Turkina and Rangitikei Groundwater Allocation

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Prepared for:

Dr Jon Roygard
Science Manager
Horizons Regional Council
Palmerston North

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Prepared by:

Neil Thomas and Chris Woodhouse
Pattle Delamore Partners Ltd
P O Box 389
Christchurch

Telephone 03-345 7100
www.pdp.co.nz

CONTACT **24 hr Freephone 0508 800 800** **help@horizons.govt.nz** **www.horizons.govt.nz**

SERVICE CENTRES
Kairanga
Cnr Rongotea and Kairanga-Bunnythorpe Roads
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Hammond Street

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34 Maata Street

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11 Bruce Road

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Torere Road
Ohotu

Woodville
116 Vogel Street

POSTAL ADDRESS
Horizons Regional Council, Private Bag 11025, Manawatu Mail Centre, Palmerston North 4442
F 06 9522 929

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PATTLE DELAMORE PARTNERS LTD
295 Blenheim Road
Upper Riccarton, Christchurch 8041
PO Box 389, Christchurch 8140, New Zealand

Tel +64 3 **345 7100** Fax +64 3 **345 7101**
Website **http://www.pdp.co.nz**
Auckland Tauranga Wellington **Christchurch**

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DOCUMENT CONTRIBUTORS

Prepared by

SIGNATURE

Neil Thomas

Chris Woodhouse

Reviewed and Approved by

SIGNATURE

Peter Callander

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Executive Summary

Groundwater use in the Turakina and Rangitikei Groundwater Management Zones (GWMZs) has increased over the past few years, with a particular increase occurring towards the coastal margin of the catchments, centred on the Santoft area. Eigen modelling analysis suggests that some, typically deeper, groundwater levels in monitoring bores in the Santoft area have recently begun to show a declining trend, which coincides with the increase in groundwater abstraction.

Estimated groundwater allocation volumes for each of the GWMZs in the Horizons Region were originally specified as 5 % of the long term average rainfall across each zone in the One Plan. The total estimated groundwater allocation in the Rangitkei and Turakina GWMZs is around 33 x 106 m^3/year, compared to a combined allocation limit of 125 x 106 m^3/year, implying that only around 19 % of groundwater is currently allocated. That estimate is in contrast to the pattern of declining groundwater levels observed in the Santoft area, which imply that currently within the Santoft area, outflows from the groundwater system in the Santoft exceed inflows.

The pattern of long term groundwater levels in the Santoft area, where rising groundwater levels preceded a period of recent decline suggests that the overall system is relatively dynamic. Such systems can be sensitive to relatively small changes in the groundwater balance but can subsequently move towards a new equilibrium. Eigen modelling indicates that the current pattern of decline is likely to be related to an increase in groundwater abstraction, but based on the available data it is difficult to accurately define recharge, or discharge from the area, and subsequently set an abstraction rate limit relative to recharge.

A preliminary groundwater balance for the Santoft area suggests that groundwater throughflow into the area is relatively small, but there is a potentially larger volume of rainfall recharge. Given the declining pattern of groundwater levels, it is likely that much of that rainfall recharge does not currently reach the deeper aquifers, so the deeper aquifers may be currently sustained via the relatively limited groundwater throughflow.

A method of managing that effect and accounting for the uncertainty is to use trigger levels in monitoring bores whereby groundwater abstraction rates progressively reduce at a series of specified levels. A series of triggers are proposed where abstraction rates during an irrigation season depend on recovery levels in the preceding winter, which would allow the abstraction limit to effectively be adapted to the state of the aquifer on a flexible basis.

It would be prudent to consult with the Santoft Water Users Group prior to establishing trigger levels and to refine the potential impact of those trigger levels on water users in the area. Further work could also be undertaken using a

simplified groundwater model as a management tool, with the objective of improving the understanding of the aquifer system and developing a value for sustainable groundwater allocation in the area. That could also be assisted by monitoring of shallow and deeper groundwater levels close to the coast, as well as undertaking some further investigation of the potential extent of seepage from the Rangitikei River in the reach between Bulls and the coast

Table of Contents

SECTION PAGE

Table of Figures

Table of Tables

1.0 Introduction

Groundwater use in the Turakina and Rangitikei Groundwater Management Zones (GWMZs) has increased over the past few years, with a particular increase occurring towards the coastal margin of the catchments, centred on the Santoft area. A map showing the location of the Turakina and Rangitikei GWMZs is presented in Figure 1.1. Some, typically deeper, groundwater levels in monitoring bores in the Santoft area have recently begun to show a declining trend and Eigen modelling for some bores indicates that the declining trend may be a response to increased groundwater abstraction.

Estimated groundwater allocation volumes for each of the GWMZs in the Horizons Region were originally specified as 5 % of the long term average rainfall across each zone in the One Plan. The total estimated groundwater allocation in the Rangitikei and Turakina GWMZs is around 33 x 10^6 m^3/year, compared to a combined allocation limit of 125 x 10^6 m^3/year, implying that only around 19 % of groundwater is currently allocated. That estimate is in contrast to the pattern of declining groundwater levels observed in the Santoft area, which imply that currently, in that area, outflows from the groundwater system exceed inflows.

Pattle Delamore Partners have been asked to prepare the following report to provide a more detailed estimate of the water balance in the Rangitikei and Turakina GWMZs and specifically consider the groundwater balance for the Santoft area.

Section 2 of this report presents the results of further Eigen modelling to define the area around Santoft where groundwater levels may be declining due to abstraction influences. Sections 3 and 4 present information regarding rates of groundwater abstraction and estimates of groundwater recharge for that area to determine a preliminary groundwater balance. Section 5 presents options for future management of groundwater abstractions in the area.

2.0 Eigen modelling

2.1 Background

An Eigen model is a one dimensional analytical modelling technique used to assess the importance of time variant recharge and groundwater abstraction on groundwater levels in an aquifer. Although simple, Eigen models provide a useful tool to determine the cause of aquifer response, particularly where long term groundwater level trends offer the key source of information on the historical and current behaviour of an aquifer.

The Eigen model attempts to find an approximate solution to the Dupuit-Boussinesq equation for one dimensional transient groundwater flow in a homogenous aquifer:

$$T\frac{\partial^2 h}{\partial x^2} \pm Q = S\frac{\partial h}{\partial t}$$

Where:

Q = aquifer recharge and/or groundwater discharge (m^3/day)

T = aquifer transmissivity (m^2/day)

S = aquifer storage (-)

h = head in the aquifer (m)

t = time (days)

x = distance from constant head discharge boundary (m)

Eigen model analysis simplifies the aquifer, representing it as a one dimensional linear system with a no flow boundary at one end and a discharge boundary, either a river or the sea, at the opposing end. The model represents changes in aquifer levels via an infinite number of storage reservoirs, which drain at an exponential rate (the Eigenvalue). In most cases, a system can be represented with a small number of reservoirs, however complex systems may require further stores.

Eigen models are most appropriate for linear systems where the discharge from an aquifer is proportional to the saturated thickness. Another key assumption is that there is no vertical flow in the aquifer. In the Horizons Region vertical gradients are pronounced, and therefore this assumption is likely to be violated. However, since the volume of water flowing vertically is small compared to the aquifer dimensions any errors associated with this limitation are expected to be minimised.

Eigen models represent the groundwater balance, in terms of inputs from time varying rainfall recharge compared to outputs from discharge. It is possible to include abstraction volumes within the model but for the Santoft area there is insufficient historical monitoring data to define these volumes. In effect the simulated hydrographs from the Eigen model provide ‘naturalised’ groundwater level patterns i.e. groundwater level time series that may be expected for a relatively low level of anthropogenic inputs and outputs from the groundwater. Therefore, any significant deviations from the simulated naturalised groundwater levels are likely due to groundwater abstraction effects.

Inputs to Eigen models include rainfall and potential evapotranspiration across an aquifer together with observed groundwater levels to calibrate model parameters to produce simulated groundwater levels. The observed groundwater level record is split into two parts. Earlier time series are used for model calibration assuming anthropogenic impacts to be minor, while the later part is used for prediction and as a check against model validity. Variables that are altered during model calibration include aquifer storage, aquifer transmissivity and the distance to the aquifer discharge boundary. The volume of rainfall recharge is coupled to the Eigen model of groundwater flow and varied simultaneously with the aquifer parameters. River recharge can also be added into the model, although in the Santoft area, river recharge does not generally appear to be a significant factor as most of the bores are located some distance from the major rivers. Therefore, it has not been included into the models.

Rainfall recharge is calculated based on a standard soil moisture deficit model. In these models, daily rainfall and potential evapotranspiration are summed to determine an input to the soil moisture store (which can be reduced on days where PET exceeds rainfall). Recharge to groundwater occurs when the soil moisture store is full, but is limited to a set maximum value to mimic soil infiltration limits. The size of the soil moisture store represents the volume of readily available water (RAW) within the soil zone and is varied as part of the model calibration together with the evaporation reduction function and crop factor.

2.2 Previous Modelling

Previously, PDP (2013) developed Eigen models for two bores in the Horizons Region. Eigen models were constructed for the Whakorongo multilevel piezometer (bore 336991) near Palmerston North, and for bore 312009 in the Santoft area. Results of the modelling for the Santoft bore implied that the recent decline was most likely caused by abstraction however, groundwater levels at that time were inferred to be generally within the range of natural long term fluctuations.

2.3 Eigen Modelling for Santoft Area

2.3.1 Purpose and Input Data

The purpose of the modelling undertaken in this study is to delineate the area of declining groundwater levels, and identify where anthropogenic abstraction is likely to be significantly affecting groundwater levels in bores within and surrounding the Santoft region.

Data provided by Horizons Regional Council indicates that there are 15 bores regularly monitored for groundwater level within and proximal to the Santoft area. Table 1 shows details of the available groundwater level data for each of the 15 bores. Groundwater levels in 13 bores are manually recorded on a monthly basis, however daily logger data is available for 312028 and 322029. Rainfall data and Penman potential evapotranspiration (PET) data were obtained from the NIWA National Climate Database (NIWA, 2014). The most proximal climate station to all 15 bores with a complete record of these two parameters is station 3715 located at Spriggens Park in Wanganui.

Table 1: Bore details for each of the 15 groundwater level monitoring bores in and around the Santoft region

Bore	Groundwater Management Zone	Depth (m)	Date Start Date	Data End Date	No. of records
302003	Turakina	121.6	13/09/1990	9/02/2012	237
302009	Turakina	109.8	17/10/1990	8/10/2012	250
302026	Turakina	112	10/06/2003	9/10/2012	103
303017	Turakina	205.26	10/12/2002	8/10/2012	100
304019	Rangitikei	268	6/11/2002	9/10/2012	114
312006[1]	Rangitikei	70	10/05/2011	8/10/2012	18
312007	Rangitikei	62.8	24/04/1992	8/10/2012	237
312009	Rangitikei	43	11/10/1990	8/10/2012	253
312028[2]	Rangitikei	16	28/05/2008	14/08/2010	757
313013	Rangitikei	93.5	4/09/1990	9/10/2012	255
313053	Rangitikei	58.5	17/09/2002	9/10/2012	115
322029[2]	Rangitikei	42	24/03/2005	10/08/2011	2326
323015	Rangitikei	112	4/09/1990	9/10/2012	258
324000	Rangitikei	Unknown	4/09/1990	9/10/2012	260
324003	Rangitikei	43.3	4/09/1990	9/10/2012	246

Notes:

1. *1. Eigen modelling not undertaken on bore 312006 due to the short length of the record.*
2. *2: Bores with logger data.In following tables*

2.3.2 Model Calibration

Eigen models were developed for 14 of the 15 bores in Table 1. Eigen modelling was undertaken using a spreadsheet tool described in MAF (2010). Groundwater level time series from the 14 bores together with the rainfall and PET data were input into the models.

Although 7 of the bores have records stretching back to 1990, the rainfall and PET data is incomplete prior to 1997 and therefore the first reading taken in 1997 was set as the earliest time of calibration for each bore. Calibration was undertaken to quantitatively minimise the sum of square residuals between the observed and simulated groundwater levels. Qualitative calibration was also undertaken to match the positions of peaks and troughs between the predicted and measured groundwater level records. Calibration was initially conducted both manually and using Solver in Excel. Values of all parameters in the model were maintained within pre-set realistic ranges during calibration.

Calibration periods were chosen by examining the groundwater level record and choosing a time frame where potential anthropogenic effects appeared small. No Eigen model was developed for Bore 312006 due the short length of the groundwater level record meaning a calibration period of adequate length, showing minimal impacts of anthropogenic abstraction, could not be selected. Any obvious anthropogenic effects (such as short term drawdown effects due to the well being pumped or nearby bores being pumped) or anomalous results identified in the chosen calibration period were manually removed from the error calculation to prevent any distortion of the results. Groundwater levels after the last calibration date were then predicted by the model. Table 2 details the calibration period for each model.

Table 2: Bore details for each of the 14 bores in and around the Santoft region used for Eigen model analysis

Bore	Calibration From	Calibration To	No. Calibration Points
302003	22/01/1997	10/12/2002	68
302009	22/01/1997	10/12/2002	70
302026	10/06/2003	13/12/2005	26
303017	10/12/2002	8/12/2005	31
304019	6/11/2002	9/12/2005	34
312007	22/01/1997	10/12/2002	70
312009	22/01/1997	10/12/2002	70
312028	28/05/2008	28/05/2009	366
313013	23/01/1997	5/12/2002	70
313053	17/09/2002	9/12/2005	36
322029	24/03/2005	24/09/2006	550
323015	23/01/1997	5/12/2002	68
324000	23/01/1997	5/12/2002	71
324003	23/01/1997	17/09/2002	67

2.3.3 Results

Eigen model predictions were compared to the measured groundwater level trend. Where predicted groundwater levels deviate from the measured data it is a reflection of the approximate nature of the model and effects that are not incorporated into the model, such as abstractions. Where there is a consistent trend where measured water levels are lower than modelled levels, particularly during summer month, the difference between measured and modelled water levels is likely due to seasonal irrigation abstractions.

Results for 6 of the 14 analysed bores suggest declining groundwater levels in recent years, all of which are likely caused by anthropogenic abstraction. The remaining 8 bores show steady or increasing groundwater levels. Graphs of Eigen modelling results showing measured and predicted groundwater levels together with the calibration interval for all the bores are shown in Figures 2.1a to 2.1n. Using these results an approximate area of declining groundwater levels has been delineated. Figure 2.2 shows the locations of the analysed bores with the Eigen modelling results and depth, with a delineated area of declining groundwater levels. This area lies across both the Turakina and Rangitikei GMZs, and lies in a north-north-west trending orientation between Bulls. There is not enough data to determine whether the area extends to the coastal margin.

Results for all 14 assessed bores are detailed in Table 3, with the bores showing a declining trend highlighted in bold. All of the declining bores are more than 40 m deep with the screen intervals ranging from around 43 m bgl to at least 112 m bgl, illustrating that the pattern of recently declining groundwater levels is widespread, both spatially and vertically through the aquifer strata. Some of the bores showing a declining trend that may be attributed to irrigation abstraction are located relatively close to major consented takes (e.g bore 323015) and the decline in those bores may reflect local drawdown effects from nearby pumping. However at least three of the bores (312007, 313053 and 313013) are around 2.5 km from the nearest large abstractions implying that the water levels observed in those bores represents the wider background pattern.

Bores 313013 and 313053 are located < 7 m apart within the zone of declining groundwater levels at depths of 93.5 and 58.5 m respectively. The difference between predicted and measured groundwater levels is more pronounced at bore 313013, suggesting that at depth groundwater levels are declining to a greater degree. However, it is difficult to draw any firm conclusions from this, as the calibration period for bore 313053 was over a shorter time frame (2002-2005) than that for 313013 (1997-2002). Over this shorter period irrigation abstraction is noticeable, and this could cause the predicted groundwater levels to be lower.

Outside the zone of declining groundwater levels, water levels are either stable, or in some cases, rising (in response to a period of higher rainfall recharge) and these bores are distributed across a variety of different depths. Predicted groundwater levels in bore 324000 rise at a faster rate, and to a greater magnitude than the measured trend. However, the magnitude of predicted troughs correspond well with the troughs in the measured trend suggesting that anthropogenic abstraction is not causing the deviation. Indeed, the most recent predicted groundwater levels begin to conform with the measured trend. It is therefore most likely that the deviation observed here is caused by natural recharge processes not represented by the Eigen modelling technique.

Table 3: Eigen Modelling Results Summary

Bore	**Screened Interval (mbgl)**	**Eigen Model Trend**	**Measured Trend**	**Magnitude of decline (m)[1]**	**Interpretation**
302003	118.6- 121.6	Steadily rising, matches peaks and recovery well until 2010.	Decline since 2010	0.2	Summer abstraction likely responsible for recent drop.
302009	Unknown (109.8 m deep)	Slight decline predicted since 2006. Poor match to peaks.	Steadily increasing		Summer abstraction noticeable, although levels rebound
302026	Unknown (112 m deep)	Stable with some variability between years.	Stable		Summer abstraction noticeable, although levels rebound
303017	196.3-205.3	Stable Levels	Stable		Minimal anthropogenic effects.
304019	256-268	Stable levels, peaks are offset – predicted are before measured.	Steadily increasing since 2007		Minimal anthropogenic effects, rise due to natural processes.
312007	59.7-62.8	Predicts stable levels.	Declining since 2006	0.5	Anthropogenic abstraction noticeable post 2006, causing deviation from predicted.
312009	Unknown (43 m deep)	Predicts steadily rising levels	Declining since 2007	0.75	Anthropogenic abstraction since 2007 causing deviation from predicted.
312028	4-16	Predicts steady groundwater levels, reasonable match to peaks and troughs	Stable		Measured levels greater than predicted due to recharge variability.
313013	90.5-93.5	Predicts steady slightly rising groundwater levels	Levels declining since 2006.	1	Measured levels lower than predicted, seasonal abstraction is apparent.
313053	49-52 and 55.5-58.5	Steady groundwater levels	Steady decline since 2007	0.5	Groundwater abstraction noticeable throughout, likely causes the recent decline.
322029	37.5-42	Steady groundwater levels, slightly under predicts peaks.	Stable		Slightly above predicted likely due to natural recharge variations.
323015	108.5-112	Very steady increase in groundwater levels.	Steady decline	0.5	Groundwater abstractions noticeable, likely cause the deviation.
324000	Unknown	Steady rise in groundwater levels.	Stable since 2004, steady rise		Troughs have not increased in magnitude – natural deviation.
324003	Unknown (43.3 m depth)	Steady groundwater levels agreeing with measured	Stable, steady rise.		System in balance

Notes: 1. Relative to eigen model predicted level

3.0 Groundwater abstraction

3.1 Available and Estimated Data

3.1.1 Groundwater Take Consents

There are currently 106 active groundwater take consents in the Rangitikei and Turakina GMZs (shown in Figure 3.0). Measured abstraction volume data, recorded at hourly intervals is available for some of these consents. In order to include the full irrigation season in each year, "water years" rather than calendar years were used, running from 1st July – 30th June. Table 4 shows the number of active take consents for each use since 2004/2005, while Table 5 summarises the available measured data provided by Horizons Regional Council.

Table 4: Numbers of active in the Rangitikei and Turakina GMZs for water years from 2004/2005 split into consent use.

Water Year	Agricultural Takes	Water Supply Takes	Industrial Takes	Total
2004/2005	18	5	5	28
2005/2006	18	5	5	28
2006/2007	21	6	6	33
2007/2008	26	6	6	38
2008/2009	38	6	6	50
2009/2010	53	6	6	65
2010/2011	63	6	6	75
2011/2012	77	7	6	90
2012/2013	86	7	7	100
2013/2014	92	7	7	106

Table 5: Numbers of consents with available measured data in the Rangitikei and Turakina GMZs for water years from 2004/2005 split into consent use.

Water Year	Agricultural Takes	Water Supply Takes	Industrial Takes	Total
2004/2005	1	0	0	1
2005/2006	5	0	0	5
2006/2007	8	0	0	8
2007/2008	9	0	0	9
2008/2009	11	0	0	11
2009/2010	18	0	0	18
2010/2011	19	1	0	20
2011/2012	24	1	0	25
2012/2013	33	2	1	37
2013/2014	32	1	1	34

Estimates of the effective annual allocated volume (EAAV) was calculated using the protocol in PDP (2012):

- For consents authorising abstraction during the irrigation season (i.e agricultural consents) the EAAV can be calculated assuming that water is used for 100 days at 80% of the maximum daily consented abstraction rate.
- For consents for full year abstraction (i.e water supply and industrial consents), the EAAV can be calculated by assuming that water is used at half the maximum daily consented abstraction rate for 365 days.

Monthly water supply and industrial take data was computed assuming that the mean daily take is equal to half the maximum consented daily take and multiplying by the number of days in each month. Monthly agricultural data was calculated by initially calculating an uptake factor for agricultural take consents with measured data available. The uptake factor was calculated by using the following equation:

$$Uptake\ Factor = \frac{\sum_1^n Actual\ Monthly\ Take}{\sum_1^n Maximum\ Monthly\ Consented\ Take}$$

Where n is the number of consents with a complete data set in a given month. Months without a complete dataset were not included in the calculation. Data from and including June 2007 – August 2010 for consent 106298 was removed from the calculation as no abstraction was recorded for these months despite there being three irrigation seasons during this time. The reason for the absence of any abstraction is unclear.

The uptake factor was then multiplied by the maximum monthly consented take for each of the consents with missing data to obtain an estimate for the actual take in that particular month. This method assumes that all agricultural takes use the same percentage volume of water regardless of crop type. However, as much of the irrigated land in this region is pasture, this calculated dataset represents a reasonable estimate of the actual take.

Figure 3.1 shows the relative proportions of calculated (using the uptake factor) and measured (from water meter data) abstractions together with monthly rainfall and groundwater levels in bore 312009, which lies within the zone of declining groundwater levels. The proportion of measured data has increased since 2005 from being negligible to approximately half the total estimated abstraction.

3.1.2 Permitted Takes

No data for permitted takes is available for the region, and therefore an estimated volume has been derived. Rule 15-2 in the One Plan allows for up to 50 m^3/day to be used for domestic and/or stockwater use without requiring a consent, although it is unlikely that this volume would be consistently taken throughout a year. To calculate the total annual permitted take, a conservative mean take of 3 m^3/day was assumed (PDP, 2012). For each water year, the number of consents active in that year was subtracted from the number of bores installed prior to and during that year, thus giving the maximum number of bores with permitted takes (i.e. without consents). This was then multiplied by the mean take of 3 m^3/day, and the number of days in a year to estimate the permitted annual abstraction, around 1.11×10^6 m^3/year. A total of 1,012 permitted take bores are located across the Turakina and Rangitikei GMZs, with 42 of these bores situated in the zone of declining groundwater levels.

3.2 Groundwater Take Analysis

3.2.1 Rangitikei and Turakina GMZs

Figure 3.2 shows a bar chart comparing the EAAV with the estimated volume abstracted each year, and Figure 3.3 shows estimated monthly abstractions split into consent type since 2005. Since 2009 the EAAV has increased approximately linearly however, the actual abstracted volume varies, increasing during periods of low rainfall. There are some anomalies to this general trend explained by storm events. For example, data for 2011 appears to show an increased summer abstraction despite an increased rainfall.

However, analysis of the rainfall record shows that an extreme rainfall event occurred on 24th January 2011 when 125 mm of rain was recorded in one day.

As expected, agricultural irrigation abstractions dominate the summer months, whilst water supply and industrial takes dominate winter abstraction. In a dry year the percentage of water actually abstracted from bores compared to that consented is typically around 70-95%, whilst in wetter years it is usually 50-70%. Abstractions in the summer months are variable year on year largely dependent on rainfall, whilst those in winter are mostly consistent, increasing through time as the number of consented and permitted takes has increased. Summer abstraction is typically greatest when preceded by a dry winter and spring.

Table 6 shows the total daily consented volume and EAAV for each consent type for 2013-2014. Agricultural consented volumes account for approximately 54% and 62% of the total daily consented volume and EAAV respectively. As a result, agricultural takes have the most influence over total annual abstraction, despite the irrigation season being limited to less than half the year. Due to the large number of bores, permitted takes account for around 32% of the total daily consented volume.

Figure 3.4 shows a plot of all consents in the Rangitikei and Turakina GMZ, showing the consent type and consented volume. Most of the largest takes are agricultural and are located in the coastal plains to the west of Bulls or along the Rangitikei River.

Table 6: Estimated Annual Volume for Groundwater Takes within the Rangitikei and Turakina GMZs for year 2013/2014.

Consent Use	Total Maximum Daily Consented Volume (m^3/day)	Method for estimating annual volume	Effective Annual Allocated Volume (x 10^6 m^3/year)
Agriculture	254,179	Water is used for 100 days at 80% of max. daily consented rate	20.3
Industrial	9,150	Water is used for 365 days at 50% of max. daily consented rate	1.67
Water Supply	9,510		1.74
Permitted Take	3,036[1]	Water is used at 3 m^3/day for 365 days (1,012 bores).	1.11
Total	**275,875**		**24.8**

Notes:

1. *Permitted maximum consented volume calculated as 3 m^3/day.*

3.2.2 Santoft Area

Figure 3.4 indicates that there are 18 consented takes within the zone of declining groundwater levels defined above (Section 2.3). Nine of these takes are consented to abstract more than 2,000 m^3/day, and six of these are consented to take more than 4,000 m^3/day. Figure 3.5 shows a bar chart comparing EAAV with the actual estimated volume abstracted each year, and Figure 3.6 shows monthly groundwater abstraction in the zone of declining water levels. Since 2008 the EAAV has increased approximately linearly, while the actual volume taken is largely dependent on the annual rainfall, following the trend highlighted in section 3.2.1 (above). Actual groundwater abstraction has been mostly constant since 2011, declining in 2012 in response to a wet year, and shows a large stepped increase in 2011 from the previous stable level in 2010, approximately doubling in volume.

Table 7 shows the total daily consented volume and EAAV for each consent type for 2013-2014 in the zone of declining water levels. Agricultural takes account for almost 90% of the consented abstraction and 93% of the EAAV and consequently aquifers within the Santoft area region are most stressed during the summer months, thus explaining the large troughs observed in many of the groundwater level records in the region (Figure 2.1). Figures 3.5 and 3.6 both show the groundwater level trend in bore 312009 (43 m deep) together with abstraction rates. There is a correlation between groundwater levels in bore 312009 and the abstraction record, with the increase in abstraction reflected by a decline in groundwater levels. Groundwater levels begin to fall in this bore around 2008, when the number of consents granted, and therefore total abstraction shows a stepped increase. Combined with the results of the eigen modelling, it is therefore likely that abstraction is the cause of groundwater level decline in this area.

Table 7: Estimated Annual Volume for Groundwater Takes within the zone of declining groundwater levels for year 2013/2014.

Consent Use	**Total Maximum Daily Consented Volume (m^3/day)**	**Method for estimating annual volume**	**Effective Annual Allocated Volume (x 10^6 m^3/year)**
Agriculture	56,574	Water is used for 100 days at 80% of max. daily consented rate	4.53
Industrial	950	Water is used for 365 days at 50% of max. daily consented rate	0.173
Water Supply	0		0
Permitted Take	126[1]	Water is used at 3 m^3/day for 365 days (42 bores).	0.046
Total	**57,650**		**4.75**

Notes: 1. Permitted maximum consented volume calculated as 3 m^3/day.

4.0 Groundwater discharge / recharge

4.1 Geology

In very broad terms, the geologic strata of the Region have been formed in three main sequences:

- The geological basement is predominantly comprised of extremely low permeability and heavily inundated greywacke strata that have been uplifted by tectonic forces to form the Ruahine and Tararua Ranges. These units also occur at depth and underlie the younger geologic strata of the Region;
- The basement rocks are typically overlain by fine grained marine sediments, which are predominantly comprised of low permeability siltstone and/or mudstone described in driller's logs as "papa". This strata does not generally support groundwater abstraction wells, although some coarser grained permeable shell beds and limestone layers are present at discrete locations such as those forming the Nukumaruan Aquifer in Wanganui; and
- In more recent geologic time (over the last 360,000 years), alluvial deposits have been formed by the erosion of the greywacke ranges (a process that is continuing today). These alluvial deposits are highly variable in terms of both composition and deposition, but often contain zones where permeable gravelly strata predominate, forming high yielding productive aquifers. These productive water bearing strata tend

to be thinner close to the inland high country and thicken towards the coast. In the western parts of the Region (particularly in the lower Manawatu and Rangitikei catchments) the alluvial deposits are much more widespread and their thickness can extend up to several hundred metres.

These main types of strata and depositional environments and their subsequent uplift by tectonic forces form four broad categories of the Region's landforms. These are mapped in Figure 4.1, which covers the western deposits of the Region.

The deposits mapped in Figure 4.1 and from oldest to youngest are:

- Unit 1: Low permeability greywacke basement rocks, which outcrop along the Ruahine ranges;
- Unit 2: Marine terrace deposits, generally comprised of low permeability fine grained and compacted strata, although some coarser grained more permeable units do occur;
- Unit 3: Marginal marine and terrestrial deposits of variable composition, although some gravelly units form productive aquifers; and
- Unit 4: More recent terrestrial deposits

Within these different types of strata, it is the younger terrestrial deposits that have the greatest potential to form permeable and high yielding aquifers. They are heterogeneous deposits, but when dominated by coarse sand and gravel and in hydraulic connection to a reliable source of recharge, they represent productive aquifers that are used for groundwater abstraction.

4.2 Groundwater Recharge from Rainfall Infiltration

Groundwater recharge from rainfall infiltration has been estimated for the Rangitikei and Turakina GWMZs based on the same protocol described in PDP (2013). However, at the time that report was prepared, electronic geology data was not available for the Hawkes Bay area, which overlapped with the northern ends of the Turakina and Rangitkei GWMZs. That data is now available and has been used to provide updated estimates of groundwater recharge from rainfall infiltration. Table 8 presents the updated estimates of rainfall recharge.

Table 8: Estimates of groundwater recharge from rainfall infiltration to the Turakina and Rangitkei GWMZs

Unit (Geology type)	**Area (x 10^6 m^2)**	**Average annual rainfall (mm/year)[1]**	**Recharge estimation protocol**	**Estimated average annual recharge from rainfall infiltration (x 10^6 m^3/year)**
1 (Basement strata)	0	989	No recharge across areas of outcropping basement strata	0
2 (Lower permeability marine strata)	1,094[2]	989	10 % of rainfall (low permeability sediments)	108.2
3 and 4 (Higher permeability strata (alluvial gravels))	1,432[3]	989	30 % of rainfall (higher permeability sediments)	424.9
Total	**2,526[4]**	**-**	**-**	**533.1**

Notes:

1. *Weighted average of mean annual rainfall over the Rangitkei (956 mm/year) and Turakina GWMZs (1041 mm/year)*
2. *Total Turakina = 339 x 10^6 m^3, total Rangitikei = 755 x 10^6 m^3*
3. *Total Turakina = 618 x 10^6 m^3, total Rangitikei = 814 x 10^6 m^3*
4. *Total Turakina = 957.4 x 10^6 m^3, total Rangitikei = 1569 x 10^6 m^3*

The estimates of groundwater recharge from rainfall infiltration in Table 8 provide an indication of the drainage to groundwater through the soil zone. However, a proportion of that drainage will move relatively rapidly through to nearby streams and rivers. Estimates of the age (as Mean Residence Time) of samples from low flows in the Rangitikei River and tributaries indicated that the typical age of groundwater discharging into the river is around three years, suggesting relatively rapid throughflow of groundwater into the rivers (GNS 2014).

The effect of that rapid movement of infiltrating rainfall towards rivers and streams is that only a proportion will continue to drain through to the deeper aquifers that are targeted by major abstractions in the area. Recharge to those deeper aquifers is governed by the hydraulic conductivity of the strata and the hydraulic gradient and is likely to be substantially less than the estimate given in Table 8. Some consideration of low flows could help to estimate the relative proportion of infiltration that rapidly moves towards the rivers, compared to that which may infiltrate to the deeper aquifers.

Patterns of recharge on an annual basis can be derived from simple soil moisture balance calculations, where recharge to groundwater occurs when the soil moisture deficit is satisfied. The results of soil moisture calculations are based on a rainfall timeseries from Sanson (NIWA Agent number 3187) and potential evapotranspiration (PET) data from Palmerston North EWS (NIWA agent number 31963 and 3228). Whilst these stations for rainfall and PET are not located directly adjacent to one another, PET data is not expected to vary widely across the region. The results therefore provide an indication of the overall patterns of recharge that may have occurred, although the absolute values will vary across the Rangitikei and Turakina GWMZs depending on local variations of rainfall, PET and soils. The calculations assume a soil moisture profile available water (PAW) of 90 mm, which is broadly representative of the soils that occur across the Santoft area.

Figure 4.2 presents annual and monthly recharge amounts between January 1990 and December 2014, together with groundwater levels from bore 323015. The results indicate that recharge is likely to have varied widely in the 25 year period for which data is available from an apparent low of just 2.9 mm in 1993 to a maximum of 375 mm in 1998. The long term average is around 205 mm/year, which is in line with the estimates provided in Table 8.

The estimates of recharge indicate that since 2012, recharge may have been below average, which may go some way to explaining the notable declines in groundwater levels observed in bore 323015. However similarly low levels of recharge occurred in 2007 and 2005, neither of which resulted in such notable declines in winter recovery levels. Therefore the decline in groundwater levels is likely to have been exacerbated by another cause, most likely related to groundwater abstraction. Further assessment of the recharge to, and discharge from, the Santoft area is presented in Section 4.6.

4.3 Groundwater contours

Horizons Regional Council recently undertook a piezometric survey of bores in the Rangitikei and Turakina GWMZ, including groundwater level measurements in 110 bores ranging in depth from 3 m to 268 m. The survey took place late October 2014 and it is worth noting that some groundwater pumping was taking place at that time, which may distort some of the resulting contours.

Figure 4.3 shows the location of bores used in the survey, with different symbols used for different depth ranges. In general, there is a good spatial coverage around the Rangitikei River and across the Santoft area.

Figures 4.4 and 4.5 present groundwater contours plotted for bores less than 20 m deep and more than 20 m deep respectively, with the surface topography as a coloured background. The distinction between bores less than 20 m deep and more than 20 m deep is relatively arbitrary, but recognises that there is likely to be a difference between shallow and deep groundwater flow. Groundwater level contours for the shallow strata are focussed around the river and suggest that there is a clear flow component towards the Rangitikei River, particularly in the reach upstream of Bulls. Downstream of Bulls the shallow groundwater flow direction appears to turn to be more perpendicular to the Rangitikei River. That groundwater flow pattern is reasonably close to the pattern of topographic contours shown in Figure 4.4.

Shallow horizontal groundwater gradients are notably steep; the approximate gradient between groundwater levels surveyed south of Marton (313064, 119 mRL) and the Rangitikei River (314050, 77.5 mRL) is 0.009. That steep gradient is topographically driven.

Likewise, groundwater contours for the deeper strata (more than 20 m deep) (Figure 4.5) generally reflect surface elevations albeit in a more muted fashion than the shallow groundwater contours. The contours indicate a strong flow component towards the Rangitikei river upstream of Bulls and downstream of Bulls, the groundwater contours appear to be largely parallel to the coast, albeit with some component of flow towards the Rangitikei River. Groundwater gradients in the deeper strata appear to be less steep than the gradients for shallower strata; the approximate gradient in the area between Bulls and Marton is around 0.004, compared to 0.009 for the shallower strata.

Contours for the deeper strata also appear to suggest a flow divide to the north-west of the Rangitikei River running approximately perpendicular to the coast from Marton and close to the catchment divide between the Rangitikei catchment and the Turakina catchment. That flow divide is particularly apparent in the north west of the area and becomes progressively less pronounced closer to the coast. The flow divide may be important because it would reduce the flux of groundwater movement towards the coast and into the Santoft area.

Figure 4.6 shows the difference between deeper groundwater level and shallower groundwater levels, where blue shading indicates that shallower groundwater levels are higher than deeper levels (i.e. a downwards gradient) and red shading indicates deeper groundwater levels are above shallow levels (i.e. an upwards gradient). Where data is available to compare the two sets of groundwater surfaces, it indicates that downwards gradients are broadly present upstream of Bulls, whereas downstream of Bulls the gradient is either neutral (i.e deep and shallow groundwater levels are in equilibrium) or upwards. That pattern would be largely typical of a groundwater system that discharges offshore, where vertical gradients are downwards inland and upwards towards the coast.

Figure 4.7 presents a cross section from the Rangitkei River in the north-east to the coast, through the area of declining groundwater levels, showing groundwater levels from the shallow and deeper contours and the ground surface. The line of the cross section is shown in Figure 4.6. In the cross section, shallow groundwater levels rise above the surface, although that reflects limited data rather than a real above surface artesian groundwater level. However, the main observation from the cross section is that deeper groundwater levels clearly reflect the ground surface.

Where groundwater levels reflect the land surface, the dominant source of water is likely to be land surface recharge, as opposed to recharge sourced from rivers. Therefore, the amount of water that reaches the deeper aquifers will depend on the vertical hydraulic conductivity of the overlying strata and the gradient between shallow groundwater and deeper groundwater. Based on the geology, which indicates that the strata consist of various intervals of lower permeability clays, silts and fine sands together with some higher permeability gravels, the vertical hydraulic conductivity is likely to be relatively low. Therefore, recharge to deeper groundwater is also likely to be restricted.

4.4 Vertical gradients

Vertical gradients can help to define areas where groundwater recharge and discharge occur, with groundwater recharge generally occurring in areas of downwards gradients and groundwater discharge occurring in areas of upwards gradients.

Vertical groundwater gradients can be determined by plotting the groundwater levels in pairs of bores of different depths. Figure 4.8 presents the location of series of pairs of bores within 500 m of each other, where one bore is more 40 m deep and the other is less than 20 m deep. This is referred to as the neighbouring bore method on Figure 4.8. In addition, bores more than 40 m deep with above surface artesian groundwater levels (implying upwards vertical gradients) are also shown in Figure 4.8, together with bores more than 40 m deep with groundwater levels at least 30 m below surface (implying downwards vertical gradients). This is referred to as the deep bore method on Figure 4.8.

Figure 4.8 indicates that upwards vertical gradients are typically present closer to the coast, with downwards gradients generally occurring further inland. Some anomalies are present in the data, for example there are above surface artesian groundwater levels present in deeper (>40 m deep) bores located towards the north-east edge of the Rangitikei GWMZ along the line of the river, which may represent the effects from isolated lenses of permeable strata intercepted by some bores.

The locations of bores indicating upwards vertical gradients are broadly consistent with the plot of upwards vertical gradients derived from the comparison of deeper and shallower groundwater contours (Figure 4.6), particularly towards the Rangitikei River mouth where groundwater may therefore be discharging. However the data further north, and in the area around Santoft township is uncertain. In general, the bores in the area around Santoft township record relatively deep groundwater levels with static levels in even deeper bores several metres below the surface. Therefore, a downward vertical gradient may be broadly present in that area, indicating that it is an area of groundwater recharge. Therefore, the discharge location for the deeper aquifers further north from the Rangitikei River mouth is likely to be off shore of the coast.

Figure 4.9 shows a plot of the lateral groundwater gradient between bore 312007, 313013 and bore 312009, compared to the groundwater level in bore 312007 (closest to the coast). In groundwater systems that have a fixed discharge point (e.g. springs at the ground surface), higher groundwater levels tend to be correlated with higher gradients and vice versa, however Figure 4.8 indicates that no such correlation is present between the three bores in the Santoft area. That absence of correlation suggests that the groundwater system in the Santoft area discharges to a series of diffuse and widespread locations, which could be consistent with discharge off the coast.

4.5 Groundwater – surface water interaction

The Rangitikei Water Resource assessment included low flow surveys of the Rangitikei river and some assessment of those flows helps to provide some indication of where the river gains from groundwater, and where it loses water to groundwater. It is useful to compare that data to indications of groundwater-surface water interaction based on the piezometric survey data (Section 4.3).

A summary of the low flow survey data is provided in Table 9.

Table 9: Low Flow survey data (from Rangitkei Water Resource Assessment)

Gauging site (from upstream to downstream)	**Flow in Rangitkei River (m^3/s)**		
	8 March 1978	**16 March 1983**	**25 March 2003**
Mangaweka	11.60	11.4	12.989
Otara			12.462
Vinegar Hill	13.02	10.436	12.783
Onepuhi			13.612
Kakariki	12.88	11.909	
Bulls Bridge			13.599
Hamptons			14.106

Mangaweka is the gauging station located at the junction between the upper and lower Rangikei catchments and downstream of that point only limited tributary inflow occurs. Therefore, the flows in the river are reasonably representative of interactions within the main stem of the river.

Based on the most recent survey from March 2003, some flow loss may have occurred between Mangaweka and Vinegar Hill (approximately 20 km upstream of Bulls). Downstream of that point, flow rates in the river increased to Hamptons, located just downstream of Bulls. That pattern would be consistent with the groundwater contour data, which suggests groundwater inflows in the reach of the river between Vinegar Hill and Bulls.

However, the pattern is not accurately duplicated in the 1978 survey data and it is worth noting that the comparisons between gauging measurements are not entirely precise, with each measurement having an error of ±8%. Therefore, the pattern of losing and gaining reaches between Mangaweka and Hamptons is uncertain and may vary seasonally and/or from year to year.

The gauging sites used in the low flow surveys do not extend all the way downstream to McKelvies, which is the present day most downstream gauging site, located around 2 km inland from the coast. That is also the reach of the Rangikei River that extends across the coastal plains, and where some effects from groundwater abstraction may occur. However some indication of the pattern of river losses between Bulls and the sea outfall are available from a concurrent gauging survey undertaken by Massey University in January 2015.

Figure 4.10 shows the locations where flow was gauged during the Massey University survey. In addition, flow rates measured at the McKelvies permanent monitoring station at the same times are shown. The data indicate that the Rangitikei River loses between Bulls and the coast, even when potential errors in flow gauging are allowed for.

The cause, or destination, of the losses is not clear. There are relatively few surface water abstractions in that reach of the river (which may imply natural losses rather than artificially induced losses) and at times the data indicate that the losses can be large, up to around 25 % of the flow recorded around Bulls.

There are various springs that occur around the northern side of the Rangitkei River, which could reflect that loss. However based on topographical maps of the area, the springs appear to flow back into the river. In addition, the loss is not clearly defined in the groundwater contours, partly due to limited data in area. The springs could equally explain the small gain in river flows observed at low flow.

This is an area which needs much more investigation, since it will have a strong influence on determining the area where groundwater levels are declining and on the water balance for the Santoft area as a whole. Further investigation could include

- detailed identification of the reaches which lose water;

- detailed piezometric surveys of shallow groundwater adjacent to the river; and
- groundwater quality sampling from shallow groundwater and the springs to help identify their source.

4.6 Water balance for the Santoft area

Recharge to the deeper aquifers in the Santoft area is likely to be via a combination of throughflow from upgradient together with a proportion of rainfall infiltration and/or river seepage from the Rangitikei River. Significant leakage into the deeper aquifers from the small number of surface water courses that cross the area is unlikely.

A simple estimate of potential groundwater throughflow into the Santoft area can be derived from Darcy's equation:

$$Q = K.A.i$$

where:

Q = groundwater throughflow (m^3/day)

K = hydraulic conductivity (m/d)

A = area of throughflow (m^2)

i = hydraulic gradient

Based on the depth of bores in the Santoft area, the effective saturated aquifer thickness is likely to be in the order of 250 m. The estimated area of declining groundwater levels is approximately 15 km wide perpendicular to groundwater flow, implying a cross-sectional area (A) of around (15,000 x 250) = 3.75×10^6 m^2.

Typical transmissivities from pumping tests conducted on bores in the area are around 500 m^2/day, although these typically represent the effects from bores screened across a 10 m interval and in gravely strata. Overall, the strata are made up of interbedded sands, muds, silts and clays and on average, the hydraulic conductivity for these types of units is likely to be around 1 m/day. Based on the groundwater contours shown in Figure 4.4, the hydraulic gradient is in the order of 0.005 (30 m change over 6,000 m).

Using these values for the parameters, average groundwater throughflow into the Santoft area would be around 6.8×10^6 m^3/year. Table 10 presents a preliminary water balance for the Santoft area:

Table 10: Preliminary water balance for the Santoft area

Water balance component	Inflows (x 10^6 m^3/year)	Outflow (x 10^6 m^3/year)
Groundwater throughflow from upgradient	6.8	
Rainfall recharge (based on an area of 150 x 10^6 m^2 and 200 mm rainfall recharge /year)	30	
Estimated actual groundwater abstraction (as at current (2014) rates)		2.5
Groundwater discharge to springs, rivers, lakes and offshore		36.3
Total	**36.8**	**38.8**

The volume of groundwater discharge to springs, river, lakes and offshore is not precisely defined. In Table 10 it has been calculated based on apparently stable groundwater levels when groundwater abstraction was around 0.5 x 10^6 m^3/year, which implies that discharge balanced recharge at that time.

The water balance presented in Table 10 indicates that outflows from the groundwater system currently exceed inflows, which is reflected in the declining groundwater levels observed in monitoring bores. Therefore the system is not currently in a steady state and groundwater is being drawn from storage. However in the long term the system will find a balance either via increased groundwater inflows, perhaps via increased throughflow due to steeper gradients, and/or reduced groundwater discharges to springs, rivers lakes and offshore.

It is also worth noting that only a proportion of throughflow and rainfall recharge in Table 10 will reach the deeper aquifers, but the majority of abstraction is taken from the deeper aquifers. Therefore, the sustainable rate of abstraction from the deeper strata may be a relatively small proportion of the overall water balance (it is currently around 6 %), although there is not yet sufficient information to determine that proportion precisely.

4.7 Potential effects of increased abstraction

To a large extent, the effects of increased abstraction, and the associated decline in groundwater levels observed in the area around Santoft, depend on where groundwater currently discharges to. Based on the groundwater contours, the discharge location appears to be generally out to sea, although there is likely to be a component of discharge to shallower aquifers, coastal lakes and springs. Therefore, declining groundwater levels may have the following effects:

- Increased risk of saline intrusion towards the northern end of the area of declining groundwater levels where coastal discharge may reduce;
- Increased leakage from shallower aquifers to deeper aquifers, leading to an eventual decline in shallow groundwater levels; and
- Reduced discharge to the springs that occur towards the Rangitikei River mouth.

These effects are likely to occur over a relatively long time period, although that will largely depend on the rates of leakage to deeper aquifers and rates of throughflow, which may vary across the area. Therefore, there may be areas where greater or lesser decline occurs depending on local abstraction pressures.

5.0 Recommendations for Future Management

The pattern of long term groundwater levels in the Santoft area, where rising groundwater levels preceded a period of recent decline related to increased abstraction pressures suggests that the overall system is sensitive to relatively small changes in the groundwater balance.

The magnitude of groundwater level decline is currently small, in the order of 1 m, but it indicates that discharges from the groundwater system in the area around Santoft are greater than recharge or throughflow into the deeper strata. In some cases where groundwater levels show an initial decline groundwater systems will find a new equilibrium by inducing additional recharge leading to stabilised groundwater levels. There is some evidence to point towards that being the case in the Santoft area, where there is apparently substantial rainfall recharge available. However, given the apparently limited throughflow into the area, it may be some time before that recharge is induced to leak into the deeper aquifers by groundwater level decline. As a result, groundwater level decline could continue for a long period and become quite large before levels stabilise. It is currently not clear what the impacts of that decline would be on surface water features that are dependent on groundwater discharge to sustain their levels and flows.

That uncertainty feeds through to uncertainty with regards to management of the groundwater resource and assessments of the sustainable rate of groundwater abstraction. In general, a pattern of continued groundwater level decline is not a desirable situation, particularly in the Santoft area where the relationship between groundwater levels, groundwater discharge and effects on coastal lakes and streams is uncertain.

5.1 Proposed trigger levels

One management approach in these situations, which allows for some uncertainty, is to develop a series of groundwater trigger levels whereby abstraction rates are progressively reduced at successively deeper groundwater levels. Setting trigger levels implicitly defines an allocation limit, although there is limited data that could define that limit. However, the trigger levels will act as an adaptive management technique until that limit can be defined. Trigger levels can be set so that either:

- Seasonal groundwater level lows are restricted i.e. if groundwater levels fall to a particular point during an irrigation season, then abstraction would be limited; or
- Alternatively, trigger levels can be set to reflect winter groundwater levels so that unless winter groundwater levels recover above a set level, irrigation during the subsequent summer would be restricted. No restriction would be placed on abstraction rates during summer.

There are advantages and disadvantages to each of these approaches, set out in Table 11.

Table 11: Trigger level approaches:

Trigger level approach	Advantage	Disadvantage
1. Restrictions are triggered if seasonal lows reach a specified level.	-Groundwater abtraction does not cause aquifer discharge to decline below a certain point during summer.	-Trigger levels could be breached by nearby pumping. -Abstractive use of groundwater is disrupted in the middle of an irrigation season.
2. Restrictions are triggered in subsequent irrigation season if winter recharge does not reach a specified level.	-May help avoid long term decline and protects the overall resource. -Allows irrigation to occur without interruption during summer. -Provides clarity with respect to the length of restrictions.	-Seasonal lows could be significant. -Setting of initial trigger levels may be subjective.

Neither of the trigger level approaches described above is perfect. However, in order to avoid long term declines, we would recommend the second approach where restrictions are triggered based on the recovery that occurs during winter, unless evidence becomes available regarding specific adverse effects occurring due to low summer or autumn groundwater levels.

A series of potential trigger levels based on that approach in each of the six monitoring bores located within the Santoft area are presented in Figure 5.1. The nature of the hydrogeological system in the area makes it difficult to set trigger levels that are directly related to an effect; for example a specific decrease in shallow water levels or a change in the saline- freshwater interface at the coast. However, at this stage it will be important to set trigger levels that prevent long term declines.

Based on groundwater level records prior to 2006 (which is approximately when groundwater level decline related to abstraction pressures began), the natural winter (June to October) groundwater level varied by around one to one and half metres, which in part reflects the long term rise that occurred in some of the bores between 1990 (when records began) and 2006, but also shorter term changes in recharge patterns from year to year.

The trigger levels therefore need to account for that natural variability and Table 12 presents a series of trigger levels for each of the six bores that show declining groundwater levels. The trigger levels are tiered, with progressive reductions in abstraction rates (in terms of the annual volume) at each step.

Table 12: Proposed trigger levels

Bore	Minimum observed winter groundwater level (m RL)	Maximum observed winter groundwater level (m RL)	Range (m)	1/3 reduction trigger level (m RL)[1]	2/3 reduction trigger level (m RL)[2]	Complete restriction (m RL)[3]
302003	22.79	21.69	1.1	20.6	19.8	18.9
312007	20.47	21.27	0.8	19.7	19.0	18.5
312009	45.91	47.07	1.16	44.8	43.9	43.0
313013	41.33	42.85	1.52	39.8	38.7	37.5
313053	40.81	42.92	2.11	39.2[4]	38.1[4]	36.9[4]
323015	22.59	23.43	0.84	21.5[5]	21.0[5]	20.5[5]

Notes:

1. The first trigger level is set as the minimum winter groundwater level minus the range (i.e. 100 %) of observed groundwater levels.

2. The second trigger level is set as the minimum groundwater level minus 175 % of the range of observed groundwater levels.

3. The third trigger level is set as the minimum groundwater level minus 250 % of the range of observed groundwater levels.

4. Defining trigger levels in bore 313053 based on the approach described above is less appropriate because of the comparatively short length of its record (2002 to present). However, since 2002, groundwater levels in bore 313053 are, on average, 0.61 m above the level in 313013 which is at the same location. Therefore, trigger levels in bore 313053 are set 0.61 m below the trigger level in bore 313013.

5. Trigger levels in bore 323015 have already been defined as part of a consent (Te Hou Farms), so the trigger levels in Table 12 are the same as those in the consent. Slightly shallower trigger levels would be used if the same approach was applied- i.e. 21.74, 21.11 and 20.48 at each of the respective reduction levels.

Setting trigger levels in several bores in the area may cause some issues around which trigger level should be applied to different consents. The most appropriate solution is to simply apply the trigger level in the two closest monitoring bores to lessen the impact of localised drawdown effects on any bore, where possible it will be important to make sure that any significant nearby interference effects can be accounted for, ideally via parameters derived from a pumping test.

Some discussion has previously occurred regarding the use of a numerical groundwater model to simulate groundwater flow patterns in the Santoft area. In general, the strata around Santoft will be difficult to precisely represent in a model, since the water bearing strata tend to occur as lenses at different levels throughout the aquifer system, rather than discrete layers. Consequently, accurately calibrating a model based on pumping test data and groundwater level data may be a difficult exercise.

Nonetheless, a groundwater model could still be used at a much simplified level to represent the overall system (for example using two layers), without the intention to represent individual water bearing lenses. It is important to recognise that the purpose of such a model would be to act as a management tool, rather than, for example, attempting to accurately estimate drawdown interference effects from individual abstractions. Such a model could effectively provide good guidance for:

- understanding the likely throughflow and recharge into, and discharge from, the hydrogeological system around Santoft;
- understanding the potential effects of abstraction on groundwater levels and coastal lakes under different scenarios (e.g. actual abstraction rates compared to fully consented abstraction rates); and
- subsequently estimating a sustainable allocation volume for the area.

6.0 Summary and conclusions

In summary, the investigations in this report indicate that:

- Groundwater abstraction is broadly well within the allocation limit set within the One Plan, but a pattern of groundwater level declines has been observed in some bores around Santoft;
- Eigen modelling suggests that longer term groundwater level declines in a series of monitoring bores in the Turakina and Rangitikei Groundwater Allocation Zones are likely to be related to increases in groundwater abstraction;
- Groundwater abstraction currently does not occur at fully consented rates. In 2012/2013 and 2013/2014 the total actual abstraction from the area of declining groundwater levels around Santoft was around 2.5 x 10^6 m^3/year, compared to an Estimated Annual Allocated Volume (EAAV) of around 4.5 x 10^6 m^3;
- Recharge to groundwater is likely to be principally from rainfall recharge, but there is an area around the Rangitikei River downstream of Bulls where flow gauging indicates that the river loses to groundwater;

- The total volume of recharge appears to be greater than the volume of abstraction. Therefore the pattern of declining groundwater levels indicates that only a limited volume of that recharge reaches the deeper aquifers and a sustainable abstraction volume may only be a small proportion of recharge;
- Given the uncertainties, the most appropriate management approach is to implement a series of trigger levels in the bores showing declining groundwater levels, which allows for some adaptive management;
- The nature of the hydrogeological system in the area makes relating those trigger levels to changes in groundwater discharge and impacts on receptors uncertain and those effects are likely to take time to occur; and
- A series of trigger levels are proposed, based on historical groundwater level variations in groundwater level monitoring bores. Trigger levels would be activated based on winter recovery levels prior to each irrigation season. Those levels intend to represent relatively large declines in groundwater levels, but the proposed levels should be discussed with the Santoft Water Users Group. Ideally implementation of the trigger levels would be on a voluntary basis.

Further work could be undertaken to help reduce some of the uncertainties that have been highlighted in this report. That work could include:

- To reduce the uncertainty with regard to losses from the Rangitikei River downstream of Bulls, a water quality survey of deep and shallow bores around the reach of the Rangitikei between Bulls and the coast should be undertaken with the result compared to water quality in the river. That survey should include oxygen isotope data, and other more general water quality indicators (e.g. nitrate, chloride, manganese and iron) to help define the sources of groundwater in that area. That information would help define the area of declining groundwater levels because areas that receive some additional recharge from the river may be less prone to groundwater level declines;
- Monitoring of likely coastal discharges, for example coastal lake levels and the gradient between that level and coastal bores at shallow and deep levels close to the coast will help to illustrate the impact of abstraction on those discharges; and
- To investigate and define a sustainable allocation of groundwater from the deeper aquifers a simplified groundwater model should be used. That model could represent the overall pattern of groundwater level decline compared to abstraction from the deeper aquifers, estimated rates of recharge, leakage and groundwater throughflow.

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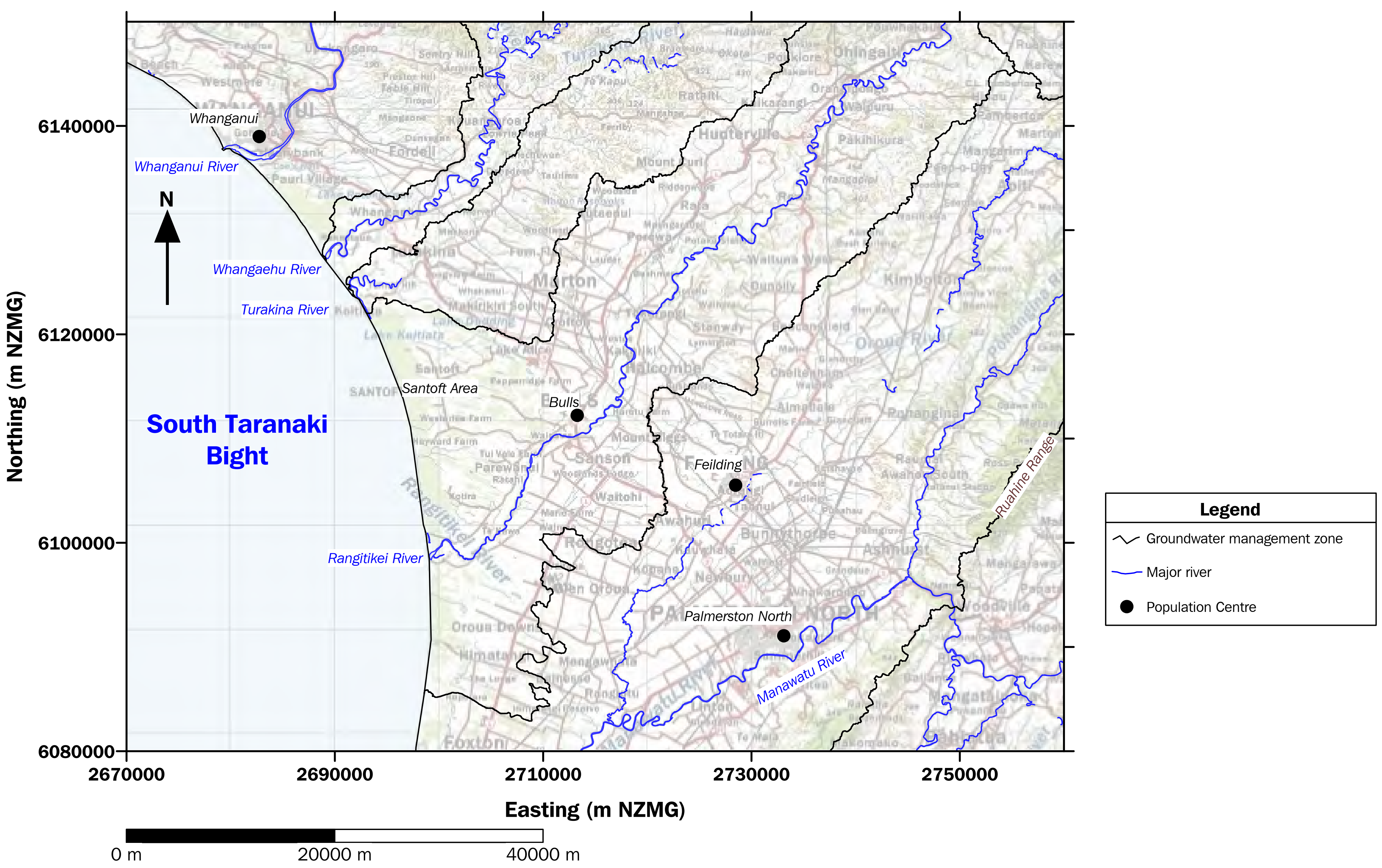


Figure 1.1: Location map showing the position of the Santoft area, and groundwater management zones

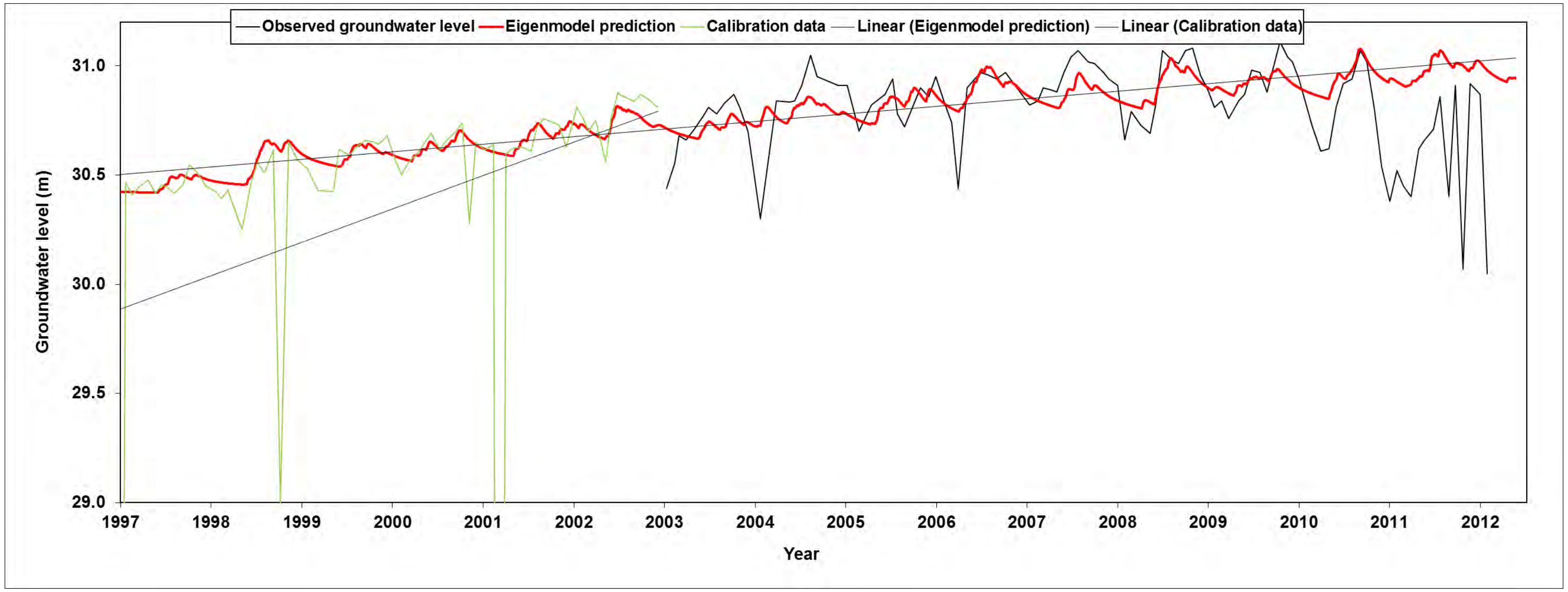


Figure 2.1a: Eigen modelling results for Bore 302003 – Screened 118.6-121.6 mbgl, declining GW levels.

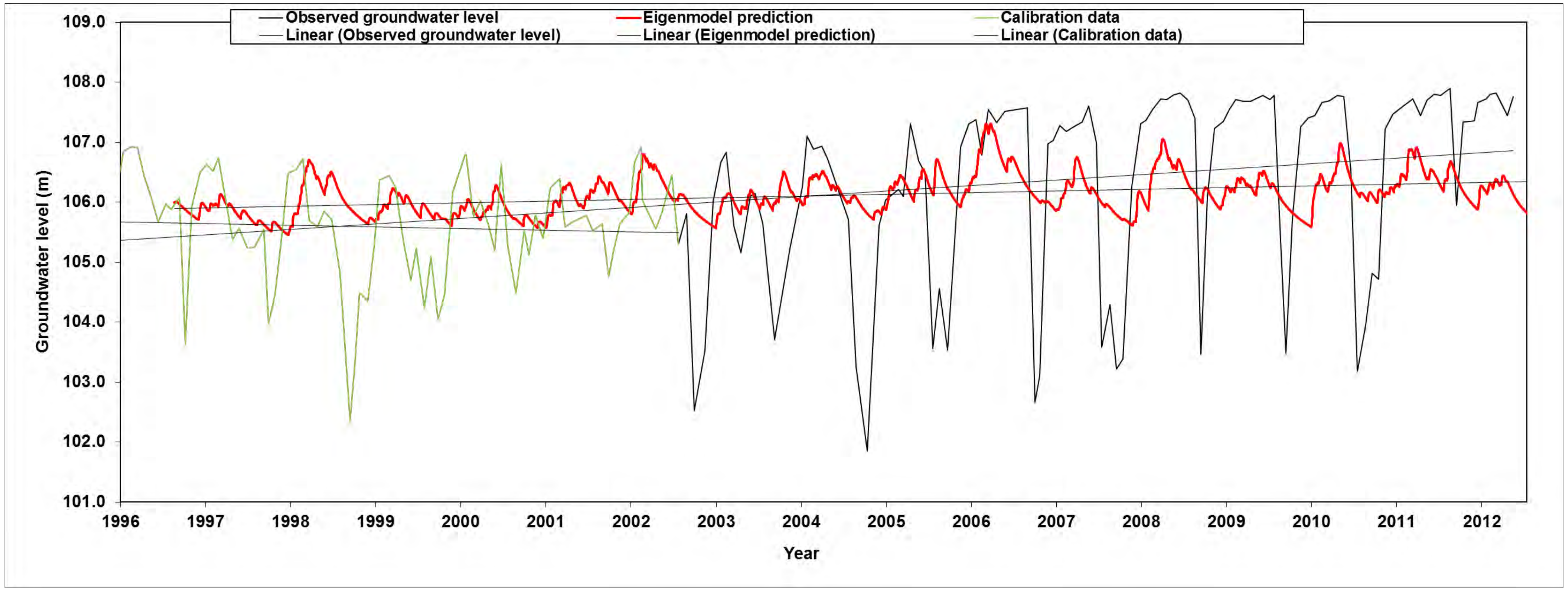


Figure 2.1b: Eigen modelling results for Bore 302009 – 109.8 m depth, steadily increasing GW levels.

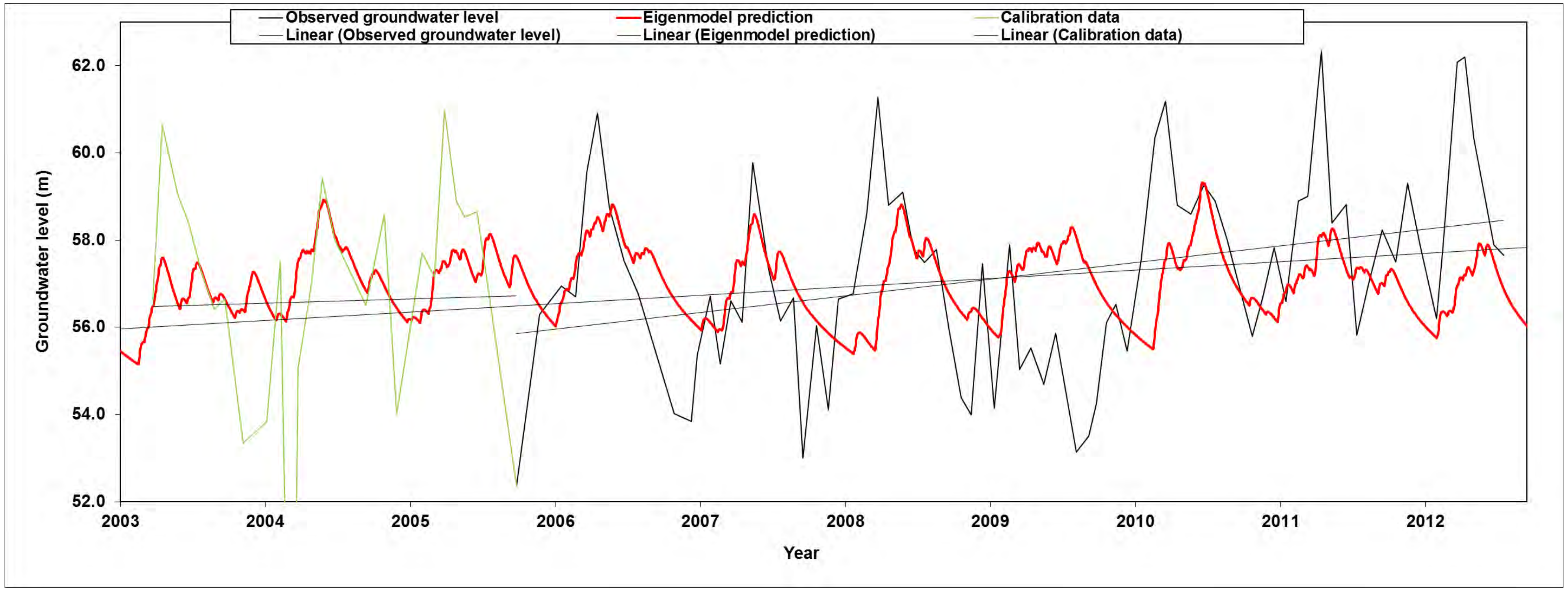


Figure 2.1c: Eigen modelling results for Bore 302026 – 112 m depth, stable GW levels.

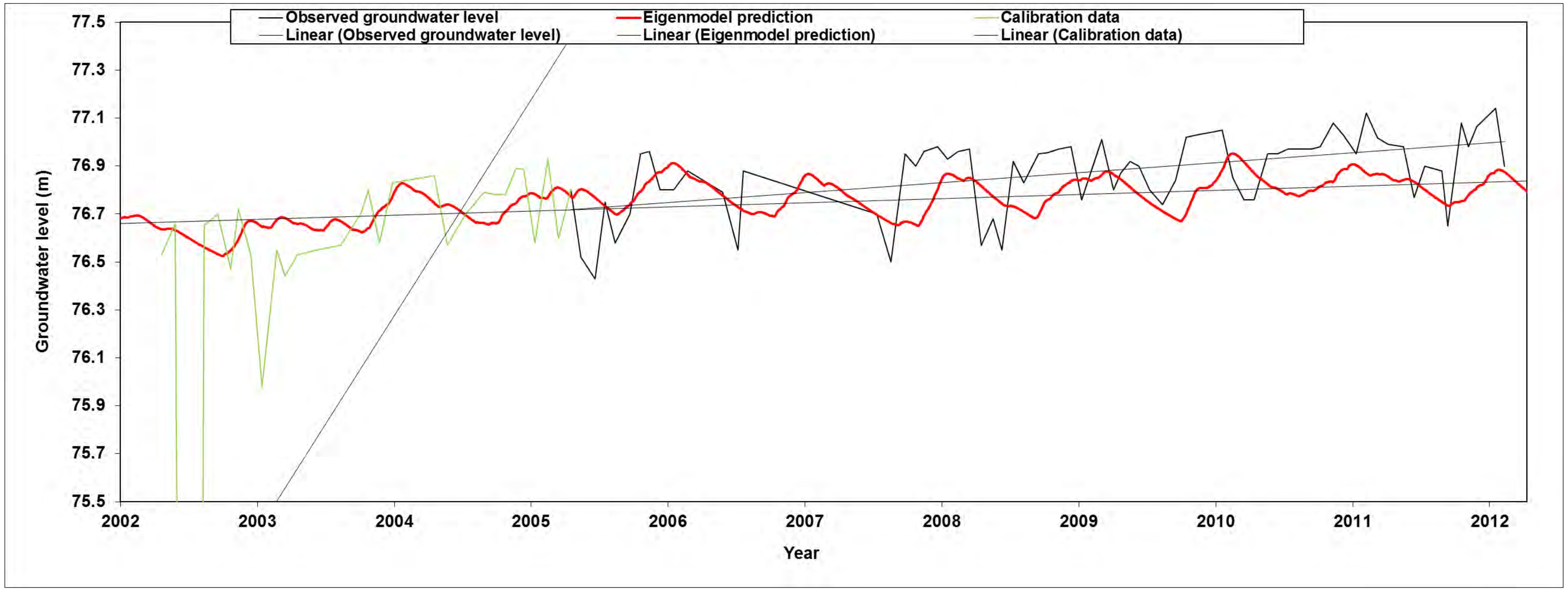


Figure 2.1d: Eigen modelling results for Bore 303017 – screened 196.3-205.3 mbgl, steadily increasing GW levels.

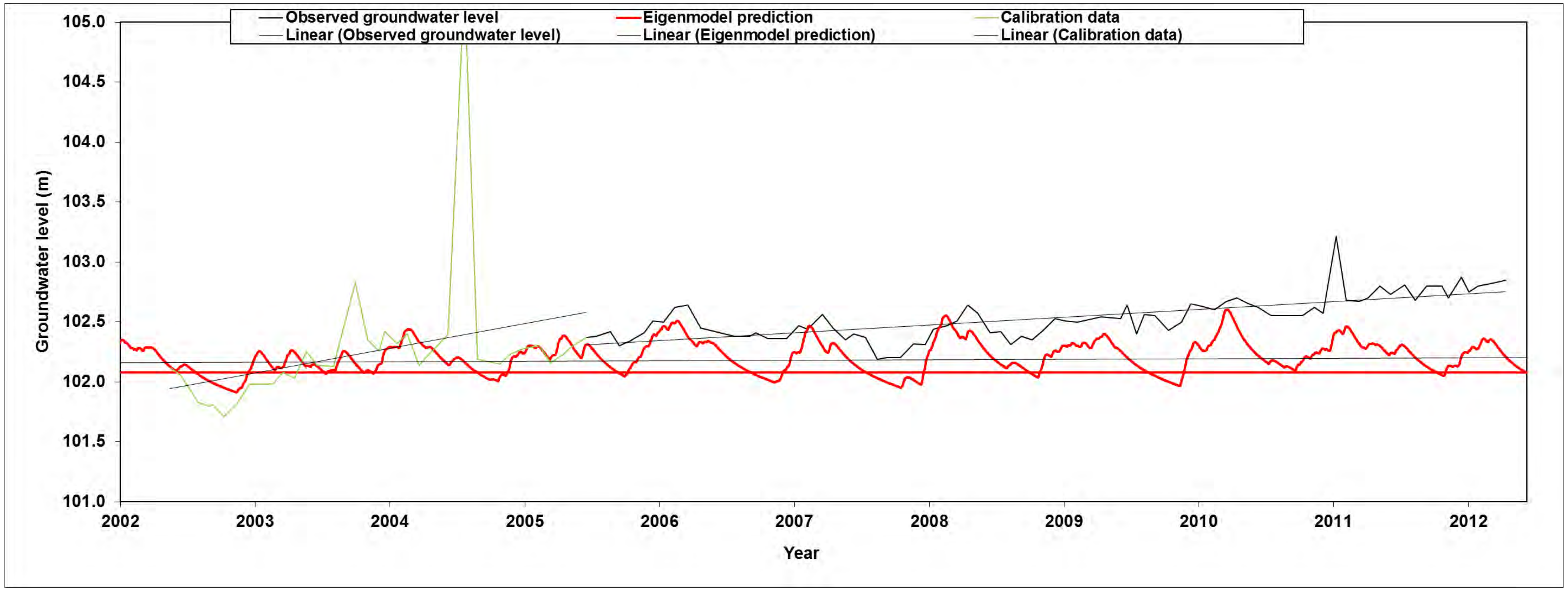


Figure 2.1e: Eigen modelling results for Bore 304019 – screened 256-268 mbgl, steadily increasing GW levels.

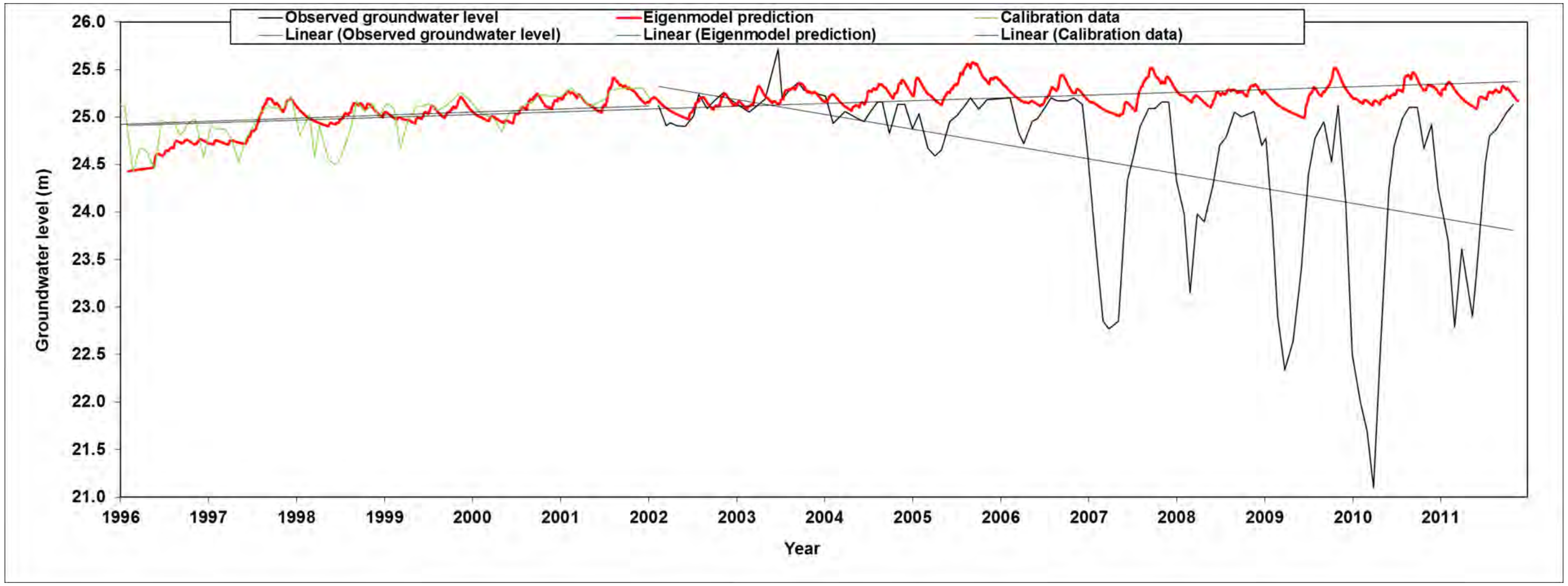


Figure 2.1f: Eigen modelling results for Bore 312007 – screened 59.7-62.8 mbgl, declining GW levels.

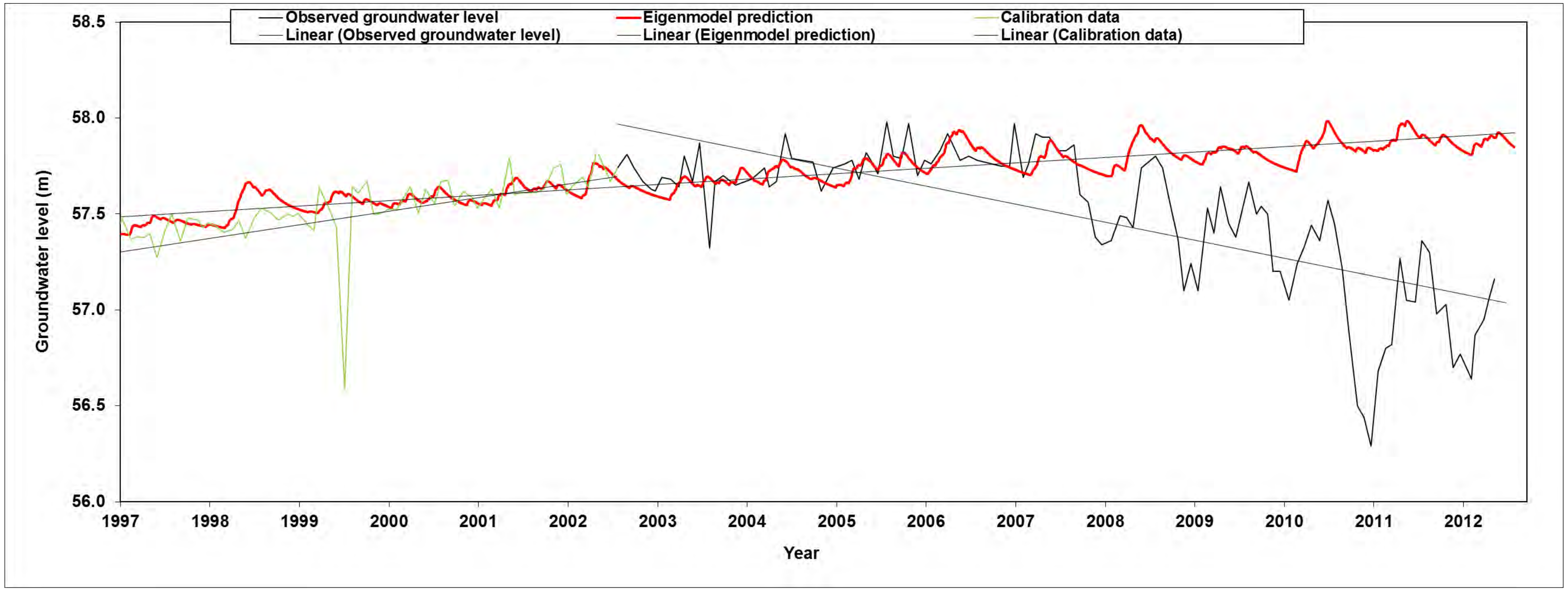


Figure 2.1g: Eigen modelling results for Bore 312009 – 43 m depth, declining GW levels.

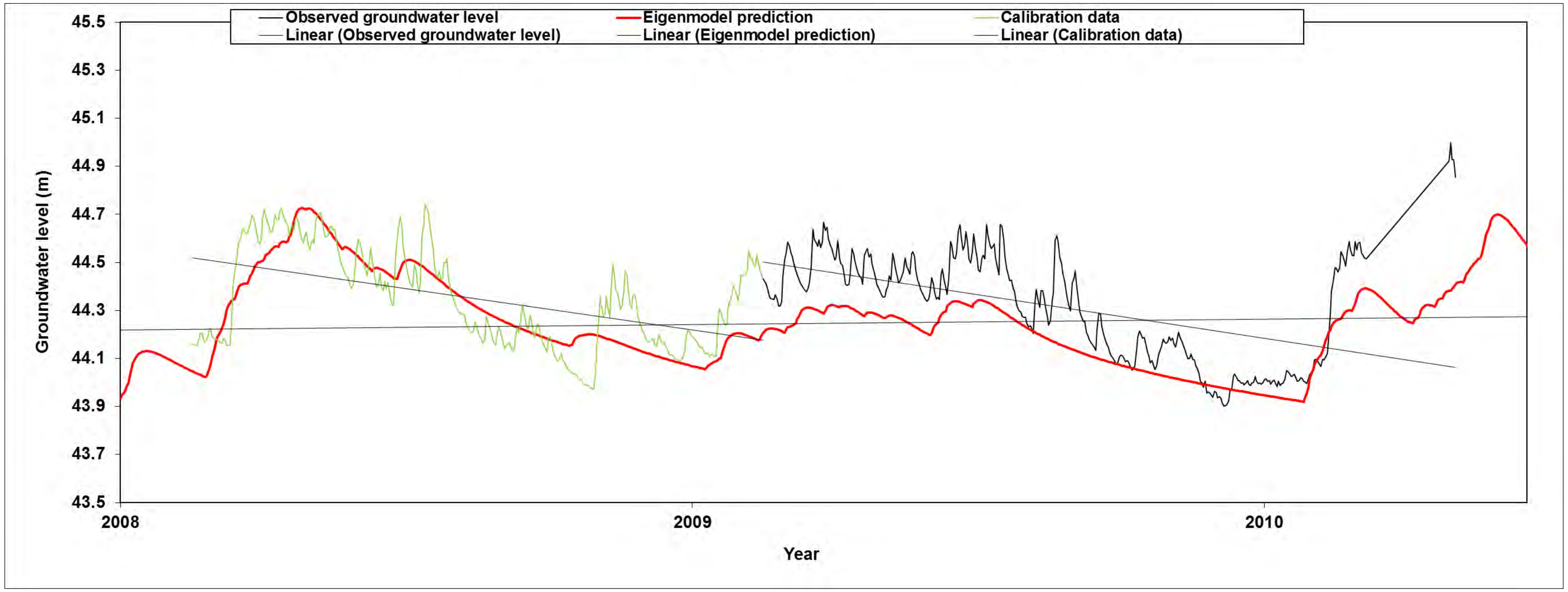


Figure 2.1h: Eigen modelling results for Bore 312028 – screened 4-16 mbgl, stable GW levels.

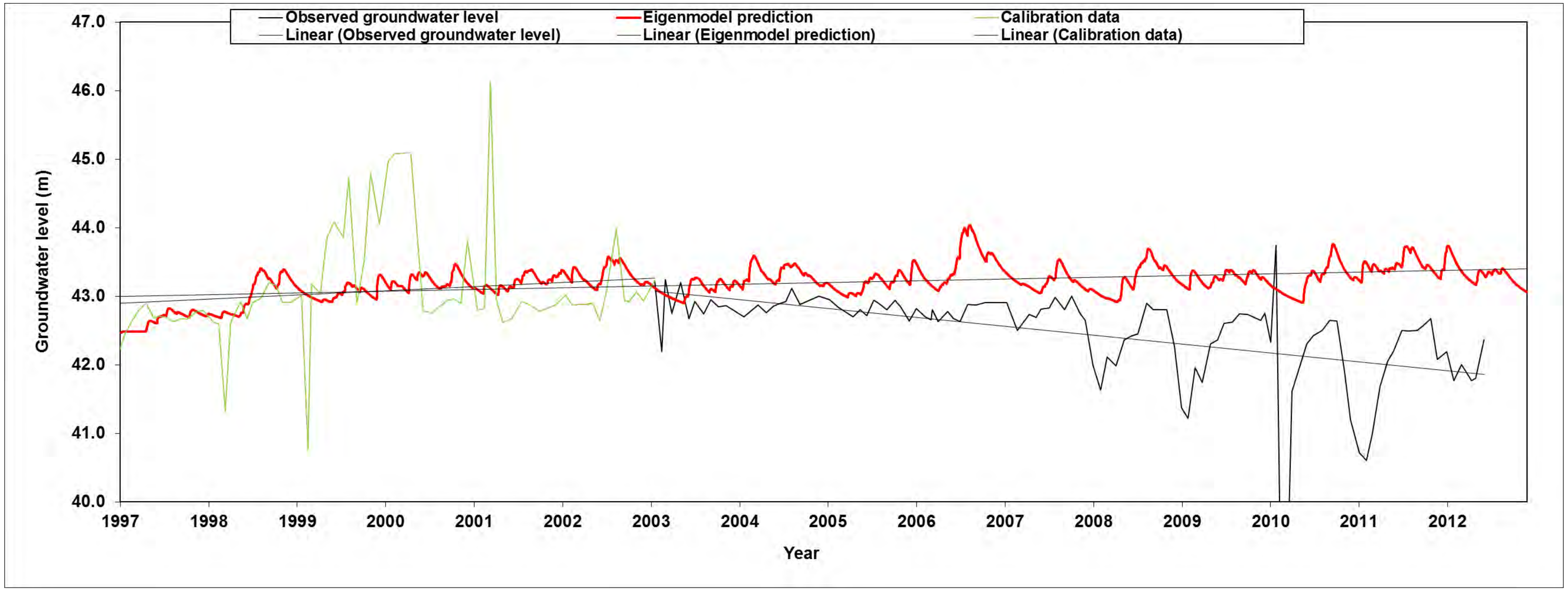


Figure 2.1i: Eigen modelling results for Bore 313013 – screened 90.5-93.5 mbgl, declining GW levels.

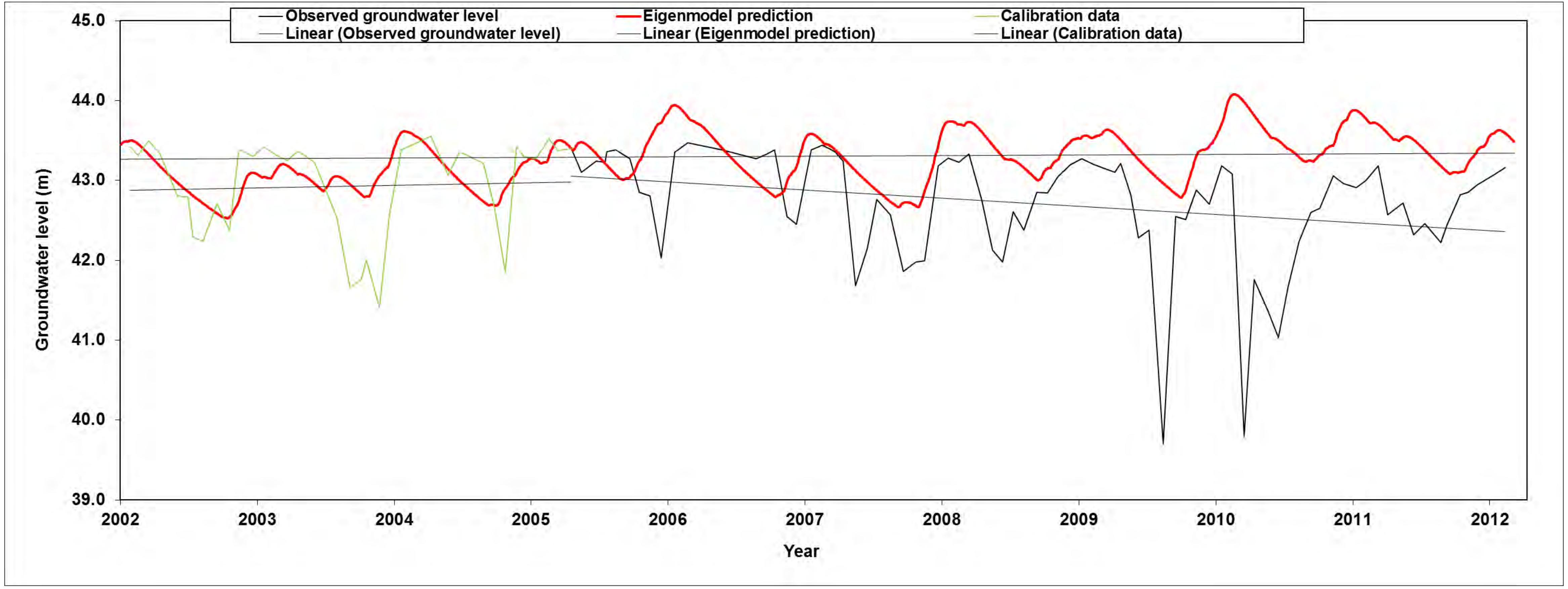


Figure 2.1j: Eigen modelling results for Bore 313053 – screened 49-52 mbgl and 55.5-58.5 mbgl, declining GW levels

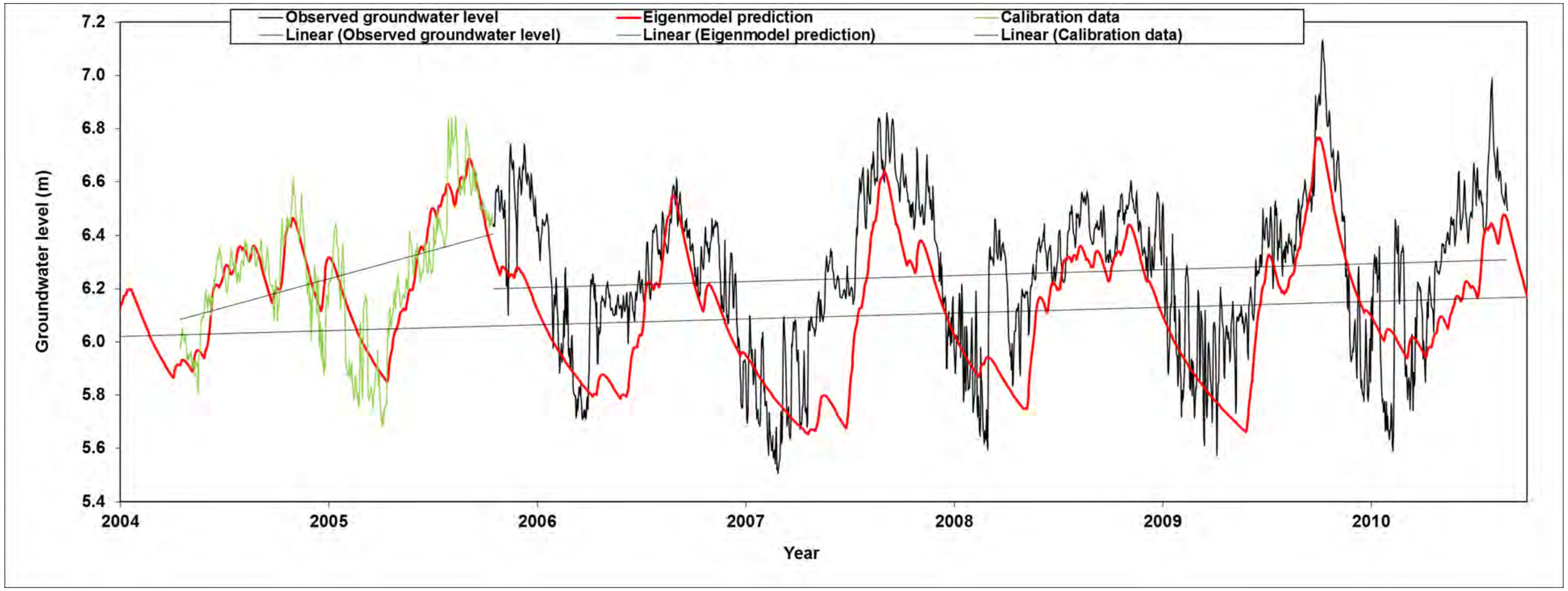


Figure 2.1k: Eigen modelling results for Bore 322029 – screened 37.5-42 mbgl, stable GW levels.

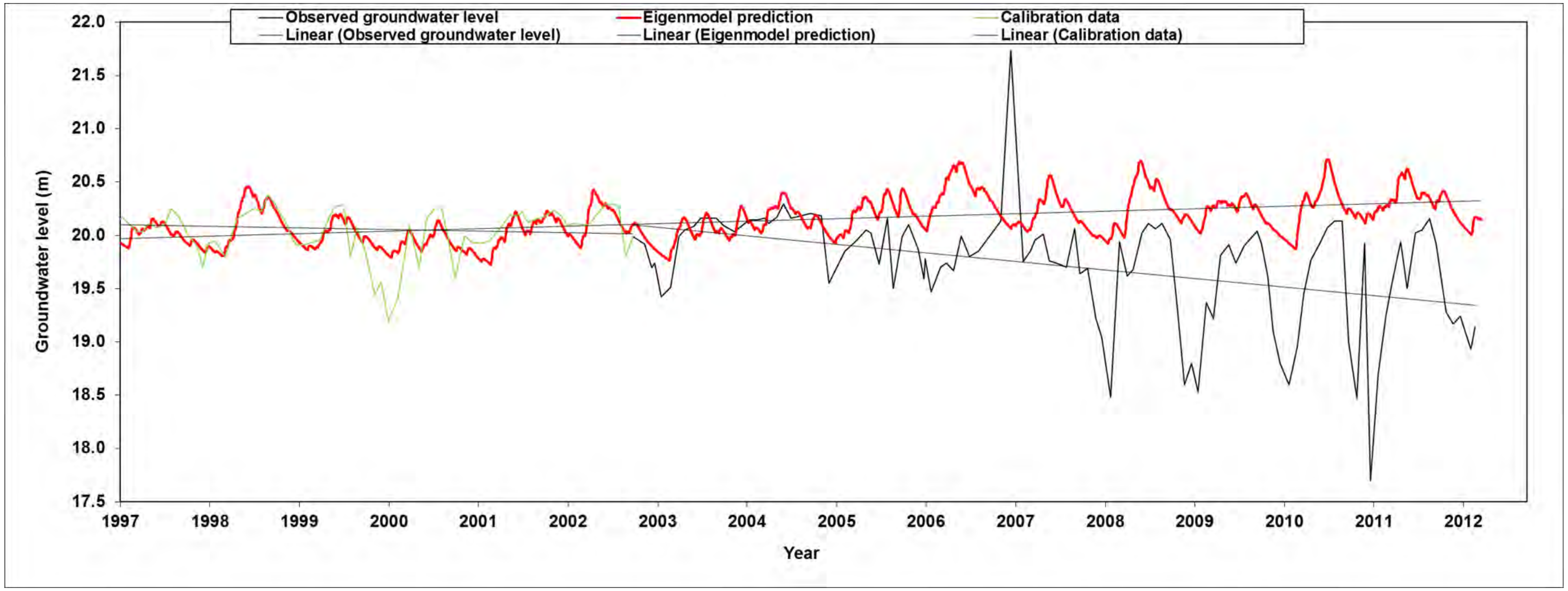


Figure 2.1l: Eigen modelling results for Bore 323015 – 108.5-112, declining GW levels.

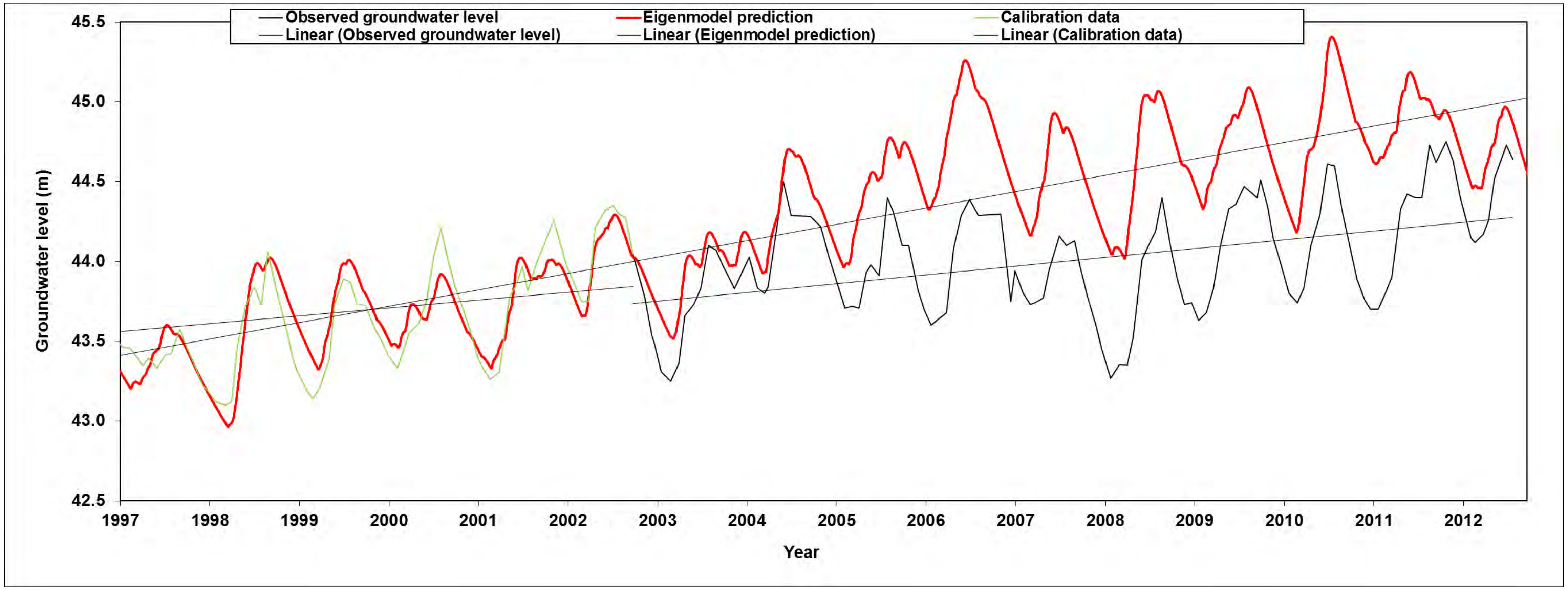


Figure 2.1m: Eigen modelling results for Bore 324000 – unknown depth, steadily rising GW levels.

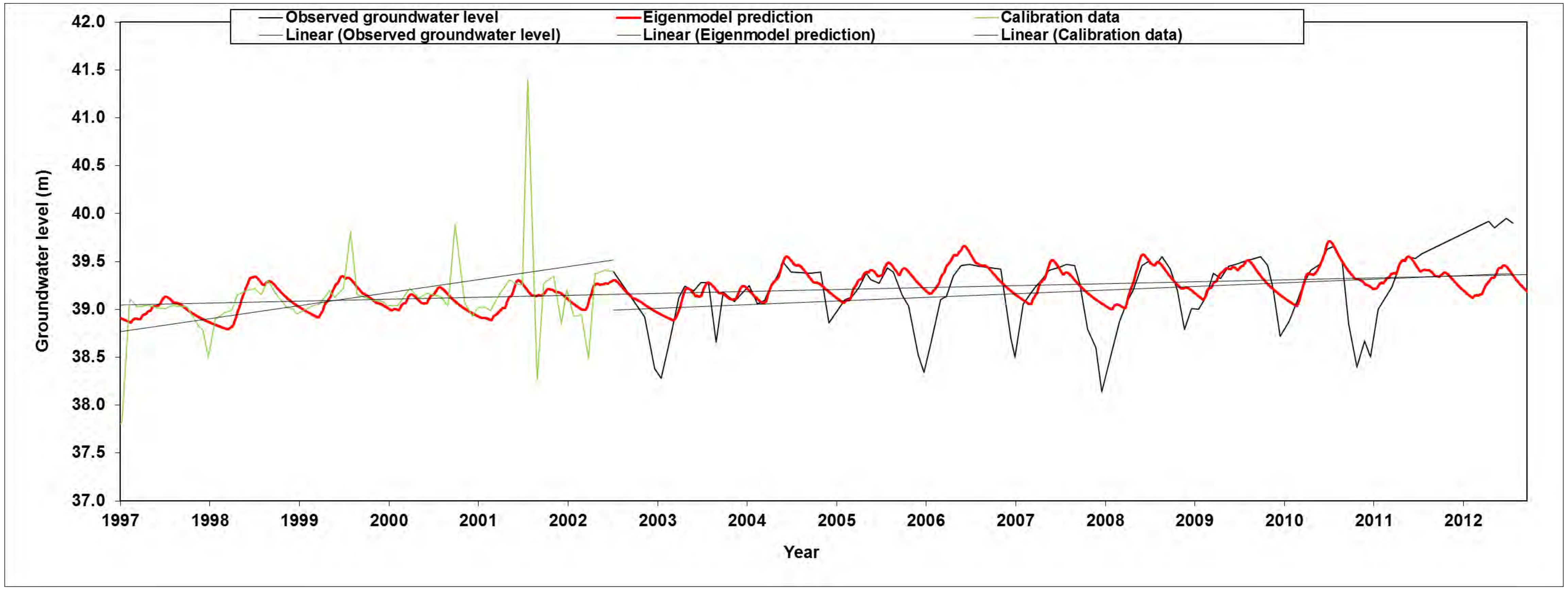


Figure 2.1n: Eigen modelling results for Bore 324003 – 43.3 m depth, stable GW levels.

Table A.1: Eigen Modlelling Results Summary

Bore	Calibration	Eigen Model Prediction	Measured Trend	Analysis
302003	Good match to peaks, recovery and general trend, poor match to troughs.	Steadily rising, matches peaks and recovery well until 2010.	Steadily increasing until 2010 then recent decline.	Summer abstraction noticeable, likely responsible for recent drop.
302009	Matches general trend but poor match to peaks and troughs – offsets	Slight decline predicted since 2006, not observed in measured data, poor match to peaks.	Steadily increasing but stabilised since 2010.	Summer abstraction highly noticeable, although levels rebound in winter
302026	Reasonable match to recovery, poor to peaks and troughs, - due to higher fluctuations in this bore.	Steady with some variability between years.	Stable	Summer abstraction noticeable, although levels rebound in winter
303017	Poor match to peaks and troughs but matches general trend.	Steady increase is matched by measured data, although poor matches to peaks and troughs	Stable	Minimal anthropogenic effects.
304019	Matches general trend but offsets between peaks and poor peak and trough magnitude prediction.	Predicts stable levels, peaks are offset – predicted are before measured.	Steadily increasing since 2007	Minimal anthropogenic effects, rise due to natural processes
312007	Good match to peaks and general trend	Predicts stable levels.	Declining since 2006	Anthropogenic abstraction noticeable since 2006, likely causing deviation from predicted.
312009	Good match to general trend and some peaks and troughs.	Predicts steadily rising levels	Declining since 2007	Anthropogenic abstraction since 2007 is noticeable likely causes deviation from predicted.
312028	Match to individual peaks is poor since this is daily logger data but matches general trend.	Predicts steady groundwater levels, reasonable match to peaks and troughs	Stable	Measured levels greater than predicted likely due to recharge variability.
313013	Good match to general trend but not to major peaks and troughs.	Predicts steady slightly rising groundwater levels	Levels declining since 2006.	Measured levels lower than predicted, seasonal abstraction is apparent and is the likely cause.
313053	Reasonable match to peaks and general trend poor match to troughs.	Steady groundwater levels	Steady decline since 2007	Groundwater abstraction noticeable throughout the record and likely causes the recent decline.
322029	Very good match.	Steady groundwater levels, slightly under predicts peaks.	Stable	Slightly above predicted likely due to natural recharge variations.
323015	Good match to peaks and general trend, poor match to troughs.	Very steady increase in groundwater levels, deviates from measured in 2005.	Steady decline	Groundwater abstractions noticeable, mostly since 2007 and likely cause the deviation.
324000	Good match to peaks and troughs.	Steady rise in groundwater levels, deviates from predicted in 2004.	Stable since 2004, steady rise	Deviation could be natural, as troughs have not increased in magnitude
324003	Good match to most peaks and general trend.	Steady groundwater levels agreeing with measured	Stable, steady rise.	Anthropogenic abstraction noticeable but does not effect peaks.

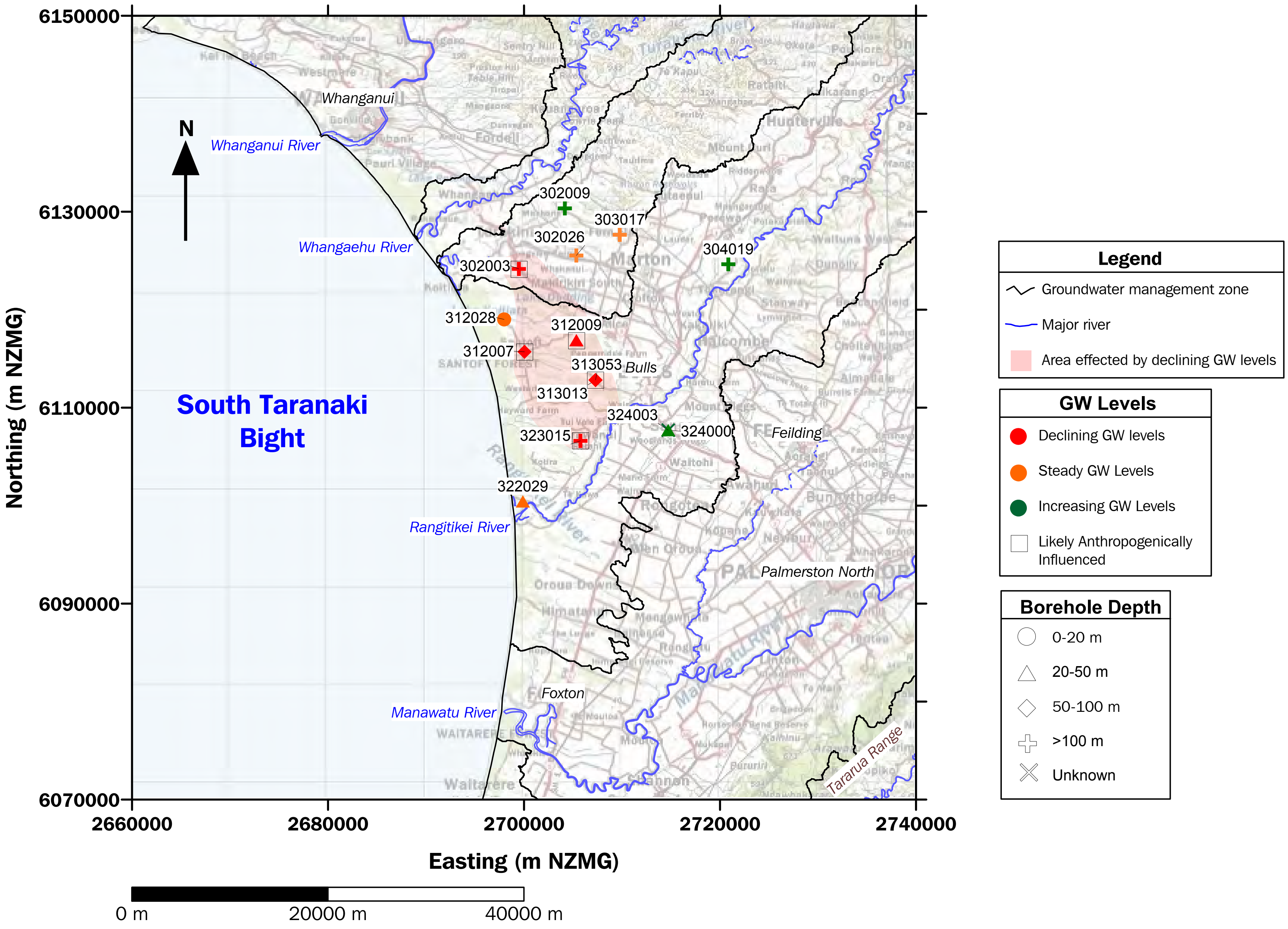


Figure 2.2: Plot of Boreholes analysed using Eigen Modelling technique showing Depth, GW level trend, and likely cause of the trend.

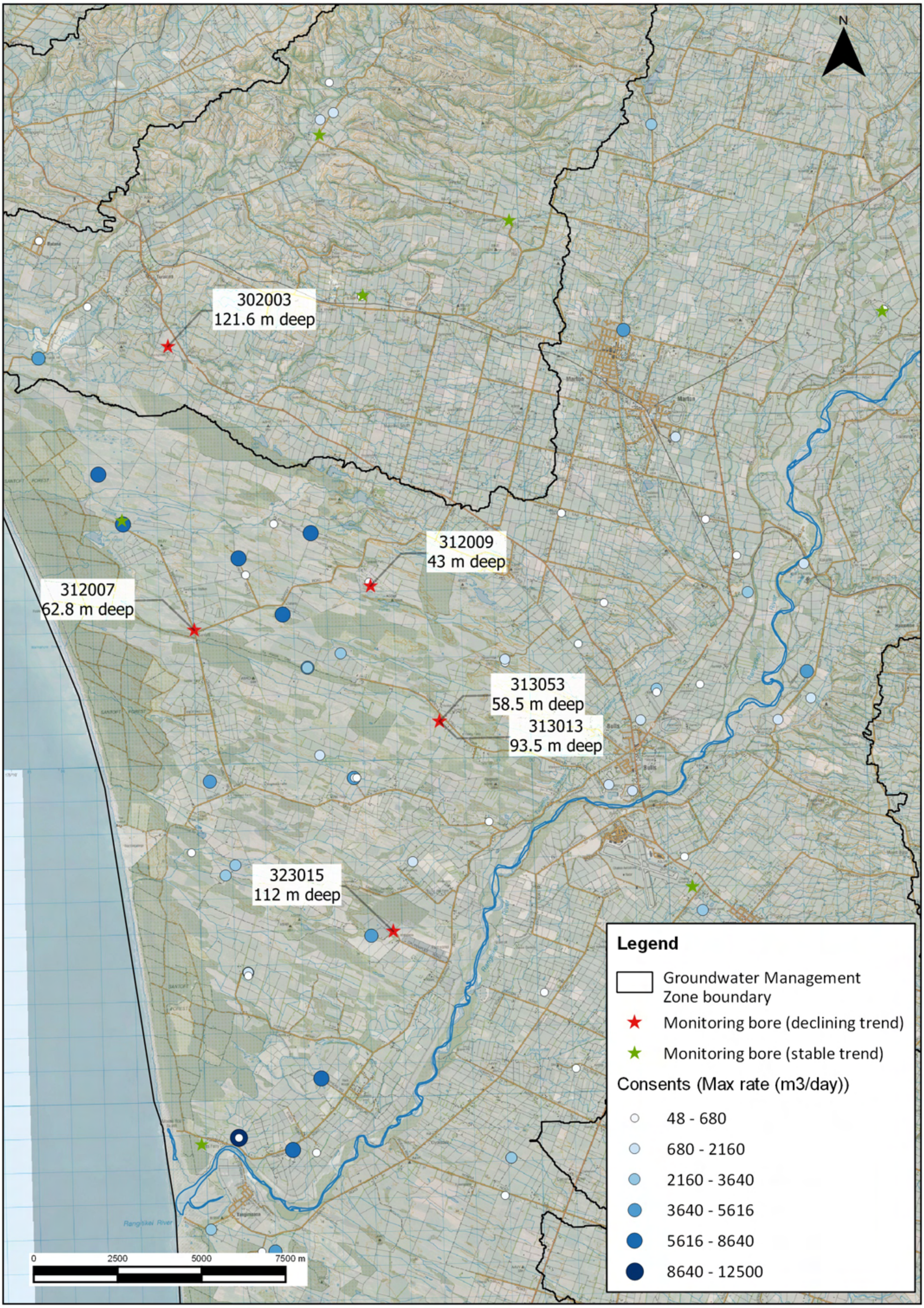
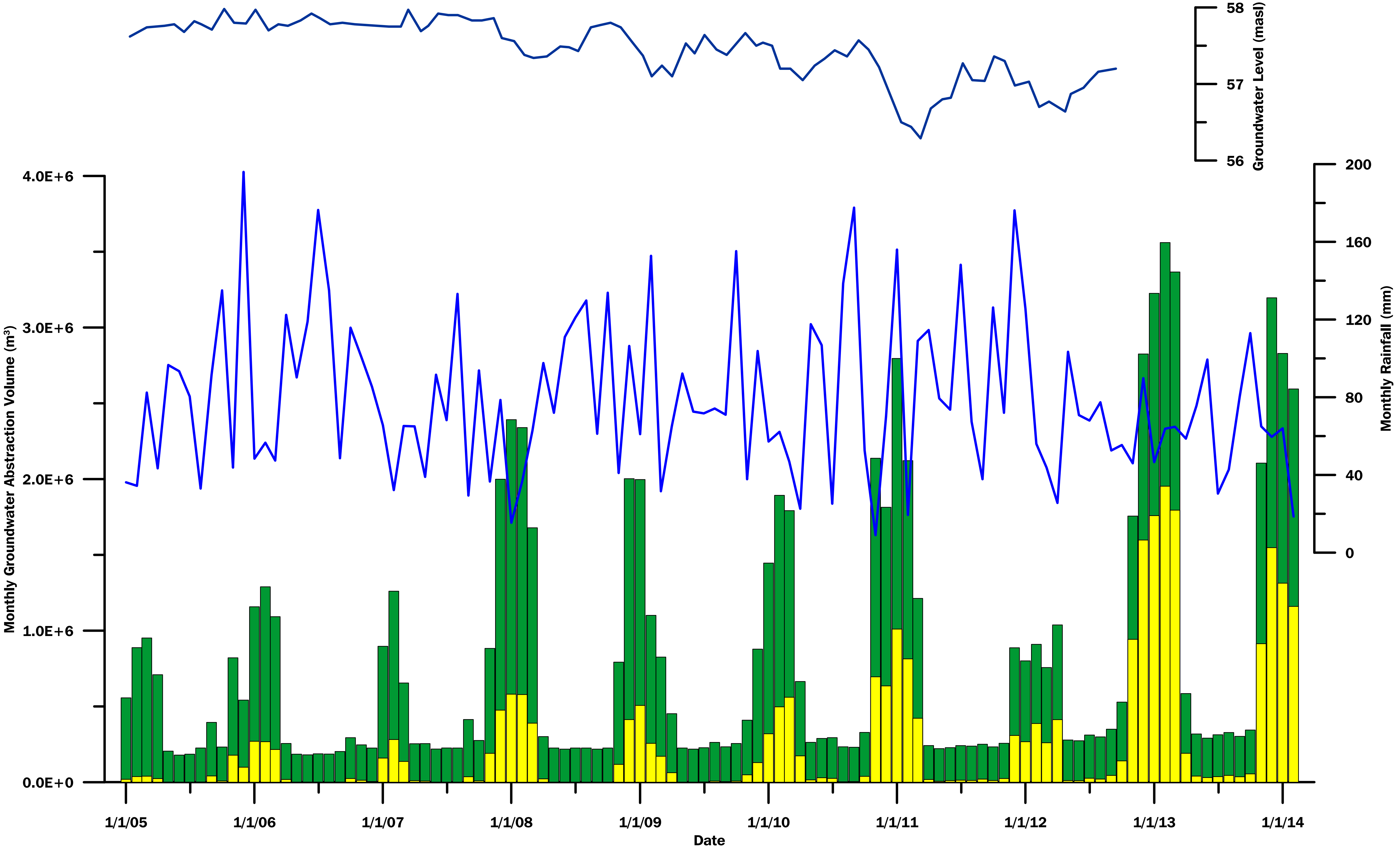


Figure 3.0: Location of consented takes and groundwater monitoring bores



Rainfall data from station 3715, Spriggens Park Wanganui

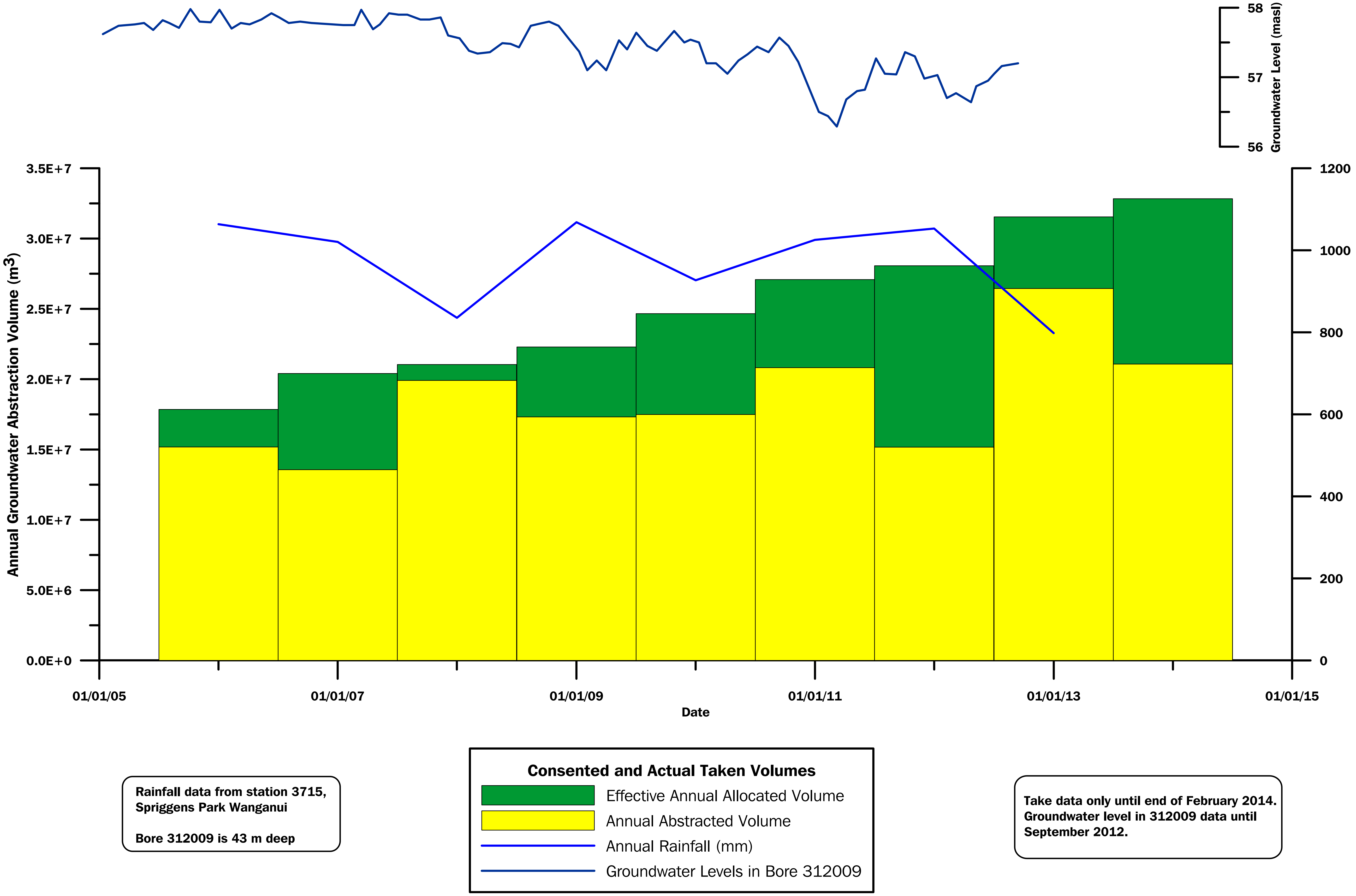
Bore 312009 is 43 m deep

Proportions of Measured and Calculated Groundwater Abstraction

- 🟩 Calculated Monthly Groundwater Abstraction
- 🟨 Measured Monthly Groundwater Abstraction
- — Monthly Rainfall (mm)
- — Groundwater Levels in Bore 312009

Take data only until end of February 2014.
Groundwater level in 312009 data until September 2012.
Consent data only - no calculated permitted take data.

FIGURE 3.1: BAR CHART TO SHOW THE PROPORTIONS OF MONTHLY CALCULATED AND MEASURED ABSTRACTIONS IN THE RANGITIKEI AND TURAKINA GROUNDWATER MANAGEMENT ZONES.

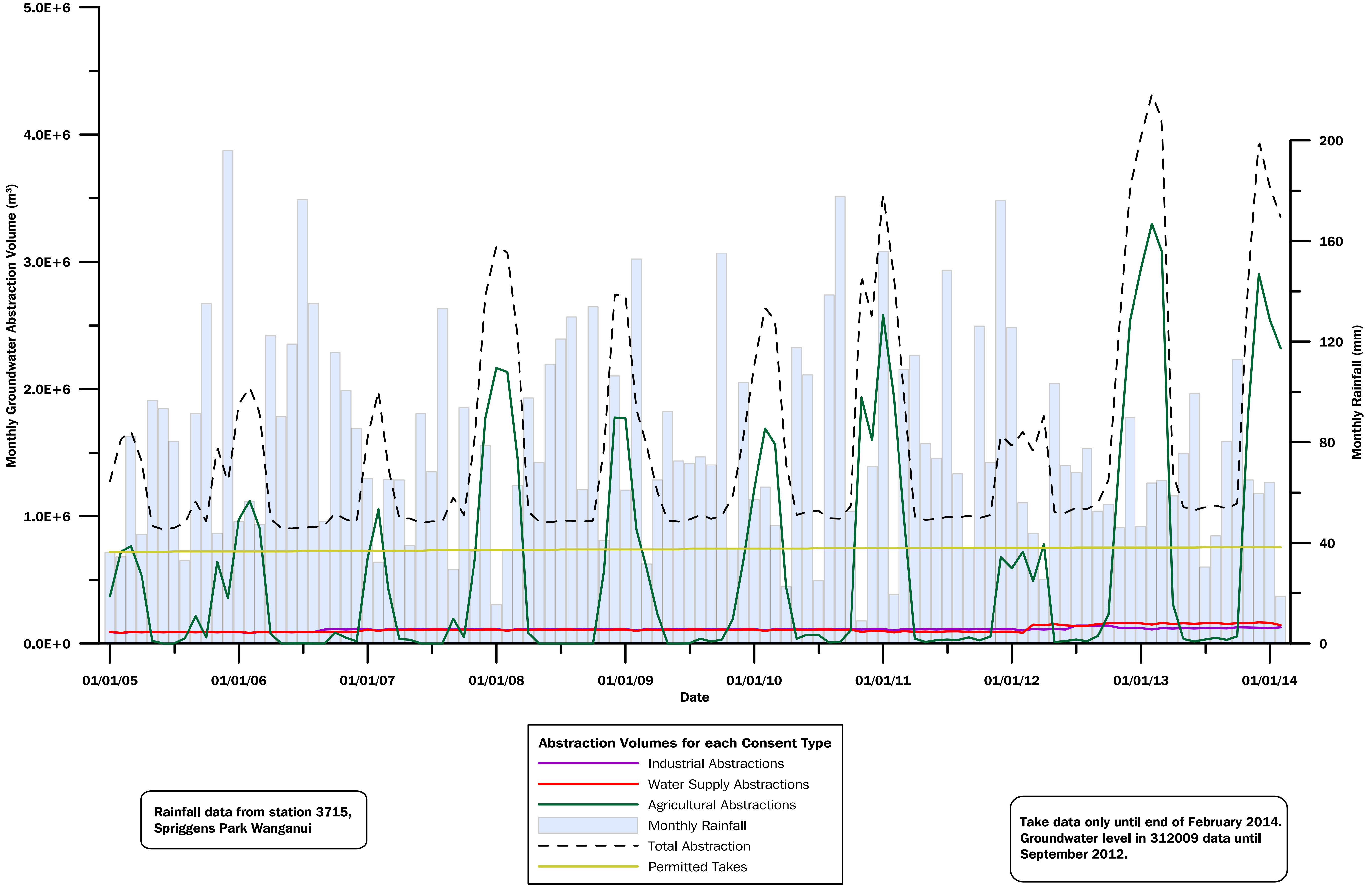


Rainfall data from station 3715, Spriggens Park Wanganui

Bore 312009 is 43 m deep

Take data only until end of February 2014. Groundwater level in 312009 data until September 2012.

FIGURE 3.2: BAR CHART COMPARING EFFECTIVE ANNUAL ALLOCATED VOLUMES WITH ACTUAL VOLUMES TAKEN FOR WATER YEARS (RUNNING FROM START JULY TO END JUNE IN THE RANGITIKEI AND TURAKINA GROUNDWATER MANAGEMENT ZONES



Rainfall data from station 3715, Spriggens Park Wanganui

Take data only until end of February 2014. Groundwater level in 312009 data until September 2012.

FIGURE 3.3: LINE GRAPHS TO SHOW TOTAL MONTHLY ABSTRACTIONS FOR EACH CONSENT TYPE FOR EACH WATER YEAR (RUNNING FROM START OF JUNE TO END OF JULY).

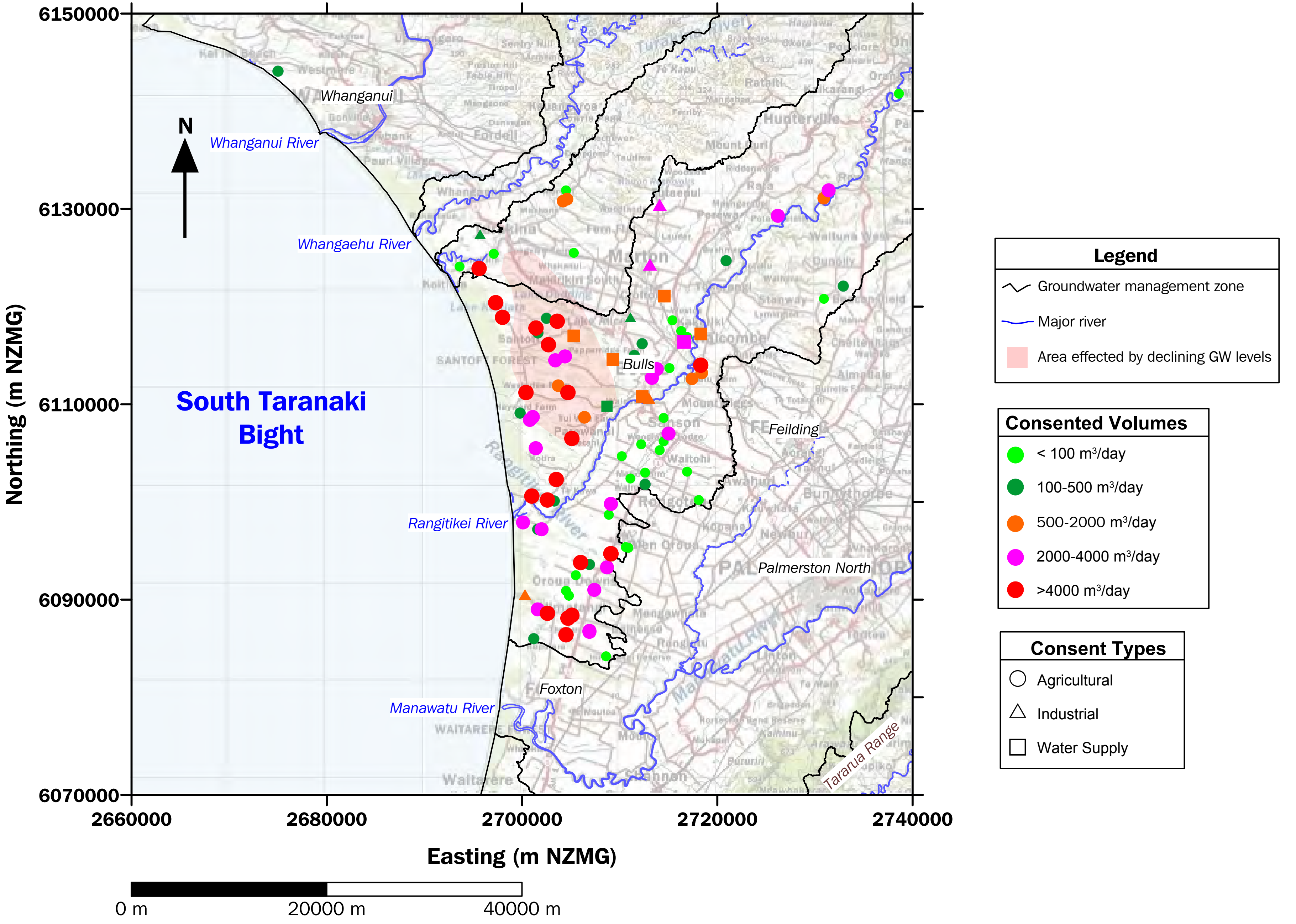
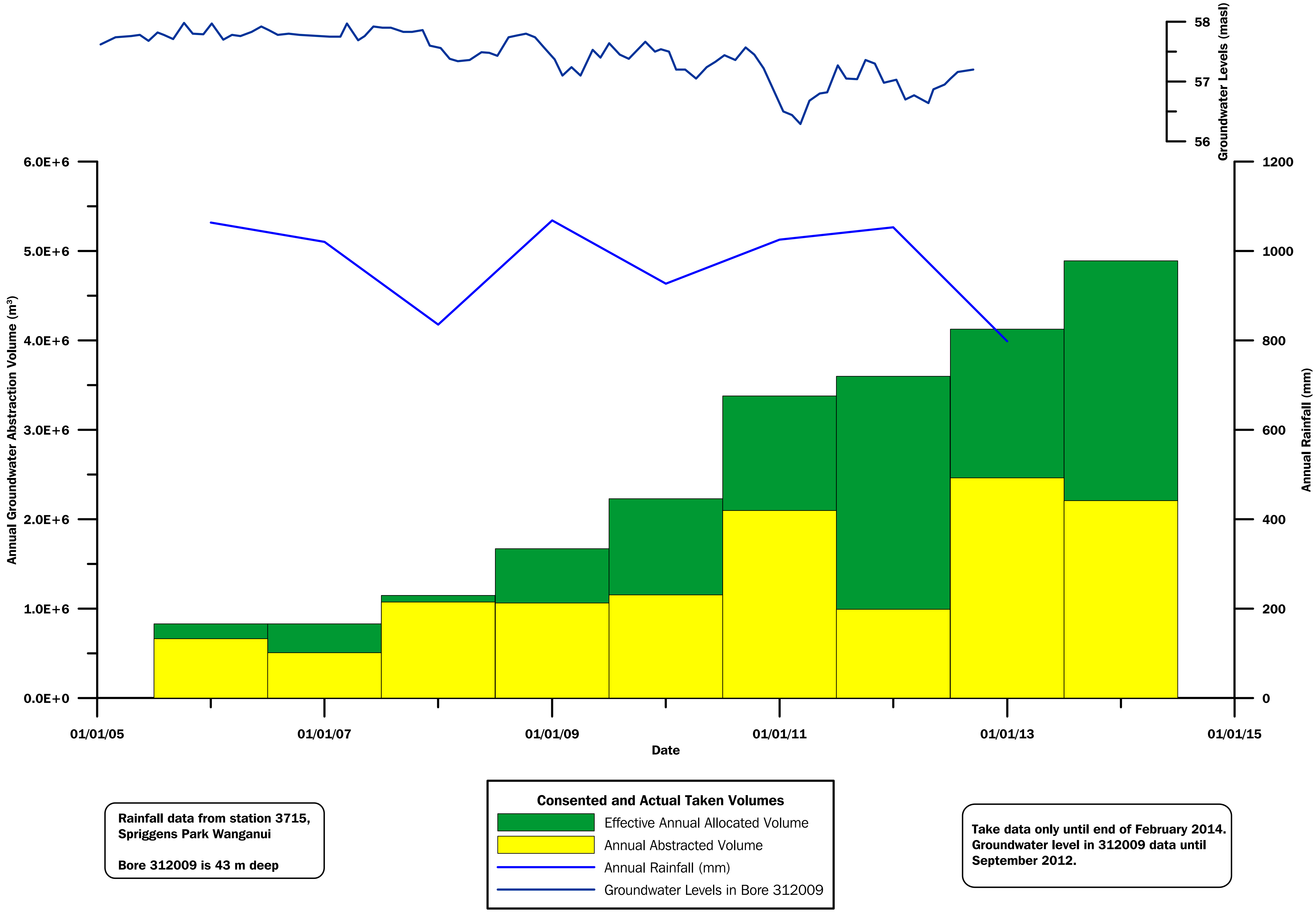


Figure 3.4: Plot of Consents in the Rangitikei and Turakina Groundwater Management Zones, showing the Maximum Consented Daily take and Consent type.

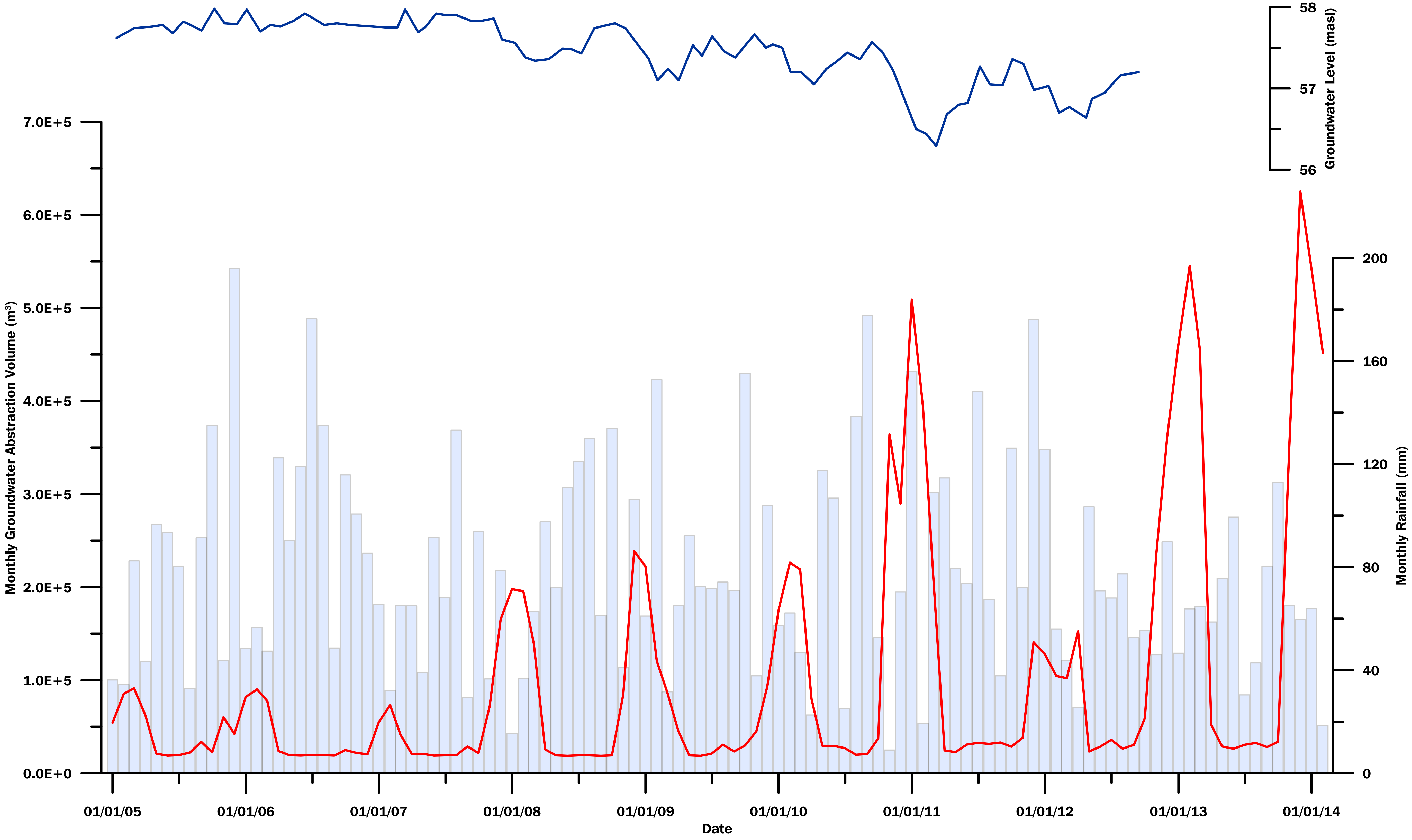


Rainfall data from station 3715, Spriggens Park Wanganui

Bore 312009 is 43 m deep

Take data only until end of February 2014. Groundwater level in 312009 data until September 2012.

FIGURE 3.5: BAR CHART COMPARING EFFECTIVE ANNUAL ALLOCATED VOLUMES WITH ACTUAL VOLUMES TAKEN FOR WATER YEARS (RUNNING FROM START JULY TO END JUNE) IN THE AREA OF DECLINING WATER LEVELS.



Rainfall data from station 3715, Spriggens Park Wanganui

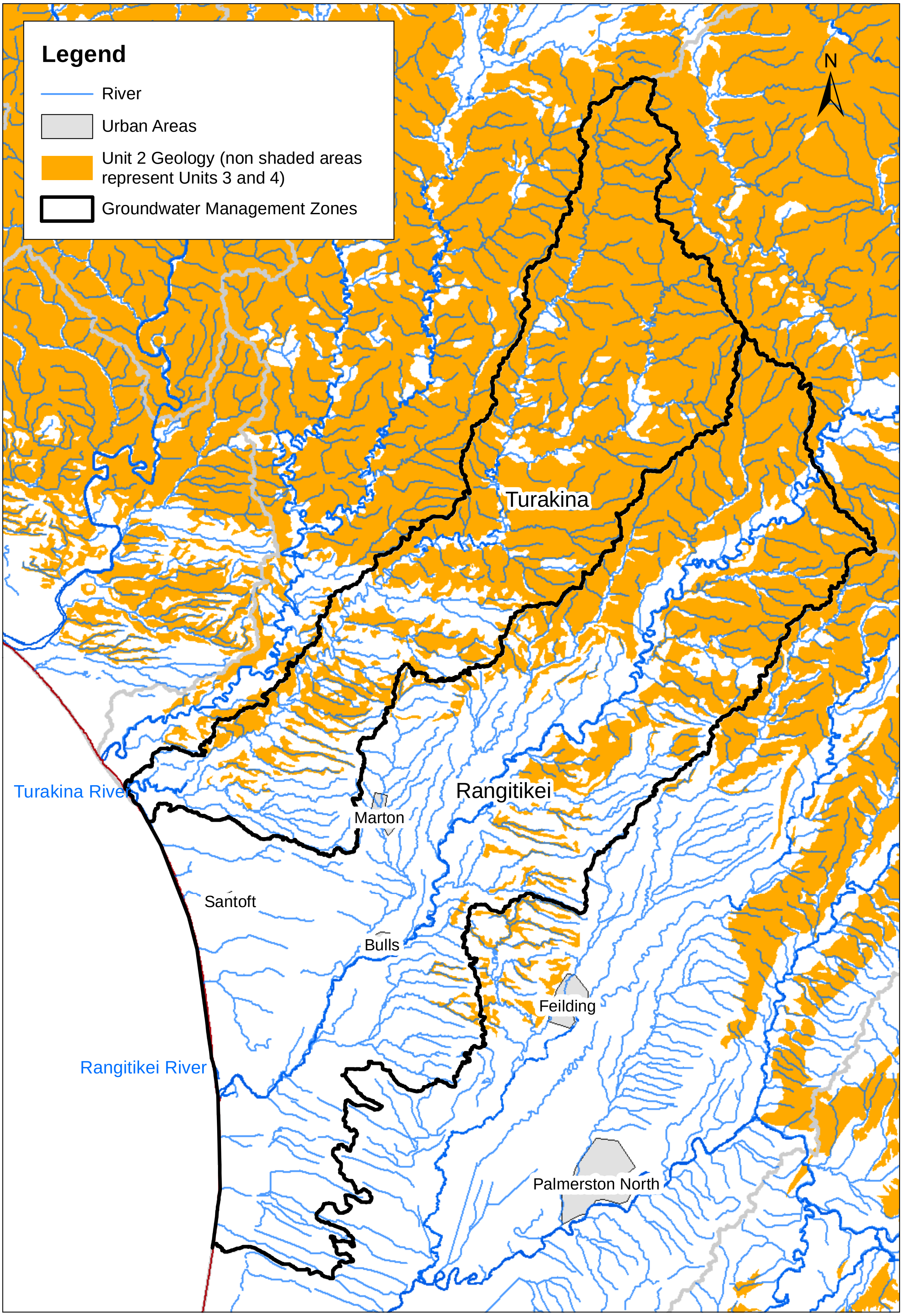
Bore 312009 is 43 m deep

Santoft Monthly Abstraction Volumes

▭ Monthly Rainfall
— Santoft Area Total Monthly Abstraction
— Groundwater Levels in Bore 312009

Take data only until end of February 2014. Groundwater level in 312009 data until September 2012.

FIGURE 3.6: GRAPH OF MONTHLY GROUNDWATER ABSTRACTION IN THE SANTOFT AREA OF DECLINING GROUNDWATER LEVELS FOR EACH WATER YEAR (RUNNING FROM START OF JUNE TO END OF JULY).



Geology data sourced from GNS QMAP

FIGURE 4.1: Simplified Geology

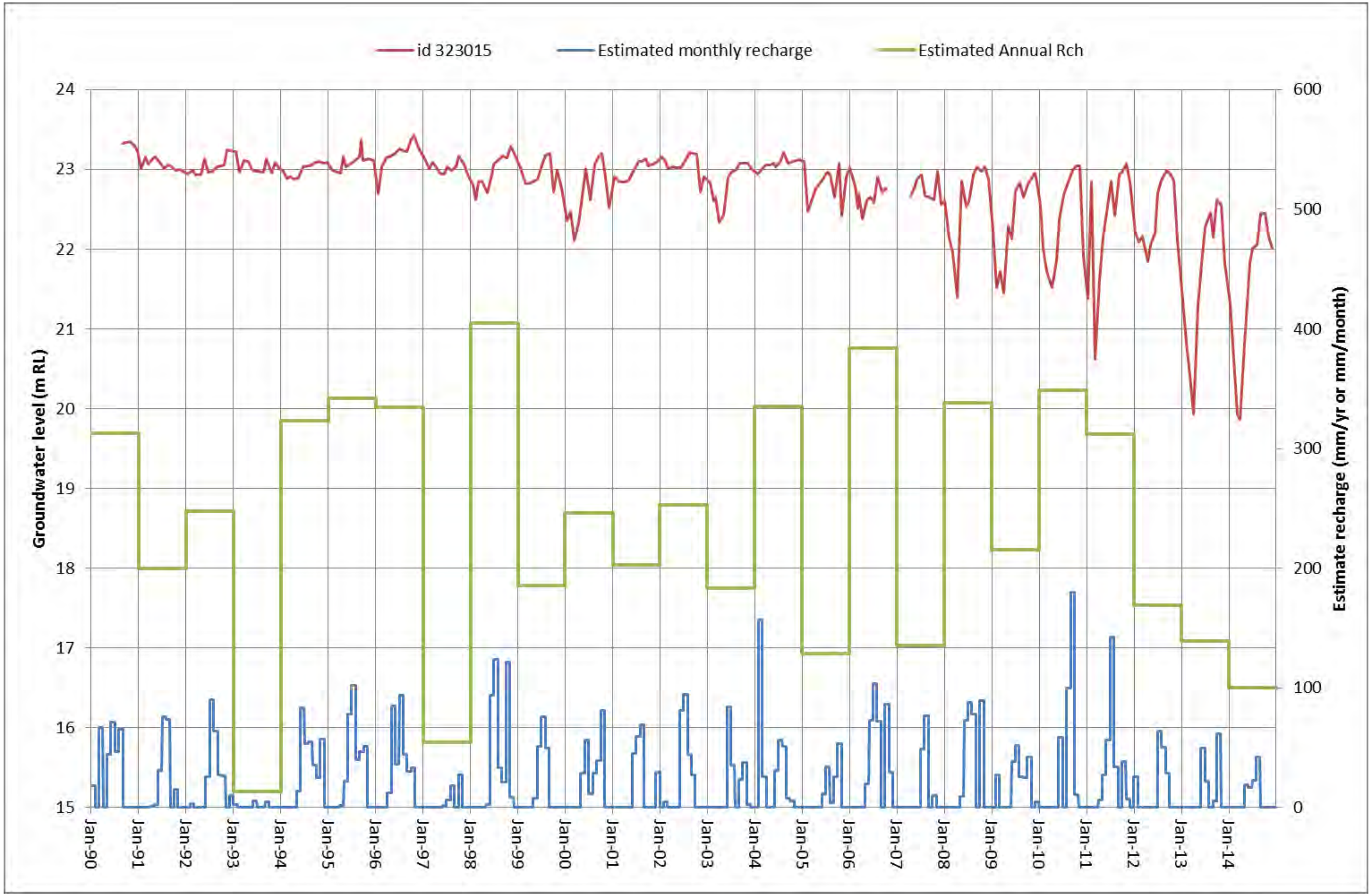


Figure 4.2 Groundwater levels compared to monthly and annual recharge

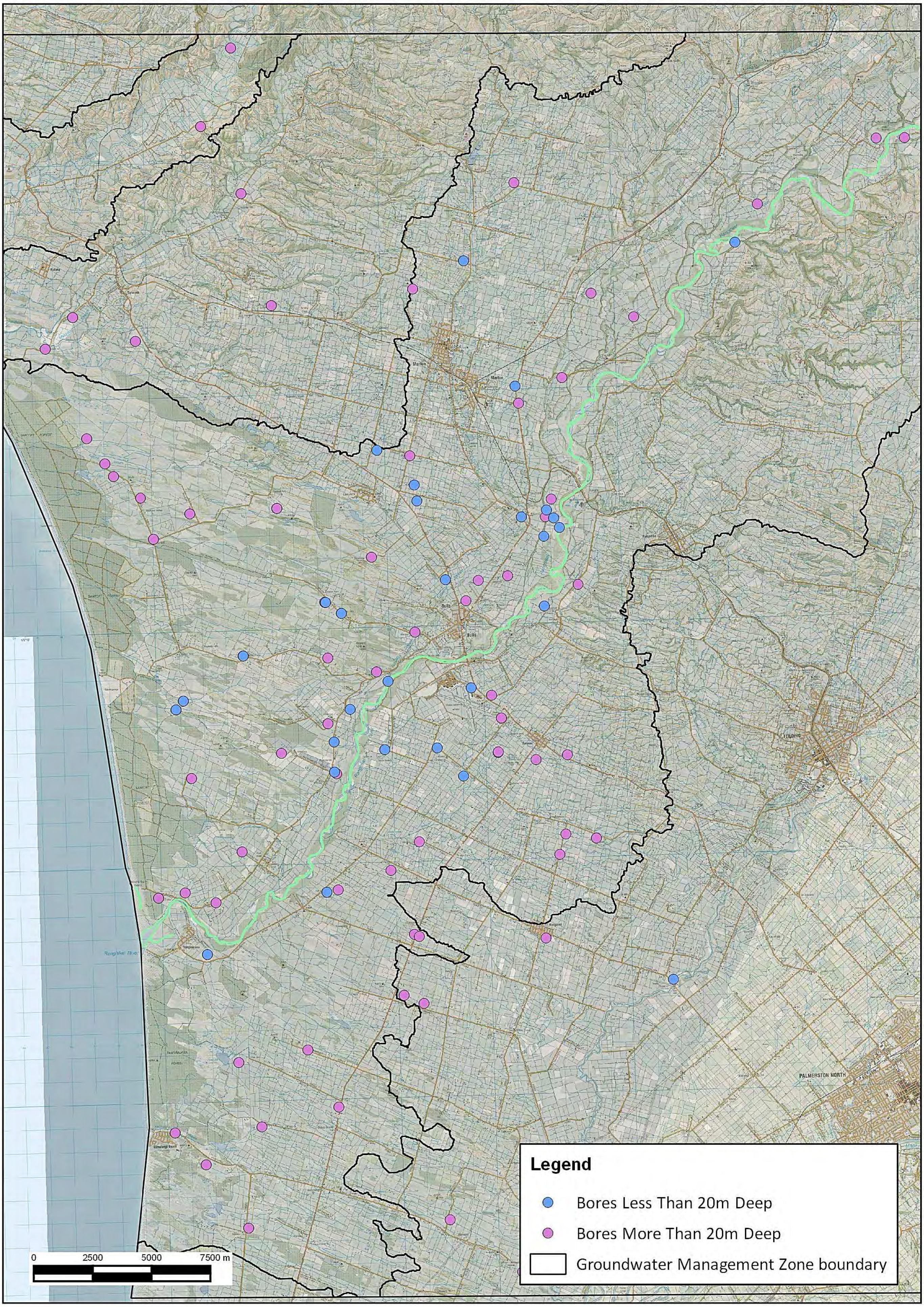


Figure 4.3: Location of bores used in piezometric survey

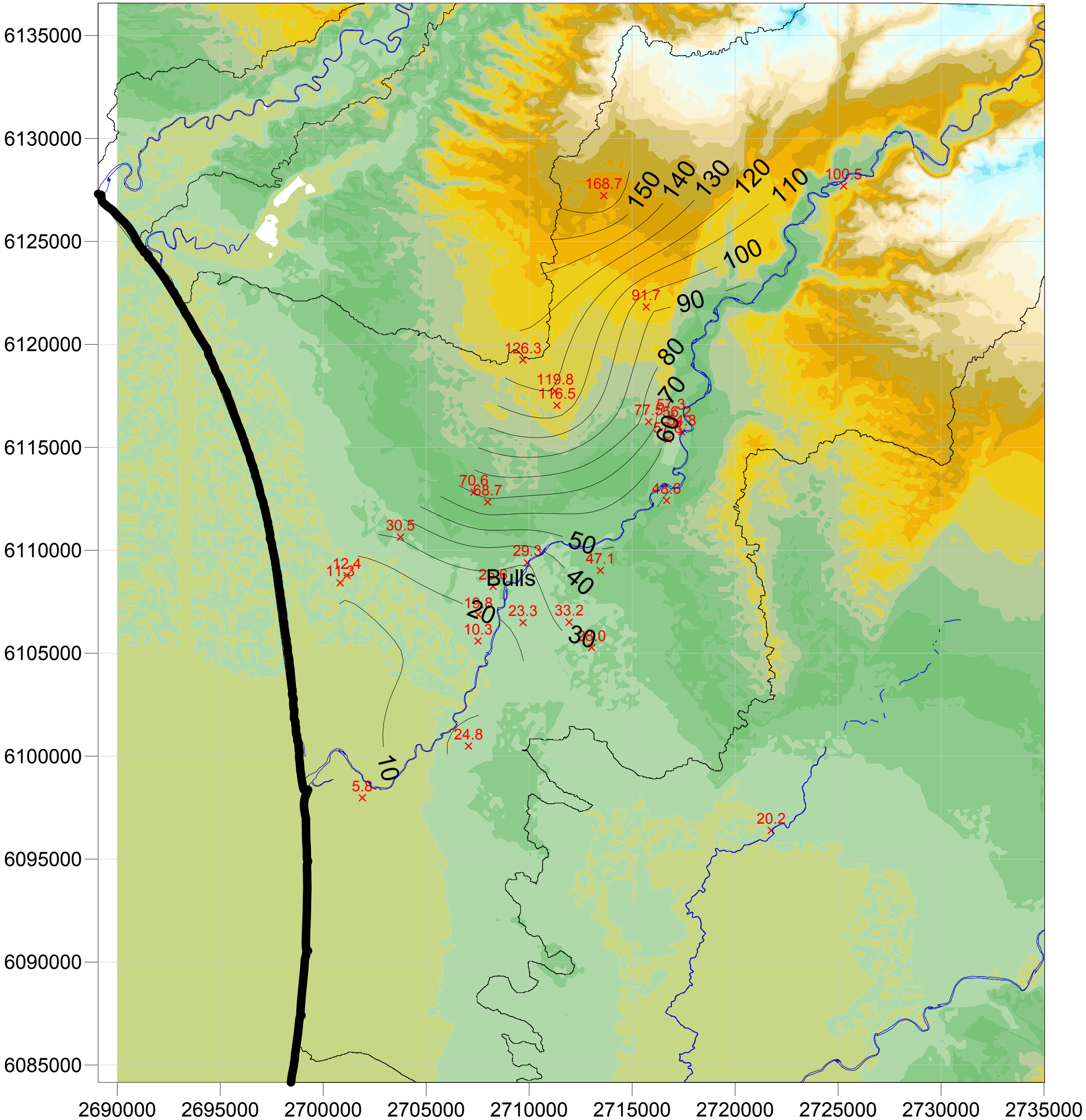


Figure 4.4: Shallow groundwater level contours

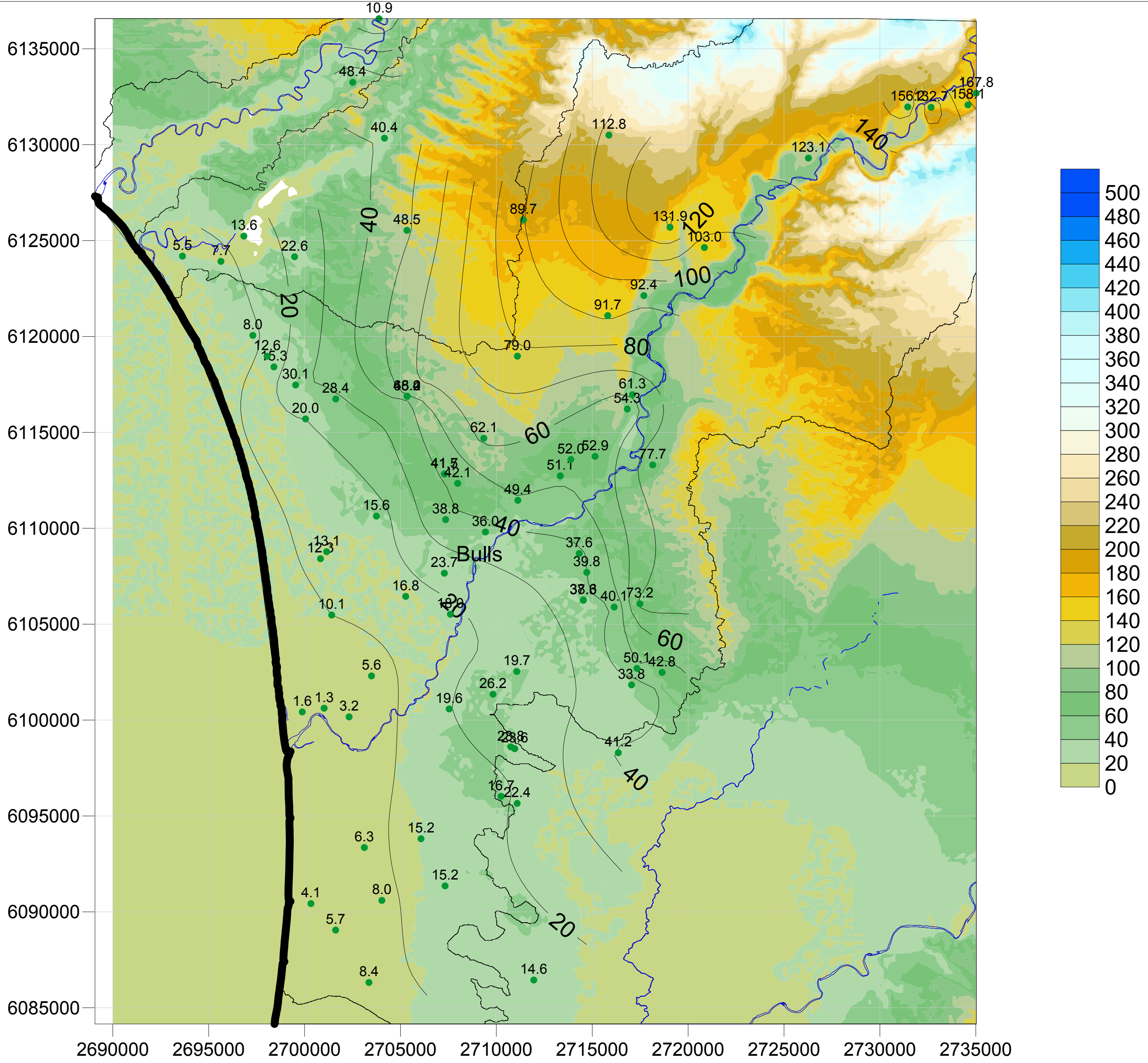


Figure 4.5: Groundwater level contours from bores more than 20 m deep

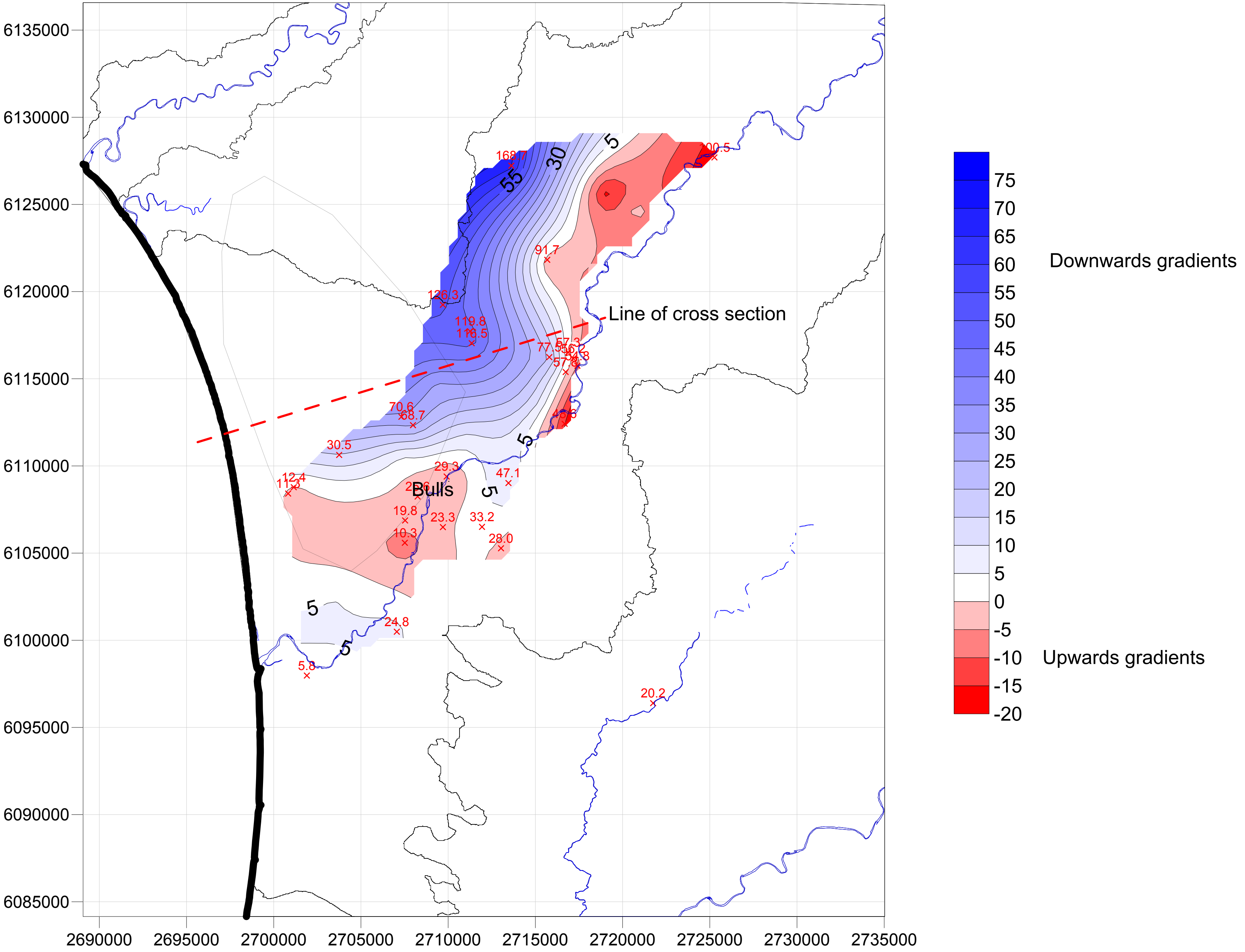


Figure 4.6: Difference in groundwater levels between deep (> 20 m deep) and shallow bores.

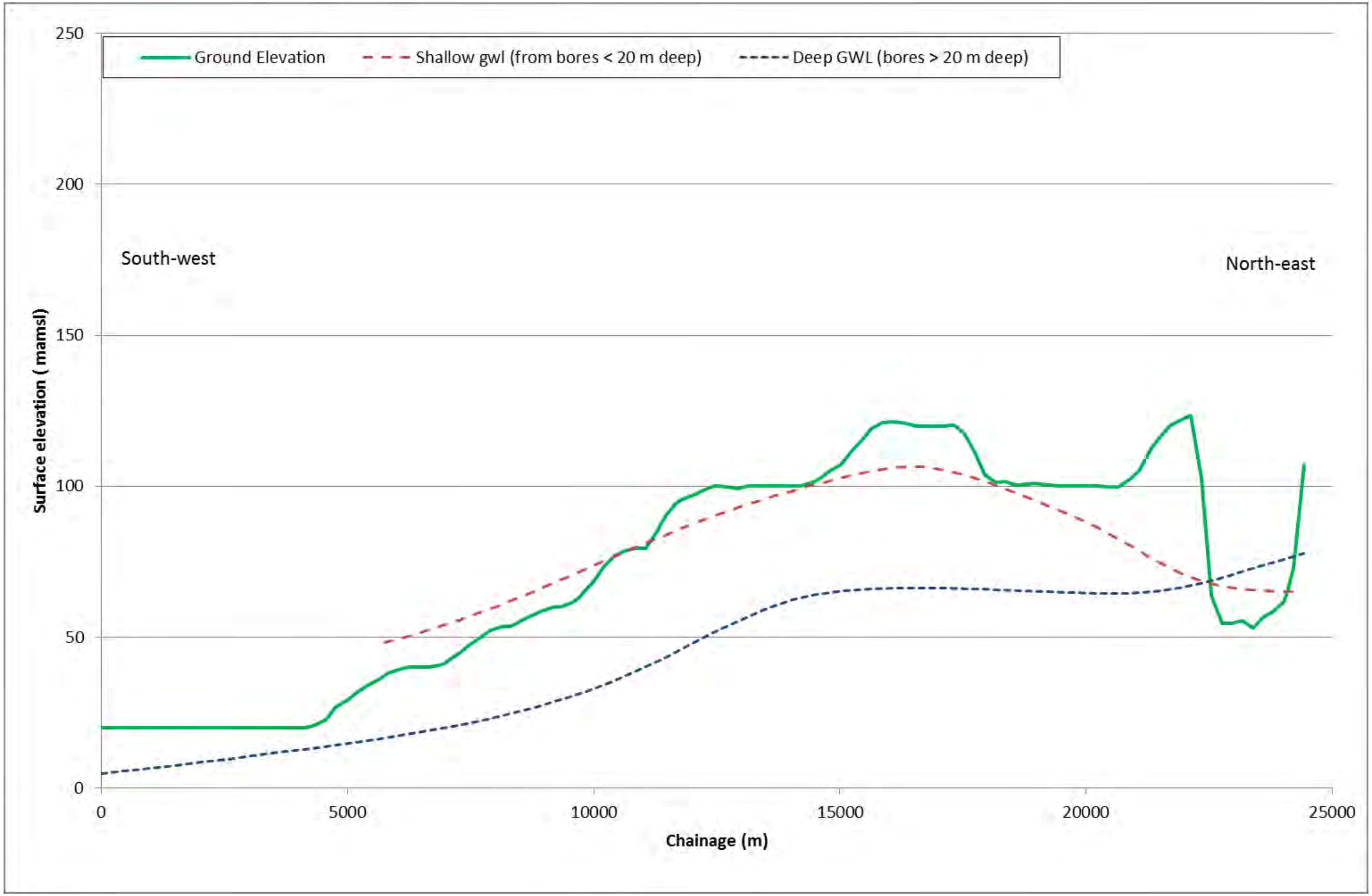


Figure 4.7: Cross section showing groundwater surface elevations from piezometric survey in October 20014

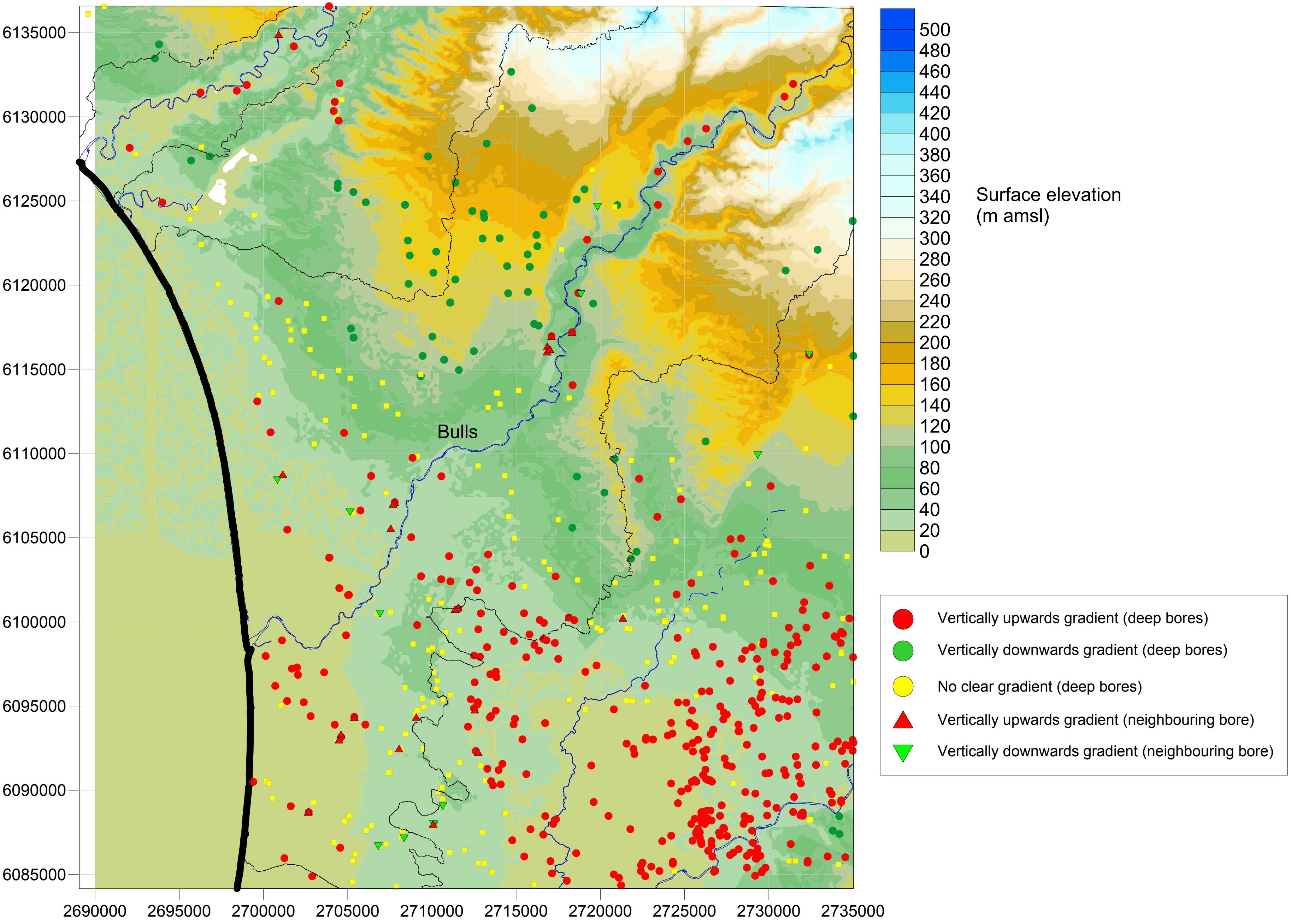


Figure 4.8: Vertical Gradients

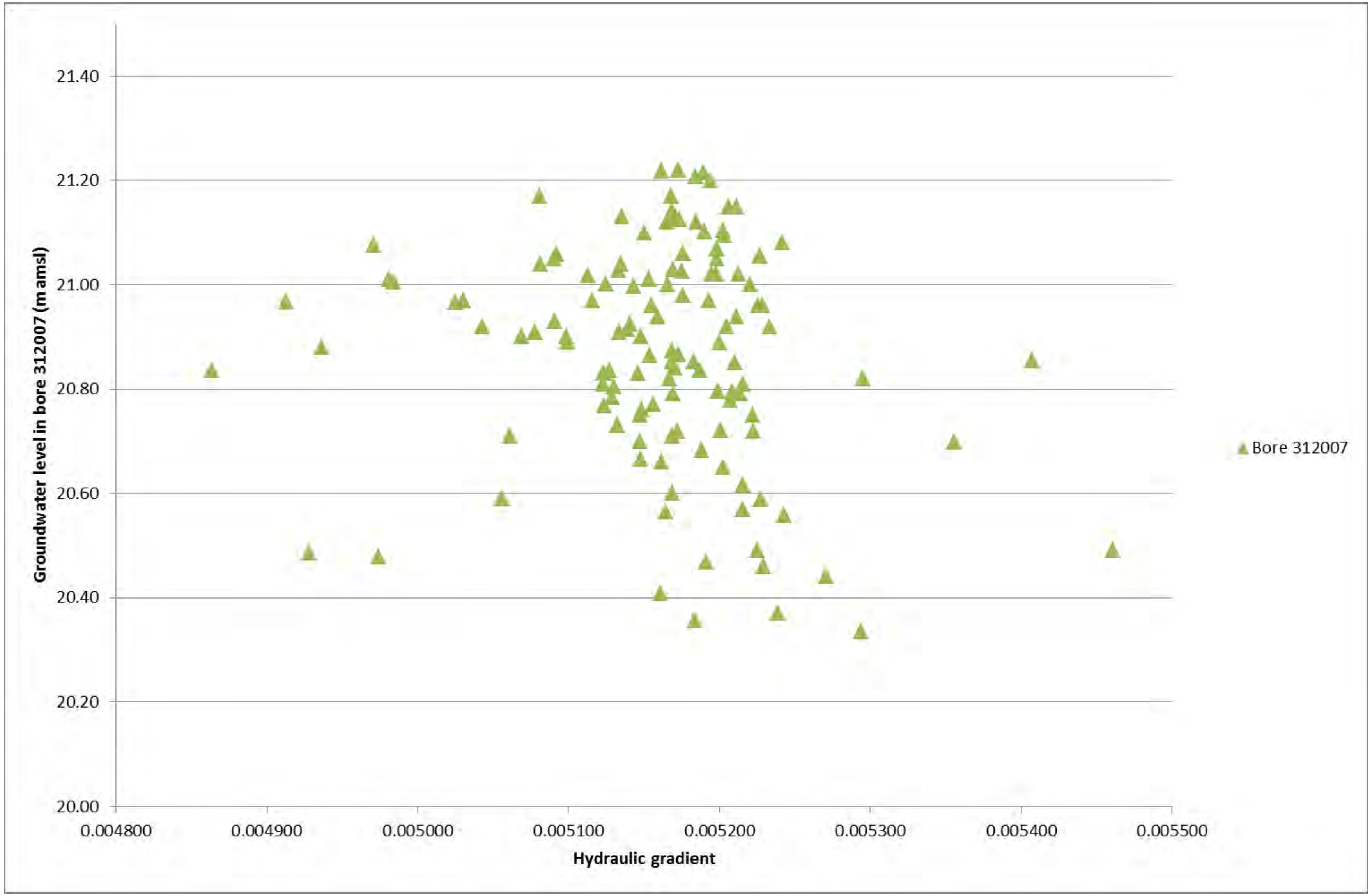


Figure 4.9: Variation in lateral hydraulic gradients compared to water levels in bore 312007 (based on data from 1990 to 2005)

Figure 4.10: River flow gauging locations from Massey University 2015 survey. Values in blue represent flow on 6 January 2015 and values in red represent flow from 20 January 2015

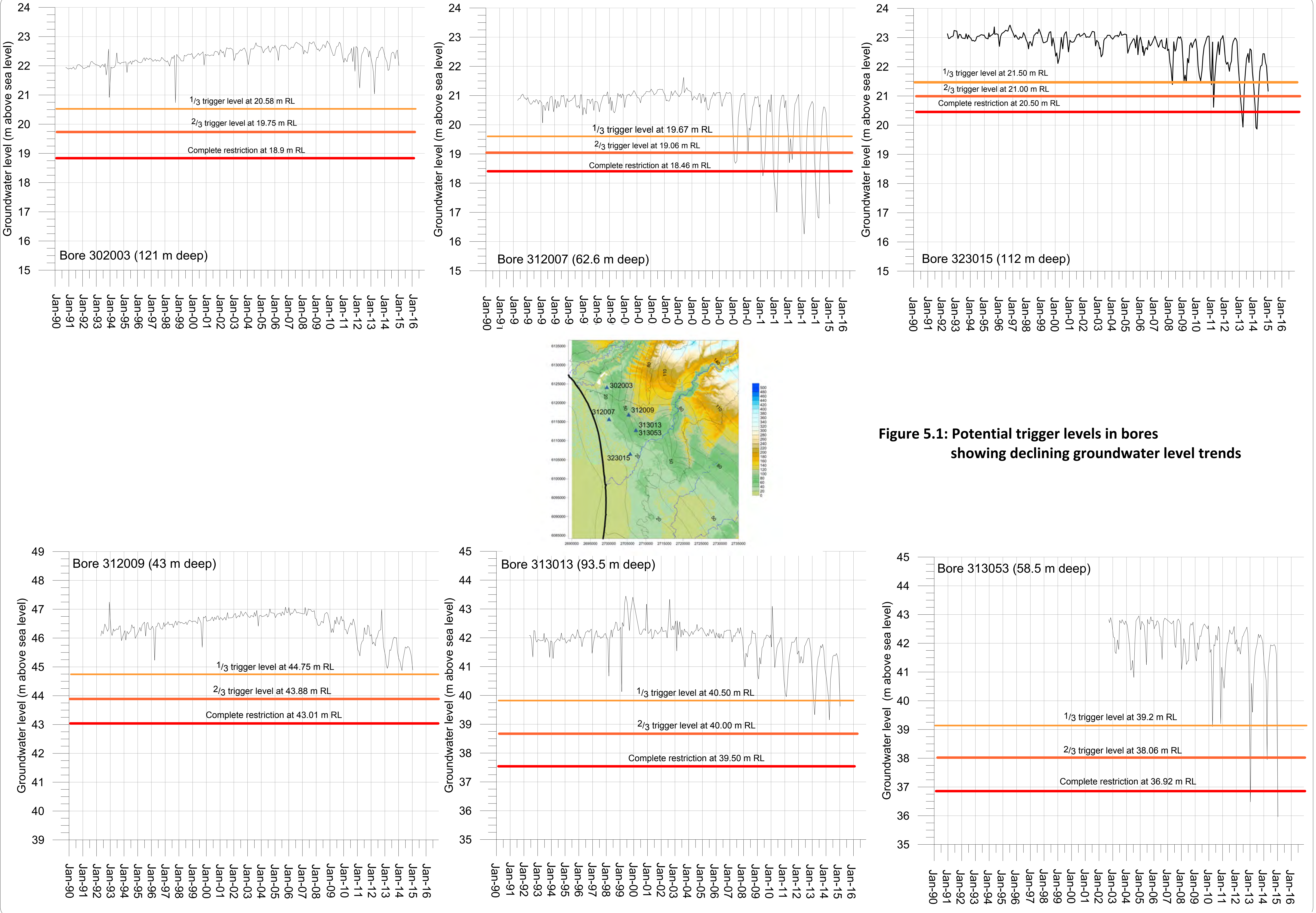


Figure 5.1: Potential trigger levels in bores showing declining groundwater level trends

horizons
regional council

11-15 Victoria Avenue
Private Bag 11 025
Manawatu Mail Centre
Palmerston North 4442

T 0508 800 800
F 06 952 2929
help@horizons.govt.nz
www.horizons.govt.nz