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Wairau Aquifer Model Recalibration and Coastal Simulation

Prepared for Marlborough District Council

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EXECUTIVE SUMMARY

The Wairau Groundwater Model has been developed in stages since 2001. In the previous stage (Aqualinc, 2005) the model was calibrated to accurately represent the ground and surface water interaction with use of MODFLOW’s stream flow routing (SFR1) package. The current stage is mainly focused on calibration to increase the predictive capability of the model for the coastal area. The spatial resolution of the previous model varied between 500 m x 1,000 and 1,000 m x 1,000. The resolution of the new model was increased with selection of 500 m x 500 m cell size over the entire area. The simulation period was extended with new data for the period of March 2003 to the end of year 2006; the total period of the updated model is 16 July 1990 to 17 December 2006.

The updated and modified model was calibrated for both wet and dry years to increase the robustness of the model. An independent dataset that also included wet and dry years was then used for verification. The mean residual error for head calibration (for 9 monitoring bores) is 0.20 m with a standard error of 0.04 (4%), which is an improvement from the previous stage that had the mean residual error of 0.41 m and a standard error of 5%. The main objective of this stage is to accurately simulate the coastal aquifers. There are three coastal monitoring bores, and the accuracy of the model is significantly increased for all three bores in terms of simulating the mean head and dynamics. However, the accuracy of the calibrated model may not be sufficient to use as a predictive tool for the north east coastal area of the aquifer.

The calibrated model was run for different management scenarios to identify the effect on the coastal aquifer due to change in irrigation pumping. The change of pumping factors (percentage change of pumping volume) within the coastal area and in the whole Wairau Plains was assessed. The increased pumping in the coastal area will have a significant effect in lowering the groundwater levels in the deeper coastal aquifer and receding the coastal springs. The predicted reduction in groundwater level of the deeper coastal aquifer is considerably higher in the summer months. However, groundwater levels are predicted to recover to almost the same level as the current levels in the following winter.

The reduction of flows from the coastal springs due to increased groundwater pumping in the coastal area will have a lasting effect throughout the year. Although spring flows will increase during the next period of high groundwater levels (in winter months), it is unlikely that flows will reach the levels simulated with current level of pumping.

The model predicts that elevated pumping will not increase the risk of seawater intrusion as heads for monitoring bores are always positive. However, fingering of the seawater interface could occur and more monitoring bores at varying depths are required to properly understand this phenomenon.

It is necessary to improve the current knowledge on land use, well information and actual water use (temporal and spatial distribution), including stock water and domestic use. Accurate information would facilitate accurate model calibration and in turn increase the reliability of the model prediction. In addition the model interface at the foothills (at north, west and south) needs be understood as the recharge into the model from the surrounding foothills, especially during the rainy periods, can be significant.

1 INTRODUCTION

The Wairau aquifer is the predominant aquifer system underlying the Wairau Plain near Blenheim. It is the source of most irrigation water for this intensively farmed area, together with the bulk of the drinking and stock water. The Marlborough District Council (MDC) Regional Policy Statement recognises the inter-connection between the Wairau aquifer and the surface water bodies in the area that include rivers, springs and wetlands. Abstraction of groundwater in the Wairau aquifer system can significantly affect flows in spring-fed surface water in a manner which adversely affects the life-supporting capacity of the water and ecosystems. Other potential issues associated with over abstraction include seawater intrusion and increased interference effects between wells.

MDC are working on a series of projects including the aquifer model, a spring ecology study, an assessment of future water demand and an inventory of current vineyard area, all designed to provide the technical basis for a council discussion document on Wairau aquifer management. The Wairau aquifer model has been developed in stages. This report outlines the latest stage of the aquifer model development in which the model has been updated for boundary conditions for the period of 2003-06, and simulates the coastal aquifers for different management scenarios.

1.1 Background

The Wairau Aquifer Model has been developed in stages since 2001. The development process has been described fully in Aqualinc (2005), this being the last (fifth) stage report. The following is a brief summary of the model development.

The model was first developed as a steady state model. The hydrogeology is characterised by four layers: the top most layer as an unconfined aquifer overlaying three confined layers. The second and bottom layers are represented as aquitards. All four aquifers are isotropic in the X and Y direction. In the second stage the model was used to investigate the sensitivity of the Wairau River and spring flows to groundwater abstractions. In the third and fourth stages the model was converted to a transient version. During the fourth stage of the model development the layer structure was modified to more accurately reflect the ground elevation and depth of each hydrogeology layer. However, the model simulation of the surface water and groundwater interaction was unrealistic.

In the fifth stage of the Wairau aquifer model development (Aqualinc, 2005), the model had been modified using the stream flow routing package (SFR1) (Prudic, Konikow et al. 2004) to improve the representation of the river channel flow in the model. The model was calibrated for head and flow data, and using qualitative information for river losses. However, the accuracy of the model for use as a predictive tool for the coastal aquifer was not sufficient.

The head calibration showed that the model failed to accurately simulate the aquifer responsiveness for different stresses.

The emphasis on the current stage of the model development is to improve the representation of the coastal aquifers. The time period of the previous model was 1 January 1988 to 1 May 2003, or 5,600 days. The time period of the current model was extended with new land use information and flow data up to year 2006, and calibrated with water level data for the extended period. However, due to the software limitation the model was run for 6,000 stress periods only (i.e. 6,000 days at daily time steps); the simulate period is 16 July 1990 to 17 December 2006.

1.2 Project Objectives

The project objectives are:

- Update the model simulation period up to year 2006, with higher spatial resolution to increase the accuracy of the model.
- Model calibration and verification.
- Run management scenarios to identify the effects due to groundwater abstractions from the deeper coastal aquifer on the shallow coastal aquifer.

1.3 Information and Data Sources

Data and information used in updating the Wairau groundwater model have been primarily supplied by MCD. This information includes land use data, river and stream flow monitoring records and water level data for monitoring bores.

Climate and rainfall data for soil water modelling was obtained from NIWA.

1.4 Overview of the Model

The upgraded Wairau groundwater model has been set up to simulate the period 16 July 1990 to 18 December 2006 using MODFLOW 2000. The software package ‘Groundwater Vistas’ (version 4) was used as a graphical user interface. The model has the following features:

- Four hydrological layers
- 6,000 recharge periods of 1 day each
- Nine hydraulic conductivity zones
- Nine storage coefficient zones
- 50 (rows) x 60 (columns) cells in each layer
- Cell size is 500 m x 500 m.

The MODFLOW packages used in the Groundwater Model to represent different parts of the system are listed in Table 1.

Table 1: MODFLOW packages used

Code	Name	Function
BAS	Basic package	Provides general information about the simulation (active/inactive cells, initial conditions, etc.).
DRN	Drain package	Allows for one-way general head boundaries that can be used to simulate drain seepage.
SFR	Stream package	Flow routing package that allows for the exchange of water between surface water and groundwater, as well as using flow routing to control mass balance in the surface water feature.
WEL	Well package	Abstraction or injection of water into the subsurface.
RCH	Recharge package	Adds water to the water table in the model. Simulates land surface drainage.
GMG	Solver package	A multigrid solver for MODFLOW 2000.
LPF	Material properties	Assigns parameters to the model domain.
DIS	Discretisation package	The spatial dimensions of the model.

The layout of the Wairau Groundwater Model is shown in Figure 1.

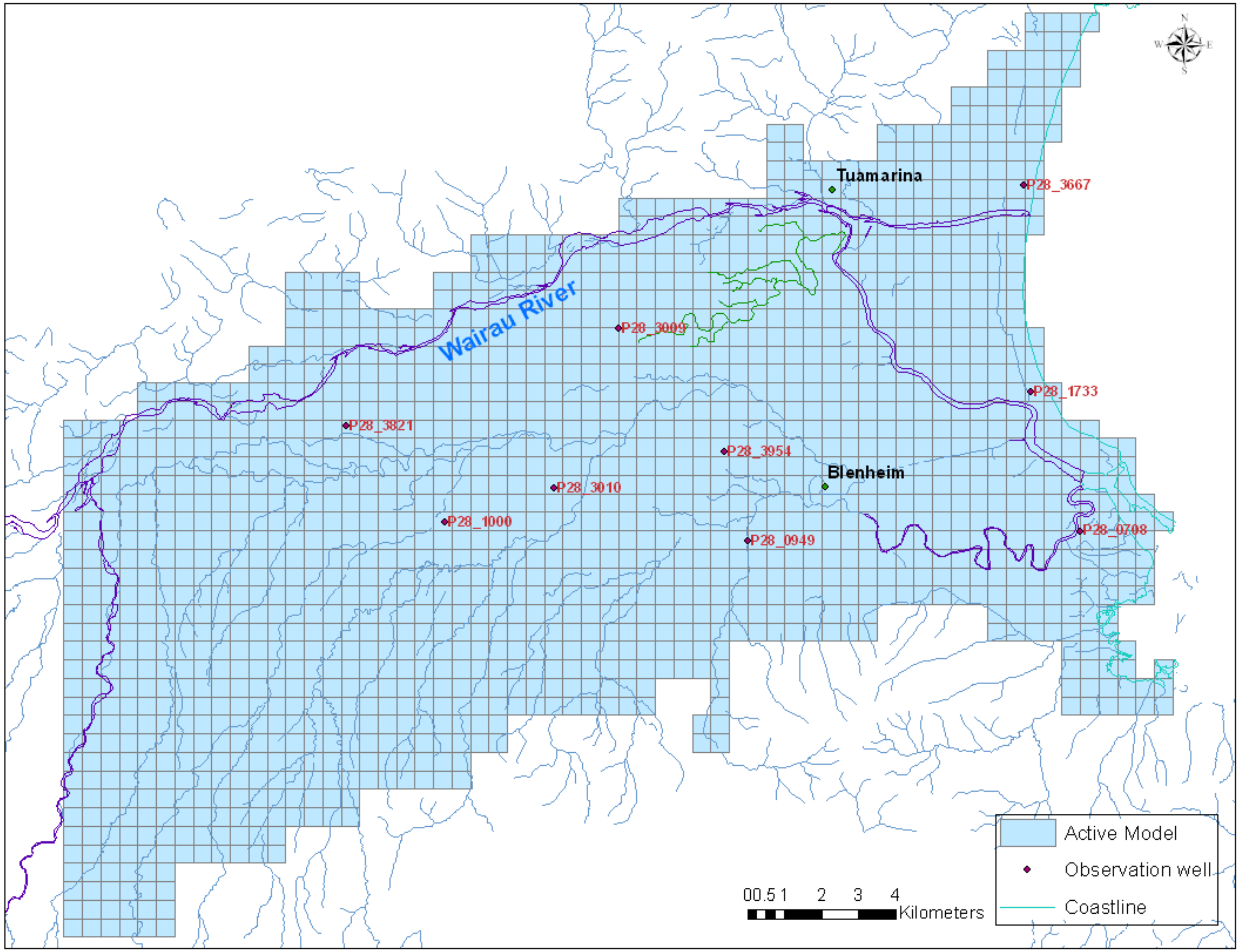


Figure 1: Model layout

2 MODEL UPDATE AND DEVELOPMENT

The main modifications made to the model in the development stage reported herein are changes of the grid size (from 1,000 m x 1,000 m and 1,000 m x 500 m) to 500 m x 500 m, and the close of the coastal boundary.

The smaller grid size increases the accuracy of representing the aquifer system and land use. In addition it enhances the accuracy of finite difference calculations in the model. The representation of land use of each model cell is important as it determines the irrigation water use and land recharge. Therefore the land use has been updated for the new time period of the model (2 May 2003 to 18 December 2006) to accurately simulate the current land use practices in each cell area.

Previous modelling indicated that the movement of water at the coast to a constant head boundary was not significant. Therefore, this model has been updated without the coastal head boundary.

2.1 Model Parameters

A description of the conceptual model can be found in the previous stage report (Aqualinc, 2005). The following overviews the zonations applied for hydraulic conductivity and storage coefficients.

2.1.1 Hydraulic Conductivity

The hydraulic conductivity parameters of the updated model for each zone is given in Table 2 and zonation for each layer is shown in Figure 2 to 4.

Table 2: Hydraulic conductivity of zones

Zone	**Horizontal hydraulic conductivity (K_X & K_Y) (m/day)**	**Vertical hydraulic conductivity (K_Z) (m/day)**
1	300	50
2	100	15
3	15	15
4	100	10
5	500	500
6	400	100
7	5,000	1,000
8	6,000	1,000
9[#]	6,000	50

[#] The ratio between horizontal and vertical hydraulic conductivities is debatable. However, lower K_Z shows an improved model calibration.

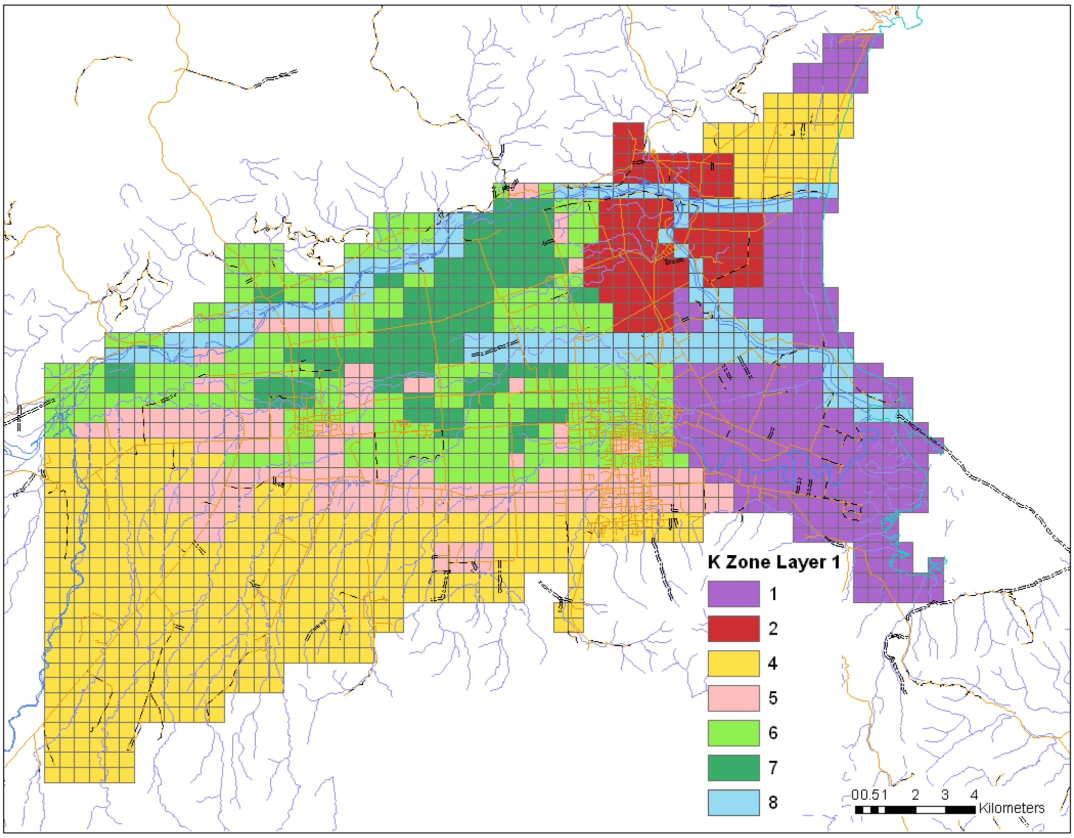


Figure 2: Hydraulic conductivity zonation for layer one, unconfined aquifer

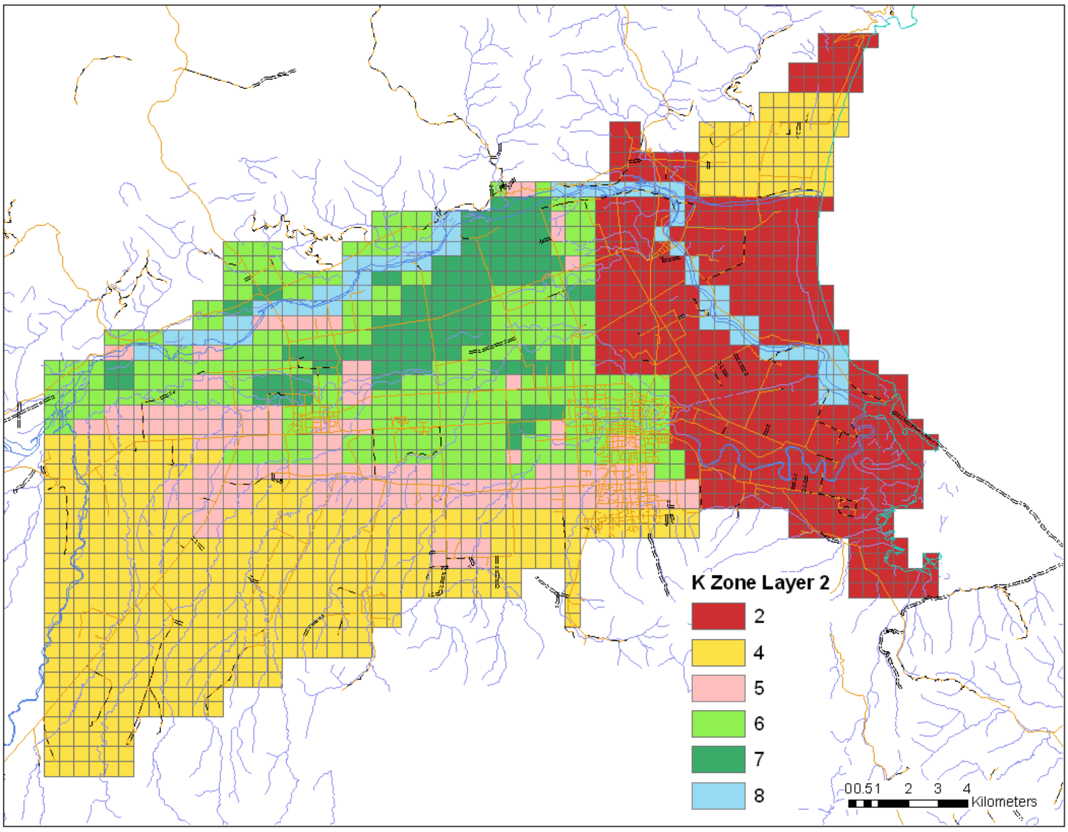


Figure 3: Hydraulic conductivity zonation for layer two, aquitard

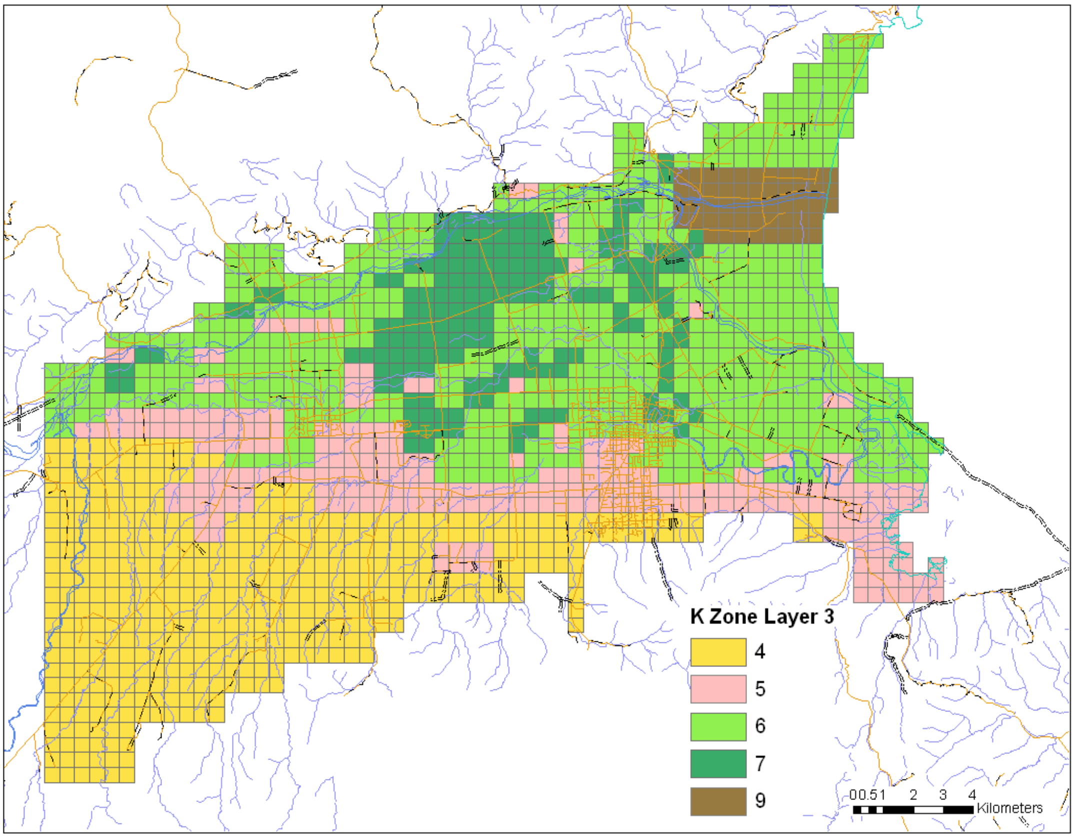


Figure 4: Hydraulic conductivity zonation for layer three, confined aquifer

2.1.2 Storage Coefficients

The storage coefficient parameters for each zone are listed in Table 3 and zonation for each layer is shown in Figure 5 - 7.

Table 3: Storage coefficients for different zones

Zone	**Specific storage (S_S) (m^{-1})**	**Specific yield (S_Y)**
1	0.001	0.2
2	0.000001	0.05
3	0.1	0.015
4	0.00001	0.05
5	0.000001	0.1
6	0.1	0.3
7	0.005	0.01
8	0.1	0.3
9	0.000001	0.3

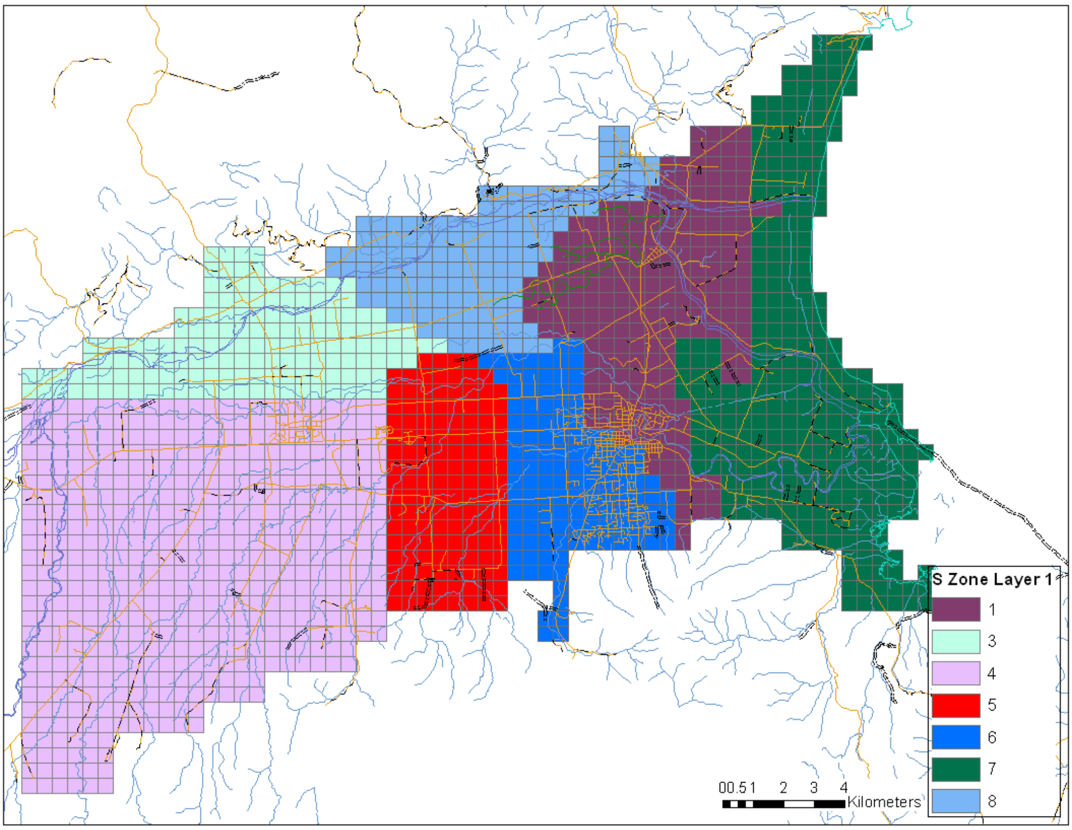


Figure 5: Storage coefficient zonation for layer one

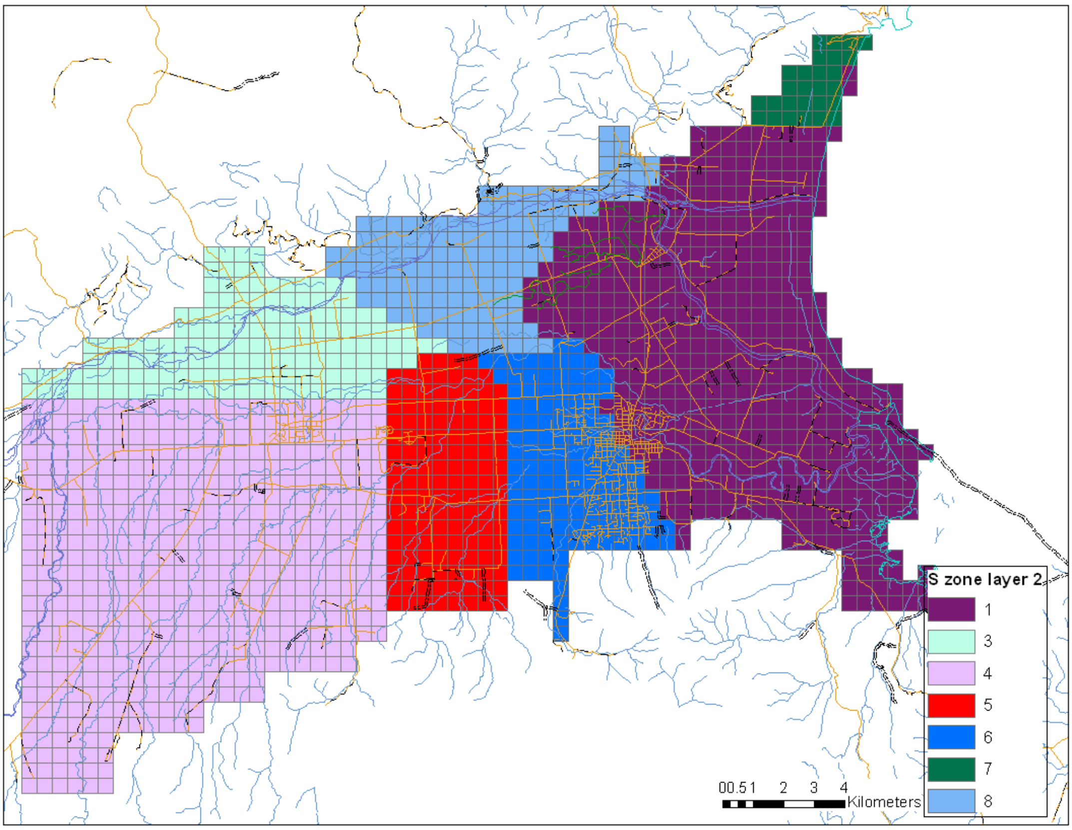


Figure 6: Storage coefficient zonation for layer two

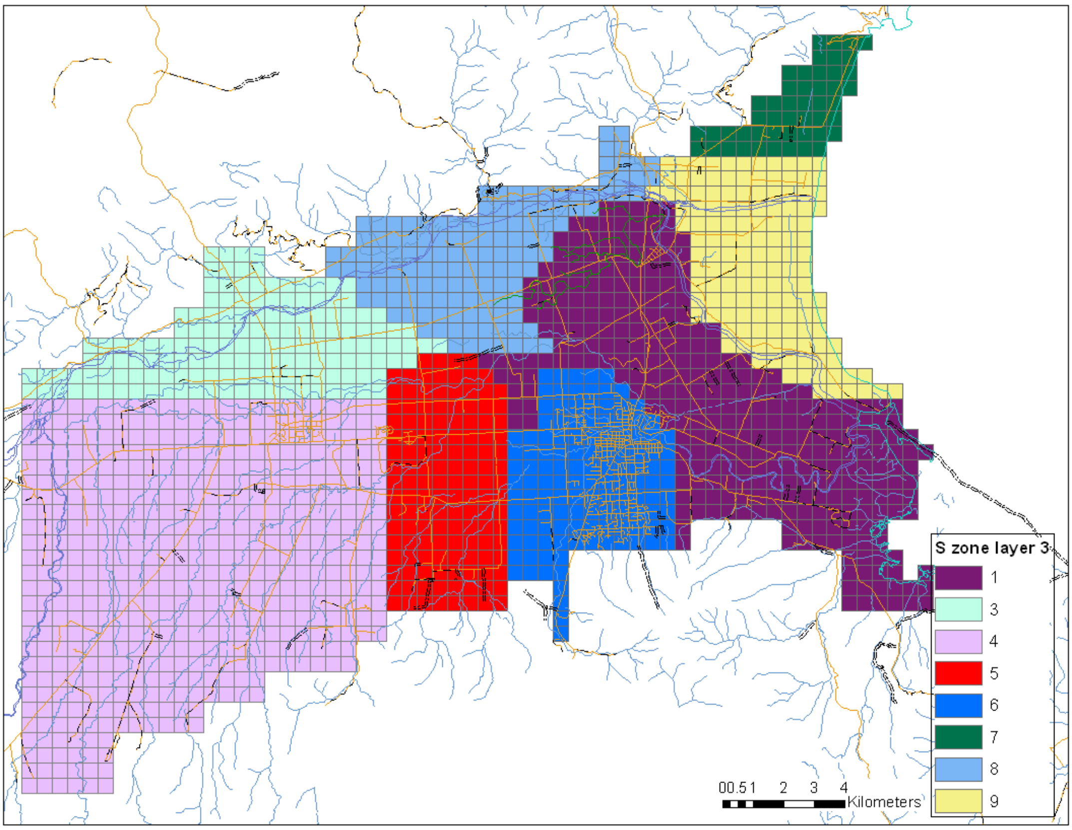


Figure 7: Storage coefficient zonation for layer three

2.2 Boundary Conditions

The boundary conditions of this updated model are similar to that of the previous stage. However, the boundary at the coast was changed from a constant head to no-flow.

The boundary conditions are:

- Streams: used for major, non spring-fed rivers
- Wells: used for municipal and agricultural abstraction
- Recharge to the groundwater from land surface drainage (details are given in Section 2.3)
- Drains: used to represent spring-fed streams and seep areas
- No-flow: used to represent the boundaries where groundwater inflow or outflow is not significant.

2.2.1 Streams

The representation of the streams in the groundwater model has been undertaken using the river flow routing package (SFR1) (Prudic, Konikow et al. 2004). The SFR1 package has been modified from previous versions of the model as the finer MODFLOW grid size meant that each river passes over more grids. Hence additional river reaches were required to simulate the same rivers.

The river system simulation using the SFR1 package in MODFLOW is shown in Figure 8, which illustrates the river segment numbers used in the SFR1.

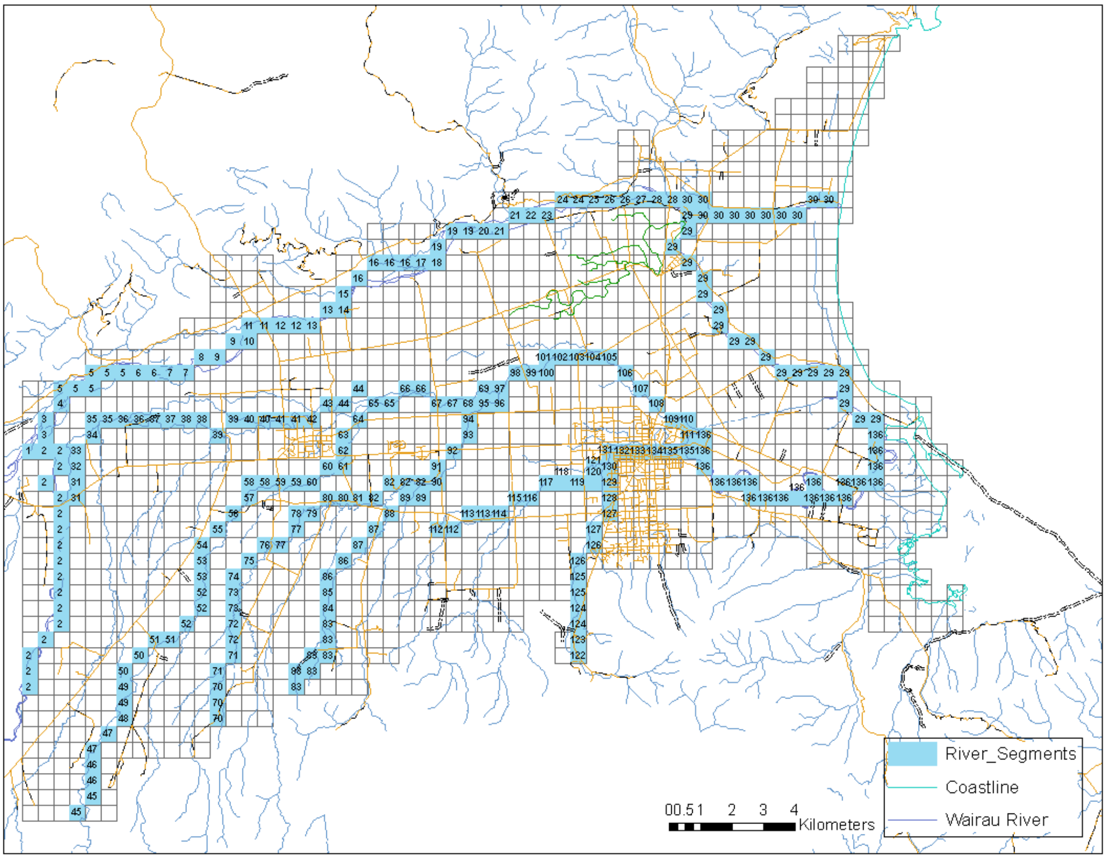


Figure 8: River and stream flow segments used in the stream flow routing (SFR1) package

2.2.2 Drains

The spring-fed streams have been implemented using the MODFLOW drain package. The location and parameters of the drains are similar to that of previous models. However, similar to the river package, additional drains were required due to the finer grid size now used. The new cell formation of the drains for the updated model grids (500 m x 500 m) is shown in Figure 9. Also show in this figure are the coastal springs and the location of Spring Creek, which have been used for calibration and evaluation for the different management scenarios.

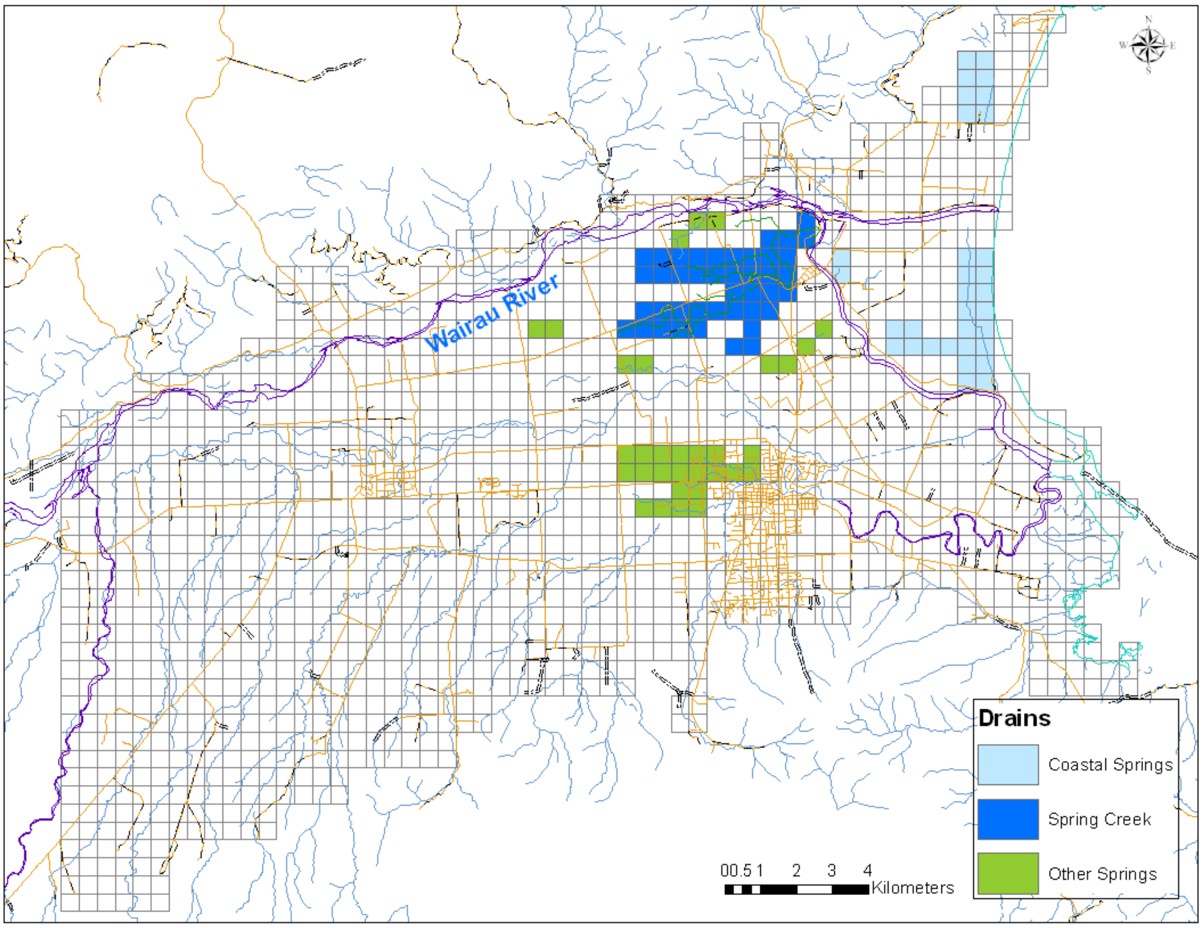


Figure 9: Drain cells implemented in the model to simulate spring-fed streams and creeks

2.2.3 Wells

There are seven municipal wells located within the model area for reticulated water supply to Blenheim, Woodbourne and Renwick. The locations of these wells are shown in Figure 10.

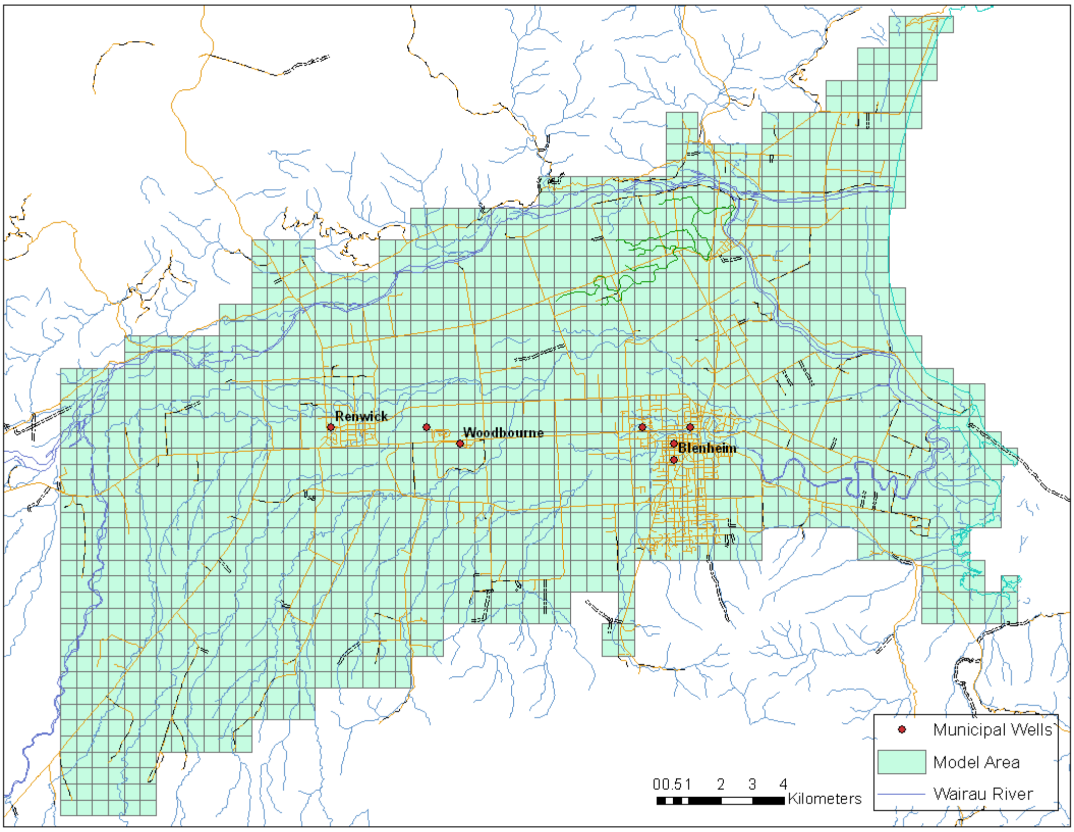


Figure 10: Location of municipal wells

The irrigation water demand has been calculated using Aqualinc's in-house soil-water balance software using rainfall and evapotranspiration data (Aqualinc, 2005). The irrigation water demand for the period prior to 2 May 2003 has been simulated in the previous stage of the model. However, the land uses have changed significantly in recent years and subsequently the water abstraction from different locations has changed. The land use since May 2003 has been distributed according to the dominant land use in any one model cell, as shown in Figure 11.

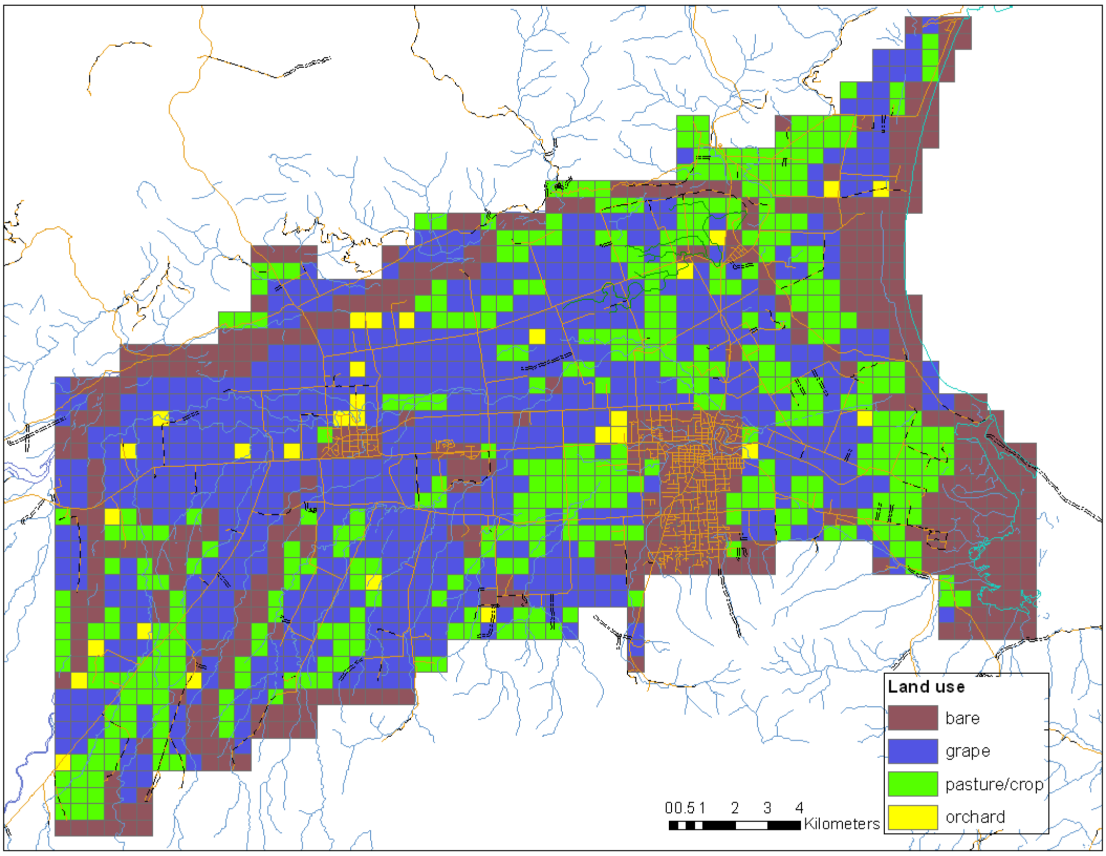


Figure 11: Dominant land use for each cell since May 2003

Although actual bore locations are known, their take rates, irrigated area and type of crops serviced by each bore are unknown. Therefore, all bores within any cell have been represented by a single bore located at centre of each cell. It is assumed that each well services that cell only and represents an amalgamation of all bores that exist within that cell.

Figure 11 shows the dominant land use for each cell. However, data is not available to accurately determine the actual irrigated area by cell. As shown in Figure 11, the land use is dominated by grapes (62%), with water demand generally stable but relatively low. MDC found that the water demand for pasture/crop (approximately 35% of the irrigated area) is more variable and a full irrigation season can be followed by reduced irrigation due to change of crop types and/or no crop to irrigate.

MDC are uncertain as to how much water is actually used because only one water permit holder measures water use in the coastal area (the current area of interest). A trial-and-error assessment was implemented to determine the approximate average percentage of agriculture land use. It was found that 50% of irrigated area by cell shows a reasonable rationalisation for the unknown spatial and temporal variation of the water use. The finer spatial grids (500 m x 500 m) used in this model assists to smooth out the error associated with this assumption.

2.2.4 No-Flow Boundary

As mentioned above it was found in the previous stage of the model development that the offshore flow of water at the coast was insignificant in terms of model accuracy.

Therefore, the model has been recalibrated by closing the coastal boundary (i.e., the coastal cells are represented as no-flow cells).

2.3 Land Use and Land Surface Recharge to Groundwater

The land surface draining to groundwater is a function of land use and its irrigation regimes. As described in Section 2.2.3, land use and recharge due to drainage over the period prior to 2 May 2003 have been simulated in the last stage of the model. Note that Groundwater Vistas calculates the recharge for new cell format (500 m x 500 m) during the update of model grids. The land use for the period since 2 May 2003 has been simulated for the new model grid formation with current information obtained from MDC.

The geographical distribution of the land use for the period of 2 May 2003 to 18 December 2006 is shown in Figure 11.

The land surface drainage is simulated using a water balance model as described in Section 2.2.3. The soil types and their parameter for the model area have been listed in the previous model development report (Aqualinc, 2005). The climate time series required for the simulation has been obtained from NIWA for the Blenheim Airport climate station.

The land surface drainage for the bare cells was simulated using non-irrigation scenario. However, only 90% of the water balance model recharge was used for model cells within the city area to account for paved areas that increase the run-off into the storm water system and reduce the groundwater recharge.

3 MODEL CALIBRATION AND VERIFICATION

The process of model calibration and verification is required to increase the predictive capabilities of the model. The process implemented in the calibration and verification is shown in Figure 12.

The updated model was calibrated for head observation data, and flow data for the Wairau River and Spring Creek. As more observation data are available for the second half of the simulated period, i.e., 2 October 1998 to 18 December 2006 (for 3,001 to 6,000 days), the groundwater model has been manually calibrated for that period. This period covers wet and dry years (as shown in Figure 13) because it is important to calibrate the model for different states of the system. The calibrated model was then verified using the observation well water level data, and the measured flow data for the Wairau River and Spring Creek for the first half of the simulated time period (first 3,000 days).

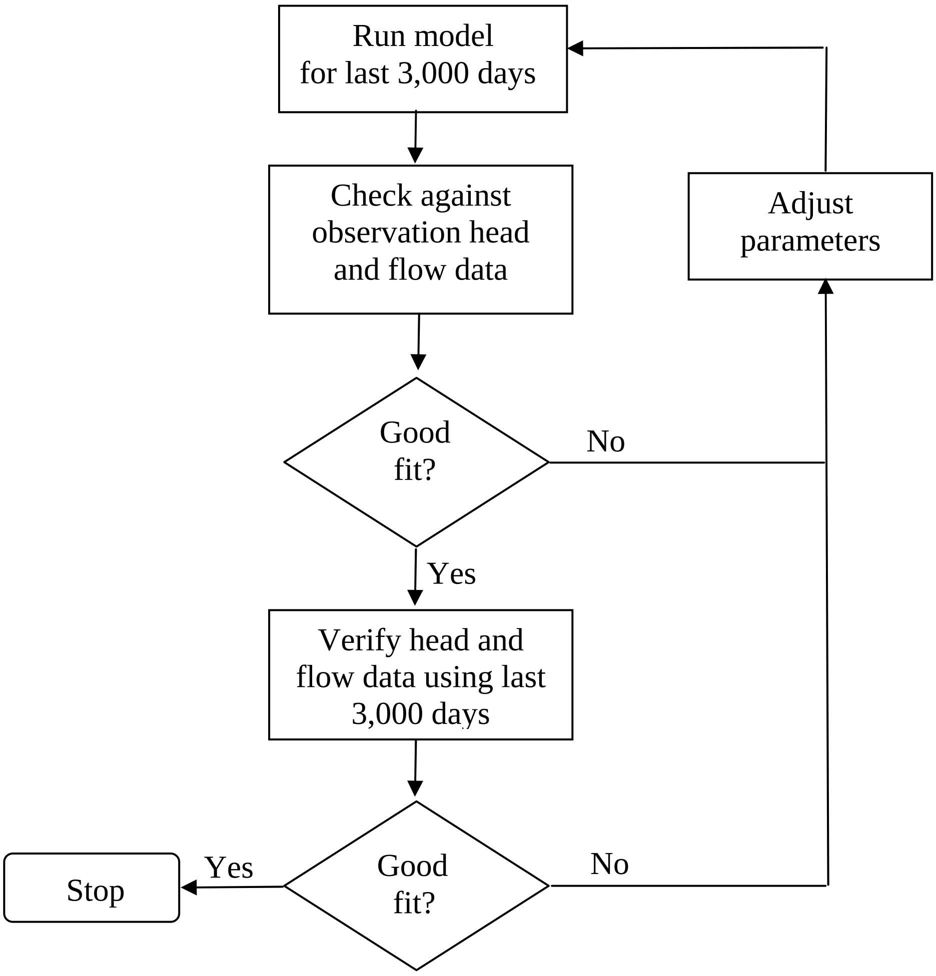


Figure 12: Flow chart illustrating model calibration and verification process

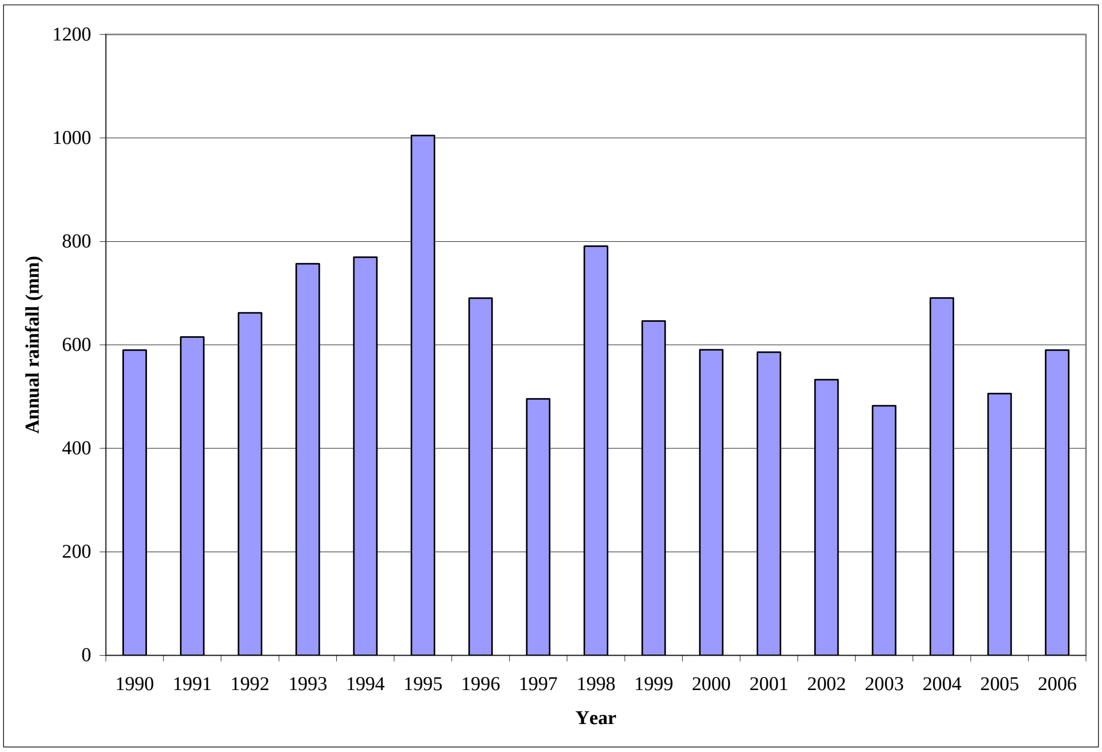


Figure 13: Annual rainfall chart

The observation well data used for calibration and verification is summarised in Table 4. The locations of observation wells and Wairau River are shown in Figure 1, and the Spring Creek is shown in Figure 9.

Table 4: summary of observation well data used in the calibration and verification

Data	Description
P28_0949	Head observation
P28_1000	Head observation
P28_1733	Head observation
P28_0708	Head observation
P28_3009	Head observation
P28_3010	Head observation
P28_3667	Head observation
P28_3954	Head observation
P28_3821	Head observation
Wairau River	River flow
Spring Creek	Spring flow

As the main objective for this stage of the model development is to increase the accuracy of the model simulation in the coastal region, the calibration is mainly focused on head observations in this area.

3.1 Calibration

Calibration has been primarily implemented by changing hydraulic conductivity and storage parameters for different zones in the model until the modelled groundwater levels satisfactorily match measured in the observation wells. In addition, the parameter zonations were adjusted to improve the calibration. However, the main modification includes an introduction of new hydraulic conductivity and storage zones around observation well P28_3667. The calibrated model parameters are shown in Table 2 and Table 3.

The statistical measures (mean residual and standard deviation of mean residual) between target and simulated heads were evaluated. In addition, the dynamics of the target head observations have been visually assessed to determine whether the model suitably captures reality. River and stream flows were then used to gauge the model's ability to simulate these features, and the statistical measures of the flow data were assessed to verify the calibration. Note that MODFLOW 2000 and PEST cannot be used to implement sensitivity analysis while using the SFR1 package.

The hydrographs comparing observed and simulated groundwater levels in coastal observation wells are shown in Figure 14 – Figure 16. Similar plots for other calibration wells are provided in Appendix A. A descriptive summary of these hydrographs is given in Table 5.

A total of 24,290 groundwater level targets were used in the calibration. The mean residual error for heads was 0.20 m with a standard error of 0.04 (4%). Table 6 shows the statistical analysis for the target head observations. The residual head (observed – simulated) has been assessed.

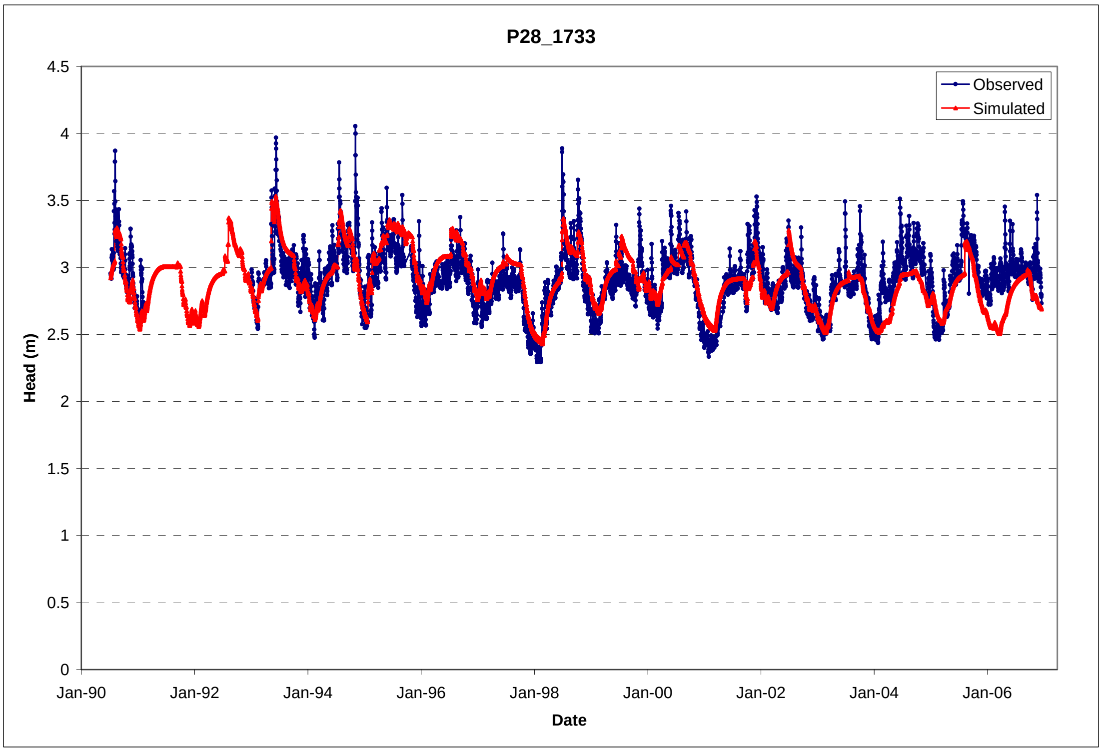


Figure 14: Hydrograph comparing observed and simulated groundwater levels for P28_1733

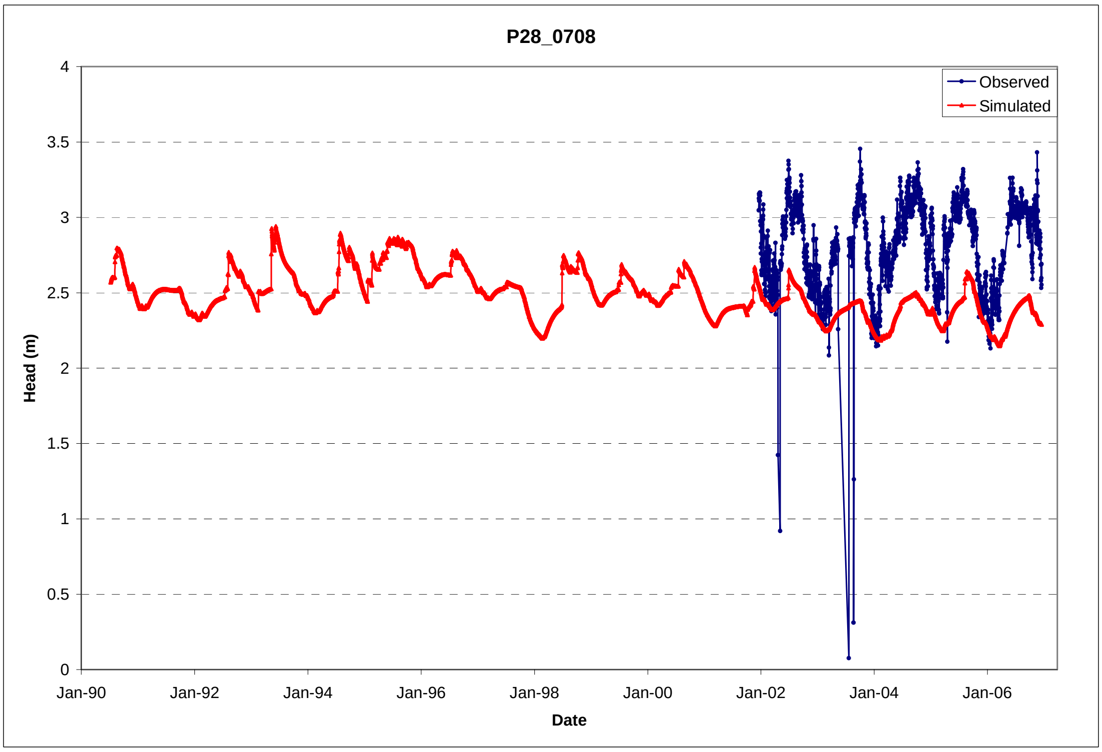


Figure 15: Hydrograph comparing observed and simulated groundwater levels for P28_0708

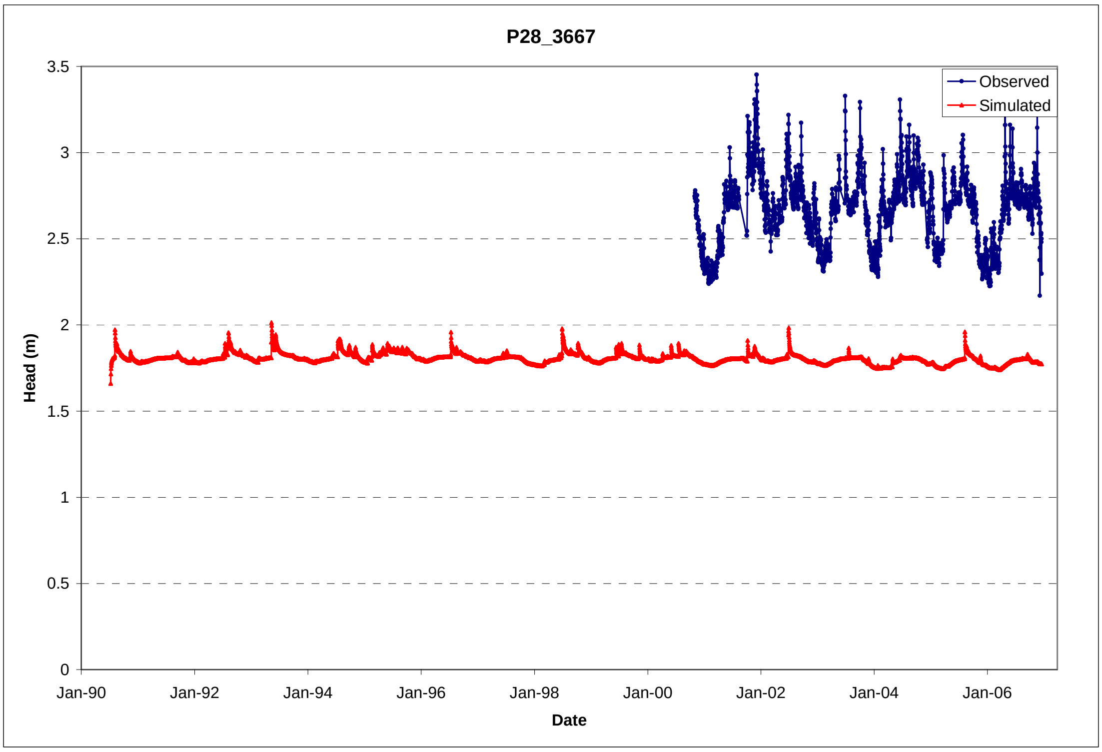


Figure 16: Hydrograph comparing observed and simulated groundwater levels for P28_3667

Table 5: Analysis of head calibration

Observation well	Analysis of calibration results
P28_1733	The simulation has captured the heads and the seasonal dynamics - this is a significant improvement from the last stage model
P28_0708	The simulated head is approximately 0.5 m lower. The highly dynamic groundwater system is not simulated (probably due to localised pumping interference of the observation well); however, the general trend of the head change is captured. - reasonable improvement compared to last stage
P28_3667	The head is simulated consistently too low. The aquifer dynamics are not adequately simulated. - the hydrograph shows the calibration has improved the head level and dynamics of the aquifer from the previous stage. - the difficulties associated with simulation of coastal aquifers and valleys near mountains are discussed in Section 3.3
P28_0949	The simulated level is too high. Although the trend of water level changes has been captured, the rapid change in head is not simulated accurately
P28_1000	The simulated levels are too low, and the aquifer dynamics are underestimated
P28_3009	The aquifer dynamics are simulated accurately, but simulated levels are too high
P28_3010	The simulated mean head levels are accurate whilst aquifer dynamics are underestimated
P28_3954	The simulated levels are too high, and the aquifer dynamics are underestimated
P28_3821	The simulated mean head levels are accurate. Aquifer dynamics are a little underestimated, though the the general trends are correct

3.2 Verification

The verification of the parameters of the calibration has been conducted using an independent dataset. The verification dataset is for the period of 16 July 1990 to 1 October 1998. The calibration and verification statistics are given in Table 6.

A total number of 14,511 head observations have been used for the verification. The mean residual error is 0.35 m with the standard error of 0.05 (5%).

Table 6: Calibration and verification statistics

Observation well	**Mean residual (m)**			**Standard deviation of residual (m)**		
	Stage 5	**Calibration**	**Verification**	**Stage 5**	**Calibration**	**Verification**
P28_0708	0.64	0.42		0.25	0.25	
P28_0949	-0.71	-0.27	-0.98	0.81	0.39	0.52
P28_1000	3.51	3.31	3.72	2.59	2.53	2.21
P28_1733	0.61	0.04	-0.04	0.20	0.16	0.15
P28_3009	-1.22	-1.34	-1.33	0.26	0.22	0.28
P28_3010	-0.17	-0.01	-0.26	1.32	1.32	1.06
P28_3667	1.33	0.88		0.21	0.19	
P28_3821	-0.22	-0.01	-0.36	0.69	0.53	0.63
P28_3954	-0.82	-1.05	-0.78	0.33	0.35	0.38

As mentioned above, the simulated Wairau River and Spring Creek flow data were compared with the observed data. However, river bed conductance was not calibrated in this stage as it had been calibrated in the last stage of the model development.

Figure 17 shows the hydrograph of the simulated and observed daily flow data for the Wairau River at the Tuamarina (Figure 1). For clarity, the high flows (maximum flow is approximately 2,500 m^3/s) are not shown. Figure 17 shows that the model has accurately simulated the flow volumes and dynamics of the Wairau River flow. Figure 18 shows the cumulative flow for the Wairau River. The model has underestimated the flow by approximately 9%, which can be expected as the model does not simulate the direct runoff due to high intensity rainfall events or discharges from the springs, drains or ditches.

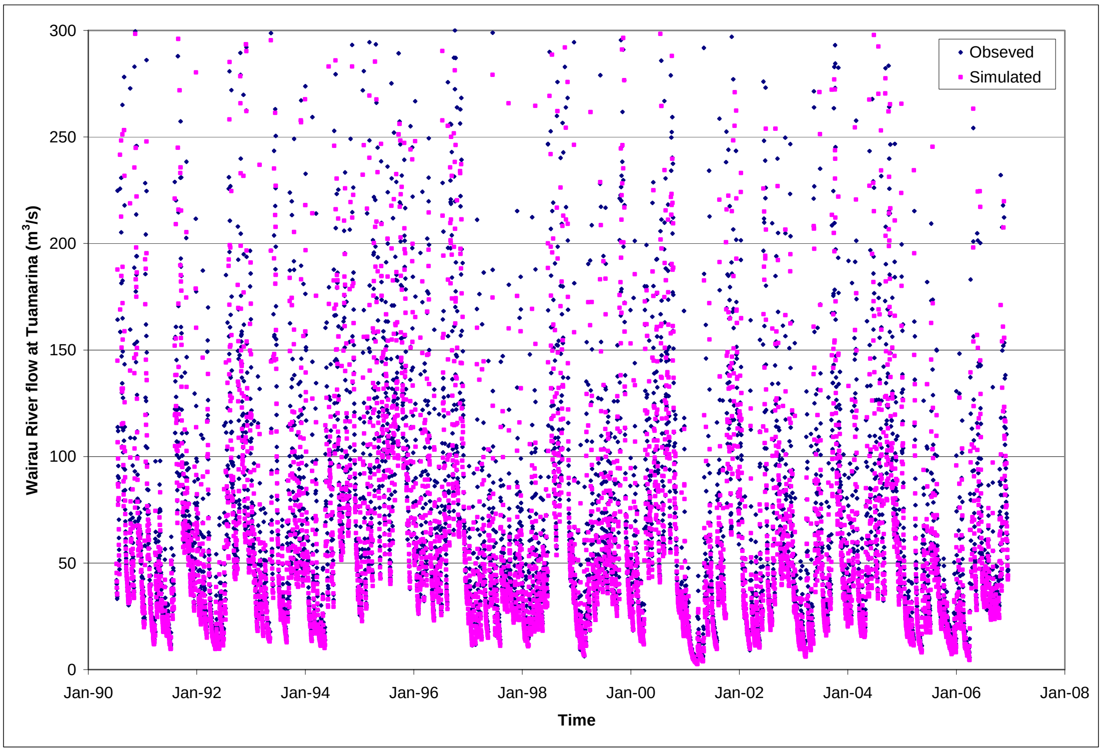


Figure 17: Hydrograph for the simulated and observed daily flow for the Wairau River at Tuamarina

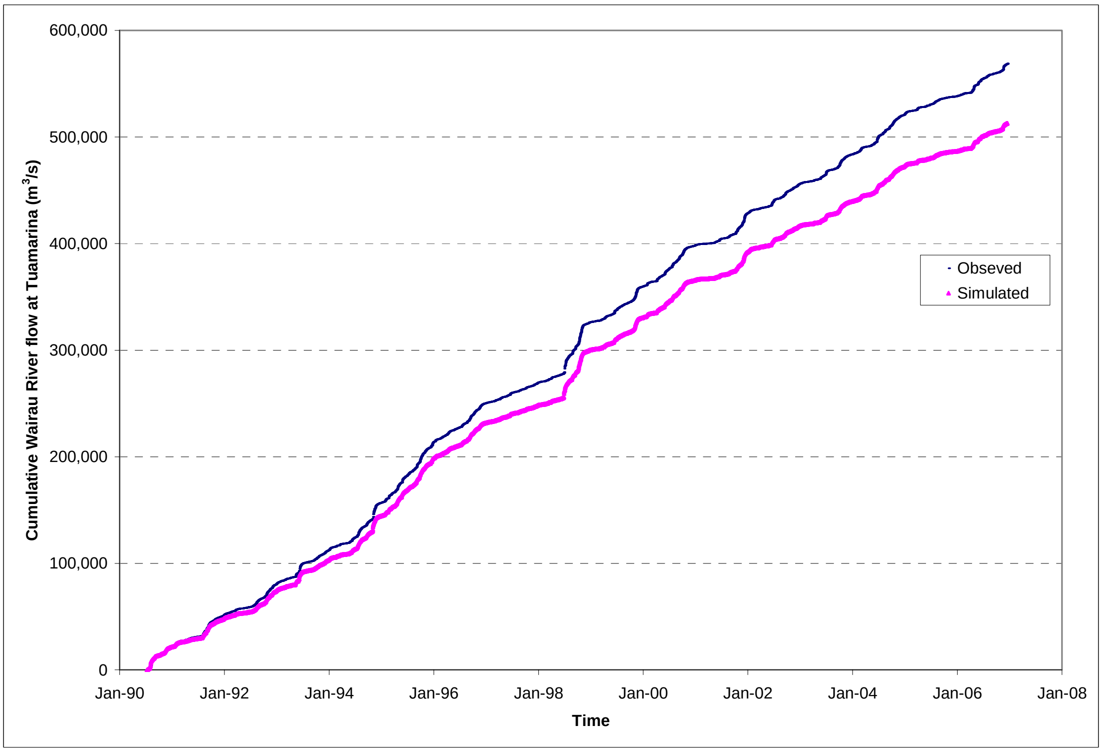


Figure 18: Cumulative hydrograph for the simulated and observed daily flow for the Wairau River at Tuamarina

The observed and simulated Spring Creek flows are shown in Figure 19. The Spring Creek has a limited number of gauging data. The model has captured the general pattern of the hydrograph. However, the high flows are underestimated. As described above, the model does not simulate direct surface water runoff and as such underestimation of flow is expected. Note that the interest of this model development stage is to accurately simulate the groundwater system during the low flow periods and the model simulates the low flows reasonably well.

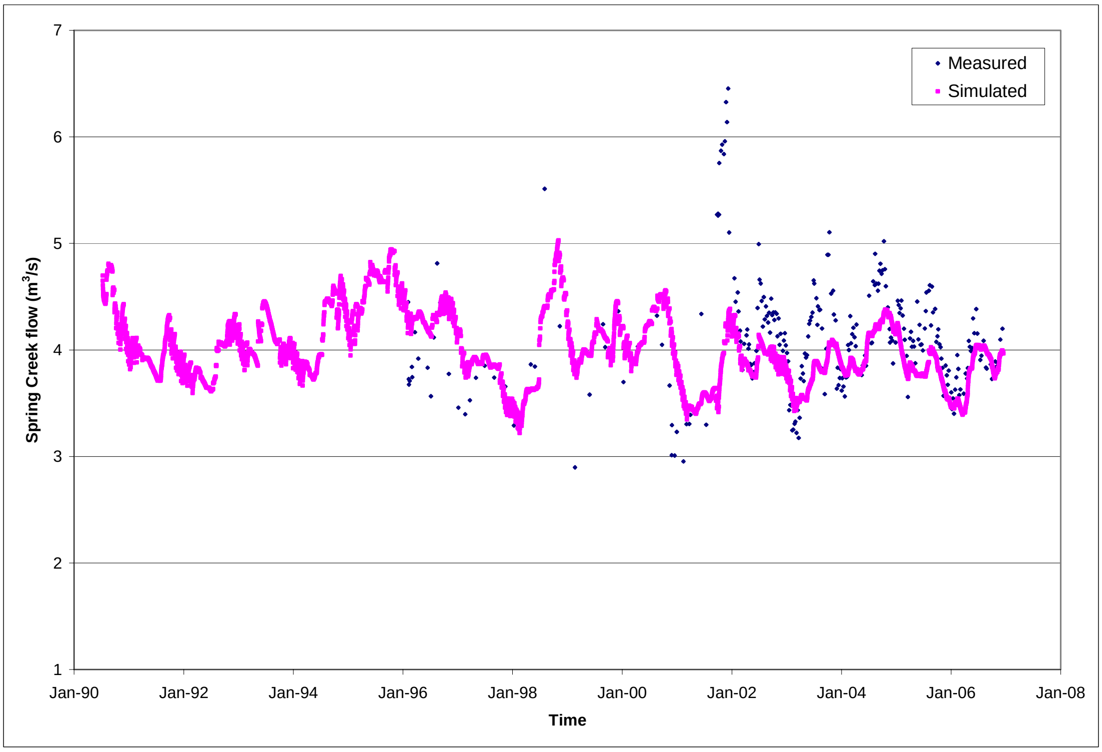


Figure 19: Hydrograph for the simulated and observed daily flow for the Spring Creek

3.3 Discussion

The updated Wairau Groundwater Model has been calibrated and verified against head and flow observations. The calibration statistics show an improvement for the prediction of groundwater levels in the coastal area, where the main interest is in this stage of model development. As indicated by Table 5, the accuracy of the simulation may not be acceptable for the middle area of the model where P28_1000 and P28_3009 are located.

The hydrographs of the simulated and observed groundwater levels in the coastal area show that the model fails to perform at a similar accuracy at all locations. Whilst the model simulation of the P28_1733 is highly accurate, that for P28_3667 is much less accurate.

The low accuracy at some parts of the coastal aquifer may be due to the following:

- The last stage of the model analysis showed that the discharge to the sea from the model is insignificant in terms of model accuracy. Therefore, the coastal boundary of the model has been set as no-flow. As a general observation, groundwater models generally fail to accurately simulate reality close to no-flow boundaries.

- The discretisation of the model grid also influences accuracy. As shown in Figure 1, the active model area covers only the Wairau Valley. The interface between the valley and the surrounding foothills are no-flow boundaries and consequently no subsurface recharge from the foothills is included in the model. However, it is likely that this recharge is significant over some seasons. Figure 20 shows the simulated head contours and illustrates that groundwater flow directions are generally towards the coast. This is a true representation for observation well P28_1733. However, the coastline is curved outwards around the centre of the valley, i.e. around P28_1733. As the effect of the recharge from the foothills is insignificant for the centre of the valley, the model accurately simulates the groundwater system around P28_1733. As P28_3667 is located closer to north foothill and curved section in the coast the model fails to accurately simulate the reality. This issue can be mitigated by simulating the subsurface recharge from the foothills, which is beyond the scope of this work.

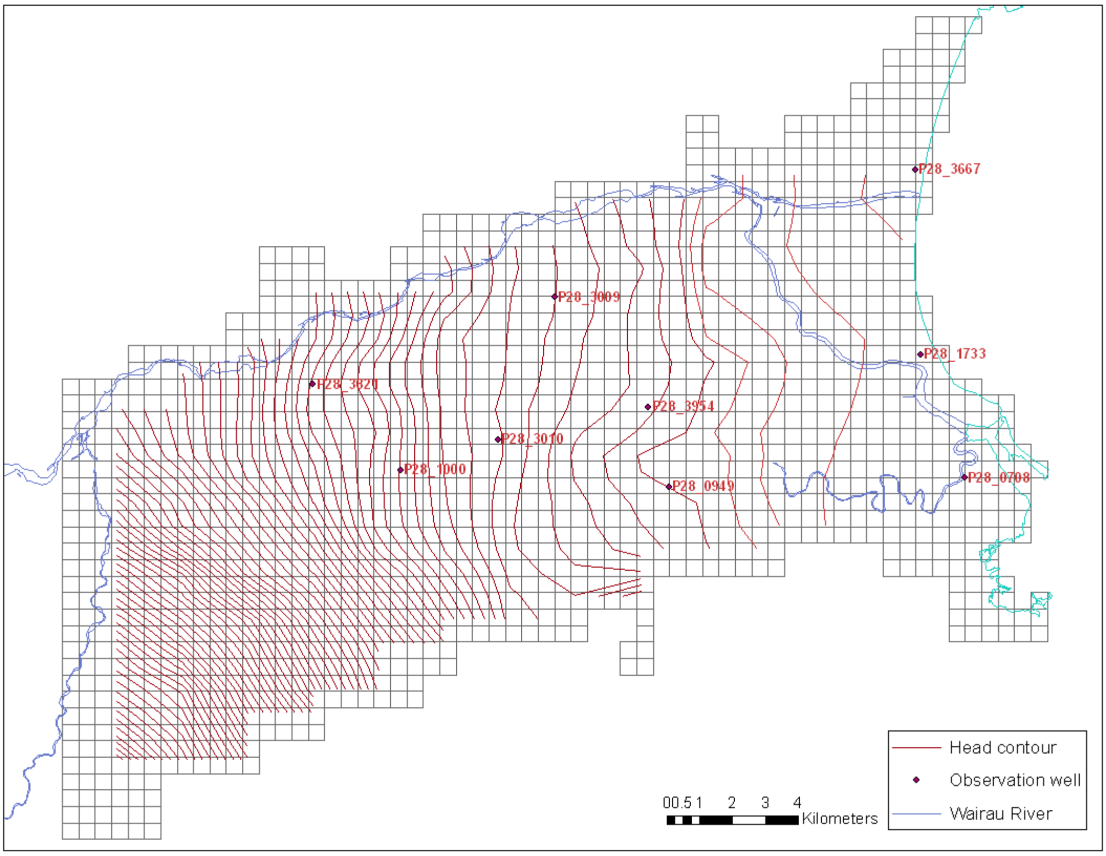


Figure 20: Simulated head contours

- The updated model consists of 3,000 cells (50 rows x 60 columns) and 6,000 stress periods at daily time steps. Calibration and verification were carried out with 3,000 stress periods at a time. The size of the model (especially the temporal dimension) limits the calibration options that can be implemented within the project time frame. The use of external SFR1 package also limits the calibration options that are available within Groundwater Vistas.

4 MODEL SIMULATION OF MANAGEMENT SCENARIOS

The calibrated model has been run for different management scenarios to identify the local effects due to groundwater abstractions from the coastal aquifer. In addition, the effects on the coastal aquifer due to increased pumping over the entire model area have also been assessed.

The most likely scenario that would affect the groundwater system around the coastal area is changes in groundwater abstraction within the coastal area itself (Figure 21). Groundwater abstraction may increase due to intensified irrigation, increases in irrigated area, climate change (e.g. droughts) and change of crops (to higher demand crops). As it is difficult to predict the actual change, the scenarios were run for five different pumping factors (percentage change in pumping) based on current land use practice (i.e. post 2003). The pumping factors used in the scenarios are 0.8 (80% of current take), 1.2, 1.5, 2.0 and 3.0. Each scenario was compared with the base line scenario (pumping factor 1).

The effect on coastal aquifers due to high abstractions over the entire model is also considered. A pumping factor of 2.0 was used in this scenario.

The analysis of management scenarios can be carried out based on certain decision variables. However, there are no past experiences to establish the environment bottom lines. The area of concern is the coastal aquifer where one of the decision variables is to manage saltwater intrusion (a certain salt water concentration level in water at the coastal bores relates to specific degree of water level reduction). However, the last stage of the model development showed that change in offshore discharge at the coast was negligible for different pumping factors.

Another limiting factor on continuing abstraction from the Wairau aquifer is depletion of the series of springs that are highly prized by the local community for their aesthetic and intrinsic qualities. Therefore, the most logical option is to assess the flux into the wetlands in the coastal area to identify the change in flows due to different levels of groundwater abstraction. The MDC recognise the potential for over-abstraction from the aquifer to lower groundwater levels and such abstractions in turn cause spring flows to recede. A management strategy involving minimum spring flows or a cap on actual water use may be needed at some stage if the Council is to continue allocating with confidence. The different management scenarios run show the level of spring depletions that will help to determine the acceptable abstraction limits.

As described in Section 3.3, the head observation calibration for well P28_3667 is not satisfactory. Therefore, the following analysis is based on the other two coastal observation wells only (P28_1733 and P28_0708), and the water levels near the coastal springs. In addition change of flows to Spring Creek is also assessed.

Figure 21 illustrates the predominant groundwater bores in the coastal area (as identified by MDC) and shows all of the consented groundwater takes within the model area. The area of interest, the coastal area, is also shown in Figure 21 which approximately comprises the area east of SH1.

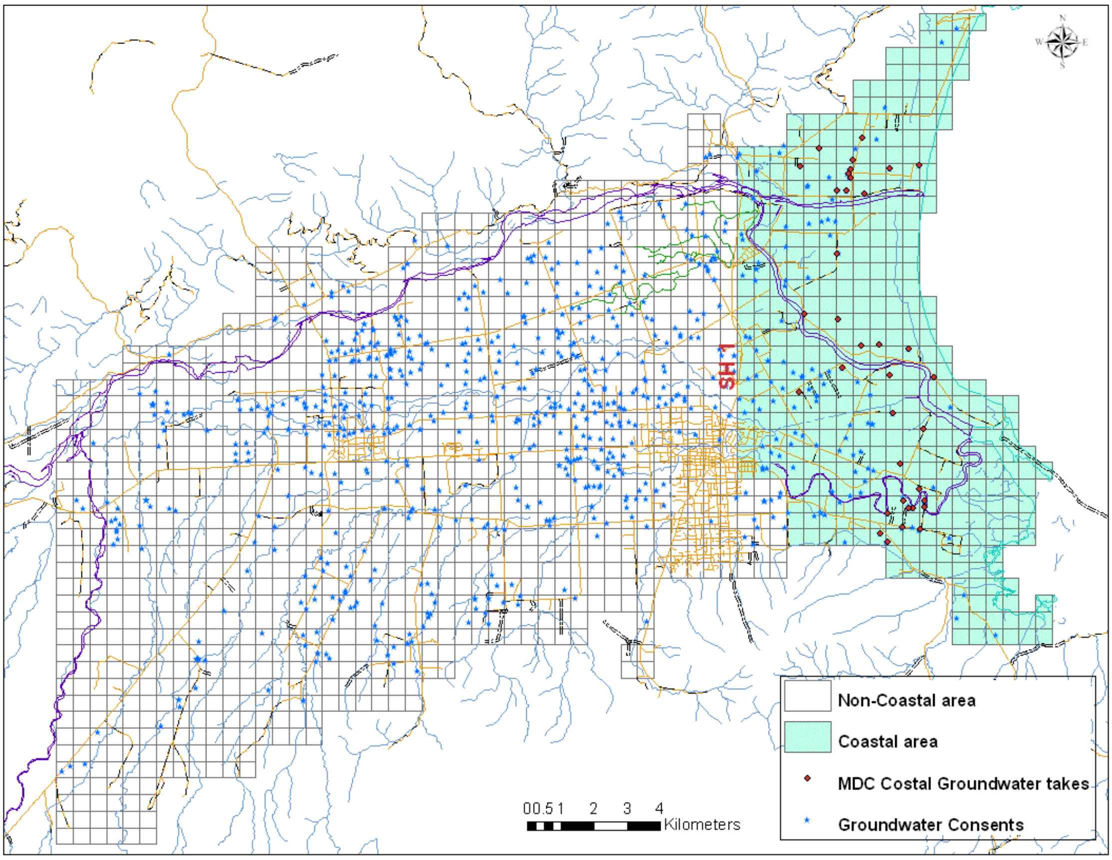


Figure 21: The coastal zones and groundwater bores

4.1 Increased Pumping in Coastal Area

Figure 22 and Figure 23 show the simulated head for the monitoring bores P28_1733 and P28_0708, respectively, due to different agriculture pumping factors from the coastal aquifers. The effects at bore P28_1733 for a pumping factor of 1.2 (20% increase) are not significant. However, increased pumping factors show higher groundwater level change effects in the summer months where irrigation is prominent. The doubled irrigation volumes in the coastal area can decrease groundwater levels by approximately 0.5 m during a high demand season. The hydrograph of the P28_0708 (Figure 23) has a similar effect to P28_1733 for different pumping factors.

As shown in Figure 1, both monitoring bores P28_1733 and P28_0708 are located closer to the coastline. However, the simulated hydrographs illustrate a positive head even for a pumping factor of 3 (300% increase). That shows that deeper groundwater aquifers will have higher (positive) head than the sea. Therefore, the potential risk of saltwater intrusion into the deeper coastal aquifer at these two monitoring bores is minimal. However, the seawater and fresh water interface is generally not sharpe and fingering effects can occur; therefore, more monitoring wells may be needed to identify saltwater intrusion phenomenon.

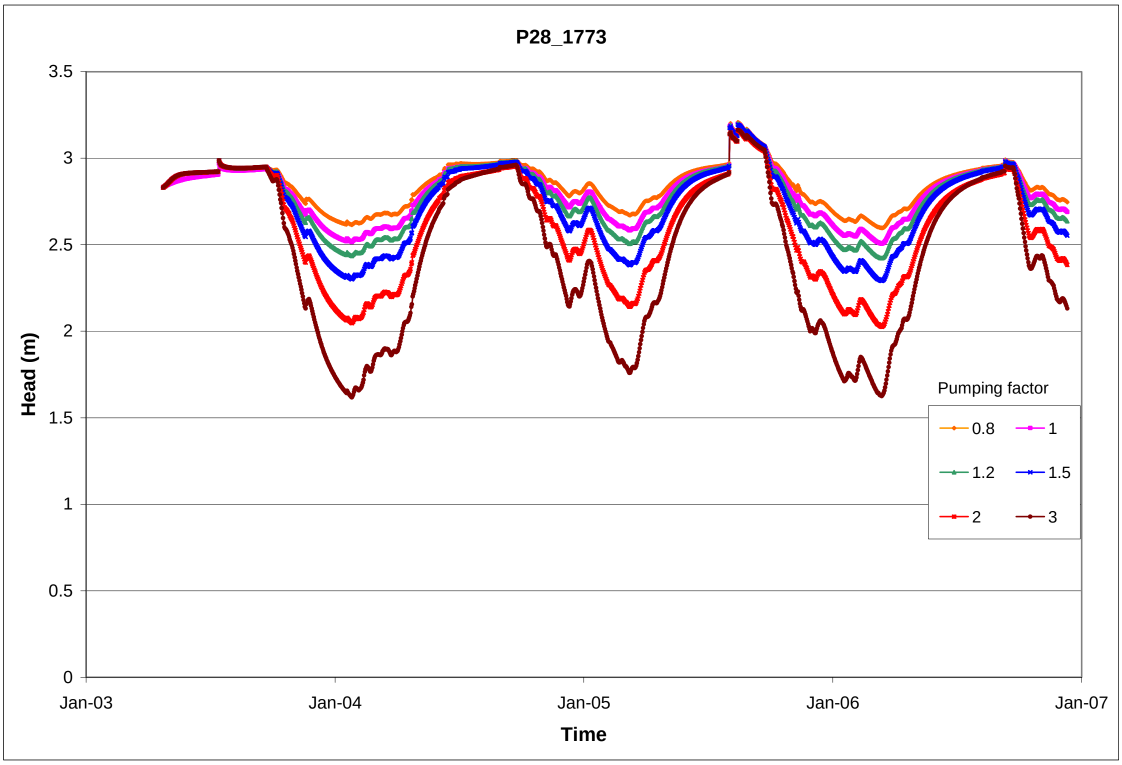


Figure 22: Simulated head change effect at monitoring bore P28_ 1733 for different agriculture pumping factors from the coastal aquifer

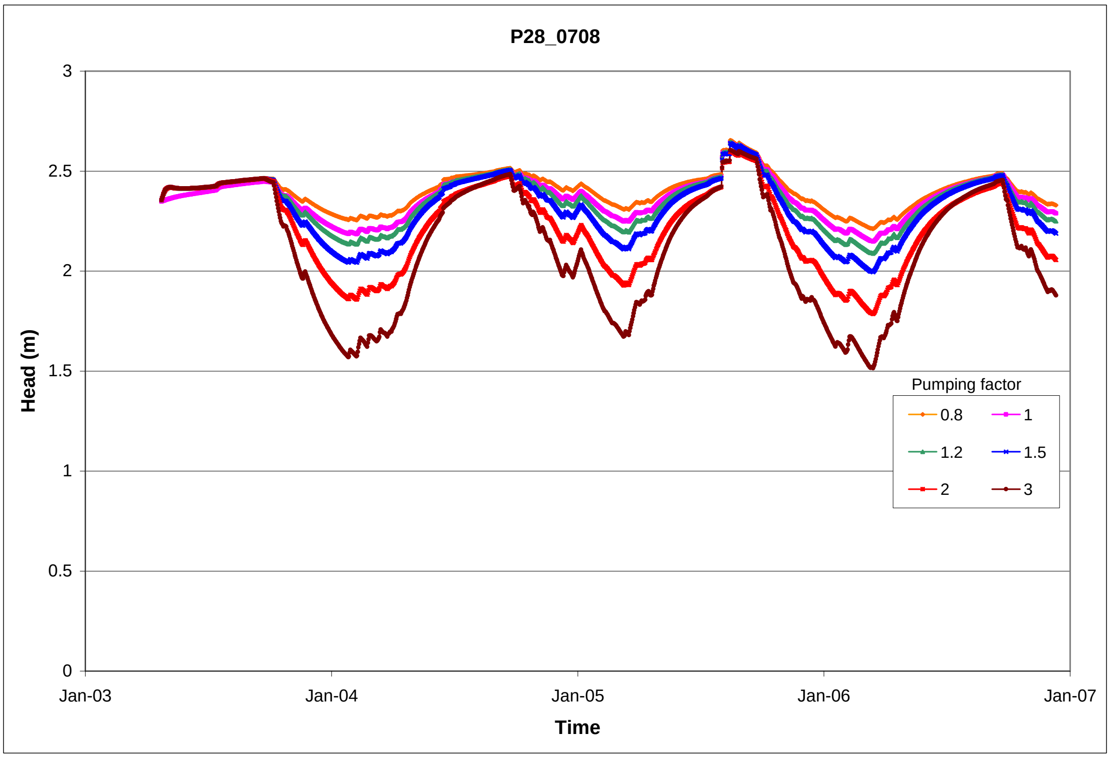


Figure 23: Simulated head change effect at monitoring bore P28_ 0708 for different agriculture pumping factors from the coastal aquifer

The simulated change in spring flows for the Coastal Springs and for Spring Creek is shown in Figure 24 and Figure 25, respectively. The location of these springs is provided in Figure 9. The coastal springs are located within the coastal aquifer area and hence groundwater abstractions from the coastal aquifer induce an obvious reduction in flows from these springs. A 200% increase in pumping is predicted to reduce the spring flows by up to 30 l/s during the summer months. A 300% increase in pumping is predicted to temporarily reduce the spring flows to zero during the peak of the irrigation seasons. Note that there is abnormal behaviour of the hydrograph immediately after the irrigation pumping was stopped; this was prominent in year 2005. This is attributed to model numerical behaviour rather than a predicted effect.

Figure 25 shows the flow depletion in Spring Creek (located west of the coastal aquifer, Figure 9). The distance from the coastal aquifer to Spring Creek is larger than the distance from the coastal aquifer to the coastal springs. Therefore, it is expected that effect of coastal pumping on the Spring Creek to be less than that on the coastal springs. However, Figure 25 shows that effect in terms of flow rate is higher on the Spring Creek. This may have resulted in larger flow rates of the Spring Creek, which is approximately 100 times larger than the flow rates of the coastal springs. However, as the distance between the abstraction area and the Spring Creek is higher than that to the coastal springs, the percentage of depletion on the Spring Creek is comparatively less with increased coastal pumping compared to the coastal springs.

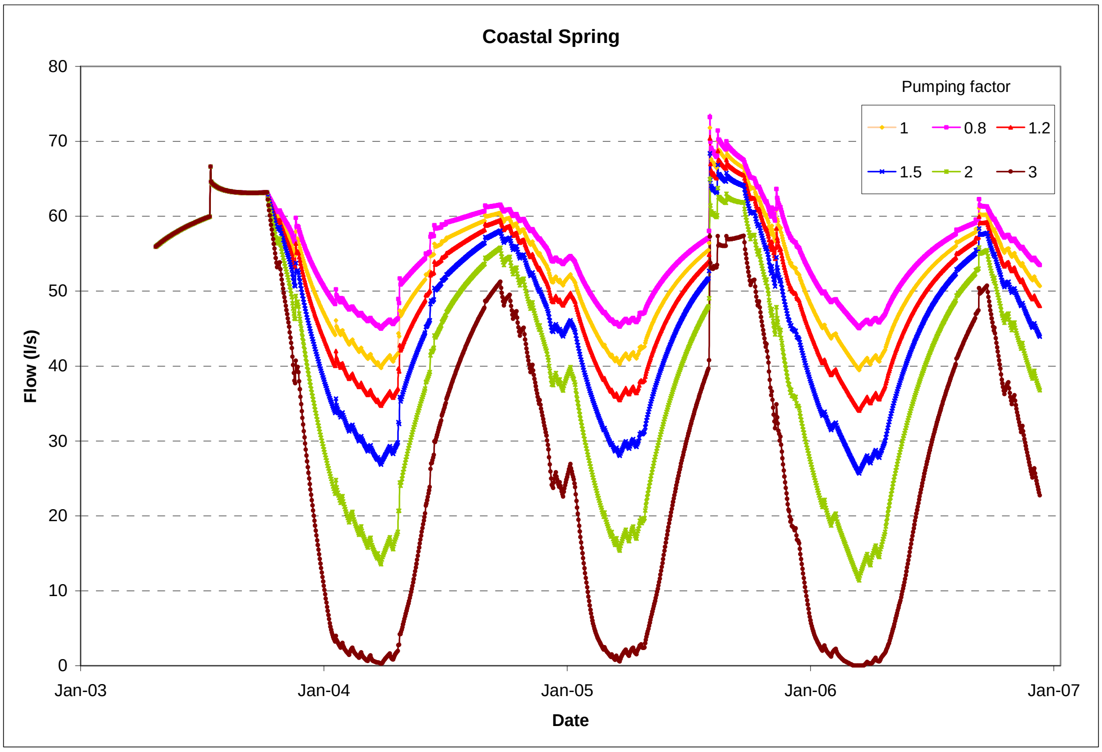


Figure 24: Simulated stream depletion effects for the coastal springs due to different agriculture pumping scenarios from the coastal aquifer

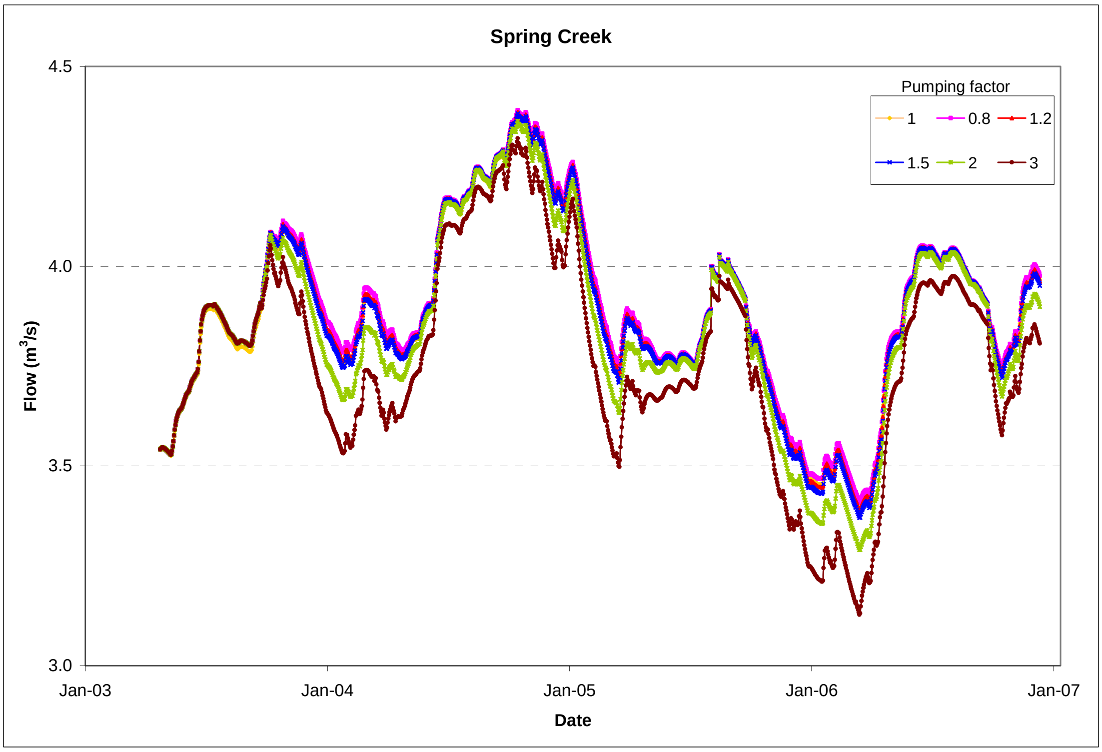


Figure 25: Simulated stream depletion effects for Spring Creek due to different agriculture pumping scenarios from the coastal aquifer

4.2 Increased Pumping Over Entire Model Area

This section shows the effects on the coastal aquifer and its hydraulically connected springs from an increase in groundwater pumping over the entire model area. This scenario has been compared with the baseline scenario and with the case of a pumping factor of 2 from the coastal area. Figure 26 and Figure 27 show the simulated groundwater level differences in monitoring bores P28_1733 and P28_0708, respectively. Groundwater levels have decreased further with increased pumping from the larger area, but differences are only prominent in the middle of the irrigation season. Once pumping ceases, groundwater levels typically return to their less developed state. There is no long-term permanent decline in groundwater levels.

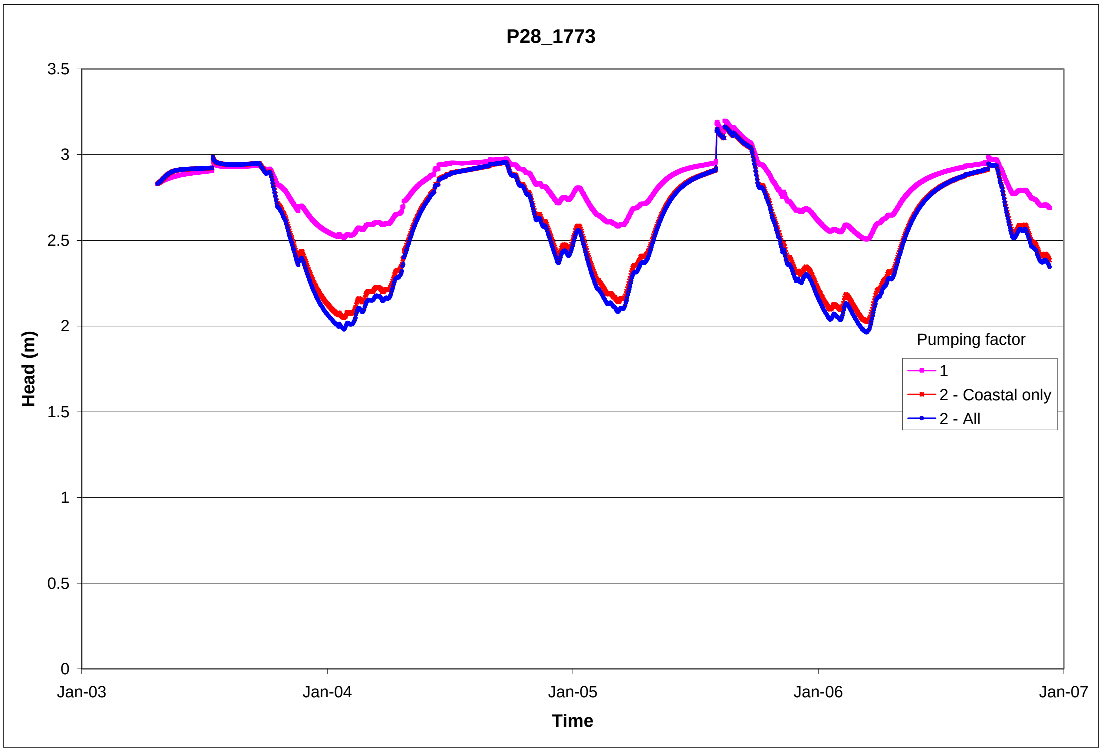


Figure 26: Simulated head change effect for monitoring bore P28_ 1733 – increased pumping for the coastal aquifer and whole model area

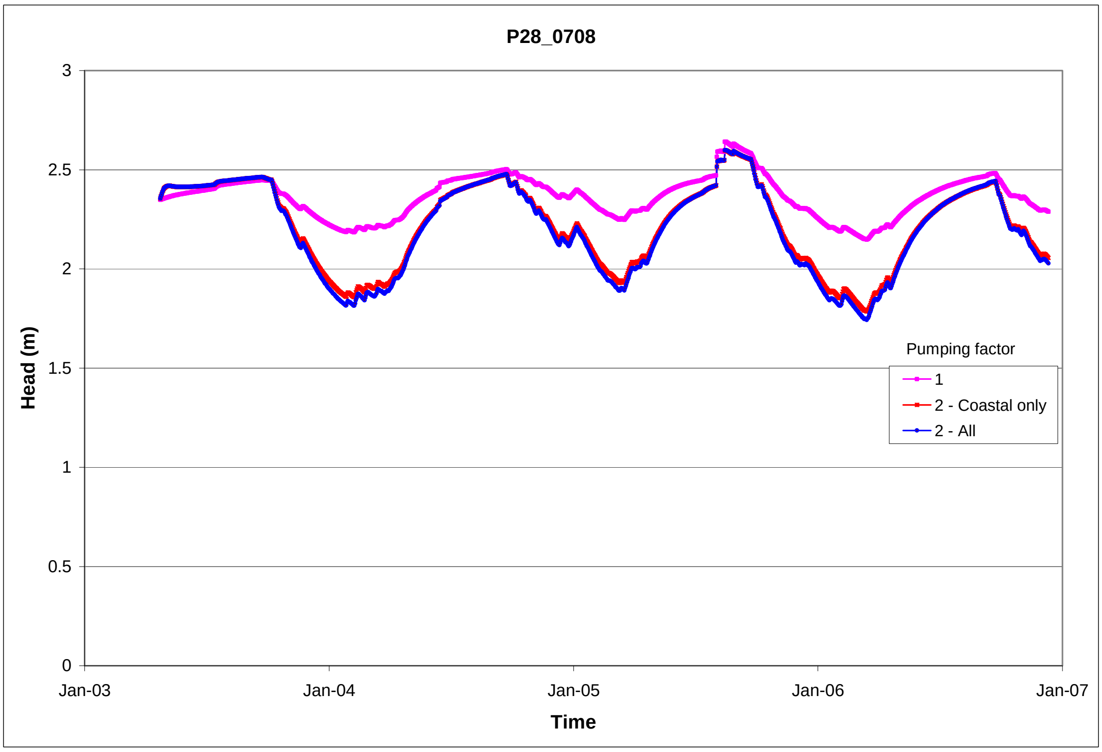


Figure 27: Simulated head change effect for monitoring bore P28_ 0708 – increased pumping for the coastal aquifer and whole model area

The change in flows in the coastal springs due to increased pumping over the whole model area is shown in Figure 28. The effects are reasonably high and spring flows can further be reduced by approximately of 5 l/s from the simulated flows for the pumping factor of 2 from the coastal area.

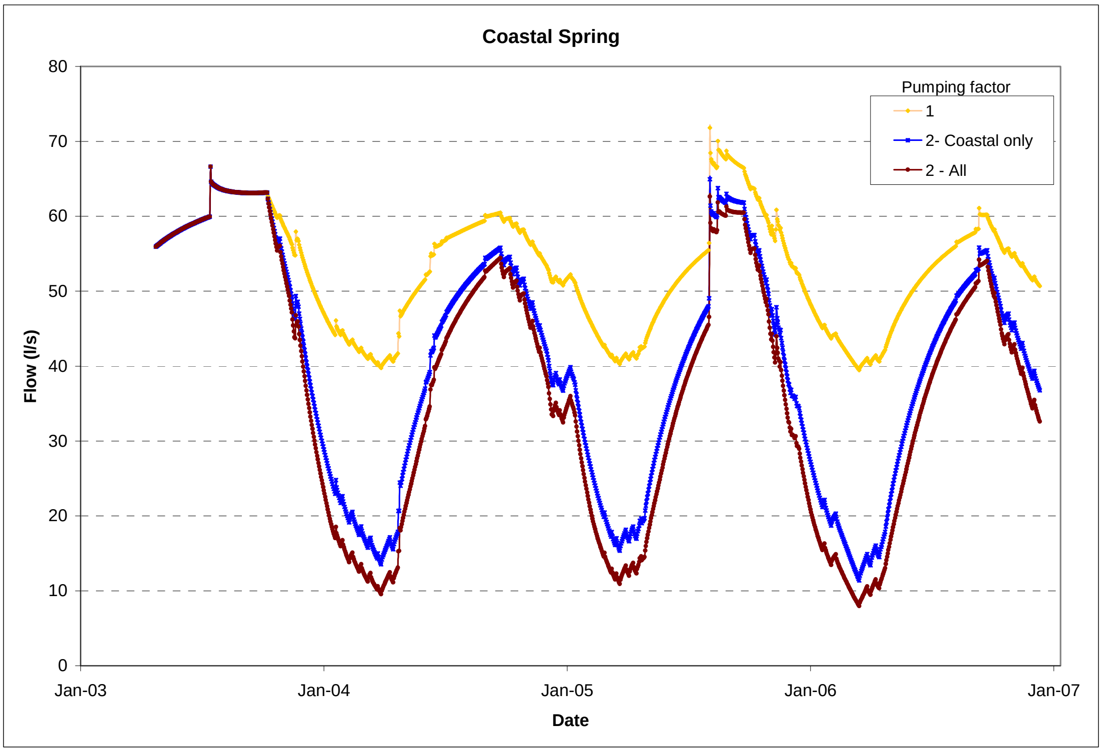


Figure 28: Simulated stream depletion effects for the coastal springs due to increased pumping from the coastal area and whole model area

4.3 Summary

The analysis of different aquifer management scenarios show that increased irrigation pumping will decrease the water levels in the deeper coastal aquifer. In addition, increased abstraction will cause a reduction in flows in the coastal springs.

The scenario analyses indicated that groundwater levels in the deeper coastal aquifer will decrease significantly but remain positive under increased pumping regimes. Therefore, the risk of saltwater intrusion into the deeper coastal aquifer is not high.

5 CONCLUSIONS AND RECOMMENDATIONS

The modified and updated Wairau groundwater model has been calibrated with the main focus on coastal aquifers. The calibration statistics show that the accuracy of the model has been increased with a standard error of approximately 4%. The calibration results show that the model is capable of simulating groundwater levels and river and spring flows with reasonable accuracy. However, the model fails to accurately simulate the groundwater levels for the north-eastern coastal area. This may be due to discretisation of the model as the model does not simulate the recharge from the foothills.

The model was used to predict the aquifer response under different management scenarios that include altered irrigation pumping regimes within the coastal area and also over the entire model area. The model predictions indicate that increased pumping will have an effect on groundwater levels in the coastal aquifers and a reduction in flows in the coastal springs. The larger the additional pumping, the greater the additional effects will be. It is recommended that MDC set minimum acceptable spring water levels as a tool to restrict seasonal water use.

Improve knowledge of aquifer and water use

Groundwater resources in the Wairau aquifer will be in greater demand in the future. Accurate information is vital to improve the understanding of the resource. It is recommended that MDC collect more information, including:

- Groundwater bore data: depth and screen intervals of bores (to determine the aquifers from which water is abstracted).
- Spatial size and location of irrigated area from each bore (to determine the land surface recharge). This information could be stored in GIS maps.
- Irrigated crop types, and land use and irrigation practises.
- Actual water use data.

A National Environment Standard (NES) for Water Measurement Devices is currently under development as part of the Sustainable Water Programme of Action (SWPoA). The accurate measurement of actual water use has been identified as a key element to the improvement of freshwater management in New Zealand. Although no timeframe has been set, the NES may be issued in 2008 (at the earliest). As water measurement devices on all new and renewed consented takes will be mandatory, it is advisable that MDC start planning this programme, with priority focussed on the most stressed areas of the Wairau aquifer system (including all of the coastal area).

Salt water intrusion

The calibrated model has been used to simulate changes in groundwater levels in the coastal aquifer by considering two monitoring wells, P28_1733 and P28_0708. The analyses show that it is unlikely that seawater intrusion would occur even with higher levels of pumping. However, the interface between seawater and fresh water is often blurred and fingering effects can occur. In addition, the coastline of the model area is approximately 40 km long. It may therefore not be desirable to make conclusive decisions based on a few monitoring wells. It is recommended to install additional small diameter monitoring bores at closer intervals along the coastline to assist in monitoring the saltwater-fresh water interface. The depth of the bores should be varied in order to measure the seawater intrusion at different levels, i.e. for different aquifers. Regular monitoring of water quality (as wells as groundwater levels) should be undertaken to better assess the state of the interface.

Model Accuracy

The updated model consists of 3,000 cells (50 rows x 60 columns) and 6,000 stress periods at daily time steps. Calibration and verification have been carried out each with 3,000 stress periods. The input data with finer temporal resolution increases the reliability of the model to use as a predictive tool. Although surface and groundwater interactions in the Wairau basin are prominent and the groundwater response is relatively fast, daily time steps may not be required. Groundwater responses are much slower than those of the surface water, and so a larger time step may be suitable.

The size of the model (especially the temporal dimension) limits the calibration options that can be implemented within the project time frame. The use of the SFR package also limits the calibration options that are available within Groundwater Vistas.

The advanced calibration techniques such as pilot point calibration are capable of calibrating the model with a higher degree of accuracy than what can be obtained from manual calibration. However, such techniques require large run times. The total time required to calibrate a model with the current model configuration is prohibitive. It is recommended that the model stress periods be lengthened to weekly intervals to allow this work to be undertaken.

General Head Boundary Representation

As described before, based on the project brief, the coastal boundary of the model has been represented as a no flow boundary. This resulted in no water exchange between groundwater aquifers and the sea at the coastline. This was done as a result of the previous stage findings that indicated that the movement of water at the coast to a constant head boundary was not significant.

However, in reality water has to diffuse up to layer 1 to discharge to the ‘sea’. Therefore, as shown in Figure 29, the cells that represent the sea can be modelled as a general head boundary (GHB). The GHB boundary condition is a head-dependent boundary condition. In a GHB cell, the flow of water into or out of the aquifer is dependent on the head assigned to the GHB and the conductance term. The head is compared to the computed head in the aquifer for the cell containing the GHB. If the aquifer head is higher than the GHB head, then the GHB removes water from the aquifer.

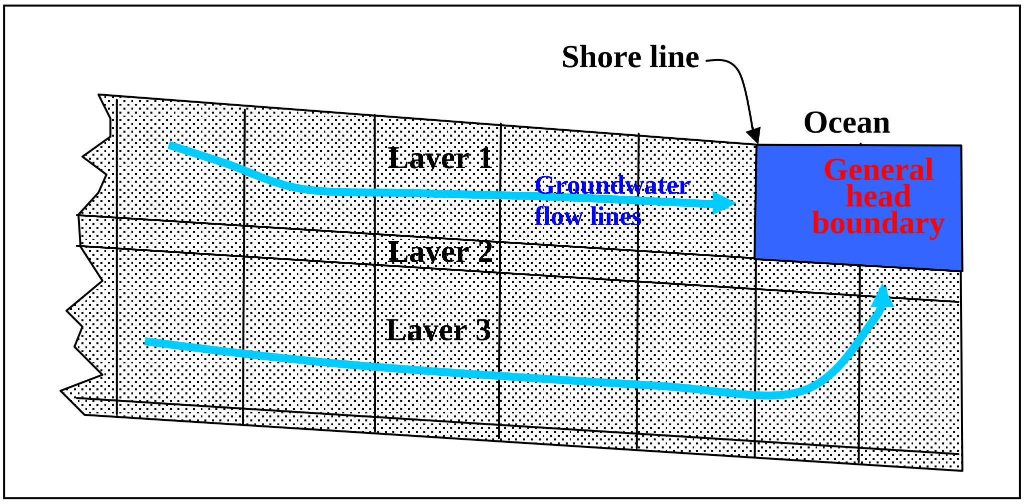


Figure 29: Conceptual model of the boundary condition at sea (the light blue arrows show groundwater flow paths)

The main attribute of this configuration is that the upper aquifer terminates at the boundary condition, while the deeper units can continue under marine sediments, as is the case in practice. This allows the model to more accurately replicate the actual system; groundwater in the deeper units must flow upward offshore to discharge to the sea.

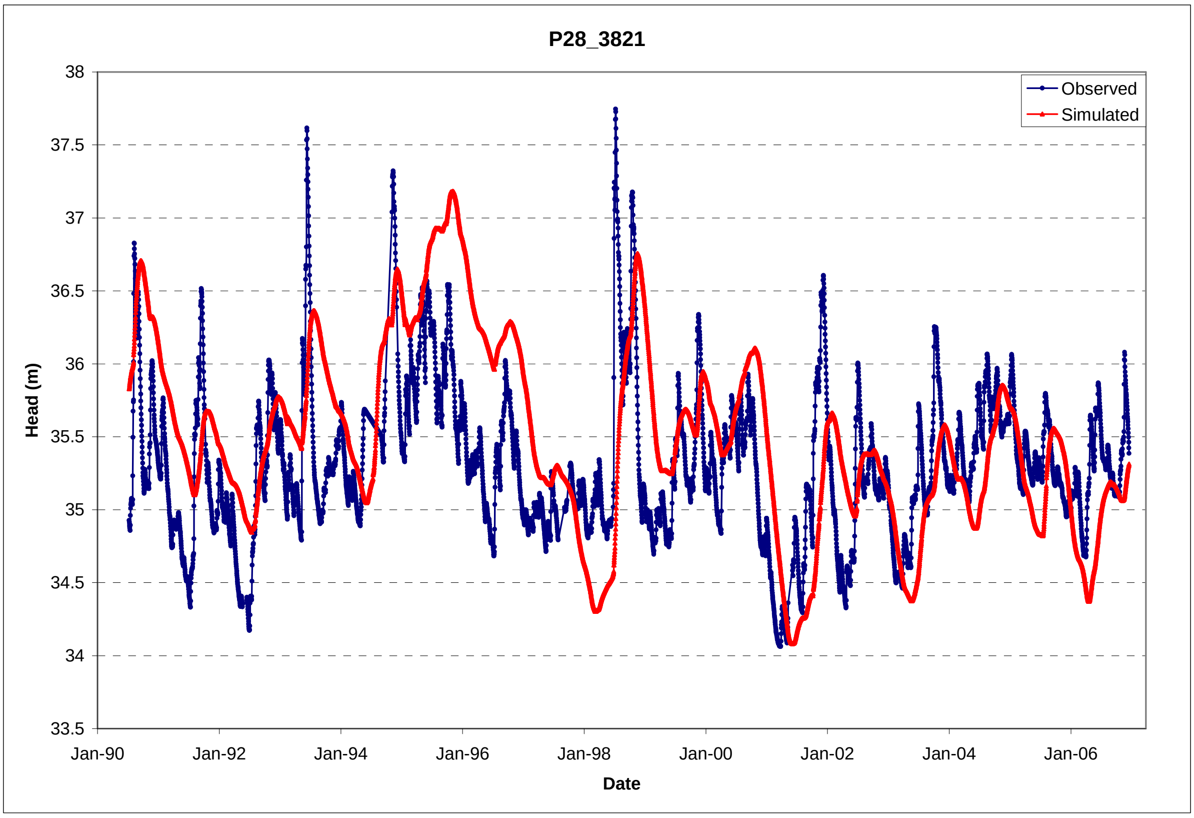
This is a more realistic representation of how the system works in practice. The water movement between GHB and the lower aquifers is only active in the vertical direction (seepage upwards or downwards).

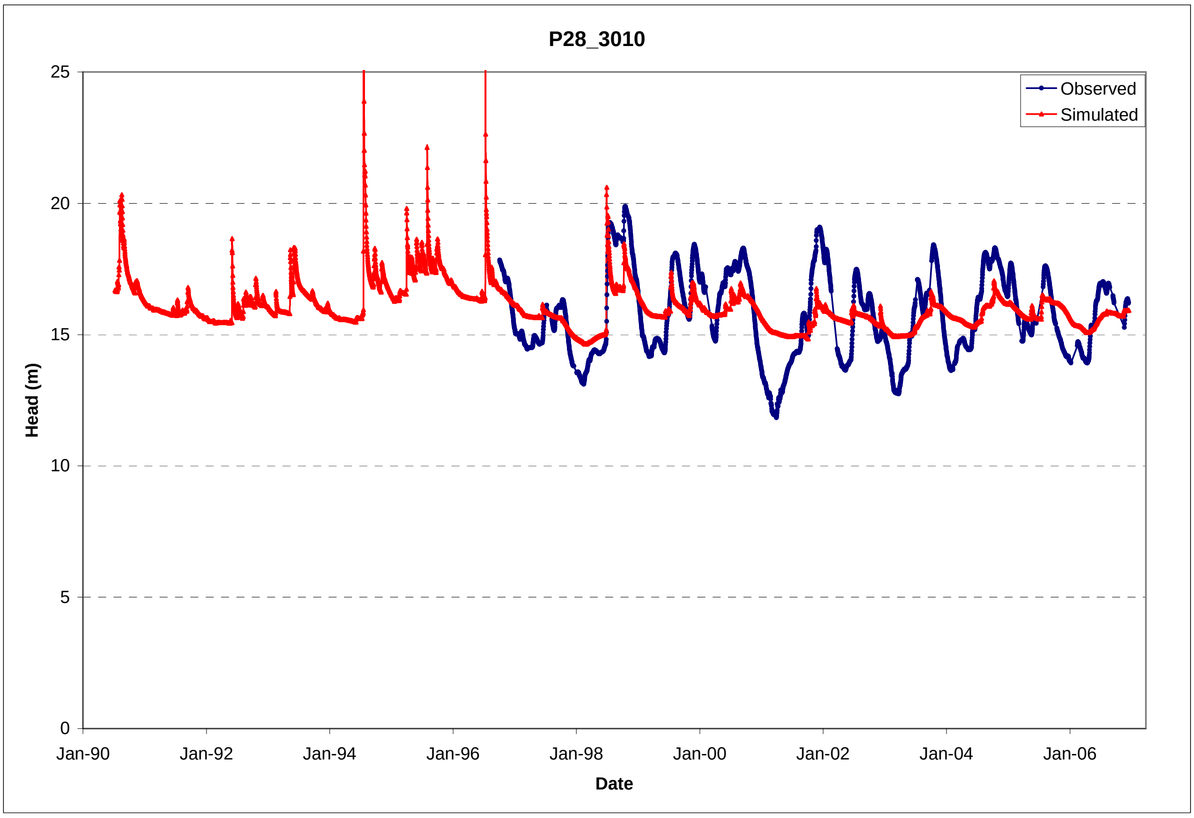
REFERENCES

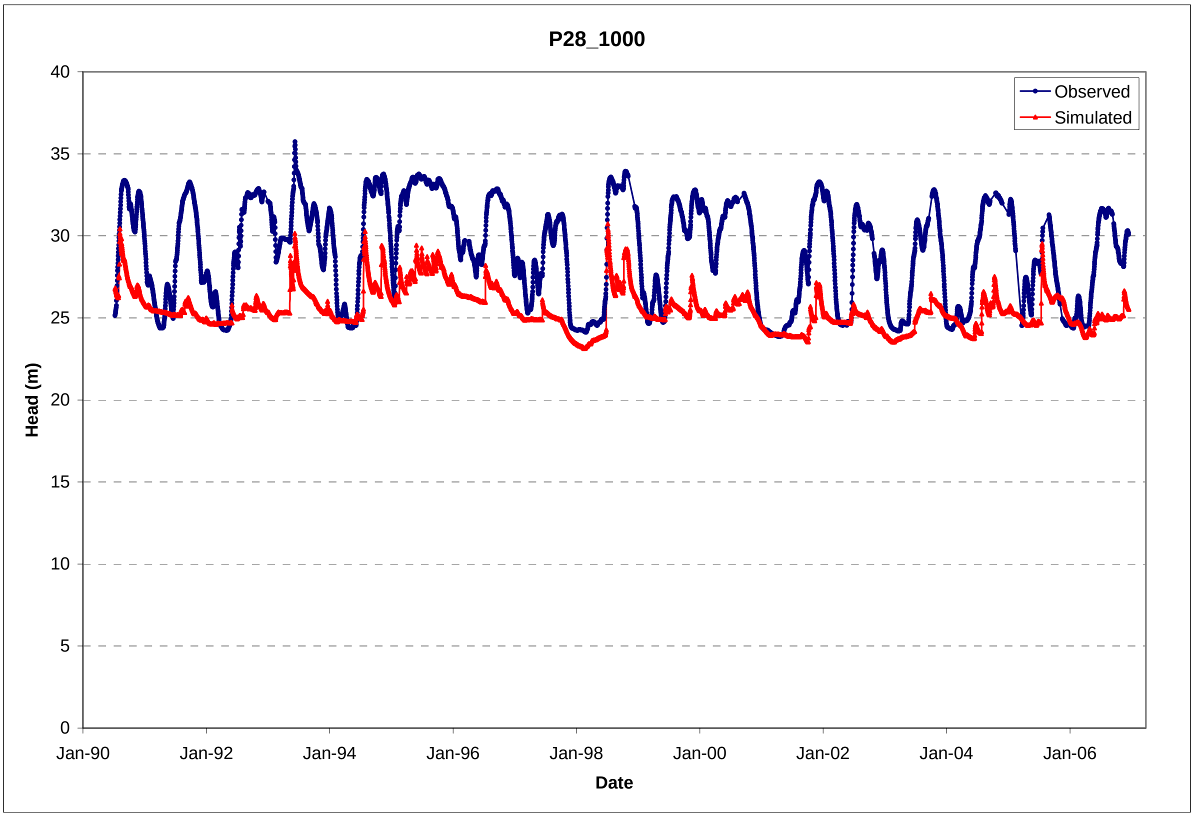
Aqualinc (2005). Wairau Aquifer Management Review – Stage 5. Prepared for Marlborough District Council by Aqualinc Research Limited.

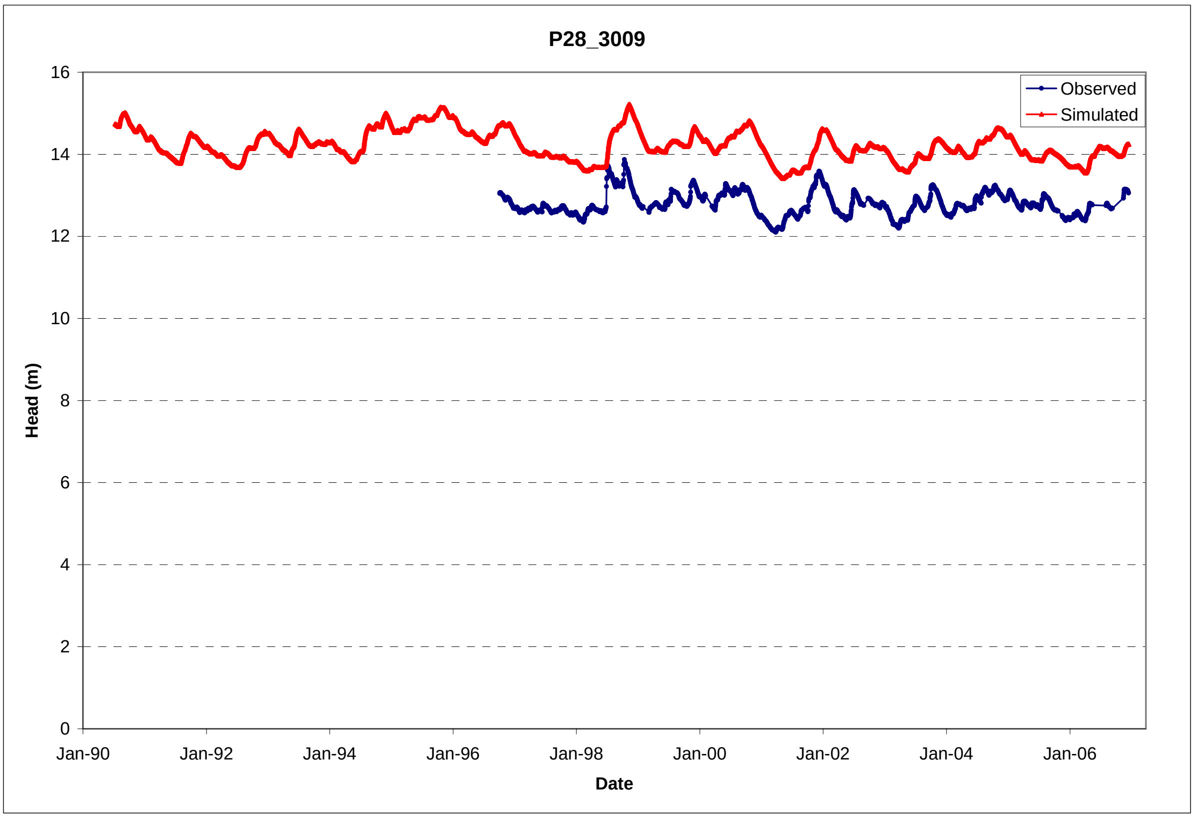
Prudic, D., L. F. Konikow, et al. (2004). "A New Streamflow-Routing (Sfr1) Package To Simulate Stream-Aquifer Interaction with MODFLOW-2000. U.S. Geological Survey Open-File Report 2004-1042."

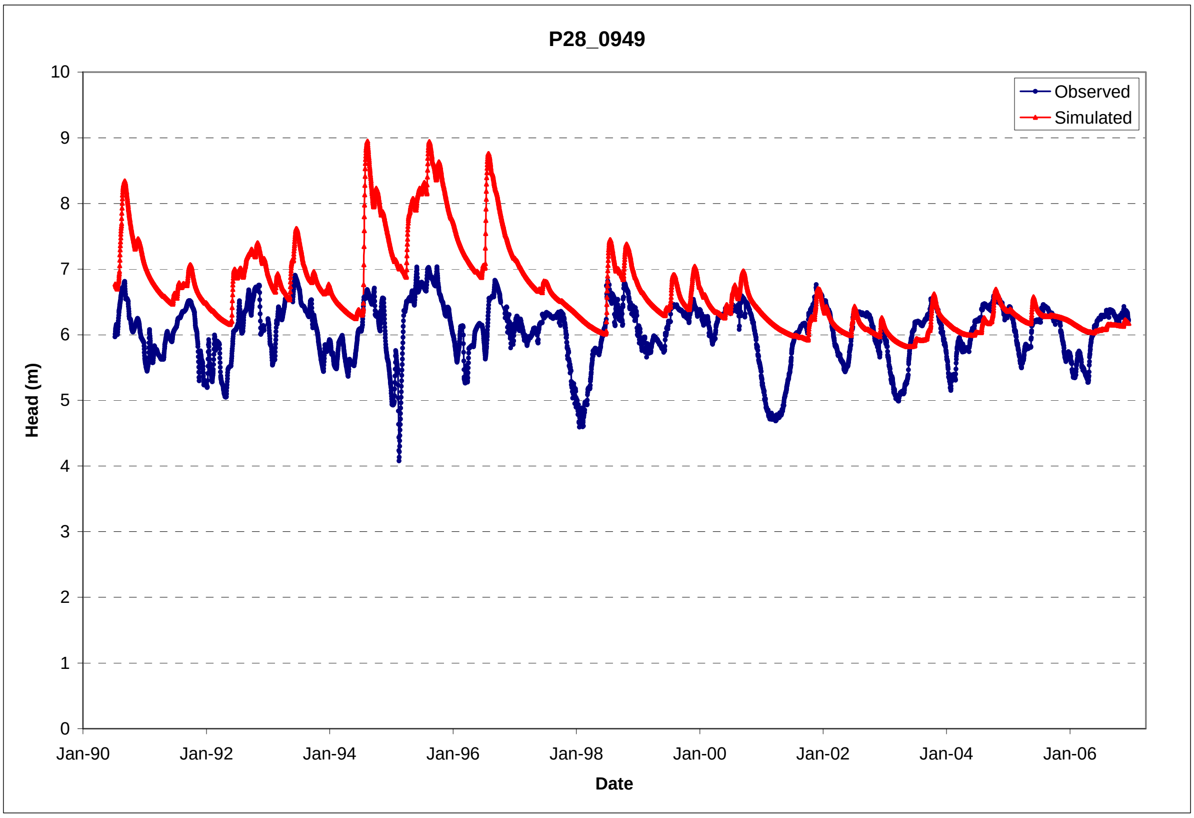
Appendix A: Hydrographs of Observation Wells






P28_1000
Head (m)
40
35
30
25
20
15
10
5
0
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Date
Observed
Simulated


P28_3009
Head (m)
16
14
12
10
8
6
4
2
0
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Date
Observed
Simulated


P28_0949
Head (m)
10
9
8
7
6
5
4
3
2
1
0
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Date
Observed
Simulated