AQUALINC

Groundwater REPORT

WAIRAU AQUIFER GROUNDWATER MODEL
Prediction of Climate Change Impacts

PREPARED FOR
Marlborough District Council

C16061

26/07/2016

PREPARED BY
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EXECUTIVE SUMMARY

Marlborough District Council (MDC) is interested in understanding how the groundwater resources of the Wairau Plains will be affected by climate variability and future climate change. The best tool to aid this understanding is a numerical computer model, the use of which is a standard approach to risk assessment. Similar risk assessments have been successfully carried out by other coastal regions recently, for example Tasman District Council and Selwyn District Council.

An existing Wairau Plain aquifer model developed by MDC and Aqualinc in 2008 has been refined and used to simulate the impacts on the groundwater resources from climate change and variability. To achieve this, several scenarios have been developed. These are:

- Sea level rise;
- Removal of flow augmentation in Gibson Creek from the Waihopai and Wairau rivers;
- Reduction of Wairau River flows (and associated recharge to groundwater); and
- Reduction in land surface recharge.

Key results are:

- Sea level rise is likely to the have greatest effect close to the coast and in rivers seaward of SH1.
- Spring Creek flows are likely to increase due to sea level rise, but only by a small amount. Conversely, flows in coastal springs are likely to increase due to a rise in shallow groundwater levels.
- An increase in shallow groundwater levels due to a rise in sea level may adversely affect land use in the coastal area.
- The artificial augmentation of Gibson Creek currently provides significant recharge to the mid-plains area of the Wairau aquifer and assists in maintaining groundwater levels and corresponding Spring Creek flows.
- Reductions in Wairau River flow results in reductions in groundwater recharge, and associated groundwater levels and Spring Creek flow.
- As land surface recharge (LSR) reduces, so too do groundwater levels and associated Spring Creek flows. However, due to the relatively small contribution of LSR to the overall aquifer through flow, changes due to a reduction in LSR are generally smaller than changes from the other three scenarios tested.
- Due to the interconnected nature of the deep and shallow aquifer systems, changes in LSR affects all aquifers, but some indirectly.

The following future work is recommend:

- Instigate regular monitoring of the saltwater interface in coastal rivers and groundwater;
- Review and analyse gaugings and other hydrological information for Gibson Creek (and other main tributaries);
- Update the model with new time series of land surface recharge and pumping (calibrated to MDC's lysimeter and pumping data, where possible) and other relevant hydrological data, and calibrate to measured data up to present date; and
- Consider using this updated model for predicting the effects on the saltwater-freshwater interface.

1 INTRODUCTION AND BACKGROUND

The Marlborough District Council (MDC) is a unitary authority responsible for providing the following utility services and managing the natural resources of the Wairau Plain surrounding Blenheim:

- Municipal water supply;
- Rural agricultural drainage;
- Surface water/groundwater allocation;
- Flood control;
- Maintaining soil and freshwater quality;
- Urban stormwater; and
- Preserving ecological habitats.

NIWA are forecasting a rise in sea level at the New Zealand coast of around 0.5 to 1 metre by 2100, and MDC has observed an apparent declining trend in Wairau River mean flows since 1960 based on results from its own regional monitoring network. It is likely that the predicted quantum of sea level rise will challenge the capacity of the artificial drainage system closest to the coast to maintain soil moisture levels by the turn of the century in 2100.

How services will be affected and how sensitive are local lowland natural resources to sea level rise or a continuing fall in catchment runoff is something that MDC as a regulator and service provider needs to quantify for future planning. The local community, businesses, water users and farmers are also very interested in how they, or their activities, will be affected. Some consequences of sea level rise (in particular) are potentially beneficial, but numerical modelling is needed to quantify the size and direction of these changes as the response won't always be obvious. For example groundwater spring flow is likely to increase based on first principles.

The recent finding published in the 2016 State of the Environment Report prepared by MDC that Wairau River catchment flow has declined over the period since records began in 1960, and particularly since 2000, lends impetus to making sure monitoring networks are capable of detecting climate change and seaelevel rise. MDC realise that more work is now needed across the board of which this project forms a starting point for identifying the impacts of future climate variability.

1.1 Model Purpose

The best tool for this type of scenario testing is a numerical computer model of the Wairau Plain which incorporates the seawater boundary. Risk assessments have been successfully carried out by other coastal regions recently, for example Tasman District Council (Aqualinc, 2015) and Selwyn District Council (Aqualinc, 2016). An existing computer model can be used and hypothetical changes in sea level and reductions in Wairau River catchment runoff trialled. The methodology is ideally suited to aid our understanding of the effects, some of which may not be obvious (for example, at depths of 50 metres or more below the surface).

This is a standard approach to risk assessment, but it does rely on having a good model so that the predictions are reliable. The advantage of using a numerical model is that they can identify some of the non-linear responses and hydraulic rebalancing that are likely to happen, and identify hidden effects.

The prime purpose of using the Wairau aquifer groundwater model for this study is to consider relative change as result of climate change. Consequently, the accuracy of calibration to absolute groundwater levels is of less importance to the hydraulic response to changes in stresses (such as seasonal variations).

1.2 Key Project Deliverables

The deliverables of this project are:

- Report documenting the results and the risk assessment process;
- Predictions of Wairau Plain water resource response to combinations of incremental sea level rise, reductions in Gibson Creek diversion, changes in upland catchment runoff and reductions in land surface recharge;
- Improved understanding of how local natural resources will respond to environmental stress; and
- Identify gaps in MDC's knowledge and monitoring networks.

2 MODEL UPDATES

The Wairau aquifer model has been progressively developed over the last 15 years. As part of the current study, the latest version of the model, as published in Aqualinc (2008), has been further updated to improve calibration to groundwater levels, Spring Creek flows and Wairau River losses. Key updates to the model are listed below:

- The graphical user interface used to operate the model was changed from Groundwater Vistas to GMS (2016). This provided greater capability for visualising model set up and results.
- A general head boundary was added along the coast. Previous studies concluded that the majority of groundwater discharged through the springs and coastal drains, with discharge to the sea forming a relatively small component of the overall water balance. Consequently, this boundary had been ignored. However, for the purposes of assessing the effects on sea level rise on the groundwater system, it was necessary to provide a coastal boundary. Hence this was added in prior to model recalibration.
- MODFLOW zone budgets were constructed to enable Wairau River losses (over a specific reach) and Spring Creek flows to be extracted from model outputs.
- Model parameter zones (for horizontal and vertical hydraulic conductivities and storage) were adjusted, along with Wairau River bed conductivity, to:
  - Improve overall model fit; and
  - Control losses from the Wairau River.
- Spring Creek drain cells were adjusted to improve fit with measured flows for this drain. Other drain cells parameters were also adjusted to improve fit to nearby groundwater levels.
- New starting heads were assigned to improve model run performance.
- PEST (Parameter Estimation software), as provided for in GMS (2016), was utilised to aid model calibration.

A key focus for model calibration was improving the fit to measured groundwater levels in two monitoring bores located near the Wairau River (P28/3821 and P28/3009). Consequently, the contribution of error from these two wells to the overall model error was increased by specifying a larger weighting factor to observations in these wells.

As part of the model update, the model run period was not lengthened to the current date as this would require a substantial amount of time and effort. Instead, model updates focussed on improving the existing model over the existing run period. As documented in Aqualinc (2008), the model was constructed to run from 16/7/90 to 18/12/06, which is a total of 6,000 days. This was not changed. Future model development should consider extending the model run period through to present date to make best use of more recent monitoring data and to replicate the more extreme climatic events of recent years.

The model has been constructed with daily-averaged stresses (land surface recharge, pumping and river flows). Consequently, the sub-daily variation in tide at the coast has not been modelled. The model will therefore predict the scale and direction of change from a given average sea level rise, rather than the time-varying effects.

2.1 Calibration Results Overview

The location of model calibration wells, along with the model grid, is shown in Figure 3. Hydrographs of the model fit to measured groundwater levels and Spring Creek flows are provided in Appendix A. Overall a good fit was achieved, and is an improvement on previous calibration. Some wells show an out-of-phase (high versus low groundwater levels) comparing modelled and measured. The cause of this was not resolved in this study and should be investigated further in future stages of development. This does not affect the model's ability to predict the magnitude and direction of the effects of a given sea level rise.

A comparison of measured Wairau River flows (at Tuamarina) versus modelled losses (between the Waihopai River confluence and Selmes Road) is shown in Figure 1.

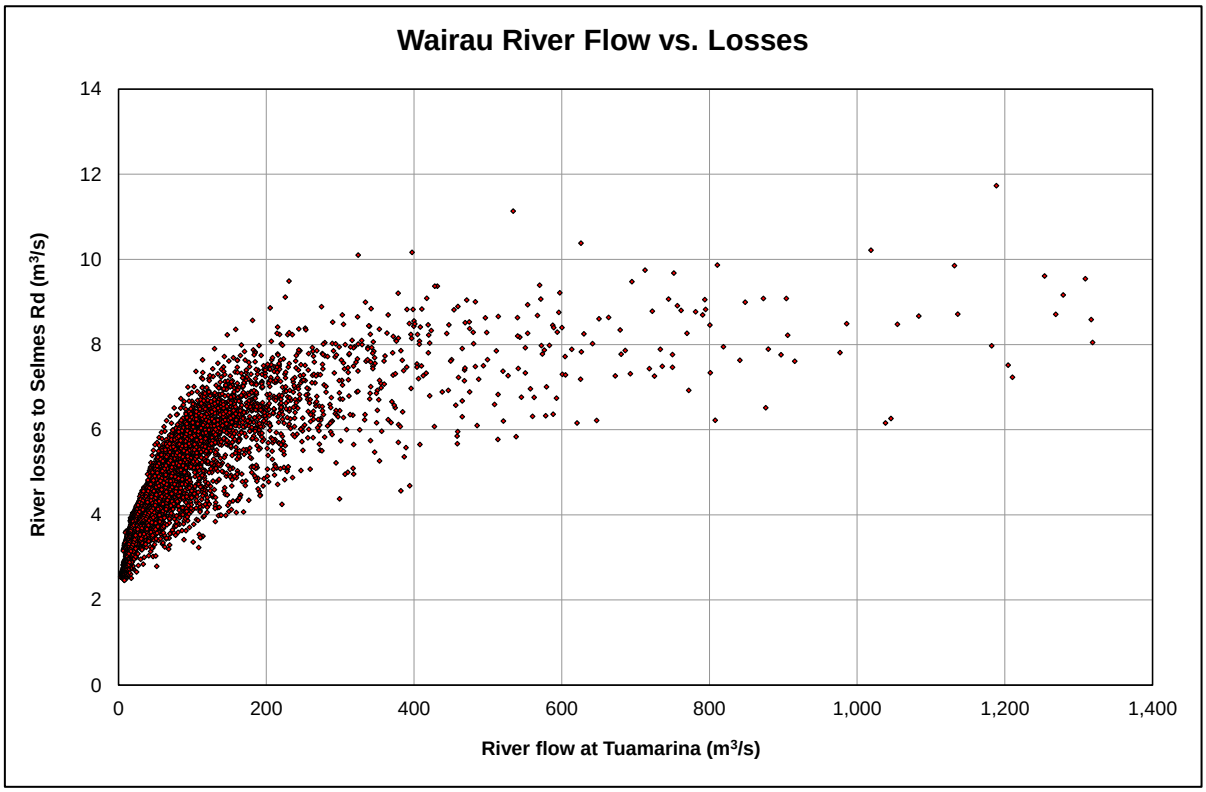

Figure 1: Measured Wairau River flows versus modelled losses

For comparison to Figure 1, MDC have estimated the equivalent 'measured' relationship between Wairau River losses and flow. This is presented in Figure 2 which compares Wairau River flows at Tuamarina with double the gauged flow at Spring Creek. The double-flow of Spring Creek has been estimated by MDC as the losses from the Wairau River based on historical simultaneous gaugings of river losses and spring discharges (Peter Davidson, MDC, *pers. comms*.). This relationship provides an indicative basis for constraining the maximum losses from the Wairau River of 10-15 m^3/s, which has been achieved in Figure 1.

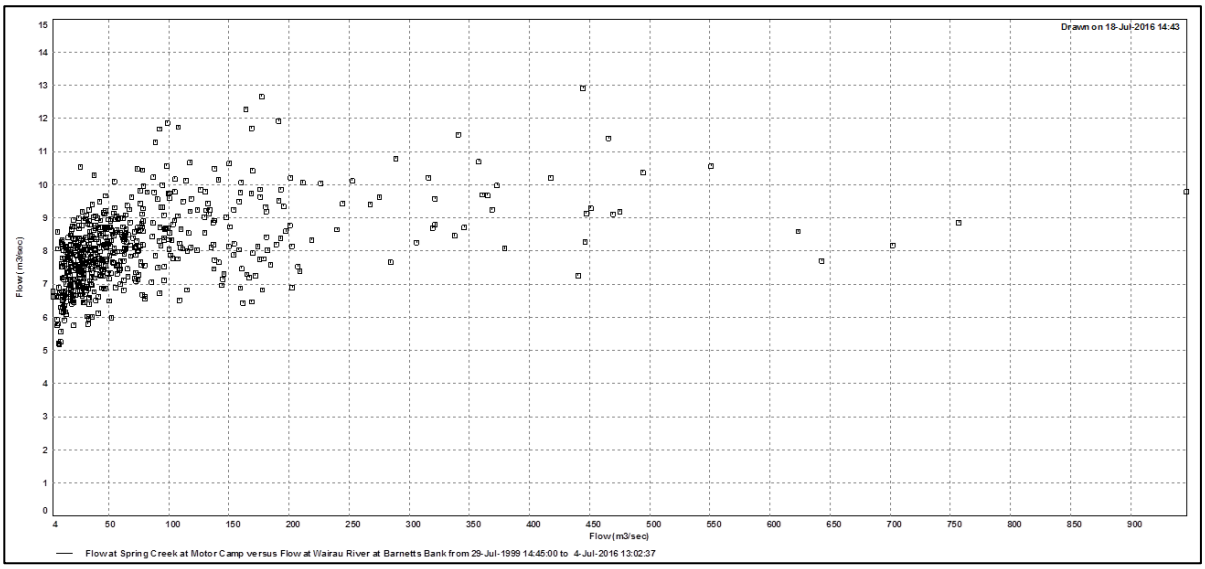

Figure 2: Measured Wairau River flows versus double Spring Creek flow

Further descriptions of model construction is provided in Aqualinc (2008).

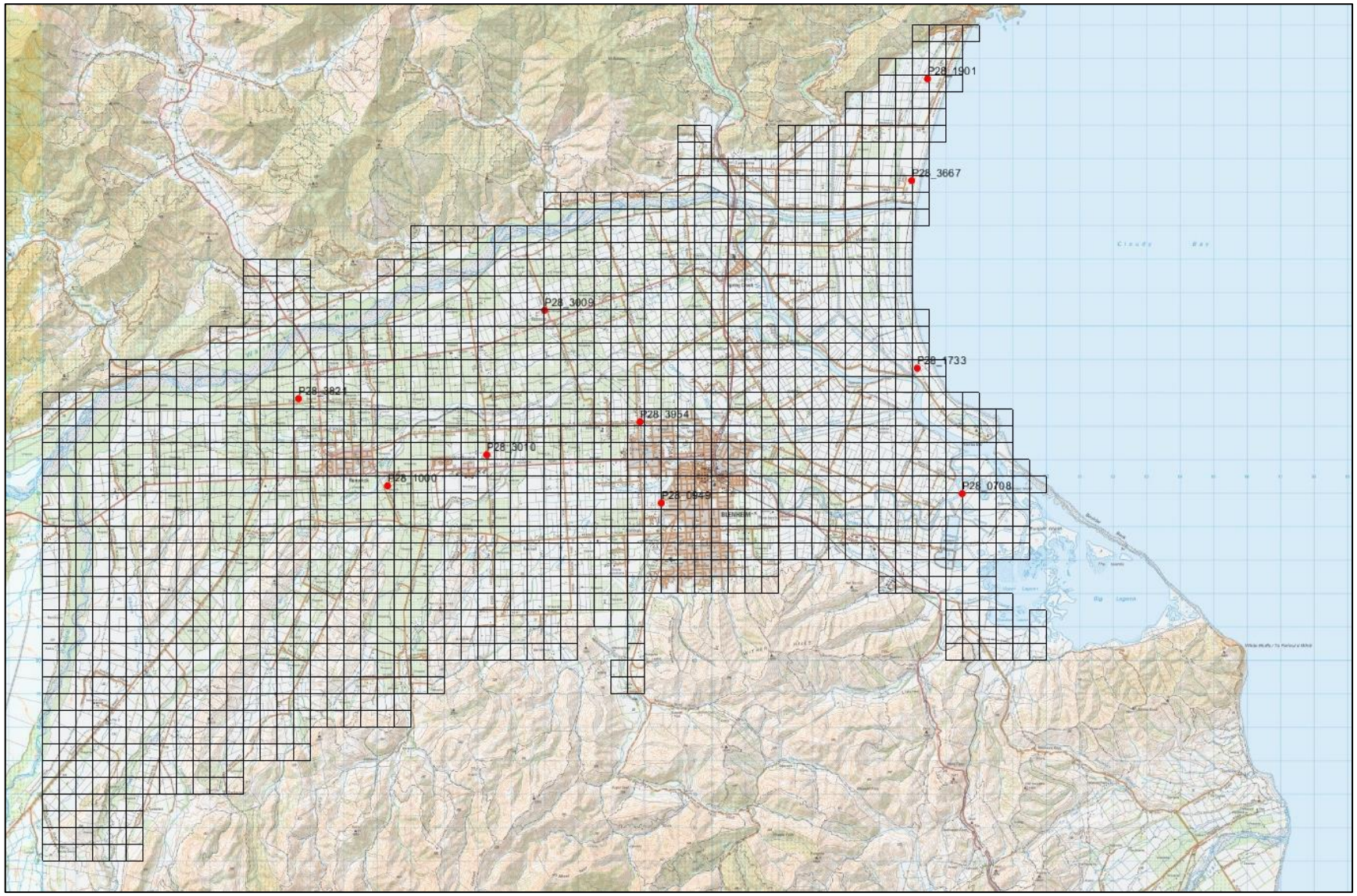

Figure 3: Model grid and location of calibration wells

3 SCENARIOS

The following scenarios were completed.

Scenarios 1a and 1b: Sea Level Rise

These scenarios are based on the calibrated model but with the head at the coastal boundary raised. For the Tasman District, Bell (2014) suggests that, through adopting a 100-year planning timeframe, sea level rives of up to 1.0 m should be accommodated. Consequently, a permanent sea level rise of 1 m has been applied to the model's coastal boundary under Scenario 1a. As a further check on the sensitivity of the aquifer system, Scenario 1b raises the coastal head by 2 m. Similarly, river inverts at the coast have also been raised 1 m and 2 m respectively with upgradient slopes also changed to match.

Scenario 2: Gibson Creek Augmentation

Currently, water is artificially routed into the top of Gibson Creek from the Waihopai and Wairau rivers which then flows into the Opawa River system. This diversion will be switched off to ascertain the hydraulic response of the system to this artificial diversion. While this scenario is not driven directly by climate change, it was included because the operation of the diversion is likely to be affected by future changes to river flows.

Scenarios 3a and 3b: Wairau River Recharge

This scenario is based on the calibrated model but with reduced flow in the Wairau River at the upstream model boundary (just above the Waihopai River confluence). Two scenarios will be considered, one that reduces the river flows uniformly (in space and time) by 10% (Scenario 3a) and another by 20% (Scenario 3b). These scenarios have been developed to ascertain the effects on the system from reduced up-catchment Wairau River flows, which in turn reduces the recharge into the Wairau Plains aquifer system.

Scenarios 4: Land Surface Recharge

This scenario is based on the calibrated model but with reduced land surface recharge (LSR) by 50% of the calibrated recharge. This scenario has been developed to ascertain the effects on the system from reduced rainfall, which is manifested in the groundwater system by reduced LSR.

For all of the above scenarios, the following outputs have been generated:

- Tabulated differences in average Spring Creek flow and Wairau River recharge (to groundwater) between each scenario and the calibrated model for the full model period.
- Tabulated differences in modelled average groundwater levels for each calibration well between each scenario and the calibrated model for the full model period.
- Maps of changes in modelled groundwater levels between each scenario and the calibrated model on 18/3/01 (day 3975 of the model simulation period). This date was chosen as an example to represent the extreme dry period of that season and corresponds to a date of lowest (or near lowest) recorded groundwater levels.

4 RESULTS AND DISCUSSION

Table 1 summarises model outputs of average Spring Creek flows and Wairau River recharge to groundwater. Values in this table are differences in long-term average flows (over the model simulation period) between the calibrated model and each scenario. Similarly, Table 2 summarises model outputs of average changes in groundwater levels for each of the calibration wells. In these tables, the '+' sign indicates an increase compared to the calibrated model and a '-' sign a reduction.

Table 1: Change in average flows from calibration scenario

Scenario	Spring Creek flow (m^3/s)	Wairau River losses (m^3/s)
1a	+0.02	0
1b	+0.05	0
2	-0.16	+0.02
3a	-0.08	-0.13
3b	-0.16	-0.29
4	-0.03	+0.01

Table 2: Change in average modelled groundwater level (m amsl) from calibration scenario

Well no	Location	Scenarios					
		1a	1b	2	3a	3b	4
1901	Coastal unconfined	+0.18	+0.39	-0.03	-0.01	-0.01	-0.15
3667	Coastal confined	+0.14	+0.36	-0.11	-0.02	-0.04	-0.07
1733		+0.15	+0.42	-0.14	-0.02	-0.04	-0.09
708		+0.16	+0.45	-0.14	-0.02	-0.04	-0.10
3954	Wairau aquifer	+0.01	+0.07	-0.69	-0.04	-0.09	-0.03
3009		0	0	-0.17	-0.15	-0.33	-0.03
3821		0	0	-0.06	-0.19	-0.42	-0.07
3010	Southern Valleys	0	+0.01	-0.56	-0.12	-0.26	-0.10
1000		0	0	-0.20	-0.13	-0.28	-0.29
949		+0.01	+0.09	-0.07	-0.01	-0.01	-0.04

Further commentary on the results from individual scenarios is provided below.

4.1 Scenarios 1a and 1b: Sea Level Rise

Scenarios 1a and 1b consider the effects on the groundwater system from a rise in sea level at the Cloudy Bay coast.

Due to the relatively flat gradient of the estuary area, a sea level change propagates further inland than it does along the Wairau River main stem, which has a steeper gradient.

A rise in groundwater levels implies that the position of the freshwater/saltwater interface will deepen below the surface and further from well screens than is currently the case. However, a more sophisticated model that accounts for fluid density differences is needed to more precisely predict the location of the freshwater-seawater interface. There is currently a lack of real observations to calibrate such a model. It is therefore recommended that MDC undertake mapping of the current position of the saline wedge in both rivers and groundwater.

The physical change in location of the coastline by the year 2100 is likely to be more of an issue for the Wairau Plains than the effects on the groundwater system, especially where no high dune or barrier exists.

Results from Scenarios 1a and 1b are discussed individually below.

4.1.1 Scenario 1a

This first model simulation involved raising sea level by 1 metre at the Cloudy Bay coastline.

The model predicted moderate rises in aquifer levels in the deep water bearing layers of the Wairau Aquifer of between 0.14-0.16 m (Table 2), along with a small increase in Spring Creek flow of 0.02 m^3/second (Table 1). The largest increase in groundwater elevation was predicted for Rarangi Shallow Aquifer levels (well 1901) of 0.18 metres. These changes are averaged for the full model simulation period.

Small increases were also forecast for inland wells near Blenheim (Substation well 3954) and Athletic Park (well 949), but these increases were very small (less than the model accuracy).

Figure 4 and Figure 5 presents contours of predicted changes in shallow and deep aquifer groundwater levels (respectively) relative to present. Overall, groundwater levels are predicted to rise with the largest increase occurring near the rivers at the coast. This is because a rise in sea level causes flow to back-up in the rivers and the aquifers until a new dynamic equilibrium is reached with the raised sea level at the coast.

4.1.2 Scenario 1b

One of the model outputs of primary interest to MDC was the effect on Spring Creek flows as a result of rising coastal sea level. Results from Scenario 1a suggested that Spring Creek flows would increase due to a 1 m change in sea level, but the quantum of flow change was very small. Therefore, sea level was hypothetically raised by 2 m to further test the sensitivity of Spring Creek flow to sea level change. It is acknowledged, however, that there is little likelihood that sea level would rise by this magnitude.

Compared to Scenario 1a, changes in flows and groundwater levels were greater, as shown in Table 1, Table 2, Figure 6 and Figure 7. Spring Creek flow increased by 0.05 m^3/s, but this is still a very small change compared to the mean flow of the creek. It is fair to say that the model simulations suggest that, in general, the groundwater fed Spring Creek system is relatively insensitive to changes in sea level due to the distance of the springs from the coast.

However, springs located closer to the coast will experience increases in flows and shallow groundwater levels may also become problematic for some land uses (e.g. agricultural or residential).

These model forecasts are consistent with results from a similar study conducted for the Motueka-Riwaka coastal plains.

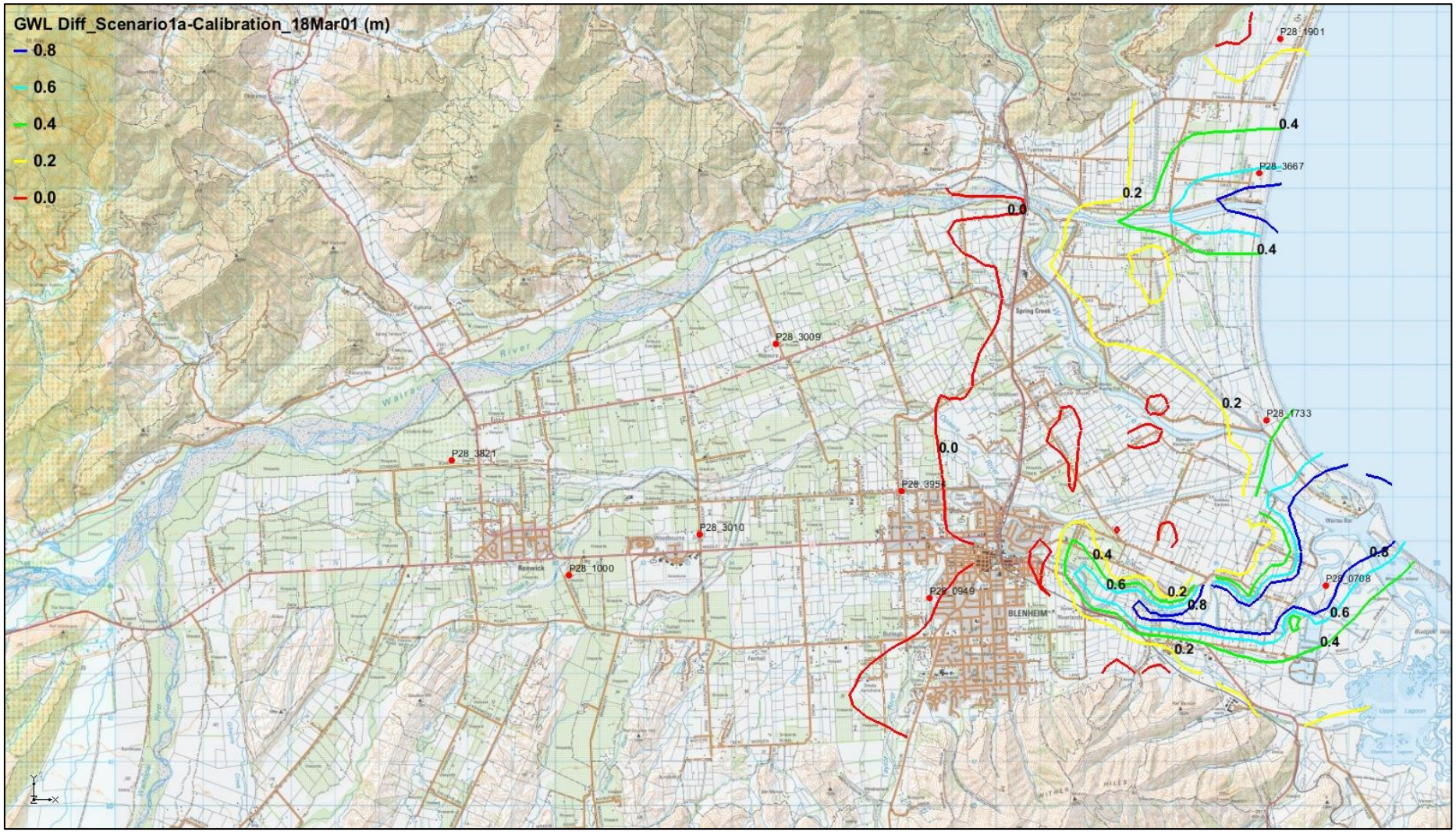

Figure 4: Modelled shallow groundwater level differences between Scenario 1a and calibration: 18 March 2001

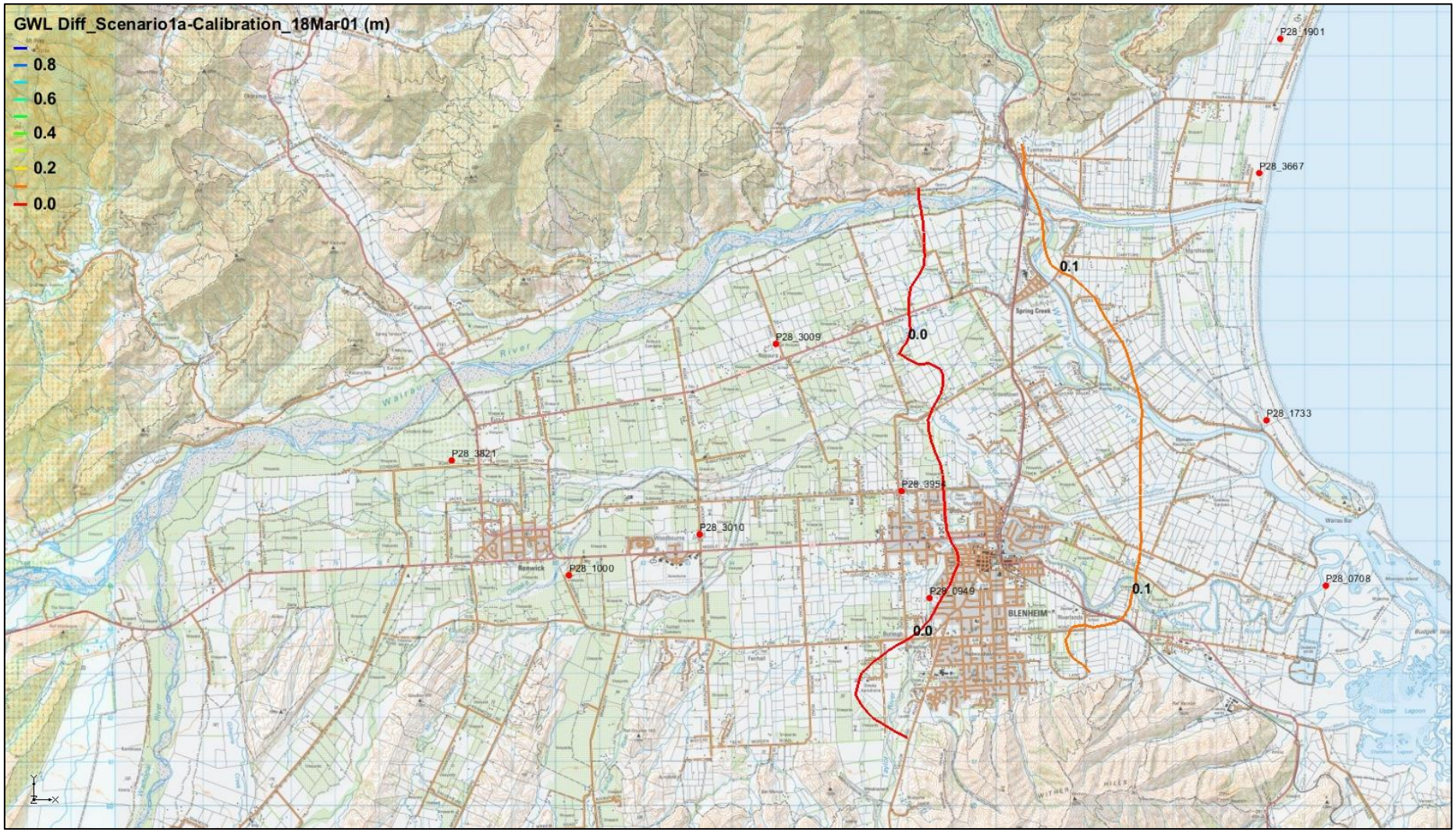

Figure 5: Modelled deep groundwater level differences between Scenario 1a and calibration: 18 March 2001

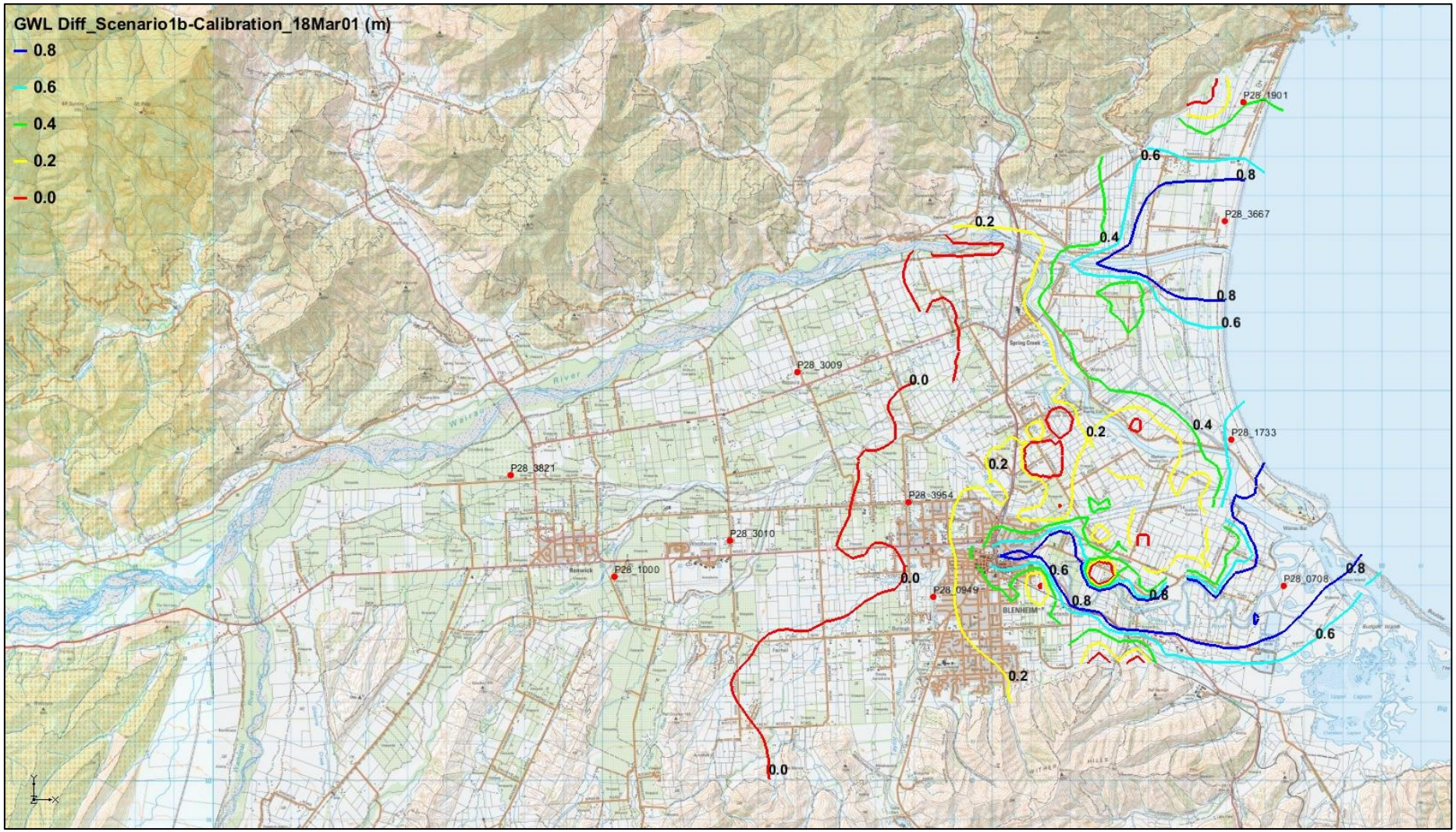

Figure 6: Modelled shallow groundwater level differences between Scenario 1b and calibration: 18 March 2001

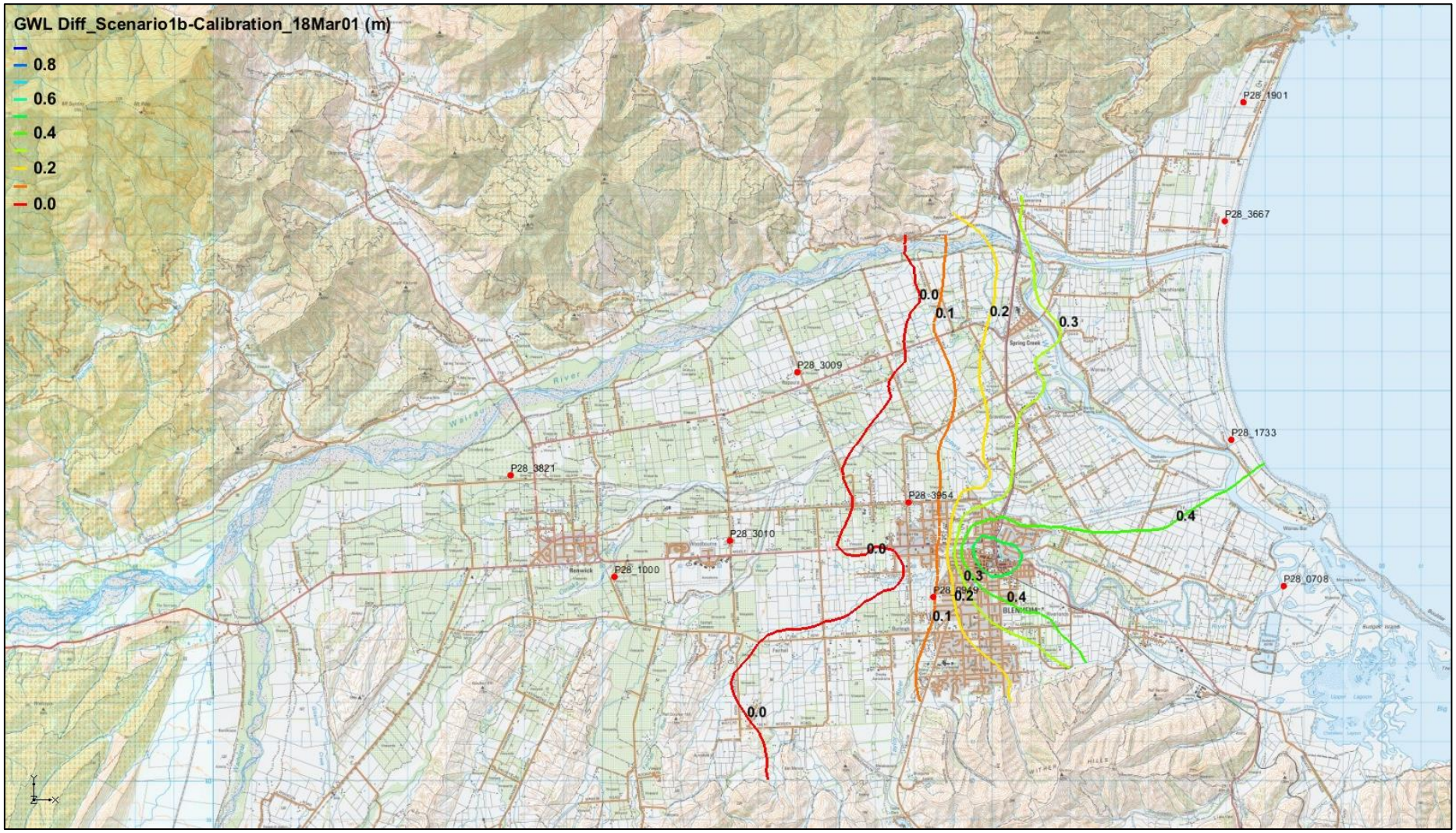

Figure 7: Modelled deep groundwater level differences between Scenario 1b and calibration: 18 March 2001

4.2 Scenario 2: Gibson Creek Augmentation

The opportunity was taken to simulate several other hydrological changes that could potentially affect Wairau Plain water resources. One change is the likely impact of shutting down the Southern Valleys Irrigation Scheme (SVIS) which is supplied by water diverted from the Waihopai and Wairau rivers into Gibson Creek. This affects flows in the downstream Opawa River which in turn provides additional recharge to the Wairau Aquifer.

Figure 8 shows contours of modelled declines in groundwater levels as at 18 March 2001 associated with a reduction in Gibson Creek flow of 0.4 m^3/s. The area of influence extended from near Renwick to almost SH1 in the east, with the largest drop in groundwater levels centred on the Hammerichs Rd area.

The model has been constructed with relatively low Gibson Creek bed conductances (down to Hammerichs Rd) which were based on observed pre-2004 state when simultaneous flow surveys demonstrated the channel was sealed with fine sediments. The area affected may extend westward if the modelled bed conductances of Gibson Creek are increased to be more consistent with post-2004 values (bed conductance was increased as a result of construction of SVIS).

The removal of Gibson Creek augmentation is predicted to reduce Spring Creek flows by approximately 0.16 m^3/s (Table 1). The largest groundwater level changes were predicted at MDC's Substation well (3954) and Jacksons Road well (3010), with falls of 0.69 and 0.56 m respectively (Table 2). These are the averaged falls for the entire simulation period from 1990 to 2006.

It is possible that declines of this order occurred during the reduction in SVIS flow in February/March 2015 when Wairau River flows dropped below the 8 m^3/s at Tuamarina. This is the main threshold for resource consent restrictions.

The model forecasts significant drops in groundwater levels would be associated with a shutoff of the SVIS water supply (and therefore removal of Gibson Creek augmentation). However, the actual maximum fall can't be verified as there is no MDC monitoring well near Hammerichs Rd.

The forecasted increase in Wairau River leakage to the Wairau Aquifer is likely to be caused by a fall in groundwater levels increasing the hydraulic gradient between the two water bodies. The predicted fall in groundwater for the RSA well (1901) is unlikely and probably due to model inaccuracies.

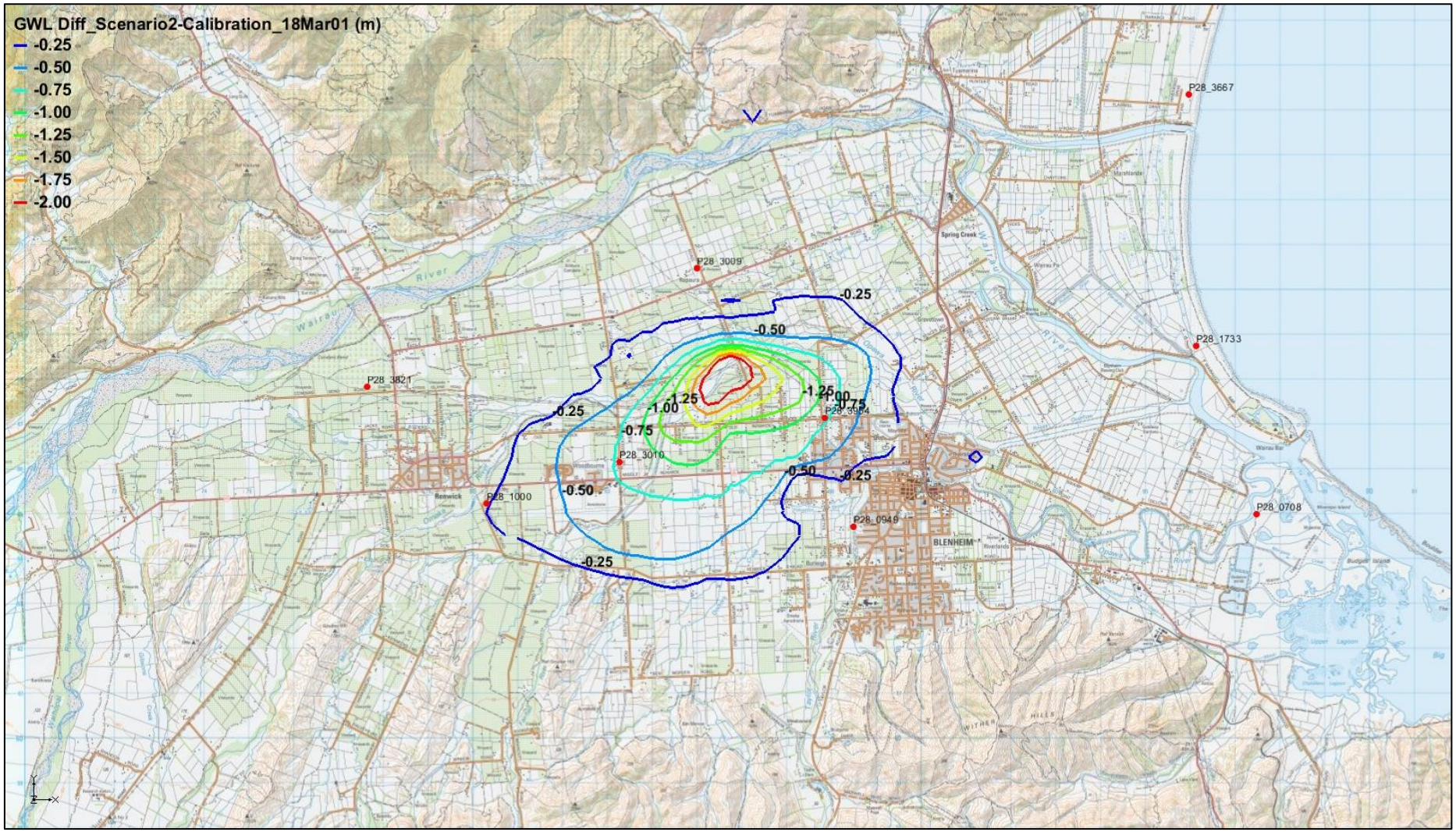

Figure 8: Modelled groundwater level differences between Scenario 2 and calibration: 18 March 2001

4.3 Scenario 3: Wairau River Recharge

The Wairau Aquifer is effectively an extension of the Wairau River and is driven by flows in the Wairau River. Scenarios 3a and 3b consider the effects on the groundwater system from a 10% and 20% reduction in Wairau River flows. Results from these scenarios are discussed individually below.

4.3.1 Scenario 3a

This first model simulation involved reducing the Wairau River flows uniformly by 10%. Table 1 summarises the changes in average Spring Creek flow and Wairau River losses, which reduce by 0.08 and 0.13 m^3/s respectively. The reduction is Spring Creek flows is caused by a lowering of groundwater levels, and Figure 9 provides the predicted spatial change in groundwater levels on 18 March 2001.

4.3.2 Scenario 3b

This scenario involved reducing the Wairau River flows uniformly by 20%. Table 1 summarises the changes in average Spring Creek flow and Wairau River losses, which reduce by 0.16 and 0.29 m^3/s respectively. Figure 10 provides the predicted spatial change in groundwater levels on 18 March 2001.

4.3.3 Check on Model Predictions

As a check on the accuracy of the model predictions, the changes in Spring Creek flows have been compared to changes in groundwater levels in nearby well 3009. Davidson & Wilson (2011) provide (in their Figure 19.9) a correlation (based on measured data) between groundwater levels in 3009 and Spring Creek flow. Using this correlation, an average groundwater reduction change of 0.15 m in well 3009 for Scenario 3a (Table 2) results in an average reduction in Spring Creek flow of approximately 0.15 m^3/s. Comparing this to the 0.08 m^3/s predicted by the model (Table 1) suggests that the model is underestimating the flow change. While this is within the right order of magnitude of change, further work is needed to improve the model accuracy.

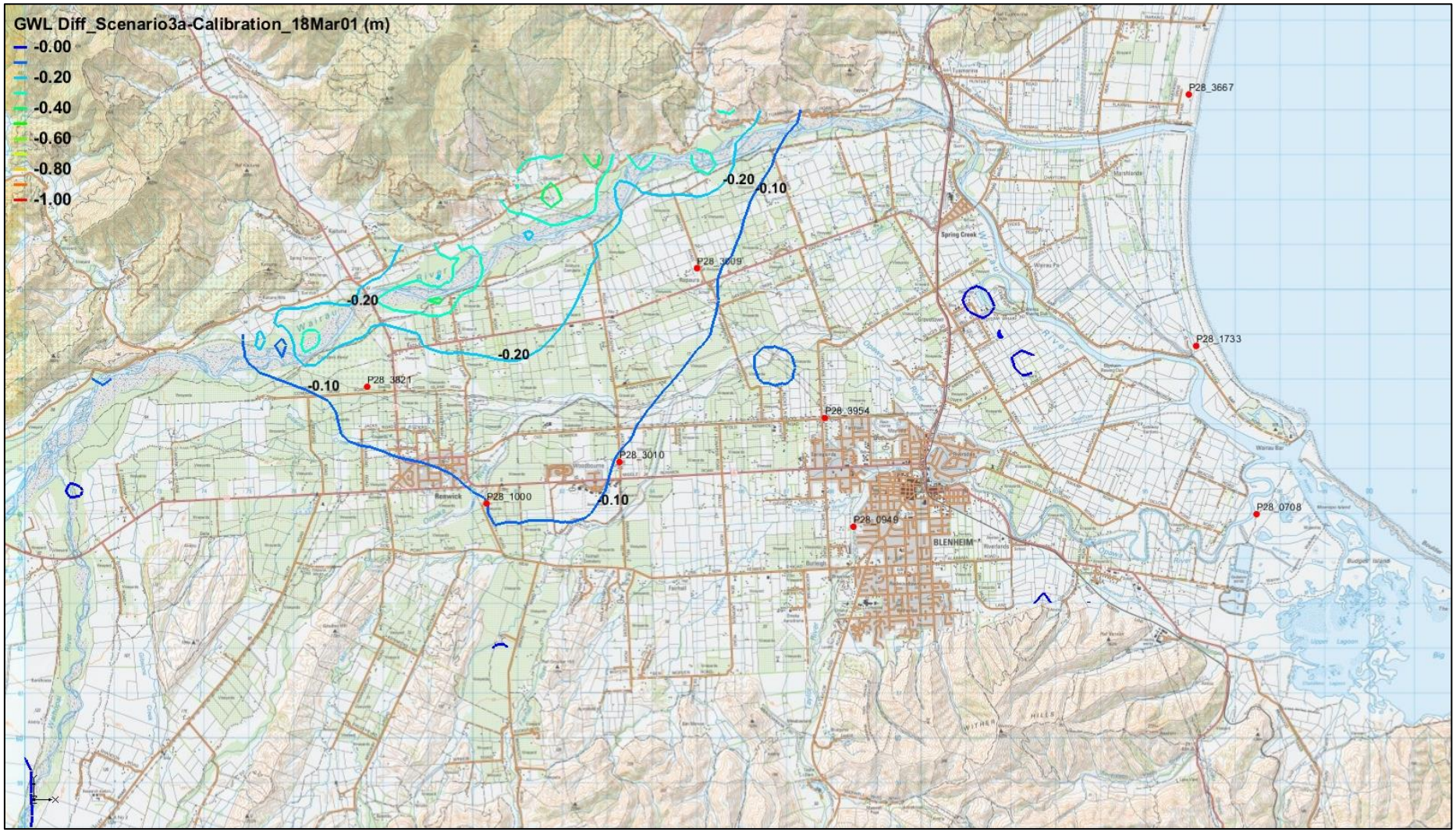

Figure 9: Modelled groundwater level differences between Scenario 3a and calibration: 18 March 2001

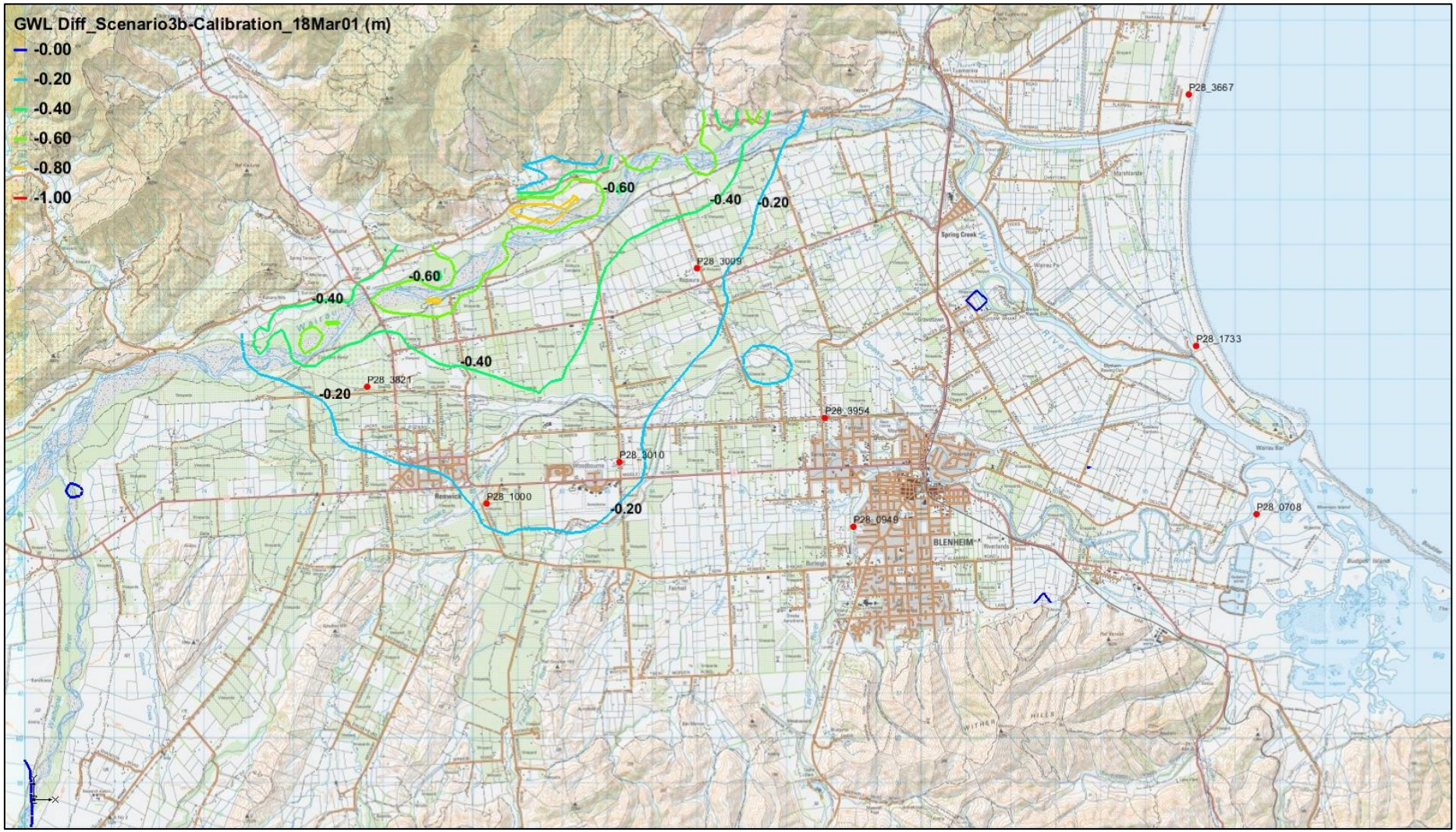

Figure 10: Modelled groundwater level differences between Scenario 3b and calibration: 18 March 2001

4.4 Scenario 4: Land Surface Recharge

Land surface recharge (LSR) is a term which accounts for the net difference between rainfall, irrigation and evapotranspiration. In the Wairau Plains, because of the efficiency of micro dripper irrigation methods and predominant grape crop, the recirculation of irrigation water is negligible.

A reduction in the rate of LSR was modelled to simulate climate variability. However the Wairau Aquifer is far less sensitive to changes in LSR than recharge from Wairau River losses which constitute 95% of inputs.

The model predicted small reductions in groundwater levels of 0.03-0.29 m over all of the plains as a result of a 50% decrease in Wairau Plain LSR (Table 2).

Although a reduction in LSR of 50% has been applied over all of the model, this generally only affects winter and spring levels, as there is little or no LSR during the summer and autumn months.

In conjunction with Pant and Food Research, MDC have operated a lysimeter located near the corner of Giffords and Rapaura roads since approximately 2012. Based on recent data from this lysimeter, the modelled LSR is likely to be underestimated. An update of this is needed for future model development. However, because of this underrepresentation, reductions of 50% have been used. A 50% reduction is large for considering the effects of climate change, but given the underrepresentation of LSR in the model, the magnitude of LSR reduction is likely to be more in-line with climate change estimates.

Although the deep aquifers at the coast are confined, recharge into these aquifers is sourced from the surface (from rivers and LSR). Recharge just travels farther and takes longer to respond in the deeper confined wells compared to shallow. Therefore, a change in LSR affects all aquifers. Due to the low storage of the confined aquifers, some of the response in deeper wells from changes in LSR are larger than the response in shallow wells.

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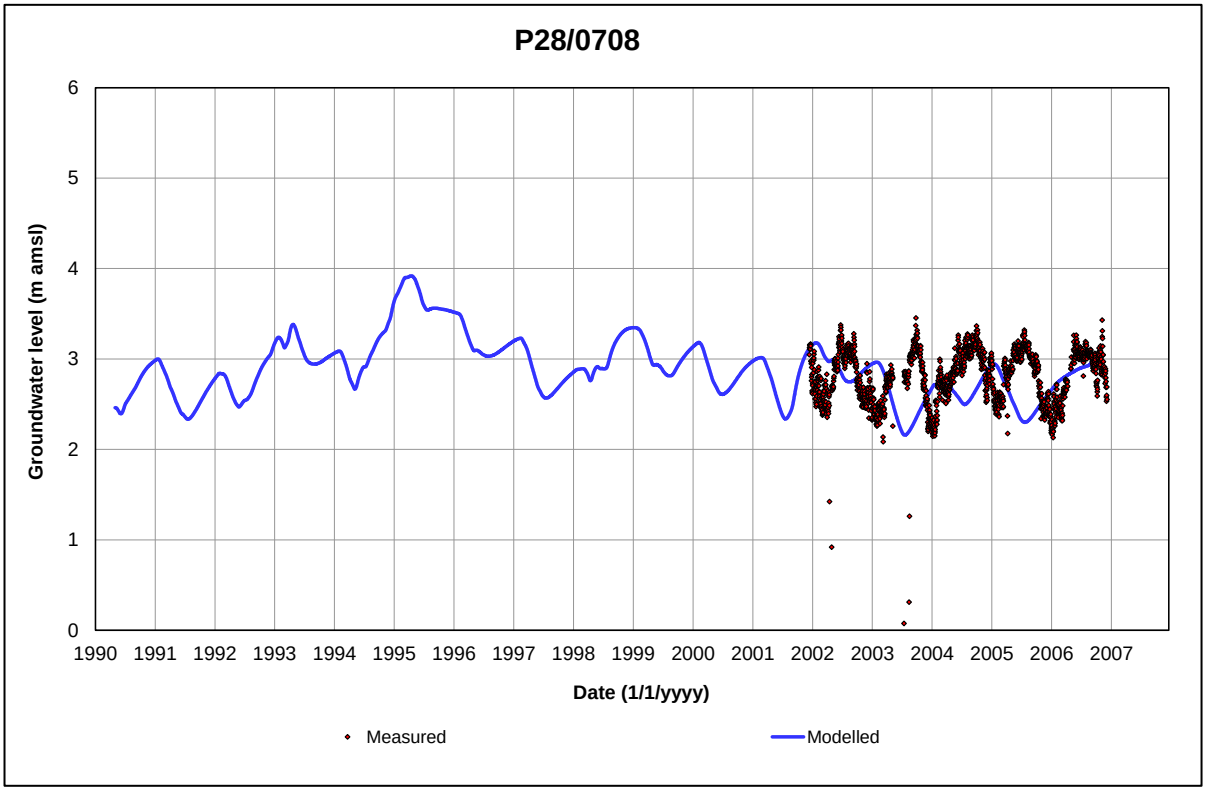
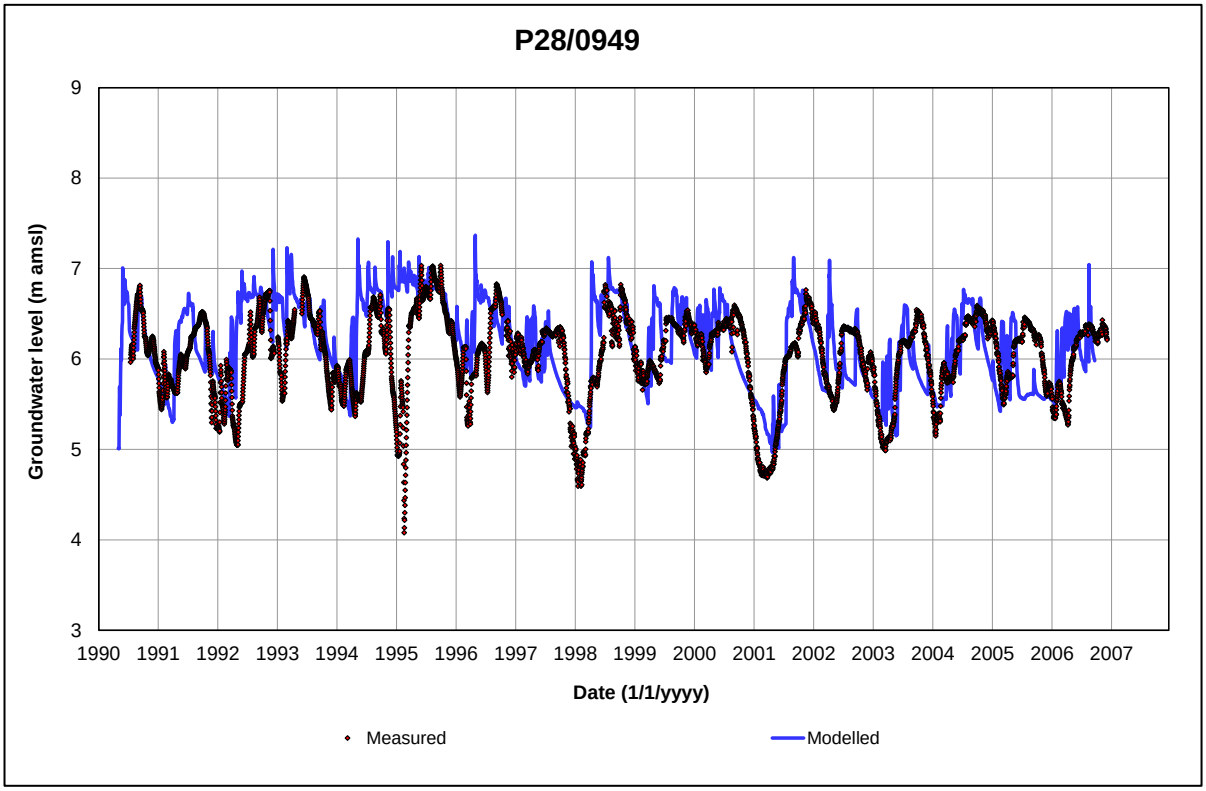
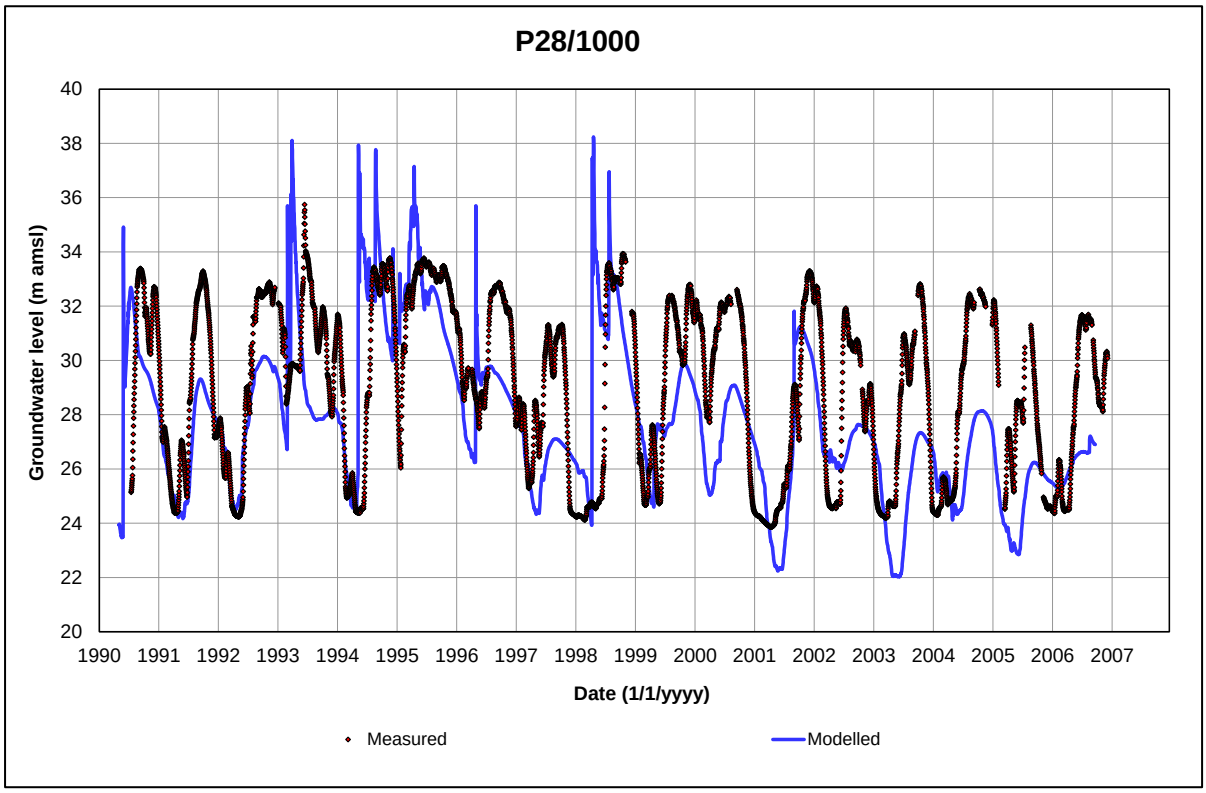
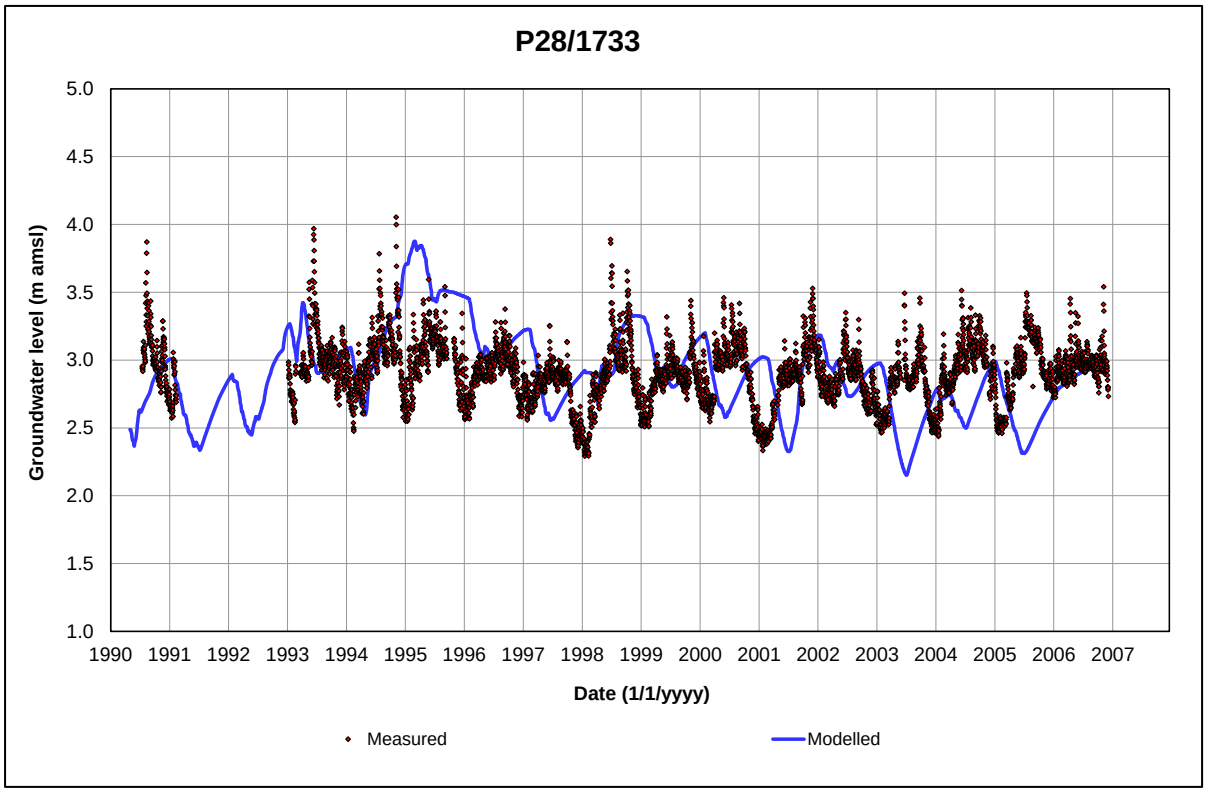
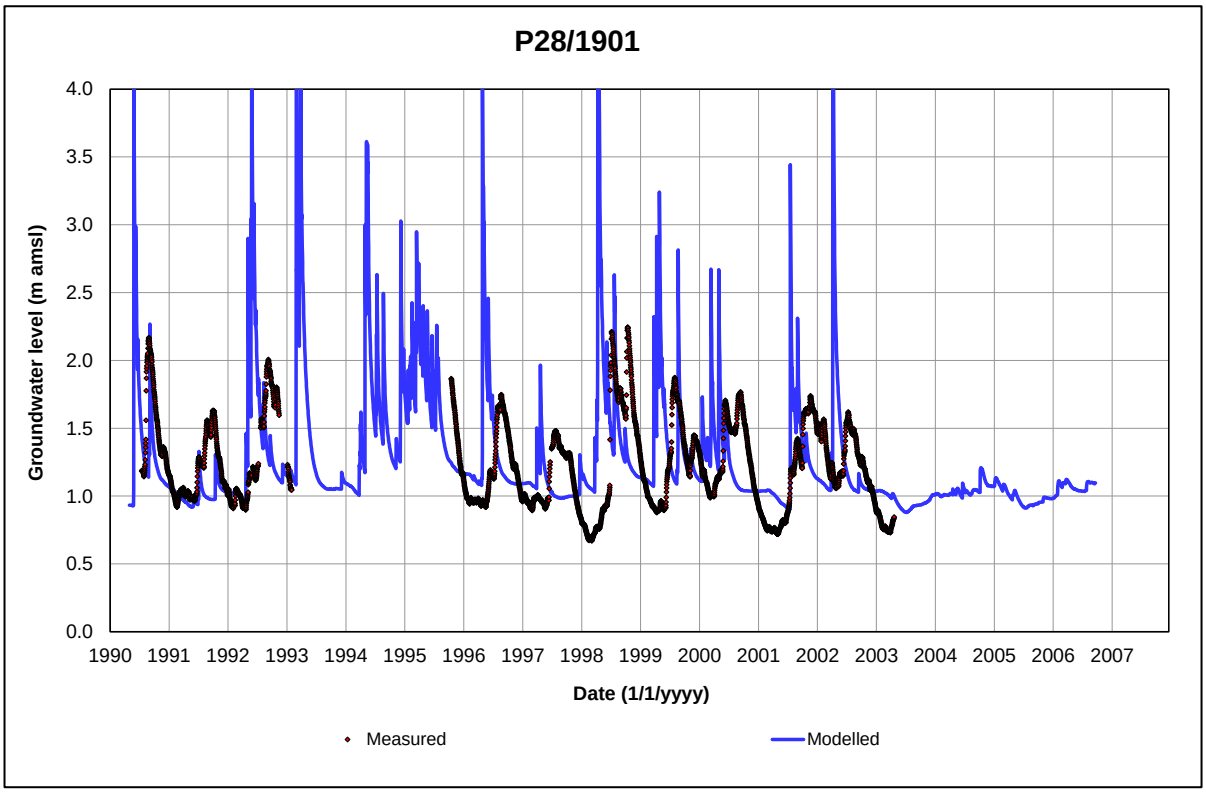
Appendix A: Hydrographs of observation wells

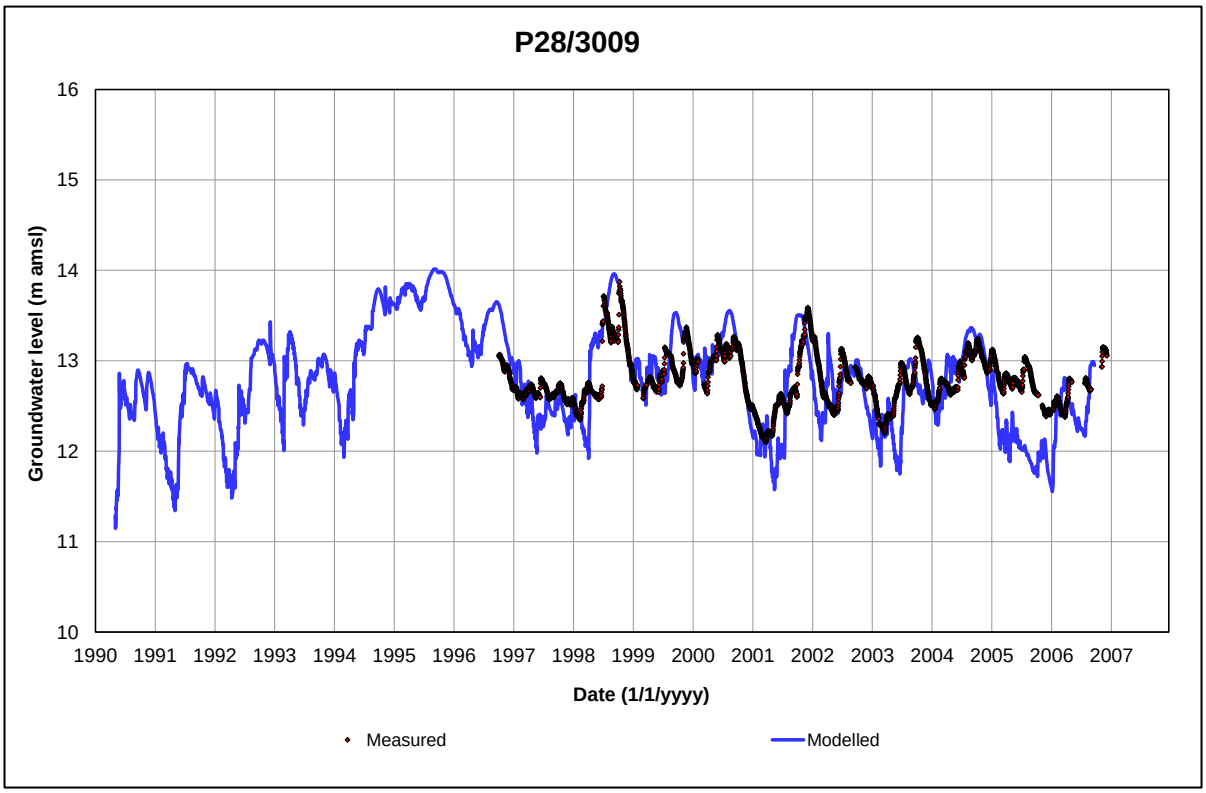


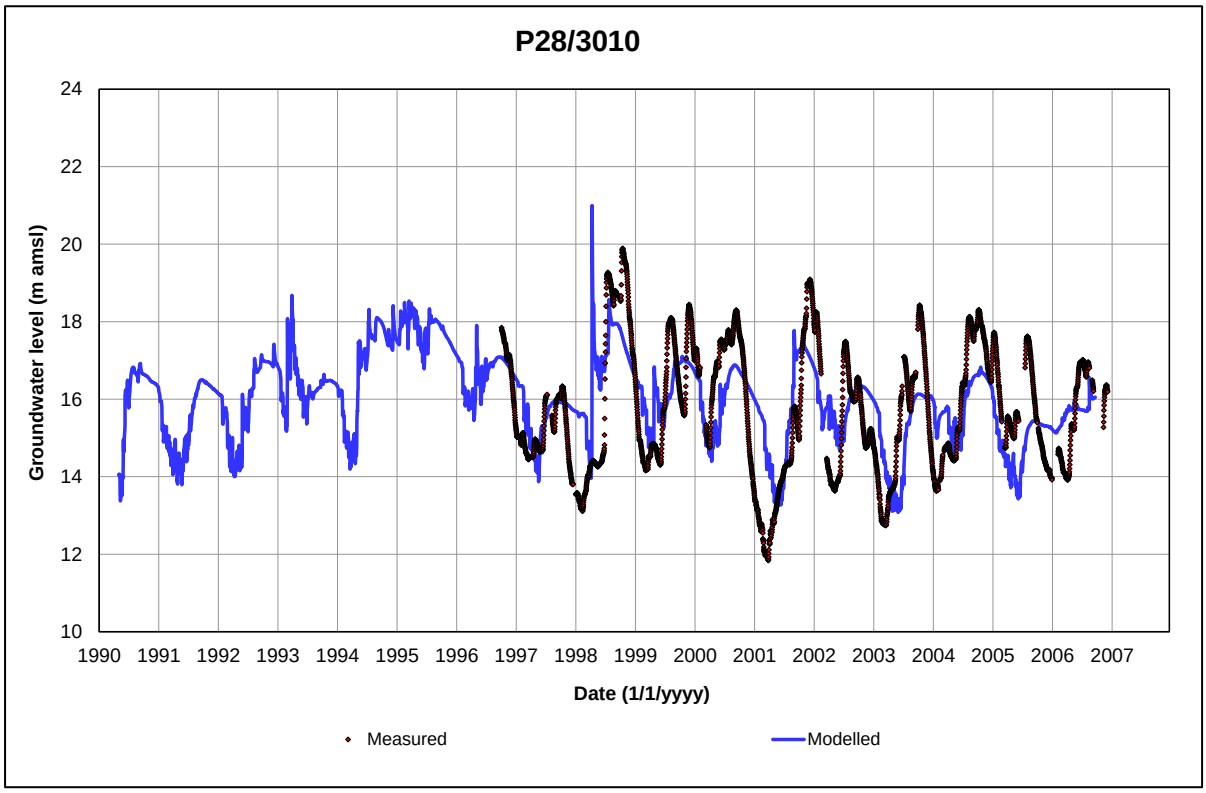


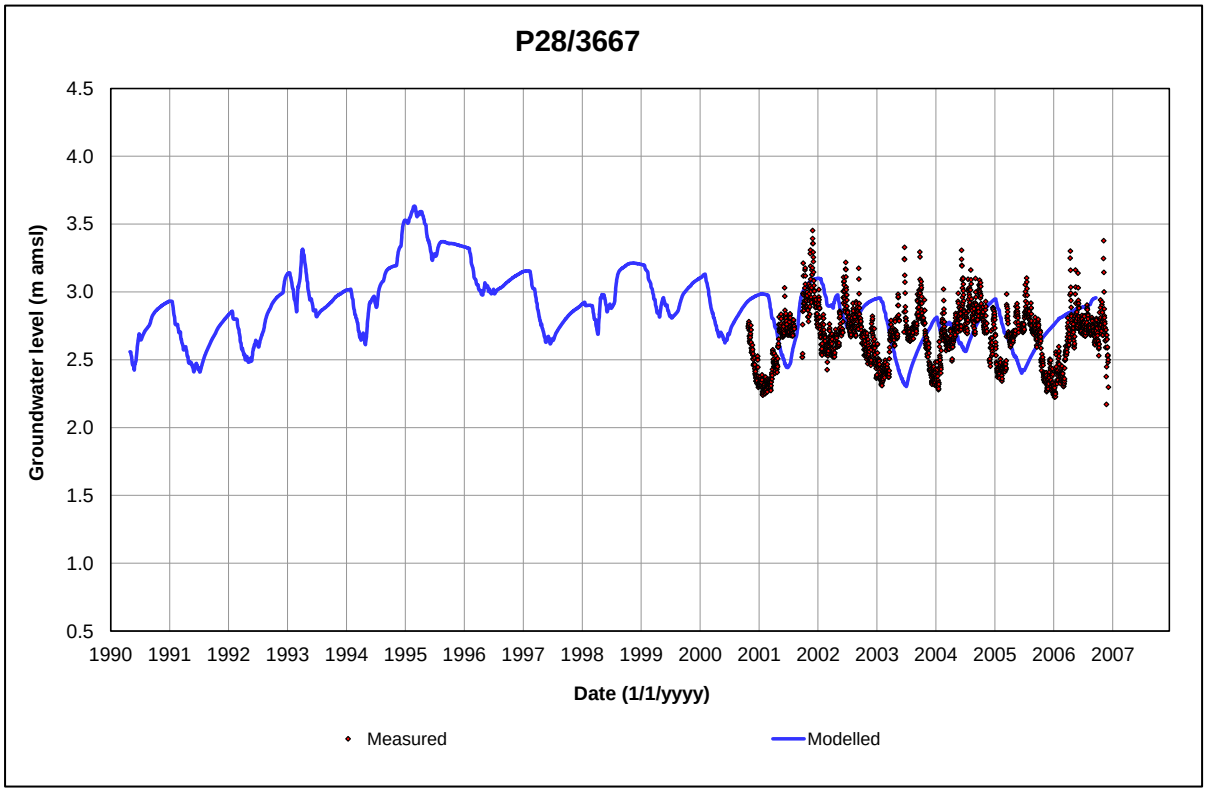


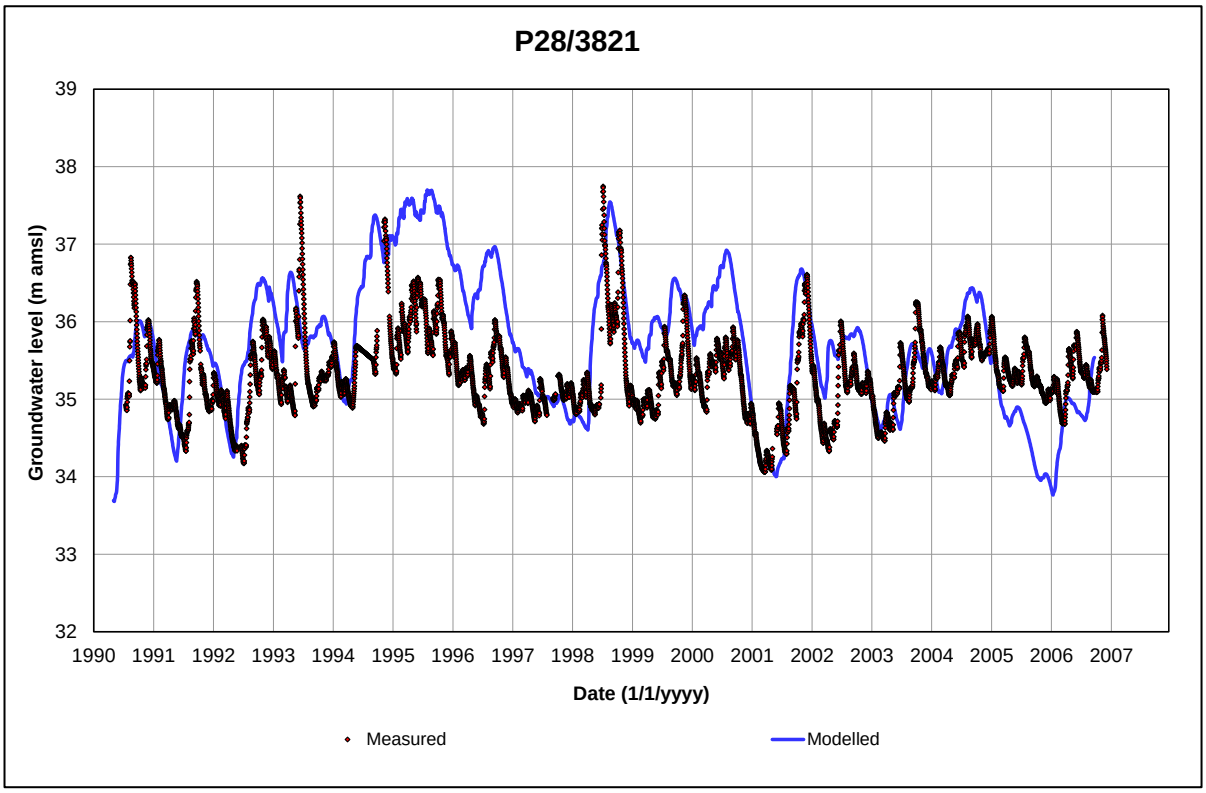


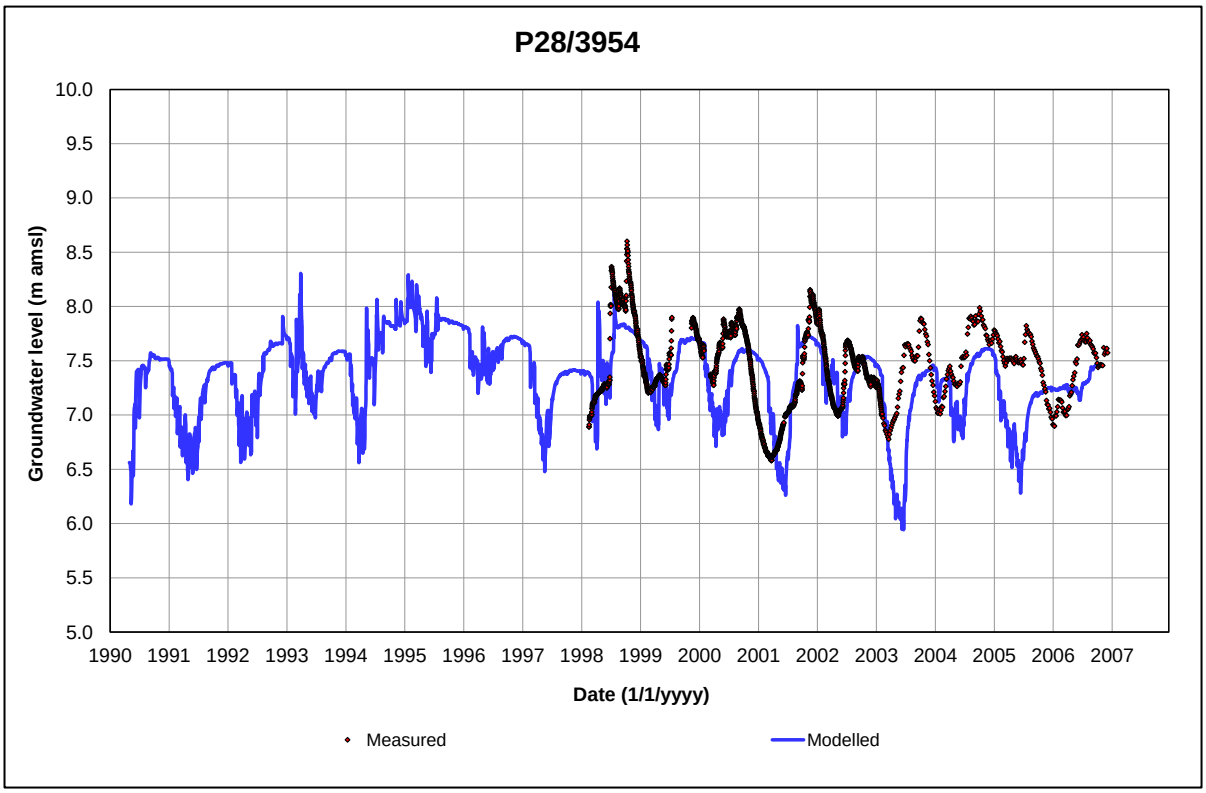

P28/1901
Groundwater level (m amsl)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Date (1/1/yyyy)
Measured
Modelled


P28/3009
Groundwater level (m amsl)
16
15
14
13
12
11
10
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Date (1/1/yyyy)
Measured
Modelled






P28/3821
Groundwater level (m amsl)
39
38
37
36
35
34
33
32
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Date (1/1/yyyy)
Measured
Modelled


P28/3954
Groundwater level (m amsl)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Date (1/1/yyyy)
Measured
Modelled