Groundwater Level Forecasting

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Water Management REPORT

GROUNDWATER LEVEL FORECASTING

PREPARED FOR
Horizons Regional Council

WL18030

20/07/2018

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EXECUTIVE SUMMARY

Horizons Regional Council contracted Aqualinc to develop a simple tool to forecast groundwater levels. This is a concept study to test the viability of a forecasting method.

First, eigenmodels were constructed using land surface recharge and groundwater abstraction calculated by IRRICALC. Spatial variation was accommodated by the inclusion of two zones (north and south) as divided by Manawatu River. These zones were further divided between the coast and the inland foothills based on the proximity of climate stations, land use, soils properties and monitoring bores. Two areas of interest, one in each of the north and south zones, were supplied by Horizons Regional Council. Two example bores in each of these areas of interest were chosen, one to represent shallower groundwater levels and one to represent deeper groundwater levels.

Each eigen model (representing each bore location) was then calibrated to measured groundwater levels. Once calibrated, the historical modelled response was then used to predict a range of future responses accommodating simple climate forecasts.

The forecasting component of the model requires the user to specify a target prediction date and a length of prediction. The method also accommodates forecasted climate based on nine different classes comprising three classes of temperature (warm, average and cold) and three classes of rainfall (wet, average, dry). Users select both the temperature and rainfall forecast, which could be based on an external climate forecast provider, or their own local knowledge.

The longer the prediction period beyond measured, the poorer the prediction will be. A prediction period of 30 days or less will produce a prediction with a relatively good confidence, but predictions beyond 90 days will be poor.

1 INTRODUCTION

Horizons Regional Council has contracted Aqualinc to develop a simple tool for forecasting groundwater levels over future months. The method would provide the Council with guidance as to what groundwater conditions might be expected based on measured groundwater levels and simple climate forecasts. This is a concept study to test the viability of a forecasting method.

Horizons Regional Council currently monitors groundwater levels in 130 bores on a monthly basis throughout the region. This programme provides Council with an excellent record of groundwater level responses to seasonal influences. However, there is currently no facility for Horizons to predict groundwater levels, particularly leading into summer months when irrigation demand typically increases and groundwater levels drop.

Eigen modelling approaches have previously been used to better understand the relative impacts of climate and abstraction on groundwater levels, but not yet used in a predictive way. This project develops a method to predict future groundwater levels based on historical climate, water use and groundwater level responses. It will assist Council in informing the community about the most probable groundwater level outcome for the end of the summer. By being able to forecast likely future groundwater levels, water managers and water users will be better placed to make judgements on water use over the forecast period. This will help water users better manage their supplies, particularly during dry conditions.

As with any modelling study, appropriate interpretation and use of results are limited by practical considerations. It is important to recognise these limitations and resist the temptation to over-interpret calibration results and conclusions. The groundwater levels on which the calibration relies are based on data from a limited number of wells within a complex aquifer system. The accuracy of the simulations are also limited by the degree to which the model is able to approximate the physical system and environmental factors that affect it. The discussions and results presented in this report are intended to be informative in the context of understanding the behaviour of the aquifer system, and its response to climate and abstraction.

2 GROUNDWATER LEVEL MODELLING

A simple eigen model approach has been used to model groundwater levels. Bidwell & Burbery (2011) discuss the following attributes of eigen models:

- They present a 1-dimensional representation of the aquifer system;
- They are a simplification compared to real aquifers (as are all models), but are adequate for situations for which dynamic response is the primary interest;
- They are useful where there is a clear correlation between groundwater inflows (land surface recharge, LSR), outflows (groundwater abstraction and spring flows) and groundwater levels; and
- They are particularly helpful in situations where the aquifer system is not known in sufficient detail to construct a more detailed numerical model, or where this is prevented by time and budgetary constraints.

In this study, eigen models have been used to simulate the response in groundwater levels as a result of changes in land surface recharge and groundwater abstraction. Eigen models utilise bulk aquifer parameters which are calibrated to match the measured groundwater level response at specific wells. Figure 1 shows the location of the wells modelled. Spatial variation is accommodated by the inclusion of two different areas across the district (a north zone and a south zone), further divided into zones between the coast and the inland foothills. Each zone has differing aquifer stresses (LSR and groundwater abstraction).

Each well is assumed to be positioned on a groundwater flow path (or slice) along which the differing time series of LSR and groundwater abstraction are applied as the slice passes through each zone. LSR and groundwater abstraction is uniform within each zone. However, different zones have different time series due to varying rainfall, soil properties and land use. River recharge is assumed to be constant and results in a constant ‘base’ groundwater level supported by the rivers. LSR provides the transient response on top of this base groundwater level.

The key eigen model inputs are LSR, groundwater abstraction and proportion of irrigated area within each zone. Measured groundwater levels are used to calibrate each model. Land surface recharge was calculated using the IRRICALC modelling software (Bright, 2009) based on historical climate data (under both irrigation and dryland scenarios) with zone-specific crop, climate and soil data.

Aqualinc’s Climate Time Series Extension method (Kerr, 2017) has been used to provide extended and gap-filled rainfall and PET time series based on measured data. Seven climate stations (with NIWA’s agent numbers 3213,3217,3231,3248,3257,3269 and 3267) have been used to represent rainfall. For PET, a single climate station (NIWA’s agent number 3243, Palmerston North AWS) has been used, as this is the only local station that has a long-term PET record.

LSR was modelled with IRRICALC for the dominant crop type (pasture) and soil plant available water (PAW) for each zone. Based on the fundamental soils layer (FSL), a range of 70% to 90% of the study area has soil with PAW at 60 mm, so this was used. Groundwater abstraction has been estimated by considering consents data and water requirement calculations from IRRICALC. These datasets have been used to synthesise a complete time series of LSR and groundwater abstraction for each model zone which were then used to build the eigen models.

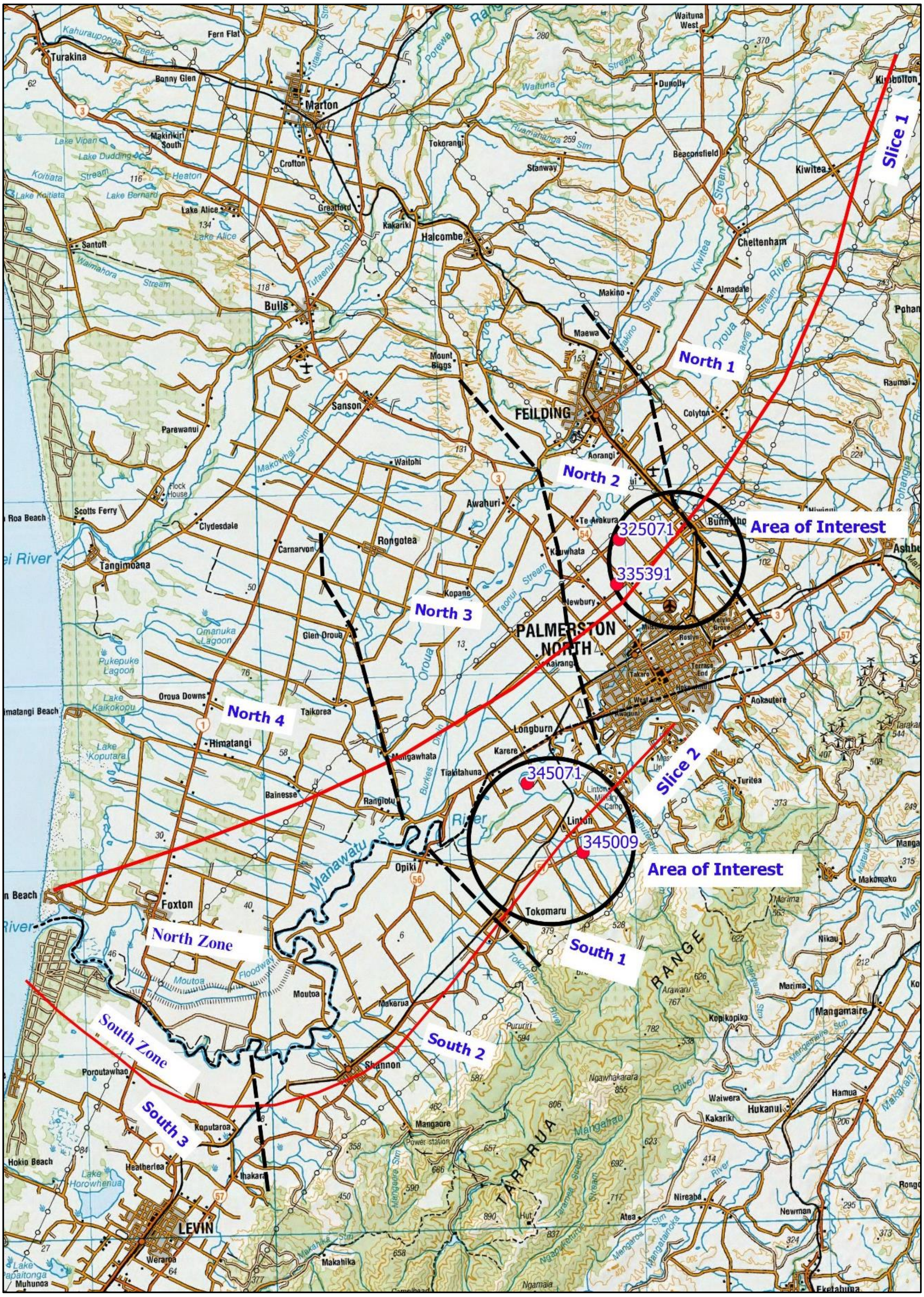


Figure 1: Well locations and conceptual eigen model slices

2.1 Selected Wells

The study area was divided into north and south zones as divided by the Manawatu River. Based on the proximity of climate stations, land use and monitoring bores, the northern area was further divided into four sub-zones and the southern area into three sub-zones (See Figure 1). Two areas of interest were delineated by Horizons Regional Council and are circled in Figure 1. Two example bores in each of these areas of interest were chosen, one to represent shallower groundwater levels and one to represent deeper groundwater levels. These are summarised in Table 1.

Table 1: Selected wells and model representation

Well number	Depth (m)	Location	Eigen model slice	Groundwater representation
325071	170	Te Arakura	North	Deep
335391	73	Newbury	North	Shallow
345009	29	Linton	South	Shallow
345071	85	Karere	South	Deep

3 MODEL DEVELOPMENT AND CALIBRATION

Each eigen model was constructed to run from 1 January 1960 through to 30 April 2018 (a 58 year model run period). The models were calibrated for the following periods based on measured groundwater data availability:

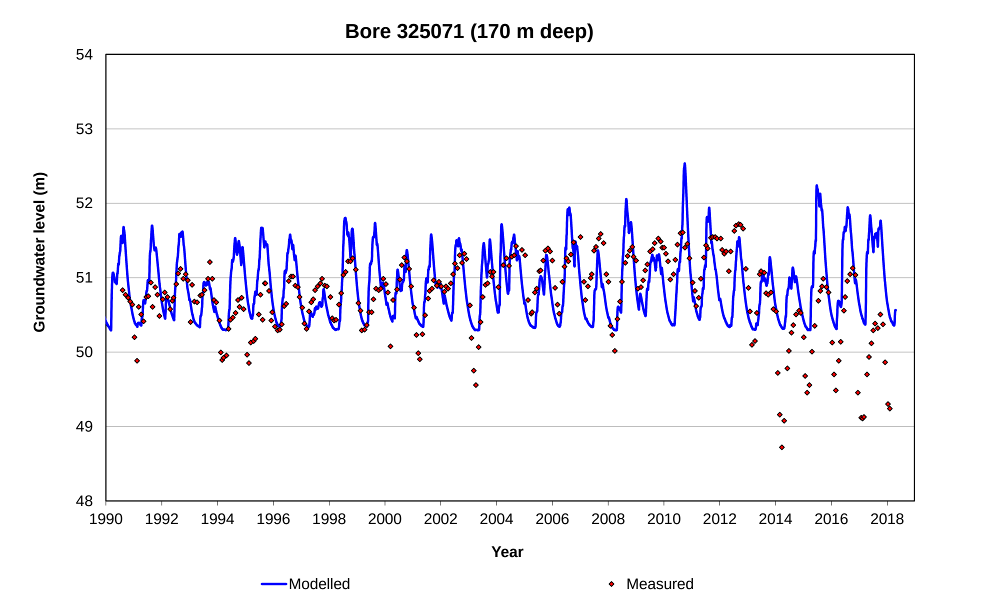
- Bore 325071: August 1990 to February 2018
- Bore 335391: August 1990 to February 2018
- Bore 345009: November 1996 to February 2018
- Bore 345071: August 1990 to February 2018

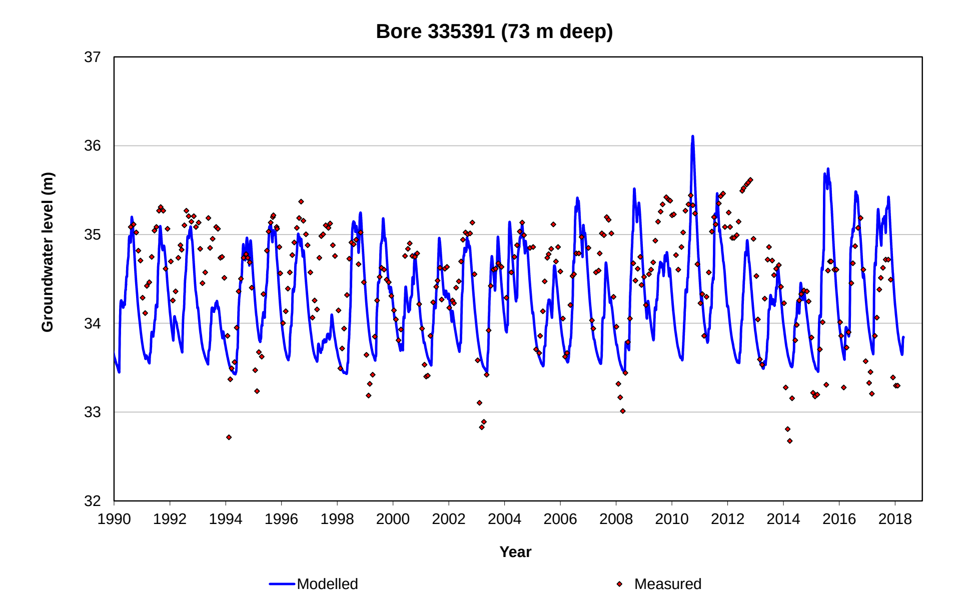
Model calibration is summarised in Table 2 and graphs showing modelled and measured groundwater levels are provided on the following page. In the southern zone, the pattern of groundwater levels is consistent between wells. Consequently, the eigen models could capture majority of the measured data. However, in the northern zone, groundwater level changes are consistent up until 2012/2013 but less so beyond this period where there is greater scatter and a poorer fit. This might be associated with changing local land use and increased groundwater abstraction which hasn't been captured by the models.

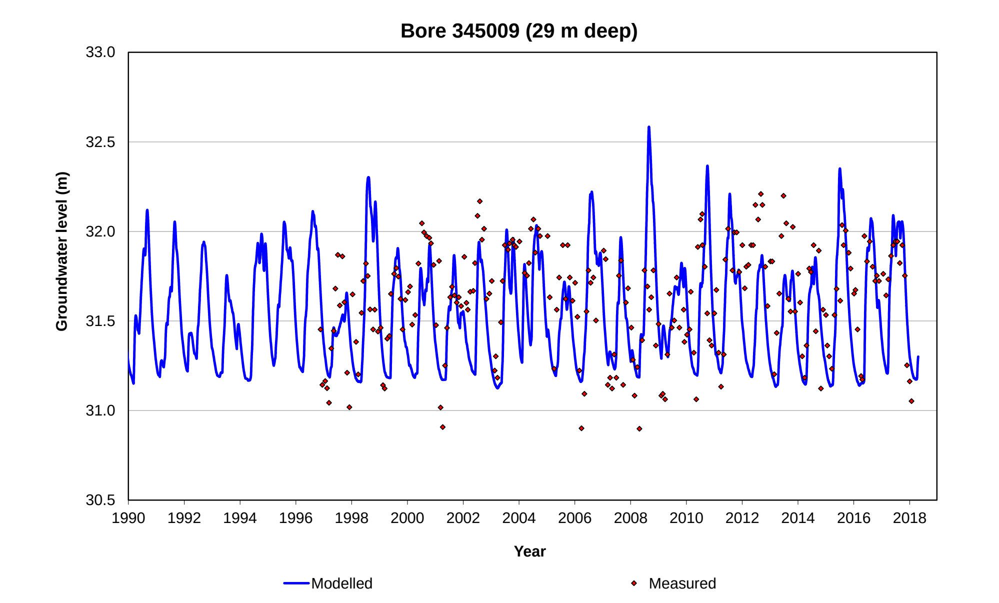
Table 2. Calibration summary

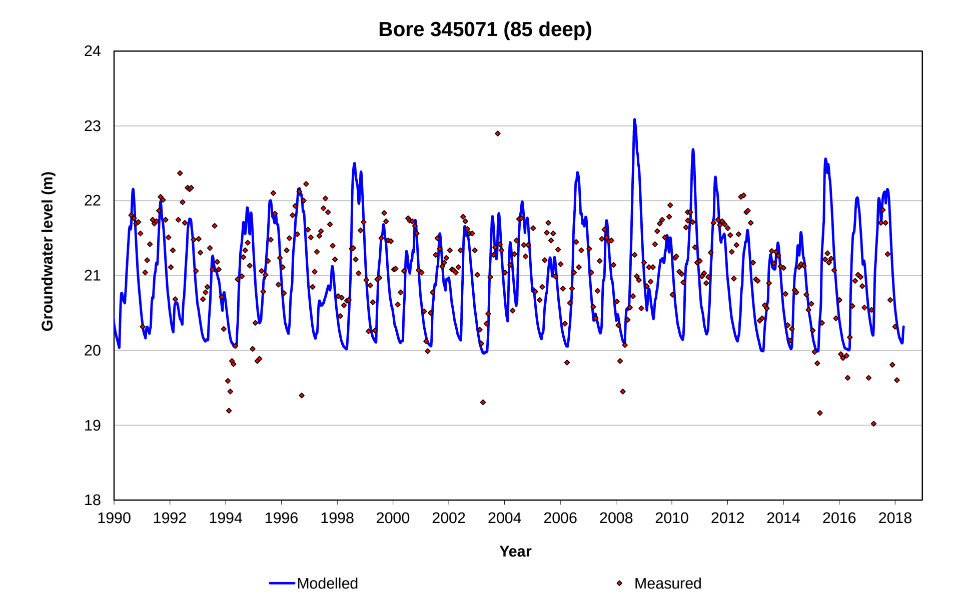
Well number	Well depth (m)	Location	Calibration comments	Mean error (for calibration period, m)
325071	170	Te Arakura	Good calibration until 2012/2013, beyond which the fit to measured groundwater levels is poor.	-0.14
335391	73	Newbury	Reasonably good calibration throughout the record	0.23
345009	29	Linton	Good calibration throughout the record	0.08
345071	85	Karere	Good calibration throughout the record	0.12

The following graphs demonstrate a comparison between the modelled groundwater levels (the blue lines) and measured groundwater levels (red dots, where available) in the four modelled bores.


Bore 325071 (170 m deep)
Groundwater level (m)
Year
Modelled
Measured


Bore 335391 (73 m deep)
Groundwater level (m)
Year
Modelled
Measured


Bore 345009 (29 m deep)
Groundwater level (m)
Year
Modelled
Measured


Bore 345071 (85 deep)
Groundwater level (m)
Year
Modelled
Measured

4 FORECASTING

Microsoft Excel spreadsheets have been developed to generate groundwater forecasts based on the historical calibrated model that accommodates a simple climate forecast. The groundwater level forecast has been based on historical modelled groundwater responses over the simulation period 1960 to 2018. The prediction involves the following steps:

1. The user enters a target prediction date (dd/mm/yy) and length of the prediction (in days).
2. The user-entered target prediction date might, or might not, coincide with a measured groundwater level. If the target prediction date does not coincide with a measured groundwater level, excel reverts to the measurement closest (in time) to the target prediction date. Otherwise, the measurement on the target date is used.
3. Excel then searches through the full time series of modelled groundwater levels and extracts the groundwater level for every year of the simulation at the specified starting day and month.
4. Excel then searches through the modelled groundwater level time series and extracts the groundwater level at the prediction interval after the start month and year (obtained in step 3 above) for every year. It then calculates the change in groundwater level between the starting day and the prediction length, for each year.
5. The change in groundwater level each year is then added on to the measured groundwater level at the starting date to forecast a range of groundwater levels at the interval beyond the measurement date.

To accommodate additional climate forecast, and to narrow the potential range of groundwater level forecasting, the methodology classifies forecasted climate for the prediction period into nine different classes comprising:

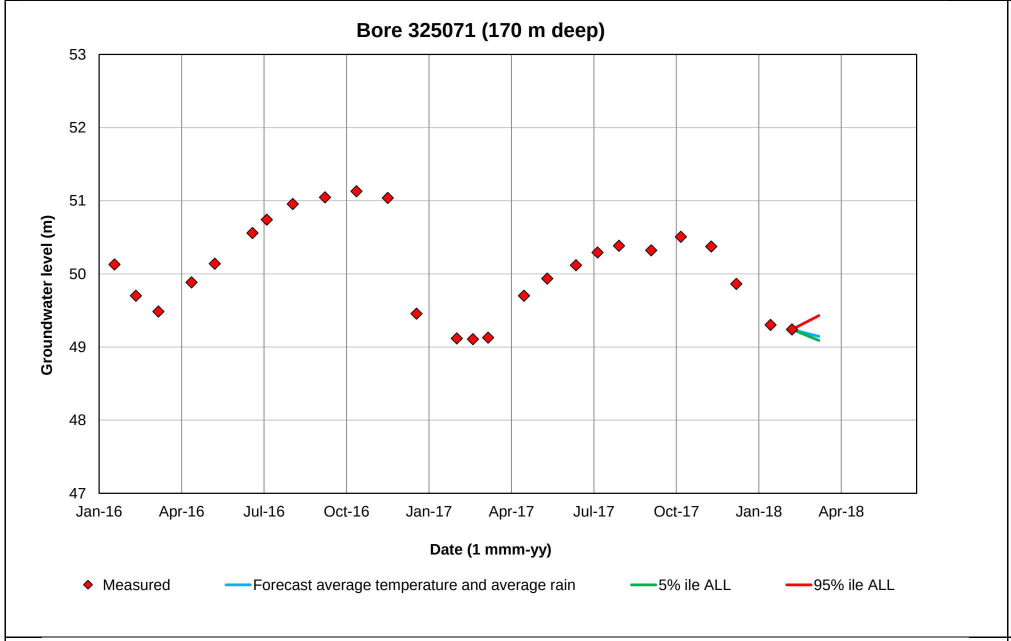
- Three classes based on temperature (warm, average and cold); and
- Three classes based on rainfall (wet, average, dry).

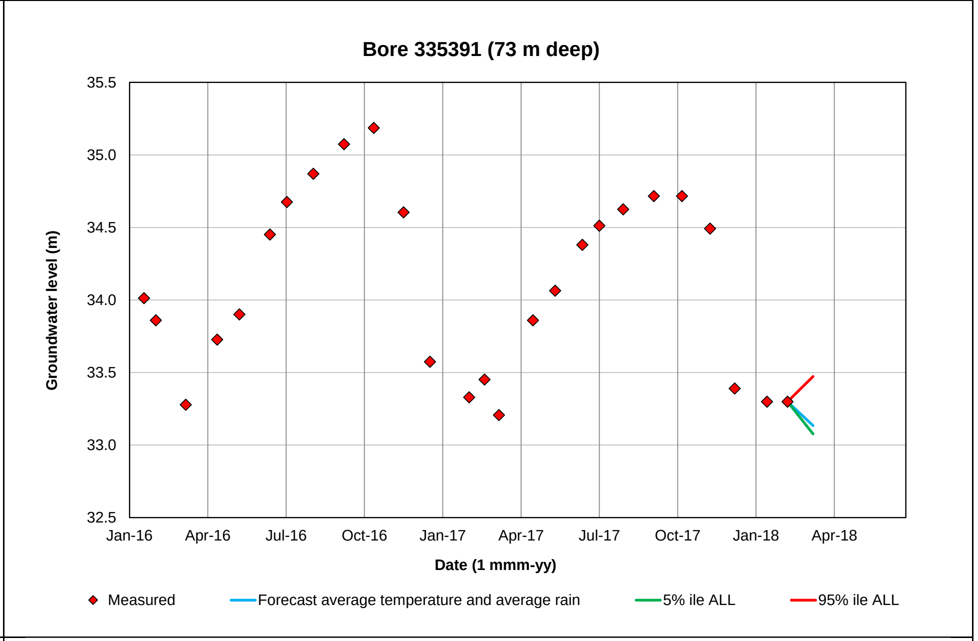
Each temperature and rainfall class covers one-third of the corresponding range in historical records. The top one-third of the temperature records have been classified as ‘warm’; the top one-third of rainfall has been classified as ‘wet’. These categories are relative to the time series of measured values at each site. Given this, predictions are therefore possible for nine different weather scenarios. The Excel spreadsheet requires the user to specify both the temperature and rainfall class that the user considers will represent the future prediction period (say, based on an external supplier’s climate forecast, or local knowledge). The resulting groundwater level prediction is then narrowed to only the historical years when the user-specified climate category has occurred.

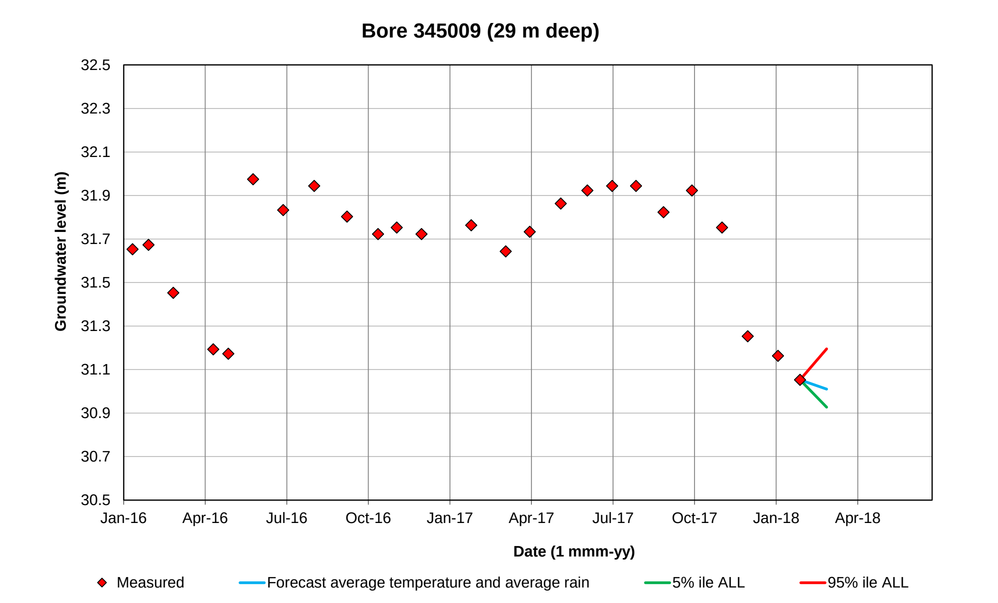
The following page presents graphs of measured groundwater levels with a mean 30-day prediction beyond the last date of measurement (for an example combination of average rainfall and temperature). Also provided on these graphs are 5-percentile and 95-percentile predicted groundwater levels from all years.

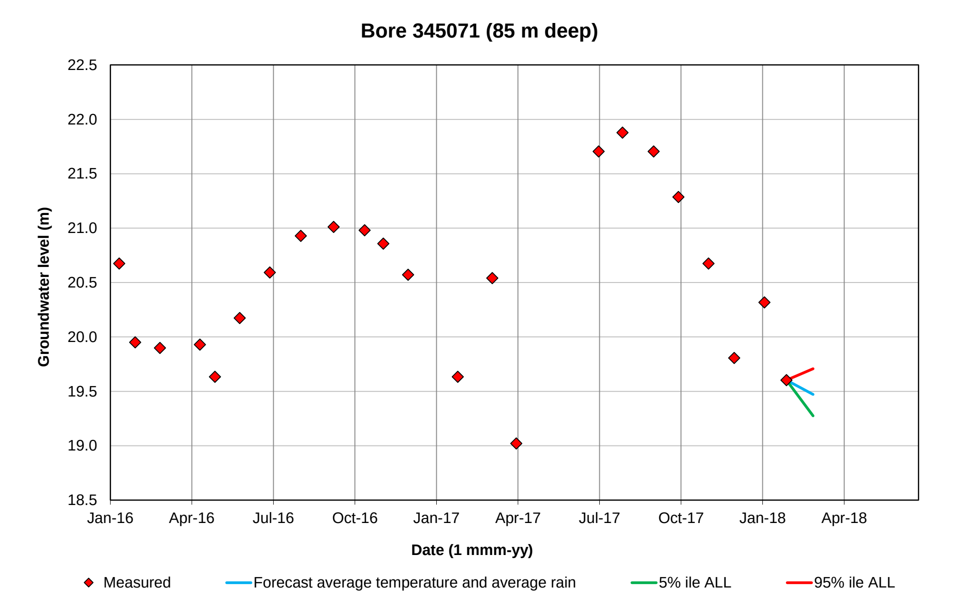
The longer the user-defined prediction period, the poorer the prediction will be. A prediction period of 30 days or less will produce a prediction with relatively good confidence, but predictions beyond 90 days will be poor.

The tool has been developed for four specific bores. Extrapolation of the results, in terms of conferring the results on other bores/areas, has not been explored as part of this project. Extrapolation of the predictions may be possible if other bores are known to respond similarly to the modelled bores. This will depend on them being within a similar hydrogeological and climatological setting, and showing a similar hydrograph response.


Bore 325071 (170 m deep)
Groundwater level (m)
Date (1 mmm-yy)
Measured
Forecast average temperature and average rain
5% ile ALL
95% ile ALL


Bore 335391 (73 m deep)
Groundwater level (m)
Date (1 mmm-yy)
Measured
Forecast average temperature and average rain
5% ile ALL
95% ile ALL


Bore 345009 (29 m deep)
Groundwater level (m)
Date (1 mmm-yy)
Measured
Forecast average temperature and average rain
5% ile ALL
95% ile ALL


Bore 345071 (85 m deep)
Groundwater level (m)
Date (1 mmm-yy)
Measured
Forecast average temperature and average rain
5% ile ALL
95% ile ALL

5 CONCLUSIONS

Aqualinc have developed a simple tool to forecast groundwater levels for four bores within two areas specified by Horizons Regional Council. This project was essentially a feasibility study to test the viability of the forecasting tool.

The eigen modelling tool is a simple approximation of reality, and should be recognised as such. In spite of its simplicity, a reasonable calibration to measured groundwater levels was obtained. The projections of groundwater levels depend on the modelled historical responses, and cannot account for future changes (such as new, localised pumping).

The predictions will have the highest degree of confidence for shorter prediction periods, due to both less certainty in climate predictions and the greater range of possible historical groundwater levels over longer periods.

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