Published by: Department of Primary Industries, 2004
Primary Industries Research Victoria
Bendigo
June 2004

Also published on http://www.nre.vic.gov.au/clpr

Authorised by the Victorian Government, Midland Highway, Epsom.
Printed by Latrobe University Media Services, Bendigo.

The National Library of Australia Cataloguing-in-Publication entry:

Cheng, Xiang, 1965-.
Assessment of the impact of groundwater pumping at Everton
Upper.

ISBN 1 74146 047 6/

1. Groundwater - Victoria - Everton Region. 2. Boring -
Victorian - Everton Region. 3. Salinity - Victoria -
Everton Region. I. Primary Industries Research Victoria.
II. Title. (Series : CLPR research report ; no. 39).

55149099455

ISSN 1447-1043

CLPR Research Report Series: No. 39

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Acknowledgments

This project was jointly funded by the Natural Heritage Trust (NHT) and Department of Primary Industries (DPI) Wangaratta. The author would particularly like to thank Ian Gamble (DPI Wangaratta) for providing all data for the analysis and invaluable comments to this report. Thanks also go to Peter Ockenden (DPI Wangaratta), Mark Reid (DPI Bendigo) and Peter Dickinson (Goulburn-Murray Water) for reviewing this report and providing comments. Leisa Macartney is thanked for providing constructive editorial comments.

Assessment of the impact of groundwater pumping at Everton Upper

Xiang Cheng

Abstract

Everton Upper has been identified as one of the high priority areas in the North East region of Victoria in terms of salinity risk. The area of saline discharge has been expanding rapidly since the early 1980s, even under the dry conditions of the last few years. To address the salinity problem, a five-phase groundwater pumping trial was conducted to investigate the benefits of pumping to lower the watertable for salinity control and irrigation purposes. During the groundwater pumping trial, a significant amount of pumping and monitoring data has been collected. This report characterises the aquifer system at the pumping site and analyses the pumping and monitoring data to determine the impact of groundwater pumping on the watertable. The observed data shows that pumping might have some local impact on the watertable, but there is very little evidence that its impact extended to beyond 300 m from the pumping well. To supplement the analysis of the observed data, the study also calculated theoretical drawdowns caused by pumping the well and estimated annual recharge volume in the area. The results of theoretical calculations also indicated that pumping is unlikely to lower the watertable across a larger area (a radius of 500 m from the pumping well).

Keywords: pumping, Everton, groundwater, salinity

1 Introduction

Salinity has emerged as a serious problem in the Everton Upper area which is located in the Ovens Valley approximately 20 km east of Wangaratta, Victoria. The occurrence of salinity was first observed near the Everton Upper State School in the early 1980s. The area of salt-affected land has expanded significantly, and has attracted attention from both government and community, particularly during the consecutive wet years from the late 1980s to early 1990s. During this period the groundwater level experienced a sharp rise and saline discharge expanded rapidly. The earliest monitoring bores were installed as part of the initial salinity investigation program at the school site in 1989. In recognition of the seriousness of the salinity problem, more monitoring bores were established in the area in the 1990s by the former Department of Natural Resources and Environment (NRE). Currently, there are 27 monitoring bores in this area which are managed by the Department of Primary Industries (DPI). In the same period, some salinity management practices were adopted, including fencing off saline discharge areas, establishing salt-tolerant vegetation in discharge areas and phalaris pasture in high recharge areas. However, there is little evidence that these measures have lowered the watertable and reduced saline discharge even under the extremely dry conditions in the last few years.

To further address the salinity problem at Everton Upper, a groundwater pumping trial commenced in late 1999. Its purpose was to investigate the benefits of pumping fractured rock aquifers to lower the watertable for salinity control and irrigation purposes. Initially, the former NRE in Wangaratta commissioned Sinclair Knight Merz (SKM) to conduct an exploratory groundwater pumping test. A pilot bore and pumping well were drilled, and the properties of the aquifer were determined (SKM 2000). Figure 1 shows the location of the pumping well, pilot bore and monitoring bores at the site.

Following the SKM groundwater pumping test, a five-phase groundwater pumping trial of the pumping well was undertaken by Ian Gamble at DPI-Wangaratta between 28 February 2002 and 23 May 2003. The purpose of this pumping trial was to determine the response of hydraulic head (groundwater level) in the shallow and deep aquifers to pumping at the pumping well. During this pumping trial a significant amount of pumping and monitoring data was collected. However, there had been no analysis undertaken. The purpose of this study is to analyse the collected monitoring data and assess the impact of groundwater pumping on the watertable during the pumping trial.

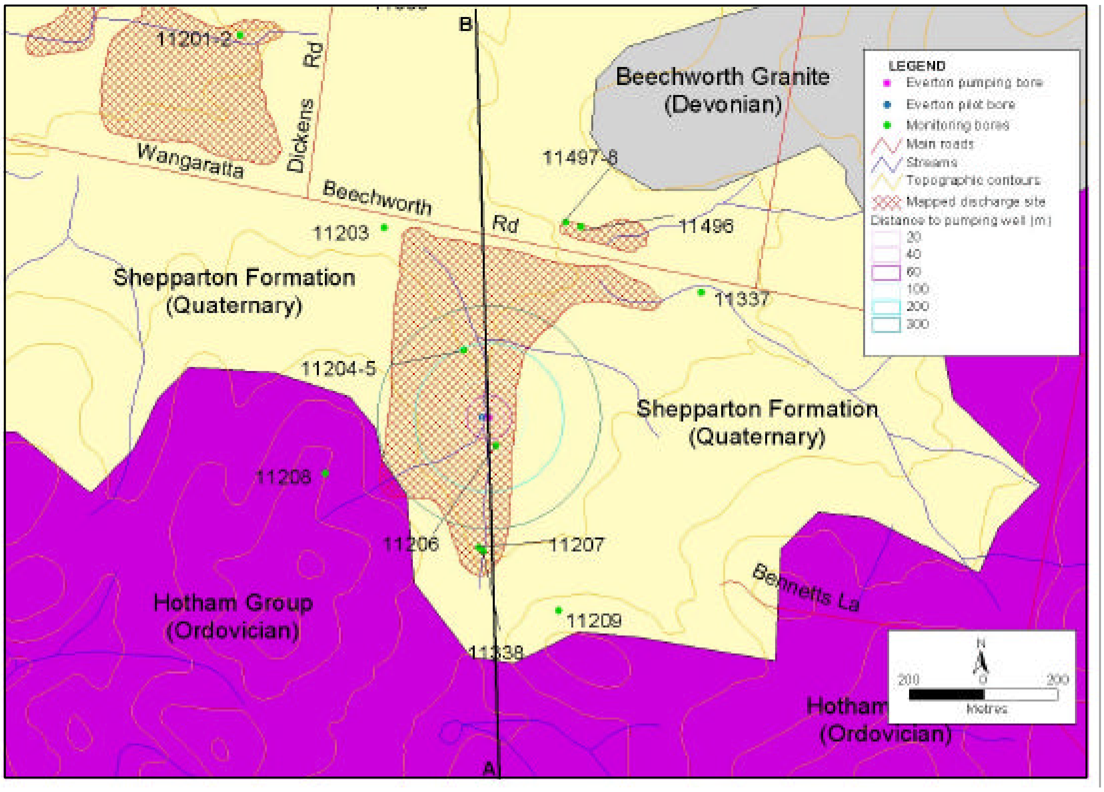

Figure 1 Location of the pumping well and monitoring bores and cross-section AB at Everton Upper

2 Aquifer characteristics

The Everton area, as shown in Figure 1, is located in the foothills of the eastern margin of the Ovens Valley. Its geology is dominated by Ordovician metamorphic rocks (Hotham Group) formed from marine sediments, and Devonian granitic rocks (Fig. 1). These rocks form gently to moderately sloping hills. The metamorphic rocks consist of alternating thinly bedded sandstone and mudstone. The sediment pile is tightly folded and highly fractured. The soil profile typically consists of thin fragment material within a silty matrix which rests upon a weathered rock zone, that is generally greater than 30 m in thickness. In the lower lying area, these rocks are overlain by thin Quaternary deposits (Shepparton Formation), which mainly consist of alluvial deposits (mainly sandy clay and clay).

Rapid infiltration into the aquifer is achieved through bedding plane partings, cleavage, joints and fractures that occur within the uppermost parts of the profile. Fracturing has been observed to persist to great depths.

The Devonian granite (Beechworth Granite) is tightly jointed and has only a thin weathered profile development. However, sandy colluvial deposits accumulate on the lower slopes in particular and offer opportunities for water to enter the colluvial aquifer system and laterally flow down to the lower landscape.

At the Everton Upper pumping site, it is interpreted that a semi-confined artesian aquifer in relatively permeable fractured Ordovician rock is overlain by less permeable weathered rock and clay which forms an aquitard (leaky confining layer). This is evidenced by the artesian groundwater pressure in the pumping well and several monitoring bores.

Figure 2 broadly portrays the conceptual groundwater processes at the pumping site based on available information. Most of the recharge and groundwater flow is believed to be occurring across predominantly cleared hills composed of the fractured metamorphic rocks. It is most likely this process is the main driver for the occurrence of saline discharge. However, other factors are also believed to have a significant influence on the groundwater processes at the site. The fresh granite bedrock in the north may play a significant role in restricting groundwater flow out of the sub-catchment due to its sparse fracturing and very low permeability. It forms a substantial barrier to groundwater flow in the metamorphic rock, forcing the groundwater upwards under pressure so that it leaks gradually through the overlying weathered material to the surface. The topography may also have some influence. The site could be regarded as a small, semi-closed catchment which lacks a well-defined drainage line. This may assist groundwater accumulating at the site.

Determining aquifer properties is always an important part of any hydrogeological investigation. SKM (2000) conducted a 24-hour constant rate pumping test to determine the properties of the fractured rock aquifer. Transmissivity and storativity were estimated from the constant rate test by using the Cooper-Jacob drawdown versus time method. The transmissivity and storativity were $32\ m^2$/day and 4.3×10^{-3}, respectively. In contrast, the values of transmissivity were calculated by the Moench w/slab block method and Theis drawdown method to be $7\ m^2$/day and $6\ m^2$/day respectively. However, these estimations were based on the assumption that the fractured rock aquifer is isotropic and homogeneous. In the real world, fractured rock aquifers are more likely to be anisotropic and heterogeneous.

The overlying clay and sandy clay layers are expected to be much less permeable. The typical range of values of hydraulic conductivity for clay is $10^{-6} - 10^{-3}$ m/day. The values of specific yield for clay vary from 0.01 to 0.18, with a mean value of 0.06.

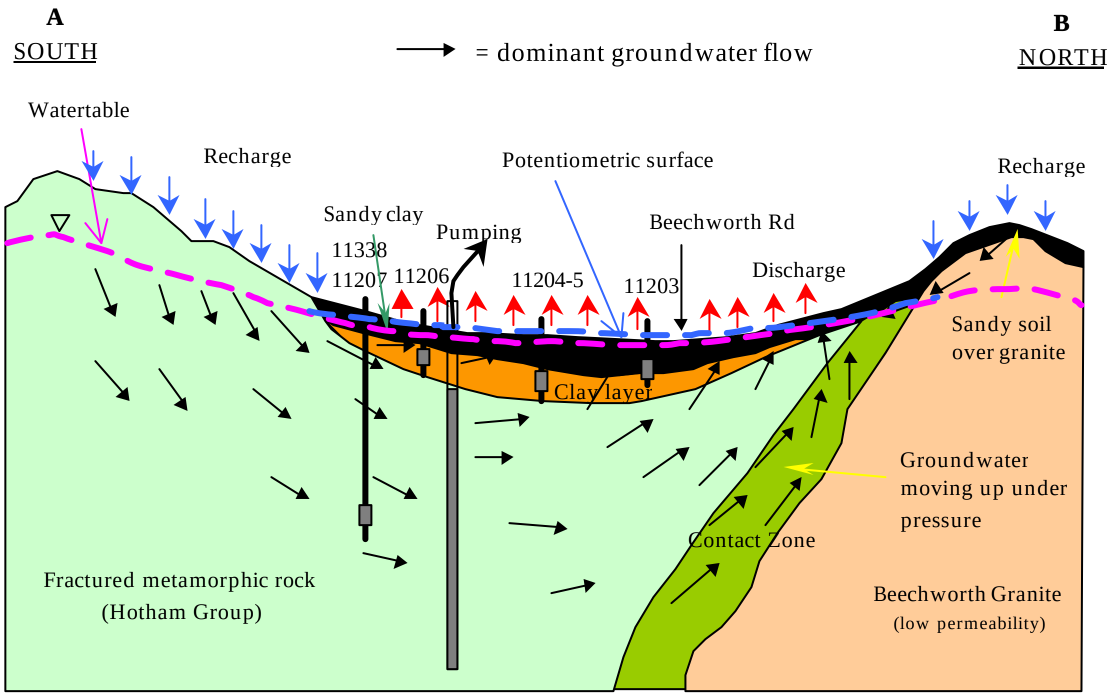

Figure 2 Simplified cross-section showing hypothetical salinity processes in the Everton Upper areas (viewed from east, not to scale). See Figure 1 for location of cross-section.

3 Impact of groundwater pumping on groundwater level

3.1 The impact of short-term pumping

To determine the response of hydraulic head in the shallow (weathered material and Quaternary deposits) and deep aquifers (fractured rocks) to groundwater pumping, five phases of the groundwater pumping trial were conducted on the pumping well between 28 February 2002 and 23 May 2003. The five pumping phases are summarised in Table 1.

Table 1 Summary of the five pumping phases

Pumping phase	Start	Finish	Duration	Volume (m^3)	Groundwater salinity (*m*s/cm)	Mean flow rate (L/s)
Phase 1	28/2/02 11:05 am	1/3/02 1:11 pm	26.08 hrs	208.452	3000 – 3200	2.22
Phase 2	2/3/02 2:30 pm	3/3/02 9:49 am	19.36 hrs	158.248	3100 – 3200	2.27
Phase 3	4/3/02 10:05 am	5/3/02 5:00 pm	30.92 hrs	245.987	3200 – 3300	2.21
Phase 4	6/3/02 4:30 pm	7/3/02 9:16 pm	28.71 hrs	226.328	3100 – 3500	2.19
Phase 5a	29/3/02 9:30 pm	19/5/02 7:00 am	Approx. 50 days	3600.78	2900 – 4100	Approx. 2.2
Phase 5b	4/9/02 10:00 am	23/5/03 3:00 pm	Approx. 7 months	16891.04	2900 – 4100	Approx. 2.2

In the first four phases, the pumping well was continuously pumped for approximately 19-31 hours. The intention of these four phases was to determine the response of groundwater level to short-term groundwater pumping. Pumping rate and groundwater salinity were measured on a regular basis (approximately 30 minute intervals) for the pumping bore. Water levels in the pilot bore and other nearby monitoring bores were also recorded. The pilot bore and other monitoring bores in which water levels were measured during pumping are listed in Table 2. Only two monitoring bores were constructed in the fractured metamorphic rock aquifer – the pilot bore and Bore 11338. Other monitoring bores are shallow, constructed in the upper weathered profile or Quaternary alluvial deposits. Water level in the pilot bore was logged at 30 minute intervals. Water levels in other bores were generally recorded at the beginning and end of each pumping period. Bores 11201 and 11202, which are located north of the Wangaratta-Beechworth Road, were not monitored in these four phases.

Appendix 1 presents the groundwater hydrographs for the monitoring bores and pilot bore during Phases 1 to 4 of the pumping trial. The hydrographs show that the pilot bore, located approximately 20 m from the pumping well, was the only bore experiencing a significant drop in water level during these phases of the pumping trial. The drop of water level in the pilot bore ranged from 1.5 m (Phase 2) to 2.1 m (Phase 3). Bore 11206, which is located approximately 70 m from the pumping well, may have also experienced a drop in the water level. The water level in this bore dropped about 22 cm during Phase 2 of the pumping trial. Unfortunately, this bore was overflowing during the other three phases and changes of water level could not be observed. The water levels in the other five monitoring bores fluctuated within 5 cm during these phases and there is very little evidence that the fluctuation correlated with drawdown in the pumping well and the pilot bore. From the observed data, it seems that the influence of pumping on the water level did not extend beyond 200 m from the pumping well during phases 1 to 4.

Table 2 Construction information of the pumping, pilot and monitoring bores

Bore ID	Zone	Easting	Northing	RLNS	Bore depth (m)	TOC height (m)	Screen interval (m)	Formation screened	Distance to the pumping bore (m)
Pumping bore	55	457480	5971600	201.9	86		38 – 86	Fractured metamorphic rock	0
Pilot bore	55	457460	5971600	202.1	86	1.7	74 – 86	Fractured metamorphic rock	20
11201	55	456811	5972630	189.06	19.25	0.4	15 – 18	Weathered rock	1230
11202	55	456811	5972630	189.06	3.25	0.5	3.25	Alluvial deposits	1230
11203	55	457199	5972113	196.81	9.25	0.6	6 – 9	Alluvial deposits	590
11204	55	457411	5971785	198.68	10.65	0.55*	7 – 10	Weathered rock	200
11205	55	457411	5971785	198.68	2.9	0.45*	2.9	Alluvial deposits	200
11206	55	457499	5971529	202.77	9.5	0.5*	6 – 9	Alluvial deposits	70
11207	55	457453	5971256	207.63	17.7	0.9	14 –17	Weathered rock	350
11338	55	457464	5971245	208.05	54.75	0.35	47 – 52	Fractured metamorphic rock	360

* The TOC heights for bores 11204, 11205 and 11206 were extended to 1.6 m, 1.75 m and 1.98 m on 29/03/02, respectively.

3.2 The impact of longer term pumping

The purpose of Phase 5 of the pumping trial was to determine the impact of longer term groundwater pumping on the groundwater level at the Everton Upper site. This phase comprised of two pumping periods:

- The first one was from the 29 March 2002 to 19 May 2002.
- The second one was from the 4 September 2002 to 23 May 2003.

There was a winter break between the two pumping periods. During these two pumping periods, the pumping well was typically pumped for approximately 9 hours a day (10 pm to 7 am) except for those days immediately after significant rain. The pump was normally shut down for a few days after a major rainfall event.

In this phase, pumping rate and groundwater salinity were also measured on a regular basis at the pumping bore. Water level in the pilot bore was automatically logged on a half-hourly basis. Water levels in the selected monitoring bores were typically recorded at the beginning and end of daily pumping. Bores 11201 and 11202 were monitored as control bores (for barometric correction) in this phase.

Appendix 2 presents the groundwater hydrographs of the monitoring bores and the two-day moving average of water level in the pilot bore (thick red line) in Phase 5 of the pumping trial. Again, the hydrographs show that the pilot bore was the only bore which experienced a significant drawdown in water level during pumping. Although there is no evidence that water levels in any of the other monitoring bores fluctuated with daily pumping, water levels in some selected monitoring bores (Bores 11204, 11205 and 11206) seemed to respond to longer periods of pumping. However, the variation of water level in these bores also correlated with the seasonal rainfall pattern at Everton Upper (Appendix 3) and the influence of pumping is difficult to determine. Therefore, from the hydrographs, it cannot be concluded whether the drop in water level in these monitoring bores was due to pumping or dry conditions. It is noted that the sharp decline of water levels in these bores during early March 2003 was due to a sampling program undertaken by Melbourne University students.

The correlation between water level in the control bores (11201 and 11202) and those in other monitoring bores may provide a good indication as to the influence of pumping on the water level (Appendix 4). The degree of correlation is expressed by R-squared value, R^2. The analysis presented in Appendix 4 shows that the water level in Bores 11202, 11203, 11207 and 11338 strongly correlate with the water level in Bore 11201. Bore 11201 is located north of the Wangaratta-Beechworth Road (approximately 1200 m from the pumping well) and its water level is unlikely to be influenced by the pumping well. The strong correlation of water levels indicate that the impact of pumping in Phase 5 on these bores was negligible. Correlation between water levels in Bores 11204, 11205 and 11206, and the water level in Bore 11201 was very poor. This poor correlation was probably due to the effect of pumping. However, in relation to Bore 11205 this poor correlation may have been due at least in part to unreliable data. Ian Gamble of DPI Wangaratta reported that unusual watertable behaviour prior to and during the pumping trial had been recorded for Bore 11205 and this seems evident in Appendix 2.

3.3 Analytical calculations

As there were only two monitoring bores constructed in the fractured rock aquifer, the influence of the pumping on the potentiometric surface (i.e. groundwater pressure in the fractured rock aquifer) could not be accurately determined from the monitoring data. It is useful, however, to calculate the drawdowns using an analytical method. There are a number of methods available for computing drawdown caused by a pumping well. Based on the pumping data and aquifer characteristics, the ‘Theis equation’ is considered to be one of the most suitable methods. To use the Theis equation to calculate drawdown, a number of assumptions about the hydraulic conditions of the pumping and monitoring bores have to be made. The key assumptions include:

- The pumping well fully penetrates a completely confined aquifer.
- The well is pumped continuously at a constant rate.
- The aquifer is homogeneous and isotropic.
- There is no source of recharge to the aquifer.

In addition to these assumptions, other basic assumptions are also made which are listed in many standard hydrogeology text books (e.g. Fetter 1994).

Drawdowns at various locations (varying from 20 m to 500 m from the pumping well) were calculated for 1-day and 10-day continuous pumping (Tble 3). According to the theoretical calculation, 1-day pumping could have a noticeable impact on the water level up to 200 m from the pumping well, while 10-day pumping could extend a significant impact to more than 300 m from the pumping well.

The calculated drawdowns at 20 m from the pumping well are very similar to the recorded drawdowns in the pilot bore, which ranged from 1.53 to 2.11 m during the first four phases (approximately 1 day of pumping in each phase). Comparison of the calculated drawdowns to the recorded values in the pilot bore in the two pumping periods of Phase 5 (which were 2.7 m and 3.8 m, respectively) is much less straightforward for the following reasons:

- The well was not pumped continuously for these two periods and therefore the drawdown cannot be calculated for the corresponding periods.
- Climate also had some influence on water level during these two pumping periods, particularly the second period which lasted for approximately seven months (during spring, summer and autumn).

However, the calculated drawdowns for 10-day continuous pumping are believed to provide a good indication for the impact of longer term pumping on the fractured rock groundwater pressure.

Table 3 Calculated drawdowns caused by the pumping well

Q (L/s)	T1 (m^2/day)	S	r (m)	t_1 (day)	t_2 (day)	h_0-h for t_1 (m)	h_0-h for t_2 (m)
2.2	32	0.0043	20	1	10	1.832	2.883
2.2	32	0.0043	40	1	10	1.172	2.203
2.2	32	0.0043	50	1	10	0.974	1.992
2.2	32	0.0043	60	1	10	0.829	1.842
2.2	32	0.0043	100	1	10	0.419	1.352
2.2	32	0.0043	200	1	10	0.084	0.765
2.2	32	0.0043	300	1	10	0.006	0.426
2.2	32	0.0043	500	1	10	<0.001	0.137

Notes:
Q - the constant pumping rate
h - hydraulic head
h_0 - hydraulic head before pumping started
h_0-h - the drawdown at the end of pumping
T - aquifer transmissivity
t - time from the beginning to end of pumping
r - radial distance from the pumping well
S - aquifer storativity

3.4 Estimate of annual recharge

The annual recharge to an unconfined aquifer can be estimated from the size of the annual recharge spikes on the groundwater hydrograph if an aquifer storage term is assumed:

Annual recharge rate = aquifer storage term × hydrograph fluctuation
(specific yield) (annual recharge spike)

It is interpreted that the shallower aquifer is unconfined across the Everton pumping site (Section 2). Therefore this method can be used to estimate the annual recharge across the site.

In a year with average rainfall (e.g. 1999 and 2000), the size of the annual recharge spikes of the hydrographs of shallow bores (constructed in the unconfined aquifer) typically range from 0.5 to 0.8 m at the Everton pumping site. If the mean specific yield of the aquifer is assumed to be 0.06 (Section 2), the typical annual recharge rates would range from 30 to 48 mm. If 70% of the total catchment area (approximately 630 ha) is considered as a recharge area with this recharge rate, the typical annual volume of recharge into the groundwater system would be in the range of 190–300 ML. This recharge value is likely to be underestimated, as discharge occurring during the same period is not taken into account in this calculation.

Based on the groundwater pumping test and trial, the annual volume extracted from the well is approximately 16 ML, which is 5–8% of the estimated annual recharge volume. This volume of groundwater extraction is equivalent to lowering the watertable by about 3 cm/year across the catchment. However, if this volume was converted to the watertable within a radius of 300 m from the pumping well, the drop in watertable would be much greater. This calculation assumes that the fractured rock aquifer has a good hydraulic connection with the shallower watertable aquifer.

4 Discussion

Confinement of the fractured metamorphic rock aquifer may be one of the reasons why pumping was not very effective in lowering the shallow watertable. At the pumping site, particularly in the lower lying area, there is an artesian groundwater pressure which results in a significant upward vertical hydraulic gradient (groundwater pressure gradient). Therefore, to lower the shallow watertable during pumping, this vertical hydraulic gradient must be downward. In other words, the groundwater pressure in the fractured aquifer must be drawn below the shallow watertable level by pumping before lowering of this watertable can occur. However, both the theoretical calculation and observed data show that short-term (Phase 1 to 4) and longer term (Phase 5) groundwater pumping might only draw the potentiometric surface (groundwater pressure in the fractured rock aquifer) below the shallow watertable within a short distance from the pumping well (less than 300 m radius).

The theoretical calculation of drawdowns is based on a number of assumptions, and theoretical results may not reflect the actual drawdowns of the potentiometric surface. The assumptions were much more likely to result in over-estimating the drawdowns. For example, the calculation assumes that there is no source of recharge and leakage from the upper aquifer to the aquifer being pumped. This assumption is unlikely to be valid for the calculation of drawdown due to the longer period of pumping. The recharge values may also have been overestimated. However, these overestimates have served the purpose of this assessment.

Another possible reason for the lack of pumping-induced response in the watertable could be poor hydraulic connection between the developed fractured rock aquifer and the Quaternary sediments containing the watertable due to the presence of a clay aquitard layer. A hydrogeochemistry study by the University of Melbourne (Weaver[1] pers. comm.) also found little evidence of interaction between the deeper groundwater in the fractured rocks and the shallow groundwater in Quaternary sediments.

It is important to point out that there may be some significant geological structures (e.g. faults) in the pumping site vicinity, which may induce highly anisotropic and heterogeneous conditions. For example, fractured zones along a major fault may be much more permeable and groundwater pumping would have a greater influence along these zones. However, it is not possible to consider this heterogeneity in this assessment due to a lack of information. This situation does add some uncertainties to the results of this assessment. The significance of these uncertainties is unknown.

Currently, there are only two monitoring bores constructed in the fractured rock aquifer – the pilot bore and Bore 11338. The other monitoring bores are shallow and constructed in the upper weathered profile or alluvial deposits. Some of these monitoring bores (e.g. Bore 11205) did not function well or were affected by other research programs during the groundwater pumping trial period. Additionally, the locations of most monitoring bores are not considered ideal for this analysis. To more accurately assess the impact of groundwater pumping from the existing well, more reliable observed data would be required, which includes:

- more monitoring bores which are strategically located and constructed
- a longer period (more than three seasons) of good groundwater pumping and monitoring data.

5 Conclusion and recommendations

Based on the analysis of the available observed data and theoretical calculations, short-term groundwater pumping (less than two days) from a single well developed in the fractured rock aquifer is concluded to have only a minor impact on the watertable to a distance up to 200 m from the well. Longer term (spring, summer and autumn) pumping from the single well might extend the impact beyond 300 m from the pumping well. However, the degree of impact, although not conclusive, is thought likely again to be only minor.

Analysis of groundwater recharge in the Everton Upper sub-catchment also indicates that the volume of groundwater pumped from a single well may only have a minor impact on the watertable in a small area (a radius of less than 500 m).

Despite some reservations with the quality of the available observed data from the pumping tests, it is concluded that longer term pumping of the single production well at Everton Upper is not likely to cause significant or beneficial lowering of the watertable in terms of area or depth.

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[1] Weaver, T (senior lecturer in hydrogeology, The University of Melbourne), 2004.

Possible reasons for the lack of pumping-induced response in the watertable could include,

(i) relatively poor hydraulic connection between the developed fractured rock aquifer and the Quaternary sediment aquifer, and

(ii) the lack of depth and spatial extent of drawdown induced in the fractured rock aquifer, thereby limiting the potential for downward leakage from the Quaternary sediments.

The results indicated that groundwater flow is dominant within the developed fractured rock zone and that only minor leakage was induced from the watertable aquifer. The results furthermore indicate that multiple wells (two or more) in the fractured rock would be required to produce beneficial impacts on the watertable. However, the costs of doing this would most likely exceed the benefits and there could be longer term management issues due to the marginal quality of the extracted groundwater. Therefore, it is concluded at this stage that groundwater pumping from the fractured bedrock aquifer does not offer sufficient potential for effective management of salinity at the Everton Upper discharge site. The alternative of intercepting groundwater from the watertable aquifer itself (ie, Quaternary sediments) may be difficult due to low permeabilities. Also, the higher salinities of this aquifer pose difficult challenges for use or disposal of the groundwater.

Unfortunately, there can only be limited conclusions drawn from the Everton Upper pumping trial in terms of knowledge transfer to other salinity areas in the North East region. This is largely due to the wide variation in catchment and hydrogeological conditions from sub-catchment to sub-catchment. Nevertheless, some general conclusions and recommendations are made below.

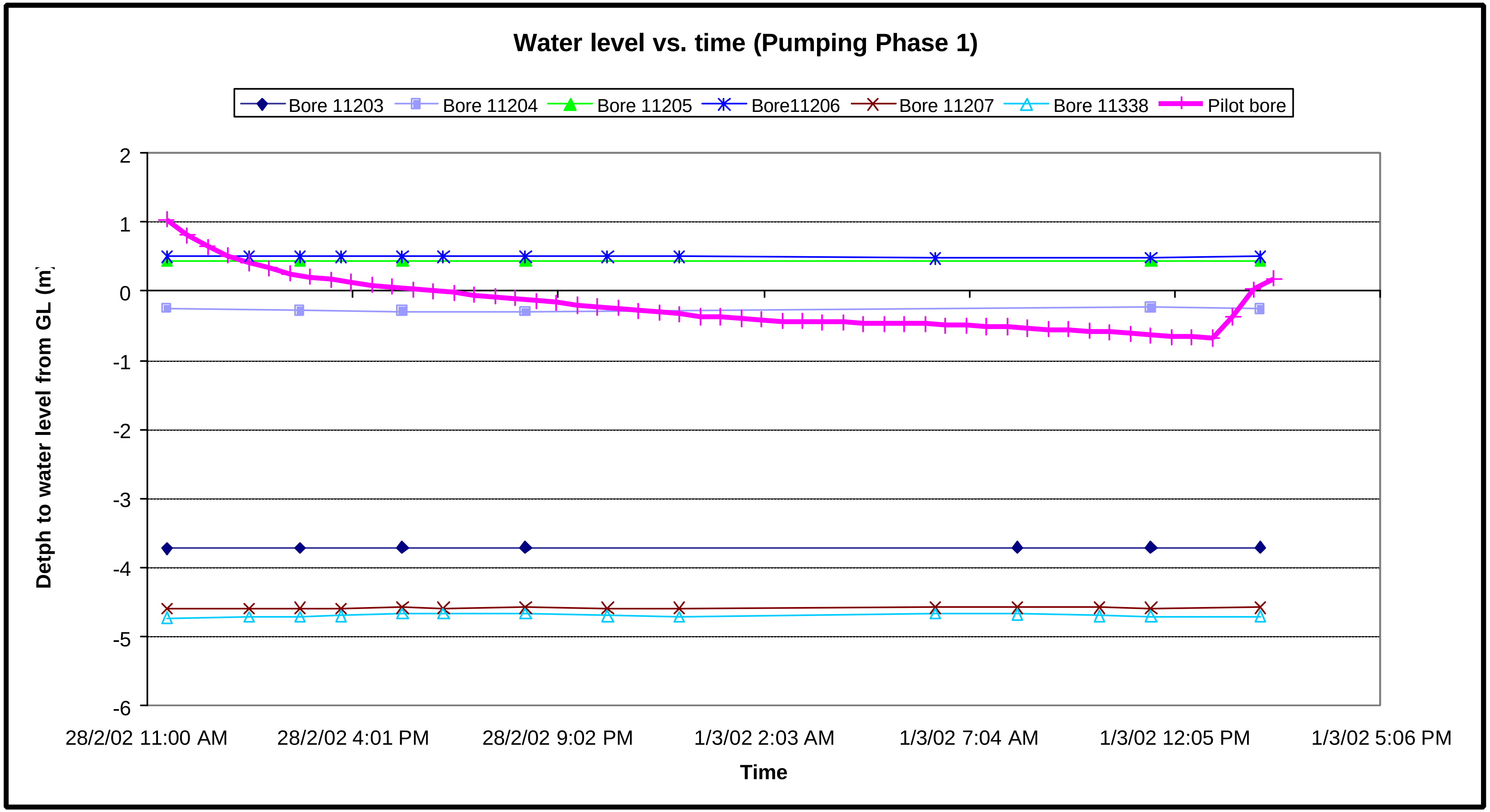
While the groundwater pumping appears to have limited success in terms of salinity benefits at Everton Upper, this is not likely to be the case everywhere else. There is still believed to be some salinity management scope for groundwater interception and reuse in other areas of the North East region. However, before any consideration of this form of salinity intervention is made at other locations, it is necessary firstly to identify whether there is a sufficiently important or valuable asset to protect, as the implementation costs are usually high. If a valuable asset is identified warranting consideration of groundwater interception, a preliminary technical appraisal of the feasibility needs to be made based on site-specific geological and hydrogeological information. This information needs to be of sufficient detail to determine the nature of the salinity process and, depending on this, determine whether,

(i) a potentially suitable target aquifer having good or reasonable hydraulic connection to the watertable exists around or adjacent the asset to be protected, and

(ii) the groundwater salinity of the potential target aquifer is of a level that can be safely utilised or disposed without significant long-term disbenefits (on-site or off-site).

It should be stressed that if such a preliminary evaluation as described here indicates potential feasibility for groundwater pumping at a location, it is still important to then undertake more detailed testing and assessment to prove the potential.

Appendix 1 Groundwater hydrographs for the monitoring bores and pilot bore during Phases 1-4 of the pumping trial



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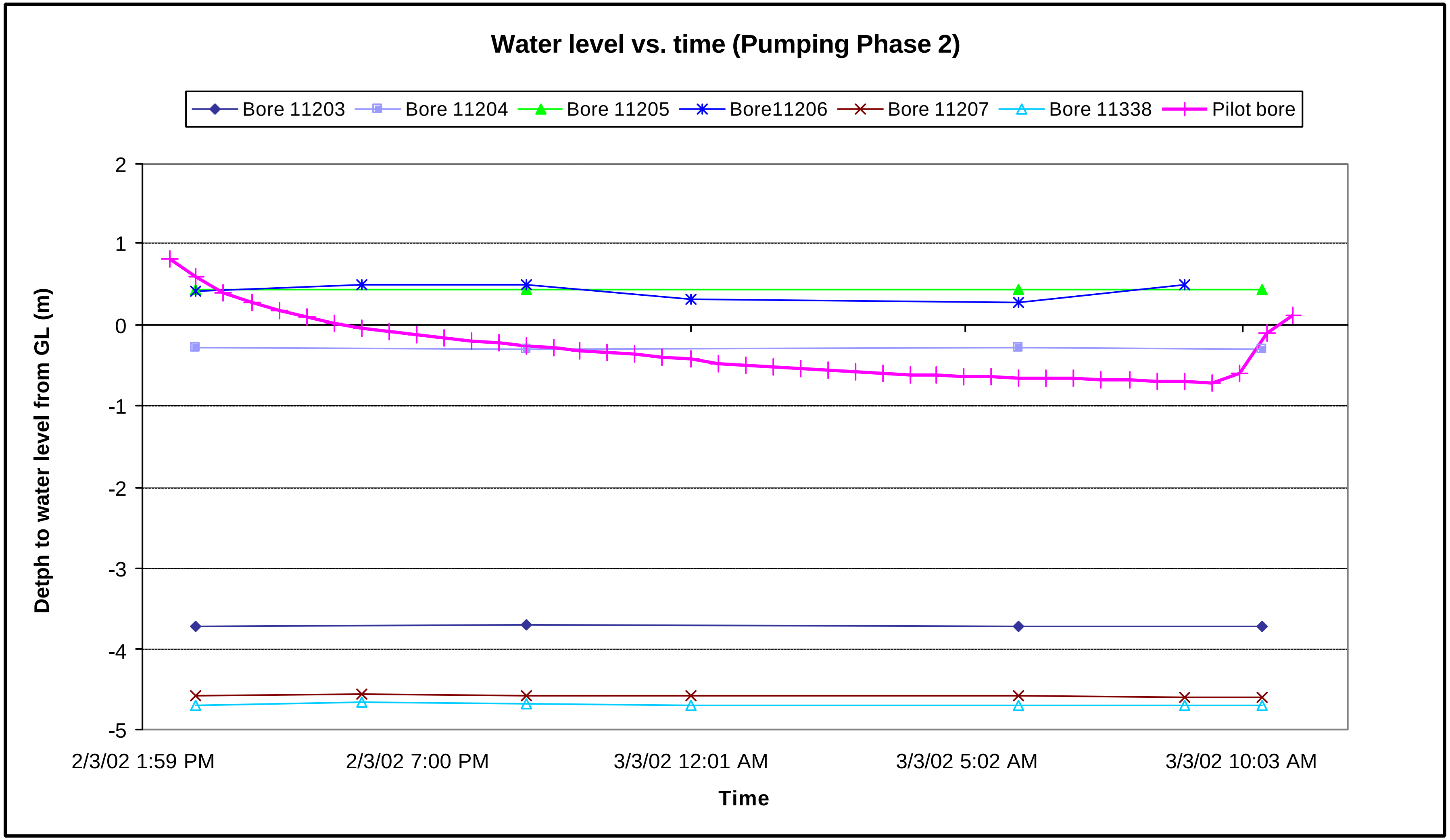

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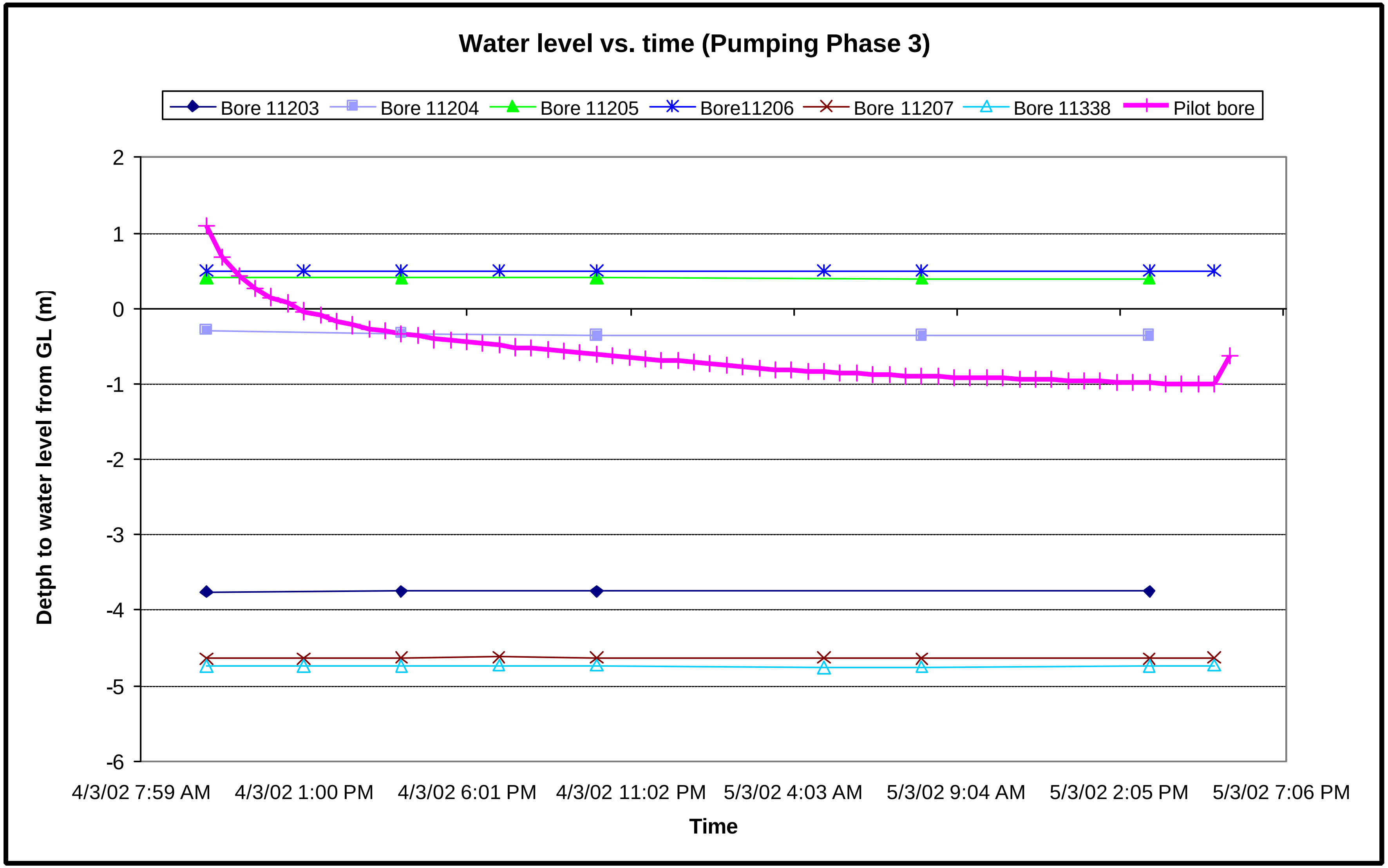

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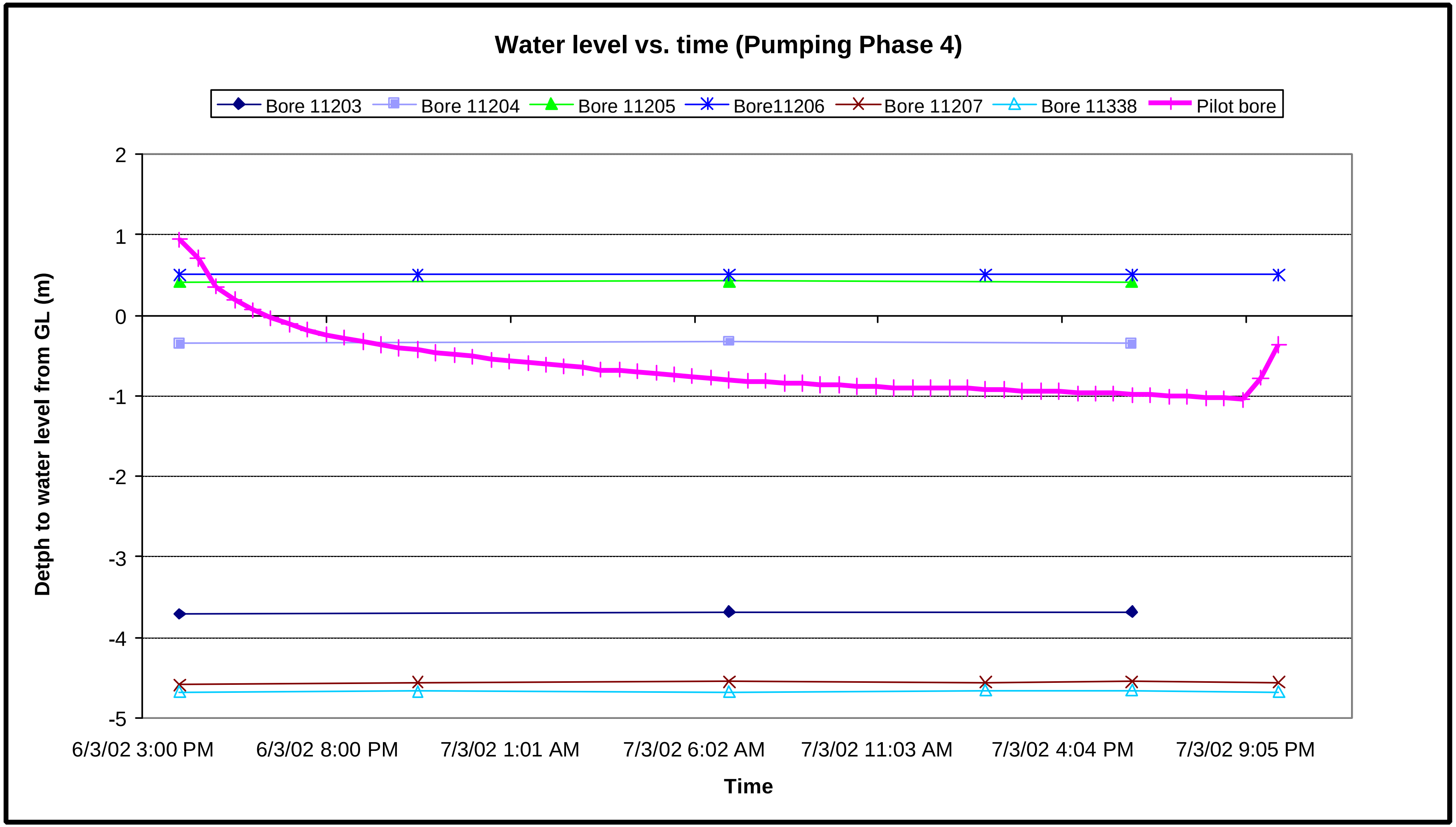
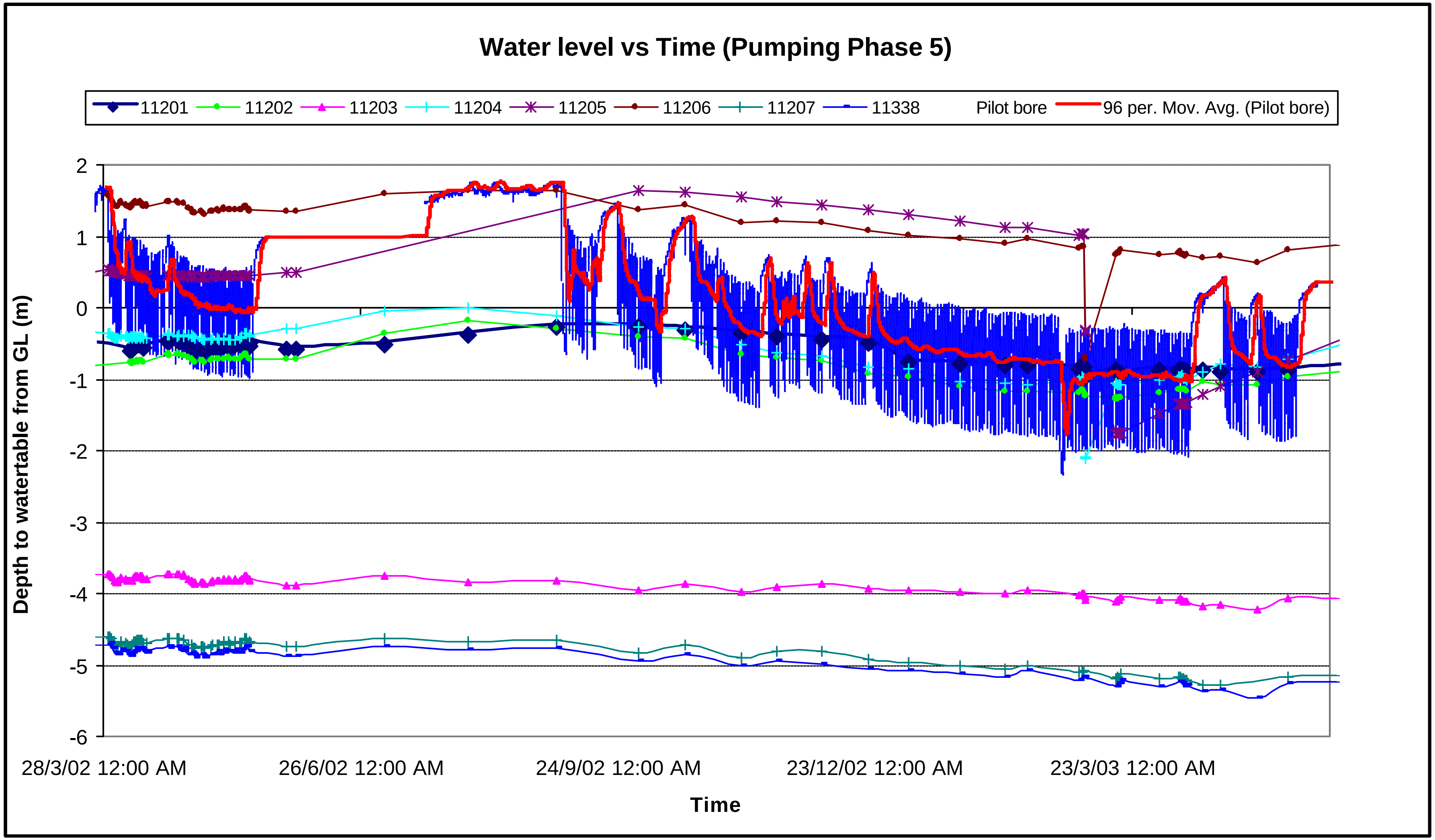
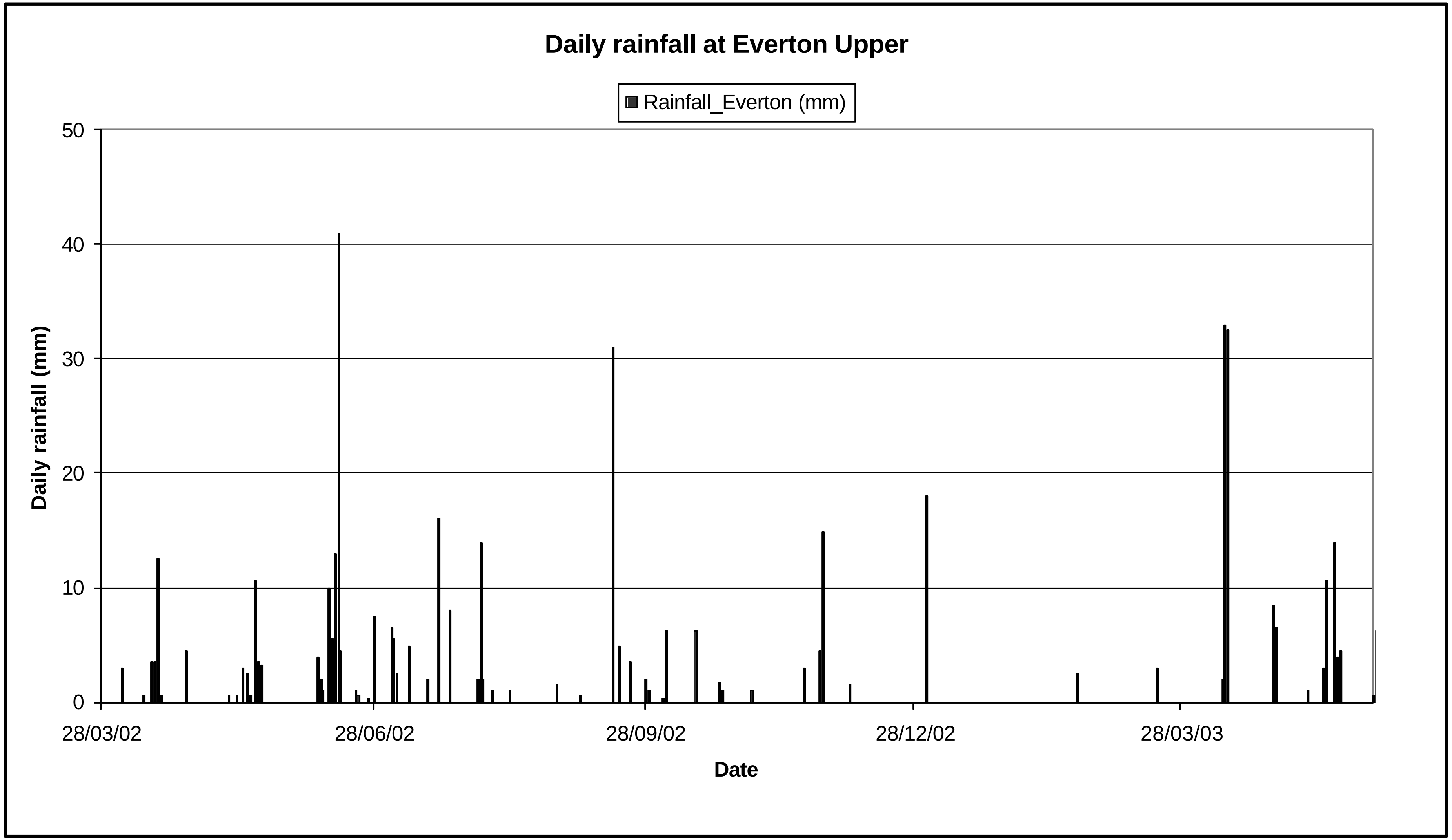


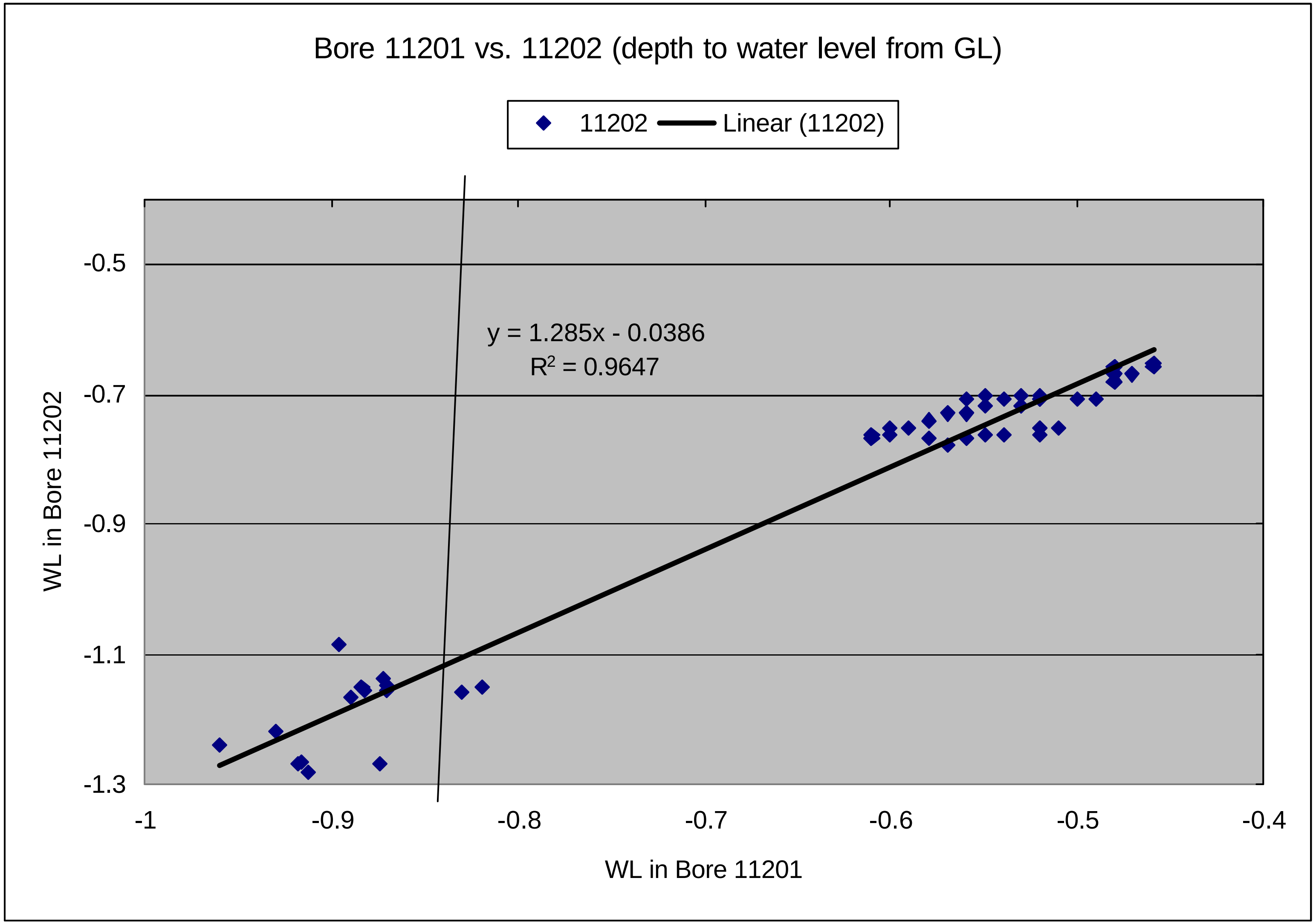
Appendix 2 Groundwater hydrographs for the monitoring bores and pilot bore during Phase 5 of the pumping trial



Appendix 3 Daily rainfall at Everton Upper in the period from 28/3/2002 to 31/5/2003



Appendix 4 The correlation of depth to water (from ground surface) between Bore 11201 and other monitoring bores during pumping Phase 5



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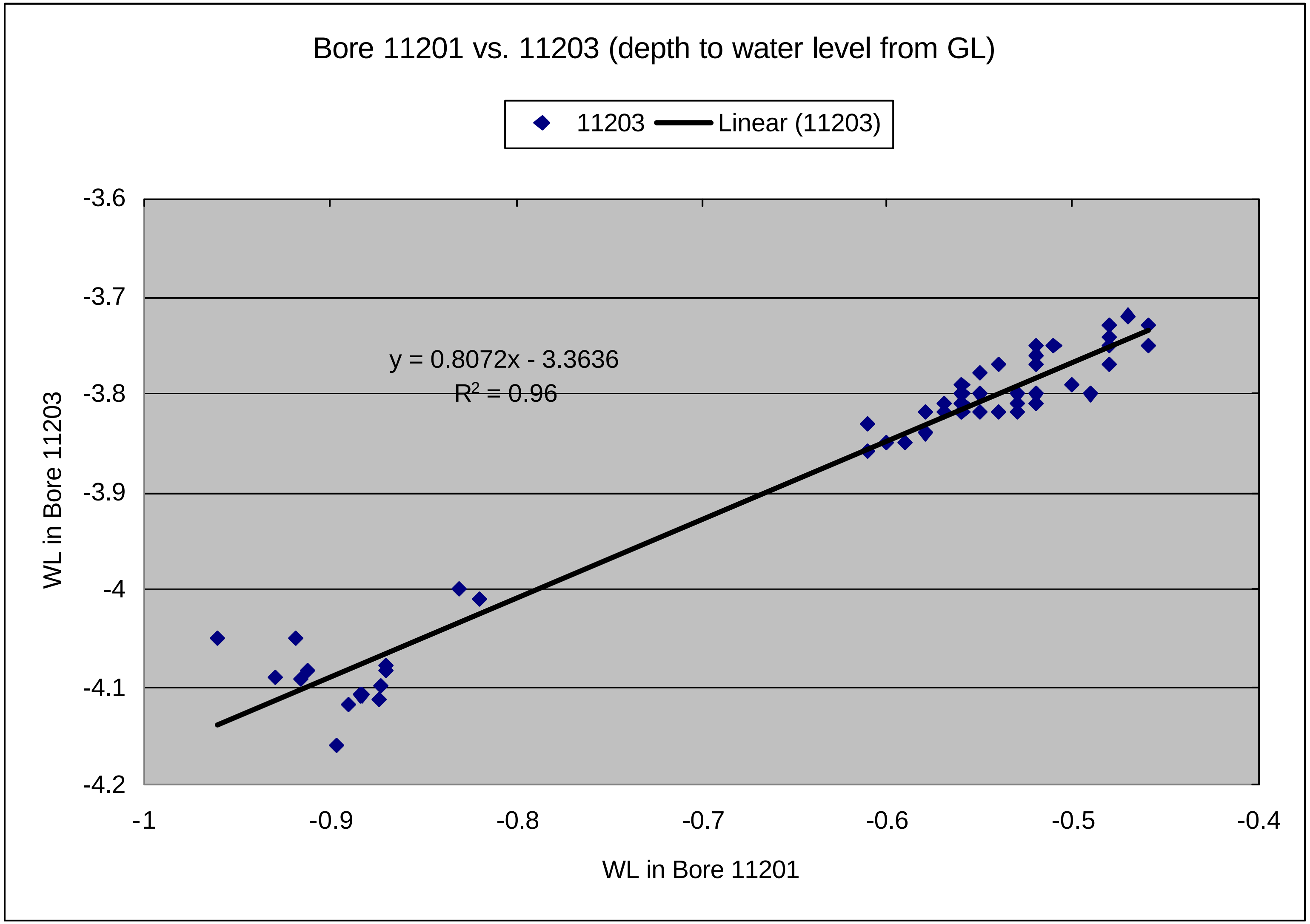
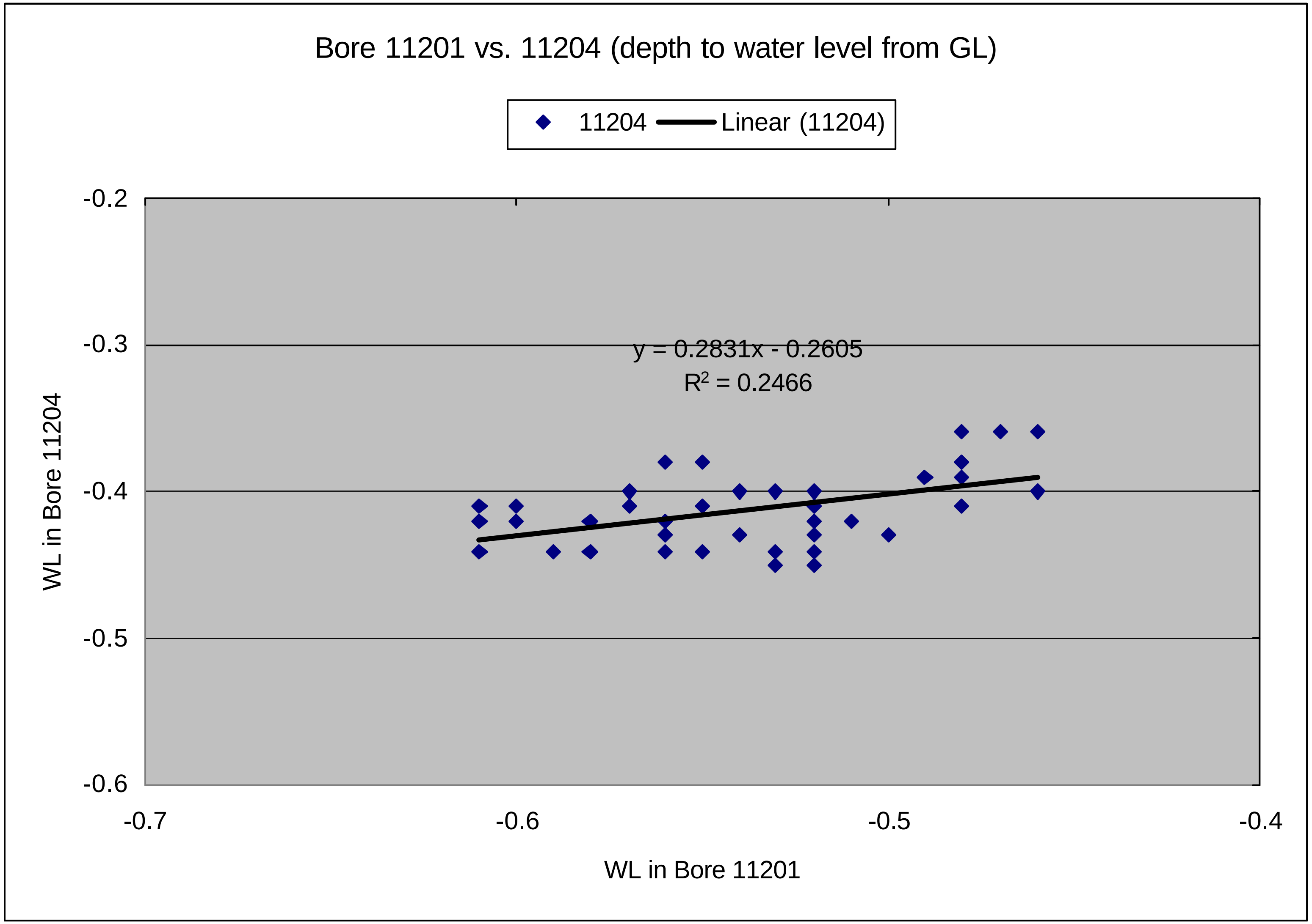


Appendix 4 (continued)



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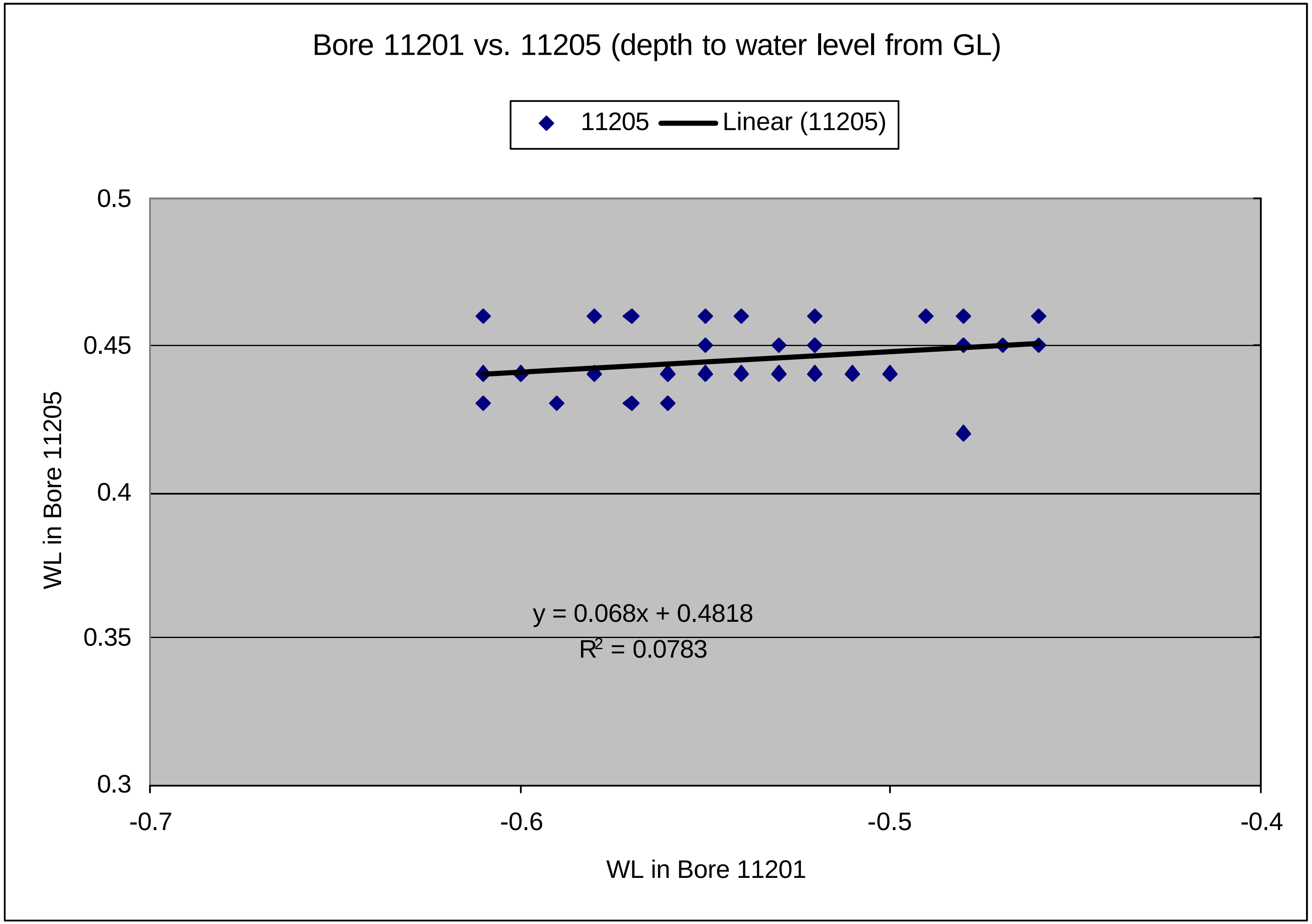

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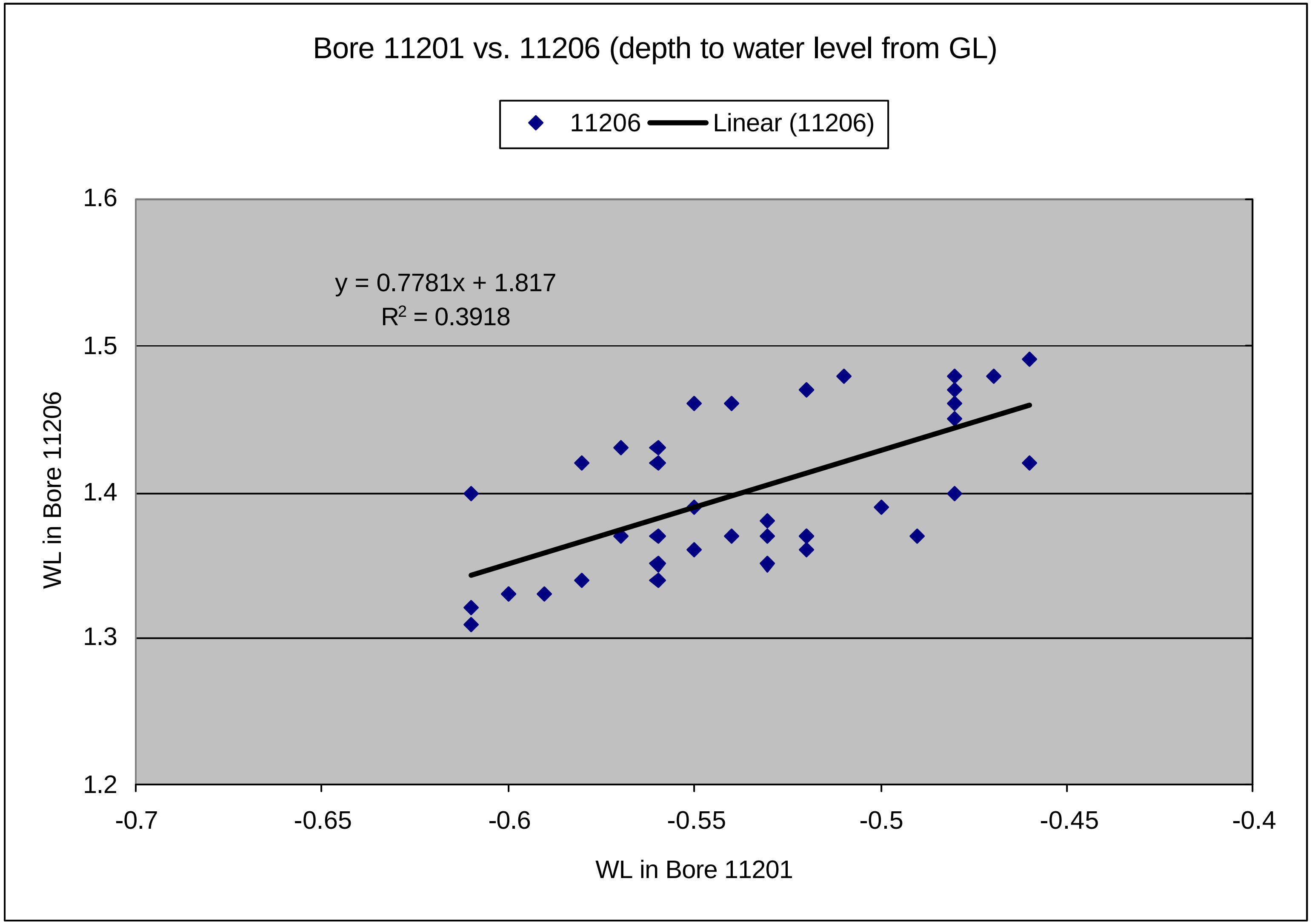

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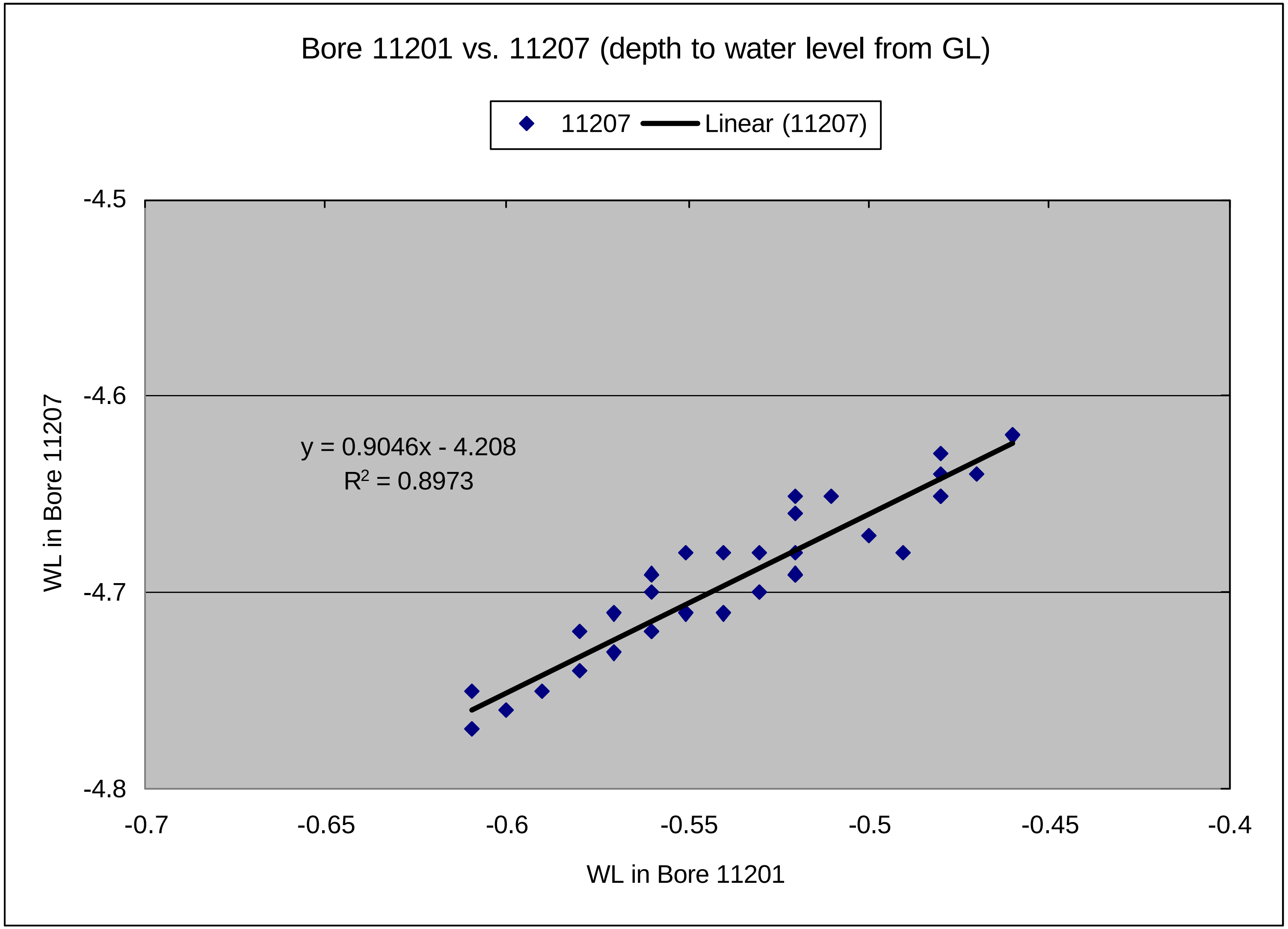

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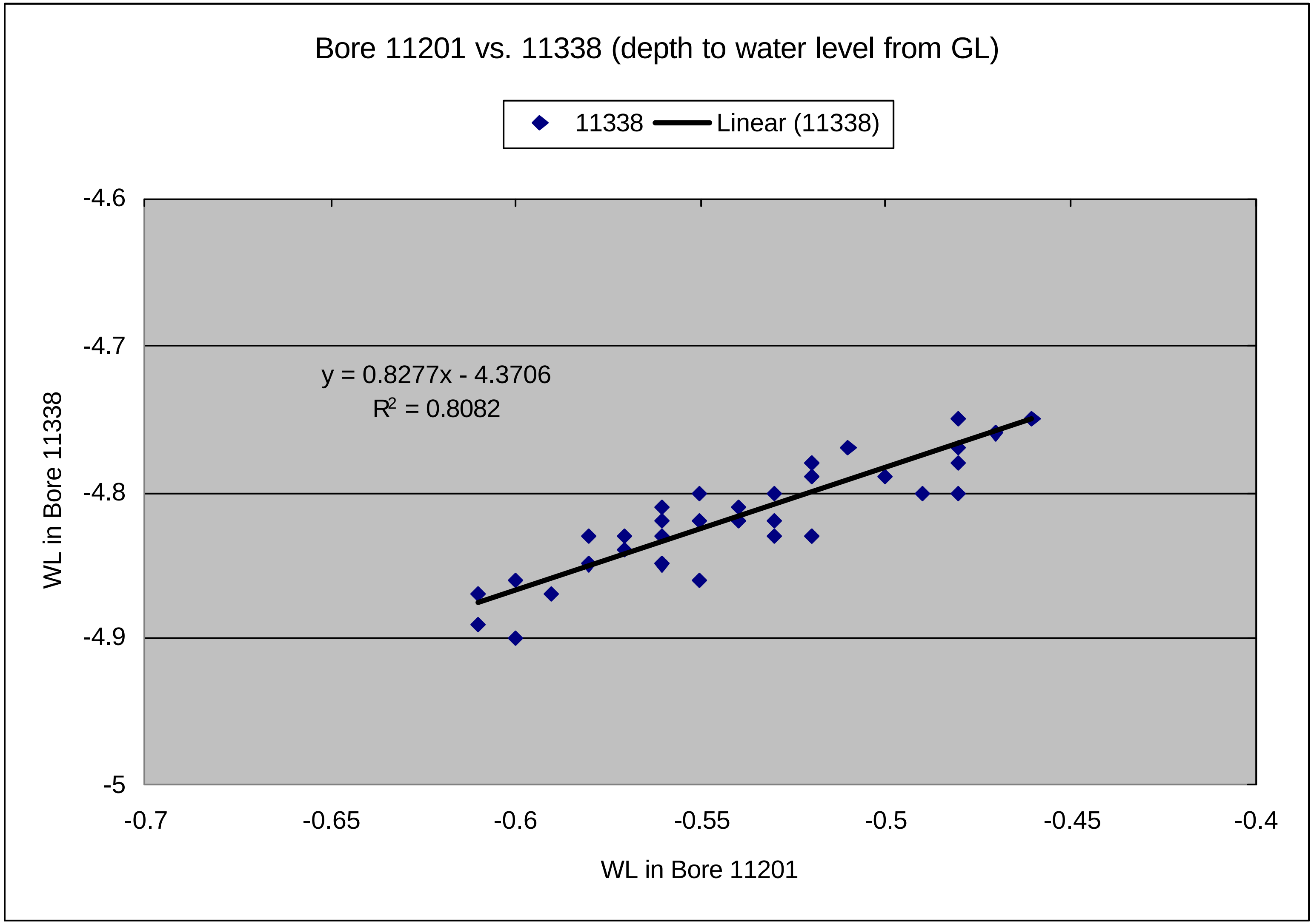

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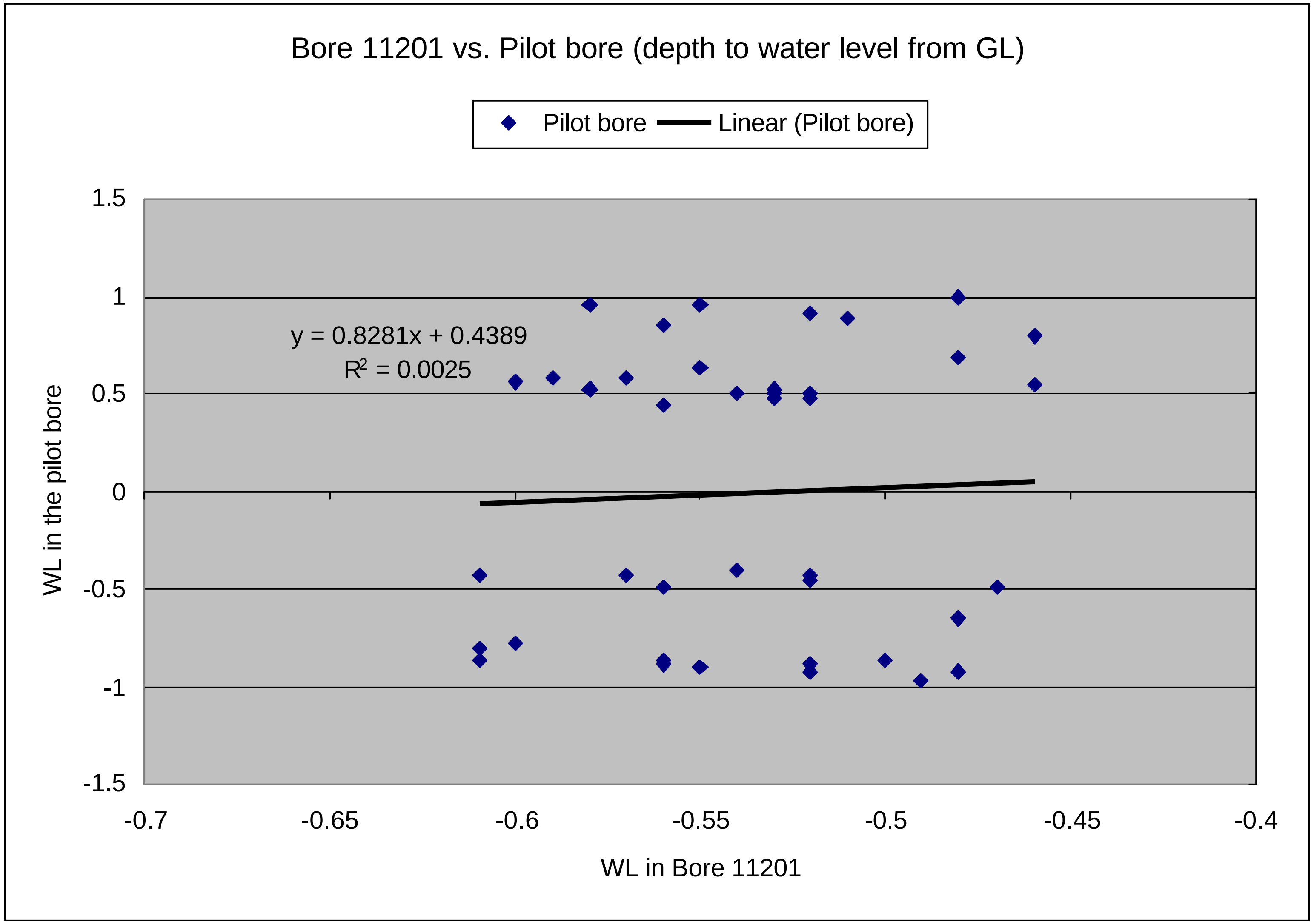

Glossary

Anisotropic	Hydraulic properties are different in all directions.
Aquifer	A water-bearing geological formation capable of yielding useful quantities of water to bores or other extraction facilities.
Aquitard	A saturated, but poorly permeable stratum which impedes the movement of groundwater
Bedrock	Unweathered hard rock that is at the base of soils or other unconsolidated surficial material.
Bore	A hole that is constructed using a drilling plant and lined with tubing (usually steel or PVC) which allows the inflow of groundwater.
Confined aquifer	A layer of water-bearing material which is overlaid by a confining layer (aquitard or aquiclude).
Colluvial deposit	A sediment deposited by natural land erosion processes. Its movement is mainly due to gravity (e.g. landslide, sheet erosion)
Discharge	Flow of groundwater from the saturated zone to the earth surface.
Discharge area	An area in which there is an upward component of hydraulic head in the aquifer. Groundwater is flowing toward the surface in a discharge area and may escape in a spring or seep by evaporation and transpiration.
Drawdown	The area of influence a drain or pumping bore has over water movement.
Fault	The movement of rock, which produces relative displacement of adjacent rock masses along the fracture.
Granite	Course grained rock of igneous origin which is composed mainly of quartz, potassium and sodium-rich silicate soils.
Head	The height above a standard datum (usually sea level) of the surface of the column of water that can be supported by the static pressure at a given point.
Heterogenous	Hydraulic properties are different at different locations
Homogeneous	Hydraulic properties are same at all locations
Hydraulic gradient	The difference in groundwater pressure head over a set distance, water will naturally move from high to low pressure positions.
Hydraulic conductivity	A measure of the ease with which water moves through the soil , expressed as metres/day.
Isotropic	Hydraulic properties are same in all directions.
Lithology	Physical character of a rock type.
Metamorphic rock	Pre-existent rocks that have been altered by extreme pressure and temperature, e.g. marble, talc.
Recharge	Infiltration/percolation into an aquifer – which may be natural or induced.
Recharge area	An area in which there are downward components of hydraulic head in the aquifer. Infiltration moves downwards into the deeper parts of an aquifer in a recharge area.
Regolith	The upper part of the Earth's surface that has been altered by weathering processes. It includes both soil and weathered bedrock.

Specific yield	The ratio of the volume of water that drains by gravity to the volume of the material (soil).
Storativity	The volume of water released from storage per unit plan area of an aquifer for unit decline in hydraulic head.
Transmissivity	The extent to which water can move though a set thickness of an aquifer.
Unconfined aquifer	A layer of water-bearing rock extending from the land surface to the base of the aquifer. Upper boundary of the aquifer is the watertable.
Watertable	The surface of a groundwater body at a pressure which is atmospheric as distinct from groundwater in a confined aquifer which may be under pressure.
Weathering	Physical and chemical disintegration, decomposition and alteration of rocks and minerals.

References

Fetter CW (1994) Applied Hydrogeology. Macmillan College Publishing Company, New York.

SKM (2000) *Everton Upper groundwater pump test, WT01347:L01 MAMUE,* Unpub. Prepared by Sinclair Knight Merz for Department of Natural Resources and Environment, Wangaratta, March 2000.