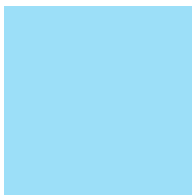
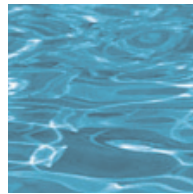




Appendix E

Aquifer Testing & Groundwater Modelling Report



Report

Kapiti Coast Aquifer Testing and Groundwater Modelling

Prepared for Kapiti Coast District Council (Client)

By CH2M Beca Limited

30 July 2010



Revision History

Revision Nº	Prepared By	Description	Date
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Document Acceptance

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1 Introduction

As part of the water supply review and options study for the Kapiti Coast District Council (KCDC) CH2M Beca Ltd has been asked to provide an assessment of the sustainable yield from the existing well field at Waikanae. The well field currently comprises 8 No. production wells and 2 No. back-up wells located between 600 m and 2000 m from the coast in three groups (including the back-up wells PW1 and PW5). The lateral distance between the wells in each group ranges from about 300 m to 800 m.

This report presents the results of three constant rate pumping tests carried out in three of the existing production wells, each of approximately two weeks duration, followed by a recovery period. Existing wells in the vicinity of the pumping wells have been monitored throughout the tests.

Hydraulic parameters have been derived from the test results and used to set up and calibrate a multi-layered numerical 3-dimensional groundwater model with the objective of simulating the drawdown and interference effects associated with abstraction and injection, in order to evaluate the long-term feasibility of various water supply options.

Notice to Reader / User of this Document

This report is the property of our Client, Kapiti Coast District Council and CH2M Beca Ltd. This report discusses groundwater at a regional scale. It is not suitable as a site investigation database and should not be used as such.

Should you be in any doubt as to the applicability of this report and/or recommendations, and/or encounter materials on site that differ from those described herein, it is essential that you discuss these issues with the authors before proceeding with any work based on this document.

2 Geology and Hydrogeology

2.1 Geological Sequence

A description of the geology and the production well design is given in the well field construction report¹. The sequence of aquifers and aquitards encountered during investigation drilling is described here. Four main hydrogeological units comprising a series of sand and gravel aquifers separated by silt, clay and peat aquitards are identified.

A shallow unconfined sand aquifer extends to a depth of approximately 30 m; existing domestic bores target this aquifer.

Beneath the unconfined aquifer is the 20 m – 30 m thick Parata aquifer. The Parata aquifer is semi-confined with unconfined conditions near the ranges and confined conditions near the coast. The aquifer consists of sand and gravel separated by silt.

An aquitard underlies the Parata aquifer. This unit is 5 m – 10 m thick and comprises mainly sand with a silt component and minor shell fragments; however a high yielding gravel layer (aquifer) of up to 3 m thick has been identified within this unit locally. The existing production well K4 abstracts water from this gravel layer.

¹ URS, 2004: Waikanae Borefield Technical Report

The deepest of the sand aquifers (the Waimea aquifer) is encountered at approximately 70 m depth. The production wells (other than K4) of the well-field abstract water from this aquifer. Greywacke basement rock underlies the Waimea aquifer. The thickness of the Waimea aquifer is generally unproven but in three of the existing production wells the bed rock has been encountered at some 90 m depth suggesting a thickness of 20 m – 30 m. The Waimea aquifer comprises brown and blue gravel with silt and silt-bound gravel layers. This aquifer is considered to be semi-confined.

2.2 Hydrogeology

The general groundwater flow direction is from the foothills (SE) towards the coastline (NW). The horizontal extent of the sand aquifer system varies from about 2,000 m to 5,000 m wide as shown approximately in Figure 1 (area enclosed by the thick red line).

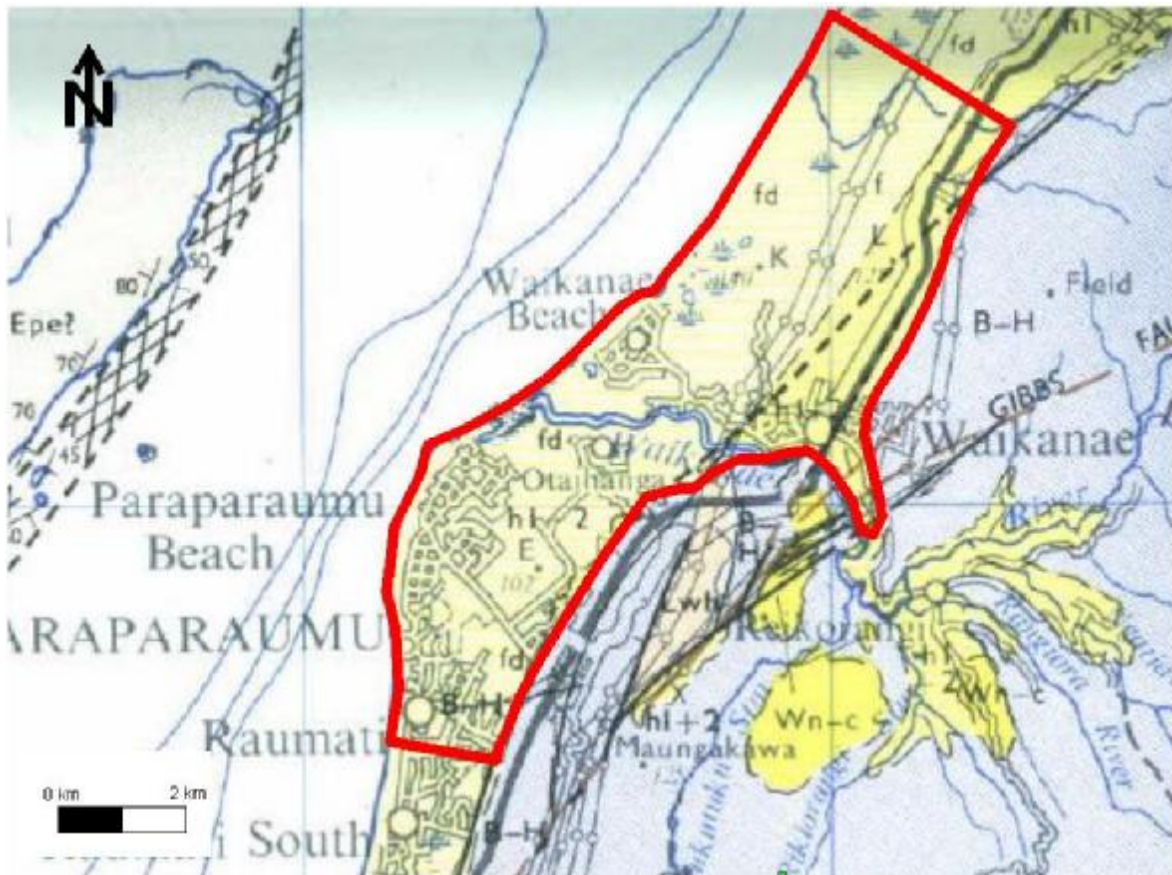


Figure 1. Geological map showing extent of the aquifer system and model (enclosed by red line).

Although the sands and gravels extend further to the South and North than identified in Figure 1, the boundaries of the groundwater model have been selected such that they are sufficiently far from the pumping wells that pumping does not result in drawdown at the boundaries. The Waimea aquifer is expected to extend offshore to the west below the seabed.

A simplified mass balance diagram is shown in Figure 2.

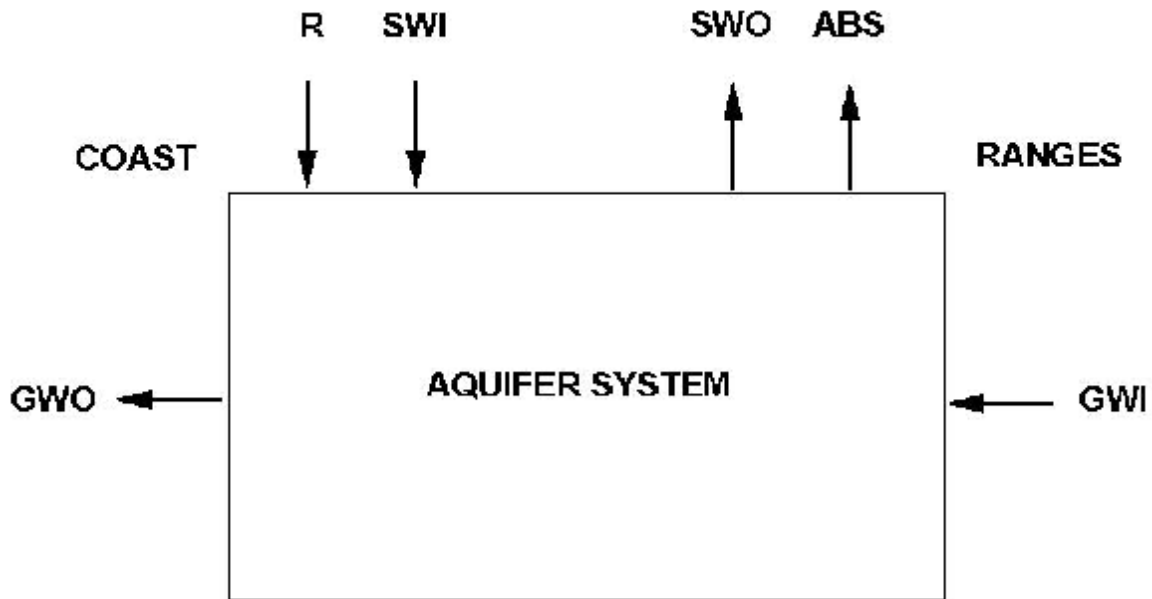


Figure 2. Mass Balance (GWI: Inflow from ranges in east, GWO: Outflow to sea, SWO: Outflow to rivers and streams, SWI: Inflow from Waikanae River, ABS: Abstraction, R: Rainfall recharge)

The geological and pumping test data available suggests that the aquifers extend to the north and south. Because the soils are alluvial, they will vary from place to place, but further successful well sites are expected to be found.

Minor settlement in the vicinity of the well heads may occur as a result of the pumping over the long term, however whether this occurs and the extent of the settlement that might occur is dependent on the existence and distribution of compressible soils within the drawdown cone. We consider that the risk of settlement is minor, and the amount of settlement caused is likely to be small.

2.3 Existing Wells and Current Consents to Take and Use Groundwater

Well construction records and details on current consents to take and use groundwater were obtained from Greater Wellington Regional Council (GWRC). A total of 1951 existing bores/wells are known to have been drilled within the aquifer area shown in Figure 1. Out of this number 1198 records have been assigned a depth of 0 m indicating that either the depth is not known or it has not been drilled. The depths recorded for the remaining wells range from 1.1 m to 123 m. Table 1 shows the depth distribution of existing wells in the groundwater catchment. 0 m deep wells are not included in the table.

Table 1 - Well Depth Distribution in Groundwater Catchment

Well Depth [m]	Number of Wells
0 – 30	630
30 – 60	79
60 – 80	22
80 – 130	28

GWRC has also provided a list of current consents to take water in the area. A summary of the consents is provided in Table 2. Only 26 existing wells have resource consents. GWRC considers a

well being pumped at a rate less than 20 m³/day as a permitted activity. It has therefore conservatively been assumed that each of the 733 unconsented wells is pumped at a constant rate of 0.2 L/s. This has been modelled by assigning a total evapotranspiration value of 0.0718 mm/year to the entire model area and thereby removing 12,666 m³/day from the mass balance calculation.

3 Pumping Testing

3.1 Test Details

Given the time constraints for this project it was decided to undertake pumping tests in three selected existing production wells (rather than all wells) with monitoring of groundwater levels in existing observation bores and existing wells nearby that are screened in shallower aquifers and the pumped aquifer. Because the wells are in the coastal domain and there is a risk that saline intrusion could occur, it is recommended that each of the production wells be tested individually in the future to better characterise the aquifers, and confirm drawdown, interference effects, hydrogeological boundaries and leakage from shallow aquifers.

The pumping test of **K6**, screened in the Waimea Aquifer, commenced on 31 March 2010. The pumping rate of 58 l/s was maintained for 9 days while groundwater levels were recorded in 19 observation wells spread across the well field. After 9 days the pump was shut down and recovery was recorded until full recovery had been achieved in the pumped well.

The pumping test of **Kb4**, screened in the Waimea Aquifer, commenced on 16 April 2010. The pumping rate of 35 l/s was maintained for 12 days while groundwater levels were recorded in 24 observation wells spread across the well field. After 12 days the pumping was shut down and recovery was recorded until full recovery had been achieved in the pumped well.

The pumping test of **K4**, screened in the gravel layer within the Parata aquifer, the aquifer overlying the Waimea aquifer, commenced on 6 May 2010. The pumping rate of 70 l/s was maintained for 11 days while groundwater levels were recorded in 13 observation wells spread across the well field. Recovery in the pumping well and the observation wells was recorded until the groundwater level in the pumped well had fully recovered.

The majority of the monitoring bores had been completed with 20 mm diameter PVC piezometers that do not allow for installation of electronic pressure transducers. Therefore frequent monitoring rounds were carried out by KCDC staff in order to collect manual water level recordings. Water levels in the production wells were recorded with the existing SCADA system.

3.2 Test Results

The full results of the pumping tests are attached in Appendix A - C.

The results of the pumping tests indicate that some vertical leakage occurs from the shallow unconfined aquifer that overlies the Waimea aquifer when pumping from the Waimea takes place. A summary of the results of the pumping tests is given in Table 2.

Table 2 - Summary of Pumping Test Results

Parameter	Value
Transmissivity, Waimea aquifer, T [m ² /day]	300
Storativity, Waimea aquifer, S [-]	5.0 x 10 ⁻⁴
Leakage Coefficient, K'/B' [day ⁻¹]	2.5 x 10 ⁻⁴

Parameter	Value
Specific Yield, shallow aquifer, Sy [-]	0.005

The results indicate that the Waimea aquifer is a relatively high yielding aquifer underlying a semi-confined/leaky aquitard. A significant tidal effect was observed in the aquifer during the tests. This is expected as the wells are located close to the coastline. Analysis of the results suggests that 100% of the abstracted volume will be from leakage through the shallower layers (the Parata and shallow unconfined aquifers) after approximately 60 days of constant pumping. This could have implications for secure status of the supply. However, the effective radius at this stage is large and the drawdown effect in the shallow unconfined aquifer relatively small but still measurable (0.03 m – 0.39 m after 9 days pumping of K6 at a constant rate of 58 L/s).

A relatively large drawdown is recorded in the sentinel wells screened in the deeper Waimea aquifer (the aquifer from pumped during testing) near the coast. After pumping K6 at a constant rate of 58 l/s for 9 days, a drawdown of 1.1 m was observed in Sentinel # 1.

The results from the pumping tests and the fact that a large number of observation wells have been monitored during the tests allows a detailed calibration of the groundwater model. Observation wells targeting shallow, mid-depth and deep aquifers have been monitored allowing for a reasonable understanding of the aquifer system as a whole.

4 3-Dimensional Numerical Groundwater Model

4.1 Numerical Code

Three-dimensional groundwater modelling was undertaken using the software package Visual Modflow Pro 2009. Visual Modflow is a user interface for the 3D finite difference model, Modflow 2000 and ModPath, developed by the United States Geological Survey.

The groundwater flow equation is solved using the finite-difference approximation. The flow region is subdivided into blocks in which the material properties are assumed to be uniform. In plan view the blocks are made from a grid of mutually perpendicular lines that may be variably spaced, and the water level in each block is calculated.

4.2 Set-up of Numerical Model

The model covers an area of 12 km by 13 km; the actual area of interest is the 5 km by 13.5 km area covering the sand and gravel aquifer system along the coastline from Raumati in the south to Peka Peka in the north. The head boundary to the east has been assigned from the geological map as the extent of the gravel aquifer. The geological layers have been derived from existing bore-logs. The model does not include the underlying greywacke. It is therefore assumed that the greywacke is relatively impermeable compared to the sand and gravel aquifers and that no vertical leakage occurs from the Waimea aquifer to the Greywacke (such leakage could perhaps occur through significant fracture zones, should these exist).

Rainfall and river recharge data have been obtained from GWRC and applied to the model as boundary conditions.

4.3 Calibration

The steady state model has been calibrated using long term average groundwater levels from KCDC's SCADA and records from GWRC as well as hydraulic conductivities for the different

geological layers derived from the pumping tests. The modelled steady state water levels versus the observed water levels are shown in Figure 3.

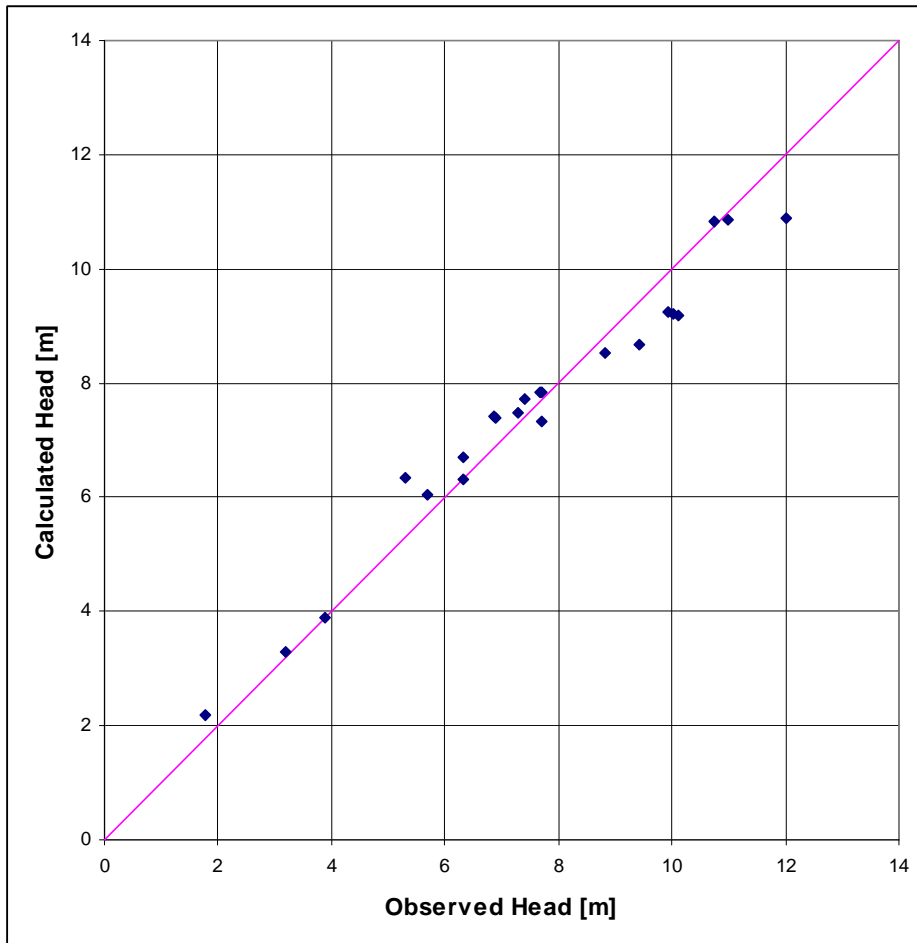


Figure 3. Steady state calibration plot

The normalised RMS of the calibration is 5.2% and the correlation coefficient is 0.98.

To further check the validity of the model, mass balance calculations have been carried out. The results are shown in Table 3.

Table 3 - Mass Balance Calculations

Mass Balance	Flow [m ³ /day]
Model in	117,318
Model out	117,315
Analytical	114,000

The results indicate that the model is well calibrated. This is confirmed by a comparison between the modelled flow into the model and the analytically calculated flow into the defined catchment zone. The difference between the two is less than 3%. The calculated groundwater levels under steady state average conditions are given in Appendix D.

Following the calibration of the steady state model a transient model has been established and calibrated to fit the drawdown results of the pumping tests. This allows a value of storativity to be

obtained for each of the different layers in order to simulate the aquifers' ability to release or receive water when being abstracted from or injected to.

The process of transient calibration involved assigning hydraulic conductivity (K) and storativity (S) properties and adjusting these parameters in an iterative process to obtain a match to the measured drawdowns in the pumping tests. Table 4 shows the calibrated model parameters.

Table 4 - Calibrated Model Parameters

Geological Unit	$K_{x,y}$ [m/s]	K_z [m/s]	S [-]
Unconfined sand aquifer	8.0×10^{-5}	8.0×10^{-6}	0.002
Semi-confined sand and gravel aquifer (Parata)	4.0×10^{-4}	4.0×10^{-5}	5.0×10^{-7}
Aquitard	2.0×10^{-7}	2.0×10^{-8}	2.0×10^{-7}
Confined gravel aquifer (Waimea)	1.3×10^{-5}	1.3×10^{-6}	8.0×10^{-6}

The model has not been calibrated to fit water quality changes over time. However the model can be applied to simulate water quality changes over time e.g. the effects of injecting river water into the Waimea aquifer and the effects from saline intrusion under the different abstraction scenarios.

The validity of the model calibration has been analysed in terms of sensitivity of the hydraulic parameters. The model is most robust in the area where most data is available (in the vicinity of the well field) but given the relative homogeneity of the aquifer system it is considered that the model allows reasonable predictions in areas further away from the well field.

4.4 Model Limitations

The model has been extended to cover the sand and gravel aquifer as far south as Raumati South and as far north as Te Horo. However, only limited geological and hydrogeological data exists for these regions. This means that the reliability of the model at its perimeter is less than it is in the vicinity of the well field. Overall calibration is good and the predictions of drawdown effects in the different aquifers either when abstracting or injecting water are instructive.

The robustness of the groundwater model will improve as more data from pumping tests becomes available.

5 Simulations

5.1 Description

The calibrated groundwater model has been used to run a series of simulations to evaluate drawdown effects in both the shallow unconfined aquifer and the deep Waimea aquifer resulting from various abstraction scenarios from the Waimea Aquifer. A summary of the simulations carried out is given in Table 5. All simulations have been run for 10 years with one abstraction or recharge/abstraction cycle per year. The simulations are run using the average rainfall recharge over the last 10 years. A 50 year drought event has not been modelled at this stage but it is recommended that the model is calibrated against rainfall extremes to simulate climate changes. However it is anticipated that the effect from a drought on the Waimea aquifer will be minimal given the depth and semi-confined nature of the aquifer.

Wells PW1 and PW2 have not been used for abstraction in simulations because they are close to the coast and pumping from them potentially puts the rest of the aquifer at risk. In all cases pumping from these wells is considered to increase the risk of saline intrusion to the rest of the aquifer system. Wells TW2 and K10 are included in Simulation 1 to check the effect of pumping from wells near the coastline for comparison with the other scenarios.

While the Waikanae River is known to provide some recharge to the shallow alluvial aquifer system, abstraction from the deeper Waimea aquifer is shown to have a limited effect on the overlying shallow aquifer and is not expected to have a noticeable effect on river flow (i.e. not more than a few percent). By keeping any new wells away from the river, and limiting the amount and extent of the drawdown in the shallow aquifer, these effects can be minimised.

The maximum drawdown provided for the Waimea aquifer in the following sections does not include the drawdown component caused by well losses in the immediate vicinity of the pumped wells. This is expected to be in the order of 10 m – 20 m and will vary as a result of abstraction rate, well construction and development.

Table 5 - Summary of Simulations

Simulation No.	Description
1	370 L/s is abstracted from 6 existing wells and 3 new wells North of the existing well field for (i) 60 days and (ii) 90 days per year
2	120 L/s is injected through 3 new wells for 150 days immediately followed by 370 L/s being abstracted from existing wells (ASR concept design)
3	370 L/s is abstracted from 6 existing wells and 6 new wells for 90 days per year
4	120 L/s is injected into the Waimea aquifer through 3 existing (K4, K5 and K6) wells for 150 days immediately followed by abstraction of 370 L/s from 6 existing wells and 3 new wells for 90 days
5	As for simulation 4 but a refined abstraction profile (variable according to likely practice) has been applied
6	As for simulation 4 but the abstraction period is extended to 180 days

Well locations for the different simulations are shown in Appendix E1, F1, G1 and H1.

5.2 Simulation 1 - Abstraction from existing wells and 3 new wells

This simulation uses the 6 existing wells and 3 new wells to abstract a total of 32,000 m³/day (370 L/s) for (i) 60 days and (ii) 90 days per year. The output of the simulation is given after abstracting groundwater at the rates shown in Table 6 for a period of 10 years. The location of the abstraction wells is shown in Appendix E1.

Table 6 - Wells and Abstraction Rates

Well No.	Abstraction Rate [m ³ /day]	Target Aquifer
TW2	1987	Parata
K10	1469	Waimea
K4	6048	Gravel layer in aquitard overlying Waimea aquifer
K5	3110	Waimea
K6	5000	Waimea

Well No.	Abstraction Rate [m ³ /day]	Target Aquifer
Kb4	3024	Waimea
NEW1	3456	Waimea
NEW2	3456	Waimea
NEW3	3456	Waimea

The head equipotentials in the Waimea aquifer and in the shallow unconfined aquifer, after 60 days and 90 days of pumping are shown in Appendix E2 and E3 respectively. The head equipotentials in the Waimea aquifer after 60 days and 90 days of pumping are shown in Appendix E4 and E5. The pumping results in drawdown of up to 1.6 m within the shallow, unconfined aquifer and up to 14 m within the Waimea aquifer as shown in Appendices E6 – E9.

Simulations were carried out for pumping over 60 days and 90 days per year abstracting 32,000 m³/day for 10 years. The results indicate that drawdown should not increase over time, that is, that the aquifer system recovers fully after 90 days of pumping before the well field is operated again.

K4 is screened in the gravel lens in the aquitard overlying Waimea aquifer. The pumping test indicated that this aquifer is very high yielding and the model is built to simulate this. However with the limited data available means that it is difficult to assess the extent of the aquifer and whether it is as efficient over its full extent, or in fact whether it is continuous.

The drawdown plots show that the drawdown induced by the wells near the coastline could potentially result in draw-in of the fresh water/ salt water interface (saline intrusion) over time.

5.3 Simulation 2 - Injection to 3 new wells and abstraction from 6 existing wells and 1 new well

This simulation models the concept design of the ASR option. It uses 3 new wells for injection of 10,000 m³/day (120 L/s) for 150 days and the existing wells plus 1 new well to abstract a total of 32,000 m³/day (370 L/s) for 60 days per year. The wells TW2 and K10 have been left out of the simulation because of their proximity to the coast. Instead, one new abstraction well has been added between K4 and Kb4. The 3 injection wells used in the simulation are located east of the wellfield along SH1. The simulation has been carried out injecting and abstracting groundwater at the rates as shown in Table 7 after running the model using these injection and abstraction rates identified for a period of 10 years. The location of the abstraction wells is shown in Appendix F1.

Table 7 - Wells and Abstraction Rates

Well No.	Injection Rate [m ³ /day]	Abstraction Rate [m ³ /day]	Target Aquifer
INJ1	3456		Waimea
INJ2	3456		Waimea
INJ3	3456		Waimea
K12		1296	Waimea
Kb7		864	Waimea
K4		7776	Gravel layer within aquitard overlying Waimea aquifer
K5		4320	Waimea

Well No.	Injection Rate [m ³ /day]	Abstraction Rate [m ³ /day]	Target Aquifer
K6		6912	Waimea
Kb4		3888	Waimea
NEW1		6912	Waimea

The head equipotentials in the Waimea aquifer and the shallow, unconfined aquifer after 60 days are shown in Appendix F2. The head equipotentials in the Waimea aquifer after 60 days of pumping are shown in Appendix F3. The pumping results in drawdown within the shallow, unconfined aquifer of up to 1.2 m and up to 16 m in the Waimea aquifer as shown in Appendices F4 and F5.

Simulations have been carried out for pumping over 60 days per year injecting and abstracting 32,000 m³/day for 10 years. The results indicate that drawdown should not increase over time, that is, that the aquifer system recovers fully after 60 days of pumping before the well field is operated again.

The drawdown in the Waimea aquifer and in the shallow aquifer are reduced by using ASR, however the saline intrusion is still a risk when injection wells are located upstream from the abstraction wells. In order to reduce the risk of saline intrusion simulations 4– 6 are run with injection wells closer to the coastline.

5.4 Simulation 3 - Abstraction from 6 existing and 6 new wells

This simulation uses 6 existing wells and 6 new wells to abstract a total of 32,000 m³/day (370 L/s) over a period of 90 days. The purpose of this simulation is to spread the abstraction over a wide area and pump each well at the lowest rate possible. The simulation has been carried out abstracting groundwater at the rates as shown in Table 8 after running the model abstracting at these rates for a period of 10 years. The locations of the abstraction wells are shown in Appendix G1.

Table 8 – Wells and Abstraction Rates

Well No.	Abstraction Rate [m ³ /day]	Target Aquifer
K12	864	Waimea
Kb7	648	Waimea
K6	3465	Waimea
K5	1728	Waimea
K4	4320	Gravel layer within aquitard overlying Waimea aquifer
Kb4	2592	Waimea
NEW1	3456	Waimea
NEW2	3456	Waimea
NEW3	3456	Waimea
NEW4	2678	Waimea
NEW5	2678	Waimea
NEW6	2678	Waimea

The resulting head equipotentials in the shallow unconfined aquifer after 90 days of pumping are shown in Appendix G2. The head equipotentials in the Waimea aquifer after 90 days of pumping are shown in Appendix G3. The pumping scenario results in drawdown of up to 2.0 m in the shallow aquifer (Appendix G5) and up to 8 m in the Waimea aquifer (Appendix G5).

The results indicate that aquifer drawdown should not increase or spread over time, that is, the aquifer system recovers fully after 90 days of pumping before the well field is operated again.

The results show that the maximum drawdown in the shallow aquifer and the deep pumped aquifer is reduced by spreading the abstraction over a wide area. However, drawdown near the coastline needs to be reduced to avoid saline intrusion.

5.5 Simulation 4 - Injection followed by abstraction from 6 existing wells and 3 new wells

This simulation uses 3 existing wells for injection of 10,000 m³/day (120 L/s) for 150 days and the existing wells plus 3 new wells to abstract a total of 32,000 m³/day (370 L/s) for 90 days per year. The 3 injection wells used in this simulation are the existing K4, K5 and K6. The simulation has been carried out injecting and abstracting groundwater at the rates shown in Table 9. This injection and abstraction scenario is run for 10 years. The location of the injection wells and abstraction wells is shown in Appendix H1.

Table 9 - Wells and Abstraction Rates

Well No.	Injection Rate [m ³ /day]	Abstraction Rate [m ³ /day]	Target Aquifer
K12		864	Waimea
Kb7		648	Waimea
K4	3456	6998	Gravel layer within the aquitard overlying the Waimea
K5	3456	4060	Waimea
K6	3456	5011	Waimea
Kb4		3974	Waimea
NEW1		3456	Waimea
NEW2		3456	Waimea
NEW3		3456	Waimea

The head equipotentials in the Waimea aquifer and the shallow unconfined aquifer after 150 days of injection and 90 days of pumping are shown in Appendix H2 and H3 respectively. This injection and abstraction scenario results in aquifer drawdowns of up to 6 m in the Waimea Aquifer (Appendix H5) and up to 1.6 m in the shallow aquifer (Appendix H4).

The results indicate that drawdown should not increase over time, that is, the aquifer system recovers fully after 90 days of pumping before the well field is operated again.

The results show that injecting water into the Waimea aquifer through the 3 existing wells reduces the risk of saline intrusion in comparison to the previous simulations in that the extent of drawdown in the seaward direction is reduced and the maximum drawdown in both the shallow aquifer and the deep aquifer is reduced (from 2.2 m to 1.6 m in the shallow aquifer) after 90 days of pumping.

Injection into the Waimea aquifer increases the head equipotential in the Waimea aquifer but because of the semi-confining nature of the overlying layer the effect of injection will be small on the shallow aquifer. It is noted that the water table is already free flowing in the area around K12 and K7 and it is therefore not recommended to use these wells as injection wells.

The following simulations are based on reinjection in existing wells.

5.6 Simulation 4 with revised demand profile

This simulation uses the same wells as simulation 4 but a revised demand profile has been applied to investigate the effects of reduced abstraction. The demand profile is summarised in Table 10.

Table 10 - Revised Demand Profile

Number of Weeks	% of Maximum Abstraction	Revised demand [m ³ /day]
3	100	32000
4	87.5	28000
4	93.8	30000
2	87.5	28000

The reductions have been split evenly over the abstraction wells.

The injection regime with 10,000 m³/day injection for 150 days in wells K4, K5 and K6 remains the same as for simulation 4.

The head equipotentials in the Waimea aquifer and the shallow unconfined aquifer after 150 days of injection and 90 days of pumping are shown in Appendix I1 and I2 respectively. The pumping results in aquifer drawdown of up to 1.4 m in the shallow aquifer (Appendix I3) and up to 6 m in the Waimea Aquifer (Appendix I4).

The results indicate that there is a small reduction in maximum drawdown in the shallow aquifer and the pumped aquifer compared with Simulation 4.

5.7 Simulation 4 with abstraction for 180 days

This simulation uses the same wells as simulation 4 with the full demand profile but the total abstraction period has been extended to 180 days in order to check the sensitivity of the extent of drawdown effects to abstraction period.

The head equipotentials in the Waimea aquifer and the shallow unconfined aquifer after 150 days of injection and 180 days of pumping are shown in Appendix J1 and J2 respectively. The pumping results in aquifer drawdowns of up to 6 m in the Waimea Aquifer (Appendix J4) and up to 2.3 m in the shallow aquifer (Appendix J3).

The results show that the maximum drawdown in the shallow unconfined aquifer increases from 1.6 m to 2.3 m when doubling the abstraction period. The changes in drawdown in the Waimea aquifer are not large because at this stage almost all of the drawdown contribution occurs through leakage from shallower layers. This is important because it suggests that more significant changes are occurring in the shallow aquifer, which in turn means an increase in the risk of saline intrusion.

6 Saline Intrusion

The well field is located in close proximity to the coastline and saline intrusion to the aquifers resulting from long term pumping is therefore considered a potential risk. Scenarios selected for modelling are those that limit this risk by abstracting groundwater from wells that are located further inland and spreading the volume of water abstracted between the wells.

GWRC collect electrical conductivity results from the sentinel wells (screened in the Waimea aquifer) located near the coast but they report that the instruments are not calibrated and the results are inaccurate. GWRC did not therefore wish to supply this data to us. There is therefore insufficient information available to allow the potential for saline intrusion to be reasonably modelled in the 3D simulations. However, an analytical assessment of the potential for saline intrusion to the shallow unconfined aquifer has been carried out using the relationship between the head equipotential above MSL and the depth to the saline wedge below MSL derived from the Ghyben-Herzberg equation. The relation is given by:

$$H_s = 40 \times H_f$$

Where H_s is the depth to the saline wedge below MSL and H_f is the height of the potentiometric surface above MSL. Figure 4 shows the relationship in principle.

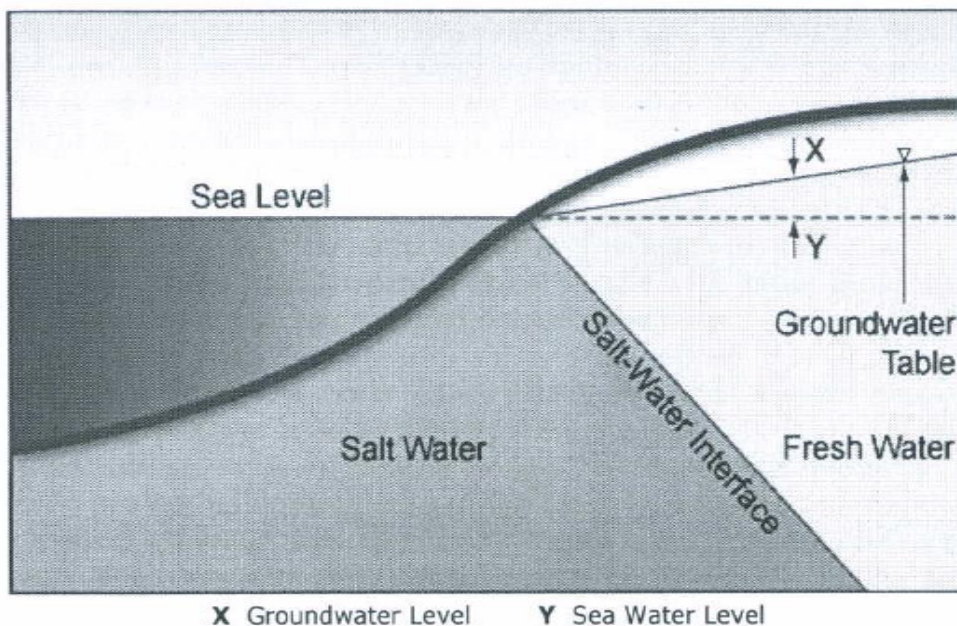


Figure 4. Saltwater-freshwater interface in the unconfined, coastal aquifer.

Using this relationship, the depth to the saline wedge has been calculated from the outputs of Simulation 3 and Simulation 6. The depth to the saline wedge after 90 days of pumping for the two different scenarios is shown in Appendix K1 and K2 respectively.

The results indicate that the saltwater interface is likely to be located some 60 m below MSL at a distance of 300 m inland of the coastline (assuming that the aquifer system consists of a single unconfined aquifer) dropping to 140 m below MSL at a distance of 800 m in from the coastline. The production wells are located more than 1700 m from the coastline and the depth to the saltwater interface is expected to well exceed the depth of the aquifer in this area.

Saline intrusion to the Waimea aquifer could occur either through vertical leakage or through horizontal intrusion through the outcrop of the aquifer under the seabed. The predicted minimum

head equipotential is above mean sea-level in all aquifers during pumping and the maximum extent of the drawdown cone in the pumped aquifer extends only a short distance offshore at one location. It is therefore considered that the risk to the pumped aquifer is low. However because saline intrusion is irreversible, an appropriate monitoring programme should be established, irrespective of the final solution selected, to provide warning of changing conditions.

It is recommended that checking of electrical conductivity in all existing wells (as far as practicable) be carried out and a programme of long term monitoring be established to allow this risk to be better quantified (in modelling) and to provide for long term protection of the water resource.

The following could also be considered:

- n Installing a series of monitoring bores screened in the shallow unconfined aquifer between the well field and the coast. These wells would be fitted with electrical conductivity probes and monitored on a continuing basis;
- n An annual survey of electrical conductivity (and chloride concentration if sampling is possible) in as many existing wells as is possible;
- n Undertaking a resistivity survey with the objective of identifying the present position of the salt water/ fresh water interface.

MfE, 2009² recommends that the consequences of a sea level rise of at least 0.45 m be considered as part of expected climatic changes to 2060 – 2069. A sea level rise would result in a small shift of the coastline and saltwater/freshwater interface inland over time, and hence an increased risk of saline intrusion to the existing wells near the coast. However even with a reduction of 0.45 m, modelling suggests that the minimum head equipotential would remain above mean sea level.

7 Conclusions

Constant rate pumping tests were carried out in three existing production wells in order to provide information about the aquifer characteristics. The pumping periods were followed by recovery until each pumping well had fully recovered. The results were analysed and used for calibrating the numerical groundwater model.

Based on existing geological and hydrogeological information a groundwater model was set up and calibrated. Steady state and transient calibrations were carried out using average groundwater levels and results from the pumping tests. The calibration is considered good. The model has then been used to predict changes to groundwater levels resulting from abstraction and injection in the unconsolidated sand and gravel aquifers.

Simulations have been run to assess the viability of abstracting 32,000 m³/day from the well field for periods of 60 days and 90 days per year for 10 years. The results suggest that without injection prior to abstraction the maximum drawdown in the shallow unconfined aquifer would be about 2 m and a drawdown of up to 14 m would occur in the Waimea aquifer (where the production wells are closely spaced). However the drawdown cone in the deep aquifer would extend beyond the coastline. In the long term this could result in inland migration of the saltwater/ fresh water boundary, and ultimately compromise the aquifer. Once the process of saline intrusion is initiated, it cannot be reversed. We would therefore recommend a significant margin of safety on the modelled viable abstraction rate; this is tested in simulation 6 with a doubled abstraction period each year.

² MfE, March 2009: Preparing for Coastal Change: A guide for Local Government in New Zealand

A lower risk option for maintaining the position of the saltwater/ freshwater interface is to recharge the wells with surplus river water in the period that abstraction is not taking place.

Simulations with injection at 10,000 m³/day (24 hours/day) over a 5 month period, followed by abstraction of 32,000 m³/day for 90 days have been run. Not surprisingly, the simulations suggest that use of injection lessens the effect on the Waimea and shallow aquifers both in terms of the maximum drawdown and in terms of the areal extent of drawdown. It is therefore strongly recommended that injection wells be used to avoid the risk of irreversible draw-in of the salt water interface. In order to reduce the risk of saline intrusion the injection wells should be located downstream of the well field or the most downstream abstraction wells could be used for both injection and abstraction.

A summary of the modelled simulations are shown in Table 11. The table shows that the key benefits of injection (compare simulation 1 with simulations 4 and 5) are the reduction of the amount of drawdown and a significant reduction in the extent of drawdown.

Table 11 - Summary of Modelling Results

Simulation	Description	Maximum Drawdown, Waimea Aquifer [m]	Maximum Drawdown, Shallow Aquifer [m]	Approximate extent of 2 m drawdown contour in the Waimea Aquifer from well field [m]	Pumping Period [days]
1	370 l/s abstracted from 6 existing wells and 3 new wells north of the existing well field for (i) 60 days and (ii) 90 days per year. Abstraction from 9 wells	14	1.6	1300	90
2	120 l/s <i>injected</i> through 3 new wells for 150 days followed by 370 l/s abstracted from 6 existing wells. Abstraction from 6 wells	16	1.2	1200	60
3	370 l/s is abstracted from 6 existing wells and 6 new wells for 90 days per year Abstraction from 12 wells	8	2.0	1000	90
4	120 l/s is <i>injected</i> through 3 existing (K4, K5 and K6) wells for 150 days followed by abstraction at 370 l/s from 6 existing wells and 3 new wells for 90 days. Abstraction from 9 wells	6	1.6	800	90
5	As for simulation 4 with a varied abstraction profile according to likely abstraction practice Abstraction from 9 wells	6	1.4	750	90

Simulation	Description	Maximum Drawdown, Waimea Aquifer [m]	Maximum Drawdown, Shallow Aquifer [m]	Approximate extent of 2 m drawdown contour in the Waimea Aquifer from well field [m]	Pumping Period [days]
6	As for simulation 4 with an abstraction period over 180 days. Abstraction from 9 wells	6	2.3	1000	180

In order to check the performance of each well, a constant rate pumping test of at least one week duration should be carried out in each of the wells not yet tested in this study, from which abstraction or to which injection is proposed.

In order to investigate the risk of saline intrusion to the aquifer systems further it is recommended that the following be considered:

- n Installing a series of monitoring bores screened in the shallow unconfined aquifer between the well field and the coast. These wells should be fitted with electrical conductivity probes and monitored on a continuing basis;
- n Checking electrical conductivity (and chloride concentration if sampling is possible) in as many of the existing wells as possible, and perhaps repeating this survey annually;
- n Undertaking a resistivity survey with the objective of identifying the present position of the salt water/ fresh water interface.