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Investigating the sustainable use of shallow groundwater on the Kapiti Coast

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Executive summary

The shallow groundwater found in the dune belt deposits along the Kapiti coast is a valuable local resource that is being widely used in some areas. In Raumati, Paraparaumu and Waikanae, the aquifer is used extensively for garden irrigation. This use has been largely driven by restrictions imposed by the Kapiti Coast District Council on the use of the public water supply system for garden irrigation. Although the individual abstractions are very small (<$5m^3$/day), the cumulative environmental impact of several thousand garden irrigation wells is of concern because there is little information on the recharge and discharge dynamics of the shallow groundwater resource. In particular, assessing and managing the potential adverse effects of abstraction upon groundwater dependent ecosystems such as wetlands, streams and springs is of critical importance. Field investigations have recently been undertaken to further understand the shallow groundwater environment and the ecohydrology of the Kapiti Coast. This work has included: a groundwater level survey, the monitoring of spring discharge (the Waimeha Stream), the instigation of a water metering survey to gauge actual volumes of groundwater being used, and the detailed investigation of an important wetland area (Te Harakeke) to provide an understanding of the interactions between wetland ecosystems and groundwater.

To help understand the cumulative effects of the development of the shallow aquifer and to assess the long-term sustainability of the groundwater resource, a numerical groundwater flow model has been developed. The model incorporates the shallow unconfined and semi confined aquifers within the Waikanae Groundwater Zone. The modelling study has provided a conceptualisation of the shallow groundwater environment, the recharge and discharge mechanisms, and an assessment of current groundwater abstraction quantities.

The model was calibrated under transient flow conditions for the period 1997 – 2003 against groundwater level monitoring data and measured river flow losses or gains to groundwater. The average flow balance predicted by the model shows the recharge to the Waikanae Groundwater Zone shallow aquifers is derived largely from rainfall infiltration which accounts for about 65% of the total recharge. The remaining 35% is derived from leakage through the beds of rivers and streams. The Waikanae River above Jim Cooke Park is the principal source of streambed leakage which provides about 90% of the total steam leakage into the shallow groundwater system. The principal outflows from the shallow aquifer system occur as discharge back into the numerous streams and drains, and as offshore discharge. About 75% of the discharge into rivers and streams occurs to the Waimeha Stream and lower Waikanae River in roughly equal proportions. Flow to the deeper Parata gravels is also significant and averages 14ML/day.

The current average daily irrigation abstraction accounts for only 3% of the aquifer recharge. However, the daily abstraction in relation to aquifer recharge is significantly higher during peak demand, low recharge periods. During dry summers, total irrigation abstraction increases up to about 6ML/day (about 35% of the recharge to the aquifer which is solely riverbed leakage). The abstraction during dry periods is largely supported by water released from aquifer storage causing the water table to seasonally decline by about 1m.

Various abstraction scenarios have been explored using the model to assess the cumulative effects of irrigation and the sustainability of the abstraction, and to provide a basis for the effective management of the resource. The modelling indicates that the cumulative effect of the abstraction upon groundwater dependent ecosystems is minor. It also indicates that if abstraction were doubled, then the effects would remain minor. The risk of saline intrusion risk relating to garden well abstraction has also been shown to be negligible.

Since larger (>20 m^3/day) individual groundwater abstractions from the shallow sand aquifer and deeper aquifers would have a much greater potential to adversely affect groundwater dependent ecosystems, several resource management actions are recommended:

- Creation of a 150m buffer zone around recognised wetlands and springs within which all groundwater abstractions, drainage and surface water diversions would be controlled.

- The adoption of stringent monitoring requirements for large groundwater takes in the Waikanae Groundwater Zone incorporating surface water and shallow aquifer monitoring where appropriate.

Additional environmental monitoring in the form of continuous recording of selected wetland water levels and spring flows is recommended.

1. Introduction

The shallow groundwater found in the dune belt deposits along the Kapiti coast (Figure 1) is a valuable local resource that is being rapidly developed in some areas. In Raumati, Paraparaumu and Waikanae the aquifer is used extensively for garden irrigation. This use has been largely driven by restrictions imposed by the Kapiti Coast District Council on the use of the public water supply system for garden irrigation. Restrictions have been necessary because the peak summer demand for water exceeds the volume that can be supplied from the Waikanae River.

Although the individual abstractions are very small, the cumulative environmental impact of several thousand garden irrigation wells is of concern because there is little information on the recharge dynamics of the shallow groundwater resource. In particular there is a need to assess and manage the potential adverse effects of abstraction upon groundwater dependent ecosystems such as wetlands, streams and springs.

Greater Wellington’s first step in response to the concern over the sustainability of the shallow aquifer was to expand the groundwater level monitoring programme. This expansion took place in 2000 and coincided with a change to the Regional Freshwater Plan that required a resource consent for all wells installed on the Kapiti Coast. The previous permitted activity approach toward shallow wells meant that the location and number of new wells was not being recorded accurately.

Field investigations have subsequently been undertaken to further understand the shallow groundwater environment and the ecohydrology of the Kapiti Coast. This work has included: a groundwater level survey, the monitoring of spring discharge (the Waimeha Stream), the instigation of a water metering survey to gauge actual volumes of groundwater being used, and the detailed investigation of an important wetland area - Te Harakeke (Phreatos, 2002).

To help understand the cumulative effects of the use of the shallow aquifers on the Kapiti Coast and to assess the long-term sustainability of the groundwater resource, a numerical groundwater flow model has been developed. This report describes the construction and calibration of the groundwater flow model. Various abstraction scenarios are then explored to assess the sustainability of the aquifer to provide a guide to the effective management of the resource.

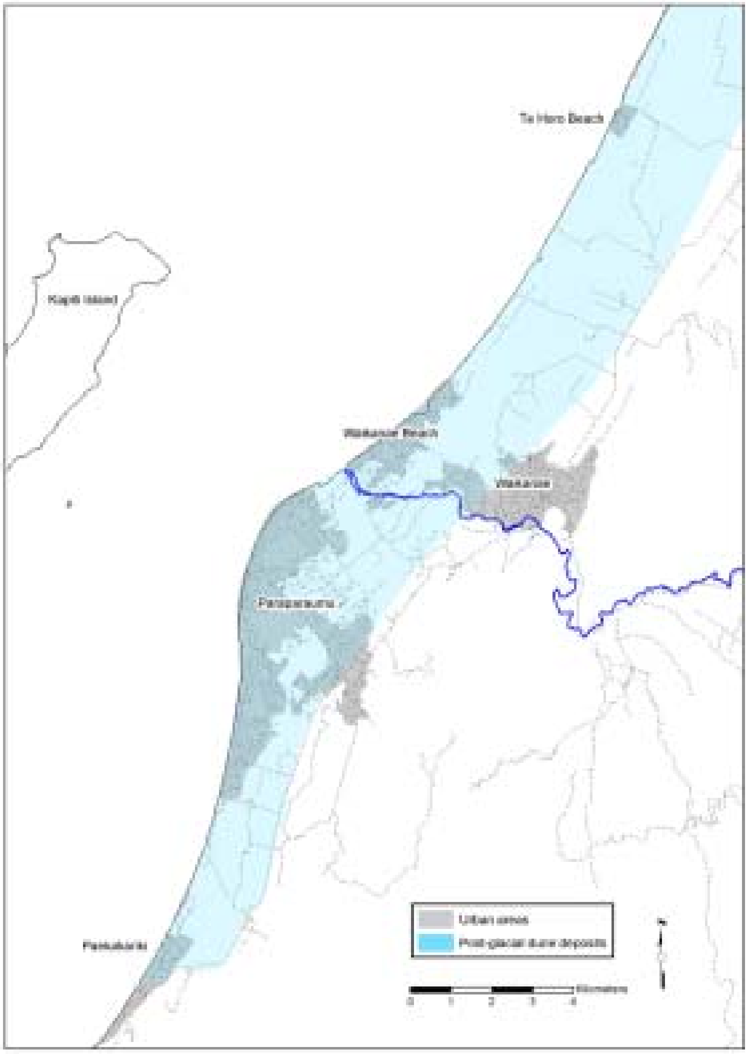


Figure 1: The Southern Kapiti Coast and the extent of the post-glacial dune deposits

2. Aims and objectives of modelling

The specific objectives of the modelling study are to:

- Characterise and conceptualise the shallow hydrogeological environment.
- Estimate current shallow groundwater abstraction.
- Characterise and quantify recharge processes.
- Assess the hydraulic properties of principal hydrostratigraphic units
- Evaluate the water balance for the shallow groundwater system including flows between surface water and groundwater.
- Predict the impacts of continued and future abstraction stresses on groundwater dependent ecosystems.
- Recommend groundwater management options for the shallow groundwater environment of the Kapiti Coast.
- Recommend further investigation or monitoring work.

3. Geological setting

The present day coastal plain and the sequence of underlying strata are the product of geological processes that have occurred during the last 400,000 years. During this time the main influence on geological processes has been climate change cycles that have produced alternating cold glacial, and temperate climatic conditions. Superimposed on these climatic cycles are tectonic events that include uplift of the Tararua Range east of Waikanae and Paraparaumu.

During the Waimea (penultimate) glaciation, severe erosion in the Tararua Ranges caused the deposition of great thicknesses of gravels in valleys fanning out westwards from the foothills. This event was followed by an interglacial period between about 130,000 and 70,000 years before present (BP) when sea level rose to between 4 and 6m above the present level. The sea cut back into the coastal hills to form a prominent line of cliffs that are clearly visible along the Kapiti Coast.

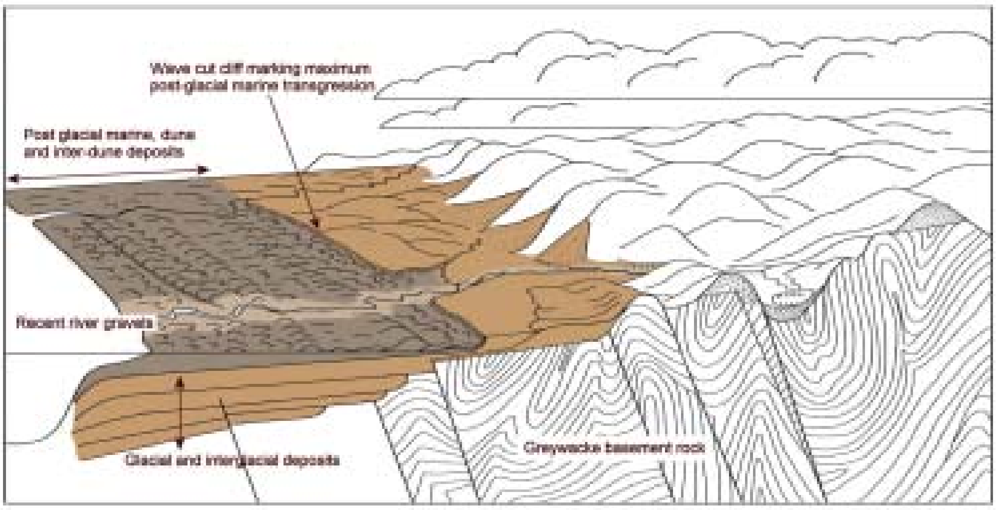


Figure 2: Diagrammatic cross section through the Waikanae area to illustrate the local geological succession

The last glaciation, the Otiran, commenced some 70,000 years BP when the sea level dropped and massive scree and debris flows filled drainage courses flowing westwards off the hills. During the peak of the glacial period, sea level was up to 120m lower than it is at present. Much of the erosional material was transported out onto broad out-wash plains by debris-filled rivers where it formed thick alluvial deposits of gravel, sand and silt. These deposits, called the Parata Gravels, are exposed in the banks of the Waikanae River.

Some 6,500 years ago the sea level attained its present level following the last glaciation (ending 10-11,000 years ago). The rising sea level eroded the land as it moved inland to the thermal maximum level, and a flat sea bed was cut back to a low cliff line (seen today at the junction between Park Avenue and Ngarara Road) and along the entire coast (largely obscured by later sand deposits). Subsequent progradation of the coast resulted in the formation of extensive lagoons and swamps. Deposits from these swamps are called the Paraparaumu Peat and underlie much of the seaward edge of the Kapiti Coast.

The withdrawal of the sea to its present position coincided with the beginning of large scale volcanic activity on the North Island which sent huge volumes of pumice and ash down rivers like the Wanganui and Rangitiki. Once this pumice and ash reached the coast it was worked into sand and mud and moved southwards down the coast where it was blown inland and formed a line of dunes parallel to the coast. The Foxton Dunesands, which mantle the thermal maximum cliff line, were formed at this time (4000-2000 BP).

Subsequently, the massive Taupo eruptions of AD130 mantled much of the North Island with ash and pumice which was transported to the coastline, broken down and deposited along the Manawatu and Horowhenua coastline. The deposits form a very prominent line of high dunes – the Taupo Dunes - marking the coastline around 1875 years BP.

Sediment continued to be added to the coastline from inland erosion and the coastline prograded as the most recent dunes formed. These dunes are divided into an older set called the Motuiti Dunes (<1000 years BP) and a younger set called the Waiterere Dunes (<100 years BP and still accumulating). These two younger dune building phases are considered to have been triggered by the destruction of vegetation on stabilised older dunes near the coast that followed the arrival of the Maori (Motuiti Dunes) and later the Europeans (Waiterere Dunes).

Along the course of the Waitohu Stream, Otaki River and Waikanae River, alluvial gravel and sand has continued to be deposited. This material and recent peat and dune deposits have formed a wedge of sediment over the older glacial gravels. This post-glacial wedge of sediment contains a shallow unconfined aquifer.

Construction of a public supply wellfield by the Kapiti Coast District Council has provided extensive subsurface information that has allowed a reassessment of the geological history of the coast (URS, 2004). This assessment has provided an improved conceptual model for the deep aquifers that were the focus of the wellfield project.

4. Hydrogeology

4.1 Kapiti Coast groundwater zones

The Kapiti Coast has been divided into six groundwater zones (Figure 3) on the basis of physical aquifer characteristics, topography and aquifer chemistry (WRC, 1994). Shallow unconfined and semi-confined aquifers occur in the wedge of post-glacial sediments in the Raumati/Paekakariki, Waikanae, Coastal and Waitohu groundwater zones.

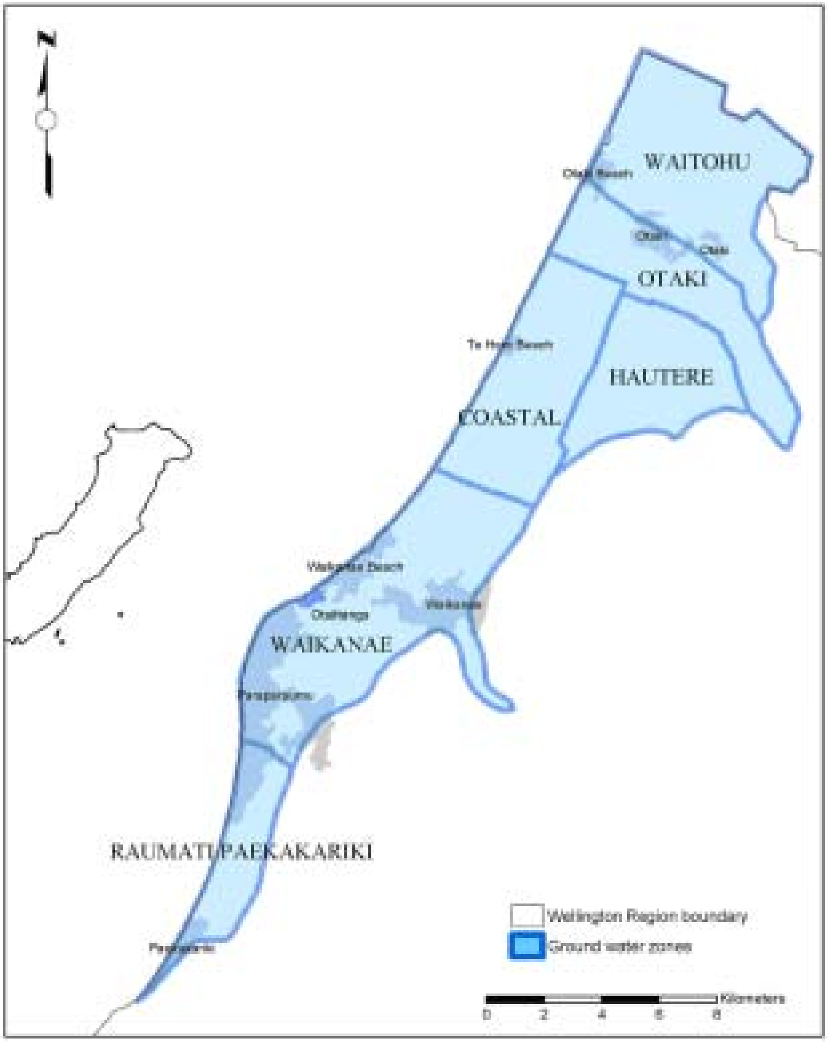


Figure 3: Kapiti Coast groundwater zones

This study focuses on the shallow ground water of the Waikanae Groundwater Zone, which has been divided into three sub-zones (Figure 4) on the basis of depositional history and lithology:

- Northern Waikanae sands - beach and dune sand deposits north of the former and present course of the Waikanae River.
- Southern Waikanae sands - beach and dune sand deposits south of the present course of the Waikanae River.
- Waikanae shallow gravel – recent gravel and sand deposited and reworked by the Waikanae River.

The northern and southern areas are very similar being predominantly sand. The central area has very different aquifer characteristics because it is predominantly gravel and in direct hydraulic connection with the river.

The sands to the north and south of the Waikanae River have a variable thickness of between approximately 5 and 30m, thickening towards the coast.

This wedge of dune sand is however, locally heterogeneous, with numerous discontinuous peat and organic layers. Aquifer conditions in this unit therefore vary between unconfined and locally semi-confined, with occasional perching above low permeability lenses.

The shape of the Waikanae Gravels sub-zone is irregular and reflects the present and recent courses of the river. The gravels are hydraulically connected with the river and become semi-confined with depth. The base of the gravels is undefined and this unit is regarded to be in hydraulic continuity with deeper strata.

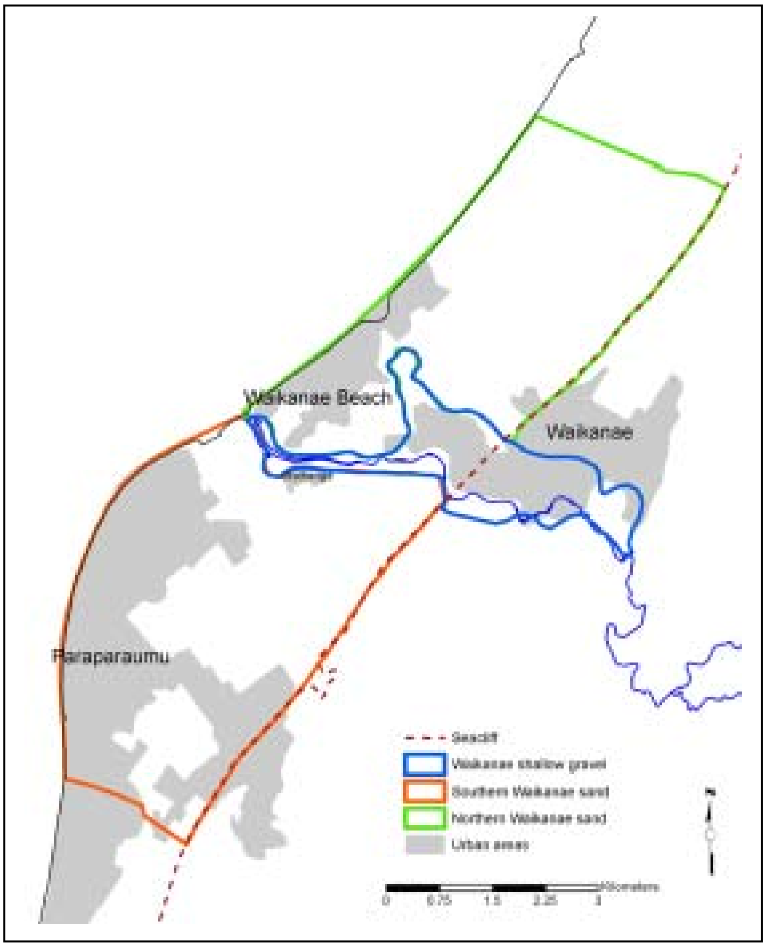


Figure 4: Waikanae groundwater zone sub-zones

Underlying aquifers

Gravel, silt and sand deposits lie beneath the post-glacial deposits that host the shallow Kapiti groundwater system. These deposits form a thick sequence of aquitards and aquifers which are being currently targeted by the District Council for public water supply. Greywacke bedrock was encountered at Waikanae Park on Park Avenue at a depth of 86.5m below ground. This depth is much shallower than expected and may reflect faulting of the basement surface.

4.2 Groundwater levels and flows

Groundwater levels in the Waikanae Groundwater Zone are measured at a number of monitoring wells to provide a record of long term level trends. Four shallow monitoring wells are located in the Southern and Northern Waikanae Sand unconfined aquifer at:

- McLean Park, adjacent to the boating club carpark.
- Golf Tech driving range on Milne Drive.
- Larch Grove children's playground.
- Rangihiroa Street, at the District Council depot.

The locations of the wells are shown on the map in Figure 5.

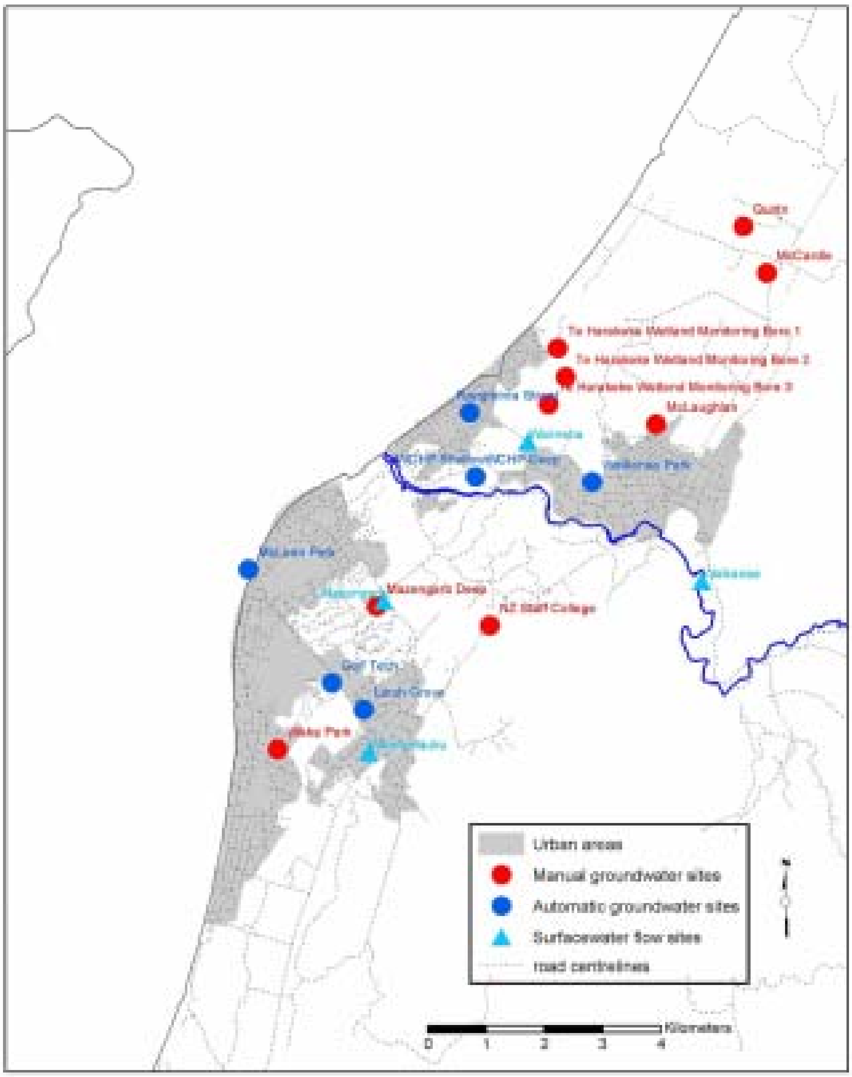


Figure 5: Water level monitoring sites in the Waikanae Groundwater Zone

Water levels in the monitoring wells are continuously monitored using data loggers and the hydrograph for each is shown in Figure 6.

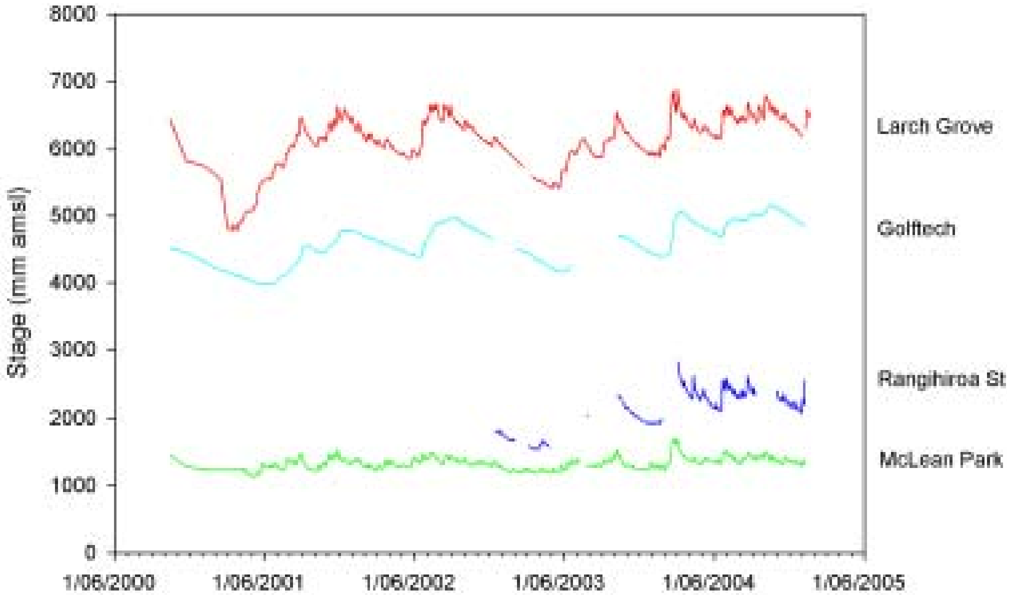


Figure 6: Waikanae Groundwater Zone monitoring well hydrographs

The hydrographs show a seasonal pattern with the lowest water levels typically recorded in April and the highest levels in October. The seasonal variation is up to 1.5 metres, but a 1 metre fluctuation appears to be more common. Marked increases in ground water level correlate strongly with significant rainfall events indicating that the aquifer responds rapidly to rainfall recharge. A strong correlation is observed when calculated recharge based on soil moisture balance modelling is compared to the monitoring well hydrographs as shown in Figure 7. The calculation of rainfall recharge is described fully in Appendix 1, and discussed further in Section 4.4.

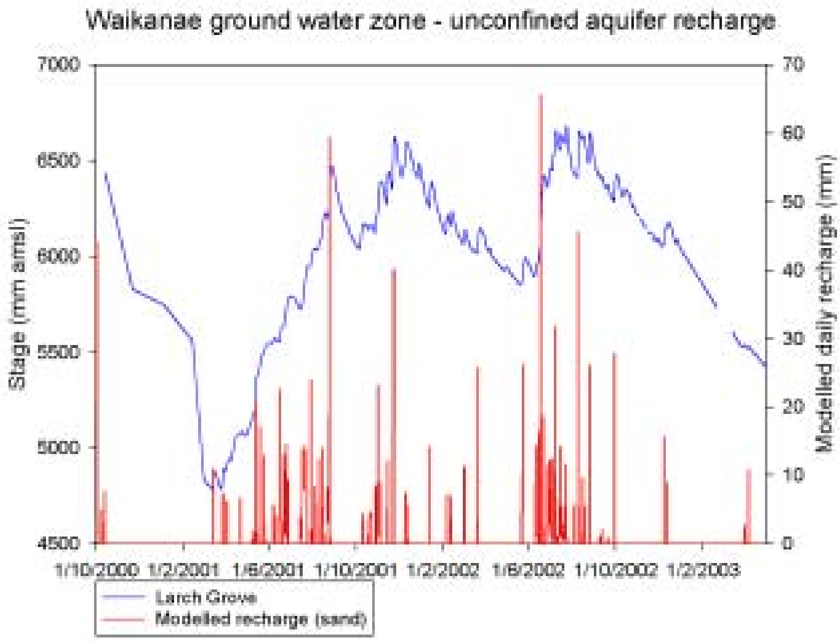


Figure 7: Calculated groundwater recharge and observed groundwater level in the Larch Grove monitoring well

To map out the groundwater flow net for the unconfined sand aquifer, a network of 40 privately owned shallow wells spread between Raumati and Waikanae Beach has been established. Elevations for each well were obtained using Trimble RTK GPS survey equipment (vertical accuracy: +/- 20mm). Since the establishment of the network in 2002, water levels have been measured on the following dates:

- 18 July 2002
- 24 September 2002
- 20 November 2002
- 23 December 2002
- 28 January 2003
- 4 March 2003
- 17 April 2003
- 2 July 2003

Water table contour plots for each survey date were interpolated and are shown in Figure 8. The large localised deflection in some contour lines is attributed to pumping in nearby wells at the time of measurement and may also reflect the influence of the local drainage network on the water table.

Overall, there is a consistent inland shift in the contour lines with surveys from July 2002 to April 2003 indicating a reduction in water level. This shift is consistent with the groundwater level recession observed in monitoring wells for that period. This shift is greatest inland, which is also consistent with the larger variation in groundwater level observed inland compared with at the coast. The survey in July 2003 shows a seaward contour shift that reflects a ground water level increase.

Figure 8 shows groundwater flow is generally concordant with the gentle seaward slope of the coastal plain. The more permeable Waikanae Shallow Gravel may deflect the contours up-gradient but there are no monitoring wells in this aquifer zone to confirm such a pattern.

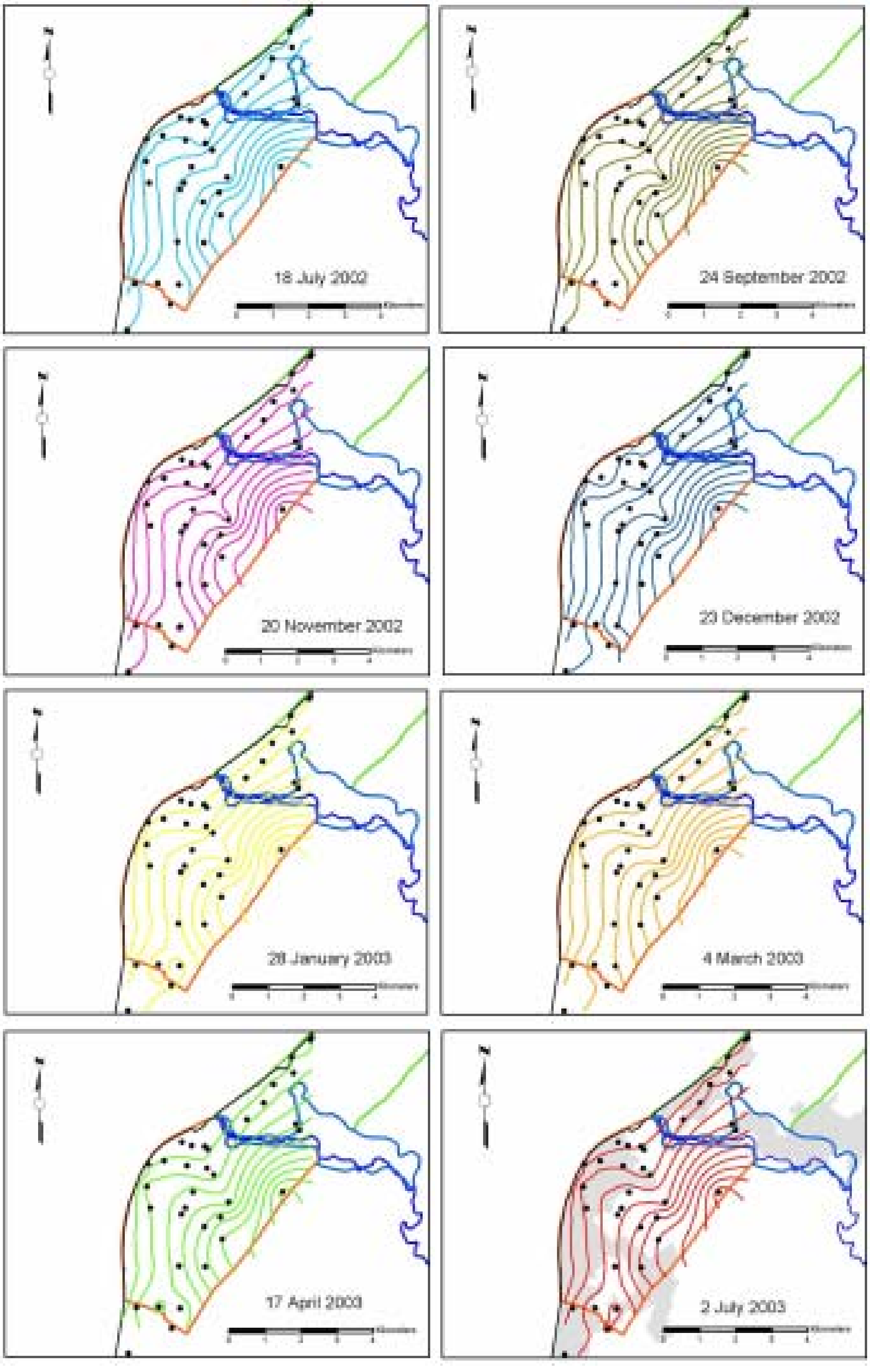


Figure 8: Water table contours for the Waikanae Groundwater Zone between July 2002 and July 2003. The contour interval is one metre with the western-most contour on each plot being one metre above mean sea level.

The observed vertical flow gradients between the shallow sand and gravel aquifers and the deeper gravel strata vary across the coastal plain. Westward of a line close to the post-glacial sea cliff the gradient is upward as shown by a head difference of 600mm between a deep well (74m) and a shallow well (21m) at the Waikanae Christian Holiday Park. The upward gradient is also shown by flowing artesian conditions at one of the District Council's wells on Smithfield Road and the emergence of the springs that create the Waimeha

Stream. Closer to the State Highway the hydraulic gradient is downward and it is in this area that the river loses flow to groundwater.

4.3 Rainfall recharge

The shallow unconfined aquifers of the Waikanae Groundwater Zone receive recharge principally from rainfall infiltration and also through streambed leakage from the Waikanae River. Other sources of inflow include upward leakage from deeper aquifers, and lateral inflow from older terrace sediments to the east.

Rainfall recharge is distributed across the area but is considered to be spatially variable due to soil type, underlying geology and land use variables. On this basis, six recharge zones have been identified:

- Urban sand
- Non-urban sand
- Urban peat
- Non-urban peat
- Urban older gravel terrace (Parata)
- Non urban older gravel terrace (Parata)

Figure 18 (Section 5.5.2) shows the locations of the recharge zones.

Recharge over areas of the same soil type in the urban areas is regarded to be less than non-urban areas due to the presence of impermeable surfaces (roads and buildings). Watts (2002) showed that approximately 30% of rainfall is intercepted in Kapiti urban areas.

Rainfall recharge has been quantified using a soil water balance model (Bekesi, 1998) similar to that employed by Scott and Thorpe (1999) and the original recharge model used for the Waikanae Groundwater Zone (Cussins, 1994).

Recharge associated with two soil types has been modelled – the Paraparaumu Peat and the dune sand. The soil properties used in the soil moisture balance modelling were derived from previous studies and published values for similar soil types. Appendix 1 contains a detailed description of the methodology, the parameters used for the soil types, and the modelled recharge outputs. Figure 9 shows the modelled weekly recharge derived from the soil moisture balance calculations for the period 1/1/97 to 1/5/03.

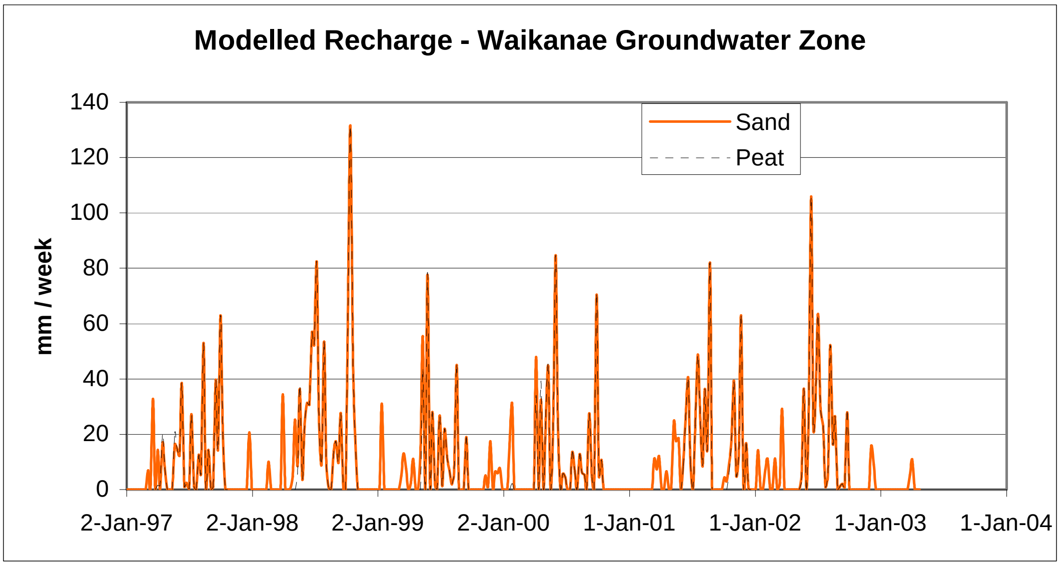


Figure 9: Calculated rainfall recharge for peat and sand soil types (non-urban)

Recharge over sand is greater than over peat, which retains a higher soil moisture store. The calculated average annual recharge is 535mm for sand, and 448mm for peat.

The two modelled recharge series have been used in the numerical groundwater model to describe the six recharge zones using an urban run-off coefficient of 0.3 (Watts, 2002), and by applying a nominal factor of 0.5 to describe recharge to the older, compact terrace gravels (Parata Gravels) along the eastern edge of the groundwater zone.

4.4 Surface water – groundwater interactions

There are a number of surface water drainage features within the Waikanae Groundwater Zone. The Waikanae River is the largest system with a catchment area of 149km^2.

Other surface water features are:

- Waimeha Stream, a spring fed stream.
- Mazengarb drain
- Wharemauku Stream
- Ngarara Stream

4.4.1 Waikanae River

It is recognised that the Waikanae River interacts with the underlying gravel aquifer and that there are large flow losses to groundwater and gains from groundwater along certain reaches. The Waikanae River loses a considerable proportion of its flow to groundwater in the reach from the State Highway 1 road bridge to Jim Cooke Memorial Park (Figure 10).

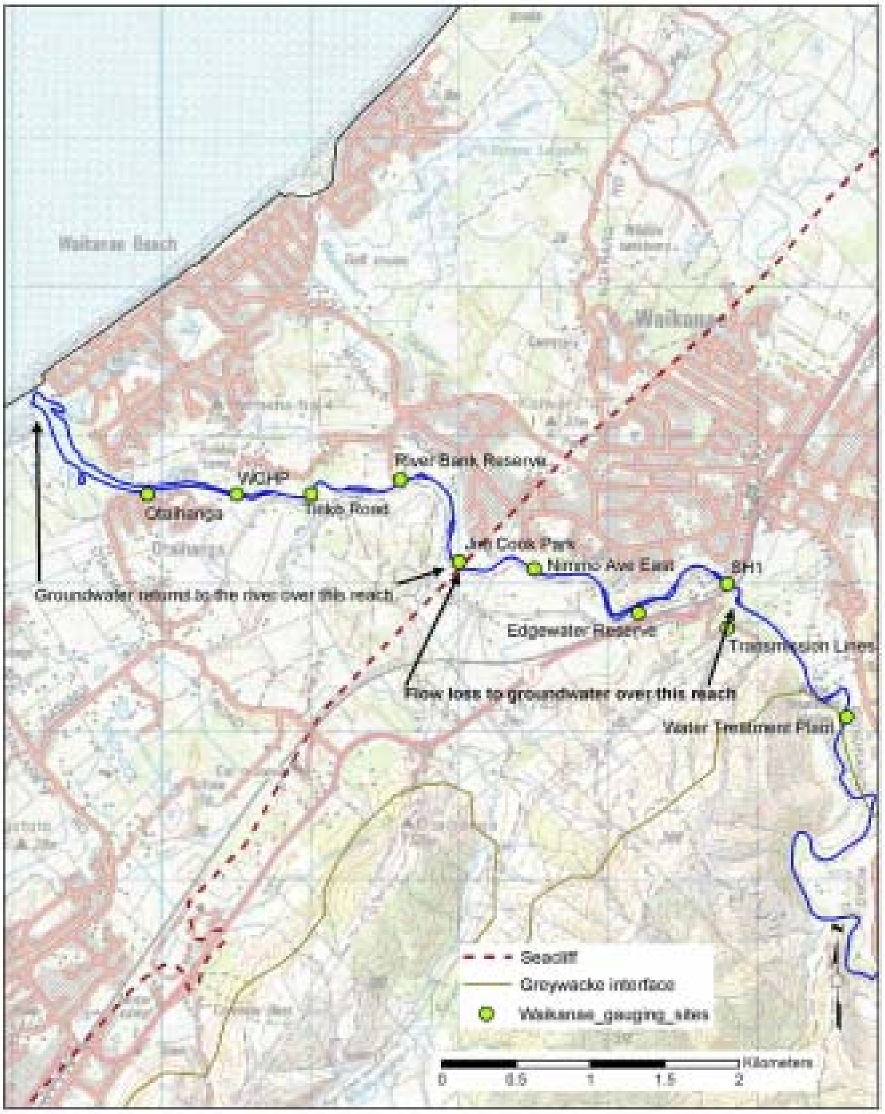


Figure 10: Waikanae River reaches and flow gauging sites

To quantify the flow losses, a series of concurrent flow gaugings were carried out during low flow conditions in early 2003. The results of these gaugings indicate there is no significant flow loss from the river between the water treatment plant and the State Highway 1 bridge. A gauging on 24 March 2003 is the only exception and indicates a loss of 80L/s from the river between the treatment plant and the Transmission Lines. Figures 11 and 12 show the gauging results.

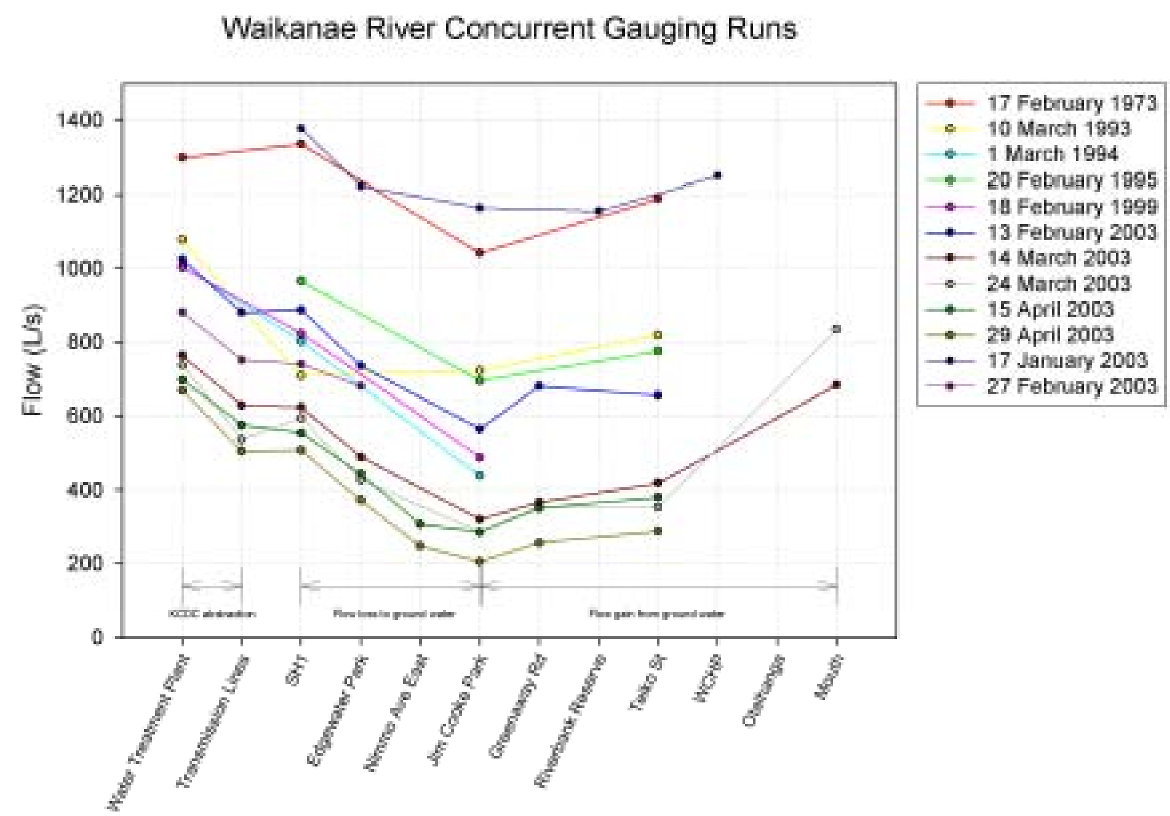


Figure 11: Waikanae River concurrent gauging data

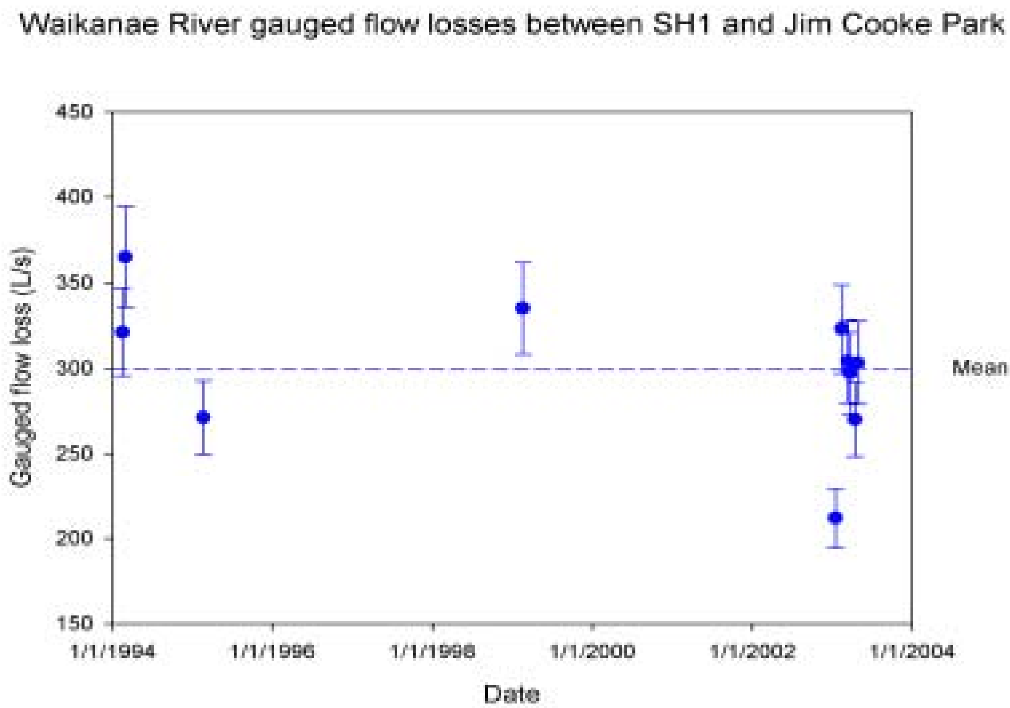


Figure 12: Waikanae River gauged flow losses between SH1 and Jim Cooke Park. The error bars show +/-8%

The gauging results indicate a mean flow loss of 300 L/s to the underlying aquifer between State Highway 1 and Jim Cooke Memorial Park. Gauging results also suggest that the river gains below Jim Cooke Memorial Park, although data are inconclusive since the flow differences are smaller than the margin of error of the measurements. The losses may be considerably higher during normal and high flow conditions.

4.4.2 Waimeha Stream

It is anticipated that much of the water lost through the bed of the Waikanae River between the State Highway 1 bridge and Jim Cooke Memorial Park remains in the shallow gravel and emerges as springs that feed the Waimeha Stream. The Waimeha Stream is entirely spring-fed and the flow in the stream near its mouth has been gauged at between 100 and 300 L/sec.

Being spring-fed, the stream water quality in the stream is very high, despite the abundant stormwater drains that empty into the stream channel. Consequently, the stream has a high ecological and aesthetic value.

4.4.3 Other streams and drains

There are numerous drains and smaller drainage systems on the Kapiti Coast (Figure 1). Besides the Waikanae and Waimeha (discussed above), the stage in the Mazengarb Drain and the Wharemauku Stream is also recorded.

Mazengarb Drain: A recorder on this drain at Scaife Drive indicates a baseflow of approximately 150 L/sec. Since the drain does not have a large catchment in the ranges, the baseflow represents groundwater inflow from the shallow unconfined Southern Waikanae Sands aquifer. However, because the Waikanae wastewater treatment plant discharges into the drain near its source, calculation of the groundwater inflow to the drain needs to take this input into consideration. On the basis of the wastewater treatment plant monitoring records, it is estimated that approximately 100 L/sec discharges from plant into the drain (Watts pers comm.). Therefore, the drain receives an average of about 50 L/sec from shallow groundwater.

Wharemauku Stream: This stream has been concurrently gauged on several occasions at the stream mouth and where the stream enters the coastal plain. The gaugings were undertaken during the summer months between 1998 and 2000 and are shown in Table 1.

Table 1: Wharemauku Stream concurrent gauging data

Gauging Date	Flow at Recorder L/sec	Flow at Mouth L/sec	Flow Gain L/sec
3/2/2000	33	40	7
28/3/2000	25	50	25
12/2/1999	18	58	40
27/1/99	18	60	50
16/4/98	15	62	47

The average flow gain for the Wharemauku Stream, using the data in Table 1, is about 34 L/sec. Because the gaugings were carried out during the summer months, and there are no significant tributaries between the gauging sites, they are likely to represent groundwater gains.

4.4.4 Wetlands

Dune accumulation and coastal progradation commenced on the Kapiti Coast about 6,000 years ago. Numerous wetlands and lagoons formed between the dunes and behind the dune belt adjacent to the ancient coastline (Section 3). The wetlands were once very extensive and were a dominant feature of the landscape prior to European settlement. Over the last century, at least 90% of the wetlands have been drained as the land was developed for agriculture. The few remaining wetland areas that escaped drainage and infilling are highly valued.

The wetlands occur where the water table in the shallow unconfined aquifer intersects (or lies very close to) the land surface in the interdunal depressions. These ecosystems are largely sustained by groundwater inflow (Phreatos, 2002) and are therefore sensitive to changes in the shallow unconfined aquifer system.

4.5 Groundwater abstractions

There are a large number of shallow garden irrigation wells abstracting from the sand aquifers in the Waikanae area. The wells are generally between 3 and 5 metres deep and abstract approximately 1-5 m^3/day. The growing number of irrigation wells – we estimate there are approximately 3000 - has created a concern that pumping of these wells may be causing adverse effects on the shallow groundwater and surface water ecosystems.

Because the abstractions are not metered, we have estimated the total amount taken from the unconfined aquifer by assuming that 50% of properties have an irrigation well. In new subdivisions this proportion of houses with wells is thought to be about right based on well records and discussions with drillers and the Kapiti Coast District Council. In more established urban areas the 50% assumption is probably conservative.

Knowledge of the quantity of water abstracted by the wells on a weekly basis, and the distribution of the abstractions, is important for the groundwater model and assessment of the potential seasonal and localized effects of the abstraction. The methodology adopted to assess this information was as follows:

- A 250 m^2 grid was laid over the area (this grid was coincident with the model grid).
- The number of properties within each grid square was analysed using GIS.
- Each grid square was assigned to one of three property density classes (Figure 13):

Class 1: 0-10 properties

Class 2: 11-60 properties

Class 3: 61 – 80 properties

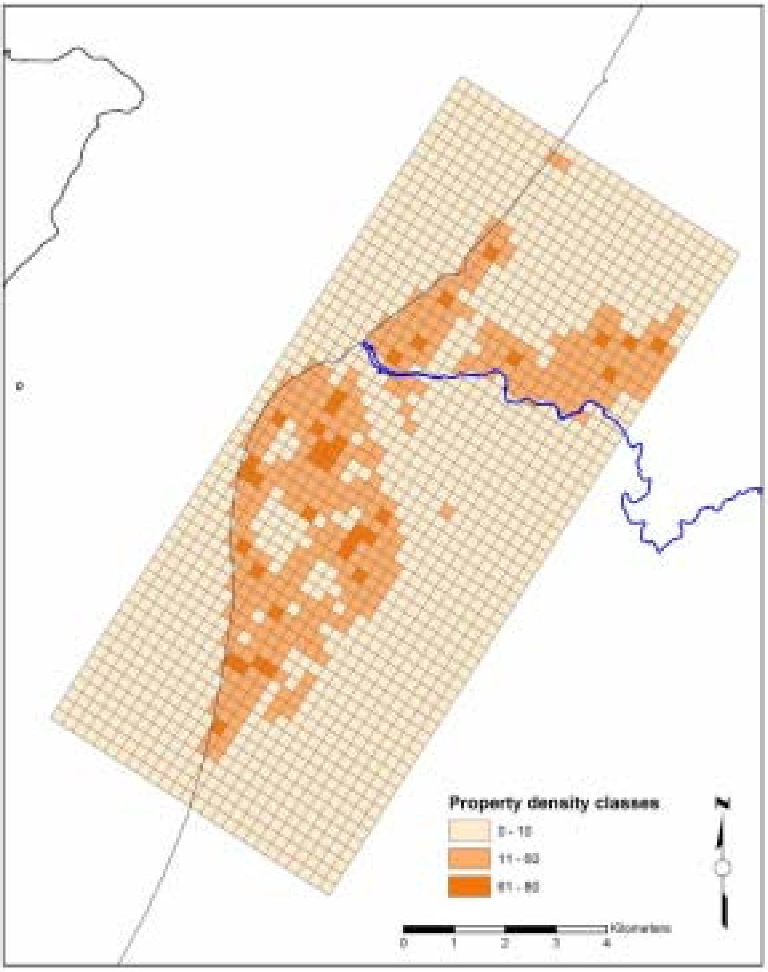


Figure 13: Kapiti Coast property density classes

- For each class, the potential irrigable area was estimated using aerial photographs (1:15000 scale) for several random grid squares representative of each class. The potential irrigable area was defined as the area that might reasonably be irrigated with shallow groundwater (i.e. gardens and lawns). The irrigable areas defined for each class, as a percentage of the 250 m^2 grid square, are as follows:

  Class 1: 5%

  Class 2: 15%

  Class 3: 20%

- We assumed that half the potential irrigable area is in fact irrigated to account for our assumption that 50% of properties have wells.

- The water abstracted from each grid cell was assumed to be the amount of water required to keep the soil profile saturated and was calculated using the soil moisture balance model (Appendix 1). The water abstracted per cell was calculated from the following relationship:

  Irrigation abstraction = (0.5 potential irrigable area) * (PET – Rainfall)

  Any over-irrigation was assumed to return directly to the groundwater.

Using the above methodology, Figure 14 shows the modelled abstraction as weekly totals for the period 1/1/97 to 1/5/2003.

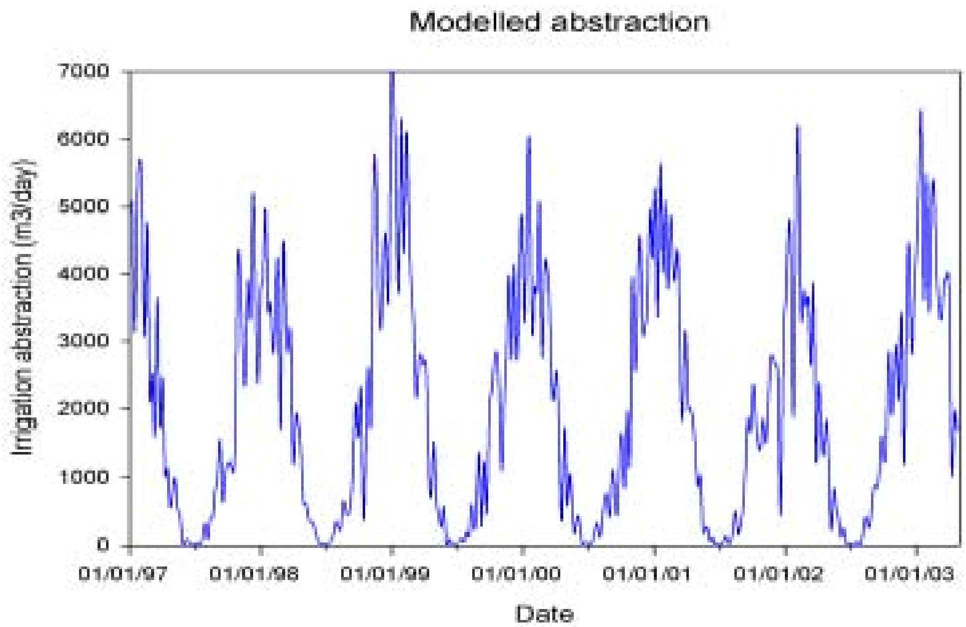


Figure 14: Calculated cumulative irrigation abstraction from the shallow sand aquifers on the Kapiti Coast

Figure 14 illustrates the highly seasonal irrigation demand that peaks at about 6,000m^3/day. The average daily abstraction is 2,000m^3/day.

4.6 Hydraulic properties

The hydraulic properties of the shallow sand and gravel units of the Waikanae Groundwater Zone, and the deeper Parata Gravels, have been assessed using historical pumping test and piezometer slug test data. The data provide a range of values for each unit (Table 2).

Table 2: Hydraulic properties of Principal Hydrostratigraphic Units

Unit	Range of Hydraulic conductivities (m/day)	Estimated Bulk Hydraulic conductivity (m/day)	Estimated Storage Coefficient
Dune Sand	0.5 – 6.0	5	0.1 – 0.2
Waikanae Gravels	3 – 220	65	0.1 – 0.2
Parata Gravels	1 – 90	20	5×10^{-4}

4.6.1 Northern and southern sand shallow aquifers

Rising or falling head tests have been performed on piezometers at seven sites in the northern and southern sand aquifers. The results of these tests show a range of hydraulic conductivities for the sand aquifer of 0.5m/day to 5.8m/day. Three sites have conductivity values less than 0.7m/day while the remaining sites have values greater than 2m/day. Sites in the northern sand aquifer tend to have higher conductivity values than their southern counterparts.

4.6.2 Waikanae gravel shallow aquifer

A limited number of single well aquifer tests for wells less than 15 metres deep within the Waikanae gravels are available. The tests indicate a wide range in transmissivity from 89 to 6655 m^2/day, and a mean value of 1700 m^2/day. The mean value is three orders of magnitude greater than the three tests available for the sand aquifers on either side of the gravel sub-zone.

4.6.3 Deeper gravels

There are a limited number of single well tests for these strata. The tests show a range of transmissivity values from 2 to 2617m^2/day. 20% of the test results have transmissivity values greater than 100m^2/day. The wide range of results indicates considerable spatial variation in the aquifer properties. However, the wide range may also be due in part to most tests being calculated using Logan’s method, which yields only approximate results that may be out by 50% or more (Kruseman and De Ridder, 1979). Consequently, most weight have been placed on the aquifer tests performed at the Christian Holiday Park (WRC, 1994) and Kapiti Coast District Council exploration wells TW2, PW1 and PW5 (PDP 1996a and 1996b).

5. Kapiti shallow-groundwater numerical model

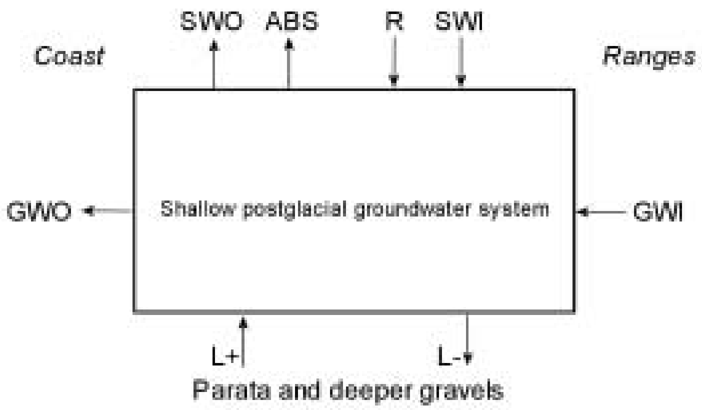
5.1 Conceptual hydrogeological model - summary

The occurrence and geometry of the various hydrostratigraphic units are described in Sections 3 and 4 of this report. In essence, the Waikanae Groundwater Zone comprises a wedge of unconsolidated sands, gravels and peats that occupy the coastal plain. These sediments host unconfined and semi confined aquifers, and overlie older gravel deposits that contain confined aquifers that are hydraulically connected to the shallow groundwater.

The principal hydrostratigraphic units are:

- dune and shallow marine sand lying to a depth of up to 30m to the north and south of the Waikanae River.
- the Waikanae River gravels extending to depth.
- Last glaciation and older, stratified gravels beneath the dune sand deposits.

The conceptual water balance for the shallow groundwater environment of the Kapiti Coast is represented schematically in Figure 15. The figure shows the principal components of the aquifer water balance.



Key:

GWI	Groundwater inflow from adjacent older glacial deposits in the east
GWO	Groundwater outflow into the sea
SWI	Surface water inflow from Waikanae River
SWO	Surface water outflow to rivers, streams, drains, wetlands and springs
R	Rainfall recharge
ABS	Abstractions
L+	Leakage from deeper aquifers
L-	Leakage to deeper aquifers

Figure 15: Conceptual Groundwater Balance – Kapiti Unconfined Aquifers

The two principal inputs to the shallow aquifer are rainfall infiltration and leakage into the aquifer through the bed of the Waikanae River. Groundwater inflows from deeper aquifers and from adjacent older material to the east of the ancient shoreline are regarded to be minor.

The principal output components of the water balance are groundwater flow into the sea, and leakage back into rivers and streams. Abstractions from wells also constitutes a significant output component of the water balance.

The groundwater flow direction within all hydro-stratigraphic units occurs towards the coast from the ranges in the east. Local distortions of this trend occur around rivers, streams and wetlands where there is a significant interaction between surface water and groundwater. There is also a significant vertical flow component between the shallow sands and gravels and deeper, older gravels. The vertical flow gradient is downwards under the inland half of the coastal plain and reverses closer to the sea.

5.2 Model code

The USGS finite difference numerical code MODFLOW (McDonald and Harbaugh, 1988) was used to model the Waikanae Groundwater Zone. The *Visual Modflow* data processing interface (Waterloo Hydrogeologic, 2003) was used to build the model and prepare the output data.

5.3 Finite difference grid design

MODFLOW uses a finite difference solution method that requires the use of a rectilinear, block-centered spatial grid and one or more layers. The model developed for the Waikanae Groundwater Zone has a grid domain of 19000m x 11000m. The grid extends some 5000m offshore to simulate the submarine discharge of deeper aquifers off the coastline. The northern and southern limits of the grid were placed arbitrarily at sufficient distance from the urbanised areas where abstraction is occurring to avoid affecting drawdown predictions.

The grid was rotated into alignment with the coastline and the cell size was set at 250m x 250m across the on-shore portion of the grid, increasing progressively to 1000m at the western off-shore boundary. Figure 16 shows the model grid and its placement over the Waikanae Groundwater Zone.

The model was designed with two layers to represent the upper unconfined aquifer and the upper portion of the deeper gravel sequence. Layer 1 was assigned unconfined aquifer conditions and represents both the dune sand and the shallow Waikanae River gravels. The base of the layer was modelled using geological data derived from well logs. The base of this layer was contoured externally using *Surfer* (Golden Software, 2003) and modified manually where data were sparse to create a consistent smoothed surface for export into *Visual Modflow*.

Layer 2 was modelled at a constant thickness of 30m below the base of Layer 1. The justification for this is two-fold: the base of the Parata Gravels is poorly defined because there are few deep wells, and the gravels are highly stratified and therefore vertical flows from depth can be regarded as insignificant. The upper 30m of this unit was considered to be the maximum thickness that would freely interact with the shallow groundwater environment.

5.4 Model boundaries

The following boundaries to the groundwater model have been assigned:

- eastern boundary: coincident with the edge of the Quaternary gravel terrace deposits and extending up the Waikanae catchment to encompass river gravel deposits.
- western boundary: placed approximately 5km west of the shoreline.
- northern and southern boundaries: placed at arbitrary distances from the urbanised areas to create a coastal aquifer zone which is 19km in length

No-flow conditions have been assigned to all external boundaries.

The model boundaries and model domain showing the finite difference grid are shown in Figure 16.

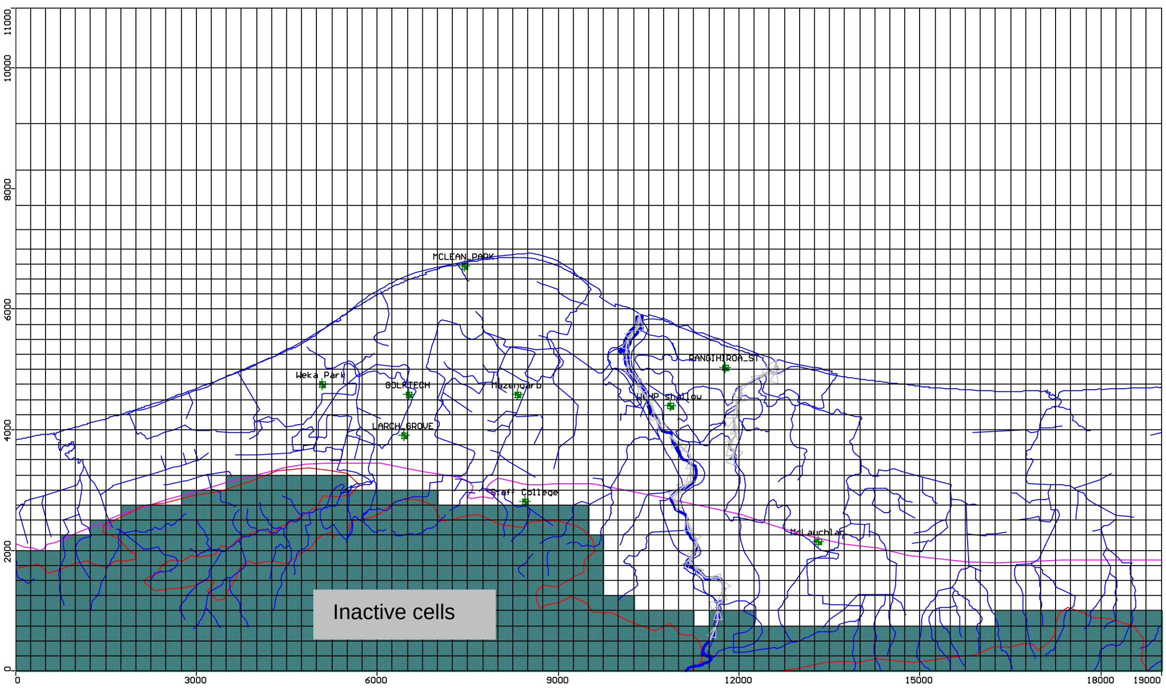


Figure 16: Model grid

5.5 Model inputs

5.5.1 Hydraulic properties

The range of hydraulic property values for the different hydrostratigraphic units is provided in Table 2 (Section 4.6).

Layer 1 of the model contains all three hydrostratigraphic units – the dune sand (north and south of the river), the Waikanae River gravels, and the Parata Gravels on the eastern terraces. The units have been mapped using geological information and extrapolated offshore as shown in Figure 17. Initially, hydraulic conductivity values were assigned in the range identified in Table 2.

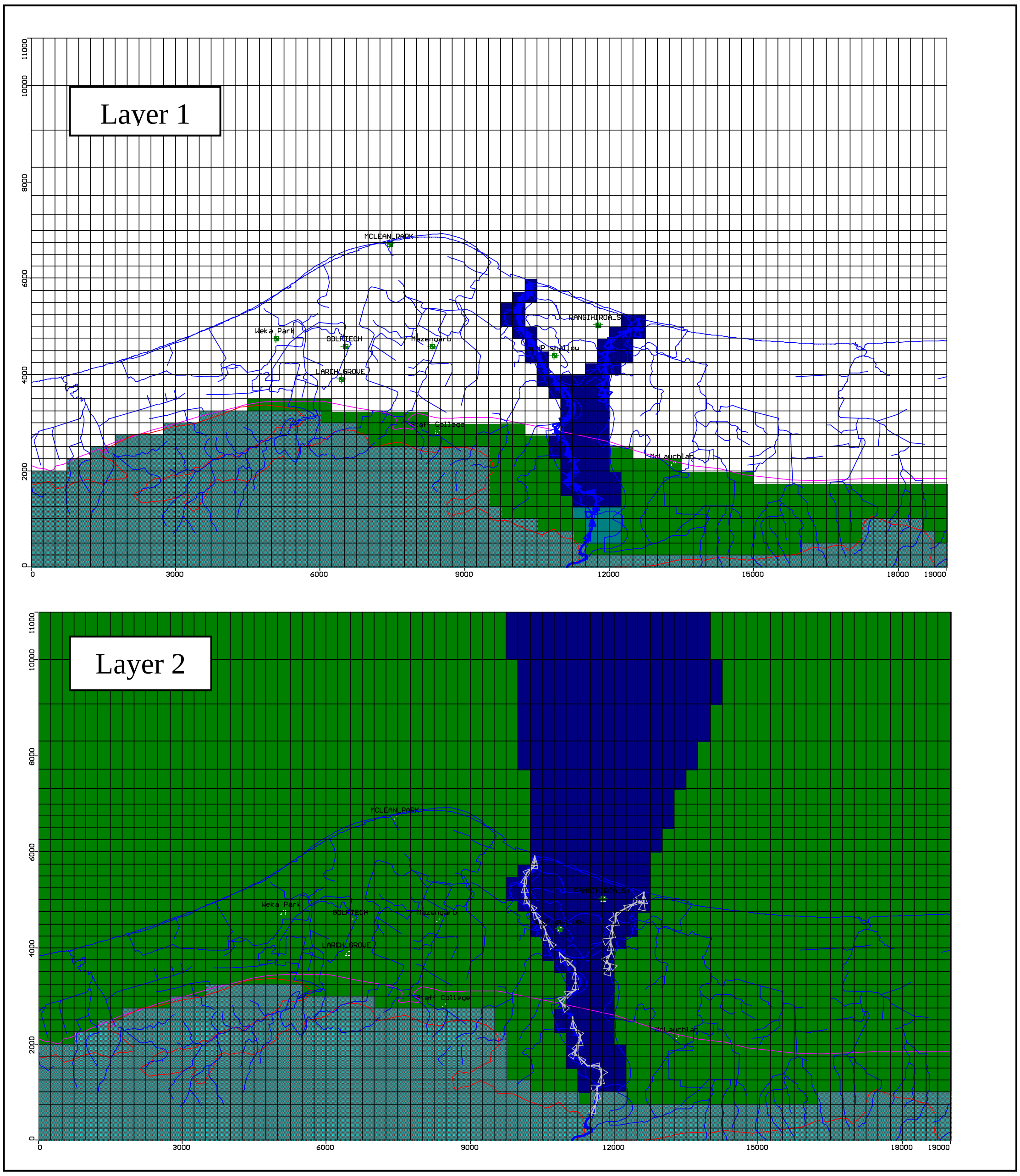


Figure 17: Hydraulic conductivity zones for layers 1 and 2. (white: dune sand, blue: Waikanae River gravels, green: Parata Gravels).

Layer 2 contains two hydrostratigraphic units, the Waikanae River gravels and the Parata Gravels. These were assigned hydraulic conductivity values consistent with the same units in Layer 1.

The flow between Layer 1 and Layer 2 is governed by the vertical hydraulic conductivity (k_z) assigned for each layer. Initially, k_z was set at two orders of magnitude lower than $k_{x,y}$ for the sands and Parata Gravels. The k_z for the

Waikanae Gravels was set higher to allow free movement of water from the river to deeper levels in order to simulate the observed flow losses from the river.

5.5.2 Recharge

Recharge was spatially assigned on the basis of the six zones described in Section 4.4 and the modelled recharge zones are listed in Figure 18:

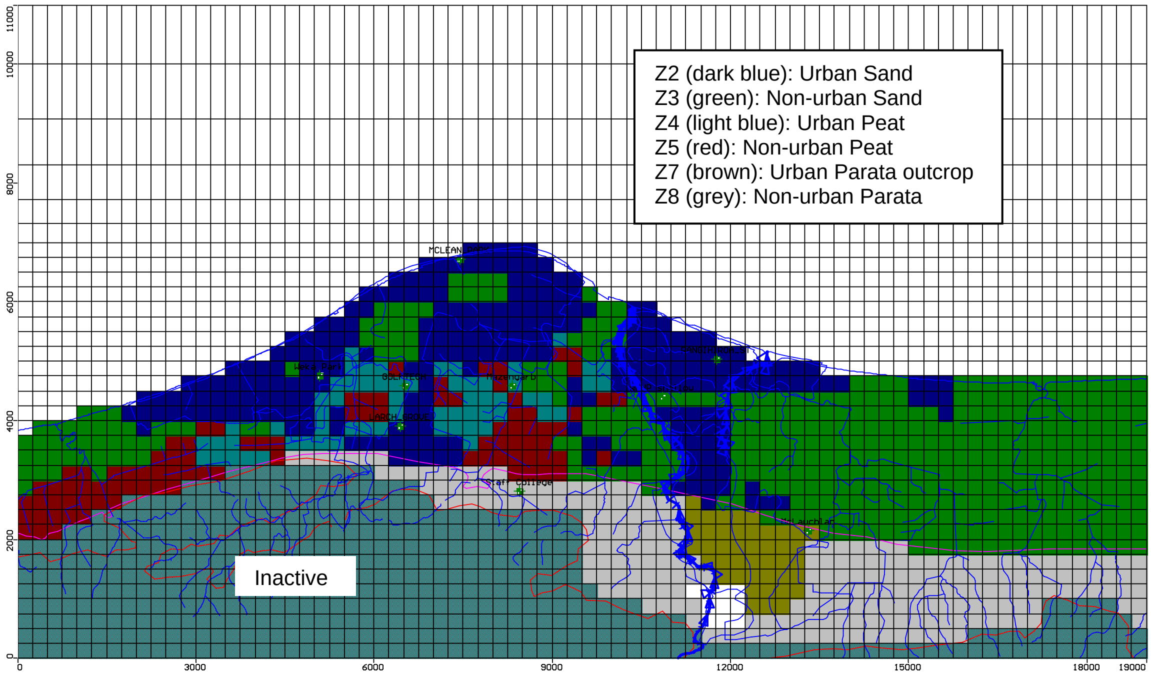


Figure 18: Recharge zones based on soil type and urban area

Recharge quantities were calculated on a weekly basis using the soil moisture balance model described in Appendix 1.

5.5.3 Abstraction

Abstraction from the numerous irrigation wells was simulated by assigning evapotranspiration (ET) cells to the urban areas. The amount of water removed by the ET cells was calculated using the methodology described in Section 4.5. The calculations were performed on a weekly basis for the period 1/1/1997 to 1/5/2003.

5.5.4 Rivers and drains

The Waikanae River and Waimeha Stream were simulated using the Modflow Stream Routing Module (STR1) because these two rivers either lose water to groundwater, or gain water from groundwater. The STR1 module provides the most flexible and appropriate method of representing these flows whilst accounting for flow in the river. The Waikanae River was divided into three segments – the Upper Waikanae (from State Highway One to Jim Cooke Memorial Park), the Middle Waikanae (to Waikanae Christian Holiday Camp), and the Lower Waikanae (to the river mouth). The bed elevation of the river was estimated from a digital terrain model held by Greater Wellington's Flood Protection Department.

The STR1 module requires the inflow to the upstream reach and subsequently accounts for losses and gains throughout the length of the river. Inflows to the Waikanae River at the eastern model boundary were derived from GWRC flow recorder at the Waikanae Water Treatment Plant. Measurements at this site are recorded every 15 minutes and were collated into 7-day totals for use in the model.

Riverbed conductance is a parameter used by MODFLOW to control the flow of water to and from the underlying aquifer. This parameter is usually derived through trial and error in the calibration process. Bed conductance is calculated using the length of the river in each river cell (L), the width of the river (W) in the cell, the thickness of the river bed (M), and the hydraulic conductivity of the river bed material (K). The stream bed conductance, C, is described as:

$$C = K L W / M$$

The river width and bed thickness has been held constant for each cell at 10m and 0.5m respectively. The length of the reach coincides approximately with the cell dimension of 250m. Assuming a hydraulic conductivity of 1m/day for the bed, the river bed conductance for the Waikanae approximates 5,000 m^2/day.

Remaining major streams and drains on the coastal plain were simulated with MODFLOW's Drain module. These are the Mazengarb Drain, Wharemauku Stream, and Ngarara Stream. Drain cells remove water from the aquifer at a rate proportional to the difference between the head in the aquifer and the elevation of the drain bed and can only remove water from the aquifer. The elevations of the drain cells were estimated from a digital terrain model held by the Flood Protection Department of the Greater Wellington Regional Council. The conductance values for the drain beds were derived from model calibration to the estimated flows contained in Section 4.4.

5.5.5 Constant heads at coast

The coastline and ocean have been represented using constant head cells in Layer 1 offshore. The underlying Layer 2 discharges by diffuse leakage beneath the ocean into the constant head cells.

6. Model calibration

6.1 Procedure

The calibration process involved running transient time simulations in several stages:

- Initial estimation of aquifer parameters within the ranges identified from field measurements and calculations.

- Modification of parameters and manual calibration against transient groundwater levels in monitoring wells, and to water balance estimations (river losses and gains).

- Assessment of parameter uncertainty using a sensitivity analysis.

6.2 Transient calibration

The objective of the transient calibration was to develop a model that can reliably simulate the shallow Kapiti groundwater system under a variety of boundary and abstraction stresses. This objective was achieved by manually matching modelled heads to the observed water table map and to transient water level monitoring records at selected sites. In addition, the observed flow losses and gains to rivers were also used as calibration targets.

The 6.5 year period of 1/1/1997 to 1/5/2003 was used for the calibration because continuous groundwater level and river flow data are available between these dates. Seven-day stress periods were employed over which flow rates (recharge, abstraction/ET, river flows) were totalled and observed groundwater levels averaged. The transient simulation has a total of 331 stress periods (2310 days).

The process of transient calibration involved assigning hydraulic conductivity ($k_{x,y,z}$) and storage properties and adjusting these parameters in an iterative process to obtain a match initially to groundwater level data and vertical flow gradients. The process was then repeated to provide an approximation to the observed flow losses from the Waikanae River, Mazengarb Drain and Wharemauku Stream, and flow gains to the Waimeha Stream, whilst retaining a match to groundwater levels. This process involved adjusting vertical and horizontal hydraulic conductivity of the Waikanae River Gravels and river bed/drain bed conductances. Recharge was reduced early on during the calibration process since it became clear that the soil moisture balance modelling provided an over-estimate. Consequently, recharge values for all zones were reduced by 25%.

Table 3 shows the calibrated model parameters.

Table 3: Calibrated model parameters

Unit	$k_{x,y}$ m/day	k_z m/day	Sy	Ss	Bed Conductance
Waikanae Dune Sand	5	0.01	0.25		
Waikanae River Gravel	80	1	0.25		
Parata Gravel	20	0.001	0.25	0.0005	
Waikanae River Waimeha Stream Drain Cells					5,000 50,000 800-1,500

Appendix Two contains the calibration plots for each of the water level monitoring sites.

6.3 Model outputs

Simulated water balances are contained in Table 4 for:

- Average flows from the 5-year simulation
- Summer flows represented by 30/12/98
- Winter flows represented by 7/7/99

The average flow balance in Table 4 shows that the dominant input to the Waikanae Groundwater Zone shallow aquifers is rainfall infiltration which accounts for about 65% of the recharge. The remaining 35% is provided by stream bed leakage. The Waikanae River above Jim Cooke Park is the principal source of streambed leakage providing about 90% of the total stream leakage into the shallow groundwater system.

The average balance shows that the principal outflows from the shallow aquifer system are as discharge back into the numerous streams and drains, and as offshore discharge. About 75% of the discharge into rivers and streams occurs to the Waimeha Stream and lower Waikanae River in roughly equal proportions. Flow to the deeper Parata gravels is also significant and averages 14ML/day.

The current average daily irrigation abstraction accounts for only 3% of the average aquifer inflows. However, the daily abstraction in relation to aquifer recharge is significantly higher during peak demand, low recharge periods. The flow balance for 30/12/98 (which was a particularly dry summer) shows that abstraction increased to over 8ML/day which was about 35% of the inflow to the aquifer.

The model indicates that river/groundwater interactions remain largely constant throughout the year and between years (Table 4 and Appendix 2), with losses to the aquifer varying very little, and gains (outflows to surface water) increasing by only about 5-10%. The baseflow to rivers and drains is therefore relatively stable.

During the summer months, when there is little rainfall recharge, the discharge from the aquifer is largely supported by water released from aquifer storage causing the water table to seasonally decline by about 1m as shown by Figure 6.

The groundwater surface water interactions during the dry summer and the long-term average are similar.

Table 4: Transient model aquifer water balance

	IN m^3/day			OUT m^3/day		
	5-year average	Dry summer 30/12/98	Normal winter 7/7/99	5-year average	Dry summer 30/12/98	Normal winter 7/7/99
Global Model flows:						
Recharge	54,000	0	146,000			
Abstraction				2,700	8,600	0
Stream Leakage	26,400	25,000	24,900	35,300	36,000	39,000
Drains				10,000	11,600	12,900
Flow offshore				36,500	41,000	39,400
Storage change		72,000				79,600
Internal flows:						
Loss from Waikanae River above JCP	24,600	23,800	23,500			
Gain to Waikanae River below JCP				16,700	17,000	18,700
Gain to Waimeha Stream				16,700	16,800	17,900

6.4 Model sensitivity analysis

A manual sensitivity analysis has been carried out on the model to evaluate the degree of uncertainty inherent in the estimation of the principal calibration parameters. The reliability of water flux estimates and the predictive capability of the model hinges on the sensitivity interrogation.

Table 5 shows the parameters that were tested during the sensitivity analysis during the calibration process.

Table 5: Sensitivity analysis parameters

Sensitivity parameter
$k_{x,y}$ – all units k_z – all units Recharge River bed conductance

Most of the parameters in Table 5 are highly correlated and therefore a unique solution can be achieved only through observance of the estimated water balance for the aquifer system and by adhering to the range of hydraulic conductivity values derived from field investigations.

The sensitivity analysis involved systematically changing each parameter in turn from the calibrated value by factors of 0.1, 0.5, 0.75, 1.25, 1.5 and 10. The observed sensitivity of the model to these changes is shown in Figure 19, expressed in terms of the root mean squared error (RMS). This measure of error is the square root of the sum of the squared differences between the calculated and observed heads. A large change in the modelled heads resulting from minor changes in the parameter value demonstrates that the model is highly sensitive to that parameter and the calibrated value is likely to be more accurate depending upon its correlation with other parameters.

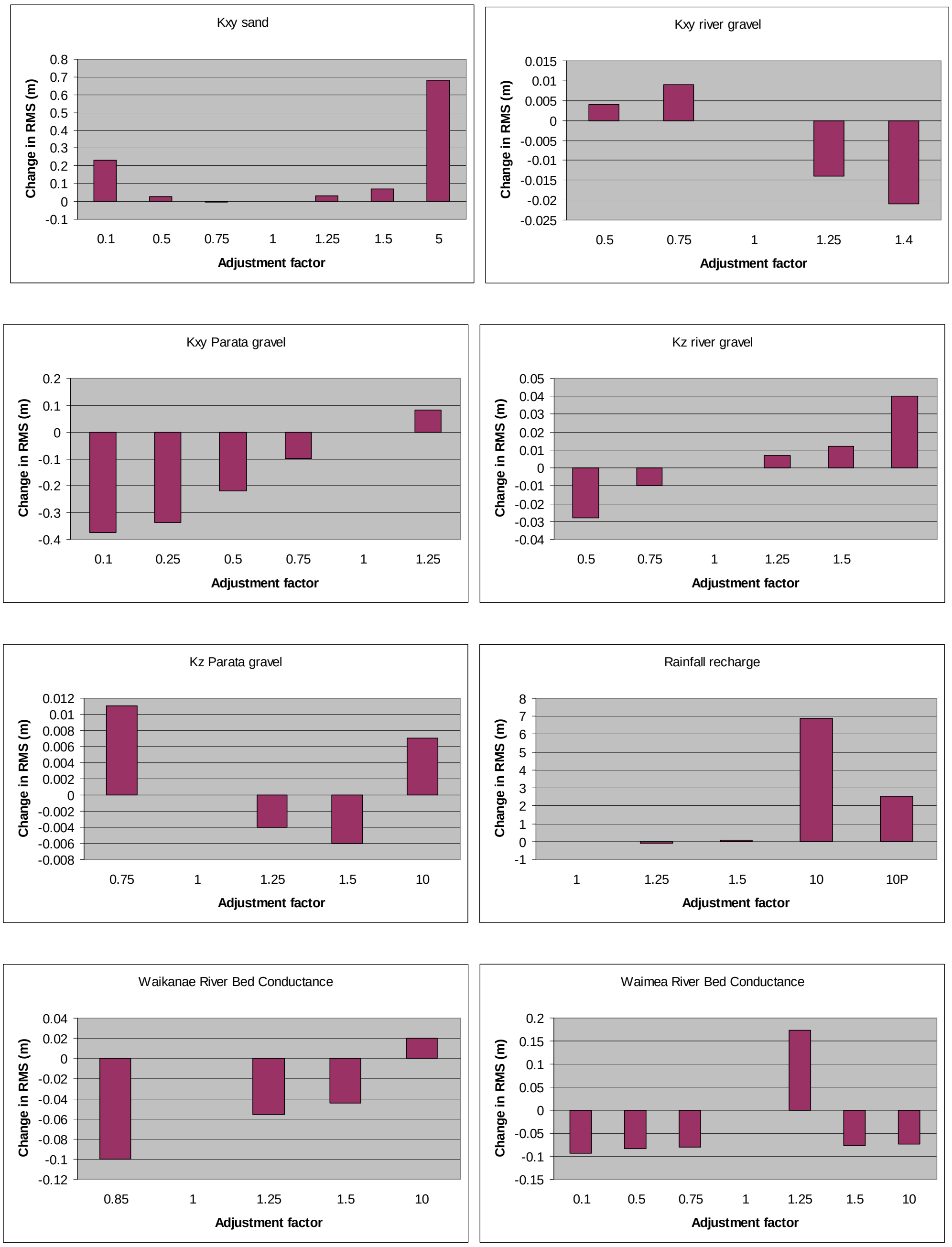


Figure 19: Model sensitivity analysis

Figure 19 shows that the modelled heads are not particularly sensitive to changes in horizontal hydraulic conductivity ($k_{x,y}$) in the dune sand or the Waikanae gravels. However, changes in the $k_{x,y}$ in the Waikanae gravels, whilst not significantly changing the modelled heads, has a large impact on leakage rates through the riverbed. This parameter was calibrated primarily against the gauged flow losses in the river. However, the modelled heads are sensitive to the vertical hydraulic conductivity (k_z) of the dune sand aquifer since this parameter controls the amount of leakage to the deeper aquifer.

Sensitivity analysis on recharge shows the model is insensitive to small changes and that a significant change in RMS could only be achieved by increasing recharge by an order of magnitude.

Riverbed conductance is also a sensitive parameter for the Waimeha Stream as it controls the release of spring flow into the stream. The bed conductance of the Waikanae River appears to be a less sensitive parameter.

We are satisfied that we have achieved a robust model calibration because there are relatively few sensitive parameters. These are the k_z of the dune sand, the bed conductance in the Waimeha Stream, and the $k_{x,y}$ of the Parata Gravels. In terms of the model water balance, the $k_{x,y}$ of the Waikanae Gravels is also significant. Prior knowledge of the range of major water balance components, such as river leakage, has enabled the model to be more robustly calibrated than if groundwater heads alone were used.

7. Scenario modelling

The Kapiti shallow groundwater model has been developed as a tool to examine the sustainability of the groundwater resource, and to investigate the current and future cumulative effects of abstraction on groundwater dependent ecosystems. The model has also been developed to assess the saline intrusion risk of multiple abstractions close to the coast.

7.1 Effects on groundwater dependent ecosystems

Groundwater dependent ecosystems are defined as any surface water body, such as streams, springs, wetlands or lakes, which are either sustained by groundwater inflow and/or feed into the groundwater environment. Two of the most important groundwater dependent ecosystems in the Waikanae area are the spring-fed Waimeha Stream and the Te Harakeke Wetland (see Section 4.4.3).

Three scenarios were run to assess current and potential future cumulative effects of shallow groundwater abstraction on the Waimeha Stream:

- No abstraction
- Current estimated abstraction
- Twice the current estimated abstraction

Figure 20 shows the results of the three abstraction scenarios by plotting the modelled groundwater flows to the Waimeha Stream. Current estimated abstraction has caused the flow in the spring-fed Waimeha Stream to decrease by only about 5-6 L/sec which is only about 3% of the summer flow. If abstraction from the shallow aquifer were to double, the model indicates that only an additional 5L/s would be lost from the stream.

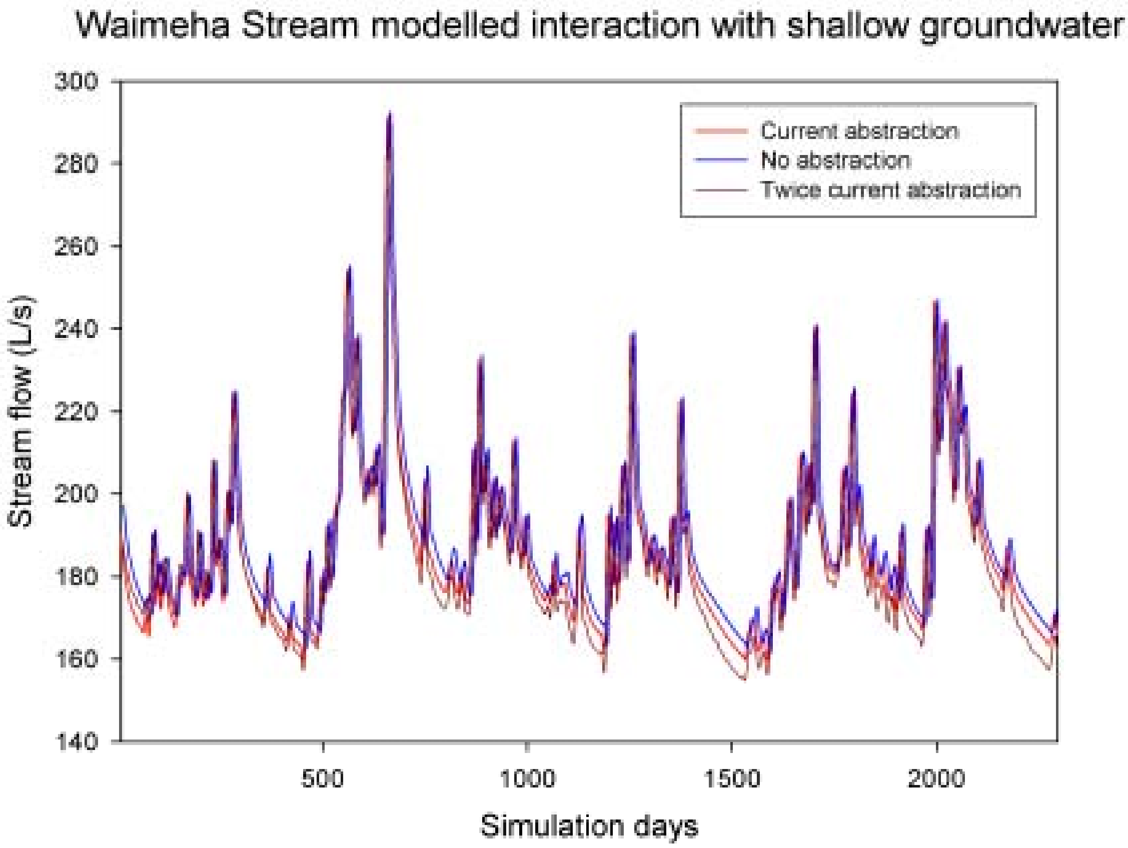


Figure 20: Modelled effects of shallow groundwater abstraction on flows in the Waimeha Stream (no abstraction, current abstraction and twice current abstraction)

The numerical model has been used to investigate the potential effects that groundwater abstraction from the shallow unconfined sand aquifer may have on water levels within important wetland areas. One of the most important and largest wetland areas in the study area is the interdunal Te Harakeke Wetland located 500m from the coastline and some 2km to the north-west of Waikanae. The hydrology of this wetland is described by Phreatos (2002). There are also numerous smaller remnant wetlands in the area.

To examine the cumulative effects of current abstraction from the unconfined aquifer on the Te Harakeke wetland, the model head outputs beneath the wetland for the three scenarios have been compared:

- Scenario 1: no abstraction from the sand aquifer
- Scenario 2: current estimated abstraction extended along the coastal strip between the wetland and the coast to simulate development occurring in this area.

- Scenario 3: as for scenario 2 but abstraction is multiplied by a factor of two to account for future increases in abstraction.

Figure 21 shows the outputs for the three scenarios for a model cell located over the central part of the Te Harakeke wetland. It is apparent that the differences between the scenarios are very small and that water levels could be expected to drop by less than 100mm as a result of the increased abstractions from low-yielding garden wells.

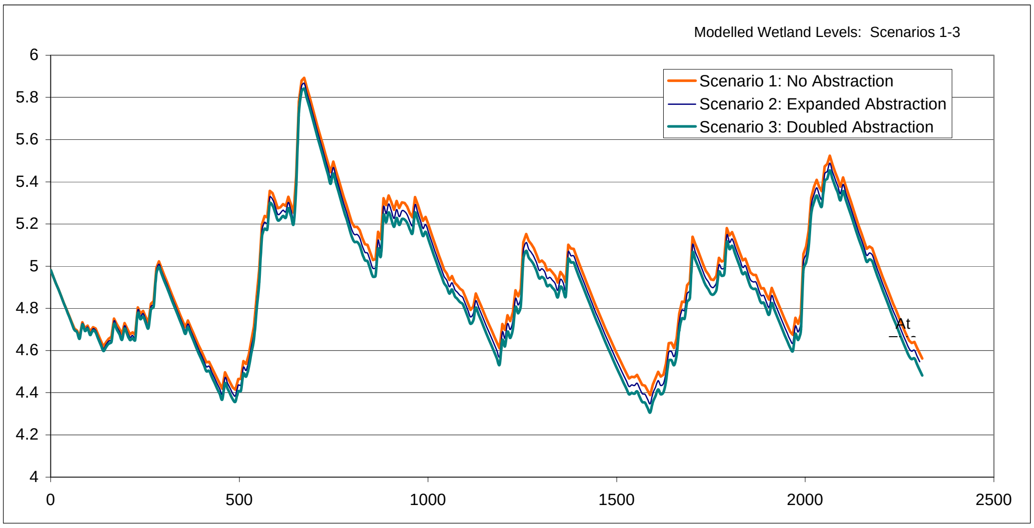


Figure 21: Modelled effects of shallow groundwater abstraction on water level in the Te Harakeke Wetland (no abstraction, current/expanded abstraction and twice current abstraction)

A drawdown effect of less than 100mm is unlikely to adversely affect the wetland ecology given that the natural fluctuations in groundwater level around the wetland appears to be about 200-300mm. Therefore, at a regional-scale the abstraction of shallow groundwater at low rates appears to not pose a threat to wetland systems. However, at a local-scale the abstraction of greater rates than garden irrigation wells may affect wetland water levels.

Numerical modelling has been used to help ascertain the area around a wetland (or spring) in which high-rate abstractions would result in adverse environmental effects. A simplified model was set up to simulate the Kapiti unconfined and aquifer and assess interference effect of wells pumping at various rates. The model used a 100-day pumping cycle and discharge rates of 50, 100 and 200 m^3/day for a 20m saturated thickness. The aquifer properties were the same as those used in the regional model, although two specific yields were used: 0.2 and 0.15.

Figure 22 shows the model results in the form of a distance-drawdown plot. For takes of up to 100m^3/day, most of the drawdown occurs within 150m of the well. For takes of up to 200m^3/day the bulk of the drawdown occurs within about 250m.

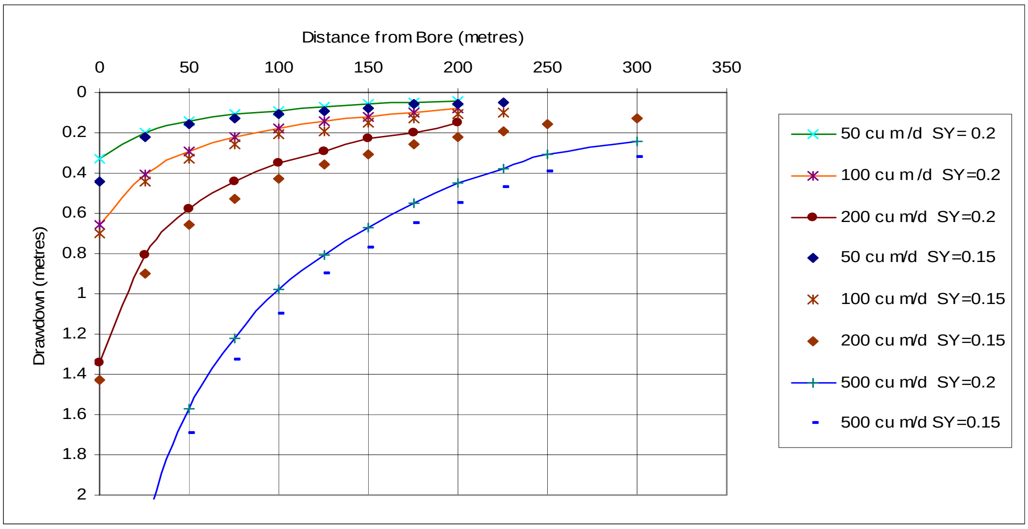


Figure 22: Modelled effects of groundwater abstraction from a single well on wetland water levels at a variety of pumping rates

7.2 Saline intrusion risk

Excessive groundwater abstraction has the potential to cause the aquifer water levels at the coast to fall below a critical level and induce the flow of salt water inland. Such an event could potentially contaminate the aquifer and render the resource unusable for garden irrigation.

The numerical model has been used to look at the effects of abstraction on aquifer levels at the coast by running the same three abstraction scenarios used to look at abstraction effects on the Waimeha Stream. Figure 23 shows the modelled water table levels at the coast.

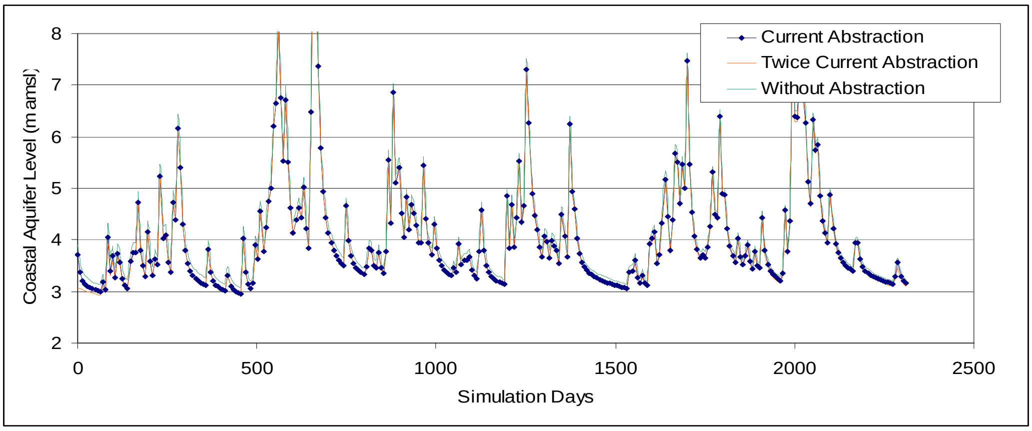


Figure 23: Modelled effects of shallow groundwater abstraction on coastal aquifer levels (no abstraction, current abstraction and twice current abstraction)

It is clear that the current and doubled abstractions do not have a significant impact on coastal aquifer levels principally because of the high storage capacity of the unconfined aquifer.

8. Resource management

8.1 Defining sustainable management

Sustainable resource management under the Resource Management Act (1991) entails management of resource use that ensures environmental bottom lines are maintained. An environmental bottom line often used for groundwater management is the concept of safe yield. The traditional concept of the safe yield of an aquifer is the attainment and maintenance of a long term balance between the average annual amount of water withdrawn from an aquifer, and the average annual amount water replenishing it. Thus the safe yield of an aquifer limits groundwater abstraction to the amount of water that is replenished (Sophocleous, 1997). The quantification of water withdrawn must include the natural discharge from the system into streams, springs and wetlands to ensure that these groundwater dependant ecosystems are included in the concept of sustainable aquifer management. If no allowance is made for surface waters that rely on groundwater, then groundwater dependent ecosystems may be adversely affected by abstraction. The safe yield of an aquifer is therefore a function of the interconnectedness of the surface water and groundwater environments. Other considerations, such as saline intrusion risk are also important considerations when assessing an aquifer's safe yield.

8.2 The sustainability of current abstractions

Scenarios investigated using the numerical model (Section 7) indicate that the current cumulative abstraction effects on groundwater dependent ecosystems are minor. The modelling also indicates that if abstraction were doubled, then the effects would remain minor. Furthermore, the risk of saline intrusion risk relating to garden well abstraction has also been shown to be negligible.

Therefore, it is our view that the numerous small-volume abstractions from the shallow aquifer represent sustainable use of that groundwater resource.

8.3 Managing groundwater abstractions

Although the garden well abstraction appears to be sustainable, larger individual groundwater abstractions (of greater than about 20 m^3/day) from wells or drains located in the shallow sand aquifer may have a much greater potential to adversely affect groundwater dependent ecosystems - in particular, wetland water levels and spring flows.

Groundwater abstractions from deeper aquifers may also affect the shallow unconfined system. The vertical hydraulic connection between aquifers is likely to be spatially variable, with higher degrees of confinement occurring with depth. In some areas, such as beneath the Waikanae River alluvial fan, fluvial processes appear to have created a zone in which the vertical movement of groundwater is less restricted. Abstraction within this area may therefore have greater potential to affect shallow aquifers and the surface water environment.

8.3.1 Recommended Water Resource Management Actions for the Waikanae Groundwater Zone

To address the potential effects of larger groundwater abstractions (from wells or drains), and the diversion of surface water, the following resource management actions are recommended:

1. The establishment of groundwater dependent ecosystem buffer zones.

The abstraction scenario modelling (Section 7) shows that large volume abstraction closer than 150m to a wetland, or other groundwater dependent ecosystem, is likely to reduce the water level in the wetland or stream. Such a reduction may have an adverse effect on biota. Therefore, it is proposed that a 150m buffer zone be established around important wetlands and springs within which groundwater abstractions would be controlled.

Figure 24 shows 150m buffer zones around the Waimeha Stream and wetlands in the Waikanae Groundwater Zone.

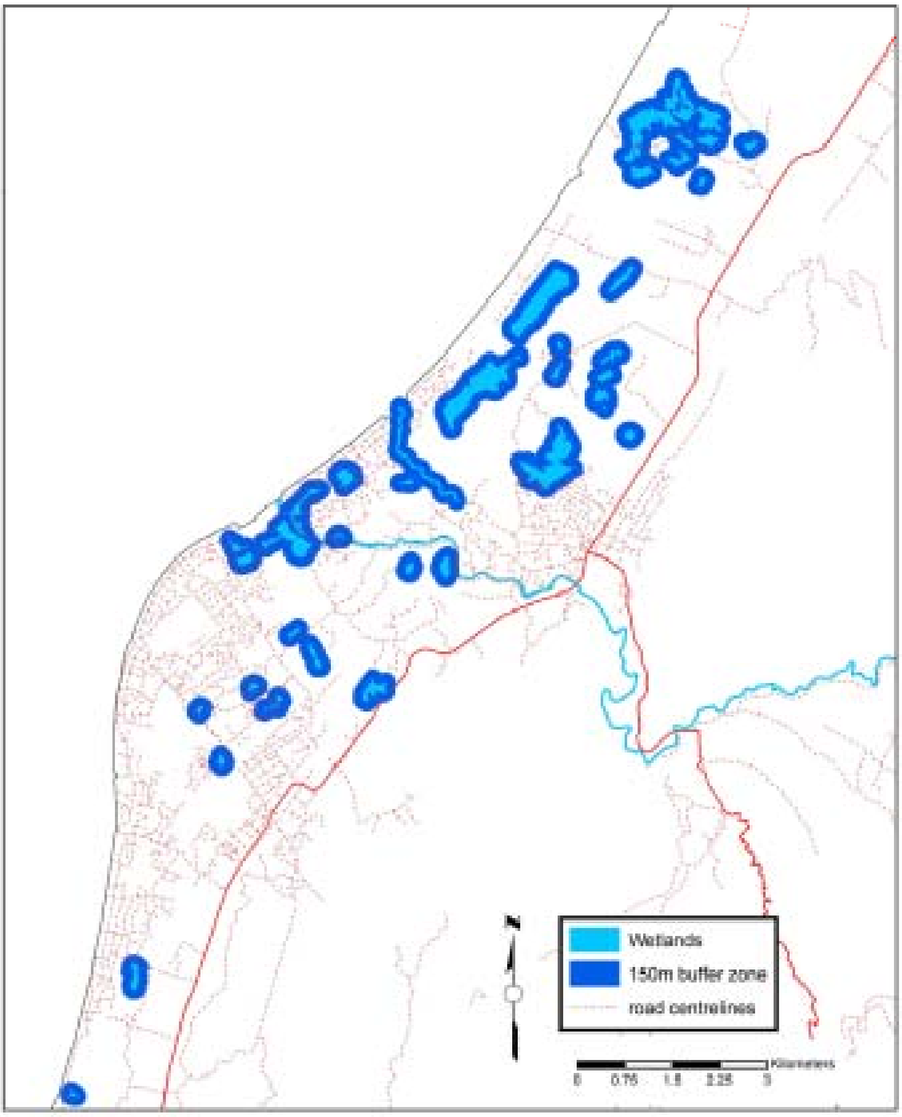


Figure 24: Possible buffer zones around the Waimeha Stream and wetland areas

Figure 24 shows buffers drawn around wetlands and the Waimeha Stream only. A similar buffer could also be drawn around other streams, such as the Ngarara, to address potential streamflow depletion effects caused by groundwater pumping. Furthermore, the extent of the wetlands shown in Figure 24 needs to be confirmed to ensure that important wetlands are included in their entirety.

2. Proposed new regional rules

We suggest that the following rules be included in the Regional Freshwater Plan to regulate groundwater abstraction and drainage within the buffer zones:

- <u>Rule 1</u>: Any groundwater abstraction of $>20m^3$/day within the buffer zone is a *non-complying activity*.

- <u>Rule 2</u>: Any groundwater abstraction of $<20m^3$/day is a *discretionary activity*.

- <u>Rule 3</u>: The construction of new drains or dewatering system, or the diversion of surface water is a *non-complying activity*.

3. Consideration of monitoring requirements for takes outside buffer zones

The drawdown effects associated with all groundwater takes of $>20m^3$/day on groundwater dependent ecosystems from aquifers located within Waikanae Groundwater Zone should be considered when assessing resource consent applications. Large groundwater takes should be subject to a monitoring regime that includes the shallow groundwater and surface water environments – particularly those takes located within the Waikanae Shallow Gravel Zone (Figure 4).

8.4 Additional environmental monitoring recommendations

Wetland level monitoring

Detailed long-term monitoring of shallow groundwater levels or surface water levels in important wetland areas is critical to the management and conservation of these areas. Such monitoring will allow the water level variation in the wetlands to be quantified and provide data to assess the hydraulic connection between the wetland and groundwater.

Continuous monitoring of the Te Harakeke and Nga Manu wetland areas is recommended. Monitoring of other selected wetlands should also be considered (such as those in Te Hapu - Peka Peka Road area).

This monitoring should be coupled with an investigation into the hydrology of specific wetland areas to assess their vulnerability to a decline in water level. Knowledge of how resistant wetlands are to a water level decline will provide a sound basis for defining minimum groundwater levels that can be used to regulate groundwater abstraction.

Stream/spring flow monitoring

Given the aesthetic and ecological importance of the Waimeha Stream and its vulnerability to the effects of large-scale groundwater abstraction, it is recommended that the flow of this stream be continuously monitored below the main spring discharge area at or about the location of the current temporary recorder.

9. References

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Appendix one – calculation of rainfall recharge

Rainfall recharge

Rainfall recharge has been estimated using a soil water balance model employed by Bekesi (1998). This model is similar to that of Scott and Thorpe (1999) and the original recharge model used for the Waikanae Groundwater Zone (Cussins 1994).

The model is based on a soil moisture balance that is calculated daily.

$SM_i = Sm_{i-1} + R_i - AET_i - RCG_i$

Where:

SM_i = soil moisture on day i

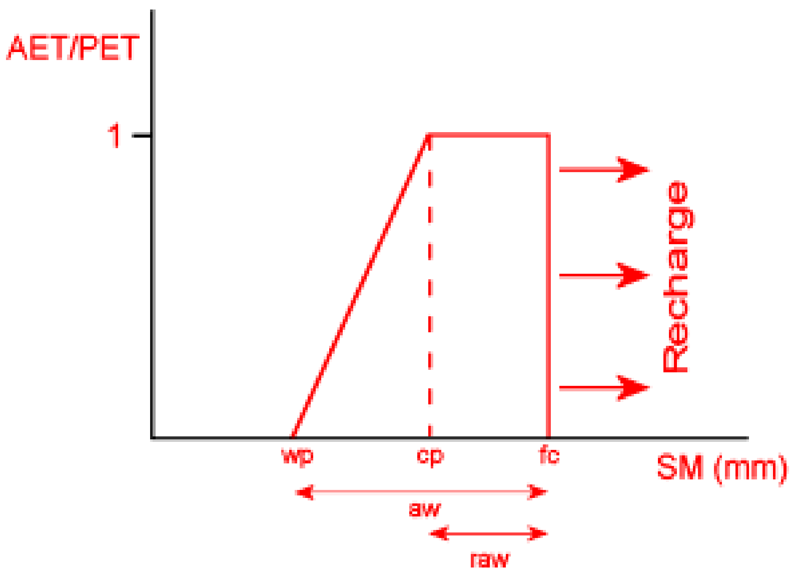
SM_{i-1} = soil moisture the day before

R_i = rainfall on day i

AET_i = actual evapotranspiration on day i

RCG_i = recharge on day i

AET is calculated on the basis of soil moisture in accordance with the following relationship (Bekesi 1998):



Where:

wp = wilting point

cp = critical point

fc = field capacity

aw = available water

raw = readily available water

This relationship reduces evapotranspiration as soil moisture declines. For high soil moisture levels AET equals the PET. Below the critical point AET is reduced linearly to the wilting point at which evapotranspiration ceases. The soil moisture parameters used are weighted averages of all soil types within each area of interest.

The model records recharge when the soil moisture exceeds field capacity. The assumption was made that the soil profile was at field capacity on day one. To support this assumption the model was run from the 2nd of July. Data were available for 2 July 1972 to 30 April 2003 and daily recharge values have been calculated for this period although only data from 1 January 1997 to 23 April 2003 were employed in the MODFLOW simulation.

Rainfall

These data are daily totals from NIWA's Paraparaumu Airport site.

Potential evapotranspiration

These data have been calculated by NIWA using the Priestly Taylor equation and climate data from their Paraparaumu Airport site.

Soil physical parameters

Soil types, areal extent and their associated physical attributes have been obtained from the New Zealand Land Resource Inventory (NZLRI), Jack McConchie (pers. comm.) and Hugh Wilde (pers. comm).

The NZLRI provides minimum, maximum and mid point values for soil parameters. For simplicity the mid-point values have been used. The soil moisture parameters depend on the depth of the soil profile. The NZLRI provides Potential Rooting Depth values, which is a soil parameter while actual rooting depth (ARD) is the product of the soil and vegetation type. Bekesi (1998) provides estimates of ARD as follows:

Pasture	0.3 - 0.4m
Tussock and sand dune vegetation	0.3 - 0.4m
Scrubland	0.4 - 0.5m

A value of 0.4m has been adopted for the Waikanae Groundwater Zone vegetation that includes domestic gardens and sand dune cover. Where the NZLRI Potential Rooting Depth was greater than 0.4m the soil parameters were adjusted as follows:

- Express AW and RAW water content values as percentages, for example:

  AW% = AW/PRD

∉ Multiply % values by the adopted ARD value of 0.4m.

Wilting point values were calculated using water content values provided by Bekesi (1998):

Soil type	Bekesi range	Adopted value
Sand	0.02-0.05	0.03
Sandy loam	0.08-0.15	0.10
Loam	0.10-0.20	0.14
Silt loam, silty clay loam	0.17-0.27	0.19
Peaty silt loam, silty clay	0.20-0.30	0.25

These adopted values were multiplied by ARD to calculate a wilting point value in millimetres.

The results of the soil moisture parameter calculations are shown the following table:

Soil series	Soil type	WP (mm)	RAW (mm)	AW (mm)	FC (mm)
Foxton	Black sand	12	22	59	71
Himatangi	Sand	12	52	83	95
Motuiti	Sand	12	26	41	53
Omanuka	Peat	100	66	211	311
Pukepuke	Brown peaty loam	100	66	126	226
Waitarere	Sand	12	7	13	25
Foxton	Sand	12	22	59	71
Paraparaumu	Peaty loam	100	66	211	311
Waikanae	Silt loam	76	22	53	129
Waikanae	Sandy loam	40	19	46	86

The soil types in the modelled area may be broadly defined as sandy or peaty in nature. To simplify the modelling process these two classes of soil have been used.

The physical attributes for the sandy soil class have been estimated by calculating a weighted mean for each parameter for the soil types north of Waikanae and Waikanae Beach – the northern Waikanae sands subzone. The attributes for the Paraparaumu peaty loam were used for the peaty soil class, as this is the dominant peaty soil in the area.

Soil class	Soil parameter			
	WP (mm)	RAW (mm)	AW (mm)	FC (mm)
Sandy soils	26	30	70	97
Peaty soils	100	66	211	311

Bekesi (1998) discusses the potential for high water tables to influence soil moisture levels. Such an influence can occur if the water table enters the ARD. In Waikanae the depth to groundwater is greater than the adopted ARD of 0.4m so no allowance for high groundwater levels has been made.

Run-off coefficient

Cussins (1994) assumed no rainfall runoff occurred. Bekesi (1998) and Scott and Thorpe (1999) made the same assumption for their soil water balance models. Recharge has been calculated initially assuming no runoff but because a large proportion of the Waikanae Groundwater Zone is an urban area, runoff was expected to be high and therefore have a significant bearing on the amount of rainfall available for recharge.

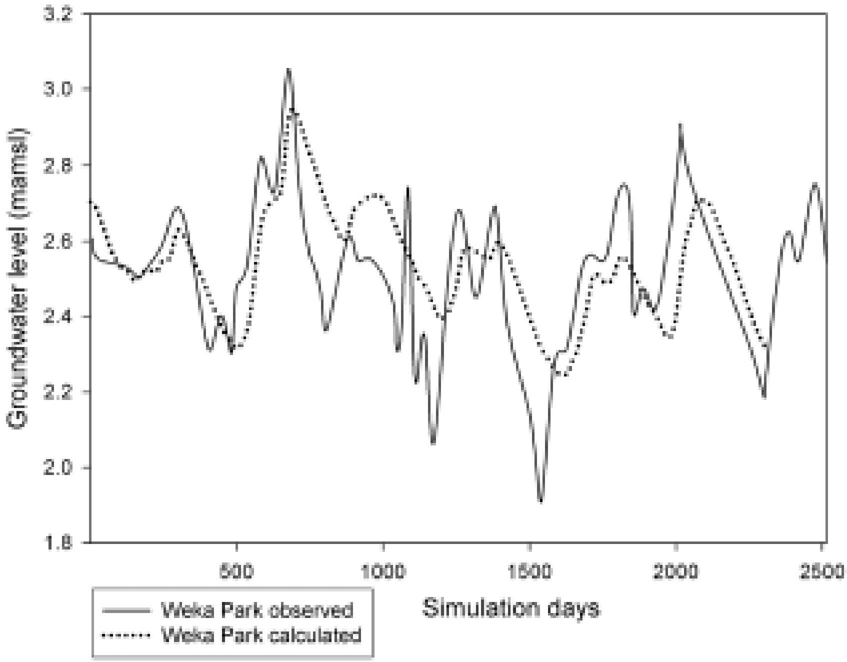
Run-off has been allowed for by reducing the modelled recharge by a factor of 0.3 in urban areas. This factor is based on the work of Watts (2002) who calculated run-off coefficients for four small sub-catchments of the larger Mazengarb catchment in the Paraparaumu area. These sub-catchments consisted of two moderate-density residential areas, one rural area and one low-density residential area. Watts' average run-off coefficients are as follows:

Catchment	Impervious cover estimate (%)	Average run-off coefficient
Rosewood	46	0.35
Realm Drive	44	0.51
Ratanui	10	0.33
Nikau	7	0.16

There appears to be some uncertainty about an appropriate run-off coefficient for non-urban areas so no run-off has been considered. The urban areas are those classed in the NZLRI as "town".

Scott and Thorpe (1999) state their soil moisture model is very sensitive to rainfall with a 10% difference in rainfall producing a significantly different result. Consequently, the estimation of runoff coefficient is likely to introduce a significant error to the recharge estimation. Nevertheless given the high proportion of urban area I consider it important to recognise that runoff will occur and the assumption that no runoff occurs is clearly inappropriate.

Appendix two – calibration plots



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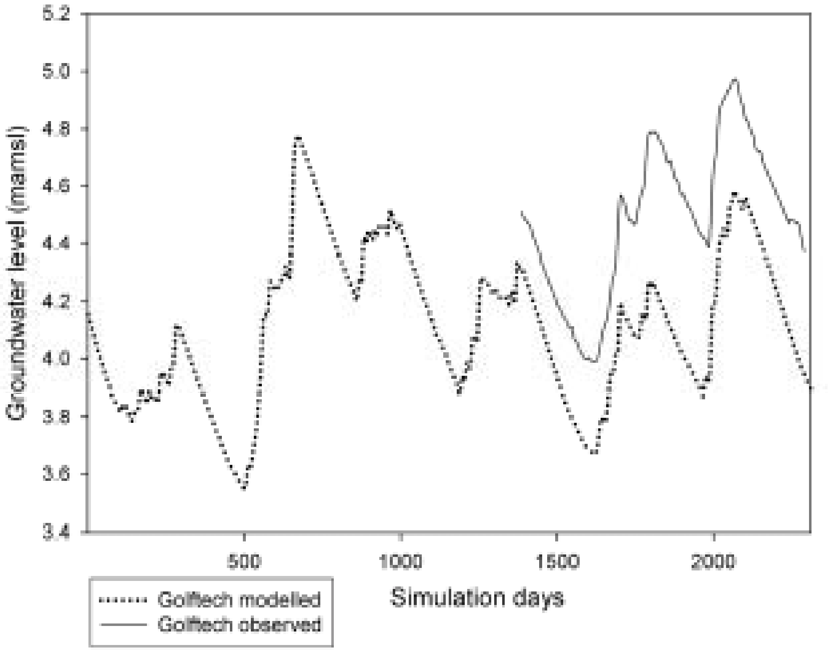

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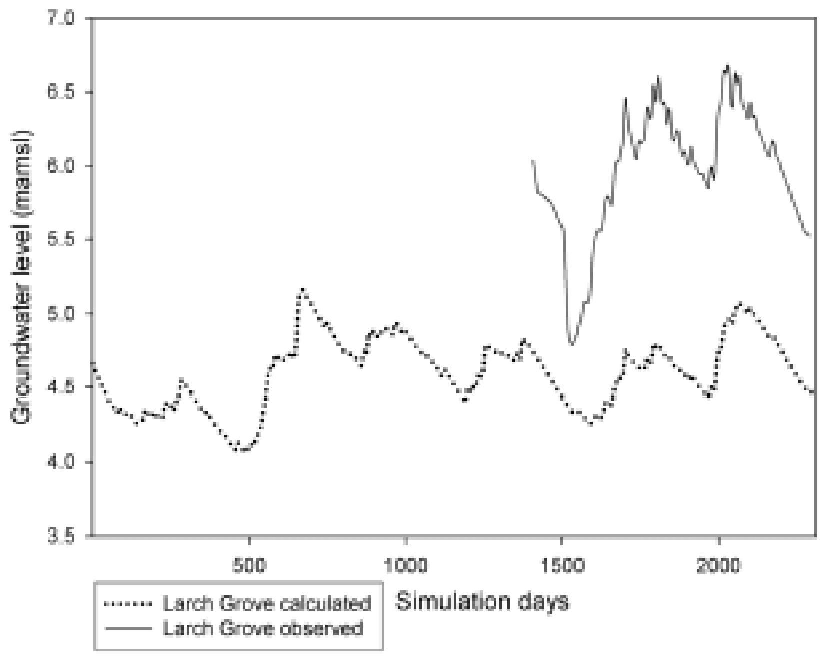
Data type	Automatic readings



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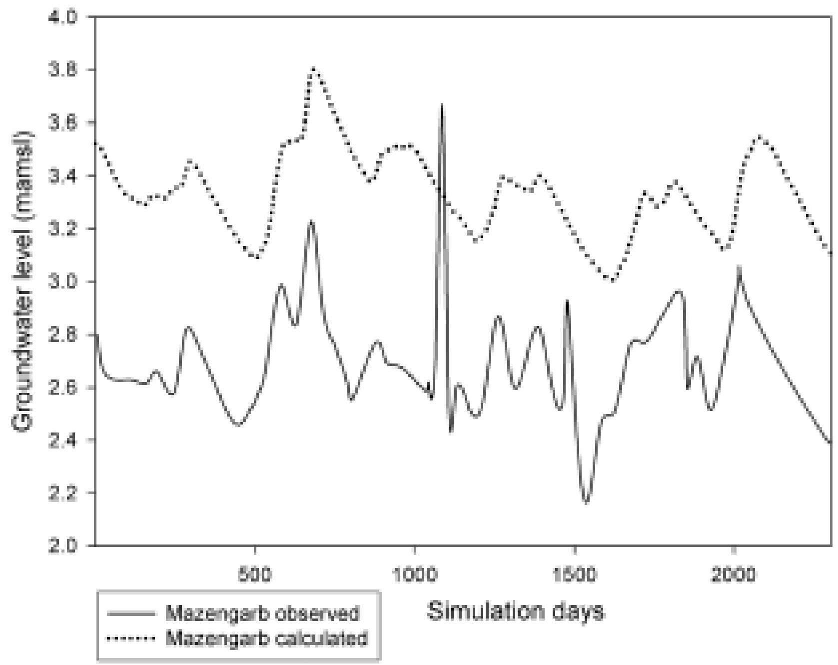
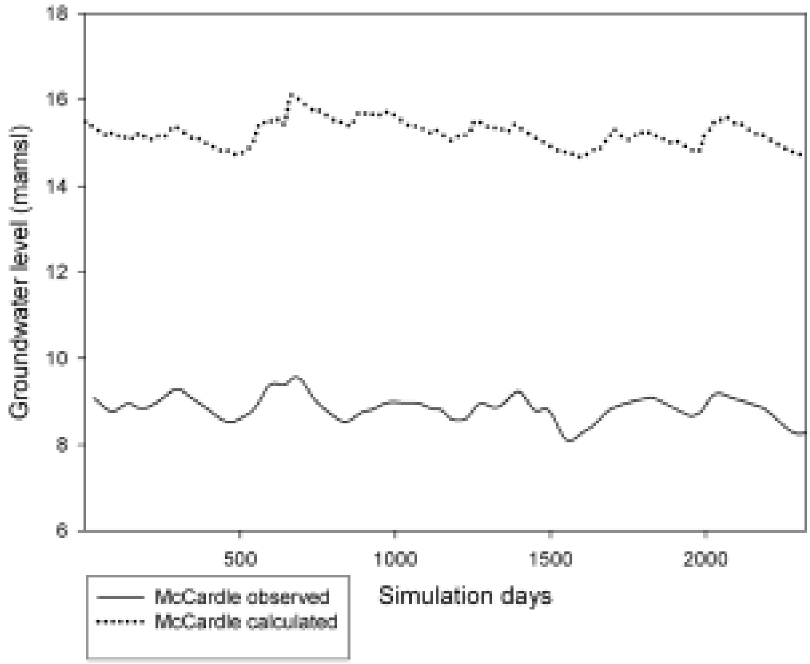
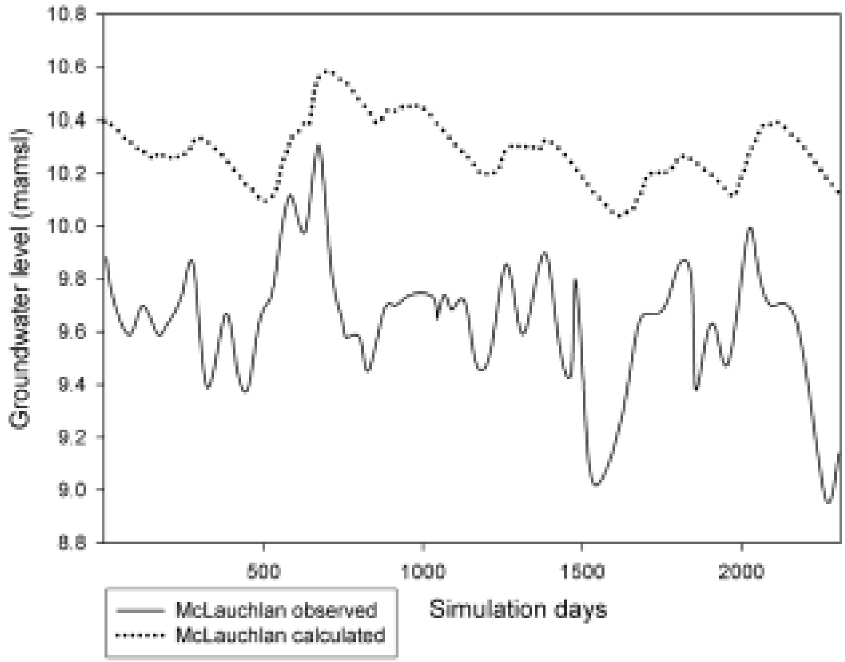
Depth	10m
Model layer	1
Data type	Automatic readings



Well number	R26/6557
Depth	25.9m
Model layer	2
Data type	Manual readings



Well number	R26/6738
Depth	5m
Model layer	1
Data type	Manual readings



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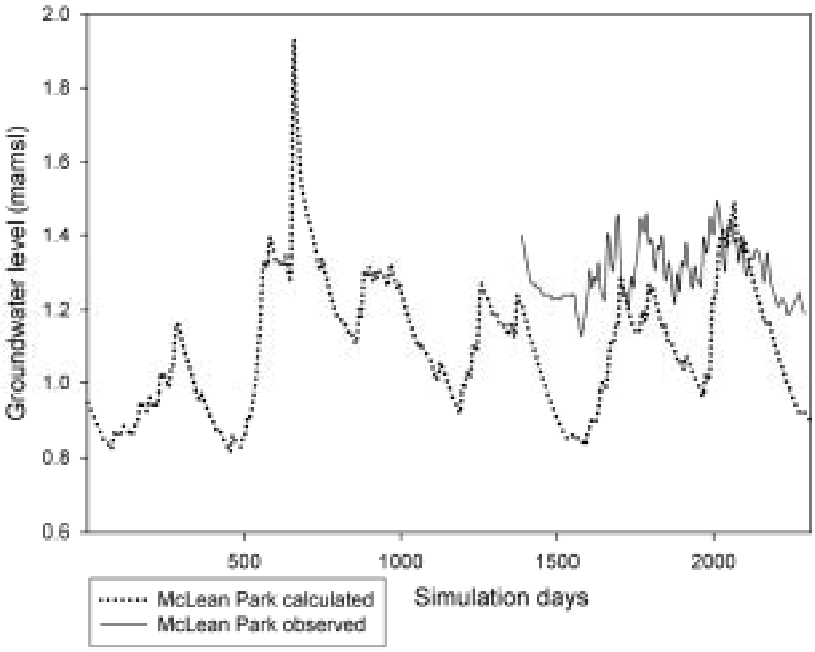
Depth	16m
Model layer	1
Data type	Manual readings



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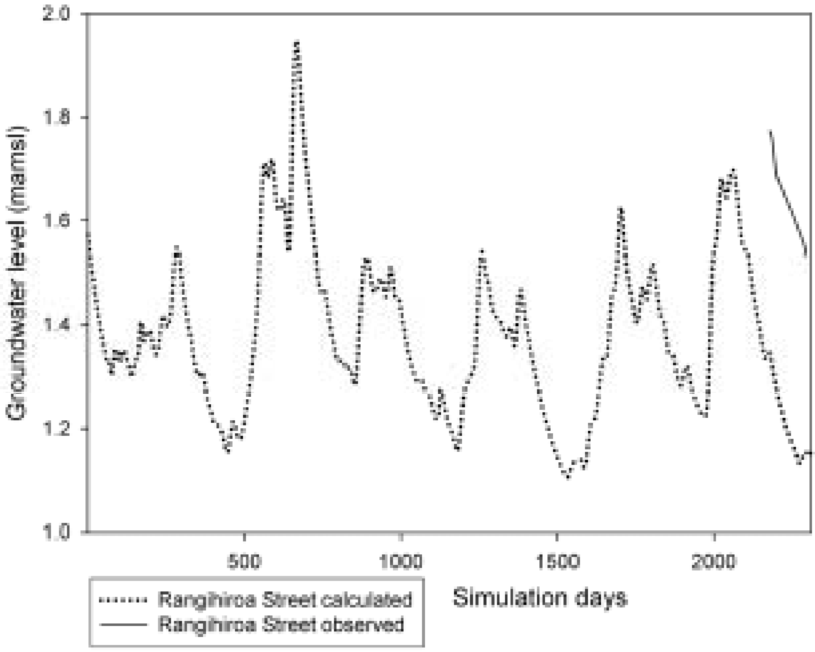
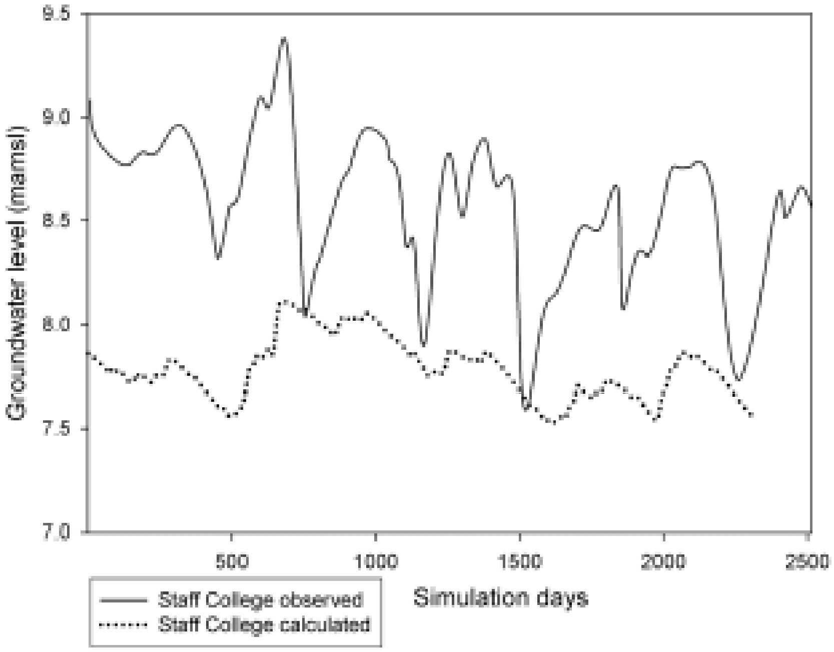
Depth	10m
Model layer	1
Data type	Automatic readings



Well number	R26/6287
Depth	6m
Model layer	1
Data type	Automatic readings



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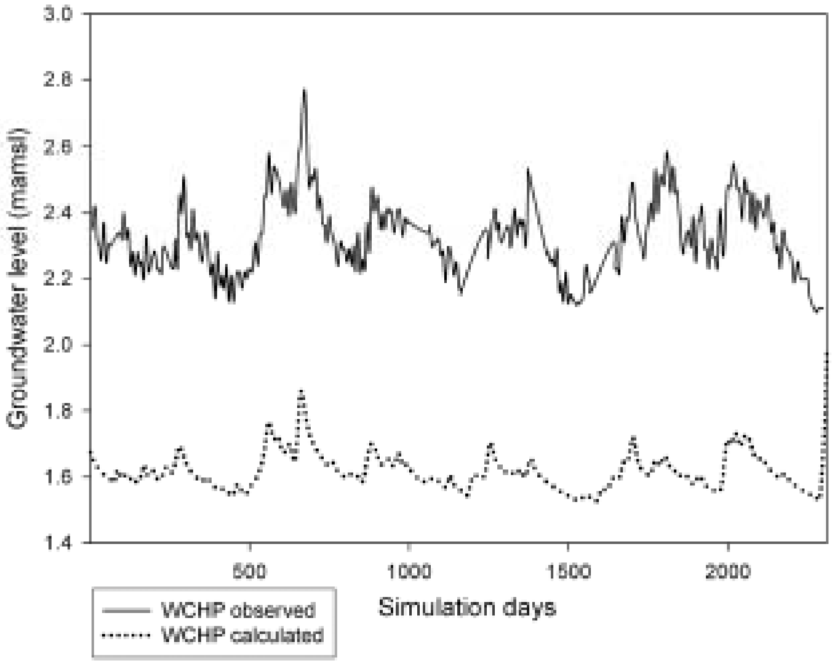
Model layer	2
Data type	Manual readings



Well number	R26/6916
Depth	21m
Model layer	2
Data type	Automatic readings