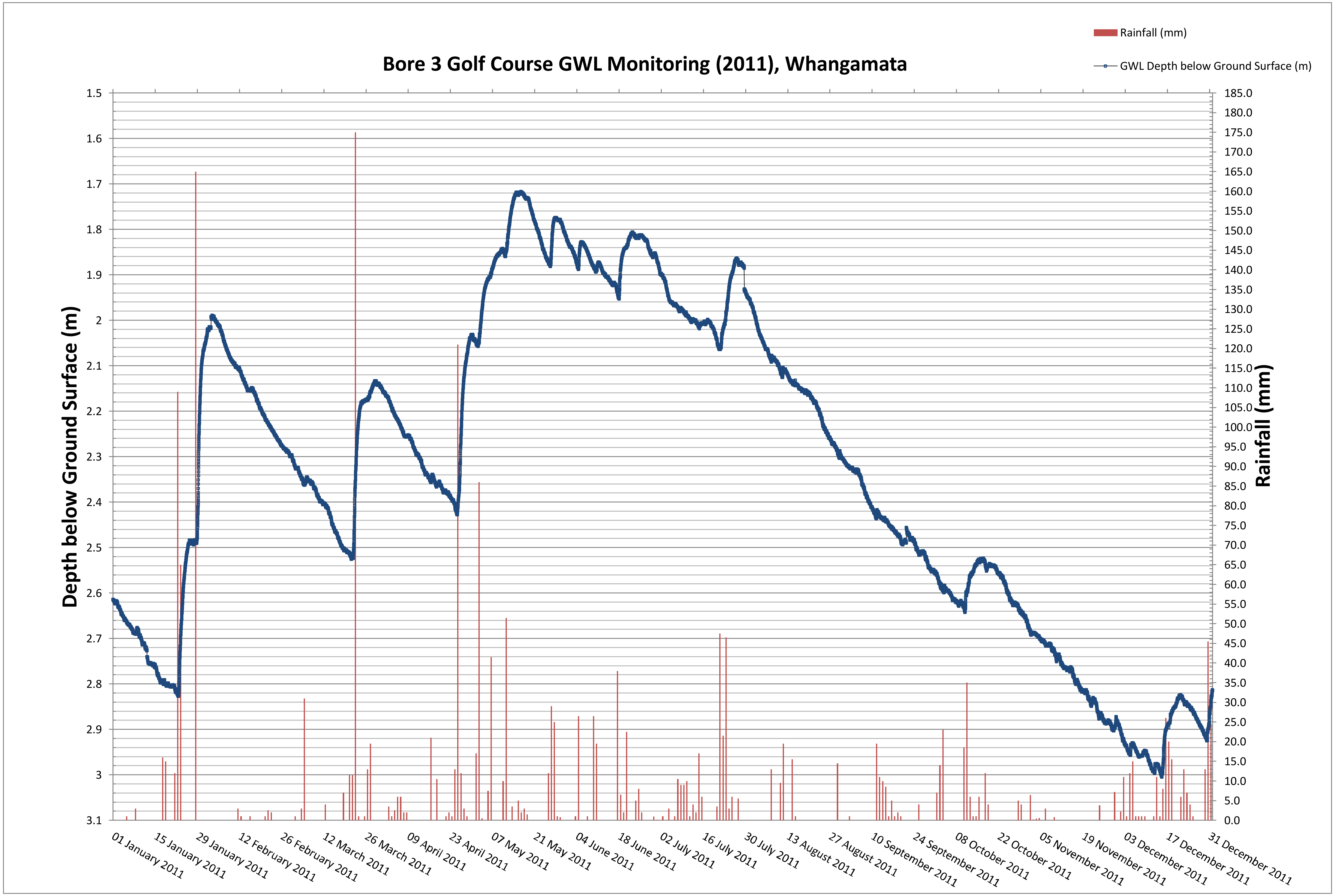
31 December 2010



Bore 3 Golf Course GWL Monitoring (2011), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
185.0
180.0
175.0
170.0
165.0
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100.0
95.0
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85.0
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65.0
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55.0
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45.0
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01 January 2011
15 January 2011
29 January 2011
12 February 2011
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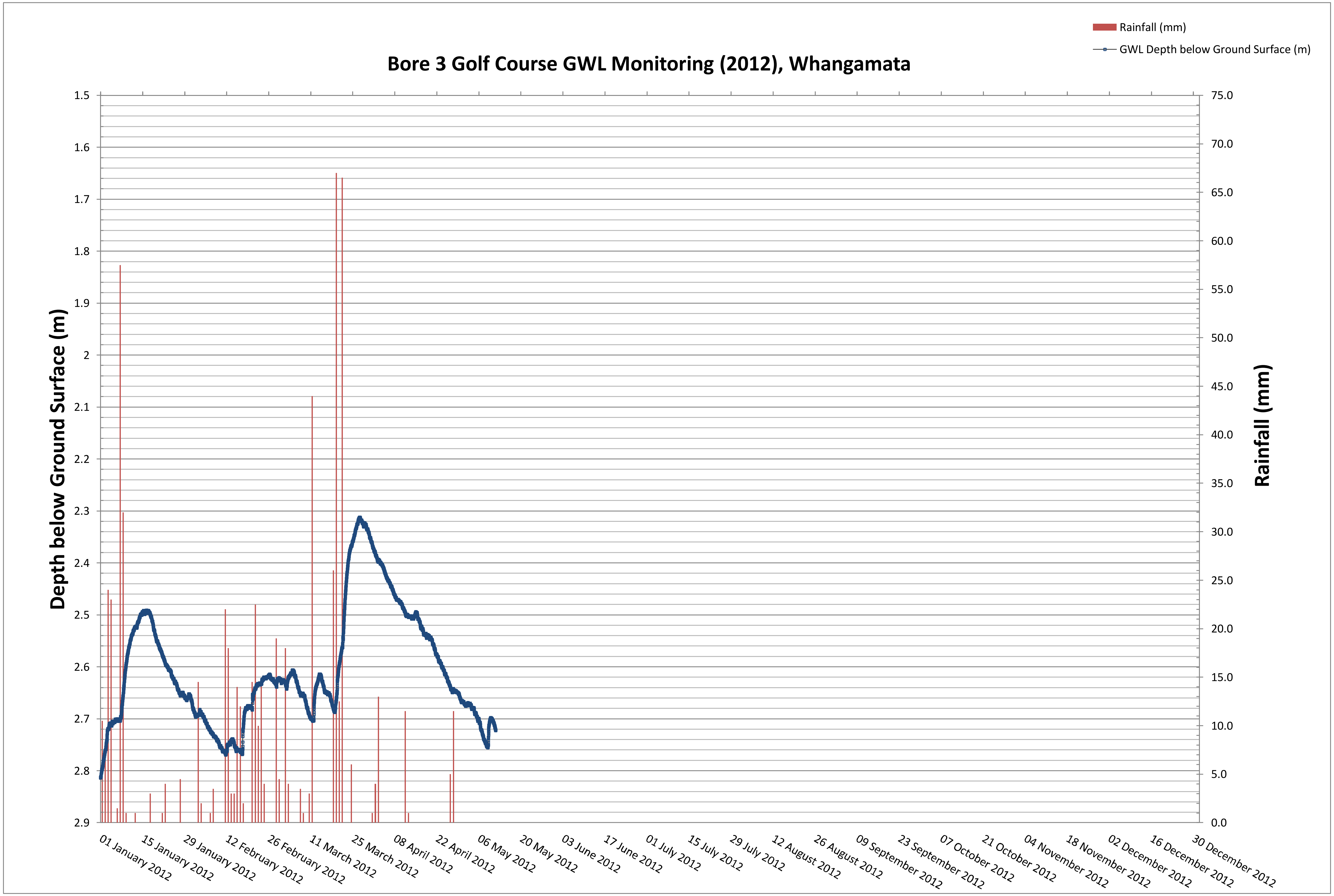

Rainfall (mm)
GWL Depth below Ground Surface (m)
Bore 3 Golf Course GWL Monitoring (2012), Whangamata
Depth below Ground Surface (m)
Rainfall (mm)
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
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15.0
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01 January 2012
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17 June 2012
01 July 2012
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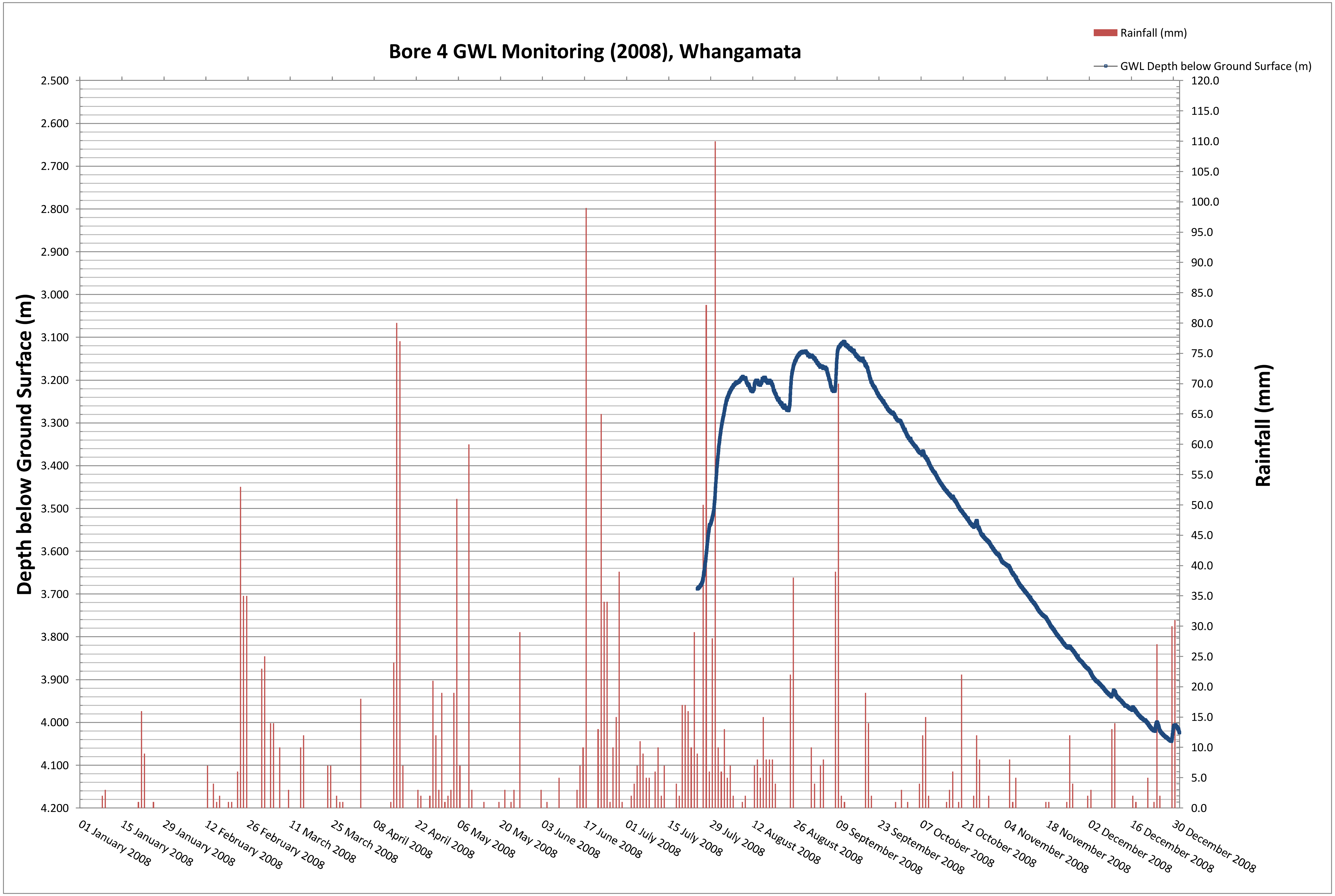
18 November 2012
02 December 2012
16 December 2012
30 December 2012


Bore 4 GWL Monitoring (2008), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
2.500
2.600
2.700
2.800
2.900
3.000
3.100
3.200
3.300
3.400
3.500
3.600
3.700
3.800
3.900
4.000
4.100
4.200
120.0
115.0
110.0
105.0
100.0
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
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01 January 2008
15 January 2008
29 January 2008
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11 March 2008
25 March 2008
08 April 2008
22 April 2008
06 May 2008
20 May 2008
03 June 2008
17 June 2008
01 July 2008
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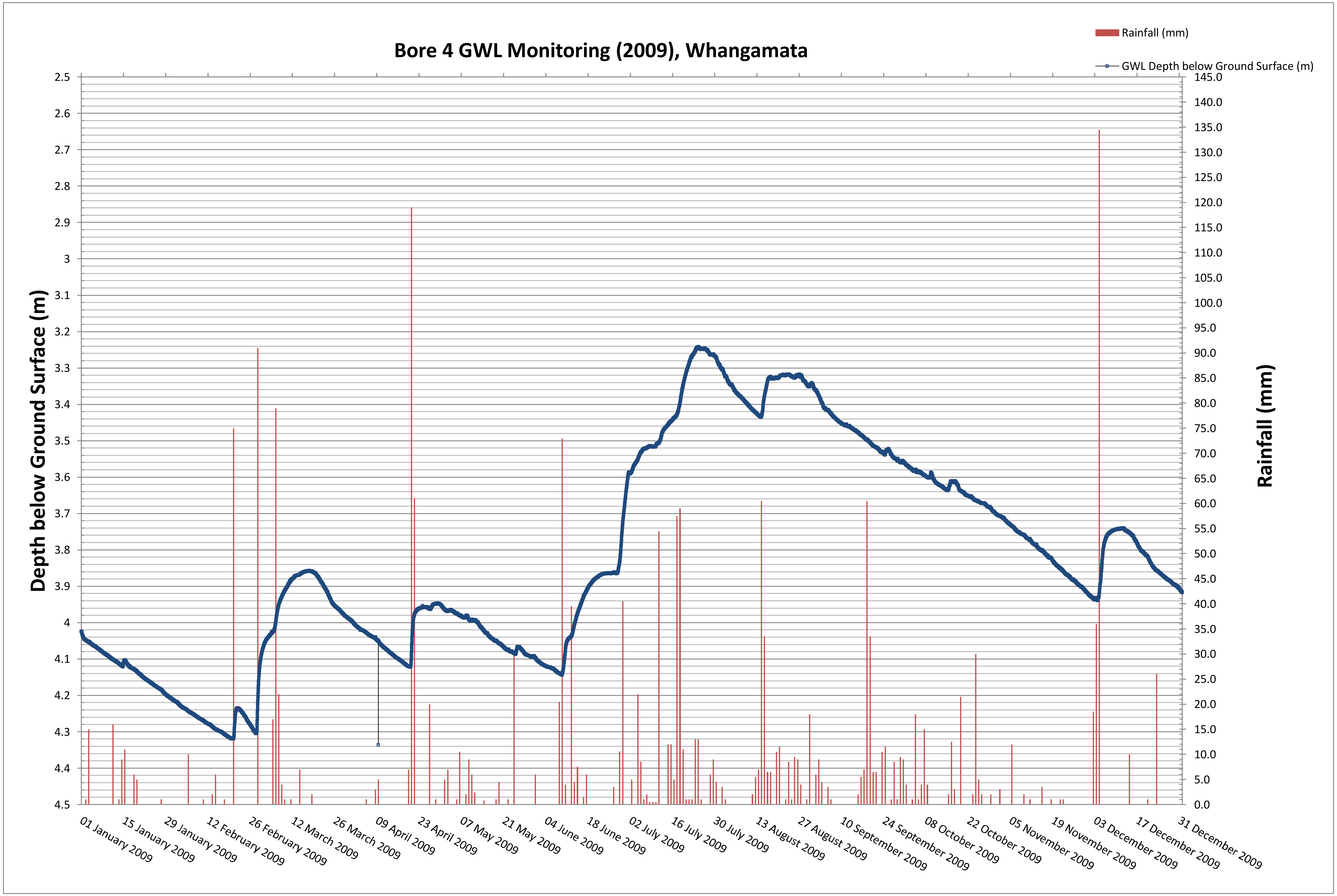
02 December 2008
16 December 2008
30 December 2008



Bore 4 GWL Monitoring (2009), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
4.4
4.5
145.0
140.0
135.0
130.0
125.0
120.0
115.0
110.0
105.0
100.0
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
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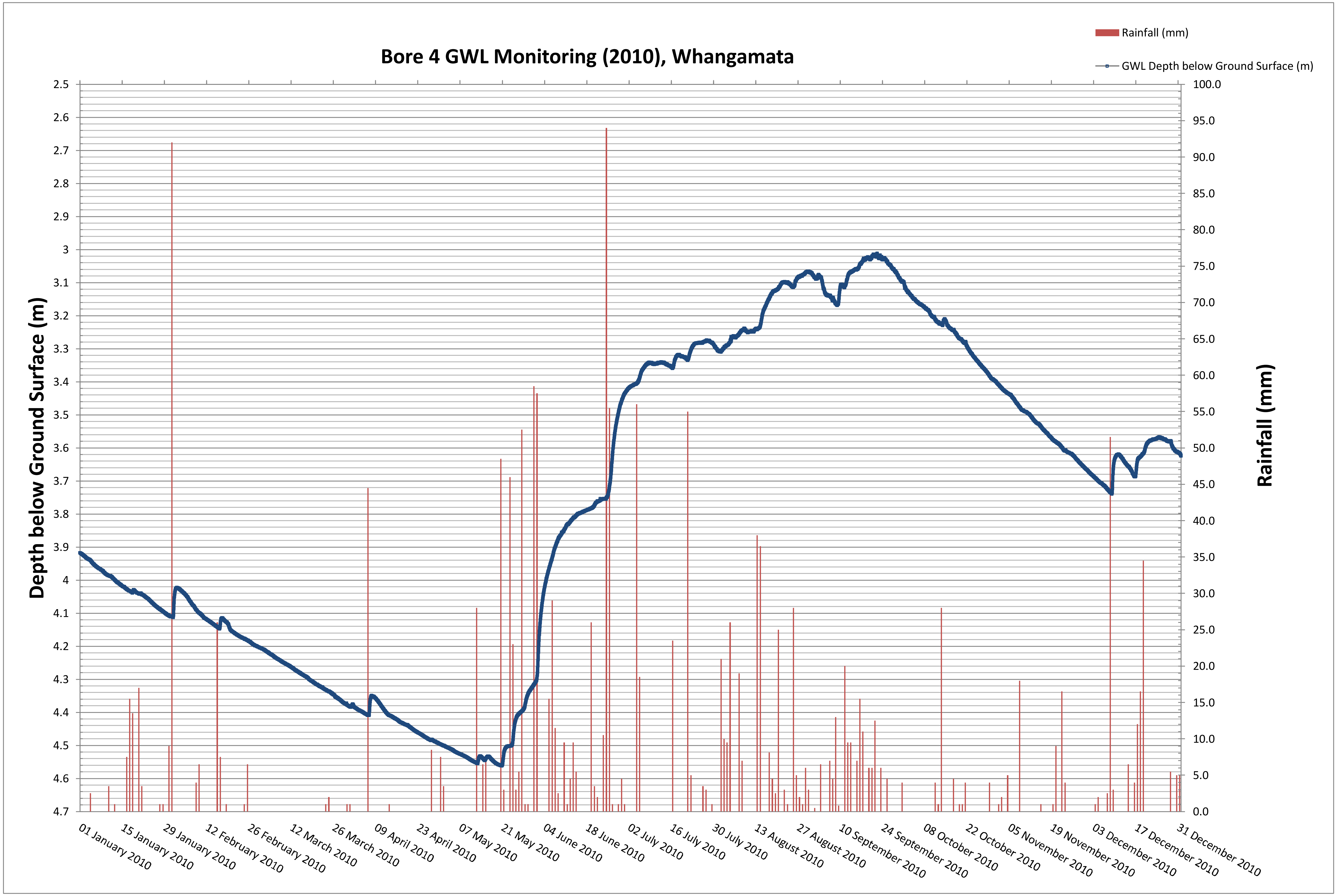
Bore 4 GWL Monitoring (2010), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
4.4
4.5
4.6
4.7
100.0
95.0
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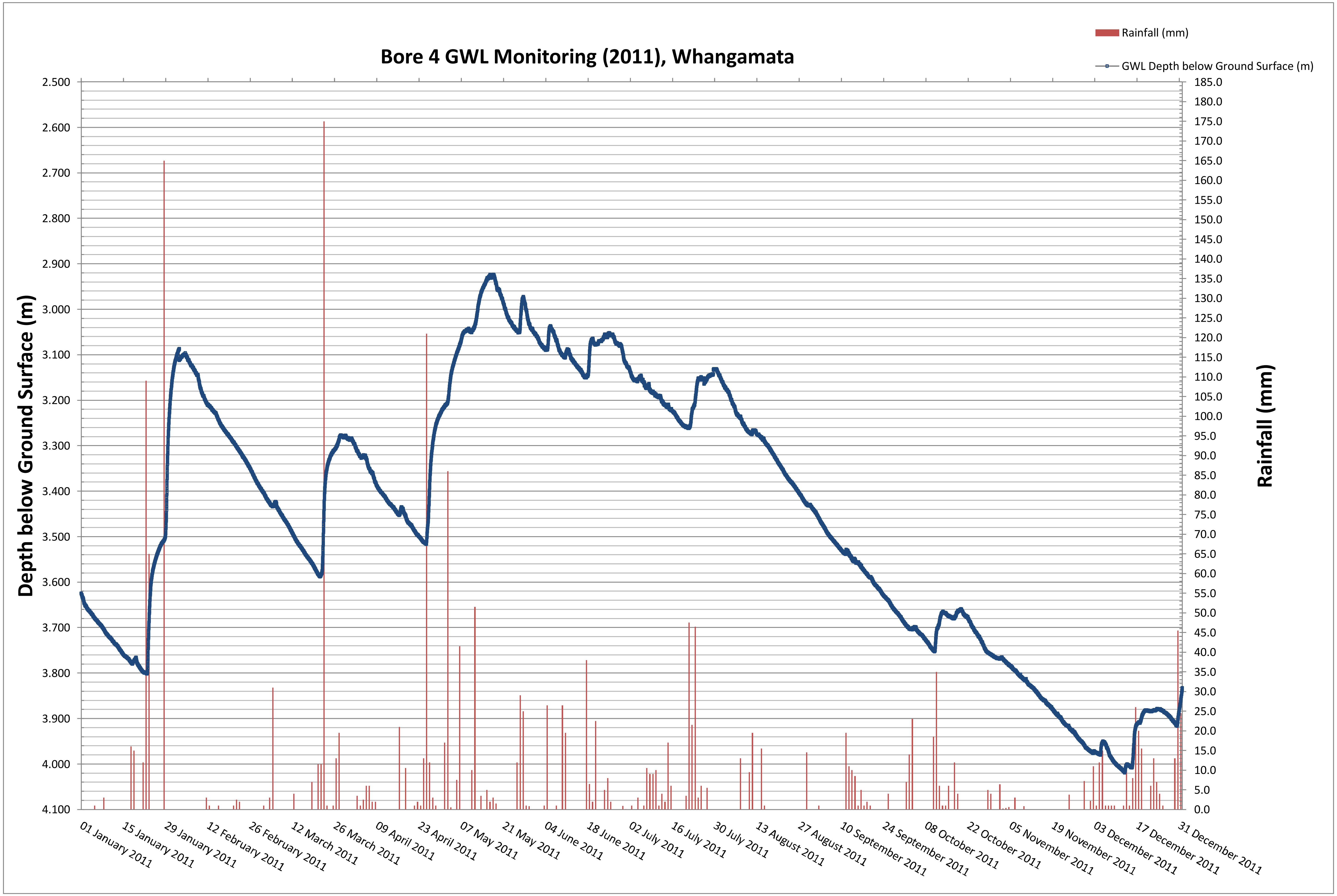
Bore 4 GWL Monitoring (2011), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
2.500
2.600
2.700
2.800
2.900
3.000
3.100
3.200
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3.700
3.800
3.900
4.000
4.100
185.0
180.0
175.0
170.0
165.0
160.0
155.0
150.0
145.0
140.0
135.0
130.0
125.0
120.0
115.0
110.0
105.0
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95.0
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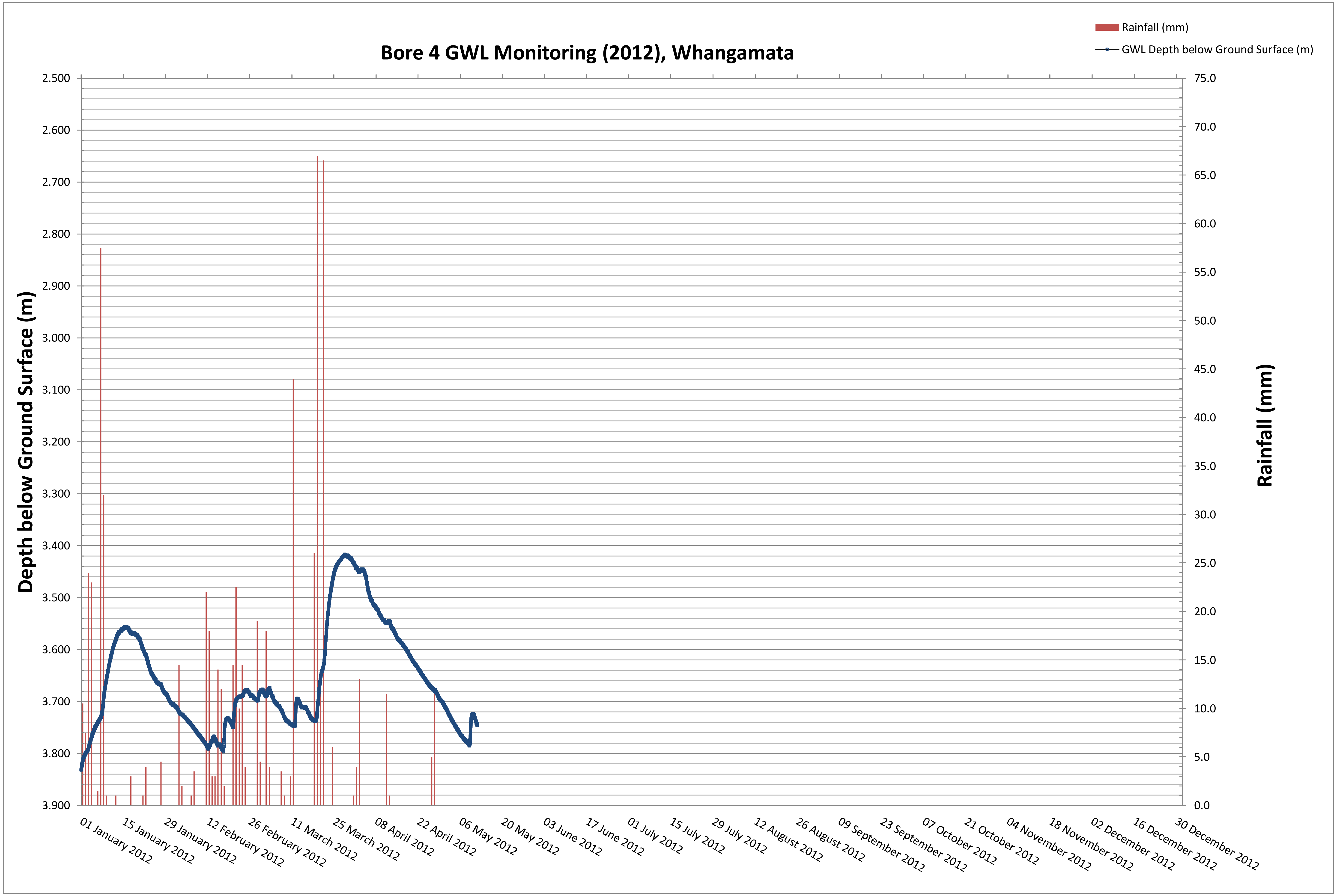

Bore 4 GWL Monitoring (2012), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
2.500
2.600
2.700
2.800
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3.000
3.100
3.200
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3.400
3.500
3.600
3.700
3.800
3.900
75.0
70.0
65.0
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16 December 2012
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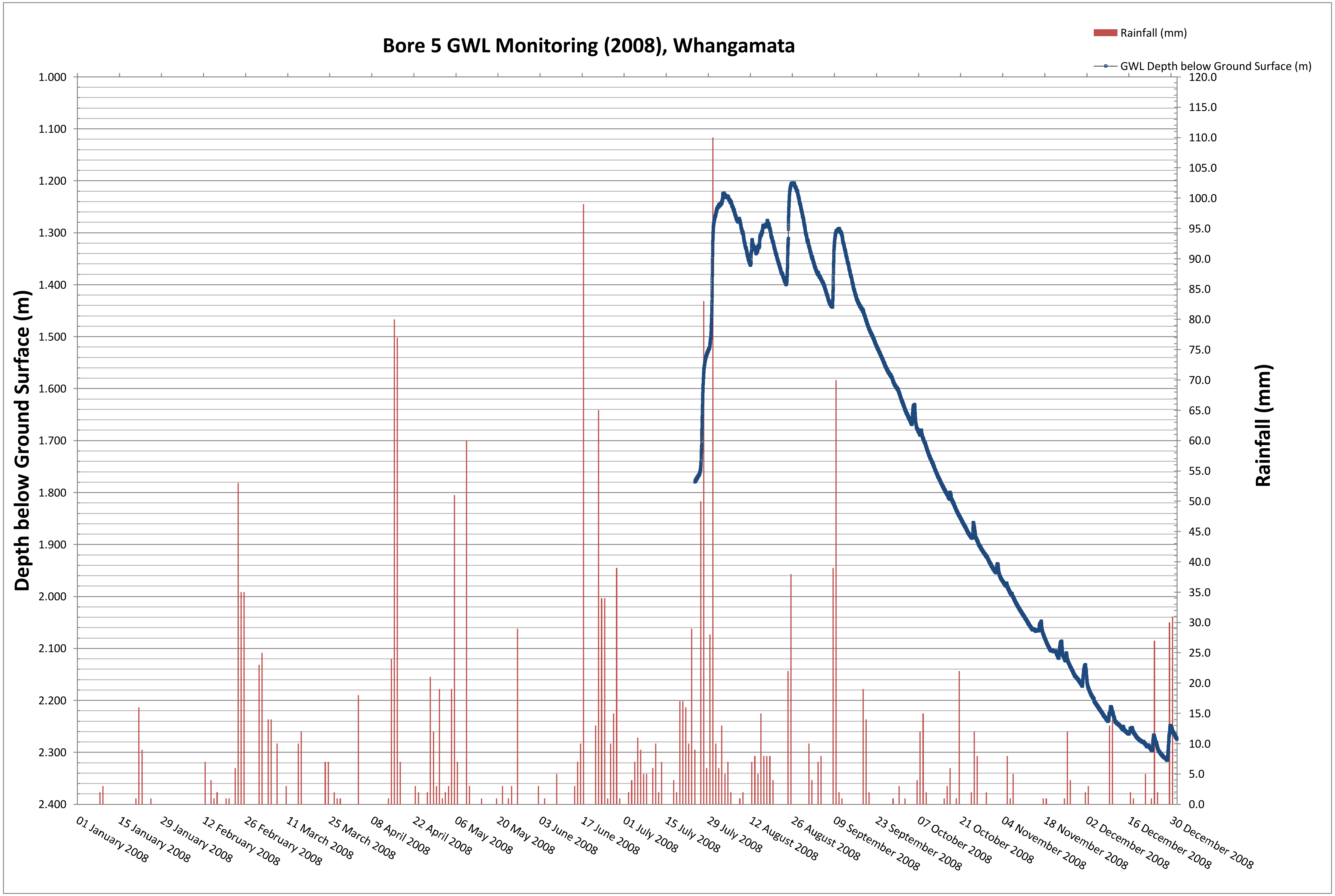

Bore 5 GWL Monitoring (2008), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
1.000
1.100
1.200
1.300
1.400
1.500
1.600
1.700
1.800
1.900
2.000
2.100
2.200
2.300
2.400
120.0
115.0
110.0
105.0
100.0
95.0
90.0
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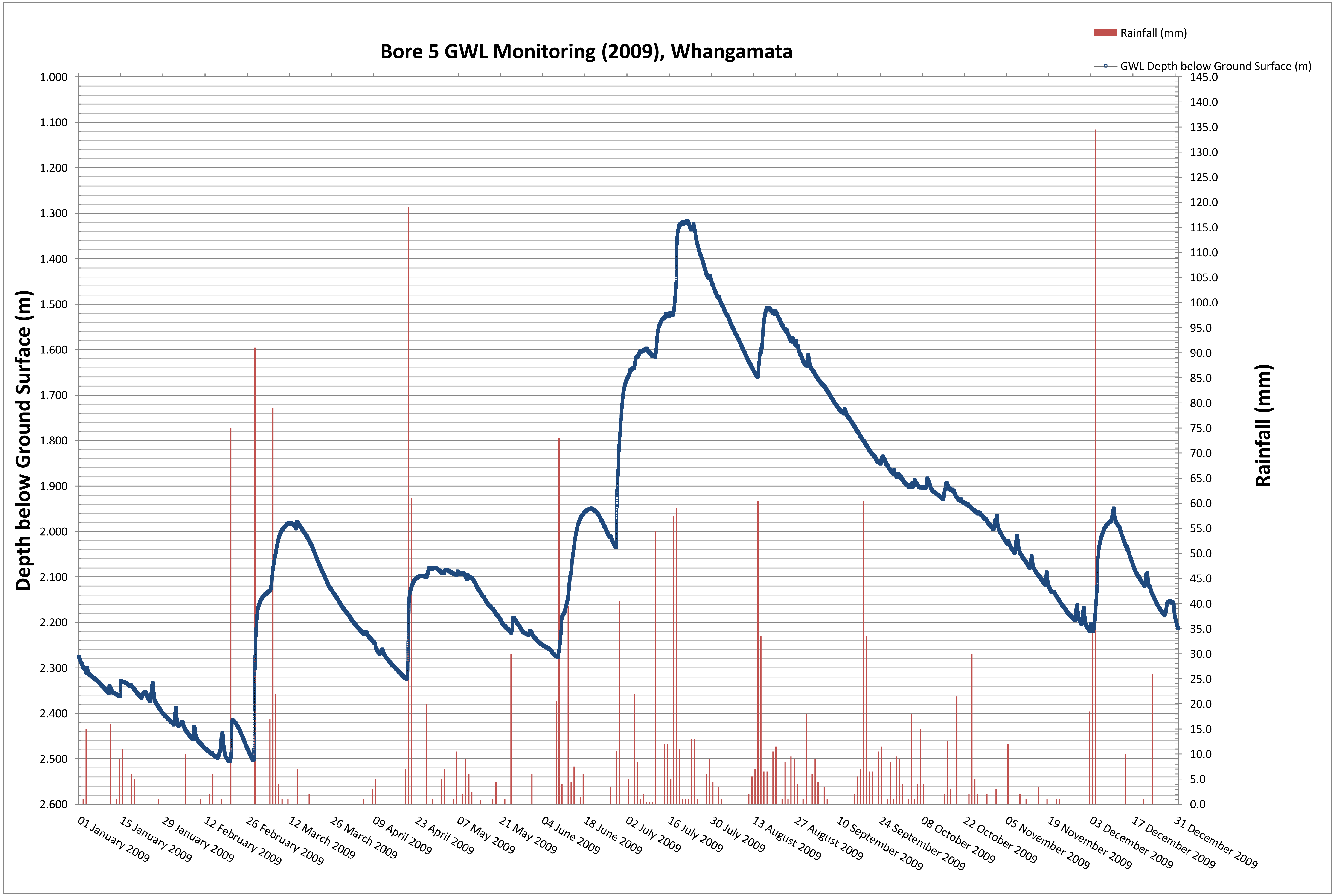

Bore 5 GWL Monitoring (2009), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
1.000
1.100
1.200
1.300
1.400
1.500
1.600
1.700
1.800
1.900
2.000
2.100
2.200
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2.400
2.500
2.600
145.0
140.0
135.0
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05 November 2009
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03 December 2009
17 December 2009
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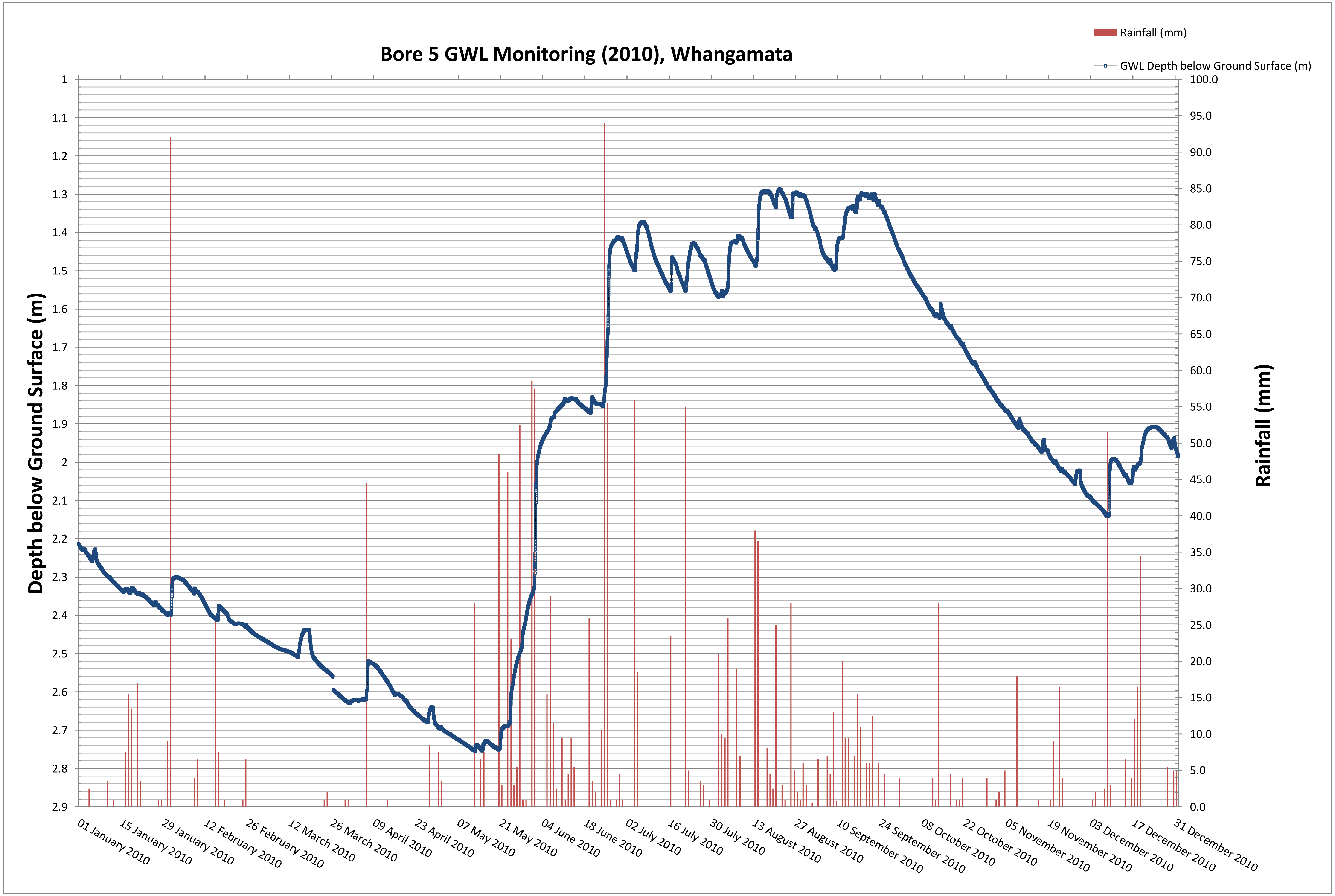

Bore 5 GWL Monitoring (2010), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
100.0
95.0
90.0
85.0
80.0
75.0
70.0
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01 January 2010
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05 November 2010
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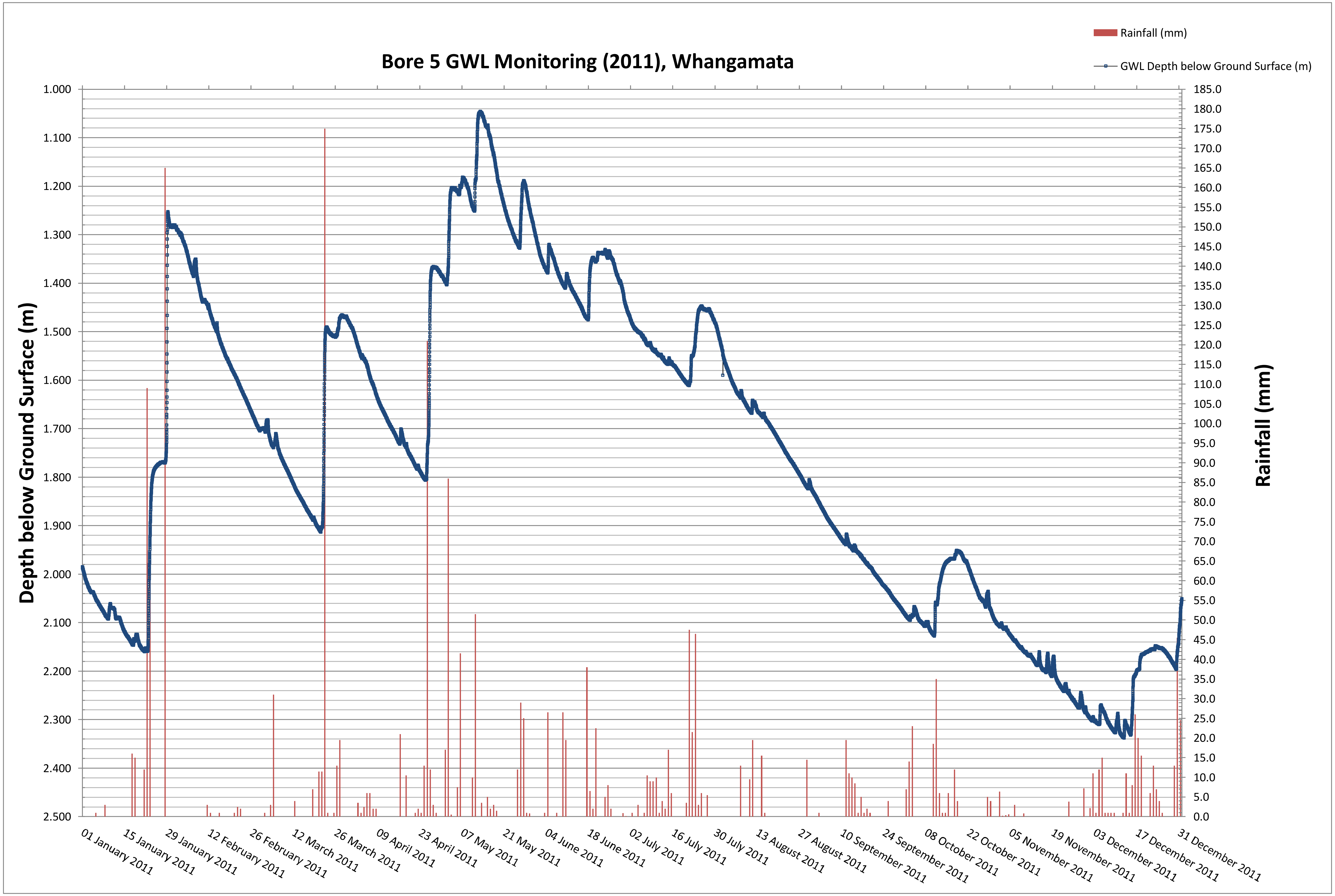
17 December 2010
31 December 2010



Bore 5 GWL Monitoring (2011), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
1.000
1.100
1.200
1.300
1.400
1.500
1.600
1.700
1.800
1.900
2.000
2.100
2.200
2.300
2.400
2.500
185.0
180.0
175.0
170.0
165.0
160.0
155.0
150.0
145.0
140.0
135.0
130.0
125.0
120.0
115.0
110.0
105.0
100.0
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
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45.0
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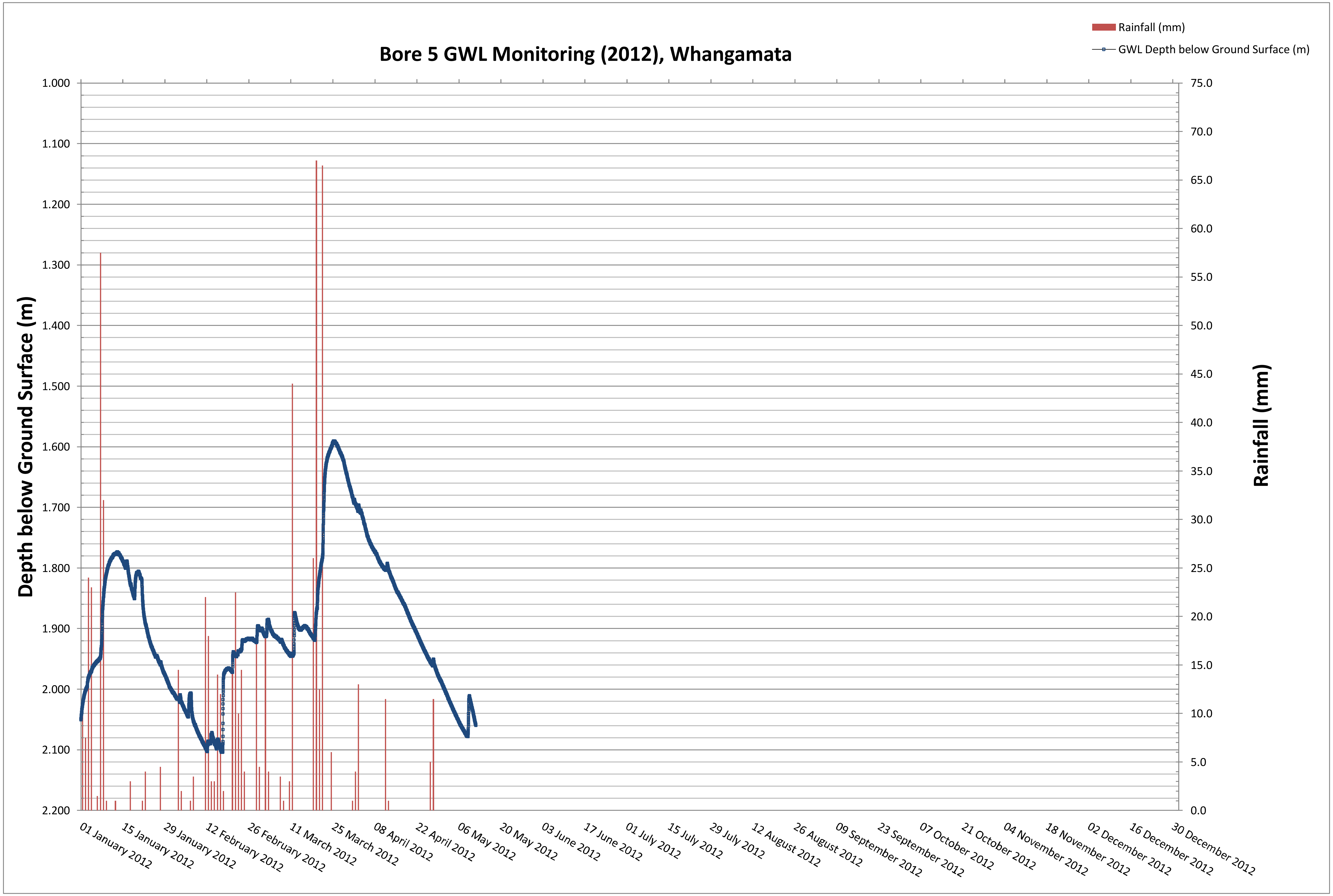
19 November 2011
03 December 2011
17 December 2011
31 December 2011


Bore 5 GWL Monitoring (2012), Whangamata
Rainfall (mm)
GWL Depth below Ground Surface (m)
Depth below Ground Surface (m)
Rainfall (mm)
1.000
1.100
1.200
1.300
1.400
1.500
1.600
1.700
1.800
1.900
2.000
2.100
2.200
75.0
70.0
65.0
60.0
55.0
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01 January 2012
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03 June 2012
17 June 2012
01 July 2012
15 July 2012
29 July 2012
12 August 2012
26 August 2012
09 September 2012
23 September 2012
07 October 2012
21 October 2012
04 November 2012
18 November 2012
02 December 2012
16 December 2012
30 December 2012

Appendix D. Summary Tables

Analysis of maximums, minimums and variation of depths to groundwater.

Values in the table reflect events which were maintained for a duration of at least four hours.

They have been obtained by visually reading of the bore charts.

Table showing the smallest and largest depths to groundwater that lasted a duration of at least 4 hours.

Bore 1	2006	2007	2008	2009	2010	2011	2012	Maximum variation between years.	Average of yearly min/max/ variation	Clearance from soakage tank
Min GWL Depth (m)	-	2.7	2.6	2.5	2.6	2.3	-	0.4	2.5	1.0
Max GWL Depth (m)	-	3.7	3.5	3.5	3.7	3.5	-	0.2	3.6	2.1
Year Variation	-	1.0	0.9	1.0	1.1	1.2	-	-	1.0	
Bore 2										
Min GWL Depth (m)	-	-	0.7	0.7	0.7	0.6	-	0.1	0.7	-0.8
Max GWL Depth (m)	-	-	1.7	1.7	1.9	1.5	-	0.4	1.7	0.2
Difference	-	-	1.0	1.0	1.2	0.9	-	-	1.0	
Year Variation										
Bore 3										
Min GWL Depth (m)	-	-	1.9	2.2	1.8	1.7	-	0.5	1.9	0.4
Max GWL Depth (m)	-	-	3.6	3.4	3.8	3.0	-	0.8	3.4	1.9
Year Variation	-	-	1.7	1.2	2.0	1.3	-	-	1.6	
Bore 4										
Min GWL Depth (m)	-	-	-	3.3	3.2	2.9	-	0.3	3.1	1.6
Max GWL Depth (m)	-	-	-	4.3	4.5	4.0	-	0.4	4.3	2.8
Difference	-	-	-	1.1	1.3	1.1	-	-	1.1	
Bore 5										
Min GWL Depth (m)	-	-	-	1.3	1.3	1.1	-	0.3	1.2	-0.3
Max GWL Depth (m)	-	-	-	2.5	2.8	2.3	-	0.4	2.5	1.0
Year Variation	-	-	-	1.2	1.5	1.3	-	-	1.3	

Same table as above, transposed.
(not including the max variation between years information)

	Bore	1	2	3	4	5	Notes on calculations.
	2006	Less than half years worth of data, therefore not used.					
Min GWL Depth (m)		-	-	-	-	-	
Max GWL Depth (m)		-	-	-	-	-	
	Year Variation	-	-	-	-	-	
	2007						
Min GWL Depth (m)		2.74	-	-	-	-	Min GWL depth obtained from charts
Max GWL Depth (m)		3.72	-	-	-	-	Max GWL depth obtained from charts
	Year Variation	0.98	-	-	-	-	Year variation = Min GWL Depth - Max GWL Depth
	2008						
Min GWL Depth (m)		2.58	0.70	1.90	-	-	Min GWL depth obtained from charts
Max GWL Depth (m)		3.54	1.72	3.63	-	-	Max GWL depth obtained from charts
	Year Variation	0.96	1.02	1.73	-	-	Year variation = Min GWL Depth - Max GWL Depth
	2009						
Min GWL Depth (m)		2.48	0.69	2.17	3.25	1.32	Min GWL depth obtained from charts
Max GWL Depth (m)		3.52	1.65	3.40	4.32	2.50	Max GWL depth obtained from charts
	Year Variation	1.04	0.96	1.23	1.07	1.18	Year variation = Min GWL Depth - Max GWL Depth
	2010						
Min GWL Depth (m)		2.58	0.68	1.84	3.20	1.30	Min GWL depth obtained from charts
Max GWL Depth (m)		3.65	1.85	3.78	4.45	2.75	Max GWL depth obtained from charts
	Year Variation	1.07	1.17	1.94	1.25	1.45	Year variation = Min GWL Depth - Max GWL Depth
	2011						
Min GWL Depth (m)		2.30	0.62	1.72	2.93	1.06	Min GWL depth obtained from charts
Max GWL Depth (m)		3.53	1.48	2.98	4.01	2.33	Max GWL depth obtained from charts
	Year Variation	1.23	0.86	1.26	1.08	1.27	Year variation = Min GWL Depth - Max GWL Depth
	2012	Less than half years worth of data, therefore not used.					
Min GWL Depth (m)		-	-	-	-	-	
Max GWL Depth (m)		-	-	-	-	-	
	Year Variation	-	-	-	-	-	
Avg Min GWL Depth (m)		2.54	0.67	1.91	3.13	1.23	Average = sum of Min GWL depths / number of years of collected data
Avg Max GWL Depth (m)		3.59	1.68	3.45	4.26	2.53	Average = sum of Max GWL depths / number of years of collected data
Avg Year Variation		1.06	1.00	1.54	1.13	1.30	Avg Year variation = Avg Min GWL Depth - Avg Max GWL Depth

Analysis of maximums, minimums and variation of depths to groundwater.

The values in the table reflect events which were maintained for a duration of at least four hours.

From the Summary charts it will good to determine what is the smallest depths to groundwater that last for a minimum week long period. This will help us understand more of the long term peak levels as oppossed to looking at just the instantaneous peak groundwater levels which only last for a very short time and have negligable influence on the ground soakage potential. The following table has been put together through inspection of the summary charts.

Table showing the smallest depths to groundwater that lasted a duration of at least 1 week.

Year	2006	2007	2008	2009	2010	2011	2012	Maximum variation between years.	AVG
Bore 1	-	3.0	2.8	2.8	2.7	2.6	-	0.4	2.8
Bore 2	-	-	0.9	1.0	0.8	0.8	-	0.2	0.9
Bore 3	-	-	2.0	2.3	2.0	1.9	-	0.4	2.1
Bore 4	-	-	3.2	3.4	3.1	3.1	-	0.3	3.2
Bore 5	-	-	1.4	1.6	1.4	1.4	-	0.2	1.4

Maximum variation between years is the difference between the bores lowest and highest experianced maximums and minimums.

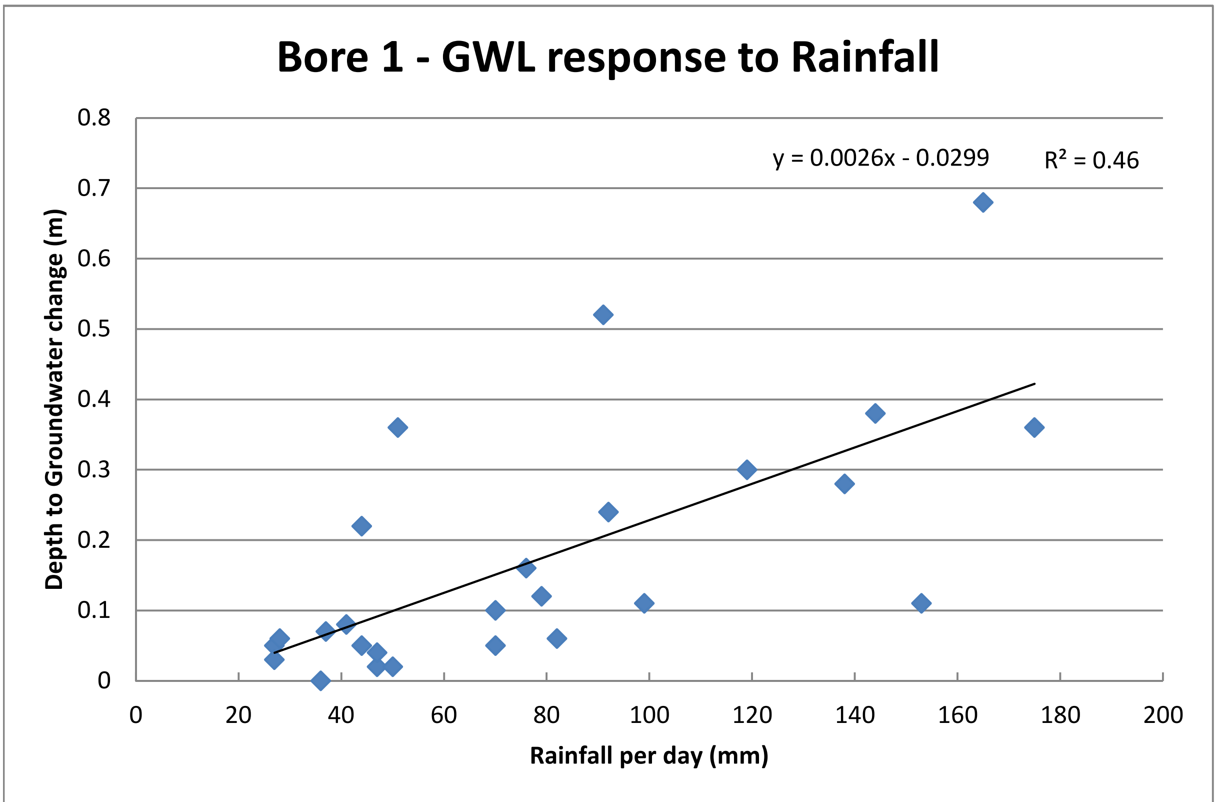
Appendix E. Groundwater Level and Rainfall Relationships

Analysis of rainfall influence on GWL
Bore 1

Note: The plots are showing the influence of daily rainfall events on the depth to groundwater. Not all rain events have been plotted. Attempts have been made to only plot events which have no significant rainfall events preceding the event of concern so its true effect on depth to groundwater is seen. Notably this analysis has not been thorough and has only been conducted to obtain an indication of any relationship that may possibly exist that could be analysed in greater depth on another occasion.

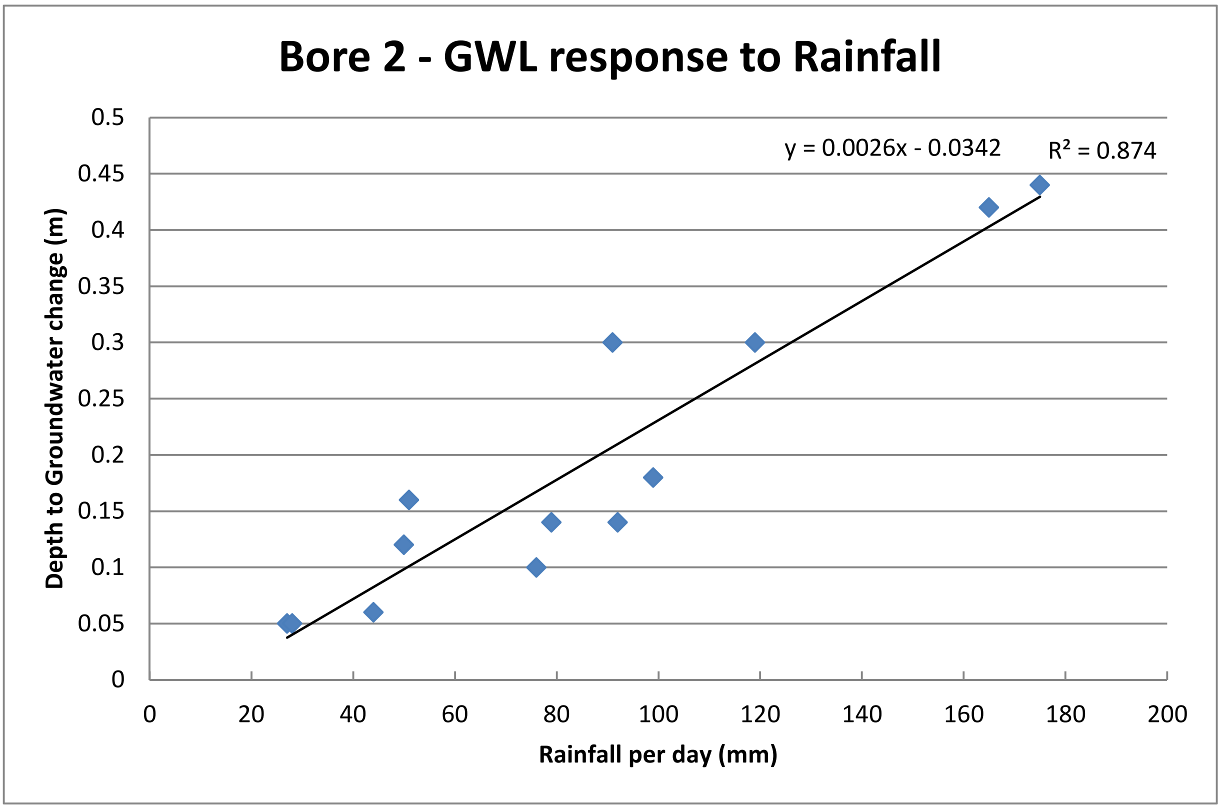
	Rain	GWL increase
2006	41	0.08
2007	37	0.07
	27	0.05
	47	0.02
	47	0.04
	36	0
	144	0.38
	153	0.11
	44	0.05
	138	0.28
	82	0.06
	70	0.05
	50	0.02

	Rain	GWL increase
2008	99	0.11
	70	0.1
	27	0.03
2009	76	0.16
	91	0.52
	79	0.12
	119	0.3
2010	92	0.24
	44	0.22
	28	0.06
	51	0.36
2011	165	0.68
	175	0.36



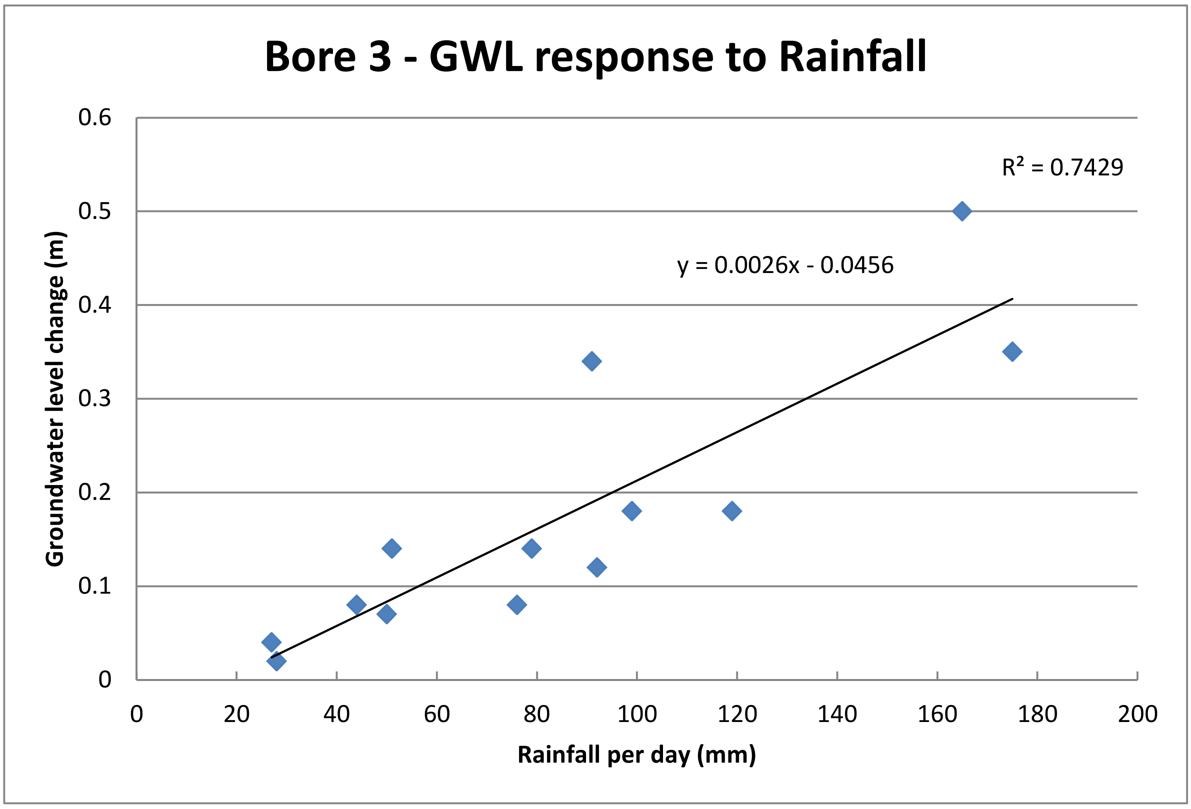
Analysis of rainfall influence on GWL
Bore 2

	Rain	GWL increase
2007	50	0.12
2008	99	0.18
	27	0.05
2009	76	0.1
	91	0.3
	79	0.14
	119	0.3
2010	92	0.14
	44	0.06
	28	0.05
	51	0.16
2011	165	0.42
	175	0.44



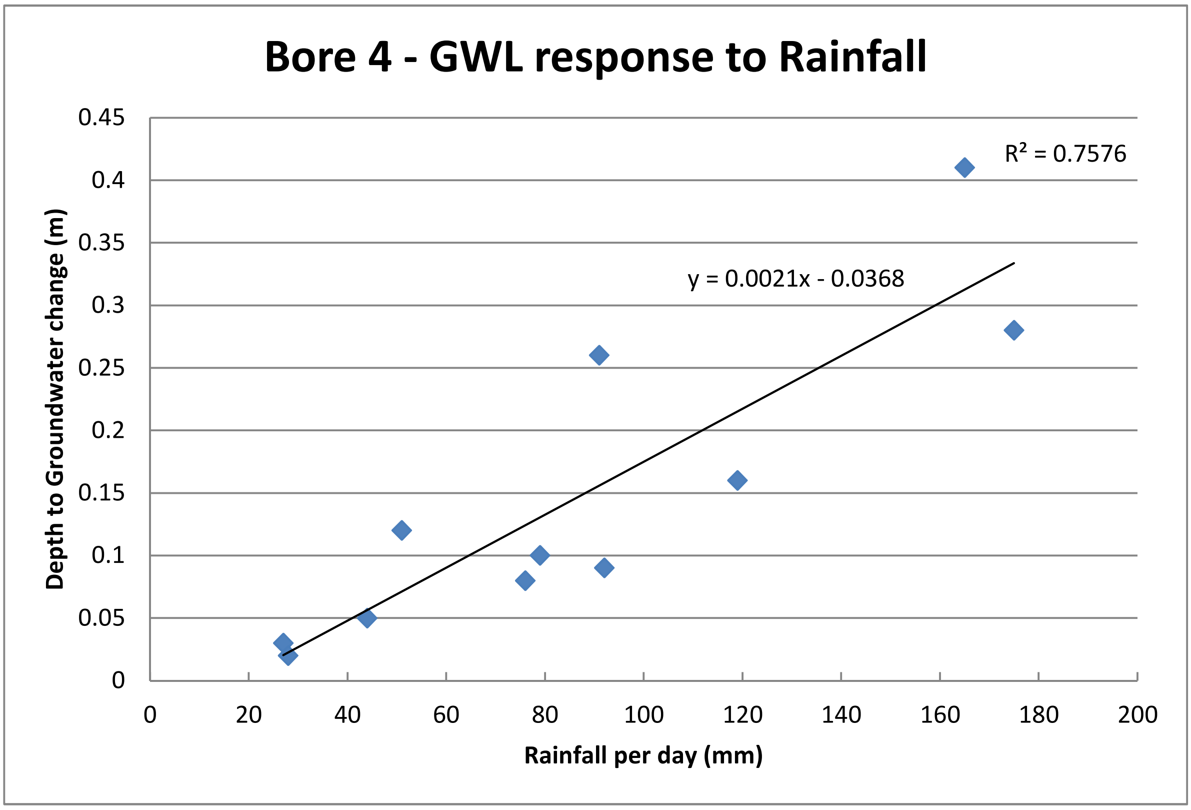
Analysis of rainfall influence on GWL
Bore 3

	Rain	GWL increase
2007	50	0.07
2008	99	0.18
	27	0.04
2009	76	0.08
	91	0.34
	79	0.14
	119	0.18
2010	92	0.12
	44	0.08
	28	0.02
	51	0.14
2011	165	0.5
	175	0.35



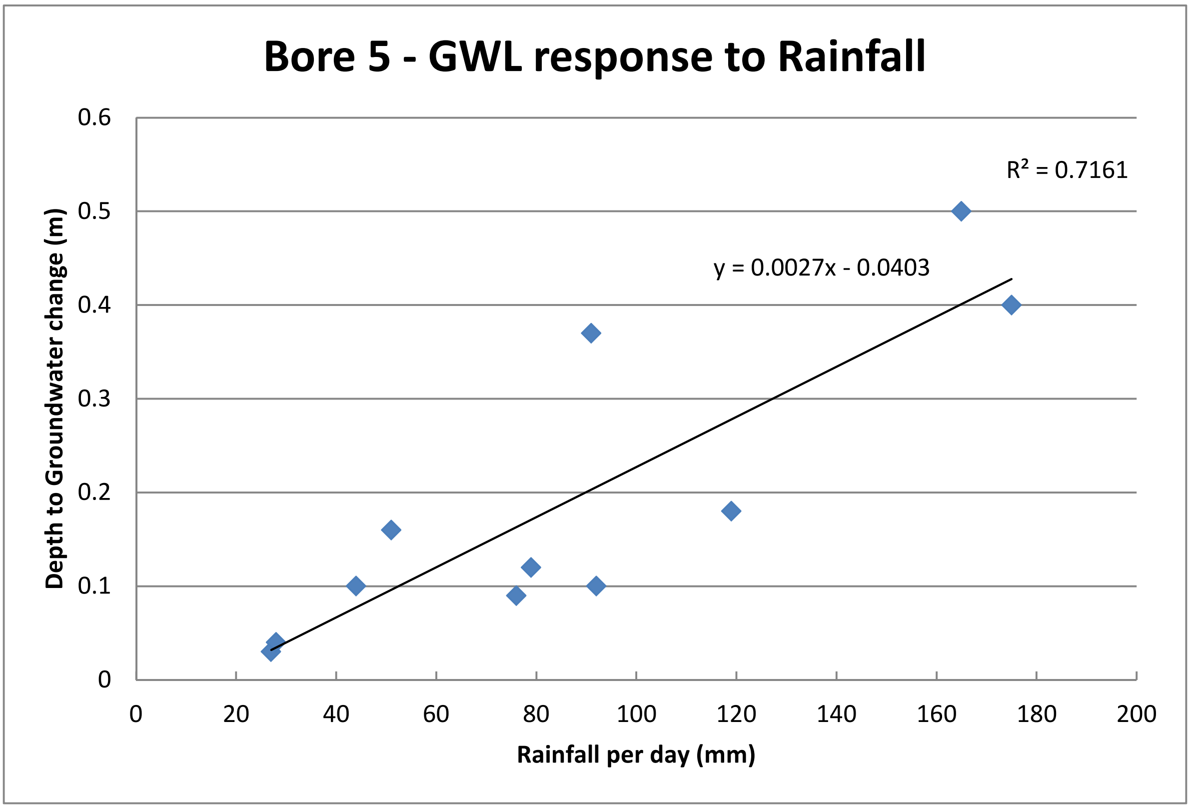
Analysis of rainfall influence on GWL
Bore 4

	Rain	GWL increase
2008	27	0.03
2009	76	0.08
	91	0.26
	79	0.1
	119	0.16
2010	92	0.09
	44	0.05
	28	0.02
	51	0.12
2011	165	0.41
	175	0.28



Analysis of rainfall influence on GWL
Bore 5

	Rain	GWL increase
2008	27	0.03
2009	76	0.09
	91	0.37
	79	0.12
	119	0.18
2010	92	0.1
	44	0.1
	28	0.04
	51	0.16
2011	165	0.5
	175	0.4



Analysis of rainfall influence on GWL

Comments on the graphs.

The plots for Bores 2 to 5 have less data points than that for Bore 1. This is because of less data being available.

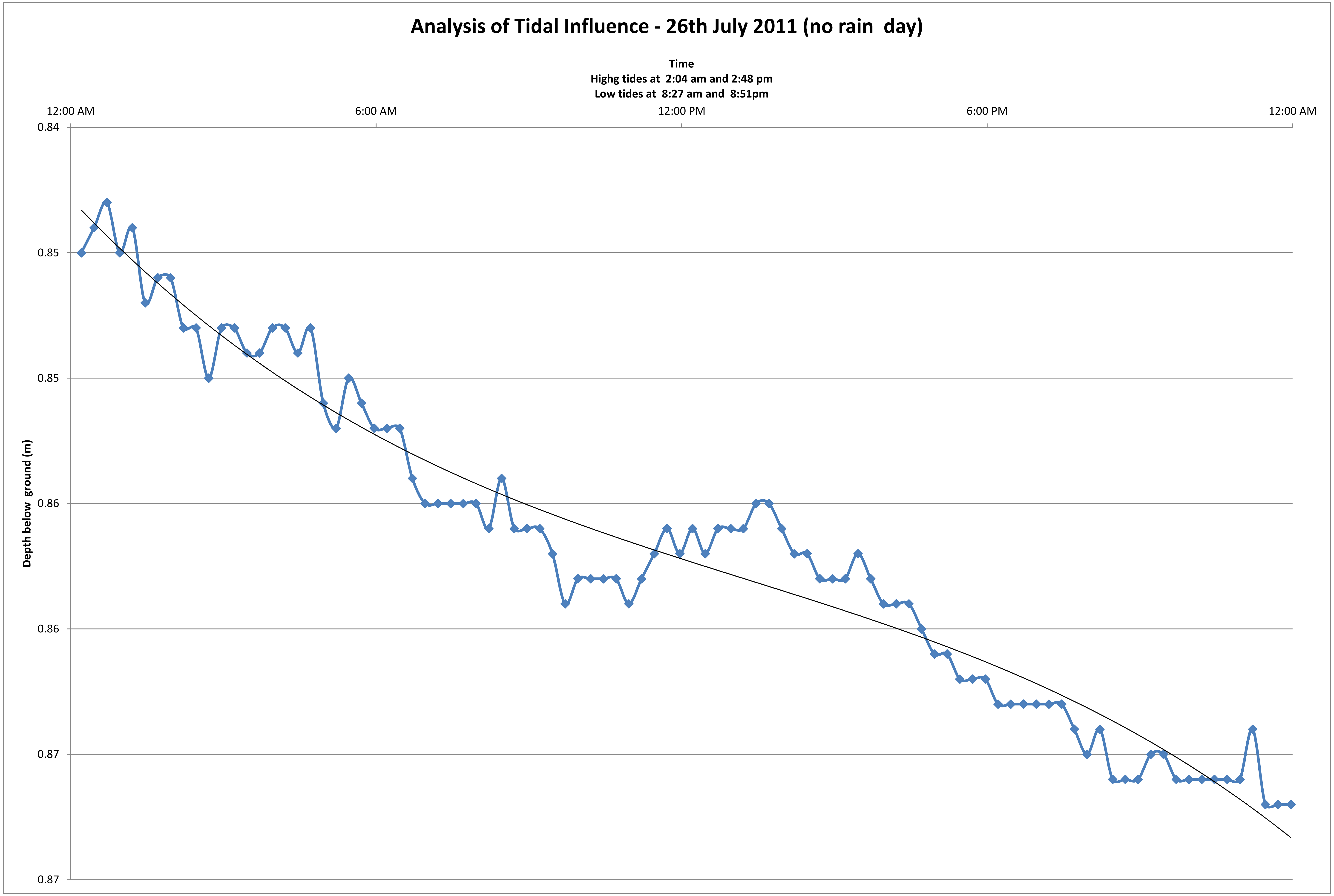
Limitations to the charts are;

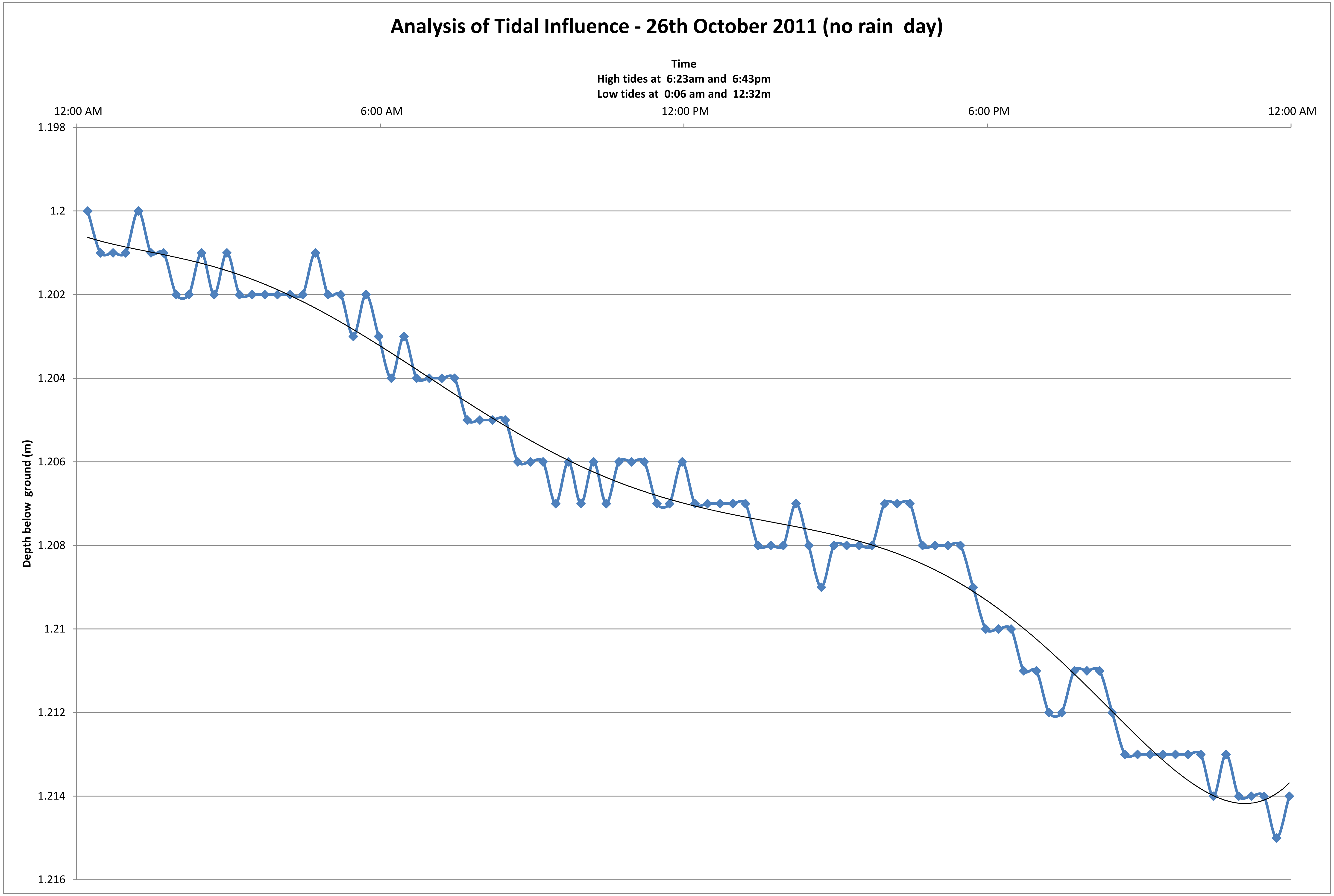
- The rainfall data used is a daily rainfall. There is no way to distinguish between rainfall that fell in short period of time for a given day, i.e. one or two hours as opposed to falling consistently throughout the entire 24 hour period.

- There is no clear distinction between rainfall events and corresponding effects on depth to groundwater for wet periods and dry periods (e.g. summer vs winter), however this could be further investigated within the available data.

- Typically, each of the rainfall events selected are events that had no significant rainfall within 1-7 days beforehand (note this was done by eye, looking at the charts). Therefore, it is unclear from our analysis whether a rainfall event with little preceding rainfall would influence the groundwater level at a given bore site to the same degree as one that did have significant antecedent rainfall.

Appendix F. Tidal Influence


Analysis of Tidal Influence - 26th July 2011 (no rain day)
Time
Highg tides at 2:04 am and 2:48 pm
Low tides at 8:27 am and 8:51pm
12:00 AM
6:00 AM
12:00 PM
6:00 PM
12:00 AM
0.84
0.85
0.85
0.86
0.86
0.87
0.87
Depth below ground (m)


Analysis of Tidal Influence - 26th October 2011 (no rain day)
Time
High tides at 6:23am and 6:43pm
Low tides at 0:06 am and 12:32m
12:00 AM
6:00 AM
12:00 PM
6:00 PM
12:00 AM
Depth below ground (m)
1.198
1.2
1.202
1.204
1.206
1.208
1.21
1.212
1.214
1.216

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